ACTION HISTORY OF RTI REQUEST No.WLIOI/R/E/21/00016

Applicant Name	Gopal SIngh Bhati
Text of Application	Particular of information required: 1. What is the present status of the establishment of GIB Conservation Breeding Facility at Ramdevra? 2. Whether eggs of GIB have been found by the scientists of the conservation centre in or around the Orans of Chhayan and Askandra villages of Pokhran tehsil? 3. Whether any objections have been raised of Wild Life Institute of India regarding establishment of solar power plants and transmission lines for the solar power plants being established at village Chhayan and Askandra? 4. Whether Wild Life Institution of India has any information regarding the existence of GIB population around Askandra and Chhayan village and what was the historical numbers and what is the present number?
Reply of Application	kindly see the attached cover letter. Due to large size Annexures mentioned in cover letter are being sent separately by email in your registered email id: gsbpokhran@gmail.com

SN.	Action Taken	Date of Action	Action Taken By	Remarks
1	RTI REQUEST RECEIVED	20/02/2021	Nodal Officer	
2	REQUEST FORWARDED TO CPIO	22/02/2021	Nodal Officer	Forwarded to CPIO(s) : (1) P.K.Aggarwal
3	REQUEST DISPOSED OF	17/03/2021	P.K.Aggarwal-(CPIO)	

Print

Print

Government of India
Wildlife Institute of India, Dehradun
Wildlife Institute of India
P.O.Box-18, Chandrabani, Dehradun, Uttarakhand,

Dated: 17/03/2021

To

Shri Gopal SIngh Bhati
Krsna Kunj Enclave
Ramdeora Road , Gomat
Pokhran
345021

Registration Number : WLIOI/R/E/21/00016

Dear Sir/Madam

I am to refer to your Request for Information under RTI Act 2005, received vide letter dated 20/02/2021 and to say that *kindly see the attached cover letter. Due to large size Annexures mentioned in cover letter are being sent separately by email in your registered email id: gsbpokhran@gmail.com*.

In case, you want to go for an appeal in connection with the information provided, you may appeal to the Appellate Authority indicated below within ***thirty days*** from the date of receipt of this letter.

Director, WII
FAA & Director
Address: Wildlife Institute of IndiaChandrabaniDehradun
Phone No.: 01352646101

Yours faithfully

(P.K.Aggarwal)
CPIO & Deputy Registrar
Phone No.: 01352646110
Email : pka@wii.gov.in

सूचना का
अधिकार
RIGHT TO
INFORMATION

ONLINE PORTAL

No. WII/RTI/CPIO/2020-21 (Qtr-IV)/101

Date: 17 March, 2021

To,

Gopal Singh Bhati
Krsna Kunj Enclave, Ramdeora Road ,
Gomat, Pokhran, Pin:345021 Rajasthan
Email: gsbpokhran@gmail.com

Sub.: Information under RTI Act, 2005–reg.

Ref.: Your Online RTI No. WLIOI/R/E/21/00016 dated 20/02/2021

Dear Shri Gopal SIngh Bhati,

Please refer to your application cited above under RTI Act, 2005. In this context, point-wise response to your queries is given below:

Information Sought under RTI	Reply
1) What is the present status of the establishment of GIB Conservation Breeding Facility at Ramdevra?	Information on the construction status of the GIB Conservation Breeding Facility at Ramdevra is attached herewith as **Annexure 1a (Soft Copy)**
2) Whether eggs of GIB have been found by the scientists of the conservation center in or around the Orans of Chhayan and Askandra villages of Pokhran tehsil?	No documentation pertaining to these specific areas is currently available
3) Whether any objections have been raised of Wildlife Institute of India regarding establishment of solar power plants and transmission lines for the solar power plants being established at village Chhayan and Askandra?	Letter and report submitted by WII on this matter are attached herewith as **Annexure 3a, 3b & 3c**. **(Soft Copy)**
4) Whether Wildlife Institute of India has any information regarding the existence of GIB around Askandra and Chhayan village and what was the historical numbers and what is the present number?	Relevant information is attached herewith as **Annexure 4a**. **(Soft Copy)**

If you are not satisfied with the aforesaid reply, you may appeal to the **Appellate Authority i.e. "Director, Wildlife Institute of India, Post Box 18, Chandrabani, Dehradun – 248 001, Ph. 0135-2640910".**

Thanking you,

NO & CPIO (RTI)

WILDLIFE INSTITUTE OF INDIA
CHANDRABANI, DEHRADUN

Encl.: as above.

ई–मेल द्वारा

भारत सरकार
केन्द्रीय लोक निर्माण विभाग
CENTRAL PUBLIC WORKS DEPARTMENT

कार्यालय :– कार्यपालक अभियन्ता, जैसलमेर,
के.लो.नि.वि., प्लॉट नं. 6, निर्माण सदन,
ट्रांसपोर्ट नगर, जैसलमेर (राज)–345001

Office :- Executive Engineer, Jaisalmer
CPWD, Plot No. 6, Nirman Sadan,
Transport Nagar, Jaisalmer- 345001

e-Mail :- jsmsecjmcd.cpwd@nic.in & eejmcd@rediffmail.com

पत्र संख्या 63(1)/का.अभि./जैसलमेर/2021/215 दिनांक :– 02/3/2021

सेवा में,

कुलसचिव,
भारतीय वन्यजीव संस्थान,
पत्रपेटी सं. 18, चन्द्रवनी
देहरादून (उत्तराखण्ड) 248001
E-mail :- wii@wii.gov.in

विषयः– आपके विभाग के कार्य पर प्राप्तियों व खर्चे का माह फरवरी – 2021 का फार्म–65 भेजने बाबत्।

उपरोक्त विषय में लेख है कि निर्माण कार्य के खर्चे से सम्बन्धित के.लो.नि.वि. फार्म–65 संलग्न कर अग्रिम कार्यवाही हेतु प्रेषित है।

संलग्न :– फार्म–65

कार्यपालक अभियन्ता
के.लो.नि.वि. जैसलमेर (राज.)

DETAILS OF WII WORKS (Form-65) for the Month of February, 2021

S. No.	Name of Work	A/A & E/S No. & Date & Amount	DEPOSITS			EXPENDITURE			Balance	Amount Required	Physical Progress	Ramarks
			Opening Balance	Received During the Month	Total Deposits	Opening Balance	Exp. During the Month	Total Expenditure				
1	C/o The Conservation Breeding Satellite Center at Ramdevra Jaisalmer (SH:- C/o Incubation Hatchery, Chick Rearing Facility and Office Room i/c toilet, (Porta Cabin Structure) and C/o 50000 Ltr. Capacity U.G. Tank.	YVJ/WII/GIB-CBC Constrctn/2018 Date 04.04.2019 Rs. 5578200/-	5578200	0	**5578200**	4124141	0	**4124141**	1454059	--	100%	Work Completed
2	C/o GIB Conservation Breeding Satellite Centre, Juvenile unit, Live-food unit, Commissary, Veterinary unit &Quarantine/PME unit at Ramdevra Jaisalmer	YVJ/WII/GIB-CBC Constrctn/2018 /22 Date 07.02.2019 Rs. 23460000/-	7000000	8000000	**15000000**	11337015	40946	**11377961**	3622039	8460000	80%	Work in Progress

Executive Engineer
CPWD, Jaisalmer

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

WII/YVJ/GIB-SOLAR POWER PRJ/2019 (GIB-28) **Date: 14th August, 2019**

Shri. M. S. Negi,
Additional Director General (Wildlife)
Ministry of Environment Forest and Climate Change
Indira Paryavaran Bhavan, Jorbagh Road,
New Delhi 110003

Sub: Opinion on Tata Solar Power Project & ESSEL Surya Urja Company in GIB habitat- Reg

Sir,

This Institute was asked for an opinion on the solar power projects coming up in the Great Indian Bustard habitat in Jaisalmer Rajasthan. We have evaluated both sites and none is within any protected area or its vicinity. However, both projects are within the only remaining habitat of the GIB identified as the GIB Arc. The projects sites by themselves are not a problem for the species but their power-lines traverse the entire width of the GIB Arc and will pose a problem by possibility of causing GIB mortality through collision. As per NGT order dated November 18, 2016 # 6, no new power lines should be permitted in the GIB Arc until a view is taken by NBWL. We have recommended appropriate mitigation measures such as undergrounding the cables within the ARC and fitting bird diverters on power-lines outside the ARC.

NOC may be considered taking into account the recommendations of CWLW Rajasthan and adherence to the mitigation measures suggested by WII (Annexure I & II).

Yours faithfully,

(Dr. V. B. Mathur)
Director

Encl: As above

Copy to:

1) Shri Arindam Tomar, Chief Wildlife Warden, Aranya Bhawan, Jhalana Doongri, Jaipur- 302004

पत्रपेटी सं० 18, चन्द्रबनी, देहरादून – 248 001, उत्तराखण्ड, भारत
Post Box No. 18, Chandrabani, Dehradun - 248 001, Uttarakhand, INDIA
ई.पी.ए.बी.एक्स : +91-135-2640114, 2640115, 2646100 फैक्स : 0135-2640117
EPABX : +91-135-2640114, 2640115, 2646100 Fax : 0135-2640117
ई–मेल/E-mail : wii@wii.gov.in वेब/Website : www.wii.gov.in

Annexure I

Opinion on the Essel Surya Urja Company of Rajasthan Limited (ESUCRL) 220 kV Transmission Line.

Background:

The Great Indian Bustard (*Ardeotis nigriceps*) is a critically endangered bird (IUCN, 2011) that is endemic to India and a Schedule 1 species as per the Wildlife (Protection) Act 1972. In the past three decades there has been a steady decline in the population of GIB (~75%) and is now estimated at ~150 in the entire world. Historically, the bird was distributed throughout the western half of India, but currently, they are found in just five fragmented pockets. The largest population among these resides in the Thar landscape of Rajasthan. The species has a very slow life-cycle, it attains sexual maturity at 3-4 years and lays a single egg during breeding season. This slow life-history and direct and indirect human exploitation is the major factor for the decline of the species.

Earlier, GIB were subjected to exhaustive hunting and egg collection. However, the critical threat that is responsible for the rapid decline of GIB is direct mortality due to collisions with over-head electrical power lines (Wildlife Institute of India, 2018). Other causes of population declines are attributed to development of irrigation projects, change in farming techniques. Infrastructure development like wind turbines and powerline has resulted in degradation maize of powerlines with which the birds collide and die. GIB are low and heavy flyers and are at a high risk of fatal collisions with power-lines, which are difficult for them to detect from afar due to lack of frontal vision. The only viable population of GIB is in Jaisalmer, Rajasthan and is found in the northern part of the Desert National Park and Pokhran Field Firing Range. The GIB population is limited primarily to a landscape of about 8,514 km^2 which forms an Arc known as the GIB ARC (Fig 1). To ensure the survival of this last remaining population within the GIB ARC it has been proposed to mitigate all existing power lines within the critical GIB habitat and not permit any new power plants and power lines within this last remaining GIB habitat (NGT Original Application No. 63/2016(CZ) & 64/2016(CZ) Order No. 6 on 18th November 2016, MoEFCC circular to power companies 22 February 2019, Dutta, et al., 2013).

Current Project of Essel Surya Urja Company of Rajasthan Limited (ESUCRL):

ESUCRL has applied for authorization for laying electric lines under the transmission scheme "Connectivity System of 750 MW Phalodi – Pokaran Solar Power Park with 765/400/220 kV Pooling Station, Bhadla through a dedicated 220kV D/C transmission along with associated line bays at both ends.

1) **Power Generating Plant –**

Area: Ugraas Village (ESUCRL Solar Park)

Location: Latitude: 26.95132 N, Longitude: 72.04541 E

Latitude: 27.42270 N, Longitude: 72.07085 E

2) Power line –

Voltage (220kV), Distance from DNP- 136 km, Distance from enclosure: 0.7km (Khara Enclosure) and 4 km (Ramdevra ABC enclosure), Length in Arc: 30.1km

Such “green energy” projects are encouraged by the Government policies to address the energy crisis in a cleaner renewable energy source.

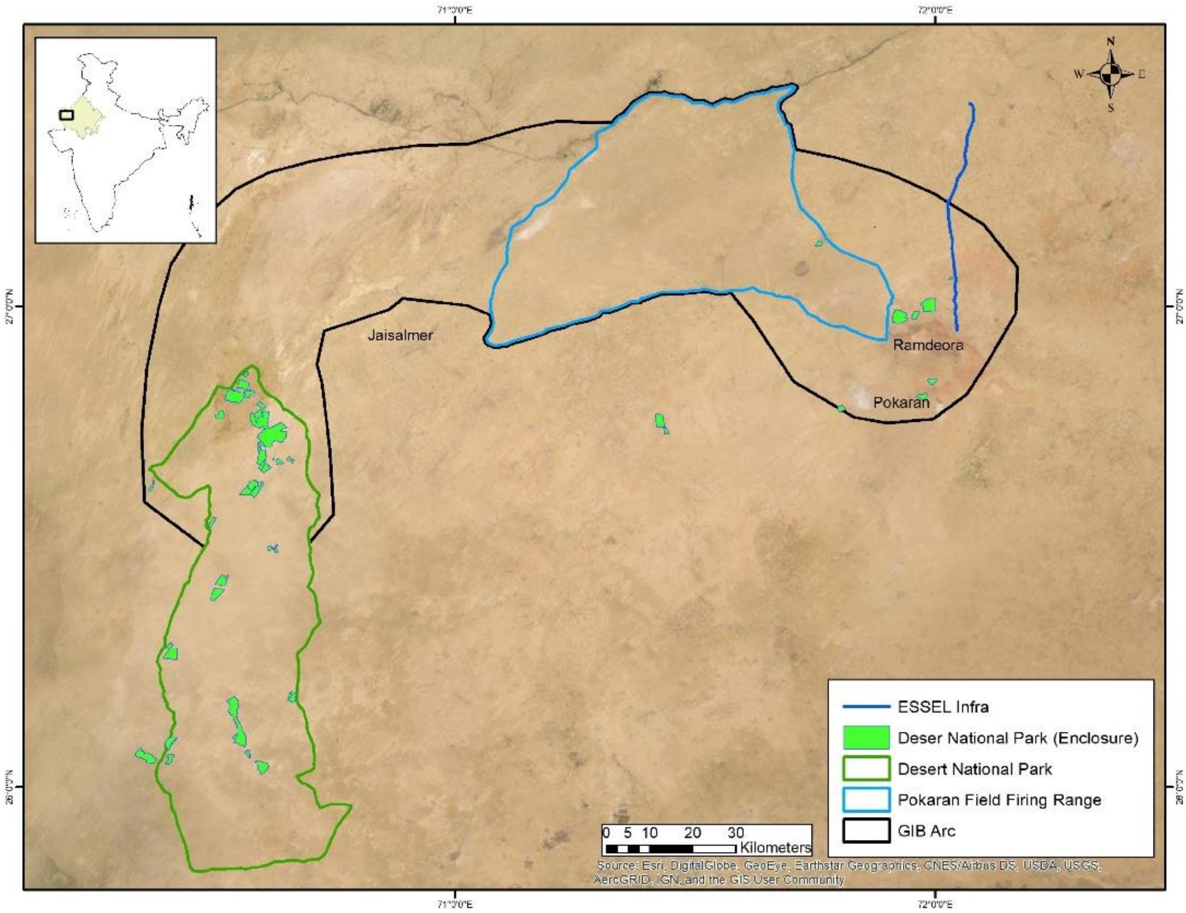


Figure 1. Location of Essel Surya Urja Company of Rajasthan Limited (ESUCRL): 220 kV Project in relation to the Desert National Park, Pokhran Field Firing Range and the Great Indian Bustard Conservation Arc Landscape.

Figure 2. A solar LED equipped bird diverter installed on a powerline in Jaisalmer, Rajasthan.

Observations and Mitigation Measures:

1) The solar power plant and its power line do not pass through any protected areas and are not within a 10 km radius of a protected area.
2) However, the solar power plant and its' associate power lines pass through the only remaining habitat of the Great Indian Bustard known as the GIB Arc.
3) According to the National Green Tribunal Order no. 6, dated 18 November 2016 Application N. 63/2016(CZ) and 64/2016(CZ) , no new wind energy projects and their power lines be allowed in the GIB Arc till a clear view is provided on the issue by the NBWL. Though the order does not mention solar power projects, its intent is clear as to no new power lines (which cause GIB mortality) be allowed within the GIB Arc
4) The solar power plant per se is not a threat to the survival of the GIB in the area but the powerline emanating from the solar plant traverses the GIB arc in a manner that is likely to cause GIB mortality due to collision with the birds as the powerline is directly in the flight path of the GIB that use the Arc extensively.
5) The line should be underground inside the GIB ARC and the line outside the ARC must be fitted with bird diverters.

References

- Dutta, S., Rahmani, A., Gautam, P., Kasambe, R., Narwade, S., Narayan, G., & Jhala, Y. (2013). *Guidelines for Preparation of State Action Plan for Resident Bustards' Recovery Programme.* New Delhi: Ministry of Environment and Forests, Government of India.

- IUCN. (2011). *IUCN Red List of Threatened Species*, 2011.1. Retrieved from www.iucnredlist.org

- Wildlife Institute of India. (2018). *Powerline Mitigation to Conserve Bustards.* Dehradun: WIldlife Institute of India.

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

Annexure II

Opinion on the Tata Power Renewable Energy Limited (TPREL) 150 MW SOLAR Power Project and 220 kV Transmission Line.

Background:

The Great Indian Bustard (*Ardeotis nigriceps*) is a critically endangered bird (IUCN, 2011) that is endemic to India and a schedule 1 species on the Wildlife (protection) Act 1972. In the past three decades there has been a steady decline in the population of GIB (~75%) and is now estimated at ~150 in the entire world. Historically, the bird was distributed throughout the western half of India, but currently, they are found in just five fragmented pockets. The largest population among these resides in the Thar landscape of Rajasthan. The species has a very slow life-cycle, it attains sexual maturity at 3-4 years and lays a single egg during breeding season. This slow life-history and direct and indirect human exploitation is the major factor for the decline of the species.

Earlier, GIB were subjected to exhaustive hunting and egg collection. However, the critical threat that is responsible for the rapid decline of GIB is direct mortality due to collisions with over-head electrical power lines (Wildlife Institute of India, 2018). Other causes of population declines are attributed to development of irrigation projects, change in farming techniques. Infrastructure development like wind turbines and power-line has resulted in degradation maize of power- lines with which the birds collide and die. GIB are low and heavy flyers and are at a high risk of fatal collisions with power-lines, which are difficult for them to detect from afar due to lack of frontal vision. The only viable population of GIB is in Jaisalmer, Rajasthan and is found in the northern part of the Desert National Park and Pokhran Field Firing Range. The GIB population is limited primarily to a landscape of about 8,514 km^2 which forms an Arc known as the GIB ARC (Fig 1). To ensure the survival of this last remaining population within the GIB ARC it has been proposed to mitigate all existing power lines within the critical GIB habitat and not permit any new power plants and power lines within this last remaining GIB habitat (NGT Original Application No. 63/2016(CZ) & 64/2016(CZ) Order No. 6 on 18th November 2016, MoEFCC circular to power companies 22 February 2019, Dutta, et al., 2013).

Current Project of Tata:

Tata Power Renewable Energy Limited (TPREL) develops, construct and operates wind and solar power assets. TPREL has commissioned 150 MW Solar Power project at Chhayan, near

Pokaran and construction of 220 kV Single Circuit transmission line on Double Circuit structure from Tata Solar Power Plant.

1) **Power Generating Plant –**
   Area: Chayyan-1, Tehsil Pokaran, Jodhpur, Rajasthan
   Location: Latitude: 27°9’39.24” N
   Longitude: 71°49’12.54” E
2) **Power line –**
   Voltage (220kV), Distance from DNP- 129 km, Critical patch: 9.99km, Distance from enclosure: 2km, Length in Arc: 16.3km

Such “green energy” projects are encouraged by the Government policies to address the energy crisis in a cleaner renewable energy source.

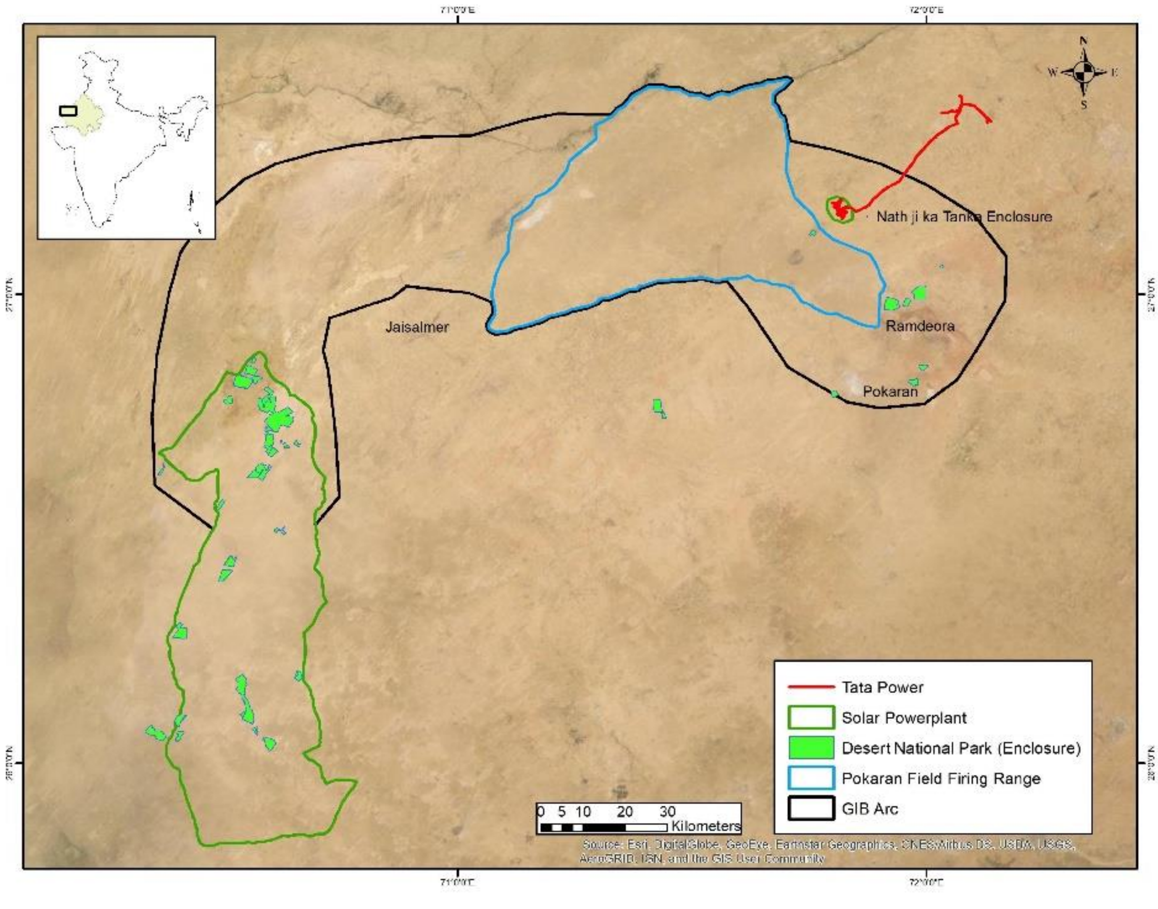


Figure 1. Location of Tata Power Renewable Energy Limited (TPREL) 150 MW SOLAR Power Project in relation to the Desert National Park, Pokhran Field Firing Range and the Great Indian Bustard Conservation Arc Landscape.

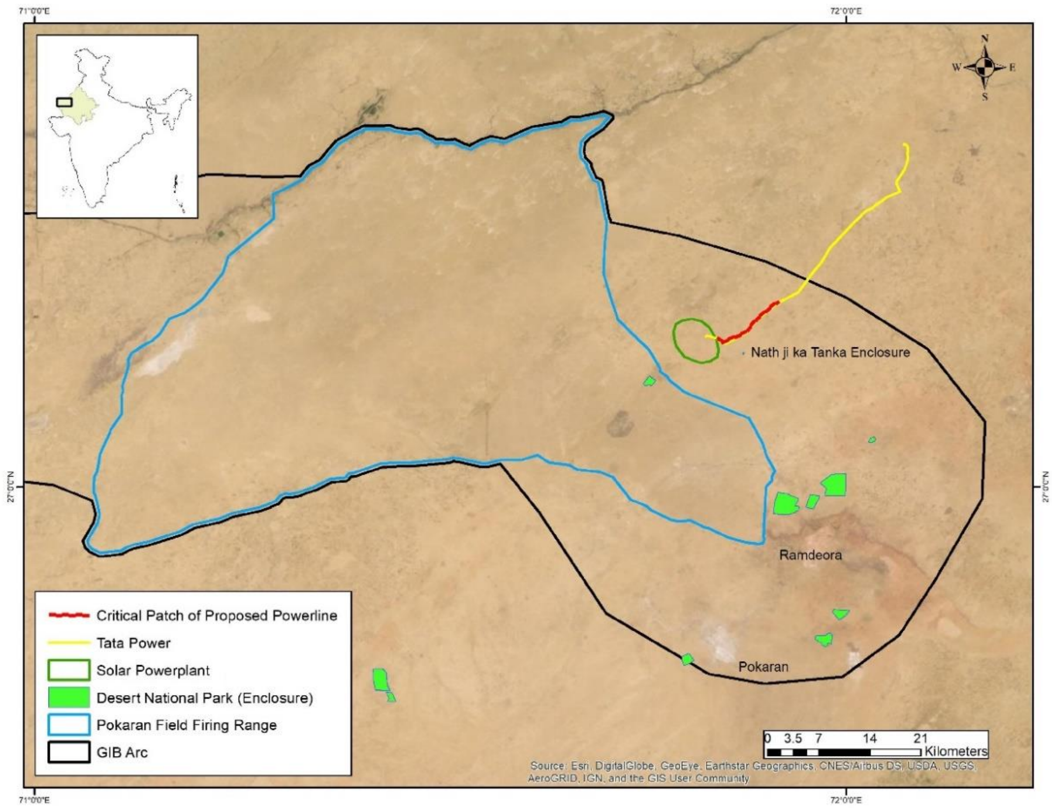


Figure 2. Critical patch of the Tata Power Renewable Energy Limited power line that passes close to Great Indian Bustard habitat enclosures and needs to be undergrounded. The remaining line should be fitted with Bird Diverters.

Figure 3. Site Visit by Wildlife Institute of India team

Figure 4. A solar LED equipped bird diverter installed on a power-line in Jaisalmer, Rajasthan.

Observations and Mitigation Measures:

1) The solar power plant and its power line do not pass through any protected areas and are not within a 10 km radius of a protected area.
2) However, the solar power plant and its' associate power lines pass through the only remaining habitat of the Great Indian Bustard known as the GIB Arc.
3) According to the National Green Tribunal Order no. 6, dated 18 November 2016 Application N. 63/2016(CZ) and 64/2016(CZ), no new wind energy projects and their power lines be allowed in the GIB Arc till a clear view is provided on the issue by the NBWL. Though the order does not mention solar power projects, its intent is clear as to no new power lines (which cause GIB mortality) be allowed within the GIB Arc
4) The solar power plant per se is not a threat to the survival of the GIB in the area but the power-line emanating from the solar plant traverses the GIB arc in a manner that is likely to cause GIB mortality due to collision with the birds as the power-line is directly in the flight path of the GIB that use the Arc extensively.
5) Due to the absence of precise GIB movements that need to be obtained through a telemetry study on the GIB so as to pinpoint critical flight paths, precautionary principle suggests that the most critical length of approximately 10 km of the power-line that passes close to important patches of GIB habitats (Grassland enclosures) should be undergrounded.
6) Since the power-line has already been installed, the remaining length of the power-line (non-ungrounded) needs to be fitted with bird diverters to minimize GIB and other bird mortality.

References

- Dutta, S., Rahmani, A., Gautam, P., Kasambe, R., Narwade, S., Narayan, G., & Jhala, Y. (2013). *Guidelines for Preparation of State Action Plan for Resident Bustards' Recovery Programme.* New Delhi: Ministry of Environment and Forests, Government of India.
- IUCN. (2011). *IUCN Red List of Threatened Species*, 2011.1. Retrieved from www.iucnredlist.org
- Wildlife Institute of India. (2018). *Powerline Mitigation to Conserve Bustards.* Dehradun: WIldlife Institute of India.

CONSERVING

GREAT INDIAN BUSTARD

LANDSCAPES THROUGH SCIENTIFIC UNDERSTANDING AND PARTICIPATORY PLANNING

Front Cover:
Arvind Venkatraman

FINAL REPORT 2020

rspcb

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

BUSTARD
RECOVERY PROGRAM

Funding agency:

- Rajasthan State Pollution Control Board
- National CAMPA Advisory Council
- National Geographic Society Conservation Trust
- Mohamed bin Zayed Species Conservation Fund
- U.S. Fish & Wildlife Service
- Wildlife Institute of India Grant-in-Aid

Implementating agency:

- Wildlife Institute of India

Collaborating agencies

- Rajasthan Forest Department
- Rajasthan State Pollution Control Board

Other partners

- International Fund for Houbara Conservation/Reneco
- Humane Society International

Project supervisors

- Dr. Yadvendradev Jhala, Dean & P.I.
- Dr. Sutirtha Dutta, Scientist – D & Co- PI.
- G. S. Bharadwaj, APCCF & Co- PI.

Supporting officers:

ADG(WL), IG(WL) & DIG(WL), MoEFCC, CWLW Rajasthan, CCF (WL) Jodhpur, DCF(WL) Jaisalmer

Project team:

- Dr. Shravan Singh Rathore
- Dr. Chittaranjan Dave
- Dr. Sujit Narwade, Project Scientist
- Dr. Tushna Karkaria, Project Veterinarian
- Mr. Bipin C. M., Project Associate
- Mr. Arjun Awasthi, Project Associate
- Mr. Vineet Singh, CAMPA Project Associate (Toxicology)
- Mr. Srinivas Yellapu, CAMPA Project Fellow (Genetics)
- Ms. Priyamvada Bagaria, CAMPA Project Fellow (GIS)
- Mr. Pravesh Saklani, Project Fellow
- Mr. Mohib Uddin, Project Assistant
- Mr. Sourav Supakar, Project Assistant
- Ms. Tanya Gupta, Project Assistant
- Mr. Devendradutta Pandey,Project Assistant
- Mr. Vishal Varma,Project Assistant
- Mr. Indranil Paul, Project Assistant
- Ms. Hrishika Sharma, Project Assistant
- Ms. Hemlata Joshi, Project Assistant

Interns & Assistants:

Anjali Nagar, Arnab Chatterjee, Ashish Jangid, Chanesar Khan, Mayuri Moitra, Monisha Mohandas, Pushkar Phansalkar, Risikesh Tripathi, Shweta Iyer, Sohan Lal Genwa, Tanerav Singh, Varun Kher, Vikas Verma, Vijay Patel

Design:

- Tanya Gupta

Special thanks to:

Dr. Asad Rahmani, Mr. Devesh Gadhavi, and Mr. Aditya Bisht

TABLE OF CONTENTS


Tanya Gupta

BACKGROUND

Status

The Great Indian Bustard *Ardeotis nigriceps* (hereafter GIB) is one of the heaviest flying birds and among the rarest species in the world. With ~150 individuals left, almost exclusively in India, it is Critically Endangered (IUCN 2018) and protected under Schedule I of the Wildlife (Protection) Act, 1972. Their populations have steadily declined by 75% in last 30 years and are facing imminent extinction risk unless serious conservation actions are put in place (Dutta et al. 2011). Historically distributed across the hot arid and semi-arid grasslands and desert, GIB are currently restricted in only five isolated regions. The largest population of 128 (19SE) birds occur in c9252 sqkm Thar landscape of Rajasthan (Dutta et al. 2018). Other populations are <10 birds each, occurring in Gujarat (Lala-Naliya Sanctuary and its neighbourhood in Kachchh), Maharashtra (GIB Sanctuary in Solapur, alongside Chandrapur and Nagpur), Andhra Pradesh (Rollapadu Wildlife Sanctuary and its neighbourhood in Kurnool) and Karnataka (Ballari) (Dutta et al. 2011).

Threats

The species has declined due to compounding effects of direct and indirect human exploitation on their slow life-history traits. Past hunting and egg collection had reduced their population to ~1260 birds in 1969 (Dharmakumarsinhji 1971). Their decline has continued under prevailing habitat loss as dry grasslands are marginalized as 'unproductive wastelands' and diverted to other land uses. Recent developments in irrigation and farming technologies have changed cropping practices from seasonal to year-round inorganic crops. This change has led to resource scarcity and pesticide contamination. Infrastructure development such as power projects and roads have caused severe habitat degradation. Being low and heavy flyers, GIB collide with power lines that are difficult to detect from afar. Populations of free-ranging dogs and pigs have increased in bustard habitats, and along with native predators (fox, mongooses, and cats), have increased the predation pressure on nests and chicks. Mismanagement of open areas by developing tree plantations and protection infrastructure are further reducing the last remaining bustard habitats.

Past efforts of creating bustard Sanctuaries over large human-use landscapes, without appropriate settlement of land rights, have generated resentment among local people, and have caused persecution and local extinctions of the birds from some sanctuaries. Traditional ways to manage these habitats are eroding due to rapid socioecological changes driven by state policies (Dutta et al. 2013). Although most remaining breeding habitats are protected to some level, vast movements expose them to these threats in the larger landscape and defeat the purpose of small breeding reserves. Since these large landscapes cannot be freed from human uses, a mixed approach of Protected Area based conservation of breeding habitats and compatible human landuses/ infrastructure in adjoining landscapes will be most effective. However, the unavailability of vital information such as ranging patterns, magnitude of threats, and how to mitigate them, impede such conservation efforts.

Conservation

Indian conservation circles have voiced the need of recovery actions for bustards as flagships of dry grasslands since many years. The National Guidelines for Bustard Recovery Plans (Dutta et al. 2013) developed by Ministry of Environment, Forest and Climate Change (MoEFCC) recommend creating inviolate breeding areas to boost recruitment, prioritize areas in the landscape for mitigating threats and improving protection, engaging communities in conservation through incentives and implementing a conservation breeding program for insurance. State Forest Departments in collaboration with research and conservation institutions are implementing these actions with mixed success.

The Project

The Rajasthan Pollution Control Board (RSPCB) funds were utilized to identify priority areas and threats in GIB landscapes for optimizing the allocation of conservation resources. These activities are being carried out in collaboration with State Governments, local NGOs and research organizations, to pool knowledge/expertise and ensure timely and effective implementation. Additionally, we are undertaking holistic ex-situ and in-situ conservation for GIB in Rajasthan and other bustard range states since 2016 with funding support from National Compensatory Afforestation Fund Management and Planning Authority (CAMPA) Advisory Council (NCAC). GIB habitats support a plethora of other endangered wildlife, such as the spiny-tailed lizard *Saara hardwickii*, chinkara *Gazella bennettii*, foxes *Vulpes spp*, Indian wolf *Canis lupus pallipes*, and blackbuck *Antelope cervicapra* that will be benefitted by some of these conservation measures.

OBJECTIVES

- Identify priority areas by undertaking population and habitat surveys
- Understand ranging patterns and habitat use through biotelemetry
- Characterize threats such as power-lines, free-ranging dogs, and pesticides
- Implement pilot GIB-friendly land uses
- Propose appropriate policy and legislative changes for conserving priority bustard areas

STUDY AREA

The area falls in Desert Biogeographic Zone (Rodgers et al. 2002) with arid (Jodhpur) to hyperarid (Jaisalmer and Bikaner) 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°C), relatively cold winter (temperature dropping below 0°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 Thorny Scrub, characterized by open woodlot dominated by *Prosopis cineraria*, *Salvadora persica* and exotic *Acacia tortilis* trees, scrubland dominated by *Capparis decidua, Zizyphus mauritiana, Salvadora oleoidis, Calligonum polygonoides, Leptadenia pyrotechnica, Aerva pseudotomentosa, Haloxylon salicornicum and Crotolaria bhuria* shrubs, and grasslands dominated by *Lasiurus sindicus* and *Dactyloctenium sindicum.*

Notable fauna, apart from the ones mentioned before, include mammals like 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 per sqkm that 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 sqkm) has been declared as Desert National Park (Wildlife Sanctuary), which is not inviolate and includes 37 villages (Rahmani 1989). A large number of renewable (solar and wind) energy projects with associated transmission lines are expanding in this landscape.

PROJECT ACTIVITIES

Dilipsingh Chaudsama

1. POPULATION AND HABITAT SURVEYS

We conducted joint surveys with Rajasthan Forest Department with the help of trained volunteers, to understand the current status, distribution patterns, and local contexts of GIB and associated wildlife in Thar. Four surveys (2014–17) were conducted and detailed reports are available as Appendices 1, 2, 3, & 4. Here we report findings of the 2017-18 survey.

Delineating the potential great Indian bustard landscape in Thar:

We mapped the past distribution area of GIB in western Rajasthan by collating historical (post 1950s) records (Rahmani 1986; Rahmani and Manakadan 1990) and bounding the outermost locations. We removed areas where the species has not been recorded in recent times (sources: Rajasthan Forest Department, Ranjitsinh and Jhala 2010). Additionally, extensive sand dunes, built-up and intensive agriculture areas were considered unsuitable based on prior knowledge (Dutta 2012). These areas were identified from land-cover maps, Digital Elevation Model and night-light layers in GIS domain, Google Earth imageries, and extensive ground validation surveys. The remaining landscape, an area of 20,000 sqkm, was considered potentially habitable for great Indian bustard and subjected to sampling (Figure 1).

The Project team assessed the status of native and conservation-dependent species such as the GIB, chinkara and desert fox, non-native species such as free-ranging dogs, pigs *Sus spp.* and nilgai *Boselaphus tragocamelus* that live alongside the habitat of the GIB, and anthropogenic pressures across 19,728 sqkm in Thar spanning Jaisalmer, Jodhpur and small parts of Bikaner and Barmer districts of Rajasthan. Systematic surveys were conducted in 144 sqkm cells from slow-moving vehicles along 29.2 ± 8.0SD km transects to record species detections, habitat characteristics in sampling plots, and secondary information on species occurrences (Figure 1).

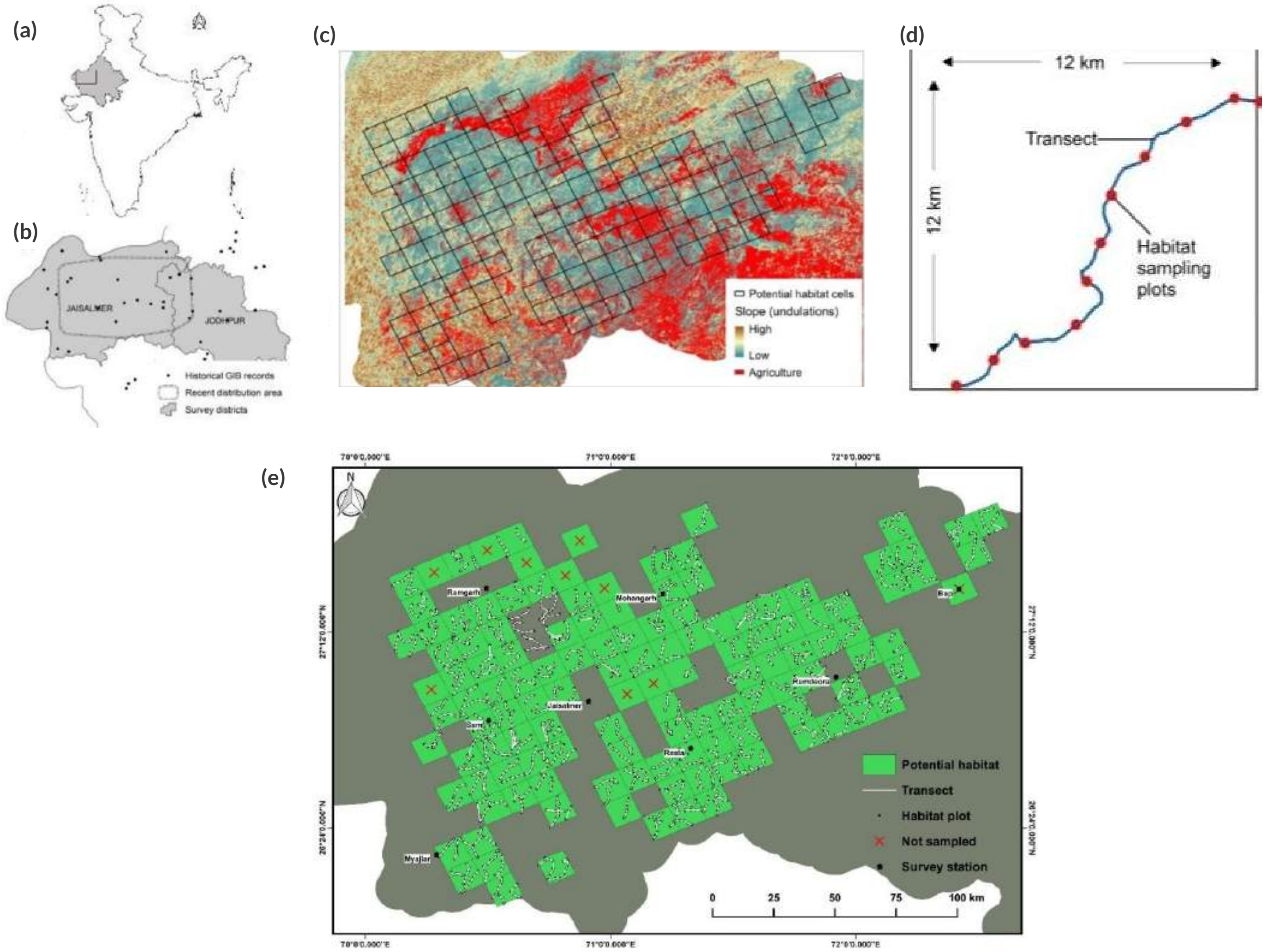


Figure 1. Sampling design for Great Indian Bustard, associated species and habitat assessment in Thar landscape: (a) location of study area; (b) delineation of bustard landscape from existing information on species' occurrence; (c) remotely sensed habitat information and distribution of transects in 144 sqkm cells overlaid on potential habitat; (d) habitat sampling plots at two-km interval on sample transect; and (e) survey efforts in 2017-18.

Multiple teams comprising of field biologists and Rajasthan Forest Department staff rapidly sampled 121 cells along 3,529 km transects (extensive surveys) with additional 635 km transects in five GIB occupied cells (intensive surveys) during 2017-18. Extensive surveys provide information on bustard (and associated species') occurrence across landscape and intensive surveys provide information on bustard density in occupied cells. GIB and other key species detection data were analysed in Occupancy (MacKenzie et al. 2006) and Distance Sampling (Thomas et al. 2010) framework to estimate proportion of sites occupied and species density/ abundance.

During 2014-17, 38 (2014), 40 (2015), 37 (2016) and 37 (2017) GIBs were detected. Their detection/ non-detection in two-km transect segments (spatial surveys) across cells (2017) showed that 6.7 ± 2.9SE % of sites were occupied (naive occupancy 5%). Bird density was estimated at 0.48 ± 0.10SE per 100 sqkm across all sites and 7.49 ± 1.63SE per 100 sqkm in used sites (cells where at least one bird was detected). Abundance was estimated at 95 ± 21SE individuals in the 19,728 sqkm landscape, pooling data across 2016-17. This estimate was negatively biased due to inadequate surveys in high-density sites within the Pokhran Field Firing Range (PFFR).

Later, the project team liaised with the Commanding Officer of the Indian Army and was granted special permission for the year 2018 to access PFFR to survey. We conducted follow-up distance based line transect surveys in the subset of landscape where the species is distributed (western Thar: 4068 sqkm area, and Pokhran Field Firing Range: 5184 sqkm area) jointly with Indian Armed Forces in March–April 2018. The PFFR has stretches of untouched grasslands that are critical for bustards. The lack of substantial human interference lends this area to be the most conducive to GIB. With an area of > 3,000 sqkm, the range offers a valuable insight into the last remnants of the species as well as to serve as an iconic representation of what erstwhile grasslands were in India.

Based on these surveys, abundance was estimated at 128 ± 19SE individuals in 9252 sqkm GIB distribution area in Thar. But, there might be a real decline in numbers, as comparison of species' encounter rate across years, keeping sampled sites constant, indicated a non-significant but declining trend between 2014-15 (1.00 ± 0.41SE per 100 km) and 2016-17 (0.83 ± 0.30SE per 100 km).

Additional ancillary information based on power line carcass surveys (two GIB mortalities in 20 km high tension power lines surveyed seven times) indicated that about 18 birds were expected to have died because of the 152 km high tension power lines distributed across bustard occupied sites (Figure 2).

Chinkara was found in 89% of sites and its' density at landscape-scale was estimated at 205 ± 14SE per 100 sqkm, yielding abundance of 40,442 ± 2,811SE in 19,728 sqkm landscape (2017). Desert fox was found in 41 % of sites, with estimated density of 15.03 ± 2.39SE per 100 sqkm, and abundance of 2,965 ± 471SE individuals in 19,728 sqkm landscape.

For meaningful comparison of population trends for our focal species, we computed mean + 1 SE animal encounter rates per 100 km across cells, which were surveyed in all years. Additionally, annual occupancy estimates were derived from our dynamic occupancy models to infer trends (Table 1). These results showed a rapid increase of free-ranging dogs, an increasing trend of pigs, declining trend of chinkara and a non-significant but declining trend of GIB that needs to be ascertained in subsequent surveys.

Table 1: Species' population trend across years (2014–2017) in Thar landscape, estimated as mean (SE) number of animals per 100 km. For each species, encounter rates have been computed for all cells sampled in a year (first row) and the subset of cells sampled in all years (same cells).

Species	Sample	2014	2015	2016	2017
Great Indian Bustard	All cells	0.82 (0.32)		0.59 (0.2)	
	Same cells	1 (0.41)		0.83 (0.3)	
Chinkara	All cells	83.44 (11.98)	85.58 (14.94)	60.71 (7.44)	80.75 (8.8)
	Same cells	78.72 (15.31)	85.48 (17.6)	59.93 (10.86)	79.37 (12.78)
Desert fox	All cells	3.56 (0.61)	2.64 (0.81)	1.87 (0.38)	2.76 (0.4)
	Same cells	3.29 (0.79)	3.06 (0.98)	2.27 (0.54)	2.64 (0.52)
Indian fox	All cells	0.21 (0.12)	0.1 (0.1)	0.29 (0.15)	0.22 (0.08)
	Same cells	0.26 (0.19)	0.12 (0.12)	0.28 (0.22)	0.18 (0.09)
Dog	All cells	3.47 (1.15)	5 (1.22)	5.08 (0.92)	18.6 (5.44)
	Same cells	4.32 (1.77)	4.59 (1.28)	5.46 (1.24)	23.11 (9.39)
Nilgai	All cells	3.07 (1.42)	4.88 (1.8)	9.28 (3.15)	3.93 (1.11)
	Same cells	4.41 (2.38)	5.06 (2.08)	5.63 (2.03)	5.42 (1.8)
Pig	All cells	0.85 (0.85)	1.28 (0.91)	2.33 (0.93)	1.98 (0.75)
	Same cells	1.45 (1.45)	0.89 (0.89)	2.92 (1.35)	2.26 (1.22)
Cattle	All cells	217.5 (32.18)	687.9 (194.62)	465.09 (67.15)	484.49 (62.84)
	Same cells	237.79 (43.93)	558.58 (166.01)	450.43 (83.28)	469.53 (101.8)
Sheep & Goat	All cells	1252.6 (124.76)	1539.42 (209.83)	2187.03 (228.66)	2065.83 (138.8)
	Same cells	1389.71 (165.7)	1622.77 (248.21)	2146.63 (291.9)	1868.28 (137.6)


G.S Bharadwaj

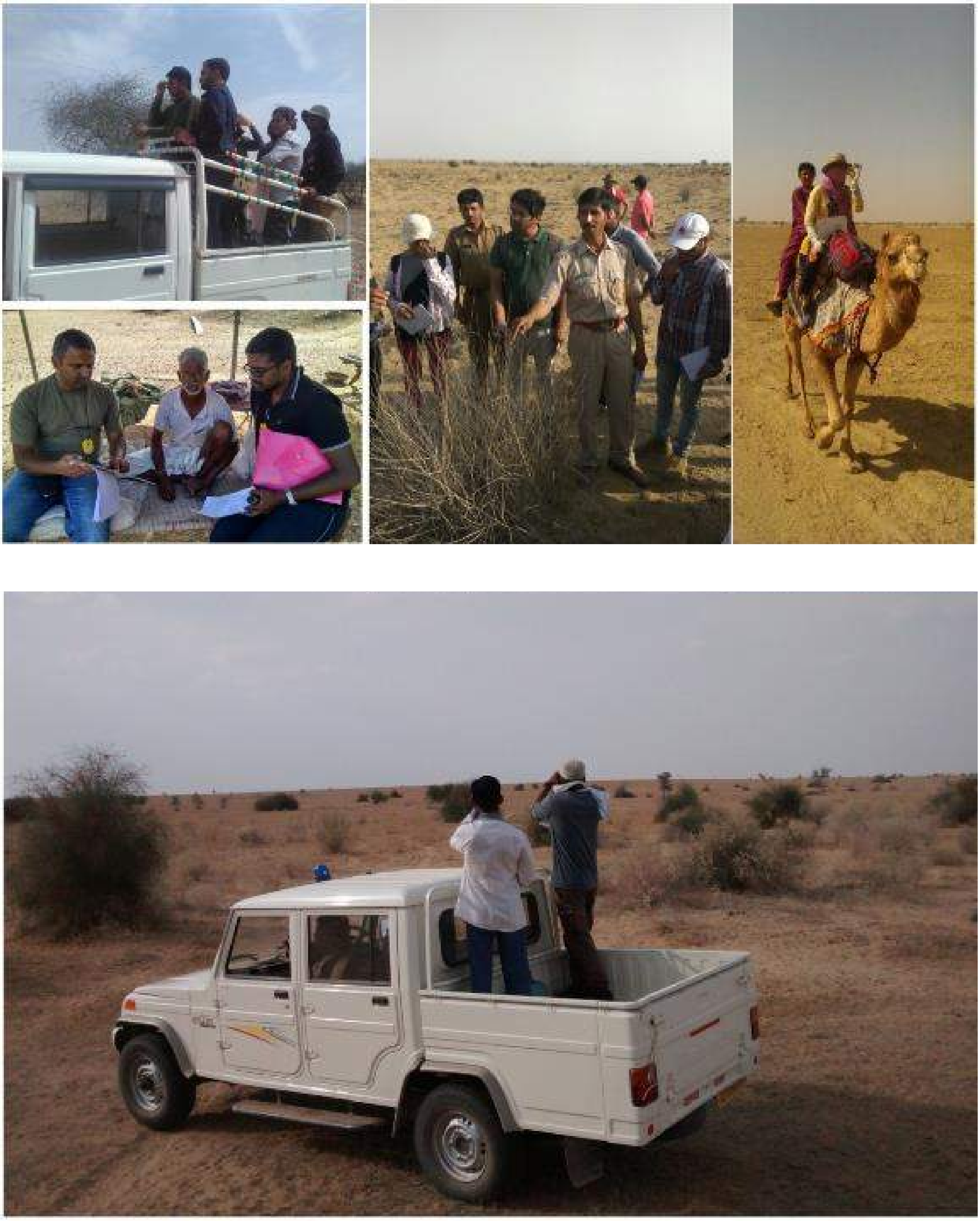


Image 1. Field activities (training, surveys and questionnaires) for status assessment of Great Indian bustard, associated fauna and habitat in Thar. © WII

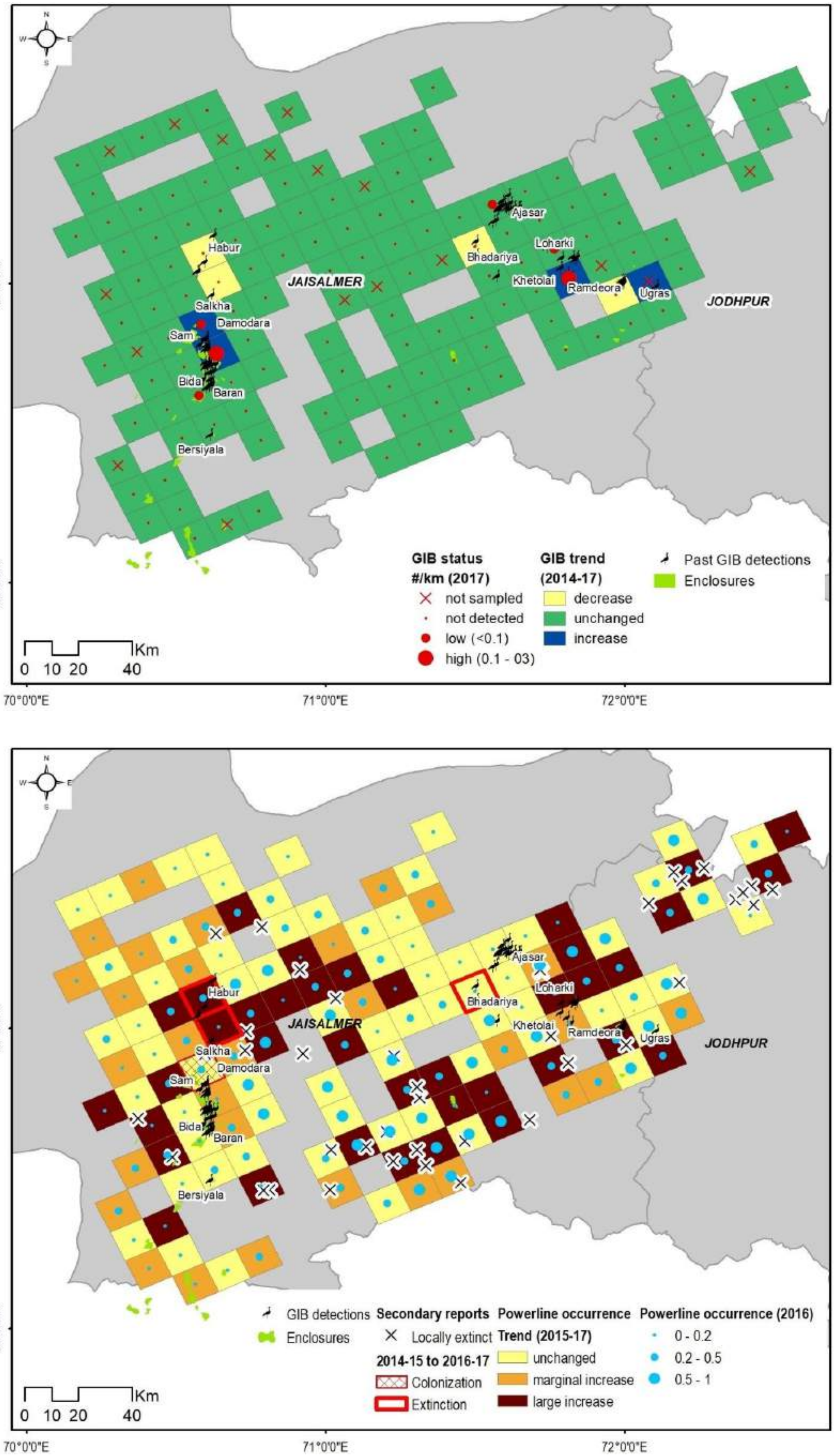


Figure 2. Status, distribution and trend of Great Indian Bustard population (pg11) against the distribution and trend of power-line networks in Thar landscape (2014-18).

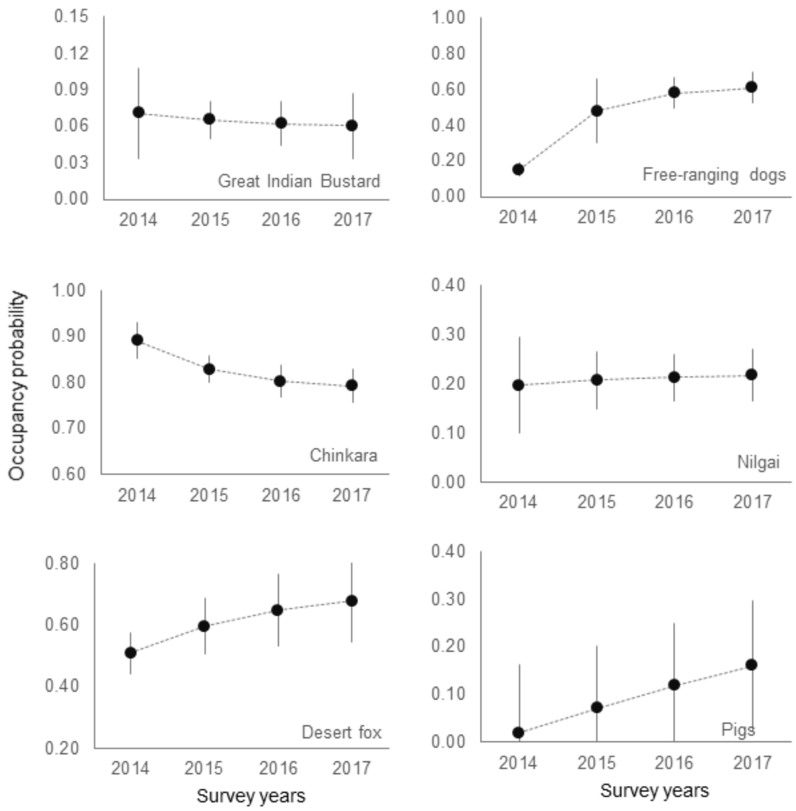


Figure 3. Species' distribution trend across years (2014–17) in Thar landscape, estimated as mean+1SE proportion of sites occupied using dynamic occupancy models, for native/ 'important' (left) and non-native / 'potential problem' species (right).

Our threat surveys showed an expansion of human artefacts across survey years, wherein the proportion of sampling plots with water source, power-lines, farm-huts and wind turbines had increased annually by 0.12, 0.09. 0.07, and 0.03, respectively, over the last three years (Figure 4). Correspondingly, population of free ranging dogs showed a remarkable expansion over these years, wherein the proportion of sites occupied increased from 0.15 ± 0.04SE (2014) to 0.61 ± 0.09SE (2017), and their encounter rate increased from 4.32 ± 1.77SE to 23.11 ± 9.39SE per 100km in sites that were monitored across all years (Table 1).

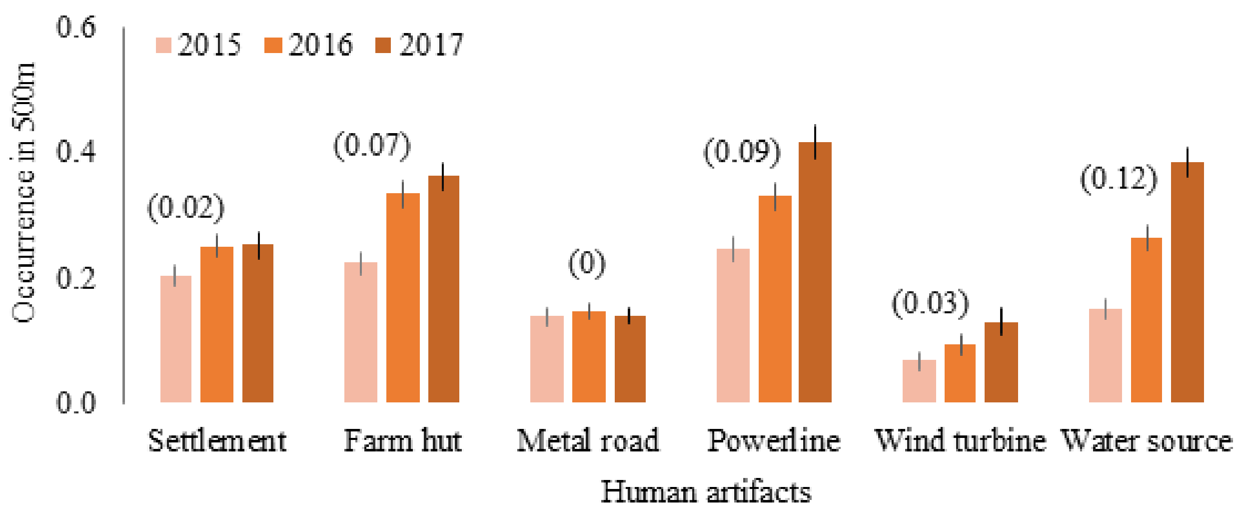


Figure 4 : Occurrence probability of human artifacts in sampling plots across Thar landscape from 2015 to 2017. Error bars are 1 SE across 144-sqkm cells, and values in parentheses are regression slopes against years that are indicative of temporal trends.

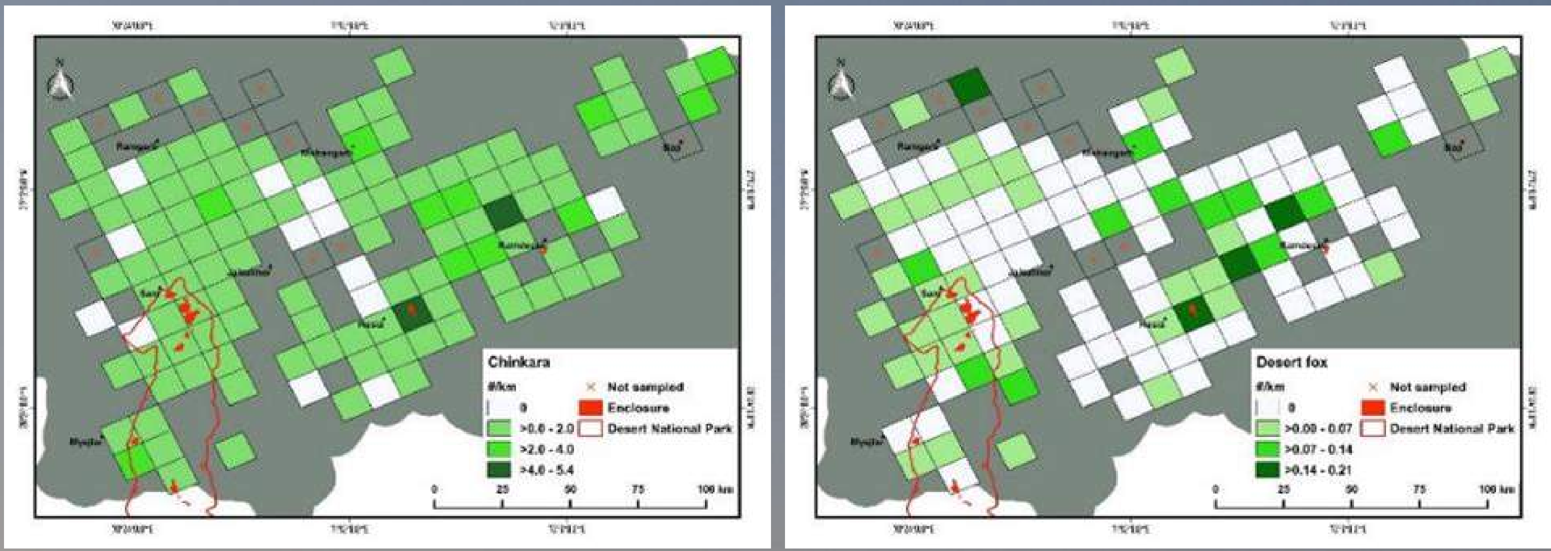


Figure 5. Status and distribution of key species associated with Great Indian Bustard in Thar landscape (2017).

Recommendations

Based on our results and from field knowledge, we strongly recommend:
a) Expeditiously mitigating power-lines by undergrounding all lines within priority area (this is the only fool proof measure for conserving the great Indian bustard), and marking lines with bird diverters in potential areas,

b) Improving Great Indian Bustard recruitment in existing enclosures using predator-proof-fences and nest-predator removal,

c) Creating more enclosures or conservation/community reserves in priority conservation cells,

d) Smart and intensive patrolling to control poaching and generate management information,

e) Continue targeted research to understand local ecology of Great Indian Bustard, characterize threats at a finer scale, and ranging patterns,

f) Balancing local livelihood concerns with conservation goals through social research and incentivized bustard-friendly land-uses, and

g) Engaging local communities to monitor and protect wildlife through outreach and incentive programs.

TELEMETRY BASED RESEARCH

Overview

We received permission to tag the Great Indian Bustard in February 2019, and tagged five birds in Desert National Park and Pokhran areas of Thar between March 2019 and July 2020. We captured birds using nylon noose traps in foraging paths, nests and water guzzlers. We fitted birds with solar powered GSM/GPRS backpack PTTs (E-obs and Microwave telemetry) using elastic harness material that weighed <1% of body weights. These tags have GPS and/or acceleration sensors and transmit data using mobile and internet networks. Birds transmitted data for 64 – 542 days. There was no mortality within the first month or any apparent anomaly in their behavior. The table below provides telemetry statistics at a glance (Table 2).

Table 2. Ranging patterns of tagged Great Indian Bustard in Thar (March 2019 – Sep 2020)

BIRD	1-HR FIXES	RADIO-DAYS	DAILY DISTANCE IN M (SE)	95% MINIMUM CONVEX POLYGON HOME RANGE AREA (SQKM)
DALI	1,409	64	7,684 (6,735)	1,037.65
5946	1,495	74	8,585 (3,583)	103.87
5947	1,865	161	4,062 (3,351)	98.28
5948	1,129	94	2,932 (3,510)	37.79
5949	8,229	542	5,747 (4,276)	158.57
OVERALL	**14,127**	935.457	**5,802 (2,375)**	

Tagging team: Dr. Y. V. Jhala, Dr. Sutirtha Dutta, Dr. Tushna Karkaria, Dr. Shravan Rathore, Bipin C.M., Mohib Uddin, Devedradutta Pandey, Sourav Supakar, project assistants, interns and field assistants. Technical assistance in trapping: Mr. Ali Hussain and Mr. Aslam. Expert inputs by Dr. Juan Carlos Alonso, Senior Professor, Natinal Museum of Science, Spanish Council for Scientific Research, Spain

In consultation with Rajasthan Forest Department officers and staff: Mr. Arindam Tomar (CWLW), Mr. G. S. Bharadwaj, Mr. Anoop K.R., Mr. Kapil Chandrawal (DFO, WL) Jaisalmer, Mr. Sagar Pawar (ACF, WL), Mr. Vijay Borana (ACF, WL), Mr. Sriram Saini (RO, Sudasari), Mr. Jethmal (RO, Sudasari), Mr. Danveer, Mr. Harish Bishnoi, Mr. Ramswaroop Meena, Mr. Amba Ram (Forest guards).

Image 2. Great Indian Bustard tagging team in Desert National Park, Jaisalmer. © WII

Image 3. Glimpses of Great Indian Bustard tagging exercise in Jaisalmer. © WII

The GPS fixes acquired from tagged birds were plotted on GIS domain to assess their home range and movement patterns with respect to conservation areas and land-uses. Bird home range was estimated from 1-hour interval fixes (for independence and uniformity between tags with varying data resolutions) using 95% Minimum Convex Polygon (MCP) technique.

HOW TAGGED BIRDS USE THE LANDSCAPE

Four birds were tagged in RKVY, Sudasari and Chowani enclosures of Desert National Park. These individuals were largely restricted in/around these enclosures of the Park with occasional movement towards Salkha and Khaba. One bird was tagged near Askandra that ranged more widely between Ajasar, Khetolai and Ramdevra. Areas used by birds matched the species census locations and were mostly within the priority landscape identified by the Wildlife Institute of India (https://wii.gov.in/gib_powerline_maps). The Didhoo-Askandra Oran used by a bird was outside the priority landscape.

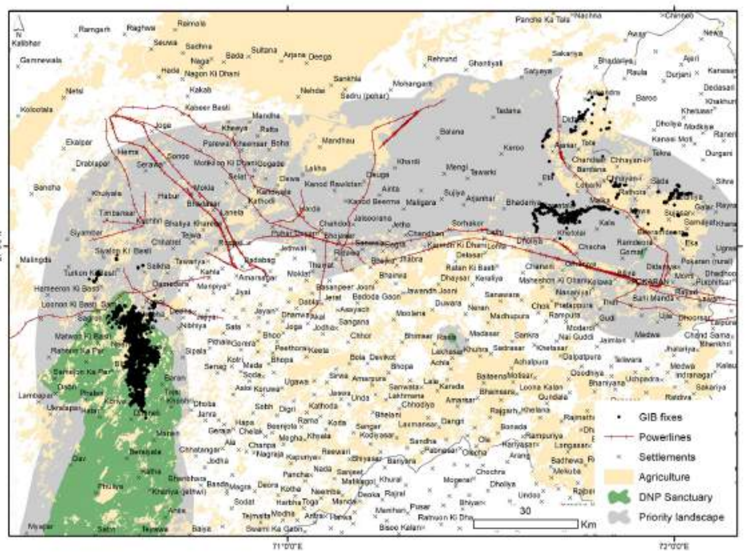


Figure 6. Landscape use of Great Indian Bustard in Thar: GPS fixes of tagged birds (Mar 2019 – Sep 2020) overlaid on conservation areas, village names, land-uses and infrastructure.

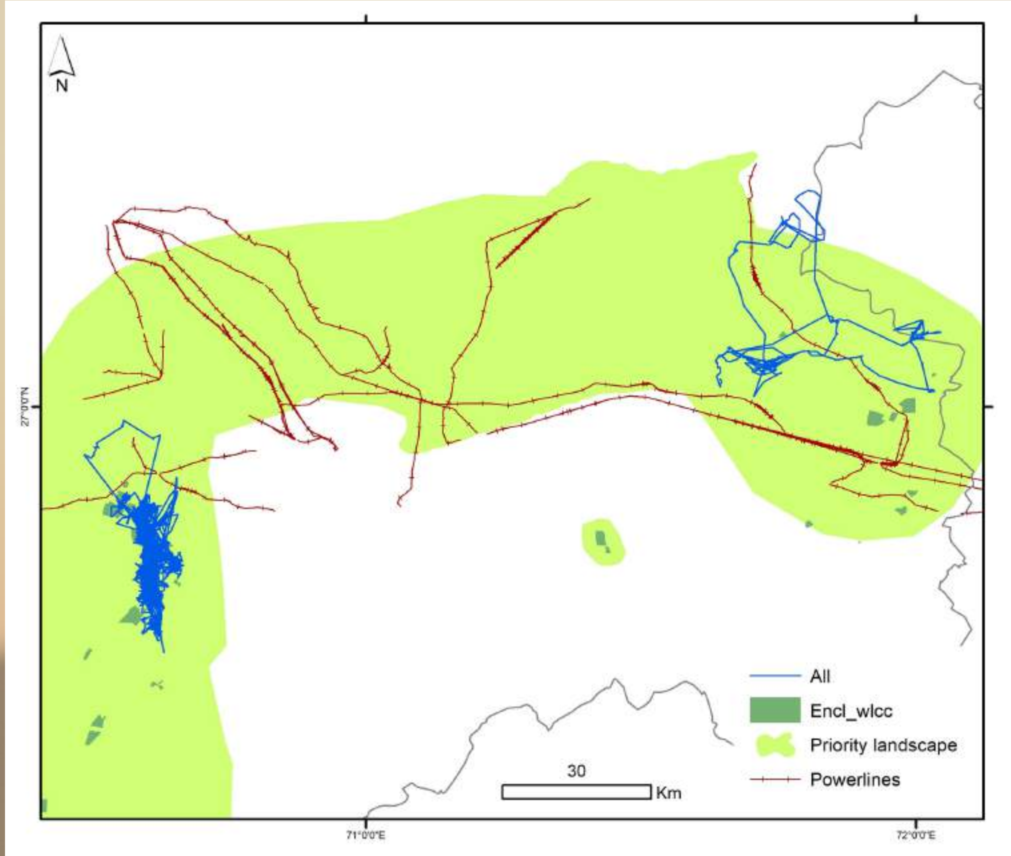
Our research identified power-lines as an important threat to GIB, by causing collision induced mortalities.(Table 3)

Table 3. Power line segments identified for immediate mitigation measures in Thar based on evidence obtained from tagged Great Indian Bustard movements.

S.N	Company	Route	Capacity	Segment Length	Segment Start location	Segment End location	GIB Crossing locations
1	**RVPNL**	Askandra - Pokran	132 kv	70 km	27.37882, 71.69873	26.89509, 71.9451	1) 27.29952, 71.70029 2) 27.09591, 71.85597 3) 27.08798, 71.87539 4) 27.14222, 71.77416
2	**Jodhpur Discom**	Sam - Dhanana	33 kv	40 km	26.90964, 70.71879	26.81479, 70.35356	1) 26.84224, 71.53579 2) 26.87938, 70.61688
3	**Windworld**	Kanoi - Salkha	33 kv	21 km	26.83226, 70.72348	26.94493, 70.57802	1) 26.86094, 70.64640 2) 26.88256, 70.61791

These power line segments were recommended for mitigation (Tables 7 & 8) and should be prioritized for immediate undergrounding of cables.

Sourav Supakar



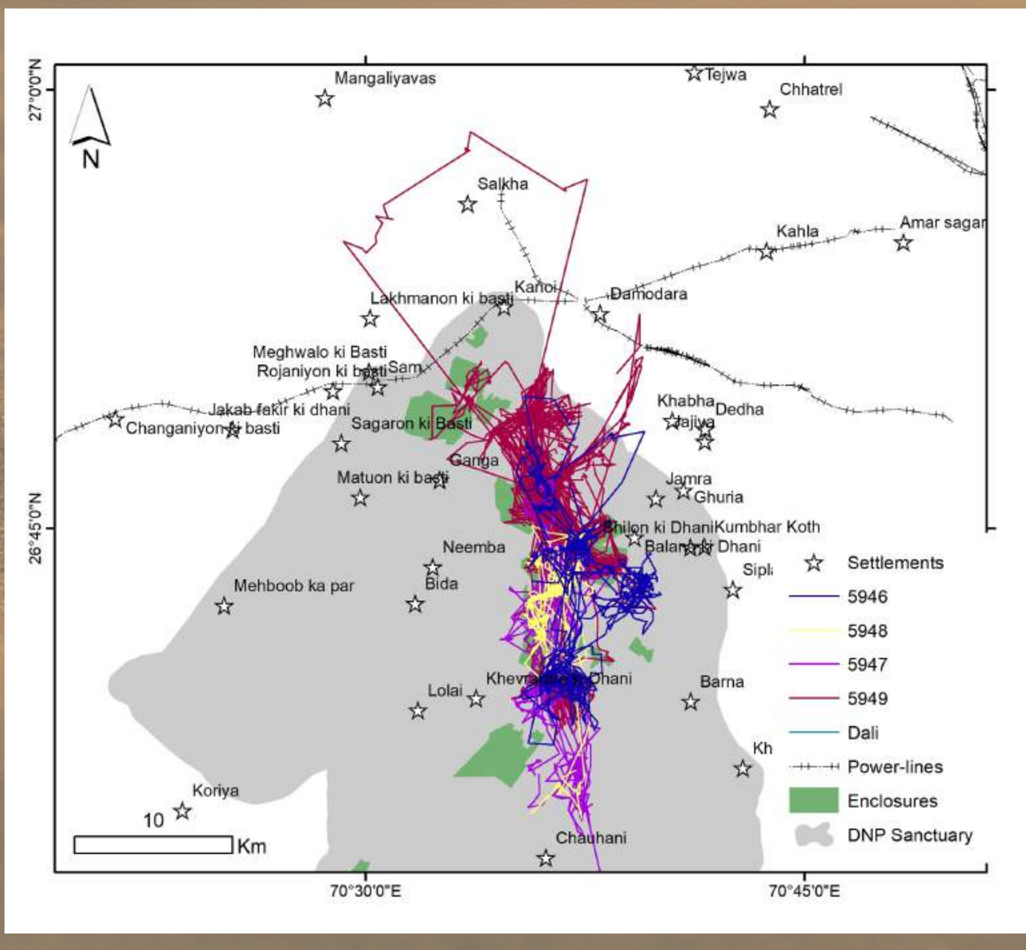


Figure 7. Great Indian Bustard movements across transmission lines in Thar at the landscape (top) and Desert National Park (bottom) scales during Mar 2019 – Sep 2020.

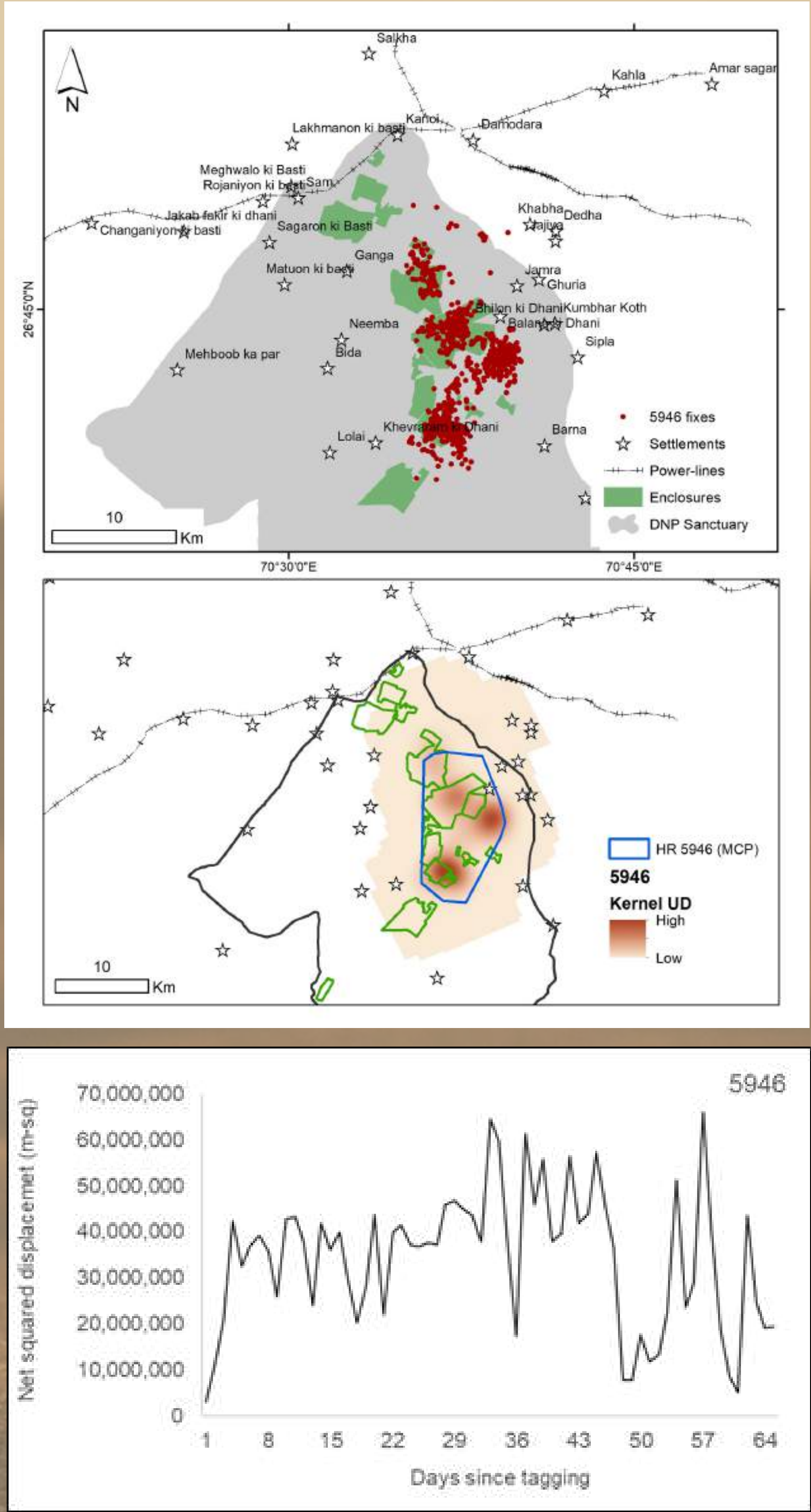


Figure 8. GPS fixes (top), home range estimated as 95% Minimum Convex Polygon (center) and net squared displacement (bottom) of tagged Great Indian Bustard 5946 in Thar.

Individual 5947 was tagged in RKVY on 15th April 2020 and continues to transmit data. In 161 radio-track days, the tag yielded 1,865 one-hour interval locations. The bird used RKVY, Sudasari, Gajaimata enclosures and Dhaneli crop fields, and nested four times in RKVY and Sudasari enclosures. One of its eggs was collected and artificially hatched in the Bustard Conservation Breeding Center at Sam, Jaisalmer. The MCP home range area was 98 sqkm (Figure 9).

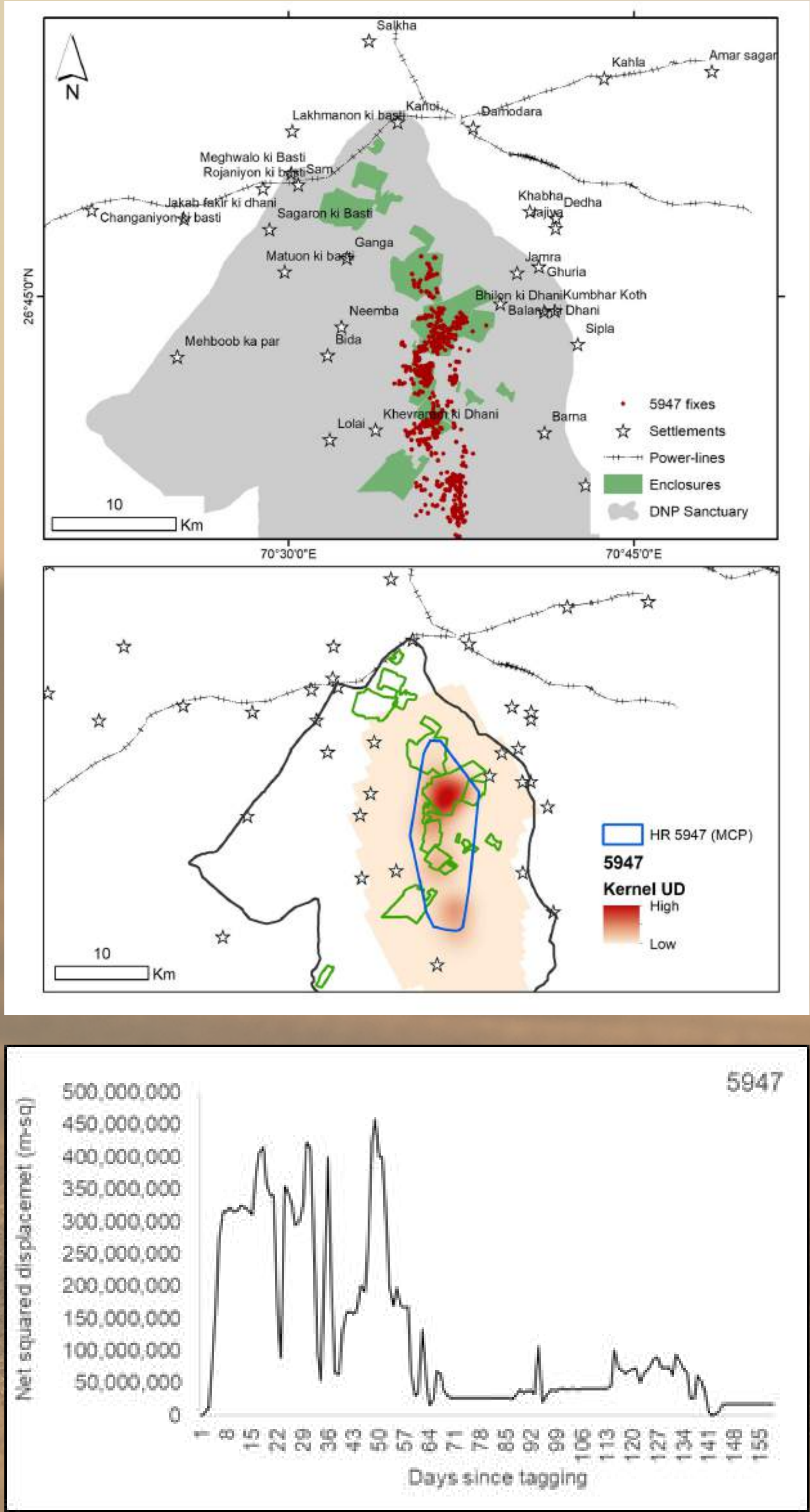


Figure 9. GPS fixes (top), home range estimated as 95% Minimum Convex Polygon (center) and net squared displacement (bottom) of tagged Great Indian Bustard 5947 in Thar.

Individual 5948 was tagged in Chowani-PPC enclosure on 21st June 2020 and continues to transmit data. In 94 radio-track days, the tag yielded 1,129 one-hour interval locations. The bird used Sudasari, Gajaimata, Chowani-PPC enclosures and Dhaneli crop fields, and nested twice since tagging.

One of its eggs has been artificially hatched in the Bustard Conservation Breeding Center. Its MCP home range area was estimated at 37 sqkm (Figure 10).

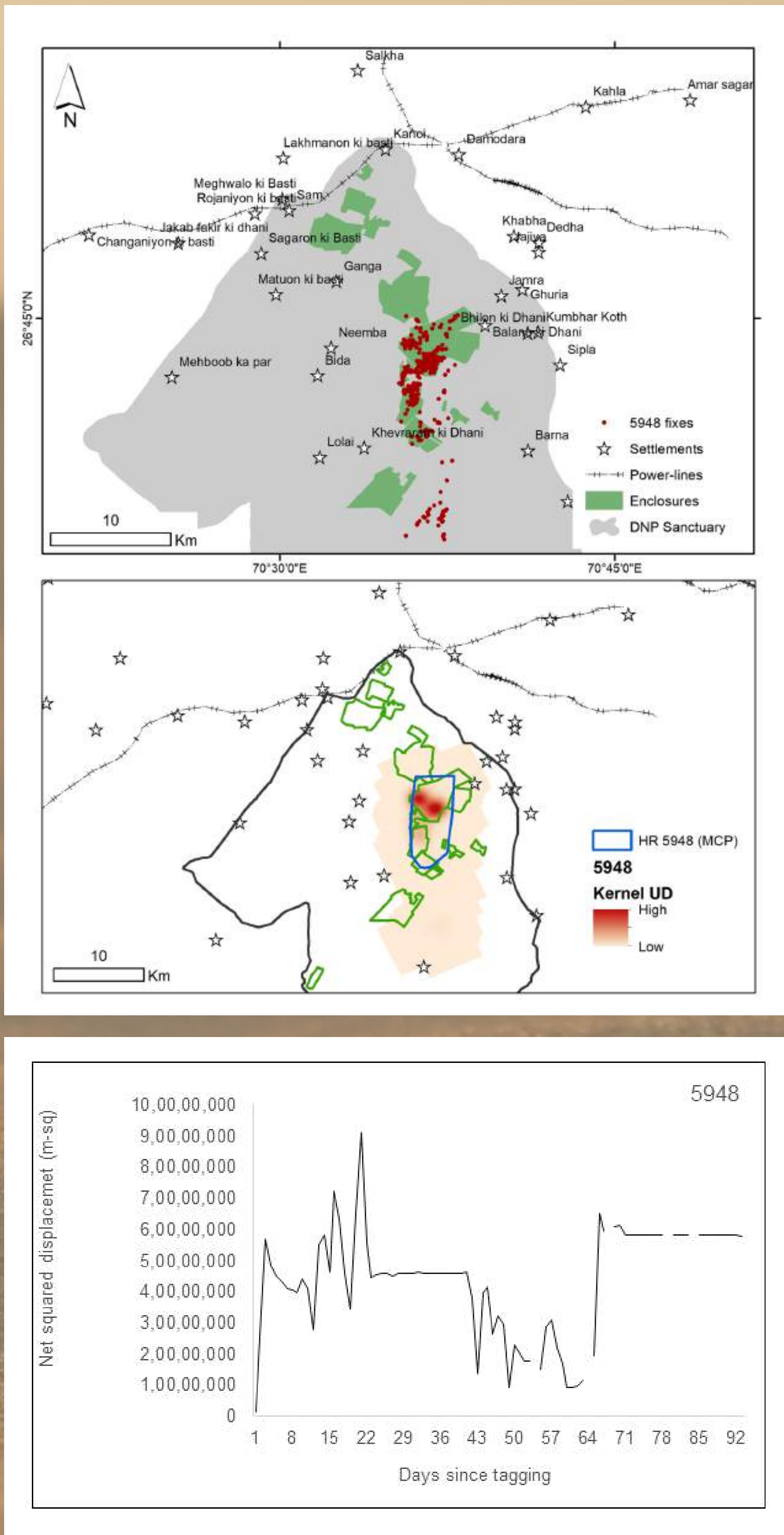


Figure 10. GPS fixes (top), home range estimated as 95% Minimum Convex Polygon (center) and net squared displacement (bottom) of tagged Great Indian Bustard 5948 in Thar.

Individual 5949 was tagged outside RKVY on 31st March 2019 and continues to transmit data. In 542 radio-track days, the tag yielded 8,229 one-hour interval locations. The bird used Kali Mali crop fields and RKVY, Sudasari, Chowani-PPC enclosures, and nested four times since tagging. One of its egg has been artificially hatched in the Bustard Conservation Breeding Center. Its MCP home range area was estimated at 159 sqkm (Figure 11).

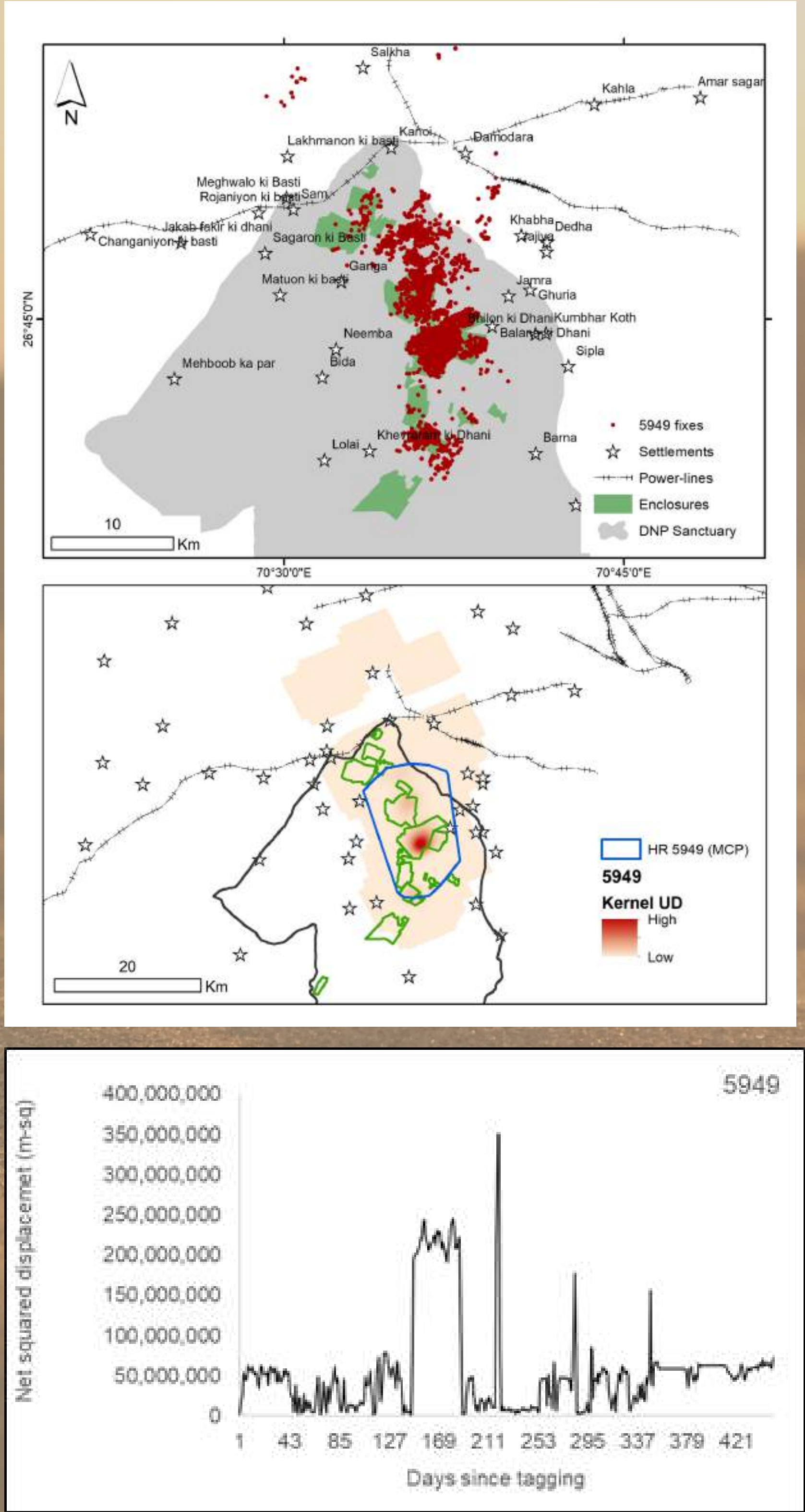


Figure 11. GPS fixes (top), home range estimated as 95% Minimum Convex Polygon (center) and net squared displacement (bottom) of tagged Great Indian Bustard 5949 in Thar.

HOW FAR DOES GREAT INDIAN BUSTARD TRAVEL DAILY ?

An average tagged bird moved 5802 (SE 2375) m daily, ranging from 2932 m (5948) to 8585 m (5946). It should be noted that these are underestimates of actual distance moved as any movement less than an hour is ignored. All birds showed large variation in daily distance moved that indicated non-uniform activity level against time (figure 12)

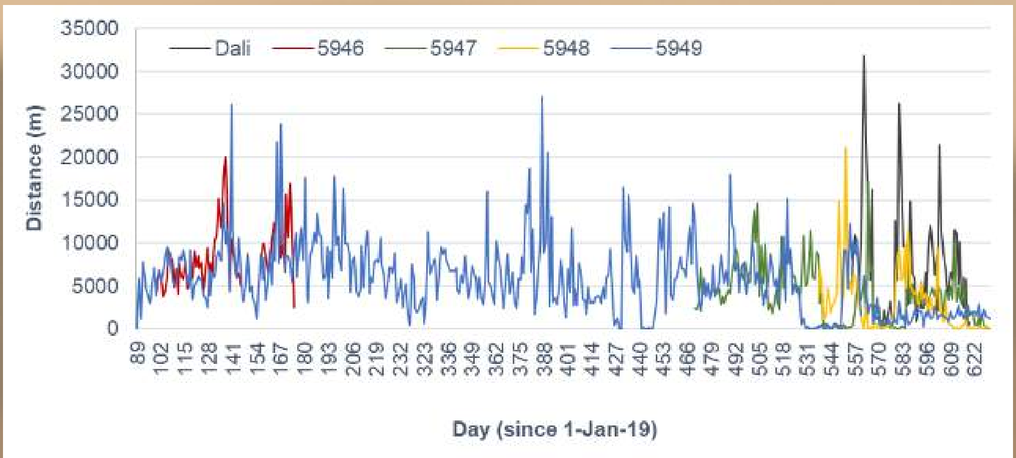


Figure 12. Distance traveled by tagged Great Indian Bustards in Thar

THE DAILY ACTIVITY CYCLE OF BIRDS

The E-obs GSM/GPRS tags collects information on the bird ground speed using Doppler effect. Ground speed is a reliable surrogate of bird activity/movement, and reflected the crepuscular pattern of GIB activity with peak movements during 6-10 h and 18-20 h in summer (figure 13)

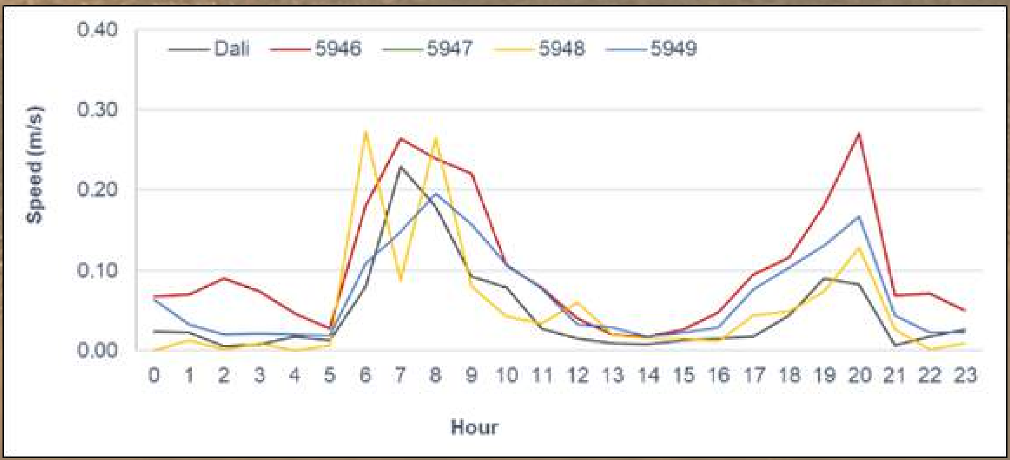


Figure 13. Ground speed estimated by tag using Doppler effect for tagged Great Indian Bustard in Thar.

Based on ground-speed, a very small proportion of movements indicated potential flights (>2 m/s or >7 km/hr ground speeds). (Figure 14)

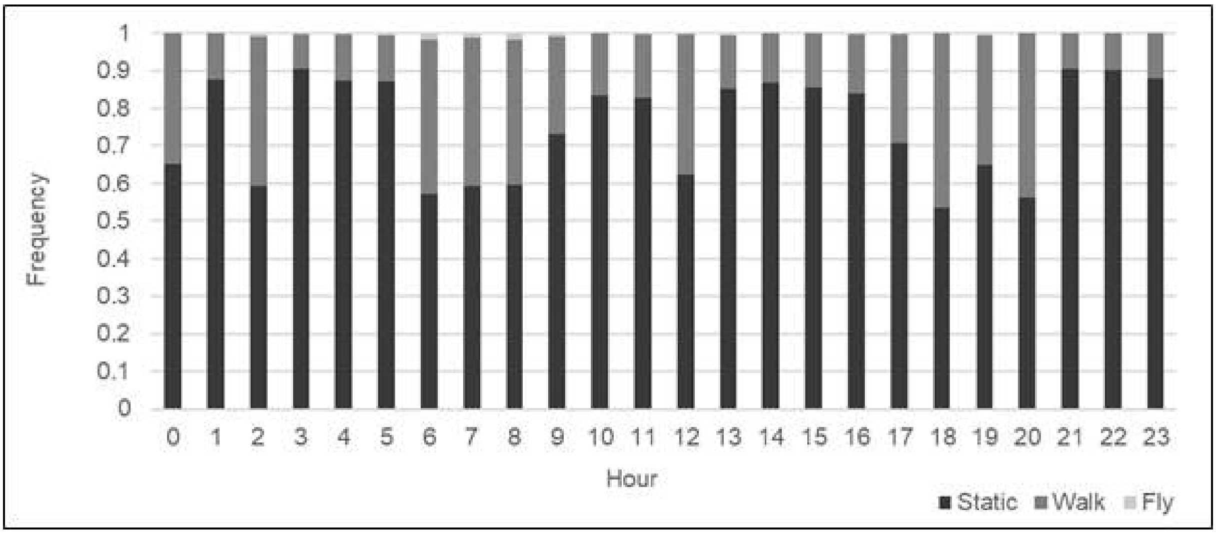


Figure 14. Frequency of independent events (separated by 1-hour for uniformity) classified into three movement classes: static (ground speed <0.3 ms-1), walk (0.3–2.0 ms-1) and fly (>2 m/s) against hour of the day for tagged Great Indian Bustard in Thar during Mar 2019 –Sep 2020.

LAND-USES THAT THE BIRDS PREFER

Enclosures established by State Forest Department occupies 1.01% of the area, yet contained 70.17% fixes of all GIB. Birds showed strong selection towards enclosures (Ivlev index 0.97, Ivlev 1961) and avoidance of outside areas (-0.54). This finding corroborate the recommendation of National Bustard Recovery Guidelines that enclosures of 10-20 sqkm that are scientifically managed (predator proofing and habitat management) can accommodate the birds' ecological needs to a great extent. We also identified three sites outside of enclosures that were extensively used by birds: Kali mali cropfields, Bhilo ka khet and Dhaneli cropfields.

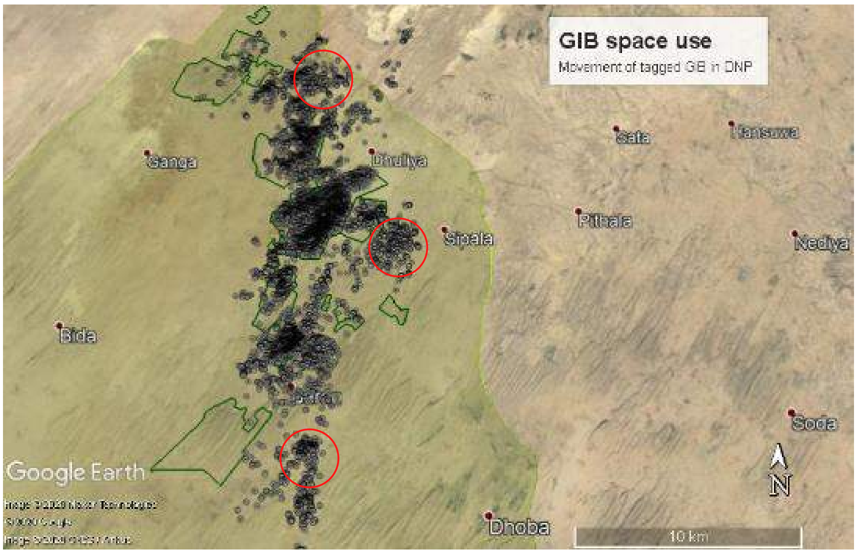


Figure 15. GPS fixes of four tagged Great Indian Bustards overlaid on enclosures and habitat, indicative of intensive usage of enclosures, and few adjoining agricultural sites (marked in open circles) in Desert National Park during Mar 2019 – Sep 2020.

Yogendra Shah

Tanya Gupta

Devesh Gadhvi

3. CHARACTERIZING THREATS

3.1. Power-line mapping

Bustard habitats are experiencing a rapid increase of wind turbines, solar farms, and power lines. Power lines pose a critical threat to bustards globally, due to their low and heavy flying nature and poor frontal vision. We mapped power lines in GIB habitats so that segments within bird usage areas can be identified and flagged for mitigation measures. We digitized an ecological boundary of prime GIB habitat in consultation with Rajasthan Forest Department based on current and past 10 years GIB locations in Thar and proposed that area as an eco-sensitive zone. The landscape is too large to map infrastructure manually. Therefore, low and high tension power lines, wind and solar power projects, roads, and settlements were digitized from very high resolution satellite imagery available with Google Earth TM. This task was outsourced to M/S. Science Pvt. Ltd. We did ground truthing of digitized power lines (Figure 16) and wind turbines (Figure 17), and refined the maps. We identified power lines and wind turbines with their owner agencies to sensitize them for mitigating this threat and also plan mitigation actions (Table 4).

Bipin C.M.

Table 4. Details of high tension power lines present in priority Great Indian Bustard habitat of Thar landscape that needs to be mitigated.

Name of Power Company	Power (KV)	Name of Line	Length (km)
Rajasthan Vidyut Prasaran Nigam Limited (RVPNL)	132	132kv Jaisalmer – Ramgarh - 1	40
	132	132kv Jaisalmer – Ramgarh - 2	40
	132	132kv Askandra	50
	220	220kv Amarsagar – Ramgarh	40
	220	220kv Amarsagar - Lilo	5
	220	220kv Amarsagar - Phalodi	125
	220	220kv Amasagar - Dechu	120
	400	400kv Akai - Ramgarh	55
	Sub total		**475**
Suzlon	33	33kv Small pylons Kuchri	20
	33	33kv Big pylons Kuchri - Habur	20
	132	132kv Kaladungar	20
	220	220kv Habur - Ramgarh	35
	220	220kv Amarsagar - Mokal	20
	Sub total		**115**
Jodhpur Discom	33	Sam - Dhanana	40
	33	-	60
	Sub total		**100**
Wind World	33	Kanoi - Salkha	20
Greenko	220	Amarsagar - Ramgarh	40
Gamesa	33	Amarsagar - Ludarva	4
	Total		**754**

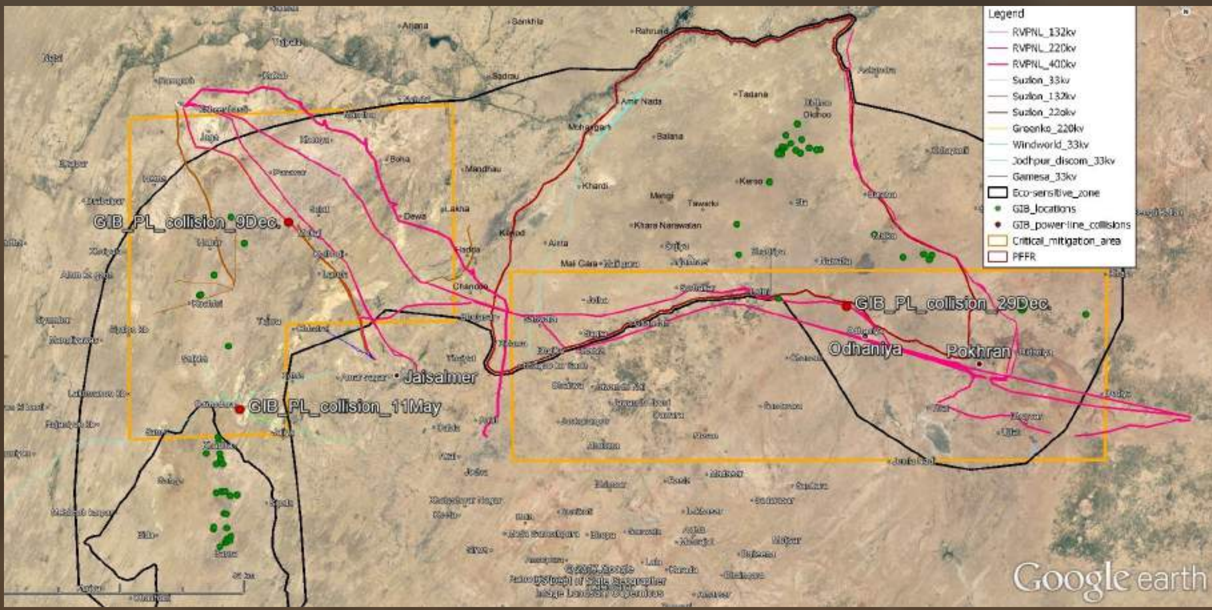


Figure 16. Map of power infrastructure (high tension power lines) in Thar with high priority mitigation areas (2017-18).

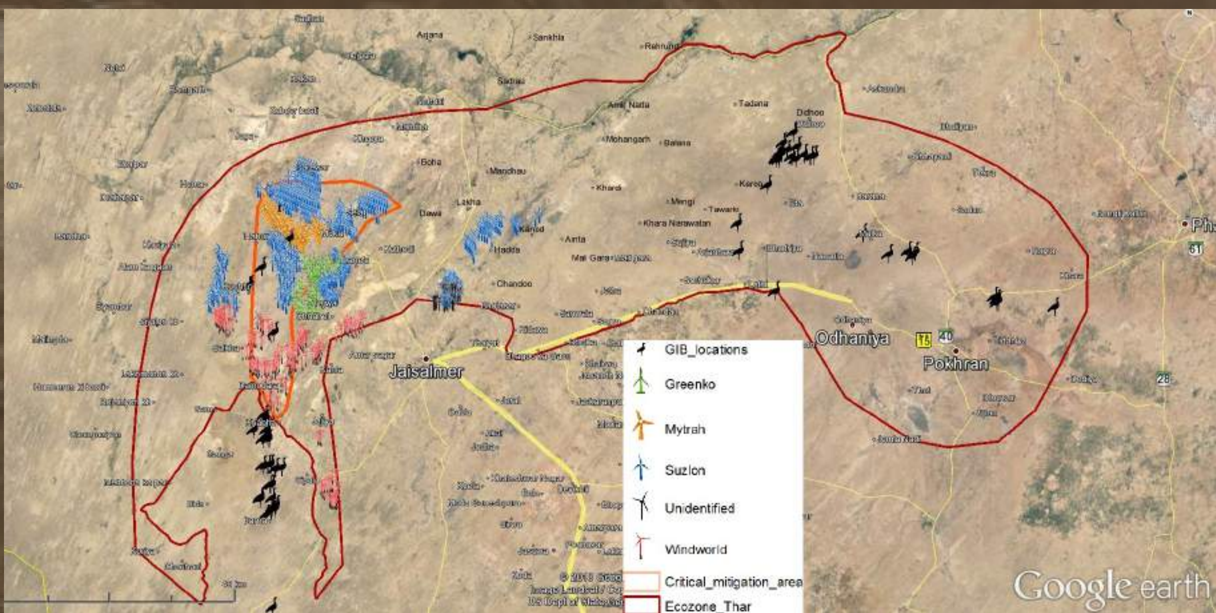


Figure 17 . Map of power infrastructure (wind turbines) in Thar landscape (2017–18).

3.2. Bird mortality due to power lines

We assessed bustard and associated bird movement and mortality rates across power lines. To compare power-line induced mortality with that due to natural agents, we surveyed beneath overhead wires (n=50) and randomly laid belt transects of similar dimension (2000 m × 60 m) without power lines (n=20), once in January 2017 (Figure 18). Bird carcasses were not detected in any random transect (n=20 transects), indicating the relatively low natural prevalence of bird mortality (Figure 19).

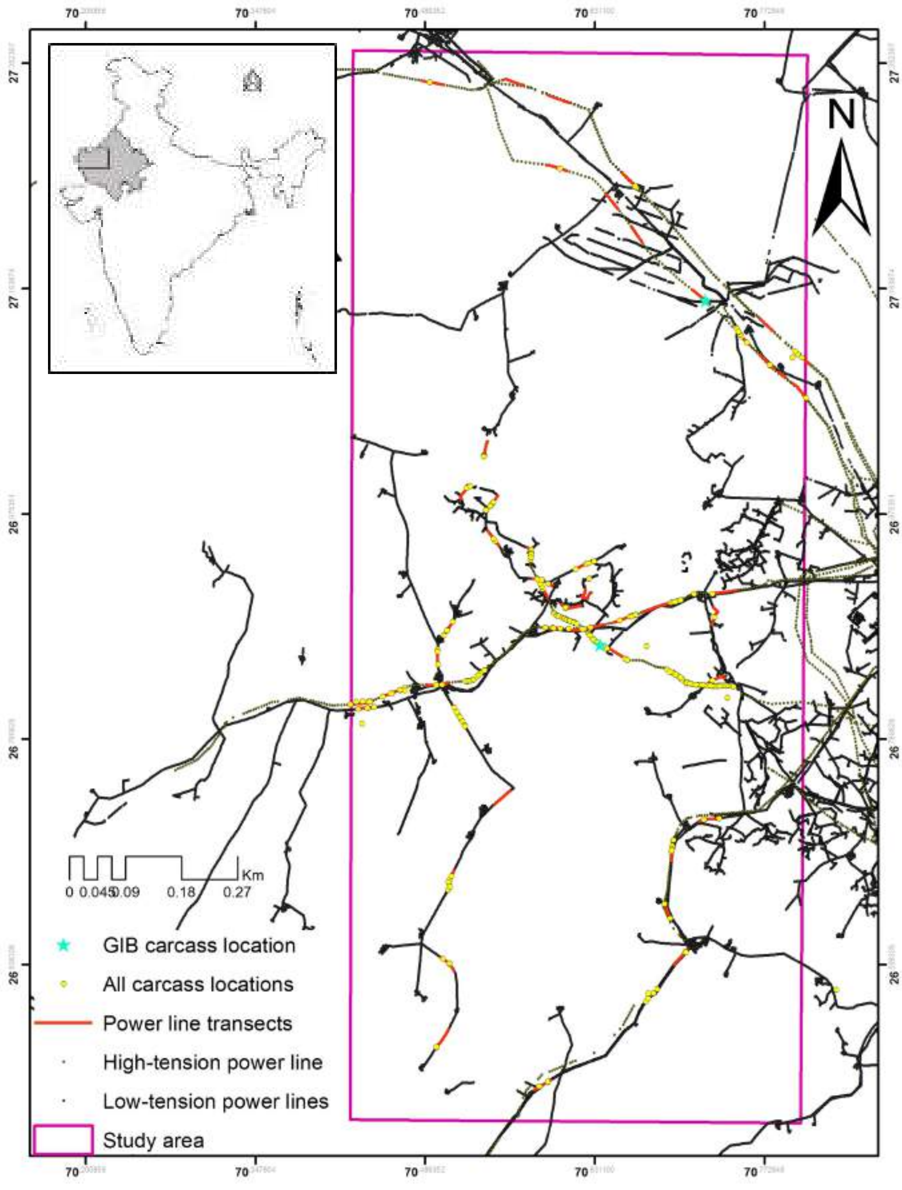


Figure 18. Map showing power line study area, high & low tension power lines, sampled transects, carcass location of Great Indian Bustard and other birds found on power line transects in Thar landscape during 2017-18.

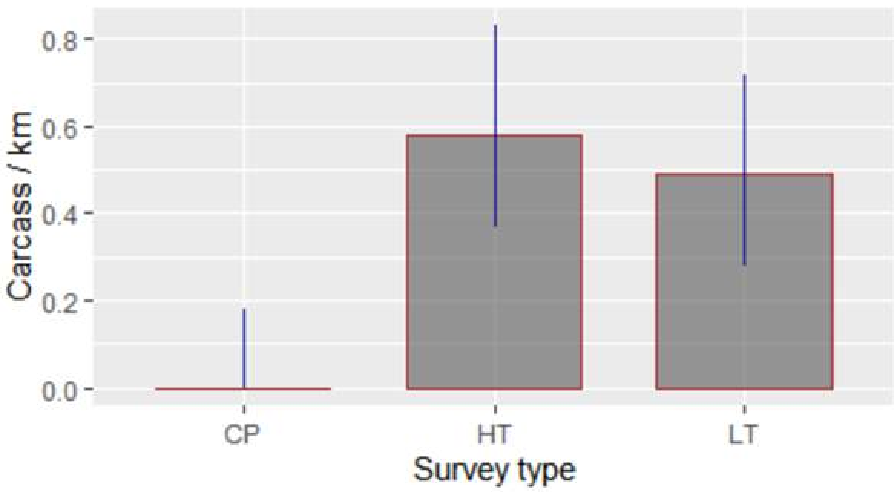


Figure 19. Mean (95% CI) bird carcass encounter rate (per km) at random transects (CP), >33 kV (HT) and <33 kV (LT) power-lines in Thar landscape during 2017-18.

To assess collision rates, we randomly selected 40 two-km power line segments (20 high tension and 20 low tension) from the network of power lines in prime GIB habitat (Figure 20) and sampled 30m width on either side under these power lines for bird carcasses six times during March – December 2017. All carcasses were removed prior to sampling.

We found 289 bird carcasses out of which 55% carcasses could be identified up to taxa level.

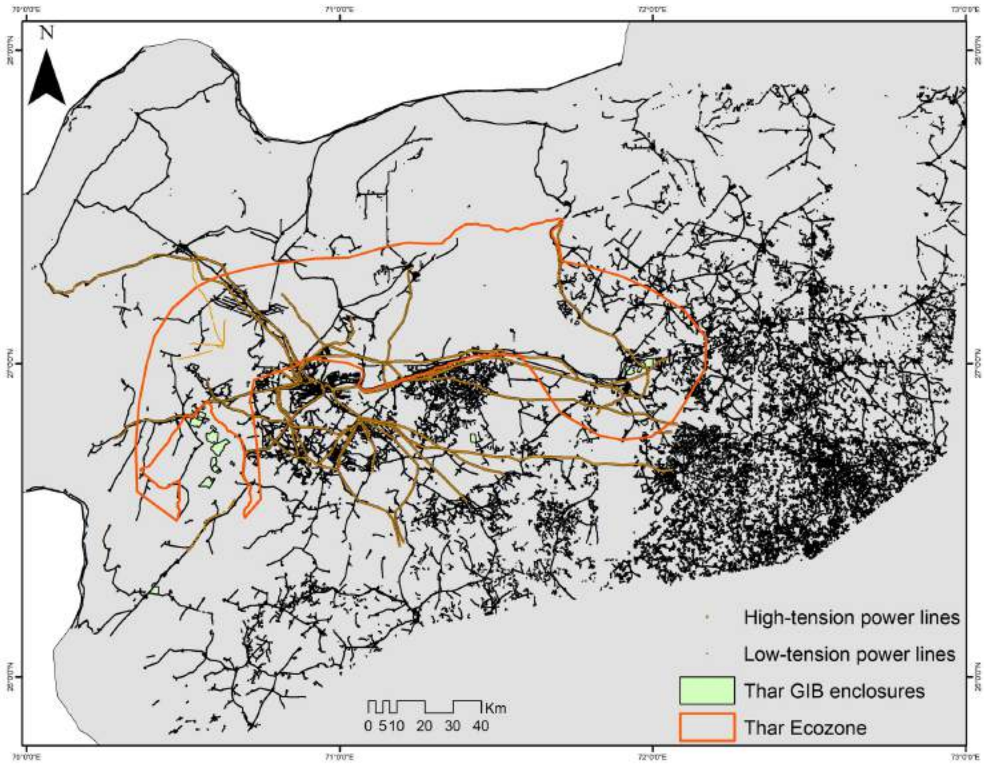


Figure 20. Map showing power line network in Thar landscape.

Since there is a chance of missing the carcasses during surveys because of observer detection bias and carcass disappearance because of decomposition, and displacement by scavengers prior to surveys, we carried out experiments to incorporate detection and decomposition rates of carcasses. To conduct these experiments 10 powerline segments of 2 km each were randomly selected and 80 fresh bird carcasses of various size (50 – 5000g) were placed under these power line segments. These carcasses were monitored on day- 2, 3, 5, 7, 10, 15, 30 and 60 since placement, to record if the carcass persisted or disappeared. To conduct detectability experiments we placed 56 of these carcasses at random locations under six power line segments. These segments were surveyed by three/ four observers to detect carcasses in a blind trial.

G. S. Bharadwaj

We found that carcass detectability increased asymptotically with body mass of bird. It was estimated at 0.64 (0.31 – 0.87) for small (<100g), 0.80 (0.68 – 0.89) medium (100-1000g) and 0.97 (0.82 – 1.0) for large (>1000g) birds (Figure 21). Carcass persistence also depended on bird size. We found median persistence time of 2 (2 – 2) days for small, 3 (3 – 4) days for medium, and 15 (4 – 32) days for large birds (Figure 22). We estimated geometric mean carcass encounter rate based on monthly surveys as 0.28 (SE 0.09) per km per month. It was comparatively higher in winter than summer. Carcass detections per km per month were estimated as 0.21 (0 – 0.46) for low – tension and 0.45 (0.21 – 0.75) for high- tension power lines (Table 3). We adjusted mortality rates using bias correction factor and pooled it over size classes, mortality rates were estimated at 3.22 (0.9 – 6.27) per km per month for low – tension and 6.25 (2.65 – 10.85) per km per month for high tension power lines. We extrapolated these estimates to 1200 km low and 500 km high tension lines and estimated annual mortalities of 83,868 (SE 24,825) birds in study area of 4,200 sqkm.

During our surveys, two GIB carcasses were detected. To understand the seriousness of this threat to bustards we extrapolated our findings on total length of high - tension power lines across prime GIB habitat in Thar estimated that ~16 GIB die annually due to collision with powerlines.

To estimate the bird crossing rates across power lines, we observed bird movements at 10 randomly selected two-km power line segments (five low tension and high - tension power lines each) in prime GIB habitat. The maximum coverage for observing movement from one point was 850m.

A team of two observers recorded bird movements across power lines for 12 hours a day using binoculars and field scopes. This exercise was conducted in winter, summer, and post monsoon to capture seasonal differences in bird composition. Bird movements across power line, flight height from wires, and use of wires, poles and pylons for perching/ roosting were recorded, and segregated into taxa/ size groups. Collision events during these observations, if any, were recorded.

We recorded a total of 6,732 individuals of 49 species. The most numerous species was Eurasian collared dove *Streptopelia decaocto* (27.59% of total individuals), followed by larks (19.38%), green bee-eater *Merops orientalis* (7.07%) and white-eared bulbul *Pycnonotus leucotis* (6.01%). Our initial results show that comparison of crossing vs. collision rates indicated Ploceidae, *Anatidae* and *Charadriidae* as the most collision-prone families.

Table 5. Mean (95 % CI) encounter rate, correction factor for persistence and detection biases, and bias-corrected mortality rate of small, medium and large birds against low (<33 kV) and high (>33 kV) tension lines in Thar Desert, 2017–18. Birds whose taxonomy / weight class could not be determined (unknown) was assumed to have similar weight composition as identified birds, based on which total carcass mortality rate was estimated.

Bird Size	Power Line Type	Bird Carcass (per km per month)	Bias Correction Factor	Bird Mortality (per km per month)
Small (< 100g)	<33 kV	0.03 (0 - 0.11)	0.04 (0.04 - 0.05)	2.32
	> 33 kV	0.11 (0.04 - 0.19)	-	5.14
Medium (>100–1000 g)	<33 kV	0.06 (0.01 - 0.12)	0.16 (0.15 - 0.18)	0.77
	> 33 kV	0.06 (0.01 - 0.12)	-	0.82
Large (> 1000g)	<33 kV	0.03 (0 - 0.07)	0.47 (0.43 - 0.5)	0.13
	> 33 kV	0.07 (0.03 - 0.11)	-	0.29
Unknown	<33 kV	0.08 (0 - 0.27)	-	-
	> 33 kV	0.23 (0.05 - 0.44)	-	-
Total	<33 kV	0.21 (0 - 0.46)	-	3.22
	> 33 kV	0.45 (0.21 - 0.75)	-	6.25

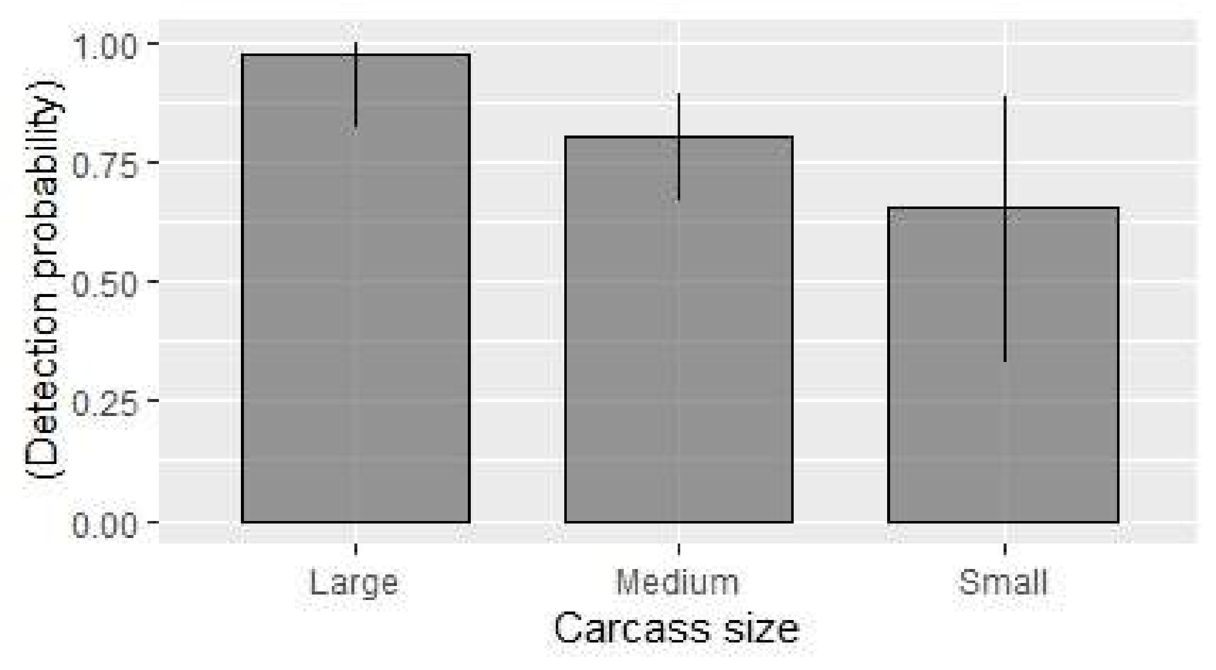


Figure 21. Probability of detection along body mass of birds estimated from carcass detection experiment in Thar landscape during 2017-18.

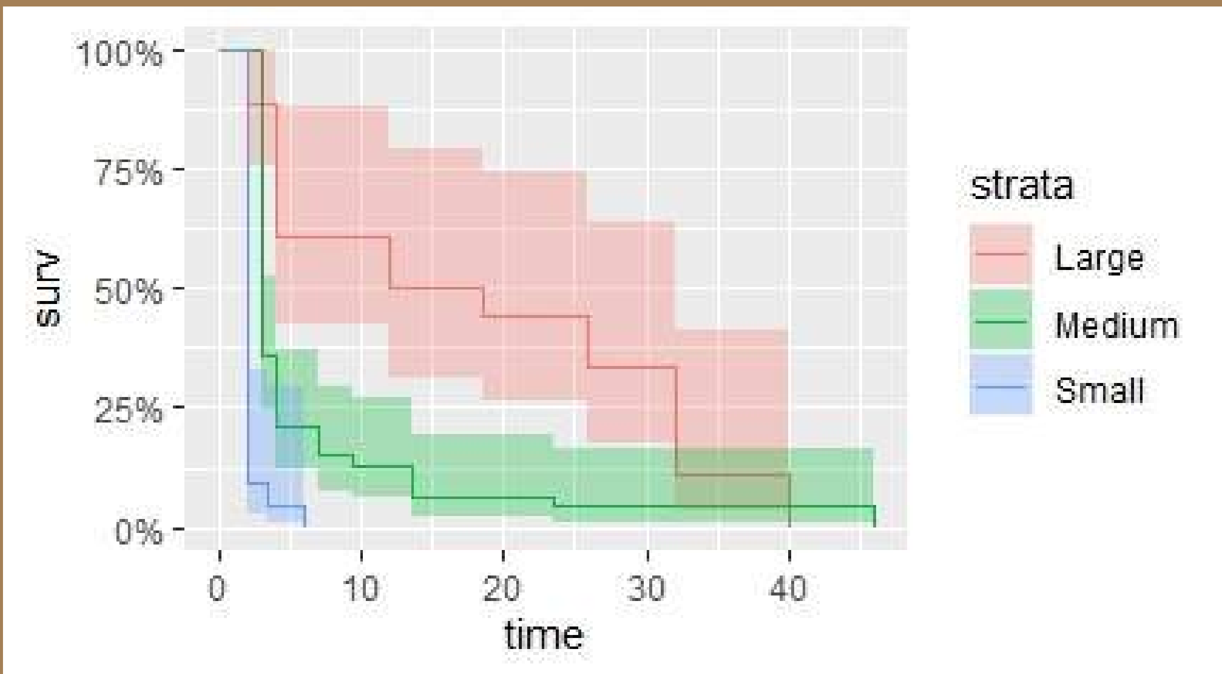


Figure 22. Probability of bird carcass persistence along time since placement under power lines for small (<100 g), medium (100-1000 g) and large (>1000 g) birds in Thar landscape during 2017-18.

Image 4. Field activities related to assessment of bird mortality caused by power-line collisions (left, middle) and power line observations (right) in Thar during 2017-18 © Mohib Uddin

Image 5. Carcass of Great Indian Bustard found during power line surveys in Thar landscape in May 2017 © Bipin C.M.


Kedar Gore

3.3. PREDATION ECOLOGY OF FREE-RANGING DOGS

How many dogs?

Thar holds a large population of free-ranging dogs that partially depend on village based resources and also depredate wildlife, including GIB nests, thereby being an important threat that needs to be managed. We assessed population status of free-ranging dogs in/ around Desert National Park. A pilot survey was carried out in select settlements during September – October 2016 in collaboration with Humane Society International – India and international consultant Dr. Lex Hiby, wherein a smart-phone application (OSM) based mark-recapture technique was used to enumerate dogs. Subsequently, a comprehensive study was undertaken that included the following activities:

Devesh Gadhavi

Count surveys: Dogs were counted in 18 settlements. Observers walked on predesigned route recording the number of dogs present with consistent effort of ~ 8 km walk in two hours per square km of settlement area. This activity generated crude counts of dogs in all settlements within the GIB habitat in/ around Desert National Park.

Mark-recapture surveys: In six of these villages (Sam, Salkha, Lakhmano, Kuchhri, Neemba and Beeda) and the dog telemetry area, dog abundance was estimated in mark-recapture framework which is robust to imperfect detection. A point and shoot digital camera with 83X magnification and zoom lens smartphone were used to capture dogs and identify individuals based on distinguishable natural marks (flanks, head, tail, other body marks). Four photo-capture surveys were conducted in each settlement and abundance was estimated following standard closed population mark-recapture analysis (Otis et al. 1978, White & Burnham 1999). Dog counts in these villages were calibrated against the mark-recapture abundance estimates to generate a correction factor (double sampling approach) that can be used to estimate dog abundance in all settlements (Figure 24).

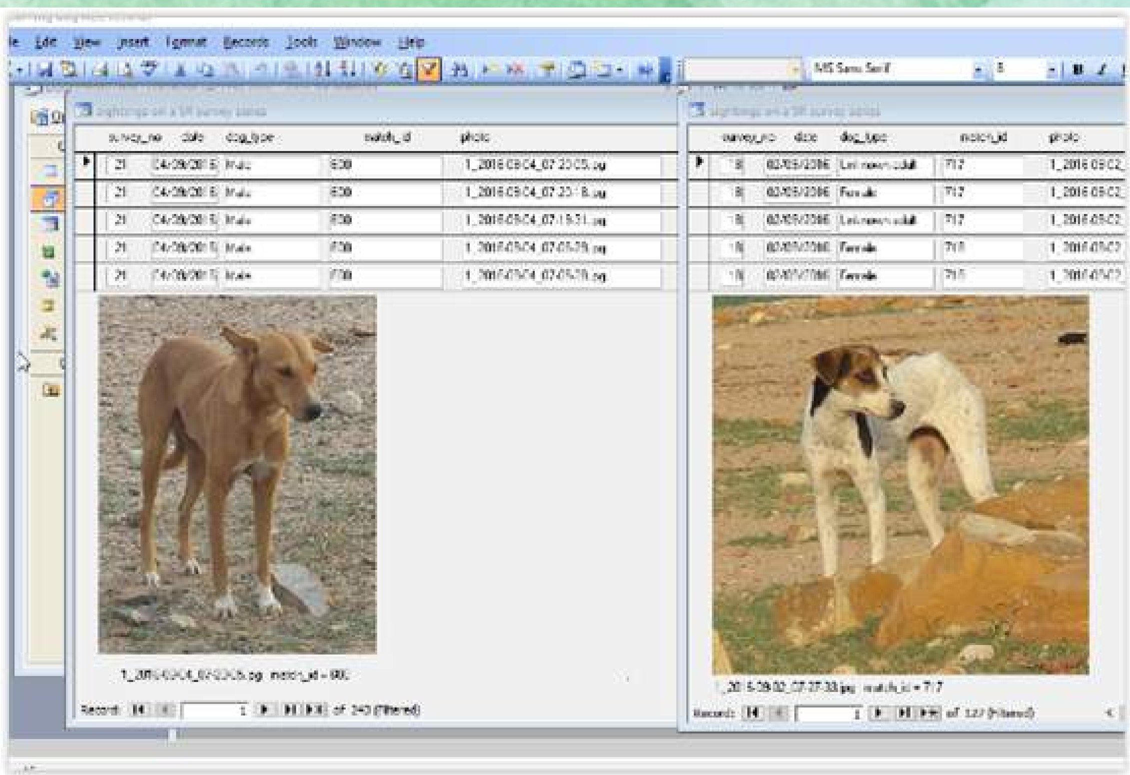


Figure 23. MS Access database to catalog and match dog photographs for mark-recapture based population assessment.

Vehicle transects were also laid to assess the density and distribution of free-ranging dogs in wildlife habitats. This activity generated baseline information on numbers and distribution of dogs in GIB habitat of Thar that helped us in planning sterilization/ control programs and monitor the effectiveness of these programs in reducing the number of dogs within manageable limits.

Where dogs range and what they eat

Radio-tracking: We determined ranging patterns and resource utilization of dogs using biotelemetry. Nine dogs were fitted with radio-collars and ground tracked using VHF technology on vehicle for 112 days. GPS locations, time and associated variables (habitat type, activity of animal and associated individuals) were recorded at every 15 minutes (Figure 23).

Locations of radio-collared dogs were analysed using Minimum Convex Polygons (MCP) and Kernel methods to estimate home range size and habitat use. Time and location data was analysed to assess temporal activity pattern, proportion of time spent in settlement vs. wildlife habitats, and time-activity budgets.

***Behavioural sampling*:**
Each radio tracked dog was observed using focal animal sampling for ~150 hours, including 24 hours continuous monitoring for five days, to determine their activity patterns, feeding habits and inter-specific interactions. Data on scavenging, active predation and interactions with conspecifics and potential competitors (fox, cat, raptor etc.) were recorded.

***Carcass availability*:**
We assess carcass availability in the combined MCP with two-km buffer. A fixed zigzag route of 127 km was digitized using Google EarthTM that was surveyed once every 15 days to record carcasses. Data on condition, distance of carcass from trail, and presence of scavengers around the carcass were collected. This field activity yielded information on predation rates of wild prey and livestock by dogs.

Image 6. Field activities related to understanding and management of the impact of free-ranging dogs on wildlife in/ around Desert National Park. © Monisha Mohandas and Devendradutta Pandey

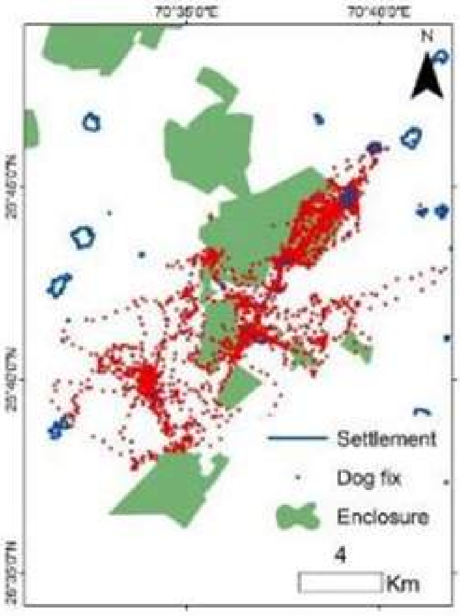


Figure 24. Radiolocations of free-ranging dogs (n=9) overlaid on enclosures and settlements in Desert National Park during 2017-18.

A total of 761 ± 109 SE dogs in human habitation and a total number of 1,804 ± 462 SE dogs in 1,008 sqkm landscape were estimated. Home range (95% MCP) estimate of free-ranging dogs was 19.81 ± 4.79SE sqkm with no difference between males (19.80 ± 2.65 sqkm) and females (17.25 ± 1.60 sqkm). Space-use was two-fold in/ around enclosures (prime wildlife resource patches) and threefold in/ around settlements (human-derived resource patches) than expected under random use (Figure 24). Activity budget and temporal activity pattern showed that dogs were crepuscular, mostly active during 0600-0900 hrs and 1800-2100 hrs, and resting for 75% of the day. Prey densities (individuals per sqkm) were estimated to be 7 ± 1.22SE chinkara, 0.46 ± 0.23SE nilgai, 4,681 spiny-tailed lizards and 2,861± 203SE jird. Goat and sheep carcasses contributed most to the diet (54% feeding time) and were also most selected (Ivlev's index = 0.96goat and 0.95sheep) followed by predation on nilgai and chinkara. Potential predation rates of chinkara and nilgai were estimated to be 9.67 and 10.95 per dog per year respectively, albiet with a small sample. Radio tagging of free-ranging dogs showed that an unsustainable 33% of chinkara population is cropped annually.


Image 7. Free ranging dogs hunting Chinkara in packs. © Devendradutta Pandey

3.4. Pesticide prevalence

Rapid assessment of locust outbreak to prevent

Locust outbreak was first reported from Great Indian Bustard habitats in Thar after a rainfall between 12th and 15th May 2019, followed by announcements of warnings and control measures by District administration. Locust swarm is one of the threats to agriculture in African and Asian countries. Natural interventions such as thunderstorms or the passage of depressions in summer are known to induce locust outbreaks (Bhatia 1939). Some of the locust outbreak centers were located within the areas intensively used by GIB. We carried out a rapid assessment of locust infestation in GIB landscape near Pokhran/ Ramdevra from 28th May to 3rd June 2019 to identify the outbreak centres and whether they overlapped with areas intensively used by GIB to suggest mitigation measures against pesticide exposure.

Data on locust population was collected based on Food and Agriculture Organization (FAO) guidelines (Cressman 2001). Survey area was divided into multiple 36 sqkm grids. Five plots in each grid was sampled to estimate locust density. At each plot, foot transect of 100 meters (length) and 3 meters (effective detection width in 300 sqm area per plot) was walked and direct count method was used to enumerate locust numbers (adults and hoppers). Other associated habitat variables viz., land cover (grassland/ agriculture/ barren), vegetation density (dense/ medium/ low), presence of soil moisture, last date of rainfall and presence of animal carcasses were also recorded.

(a)

(b)

Image 8. Locust outbreak in Thar (a) Locust congregation on khimp- Leptadenia pyrotechnica shrub. © Bipin C.M., (b) Dead locusts collected from Malathion spray site. © Devendradutt Pandey

Total 29 grids encompassing 1,044 sqkm area was surveyed. Locust presence was recorded in 21 survey grids (Figure 25). Average density of locust in the surveyed area was estimated as 2,940.46 individuals per sqkm. Other animal carcasses were not detected during the survey.

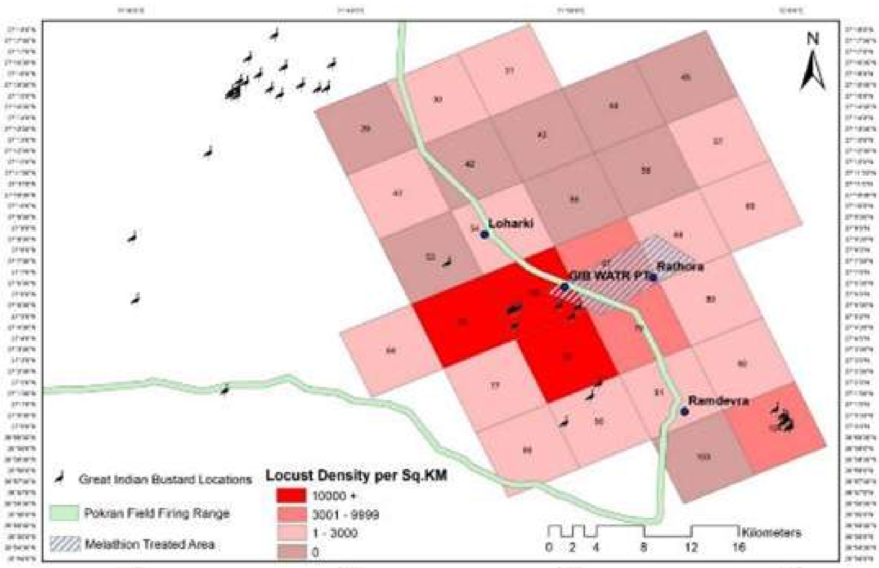
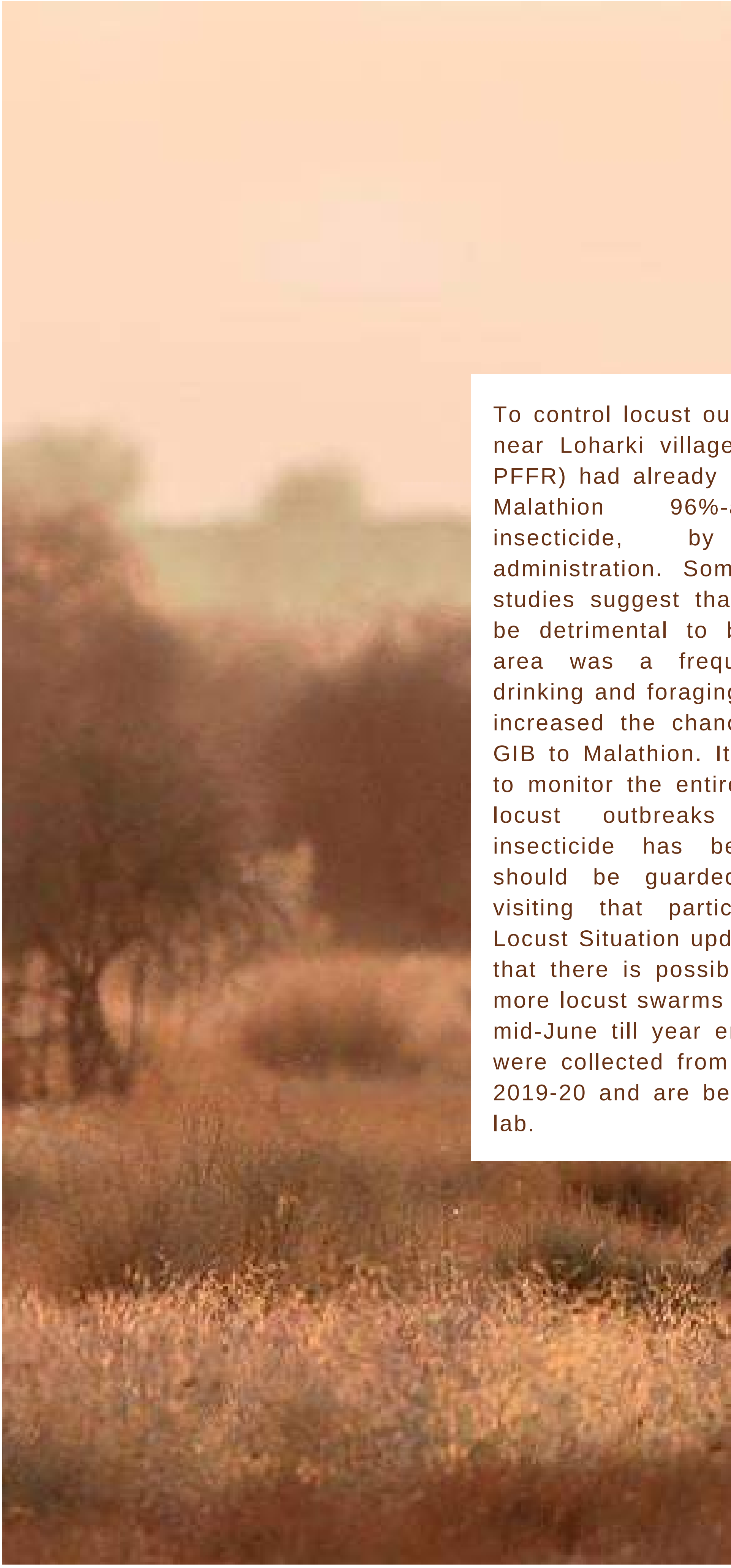


Figure 25. Map of the surveyed area for estimating locust abundance using grid based sampling in Thar, Jaisalmer.



To control locust outbreak, a few areas near Loharki village, Jaisalmer (inside PFFR) had already been sprayed using Malathion 96%-a contraceptive insecticide, by the District administration. Some of the previous studies suggest that the chemical can be detrimental to birds. The sprayed area was a frequently used water drinking and foraging site of GIB, which increased the chances of exposure of GIB to Malathion. It was recommended to monitor the entire landscape, where locust outbreaks have occurred, insecticide has been sprayed, and should be guarded to prevent GIB visiting that particular area. Desert Locust Situation update by FAO notified that there is possibility of migration of more locust swarms in Thar Desert after mid-June till year end. Locust samples were collected from GIB habitat during 2019-20 and are being analysed in the lab.

PILOT GIB-FRIENDLY LAND-USES

Pilot installation of bird diverters

The infrastructure maps and priority mitigation areas were shared with State Forest Department, MOEFCC, power agencies and power/energy regulatory bodies such as Ministry of New Renewable Energy (MNRE), Ministry of Power and Central Electricity Authority. Several joint meetings with Forest Department were held, where we sensitized power companies on the need of mitigating power lines for conserving bustards. We distributed diverters to power agencies such as RVPNL, Jodhpur Vidyuth Vitraran Nigam Limited (JDVVNL) and Suzlon that were installed in transmission lines in Khetolai, Mokla, Habur and Sanu villages during January- February 2018. We provided technical inputs to local vendors to manufacture indigenous low cost bird diverters. We procured these units and distributed to Suzlon for installation. These diverters were installed according to the design provided by WII on 250m segment of 33KV line near Mokla during July 2020. Total 105 diverters were installed in this pilot step to examine their field longevity and efficacy (Table 6). To this end, long-term studies are ongoing, since it requires many years and bird crossing/ collision events to detect the field life and effectiveness of these products in reducing crossings and/ or collisions.

Table 6. Details of bird diverters distributed to power agencies by Wi ldlife Institute of India and installed on power lines in Great Indian Bustard habitat in Jaisalmer, Rajasthan.

S No.	Power line agency	Diverter Type & Number	Manufacturer	G.P.S. coordinates	Installation	Capacity	Route	Area
1	SUZLON	Fire Fly and Bird Mark-3#	P & R Technologies-USA	27.05499 70.6035	February-2018	33 KV	Khuchri - Suzlon Mokla GSS	Khuchri
2	SUZLON	Fire Fly and Bird Mark -10#		27.19602 70.57894	February-2018	220 KV	Mokla - Ramgarh	Habur - Sanu
3	SUZLON	Fire Fly and Bird Mark-9#		27.03802 70.57811	February-2018	220 KV	Habur - Mandal Ka Gaon	Habur
4	RVPNL	RAPTOR CLAMP and Overhead Warning Light (OWL) -35 #	Preformed Line Products (PLP)- USA & Thailand	27.01168 71.69339	May-2018	220 KV	Amarsagar - Phalodi	Khetolai
5	SUZLON	Bird Flight LED Diverters - 48	A & S Creations, New Delhi	27.16142 70.6858	July-2020	33kV	Mokla - Ramgarh	Mokla

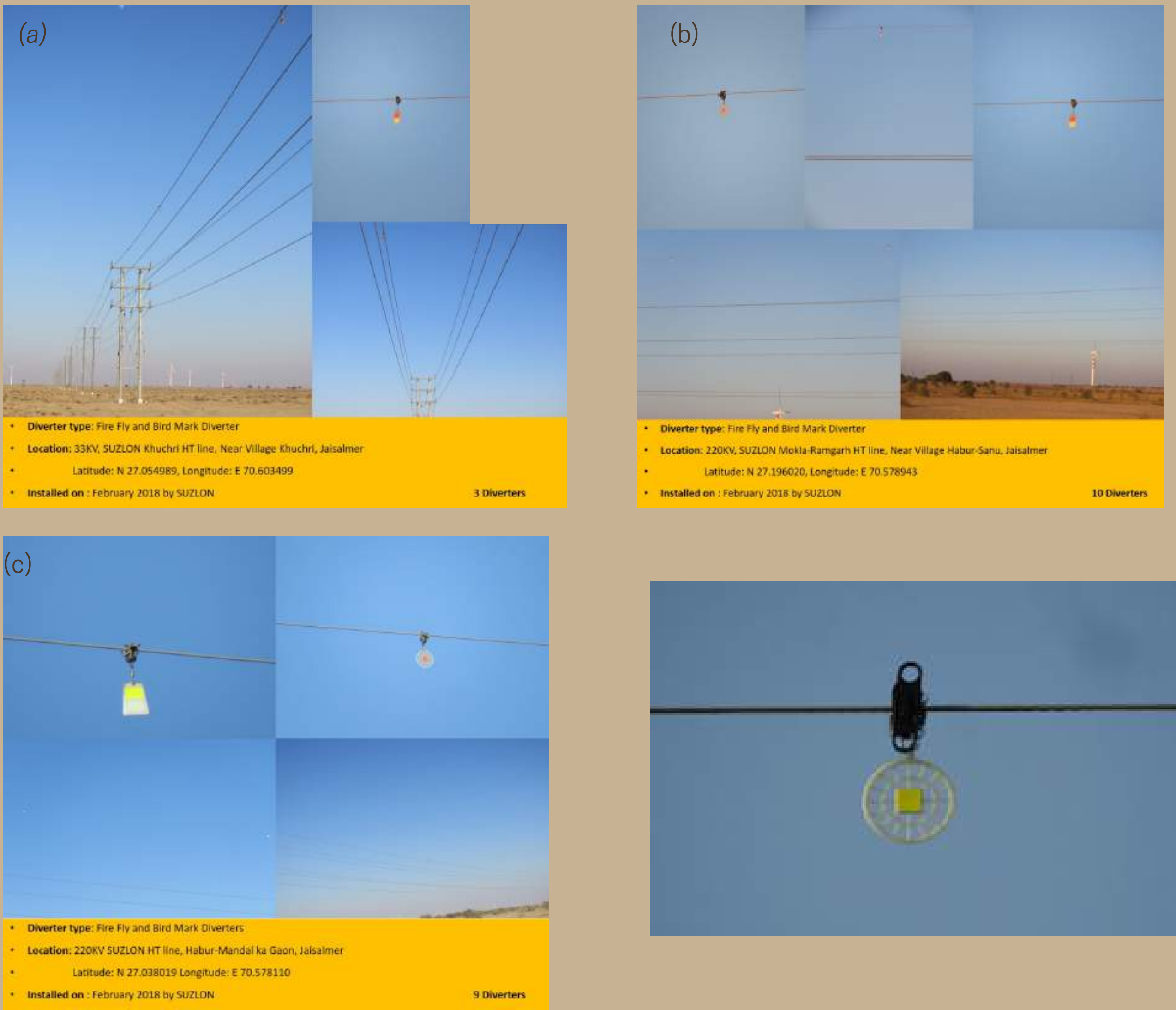


Image 9. Pilot installation of bird diverters on power lines near (a) Khuchdi, (b) Habur- Sanu and (c) Mandal ki gaon villages – priority areas for mitigating power lines for Great Indian Bustard conservation in Jaisalmer, Rajasthan. © Mohib Uddin

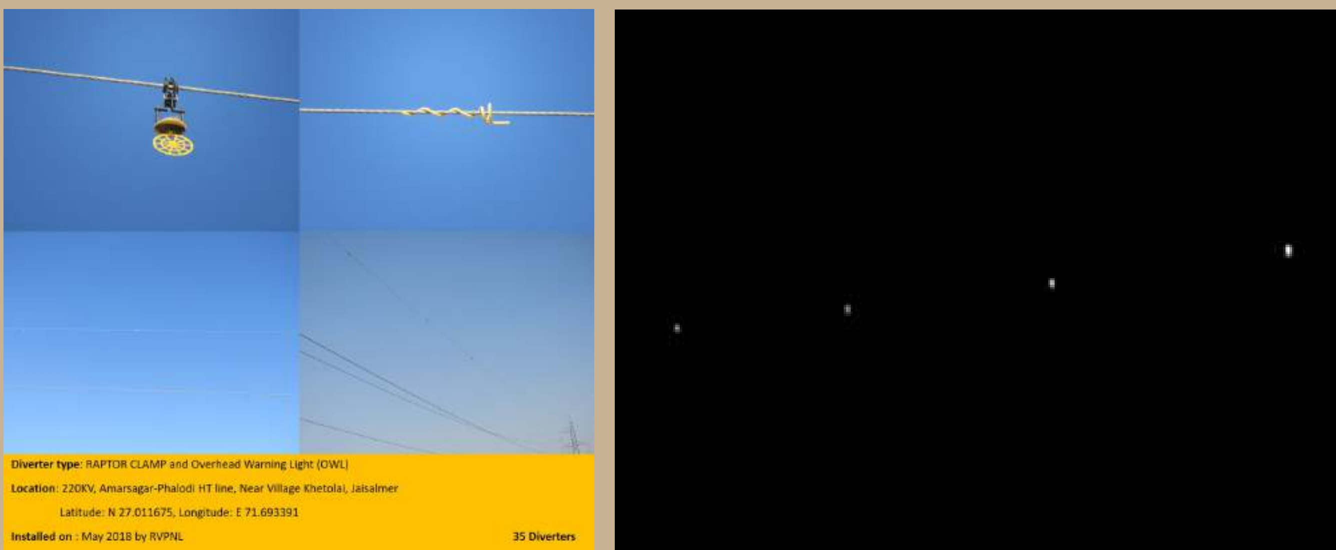


Image 10. Pilot installation of LED bird diverters on power lines near Khetolai village– priority area for mitigating power lines for Great Indian Bustard conservation in Jaisalmer, Rajasthan. © Mohib Uddin and Sourav Supakar

Image 11. Pilot installation of indigenous LED bird diverters according to the design provided by Wildlife Institute of India on power lines in Mokla – priority area for mitigating power lines for Great Indian Bustard conservation in Jaisalmer, Rajasthan. Photo credit: Suzlon and Devendradutta Pandey

Mitigation plan for power lines

Global research and our study show that power lines, especially high-voltage transmission lines with multiple overhead wires, is the most important current threat to the Critically Endangered GIB. We found unsustainably high mortality rate of GIB (~15% annual mortality and 5 deaths detected in 2017-18), and mortality of ~90,000 birds of over 49 species annually in ~4000 sqkm area in/around Desert National Park. There is an urgent need of mitigating this threat by burying high-risk power lines and installing markers on medium-risk power lines. After a series of joint meetings by Rajasthan Forest Department (RFD) and WII with power agencies (2016–18) to implement these mitigation measures, a high-level meeting was held on 20th December 2018 under the chairmanship of Principal Secretary Energy, Govt. of Rajasthan that was attended by RFD and WII representatives. This meeting decided that mitigation measures should be urgently implemented, and directed the power agencies to place proposals with cost-estimation for this action. We were mandated with developing a technical and financial proposal for mitigating existing power lines in priority GIB habitats. To this end, we carried out the following activities:

Mapping: We mapped power lines across ~20,000 sqkm Thar landscape through digitization of very high resolution Google EarthTM imagery in the first phase. Power lines within the priority GIB habitat (GIB Arc), as identified by long-term collaborative surveys of WII and RFD (Dutta et al. 2016) were then ground validated (2016–17). Since the chance of missing power lines is high because of the vastness of GIB landscape, it was decided in the meeting that the available information on power lines should be verified by power line companies and the same should be submitted by Superintendent Engineer (SE) Rajasthan Vidyut Prasaran Nigam Limited (RVPNL) within a month's time. A follow up meeting was called by SE RVPNL Jaisalmer on 31st December 2018 in Jaisalmer that was attended by representatives from WII and power line companies including RVPNL, SUZLON, Innercon, Jodhpur Discom, Today Green Energy Private Ltd, Siemens Gamesa and Greenko. The SE RVPNL Jaisalmer asked all power line authorities to submit details of power lines (name, length, GPS coordinates of power lines) inside the GIB Arc to WII. WII team followed up with every power line company operating in this area and obtained available data by 15th January 2019. Wherever this data was non-existent, WII team digitized the risky power lines on ground and cross verified this information with the SE RVPNL Jaisalmer on 19th January 2019.

Cost calculation: Based on this information, cost of undergrounding power lines and installing bird diverters were separately calculated to aide in deciding the optimal mitigation strategy. Cost of undergrounding cables was computed based on information shared by the SE RVPNL Jaisalmer for medium voltage (33–66 kV) lines. However, the cost or technology of undergrounding high voltage lines (>132 kV) were not available locally and could not be calculated. The cost of bird diverters was calculated at 10,000 INR per piece (inclusive of production and shipping costs from abroad), which is a liberal estimate, based on procurement of small numbers of high-quality devices by WII.

In total, 1,342 km of power lines have been prioritised for mitigation by undergrounding 104 km of 33 kV lines in areas that are most intensively used by GIB and installing diverters on remaining 1238 km of overhead cables. The total cost of this implementation has been estimated at 287.16 Cr INR. However, this cost could be reduced to approx. 150 Cr INR by opting for economic but quality diverters.

The details of power lines with cost calculation and total costs of diverters and undergrounding are provided below (Tables 7, 8 & 9), along with the priority map of mitigation measures (Figure 25), and image of a prototype bird diverter/ reflector (Image 12). This mitigation plan has been submitted to the concerned ministries and power agencies for further actions. However, mitigation action on ground has not been initiated.

Table 7. List of power lines prioritised for bird diverter installation and undergrounding in Thar, Jaisalmer. Cost of installation (undergrounding)- 40% of cost of wire, Cost of bird diverter per unit- Rs. 10,000/-, Cost of bird diverter installation- 20% of bird diverter cost, ++ For 33 kV lines prioritized for undergrounding, cost of diverters have also been indicated.

					Number		Cost (Rs. in lakhs)		
Phase	Company	Power (KV)	Name Of Line	Length (km)	Wires	Diverters	Diverter (D) / Undergrounding (U)	Installation	Total
1	Wind World/ Innercon	33	Kanoi – Salkha	21	13(7)		20.414 per km (4 Cables) 1714.776 (U)	685.91 (U)	2,400.69 (U)
					-	6895	689.50 (D)	137.90 (D)	827.40 (D)
	Jodhpur Discom	33	Sam – Dhana na	45	4(3)		20.414 per km (1 Cable) 918.63 (U)	367.452 (U)	1,286.08 (U)
						6332	633.20 (D)	126.64 (D)	759.84 (D)
	Suzlon	33	Tejuva-Kuchri	17	7(4)	-	20.414 per km (2 Cables) 694.076 (U)	277.63 (U)	971.71 (U)
						3190	319.00 (D)	63.80 (D)	382.80 (D)
		33	Khuchri horizon tal - parallel	21	6(3)		20.414 per km (2 Cables) 857.388 (U)	342.96 (U)	1,200.34 (U)
					-	2955	295.50 (D)	59.10 (D)	354.60 (D)
Total		Undergrounding (U)		104	-		4,184.87(U)	1,673.95 (U)	5,858.82 (U)
		Diverter (D)		-	19372		1,937.20 (D)	387.44 (D)	2,324.64 (D) ++

Table 8. List of power lines prioritised for bird diverter installation in Thar, Jaisalmer. Cost of bird diverter per unit- Rs. 10,000/-, Cost of bird diverter installation- 20% of bird diverter cost.

Phase	Company	Power (kV)	Name of power line	Length (km)	Number		Cost (Rs. In lakhs)		
					Wires	Bird Diverters	Bird Diverters	Installation	Total
1	Rajasthan Vidyut Prasaran Nigam Limited (RVPNL)	132	132kV Jaisalmer – Ramgarh – 1	40	4(3)	5628	562.80	112.56	675.36
1		132	132kV Jaisalmer – Ramgarh – 2	40	4(3)	5628	562.80	112.56	675.36
1		132	132kV Askandra (Pokran-Askandra)	30	4(3)	4421	442.10	88.42	530.52
2		132	132kV Askandra (Pokran-Askandra)	20	4(3)	2814	281.40	56.28	337.68
1		220	220kV Amarsagar – Ramgarh	40	4(3)	5628	562.80	112.56	675.36
1		220	220kV Amarsagar – Lilo	8	7(4)	1501	150.10	30.02	180.12
1		220	220kV Amarsagar – Phalodi	54	4(3)	7598	759.80	151.96	911.76
3		220	220kV Amarsagar – Phalodi	71	4(3)	9990	999.00	199.80	1198.80
1		220	220kV Ramgarh-Dechu	49	7(4)	9193	919.30	183.86	1103.16
3		220	220kV Ramgarh-Dechu	43	7(4)	8067	806.70	161.34	968.04
2		220	220kV Ramgarh-Dechu	50	7(4)	9380	938.00	187.60	1125.60
2		400	400kV Akai – Ramgarh	55	8(4)	10,318	1031.80	206.36	1238.16
Sub-total				**500**		**80,166**	**8016.60**	**1603.32**	**9619.92**
3	Suzlon	33	Tejuva – Kuchadi	138	7(4)	25889	2588.90	517.78	3106.68
2		33	Kaladongar	70	4(3)	9849	984.90	196.98	1181.88
3		33	Mokla – Habur – Sanu	301	4(3)	42,350	4235.00	847.00	5082.00
3		132	Tejuva – Kuchadi	25	4(3)	3518	351.80	70.36	422.16
2		132/ 220	Kaladongar	47	4(3)	6613	661.30	132.26	793.56
1		132/ 220	Mokla – Habur – Sanu	43	4(3)	6051	605.10	121.02	726.12
Sub-total				**624**		**94,270**	**9427.00**	**1885.40**	**11312.40**
2	Jodhpur Discom	33	Chandan Via Bhagu ka Gaon-Mohangarh	70	4(3)	9849	984.9	196.98	1181.88
1	Greenko	220	Amarsagar – Ramgarh	40	4(3)	5628	562.8	112.56	675.36
3	Gamesa	33	Amarsagar – Ludarva	4	4(3)	563	56.3	11.26	67.56
Total		**1238 km of power line for bird diverters**				**1,90,476**			**22857.12**

Table 9. Summary of cost for implementing mitigation measures for power lines in Thar.

S. NO.	MITIGATION MEASURE	NUMBER OF BIRD DIVERTERS	COST (RS. IN LAKHS)
1	1238 km of power line for bird diverters	1,90,476	22,857.12
2	104 km of 33 kV lines (for bird diverters)	19,372	2,324.64
3	104 km of 33 kV lines for undergrounding	-	5,858.89
Grand total (S No. 1+3)			**28,716.01**

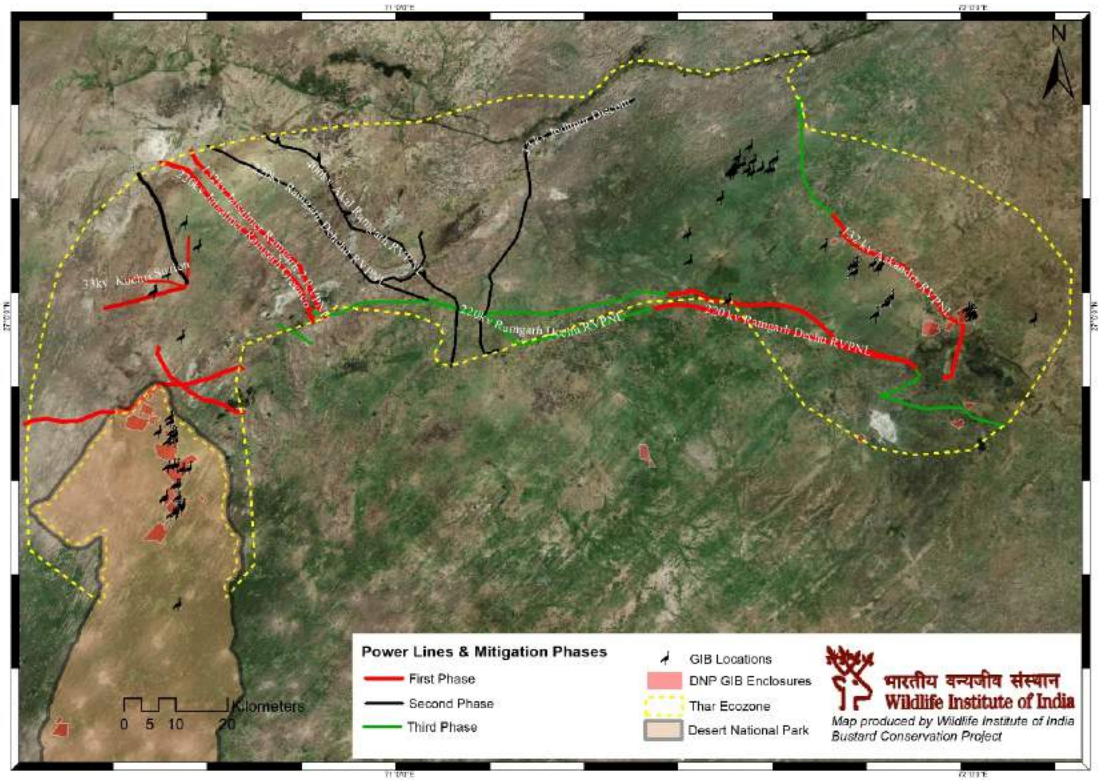


Figure 26. Map showing high tension (≥33 kV) power-lines divided into three phases for undergrounding and bird diverter installation.

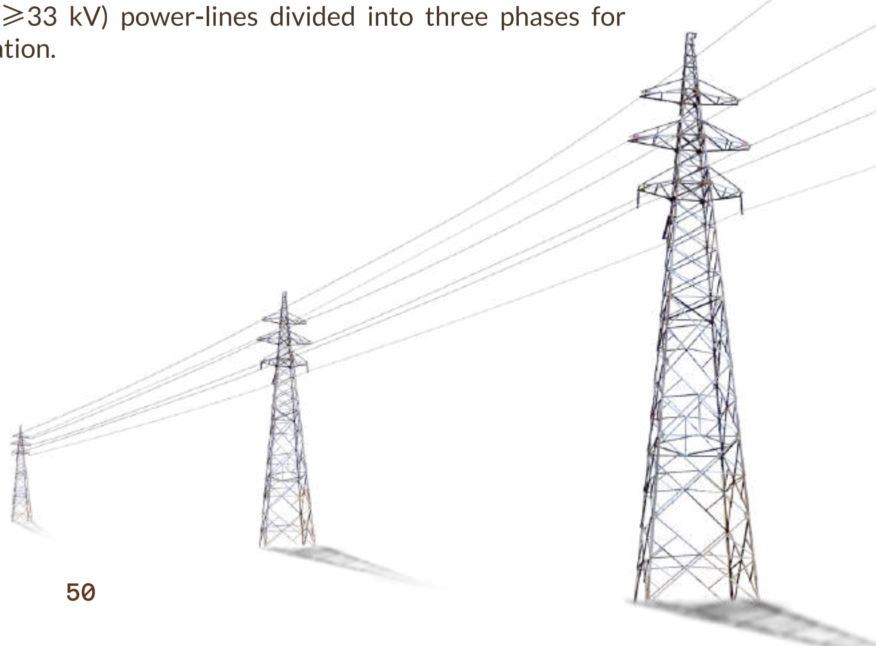


Image 12. Model Bird diverter/ reflector with rotating, reflecting and night blinking properties that has been pilot installed and field tested by Wildlife Institute of India with the assistance of power agencies in Jaisalmer.

POWER LINE MITIGATION REPORT

Technical report on power line mitigation to conserve bustards based on our findings was published for wider dissemination and public sensitization on this critical issue. The report includes scientific evidence of power-line impact on birds in general and bustards in particular, how to mitigate such threats, maps with identified critical power lines in GIB habitats of Rajasthan and Gujarat, information regarding available bird diverters and installation design as a quick reference guide. The technical report was widely disseminated to power agencies, State Forest Departments, defence personnel, conservation agencies and media. This report is available as Appendix 5.

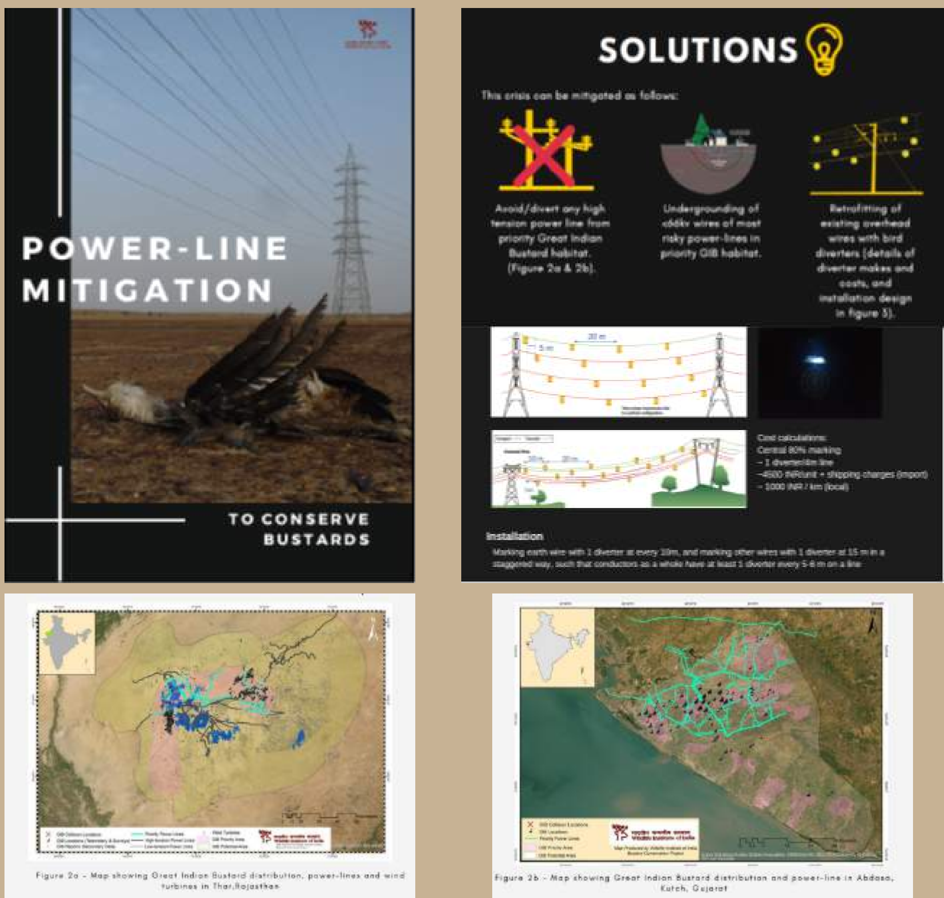


Image 13. Technical report on power line mitigation to conserve bustards published by Wildlife Institute of India.

GIB LANDSCAPE MAPS FOR POWER LINE MITIGATION

Based on our long term GIB surveys in Rajasthan, maps depicting priority and potential GIB landscape in Thar for power line mitigation were developed. The priority area and potential area identified in Rajasthan spans ~13,100 sqkm and ~ 78,500 sqkm respectively (Figure 27). In priority areas which is intensively used by GIB, it is recommended that all power lines have to be made underground or disallowed. The surrounding potential area require mitigation measures such as installation of bird diverters. The delineation of mitigation zones is an evolving exercise that needs to be refined as telemetry based information becomes available. However, since many power projects are being established in GIB habitats, the 'priority zone' will serve as a minimum area where such projects are recommended to be disallowed, to safeguard most critical bustard habtiats.

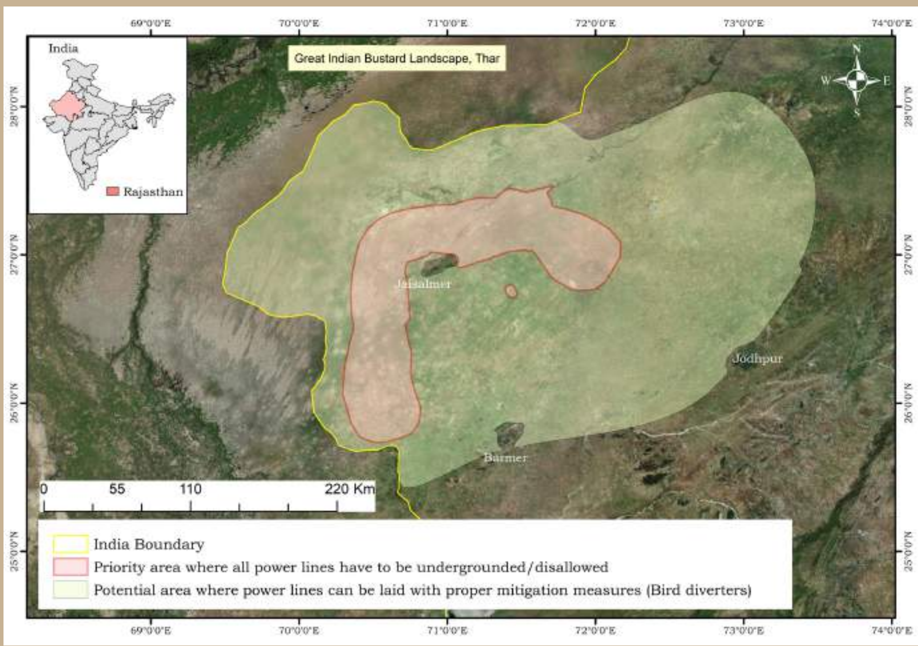


Figure 27. Great Indian Bustard landscape in Rajasthan delineating the priority and potential areas for power line mitigation.

Image 14. Great Indian Bustard mortality due to power line collision in June 2018 at Ramdevra, Jaisalmer © Bipin C.M.

MITIGATION MEASURES FOR FREE-RANGING DOGS

Free ranging dogs are a known threat to wildlife. Our assessment showed that the free ranging dogs are responsible for hunting ~33% of chinkara population annually from Desert National Park (DNP). Hence, we initiated the sterilization of dogs in/ around DNP in collaboration with Humane Society International (HSI)-India and Rajasthan Forest Department (October 2018 – January 2019). For the first phase of sterilization, 23 villages/ settlements were targeted. A temporary post-op facility was setup in Sam village. The surgeries were performed in a well-equipped mobile operation theatre van. The highest number of dogs captured for sterilization were from Sam (133) followed by Khuri (117) and Kanoi (95) (Table 10). These three villages have maximum tourism activities in their proximity that have probably attracted large dog numbers. Total 801 dogs (454 males and 347 females) were spayed/ neutered and vaccinated against rabies from 20 villages which surround the enclosures in DNP. Post-sterilization, the dogs were monitored in the post-op facility till they recuperated. Operated dogs were ear notched for future identification and released back in their respective villages as per HSI Animal Birth Control (ABC) guidelines. To evaluate the effectiveness of sterilization program and to assess the ratio of sterilized and non-sterilized dogs mark- resight based abundance surveys in six major villages (Sam, Kanoi, Salkha, Neemba, Bida, Keshawon ki Basti) and crude count in all the treatment villages were conducted in February- March 2019.

Image 14. Great Indian Bustard mortality due to power line collision in June 2018 at Ramdevra, Jaisalmer © Bipin C.M.

Table 10. Number of dogs captured for sterilization village wise in and around Desert National Park, Jaisalmer.

S. NO.	VILLAGE	DOGS CAPTURED
1	Sam	133
2	Khuri	117
3	Kanoi	95
4	Sipla	93
5	Neemba	66
6	Kumbhar Kotha	60
7	Ghuriya	54
8	Barna	38
9	Salkha	38
10	Khaba	32
11	Bida	21
12	Jamra	20
13	Bhilon ki dhani	13
14	Keshawon ki Basti	13
15	Meghwalon ki Basti	13
16	Ganga	6
17	Raydhan ki Dhani	6
18	Balanio ki Dhani	4
19	Singhalon ki Basti	4
20	Haider ki Dhani	1
Total		**827**

DOG POPULATION SURVEYS TO ASSESS THE EFFECTIVENESS OF SPAY NEUTER PROGRAM

We estimated the population status of free-ranging dogs in/ around DNP in 2017-2018 and again in 2019 after the dog spay neuter program, to examine the effectiveness of program and to estimate the sterilized, unsterilized dog ratio and number of lactating female which will in future add up more dogs in the population. We conducted dog population assessment using crude count and mark-resight survey that have been described in details earlier.

Count surveys were done in the 11 settlements where dog sterilization program was conducted. This exercise in conjunction with the correction factor developed through the earlier double sampling approach (described above), yielded dog abundance estimate.

Mark-resight surveys in six villages (Meghwalon ki Basti, Salkha, Kanoi, Keshawon ki Basti, Neemba and Bida) in treatment block (villages with sterilization program) and two villages (Bandha, Soro ki Basti) in control block (villages without sterilization program) were targeted for estimation of dog abundance in mark-resight framework which is robust to imperfect detection, following field and analytical methods described earlier.

Dog numbers

A total of 351 dogs were counted during the survey. The highest ratio of unsterilized dogs was found in Ghuriya Village (0.87) followed by Ganga Village (0.81). From count surveys, maximum number of dogs were estimated for Meghwalon ki Basti with 177 (5.3SE) dogs, followed by Salkha and Bida villages (Table 11). All villages showed high ratio of unsterilized dogs. The treatment and control village dog populations will be monitored in future to understand the effectiveness of this pilot sterilization program.

Table 11. Estimated population of dogs in 11 villages/settlements in and around Desert National Park using count surveys.

Village/ Settlement	Count				Ratio			Abundance ± SE (Count ÷ detection probability)	95% CI
	Sterile dog	Unsterilized dog*	Uniden-tified dog	Total	Sterile dog	Unsterili-zed dog*	Unidentified dog		
Meghwalon ki Basti	24	82	1	107	0.22	0.77	0.01	176.55 ±5.3	166 - 187
Salkha	24	67	2	93	0.26	0.72	0.02	153.45 ±4.6	144 - 163
Bida	14	26	0	40	0.35	0.65	0	66 ±1.98	62 - 70
Keshawon ki basti	8	30	0	38	0.21	0.79	0	62.7 ±1.88	59 - 66
Ganga	2	21	3	26	0.08	0.81	0.12	42.9 ±1.29	40 - 45
Ghuriya	3	20	0	23	0.13	0.87	0	37.95 ±1.14	36 - 40
Jamra	2	7	0	9	0.22	0.78	0	14.85 ±0.45	14 - 16
Lolai	0	6	0	6	0	1	0	9.9 ±0.3	9 - 11
Lakhmanon ki Basti	1	4	0	5	0.2	0.8	0	8.25 ±0.25	8 - 9
Loonon ki Basti	2	0	0	2	1	0	0	3.3 ±0.1	3 - 4
Sagaron ki Basti	0	2	0	2	0	1	0	3.3 ±0.1	3 - 4

*lactating female with pup

Table 12. Estimated population of adult dogs in four villages/ settlements in and around Desert National Park using mark- resight survey.

Village/ Settlement		Adult dog population (SE)	95% CI
Treatment (Sterilization)	Meghwalon ki Basti	105 (5.58)	94 - 116
	Bida	26 (0.90)	24 - 28
Control (No Sterilization)	Bandha	62 (1.69)	59 - 65
	Soro ki Dhani	32 (0.51)	31 - 33

PESTICIDE CONTROL

To control the outbreak of locusts, the District Collector of Jaisalmer issued an order to spray pesticides in May 2019. The spraying of pesticides was being carried out even in GIB habitats and was counterproductive to the ongoing efforts of the Government to recover the GIB populations.

The pesticide in use - Malathion (50% and 97% concentrations) – is an organophosphate. Organophosphates act on the nervous system by inhibiting the enzyme cetylcholinesterase which plays a similar role in all insects, birds and animals. Many organophosphates are acutely toxic to birds at very low doses (Cox 1991). There have been documented bird kills caused by the organophosphates diazinon, isofenphos, and chlorpyrifos with one kill involving thirty to forty thousand birds (Stone 1985, 1987 & 1989). A review of aerial forestry applications showed that four organophosphates reviewed, phosphamidon, fenitrothion, acephate, and trichlorofon, caused reductions in the abundance of singing males, the number of birds present, or the number of species present (Peakall & Bart 1983). In addition, organophosphate insecticides are known to cause anorexia (loss of appetite) in birds. The resulting starvation can be an important cause of death. An invitro toxicity study of malathion indicated a higher toxic potential of malathion than that is generally declared. The environmental consequences of delayed effects and embryotoxicity for bird populations in areas exposed to organophosphate insecticides, such as malathion, are obvious (Mueller-Beilschmidt 1990, Jira et al. 2012). Since Malathion has a half-life period of 2–18 days depending on the soil type, any GIB feeding on Malathion sprayed crops would likely suffer from the above stated health hazards and possible mortality. The long-term effects of the pesticide on the ecosystem and on birds that have ingested less than lethal dose would be insidious and very detrimental. Studies across the globe have conclusively shown that populations of many birds, particularly agro-grassland species have declined due to the use of chemical pesticides and fertilizers and in turn causing severe cascading effects in the ecosystem (Carson 1962, Donald et al. 2001).

GIB is a large omnivorous bird that feeds largely on insects, fruits and harvested crops. It breeds during mid-summer through monsoon (April – October), when it largely depends on protein-rich insectivorous diets. Ecological studies conducted on this species (Rahmani 1989, Dutta 2012) indicate that grasshoppers/ locusts and beetles contribute significant portion of their diet, and their breeding activity is strongly correlated with the population bursts of grasshoppers/ locusts.

Further, the survival of chicks and juveniles largely depend on the availability of insects and other food in the environment, particularly during the initial few months after breeding (Kålås et al. 1997, Lane et al. 1999, Bravo et al. 2012). Since the pesticide used affect a large spectrum of insect taxa, grasshoppers/ locusts and other invertebrate resources may be depleted, the ensuing food scarcity will be detrimental to birds. The GIB is range restricted and its distribution is currently patchy, restricted to only about ~4500 sqkm area of the Jaisalmer district, and largely to grasslands interspersed with agriculture. Based on joint surveys of the WII and Rajasthan Forest Department, the intensive use areas have been identified and overlaid on agricultural areas digitized by WII (Figure 28).

We communicated following recommendations to the Chief Wildlife Warden (CWLW), Rajasthan regarding the need of regulating pesticides in Great Indian Bustard habitats, based on the above scientific reasons:

(a) spraying of pesticides should be strictly avoided in the identified intensive use areas of GIB, apart from all other areas where such activity is legally restricted. The agricultural area identified for strict avoidance of pesticide use comprises of less than 10% of the total agriculture area in Jaisalmer. Farmers with existing crops in these areas could be compensated for their foregone production cost, based on appropriate quantification, as an incentive for not using such pesticides, using State Government funds such as CAMPA allocations.

b) Any GIB site that has already been sprayed with pesticide should be cordoned off by temporary fence with patrolling teams to ensure that these birds are not feeding on toxic crops/ insects for a period of 15-20 days until the toxicity levels are reduced.

(c) In areas adjoining the intensive usage of GIB, use of biopesticides may also be explored by the Ministry of Agriculture involving appropriate expertise. Metarhizium anisopliae, a biopesticide recommended by FAO for desert locust management has been tried extensively in Africa, Australia and Brazil with evidence of up to 90% control of the locust population (FAO 2007, Lomar et al. 2001). This biopesticide is available by the trade name of Green Muscle, BioMetaz, GreenMeta and Kalichakra available locally and internationally.

The CWLW Rajasthan was appraised of the situation and requested to inform the administration to prevent spraying of pesticides in areas intensively used by GIB and take urgent measures to reduce the impact of pesticides .

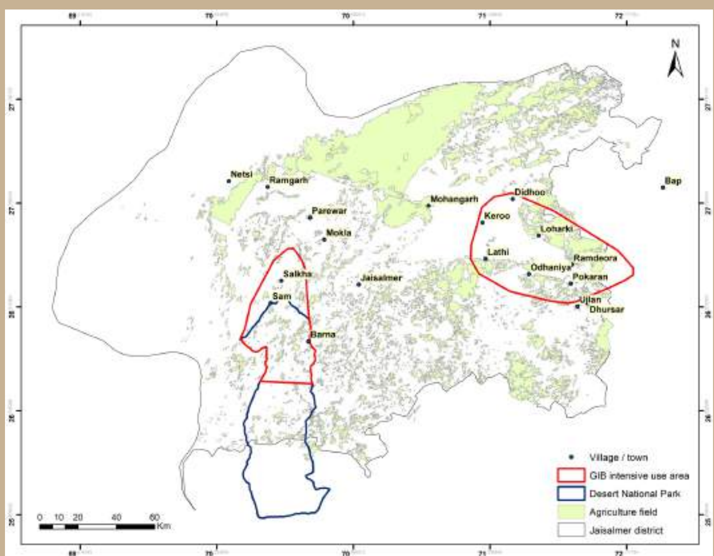


Figure 28. Map showing Great Indian Bustard intensive use areas in Jaisalmer, Rajasthan, overlaid on agriculture and Protected Area expanse for deciding the management of pesticide usage.

MEETINGS WITH STAKEHOLDERS REGARDING GIB CONSERVATION

- -Discussion with concerned officers of Rajasthan Forest Department for developing a mutually agreed roadmap on GIB conservation program in Jaipur during July 2016.
- Collaborative workshop between WII, Bombay Natural History Society and Rajasthan Forest Department on 12th July 2016 at Jodhpur to sensitize Indian Army on GIB conservation and obtain permission to monitor the GIB population in Pokhran Field Firing Range.
- Meeting with the Hon. Chief Minister, Additional Chief Secretary Forest, & Principal Chief Conservator of Forests (Wildlife) of Rajasthan State on 20th October 2016 in Jaipur wherein measures for GIB conservation were discussed in detail.
- Meeting with Rajasthan Forest Department and power agencies during December 2016 to provide technical inputs on installation of bird diverters on power lines in priority GIB areas in Thar. Based on this meeting, WII was given the responsibility to procure samples of bird diverters for installation on pilot basis by Suzlon for design/ installation demonstration.
- Consultative meeting with Rajasthan Forest Department to provide inputs in Desert National Park management plan during January 2017 in Jaipur. Meeting was attended by Chief Wildlife Warden, Chief Conservator of Forests (CCF)- Jodhpur and Deputy Conservator of Forests (Jaisalmer) where GIB census methods and priority conservation actions were discussed.
- Meeting with Hon. Minister- Environment and Forests, Rajasthan State on 31st January 2017 at Jaipur regarding measures being taken to conserve the GIB. The Minister appreciated the efforts and science behind the initiatives and assured all support for moving ahead.
- Meeting with Hon. Chief Minister, Rajasthan; Forest Minister; Forest Department, Rajasthan and Rajasthan State wildlife board on 28th April 2017 to discuss on implementing measures for GIB conservation.
- Review meeting of project updates with RSPCB and meeting with CWLW, Rajasthan on project updates at Jaipur on 29th August 2017.
- Meeting with Sarpanch and villagers of Khetolai, Jaisalmer near PFFR along with Forest Department staff during November 2017 regarding collaborative measures for conservation of GIB.
- Meeting with CCF-Jodhpur, representatives of RVPNL, SUZLON, Jodhpur Discom powerline companies, and Divisional Forest Officer (DFO)-Desert National Park on mitigation of high tension power lines in GIB habitat at Jodhpur during January 2018.
- Meeting with village representatives regarding permission & support for dog sterilization in the villages around GIB habitat in and around Desert National Park during January- February 2018.
- Meeting with officers of Indian Armed forces on the need and importance of GIB conservation in PFFR, Jaisalmer during April- May 2018.
- Meeting with District Collector, Jaisalmer on harmonizing project activities with government outreach programmes during April 2018.
- Meeting held on 20th December 2018 under the chairmanship of Principal Secretary Energy, Govt. of Rajasthan that was attended by RFD and WII representatives decided that the mitigation measures should be urgently implemented, and directed the power agencies to place proposals with cost-estimation for this action. Principle Secretary- Energy directed power agencies to install time tested imported bird diverters on all priority power lines. A mitigation plan for high tension power lines in GIB habitat of Thar Desert, Jaisalmer was developed. This plan identified critical power lines and prioritised for bird diverter installation and undergrounding in Thar, Jaisalmer including the length and cost and was submitted to Rajasthan Vidyuth Prasaran Nigam Limited (RVPNL) for further action.

- Workshop was organized at WWF-India headquarters, New Delhi on 21st February 2019 with partner agencies to sensitize power agencies and the media on GIB conservation. The workshop was attended by ~100 participants including officials from MoEFCC and State Forest Department, representatives from power agencies, conservation organizations, legal fraternity and media. The immediate need to mitigate power lines caused bustard collisions and deaths, and the necessity of conservation breeding were highlighted. The objective of this workshop was to create awareness about the plight of the bustard, develop a branding strategy to communicate to the public and all stakeholders in one language about the bustard, and to communicate to power agencies (government and private) the integral role they serve in saving this iconic species of the Indian grasslands.

Image 16. Sensitization workshop on Great Indian Bustard Conservation at New Delhi. © Tanya Gupta

- Meeting with representatives of Tata Power Mr. V.K. Nori- Chief (Corporate Affairs), Prashant Kokil- Head (Environment & Climate Change) and Mr. Amar Nayakvadi- Lead Associate (Environment & Forest, Trans. Project) on 08th July 2019 at WII regarding mitigation of power lines in GIB habitat near Pokhran area in Jaisalmer. A site inspection of Tata power 150 MW Solar Power project and 220 KV transmission line was carried out by the team along with Dr. Asad Rahmani- Former Director of Bombay Natural History Society and renowned GIB expert, representatives from TATA Power- Mr. Abhishek Ashok Bhagat- Station head- Chhayan (Operations) and Mr. Saket Porwal- Project head (Large projects) on 22nd July 2019. As a mitigation measure based on our recommendations they have installed bird diverters on the transmission line.
- Meeting with Essel Infra official- Mr. Rajnish Mehrotra, Head (Environment, Forest & Wildlife) on 08th July 2019 at WII regarding mitigation of power lines in GIB habitat in Jaisalmer.
- Meeting through skype on 31st May 2019 with representatives from Enel Green Power- Ms. Suvalaxmi Sen, Environmental Design Specialist, and other officials, for mitigation of power line in GIB habitat near Ramgarh, Jaisalmer. They decided to shelve the project which was situated inside the GIB priority zone .

- Sterlite power for procurement of bird diverters to install on power lines for prevention of bird mortality. Details regarding international and Indian bird diverter manufactures and suppliers, cost of procurement were shared with them.
- Meeting with representative from General Electric- Mr. Dheeraj Jain, Regulatory Leader- Turnkey at WII on 14th November 2019 for mitigation of power line to prevent bird mortality across India. Information on power line mitigation including the GIB priority and potential zones in Rajasthan and Gujarat, report on power line mitigation to conserve bustards, Lesser Florican status assessment report and details regarding international and Indian bird diverter manufactures and suppliers, cost of procurement were shared with the firm.
- Sitac Management & Development Private Limited for our assistance in identifying the habitats of GIB in India, whether their wind projects fall in the GIB habitat zone and accordingly take preventive measures. Information on power line mitigation for GIB priority and potential zones in Rajasthan and Gujarat were shared with them.
- Correspondences with - Mr. Amit Gupta, Head (ESG), Sprng energy for mitigation of power lines in Jaisalmer and Jodhpur.
- Meeting with private companies for diverter procurement and manufacturing
  -Welkin conservation LLP for procurement and installation of bird diverters in Jaisalmer.
  -Indolite and A & S Creations for development of indigenous, low cost bird diverters in the country.
- Meeting at MoEFCC to draft a time bound action plan to conserve GIB as directed by National Green Tribunal (NGT) Principal Bench;

To draft a time bound action plan to conserve GIB based on the recommendations by WII as directed by NGT, meetings were held at MoEFCC on 04th September and 11th November 2019 under the chairmanship of Director General of Forest & Special Secretary. The participants included Additional Director General (Wildlife), Deputy Inspector General (Wildlife), CWLW Rajasthan, officials from MoEFCC, MNRE, Central Electricity Authority, RVPNL, Gujarat Energy Transmission Corporation, Essel Saurya Urja Company of Rajasthan Ltd, Power Grid Corporation of India Ltd, Tata Power Renewable Energy Ltd, Sprng Energy Pvt. Ltd, Actis, Siemens Gamesa & WII representatives. The meetings concluded with suggestions such as exploring possibilities for declaring GIB priority zone or the arc as Conservation or Community Reserve, principle of avoidance being the best option to adopt in GIB habitat and the techno- feasibility of the mitigation measures such as undergrounding high tension power lines.

- Meeting with Mr. Yash Arora (Environmental Specialist) International Finance Corporation, World Bank Group during February 2020 regarding GIB conservation and mitigation of power line impacts.
- Indigenously manufactured bird diverters developed based on our suggestions were procured from A & S Creations, New Delhi and to check their efficacy, a batch has been distributed to Suzlon and installed on power lines in Thar.
- Meeting convened by MoEFCC through video conferencing under the Chairmanship of Director General of Forest & Special Secretary on 05th May 2020 attended by Inspector General (Wildlife), Joint Secretary- MNRE, DIG (Wildlife), CWLWs of Rajasthan & Maharashtra, Additional Principal Chief Conservator of Forests (Wildlife) of Gujarat and Karnataka, officials from Ministry of Power, RVPNL, Gujarat Energy Transmission Corporation, Power Grid Corporation of India limited, National Highway Authority of India, Sprng Energy, other wind and solar farms/ projects agencies operating in Rajasthan and Gujarat to discuss on plans for protection and conservation of GIB in the country with emphasis on power line mitigation.

- Correspondences with Mr. Soumik Sarkar Dy. Manager- Project Skipper Limited, Bikaner (Rajasthan) during August 2020 regarding technical specifications & drawings of bird diverters to be installed in the upper conductor of 132 KV D/C Chhatargarh Loonkarnsar transmission line under forest area.
- Correspondence with Mr. Devesh Kumar Singh, Chief Manager, Power Grid Corporation of India Limited regarding identification of transmission line stretch infringing GIB habitats zones in Rajasthan during August 2020.
- Correspondence with Shri Dinesh Kumar, Chairman & Managing Director, Rajasthan Rajya Vidyut Prasaran Nigam Ltd during August- September 2020 regarding design of bird deflectors/ diverters and the span length & distance at which bird diverters are to be installed on the earthwire of transmission line passing through forest area (other than DNP and GIB arc) and on all conductors of transmission line passing through DNP and GIB arc for fixing of bird diverters on RVPN transmission lines to avoid bird collisions.
- Correspondence with Ms. Emma Marsden, Senior Environment Specialist, South Asia Energy Division, Asian Development Bank during September 2020 regarding mitigation measures for upcoming power projects in GIB habitat in Rajasthan.

ACTIVITIES RELATED TO LEGAL ISSUES

On matters concerning the court cases filed for conservation of GIB, the following activities were carried out-

1. Hon’ble High Court of Rajasthan, Jodhpur- Regarding the Suo moto case D.B. Civil Writ Petition (PIL) No.825/2019 filed at Hon’ble High Court of Rajasthan, Jodhpur for the conservation of GIB, responses were prepared about the details of the work on habitat improvement and conservation breeding of the GIB carried about by WII including recommendations for GIB conservation. Subsequently, meetings were held with Additional Solicitor General, Mr. Sanjit Purohit and affidavits were filed at the Court on behalf of WII.

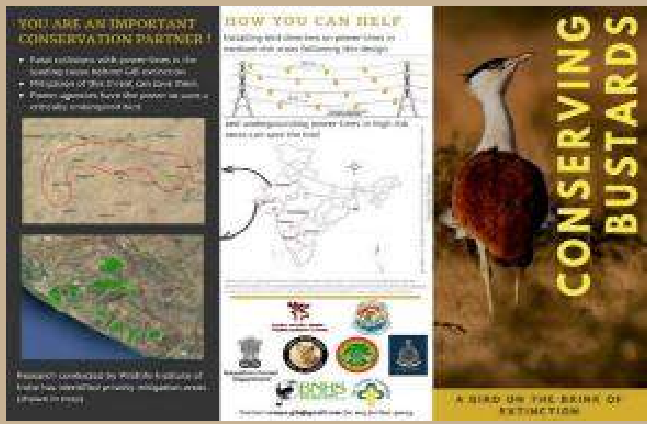
2. Principal bench of Hon’ble National Green Tribunal (NGT)- For the Original Application No. 385/2019 filed by Centre for Wildlife and Environment Litigation before the Principal Bench of National Green Tribunal against adverse impact caused by power and wind projects on GIB, a factual report on the status of GIB and threats to their population, progress of the WII project and key recommendations based on our findings was prepared and submitted on behalf of MoEFCC. Meetings were held on 16th October and 11th November 2019 at MoEFCC to draft a time bound action plan to conserve GIB based on our recommendations as directed by NGT under the chairmanship of Director General of Forest & Special Secretary. The meetings were attended by officials from the Ministry, representatives from power agencies and WII representatives.

3. Hon’ble Supreme Court of India- Regarding the Writ Petition (Civil) No. 838 of India with I.A. No.95438/2019-Clarification/ Direction) filed by Dr. M.K. Ranjitsinh in the Hon’ble Supreme Court of India for the conservation of GIB and Lesser Florican, a report on the status of the GIB conservation breeding program and emergency response plan was drafted and submitted for further action. To represent WII and MoEFCC at the Hon’ble Supreme Court, Advocate Mr. Devendra Singh was appointed with approval from MoEFCC.

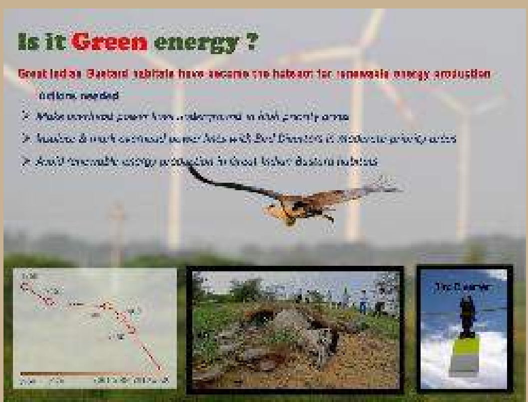
G.S. BHARADWAJ

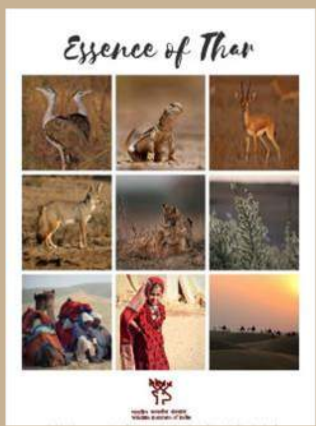
AWARENESS MATERIALS AND PUBLICATIONS

Sensitization Brochures

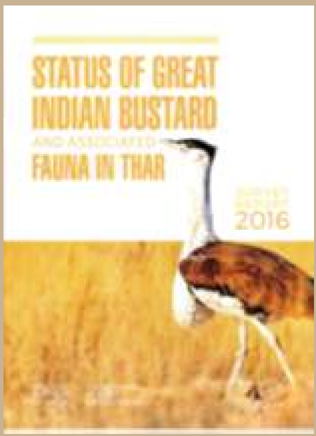


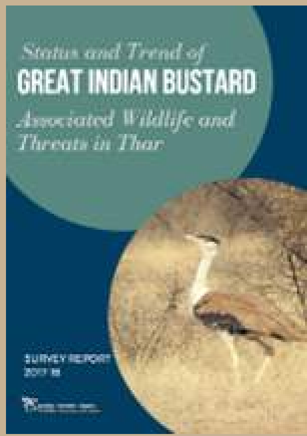
Posters

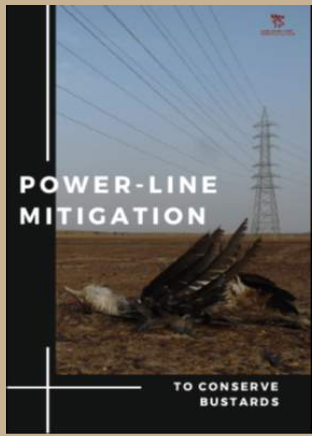




Reports







Bookmarks

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APPENDICES

1. Status of Great Indian Bustard and associated fauna in Thar- Survey report 2014

2. Status of Great Indian Bustard and associated fauna in Thar- Survey report 2014 & 2015

3. Status of Great Indian Bustard and associated fauna in Thar- Survey report 2016

4. Status and trend of Great Indian Bustard, associated wildlife and threats in Thar- Survey report 2017-18

5. Power line mitigation measures to conserve bustards- Technical report 2018- Second edition (2020)

Status of Great Indian Bustard and Associated Wildlife in Thar

Survey Report 2014

Wildlife Institute of India
&
Rajasthan Forest Department

Survey Team

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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 km² of potential bustard landscape in Thar spanning Jaisalmer and Jodhpur districts of Rajasthan. Systematic surveys were conducted in 144 km² 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 km², yielding abundance estimates of 103 ± 62 in the sampled area (16,992 km²) and **155 ± 94 GIB in Thar landscape** (25488 km² 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 km² 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 km² 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.

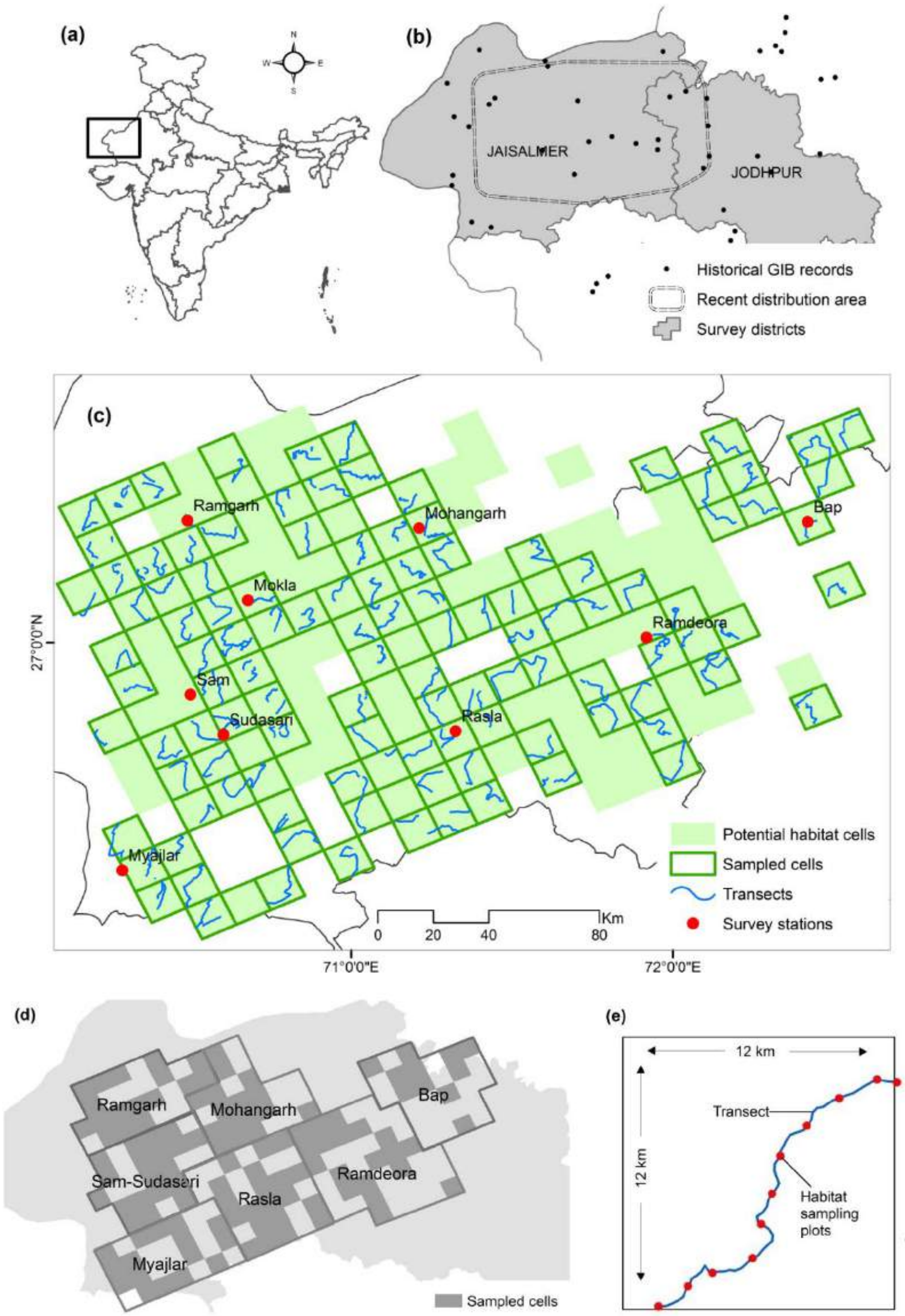
Our survey covered the potential bustard habitat in Jaisalmer and Jodhpur districts (hereafter, Thar landscape). Ground data collection was carried out by researchers, qualified volunteers and Forest Department staff who were trained through workshops and field exercises prior to the survey. This report 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 km² 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}, $1\text{-}5_{\text{Range}}$) were deployed along $8.6_{\text{Mean}} \pm 2.8_{\text{SD}}$ 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 $8.9_{\text{Mean}} \pm 2.1_{\text{SD}}$ 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 $77.63_{Mean} \pm 11.09_{SE}$ 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

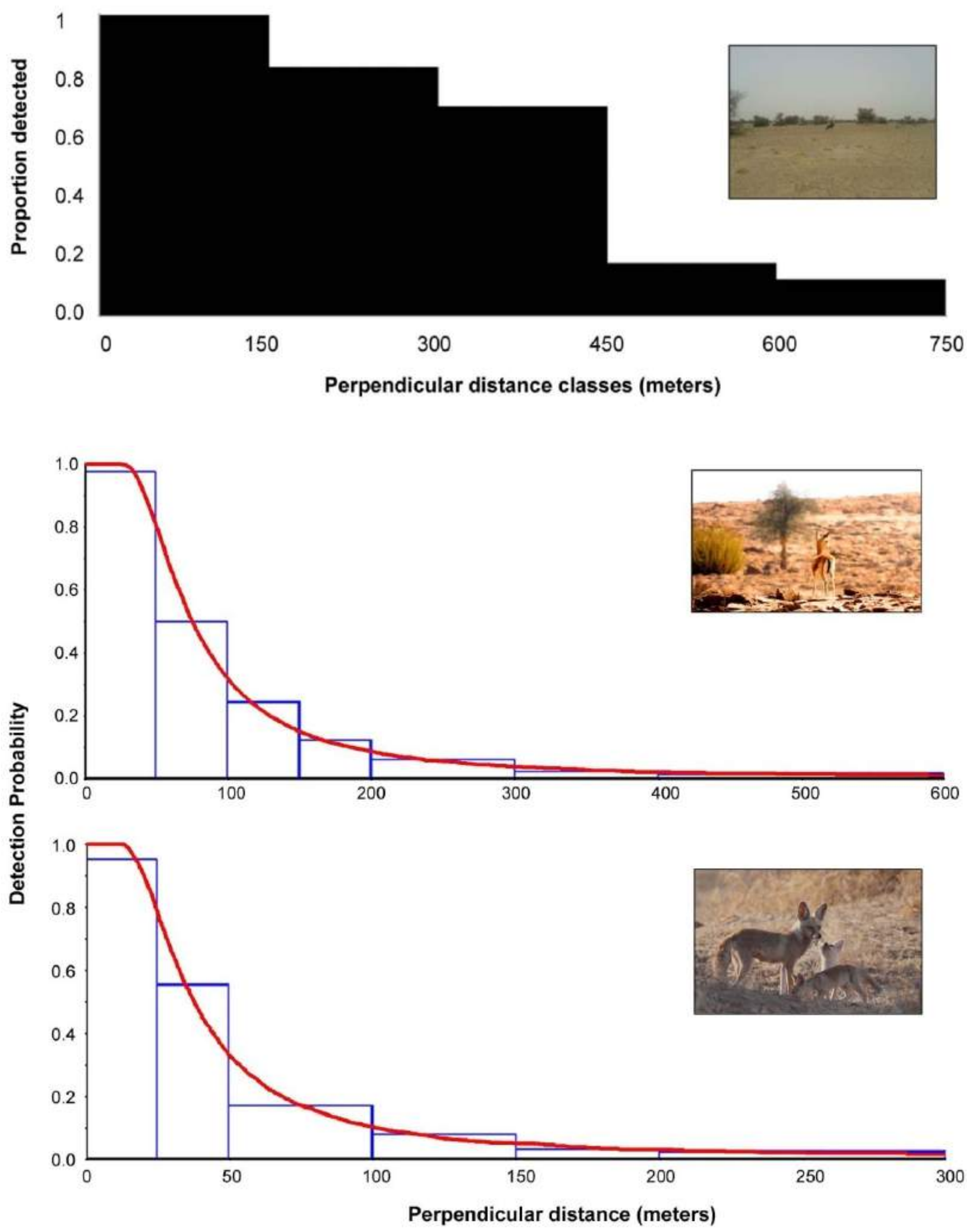


Figure 3. Great Indian Bustard sightings and occurrence status in 144 km² cells based on surveys (primary data) and reports by local people (secondary data) in Thar landscape (February-June 2014)

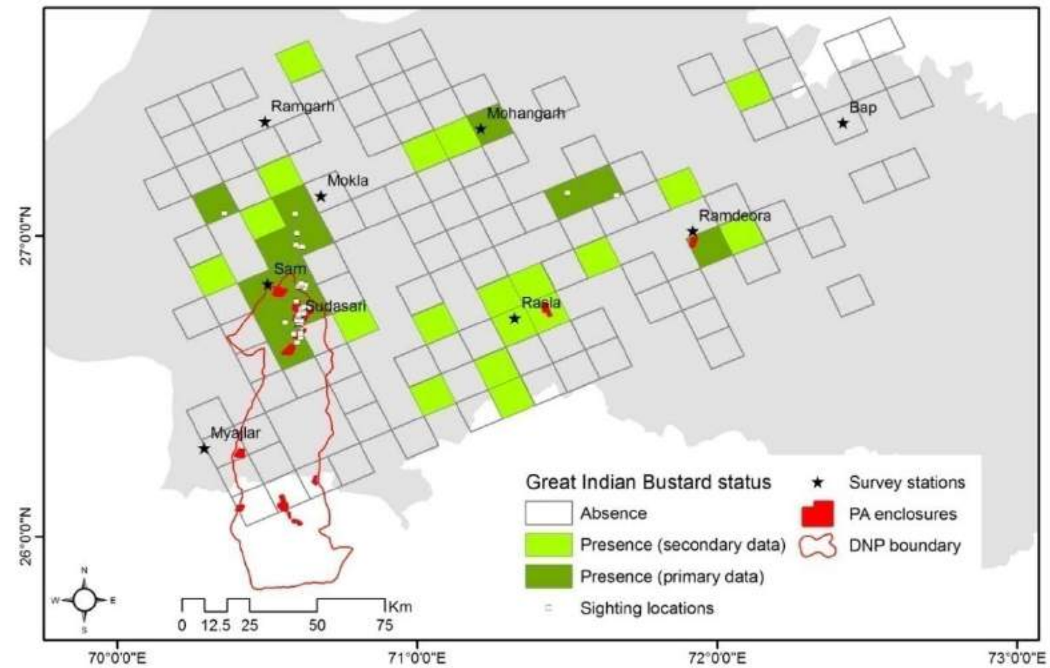
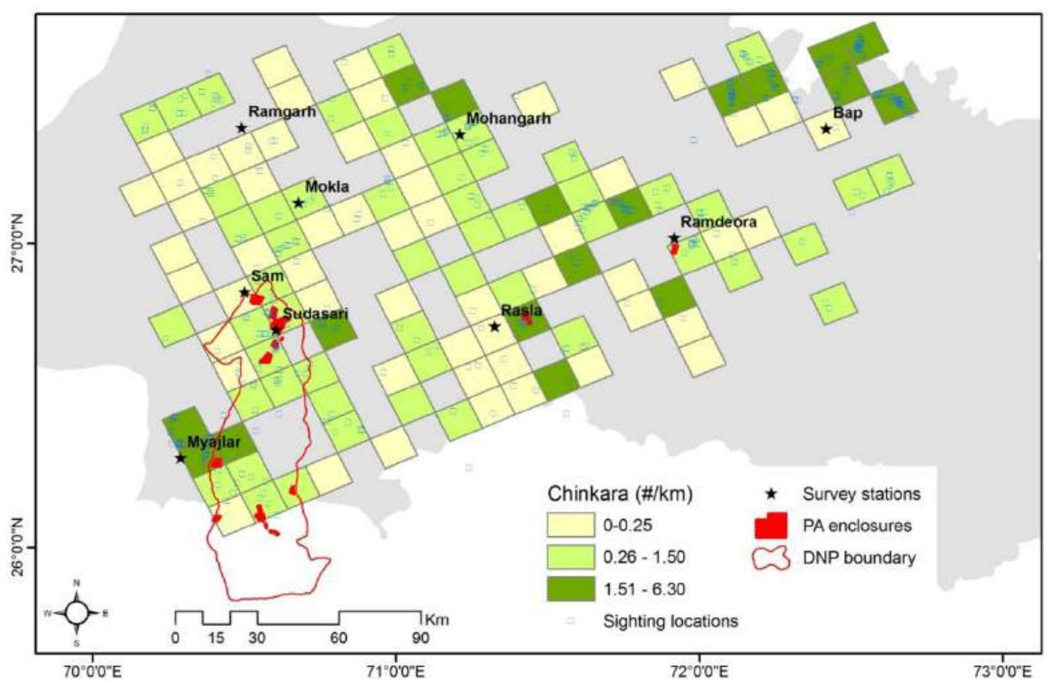


Figure 4. Chinkara sightings and encounter rates in 144 km² cells of Thar landscape (March 2014)



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)

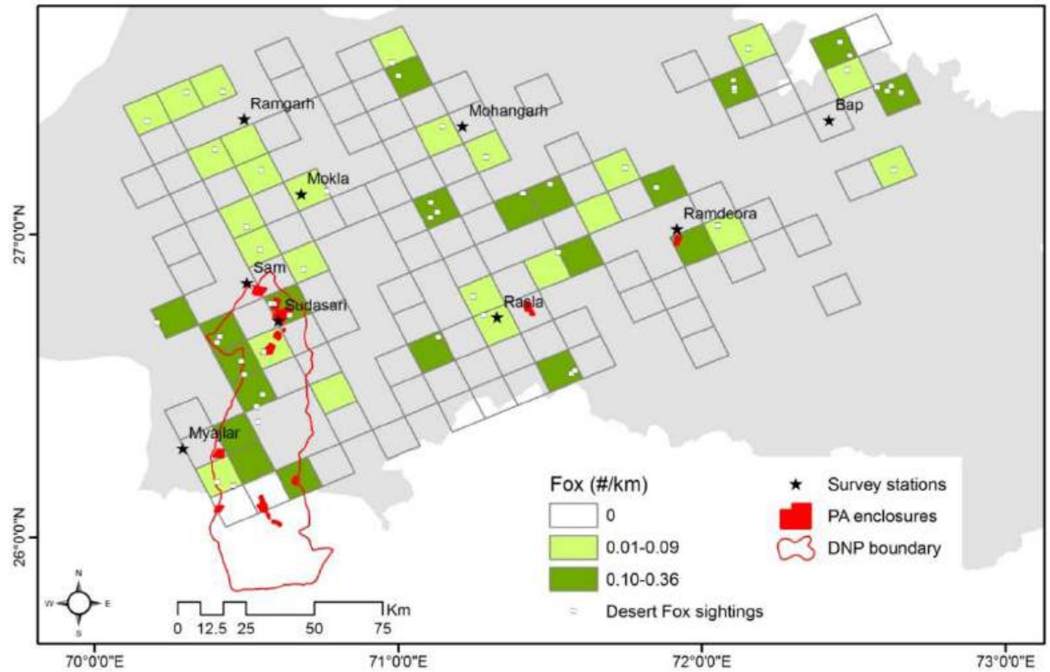
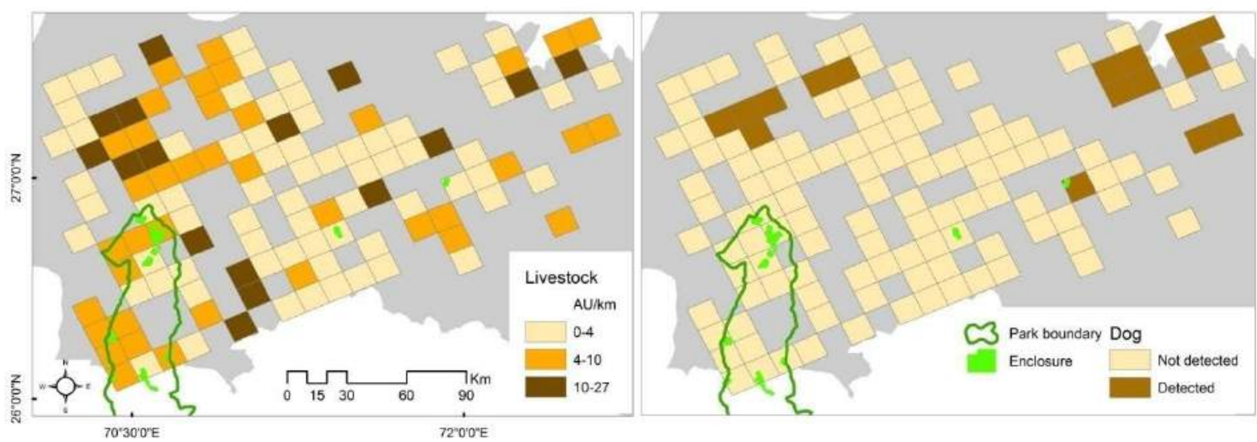


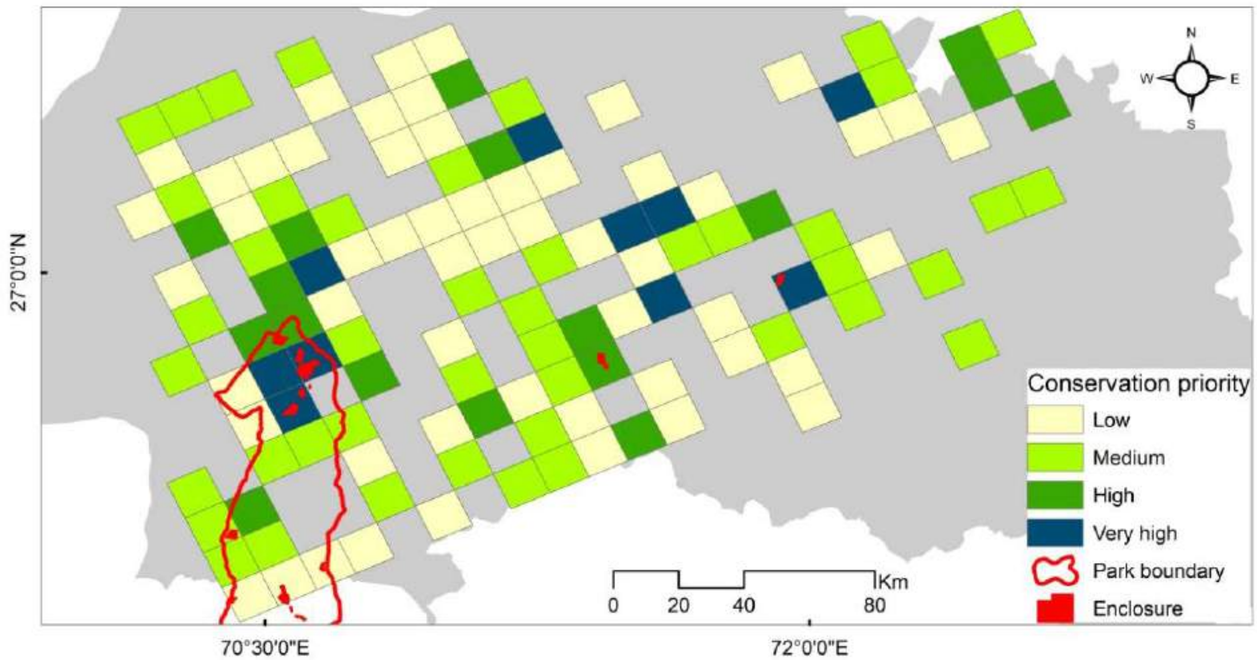
Figure 6. Livestock and dog detections rates in 144 km² cells of Thar landscape (March 2014)



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

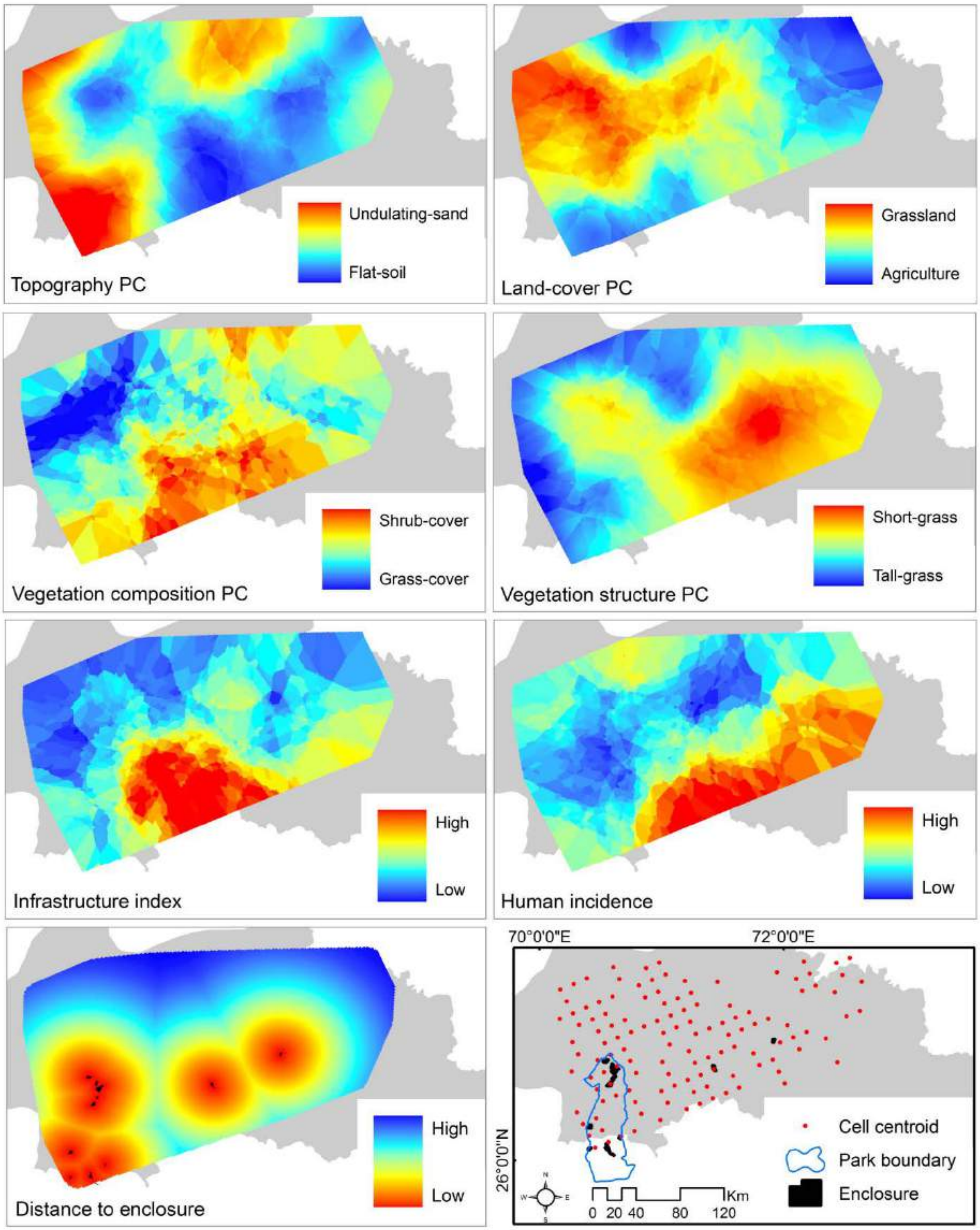
Ecologically meaningful gradients were identified using Principle Component Analysis (PCA) on habitat variables (table 4). The first PCA was conducted on terrain, substrate and land-cover variables, which extracted three components cumulatively explaining 58% of information in the data. Of these, two 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

STATUS OF GREAT INDIAN BUSTARD AND ASSOCIATED FAUNA IN THAR

SURVEY REPORT 2016

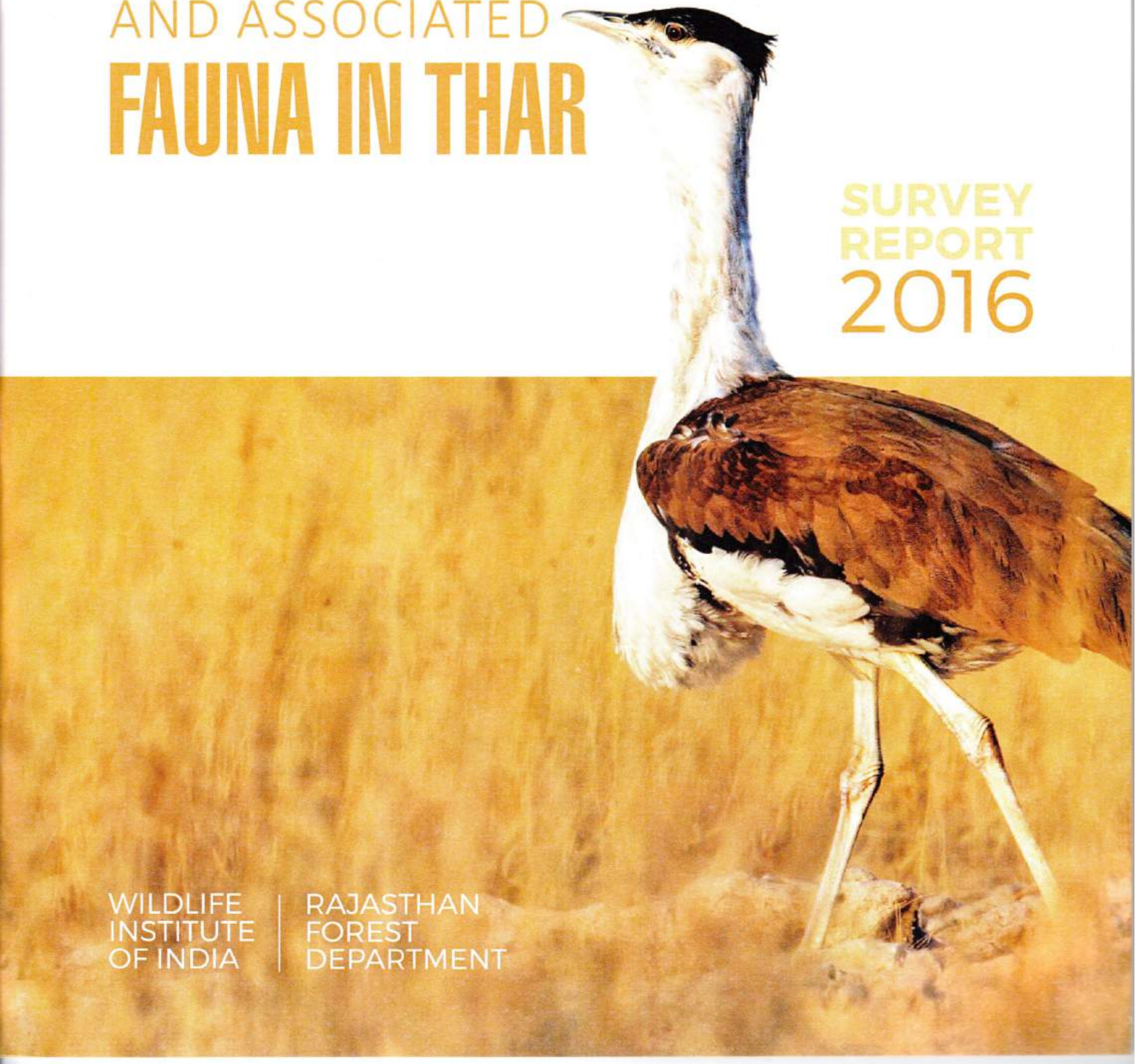

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Photo credit: Dr. Gobind Sagar Bhardwaj

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Executive Summary

Arid ecosystems of India support unique biodiversity and traditional agro-pastoral livelihoods. However, these habitats are highly threatened due to large-scale land-use changes and historical neglect of conservation policies. The Critically Endangered great Indian bustard acts as a flagship and indicator of this ecosystem, for which Government is planning conservation actions that will also benefit associated wildlife. Persistence of this species critically depends on Thar landscape, where ~75 % of the global population resides. Since 2014, Wildlife Institute of India and Rajasthan Forest Department have been jointly conducting scientific surveys to better understand the current status, distribution patterns, and local contexts of key conservation-dependent species in Thar for informing management actions.

This study assessed the status of great Indian bustard, chinkara and fox alongside their habitat and anthropogenic pressures across 19,728 km^2 of potential bustard landscape in Thar spanning Jaisalmer, Jodhpur and Bikaner districts of Rajasthan. Systematic surveys were conducted in 144 km^2 cells from slow-moving vehicle along $17.9 \pm 3.9_{SD}$ km transects to record species' detections, habitat characteristics in sampling plots, and secondary information on species' occurrences. Multiple teams comprising field biologists and Forest Department staff simultaneously and rapidly sampled 108 cells along 1697 km transects in March 2014, 77 cells along 1246 km transects in March 2015, and 120 cells along 2273 km transects in March 2016. Sampling was carried out in two phases: extensive surveys to assess great Indian bustard occurrence across the landscape and intensive surveys to estimate their density in used cells. Great Indian bustard and other key species' detection data were analyzed in Occupancy and Distance Sampling framework to estimate proportion of sites used and density/abundance.

Detection/non-detection data from multiple year surveys (2014-16) showed that great Indian bustard used $10.9 \pm 3.4_{SE}$ % sites (naive occupancy 8.4%). Bird density in **used sites** (cells where at least one bird was detected during 2015-16) was estimated at $6.5 \pm 1.4_{SE}$ /100 km^2. Random sampling of the potential bustard landscape in Thar using line transect distance sampling yielded density and abundance estimates of 0.84 ± 0.38 birds/100 km^2 and 166 ± 74 birds in 2016. During the surveys 38 (2014), 40 (2015) and 37 (2016) individual birds were detected. Bustard-habitat relationships, assessed using

multinomial logistic regression, showed that disturbances and level of protection influenced distribution in this landscape. Great Indian bustard occurrence in the landscape declined with distance from enclosure (regression effect size = -0.06 ± 0.02_{SE}), human presence (-3.22 ± 1.52_{SE}) and infrastructural intensity (-3.97 ± 1.61_{SE}).

Chinkara was found in 78% sites and its density at landscape-scale was estimated at 187.5 ± 25.1_{SE} animals/100 km^2, yielding abundance of 37,000 ± 4970_{SE} in 19,728 km^2 area (2016). Desert and Indian fox used 60 ± 7_{SE} % of sites, at densities of 14.35 ± 3.46_{SE} desert fox/100km^2 and 2.28 ± 1.19_{SE} Indian fox/100km^2 at landscape-scale, and abundances of 2830 ± 683_{SE} desert fox and 450 ± 235_{SE} Indian fox in 19,728 km^2 area. Eleven percent of sampled cells were found to be of high conservation value, out of which, 62% cells were outside Protected Area. Although some of these 'unprotected' areas benefit from community protection or inviolate spaces created due to Army occupation, others continue to be threatened by hunting and unplanned land-uses.

Our study provides robust abundance estimates of key species in Thar. It provides spatially explicit information on species' distribution and ecological parameters to guide site-specific management and policy. Our questionnaires generated spatial patterns of community composition, livelihoods, livestock holdings and species' occurrence reports that will help in designing community outreach and conservation programs.

Thar supports the largest global population of great Indian bustard and offers the best hope for its persistence. This survey captured snapshots of great Indian bustard distribution that needs to be augmented with satellite telemetry based information on seasonal landscape use to mitigate threats. Based on results and field experiences, we strongly recommend: a) improving great Indian bustard recruitment in existing enclosures using predator-proof-fences and nest-predator removal, b) creating more enclosures or conservation/community reserves in priority conservation cells, c) smart and intensive patrolling to control poaching and generate management information, d) targeted research to understand local ecology of great Indian bustard, characterize threats, and ranging patterns, e) addressing local livelihood concerns through social research, and f) engaging local communities to monitor and protect wildlife through outreach and incentive programs.

Great Indian bustard is a majestic but Critically Endangered bird with small fragmented global population of about 200 individuals. Thar landscape, supporting the largest population numbering > 100 birds, is the only hope for its persistence. If in-situ threats are not urgently mitigated, this bird will become extinct in near future.

1. Introduction

The great Indian bustard (*Ardeotis nigriceps*) is Critically Endangered (IUCN 2011) with less than 300 birds left. Rajasthan State in India holds the largest population and prime hope for saving the species (Dutta et al. 2011). As the range States across the country are developing species' recovery plans (Dutta et al. 2013), baseline information on current distribution, abundance and habitat relationships are scanty. Such information are essential for conservation planning and subsequently 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 study was aimed at generating information on population and habitat status of these species for the crucial bustard landscape of western Rajasthan.

Great Indian bustard are cryptic and vagile birds occupying large landscapes without distinct boundaries that make complete enumeration of population impractical and unreliable. Their population status has to be estimated using robust sampling and analytical methods that incorporate imperfect detection, allow statistical extrapolation of estimates to non-sampled areas, and are replicable. However, the extreme rarity of bustards makes precise estimation of population abundance difficult and logistically demanding. Through repeated surveys from March 2014 to 2016, we have attempted to develop a protocol for monitoring the population status of great Indian bustard and associated wildlife in Thar and other bustard landscapes across the country.

Our survey covered the potential great Indian bustard habitat in Jaisalmer and parts of Jodhpur, Bikaner and Barmer districts, Rajasthan (hereafter, Thar landscape). Ground data collection was carried out by researchers, 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).

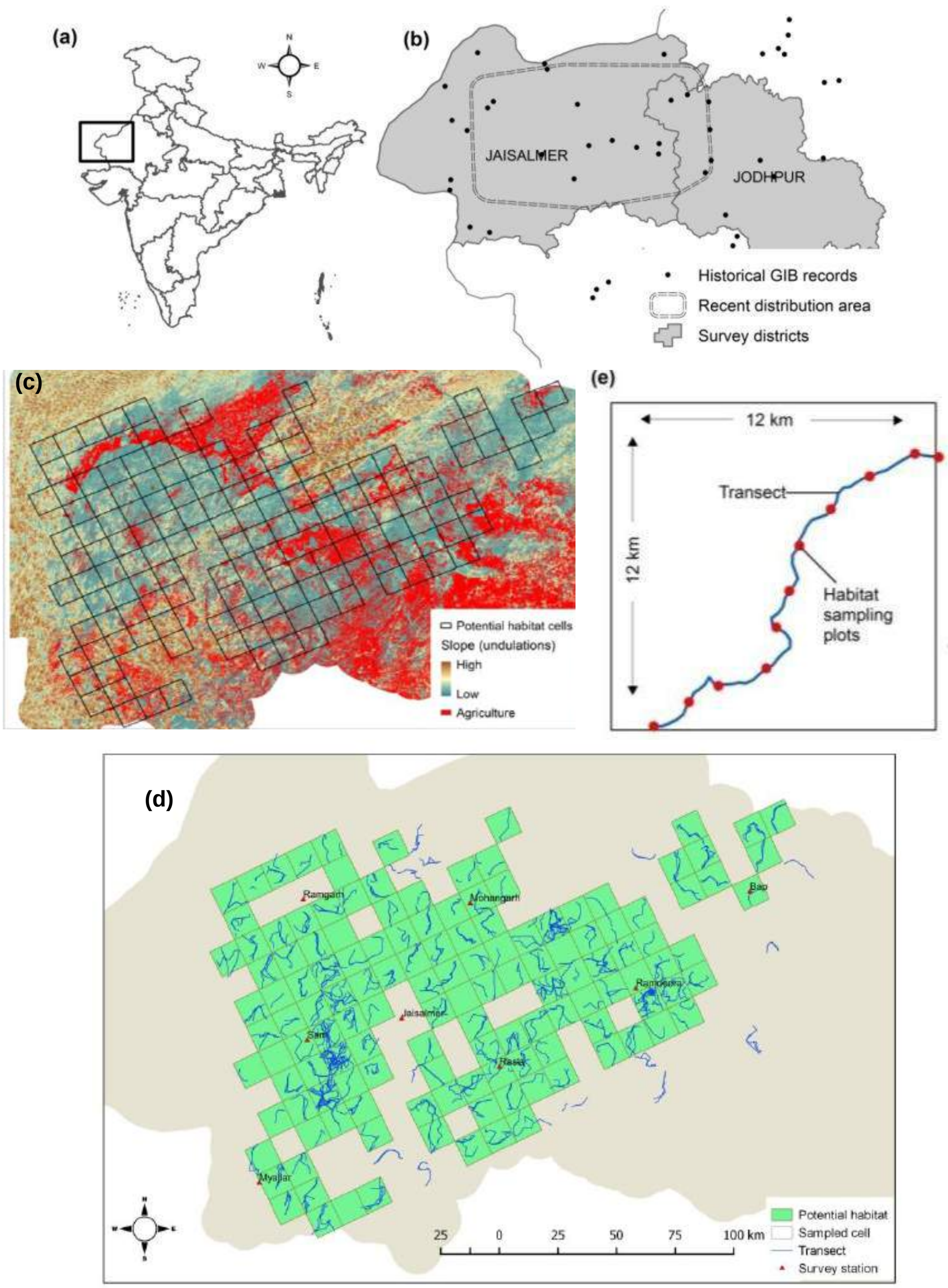
2. Thar landscape

The potential great Indian bustard landscape in Thar was identified in a stepwise manner. Past records (post 1950s) of great Indian bustard in western Rajasthan were collated (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, extensive sand dunes, built-up and intensive agriculture areas were considered unsuitable based on prior knowledge (Dutta 2012). These areas were identified from the combination of land-cover maps procured from NRSC (ISRO), Digital Elevation Model and night-light layers in GIS domain, Google Earth imageries, and extensive ground validation surveys during 2014-2015. The remaining landscape, an area of 20,000 km^2, was considered potentially habitable for great Indian bustard and subjected to sampling (figure 1).

The study area falls in Desert Biogeographic Zone (Rodgers et al. 2002) with arid (Jodhpur) to superarid (Jaisalmer and Bikaner) 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 Thorny Scrub, characterized by open woodlot dominated by *Prosopis cineraria*, *Salvadora persica* and exotic *Acacia tortilis* trees, scrubland dominated by *Capparis decidua*, *Zizyphus mauritiana*, *Salvadora oleoidis*, *Calligonum polygonoides*, *Leptadenia pyrotechnica, Aerva pseudotomentosa*, *Haloxylon salicornicum* and *Crotolaria bhuria* shrubs, and grasslands dominated by *Lasiurus sindicus* and *Dactyloctenium sindicum*. Notable fauna, apart from the ones mentioned before, include mammals like 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 that 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 km²) has been declared as Desert National Park (Wildlife Sanctuary), which is not inviolate and includes 73 villages (Rahmani 1989).

Figure 1 Sampling design for great Indian bustard population and habitat assessment in Thar landscape (2014-2016): location of study area (a); delineation of bustard landscape from existing information on species' occurrence (b), remotely sensed habitat information and reconnaissance surveys (c); distribution of transects in 144 km² cells overlaid on potential habitat (d); and habitat sampling plots at 2 km interval on transect (e)



Glimpses of rich, unique biodiversity of Thar: (clock-wise from top) migrating houbara bustard Chlamydotis macqueenii, laggar falcon Falco jugger, chinkara Gazella bennettii, desert cat Felis silvestris, desert fox Vulpes vulpes pussilla, and spiny-tailed lizard Saara hardwickii.

3. Methods

3.1. Organization of survey

The potential great Indian bustard landscape in Thar was divided into seven sampling blocks which were simultaneously surveyed by 18 teams during March 22-26, 2014, 17 teams during March 21-25, 2015, and 40 teams during March 15-19, 2016. This enabled us to cover such large expanse within brief time period in order to minimize bird/animal movements between survey areas. The sampling blocks were named after their respective field-stations, as: a) Ramgarh, b) Mohangarh, c) Bap, d) Ramdeora, e) Rasla, f) Myajlar, and g) Sam-Sudasari. Two-five teams operated for four-five days in each of these blocks. 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 several years of field experience on wildlife surveys. Team members were trained through workshops and field exercises on a standardized data collection protocol for two days prior to block surveys. Data collected by different teams were collated after the completion of surveys and analyzed.

3.2. Sampling design

Species and habitat status were assessed using vehicle transects in a systematic sampling design. A grid of 137* cells, each 144 km² in size (12 km x 12 km), were overlaid on the potential great Indian bustard habitat (covering **19,728 km²**) and realized on ground by handheld GPS units and Google Earth imageries. Sampling was carried out in two phases: firstly **extensive surveys**, wherein we randomly sampled 108 cells in 2014, 77 cells in 2015 and 120 cells in 2016. Cells were surveyed along dirt trails of $17.9_{Mean} \pm 3.9_{SD}$ km length (single continuous or two broken transects) from a slow moving (10-20 km/hr) vehicle on each occasion. Surveys were conducted in early morning (0600-1000) and late afternoon (1600-1900), when bird/animal activity was highest. This sampling scheme was chosen to optimize the combination of cell-size, transect length and efforts required to cover ~20 % of cell-area (assuming that species' would be effectively detected within ~250m strips, following Dutta 2012) given our

Earlier, 25,500 km² area was considered potentially suitable and 177 grid-cells were overlaid, out of which, 118 cells were sampled (Dutta et al 2014). Subsequently, as more refined information on habitat and species' distribution became available in 2015, 40 of these cells, inclusive of 10 sampled cells, were considered unsuitable and dropped from sampling/analysis target (systematic coverage of ≥70 % area) and logistic constraints (six days, eight hours/day for sampling). Secondly, **intensive surveys** were conducted, wherein cells where great Indian bustard was detected (during the extensive survey) were sampled along multiple (7-12) transects of $12.0_{Mean} \pm 4.2_{SD}$ km length following similar protocol. Intensive surveys allowed more robust estimation of great Indian bustard population status in used areas.

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 disturbances (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 collected. Earlier (2014-15), perpendicular distances were directly 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 improve accuracy of these measurements, in 2016 survey, distance and angle of sighting were measured through Bushnell Laser Range-finders and Suunto Compasses, respectively, wherefrom perpendicular distances were computed. Consequently, estimates of Effective Detection Width (explained below) in 2016 survey are more reliable than that from past surveys, and the use of these tools will be continued in future surveys. 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/shrubland/woodland), 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 structure 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. These covariates were 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. Vegetation composition was recorded as three dominant plant taxa within 100m radius of the point. Presence of human structures (settlement/farm-hut/metal-road/power-lines/wind-turbine/water-source) was recorded within 500-m radius of the point. Status of spiny-tailed lizard, another key associate of bustard with a relatively small activity range (Dutta and Jhala 2014), was recorded as occurrence of their burrow(s) within 10 m radius of the point.

3.3.3. Community surveys

Community surveys were conducted in 193 randomly selected villages, by opportunistically interviewing up to three residents per village (questionnaires in appendix 3). Village-level information on social composition (major communities and livelihoods), livestock holding (approximate cattle and sheep/goat counts in village), and reports of bustard (present and ten years back) and associated species' (chinkara, fox, nilgai and crane) occurrences from village areas were collected.

3.4. Data analysis

3.4.1 Population status

Density/abundance and (as a cheaper alternative) occupancy/use are commonly used parameters to assess population status.

Species' density was estimated using Distance analysis in program DISTANCE (Thomas et al. 2010). This technique models the declining probability of detecting individual(s) along increasing distances from transect, wherefrom effective detection/strip width ($\overline{ESW}$) and effective sample area ($\overline{ESA}$) are derived. This metric is used to convert encounter rate into density estimate ($\overline{D}$) (demonstrated in the footnote, also see Buckland et al. 2001). Since extensive transects were random samples, species'

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

abundances could be estimated by multiplying density estimate with landscape area. We used this framework to estimate density/abundance of chinkara and fox.

However, great Indian bustard sightings were too few and spatially clustered for modeling detection function, and estimating density/abundance precisely in this framework. To circumvent this issue, we used two phase sampling - extensive surveys in the first phase generated estimate of proportion of cells used by great Indian bustard and intensive surveys generated estimate of density in used cells. To estimate proportion of cells used by great Indian bustard (i.e., its asymptotic occupancy integrated over time, see Efford and Dawson 2012), we used Occupancy analysis in program PRESENCE (Mackenzie et al. 2006). This technique accounts for the probability of missing species at a site by using detection data from repeated surveys, thereby yielding more accurate estimates of occupancy/use. We generated detection/non-detection matrix for sampled cells from species' sightings along transects in three years: 2014-2016 (temporal replicates). Proportion of sites used was estimated from this matrix following the traditional model of Mackenzie et al (2003) that assumes constant detection probability (across replicates) and occupancy (across sites). In our intensive surveys, cells used by great Indian bustard were intensively sampled following similar Distance sampling protocol as described earlier, the only difference being that multiple teams simultaneously surveyed different portions of these cells on two-three occasions. This increased sample size (efforts and sightings), allowing reliable estimation of detection probability (as described above) and bird density in used cells through Distance analysis. To further validate detectability estimate obtained from distance data of actual bird sightings, we developed detection function using dummy birds in blind tests on two separate occasions - June 2014 and March 2016 (Dutta et al. 2014). Finally, we estimated density/abundance of great Indian bustard as the product of proportion of cells used and density in used cell.

This method is a refinement over the traditional approach that we followed in 2014-15 assessments (Dutta et al. 2015), where detection probability was estimated by pooling data from extensive and intensive surveys (to yield sufficient sightings), and density was estimated only from extensive surveys (to ensure that abundance was extrapolated through random sampling). For the purpose of comparison with past estimates, we also reported density/abundance for 2016 survey, estimated by this traditional approach.

For other species, we provided Mean ± SE estimates of encounter rates.

Great Indian bustard use structurally diverse habitats for various ecological needs, such as (left, top to bottom) open scrubland, seasonal agriculture, and grasslands. They prefer flat undisturbed grasslands with sparse shrubs/trees for breeding, where they (right, top to bottom) display, nest, and rear chicks.

3.4.2. Habitat status and use

Habitat characteristics of a cell were summarized from covariate data collected at $22_{Mean} \pm 2_{SE}$ sampling plots along extensive and intensive transects of 2015-16. a) For categorical covariates (land-cover and substrate types), frequency of occurrence of each category was estimated. b) For interval covariates (vegetations structure), mid-values of class-intervals were averaged across plots. c) Vegetation composition was characterized from the frequency of occurrence (%) of dominant plant taxa across plots. c) Disturbance covariates were grouped into: infrastructure intensity – measured as summed occurrence of metal road, power lines and wind turbines; and human incidence – 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. Mean $\pm$ SD estimates of covariates were computed across sampled cells to describe landscape characteristics.

Great Indian bustard occurrence pattern was examined by modeling its presence (sighting or confirmed signage) and secondary report vs. absence (reference category) on potential habitat covariates at the cell-level using multinomial logistic regression in program SPSS (Quinn and Keough 2002). Data from 2014-15 surveys were used for this analysis. Among the covariates collected, the following were selected as potentially important for explaining bustard occurrence based on our ecological understanding: 1) flat or 2) undulating [terrain]; 3) grassland, 4) woodland or 5) agriculture [land-cover]; 6) rock/gravel or 7) sand [substrate]; 8) human incidence in 100m , 9) infrastructure intensity in 100m and 500m, and 10) grazing intensity (livestock encounter rate Animal Units/km) [disturbances]; and 11) mean distance to enclosure [protection]. Some of the covariates were inter-correlated (see Results), which could complicate interpretations of regression parameters (Graham 2003). After inspecting the data, Principal Component Analysis (Quinn and Keough 2002) was carried out on terrain, substrate and land-cover covariates in program SPSS that extracted synthetic components to surrogate prominent and independent habitat gradients. A global model incorporating the habitat components, disturbance and protection covariates and its ecologically meaningful subset models were built. These models were compared using Information Theoretic approach (Burnham and Anderson 2002) and goodness-of-fit statistic (R^2) to draw inferences on factors influencing bustard distribution.

3.4.3. Spatially explicit information on ecological parameters

Spatially explicit information on species and habitat status help prioritize conservation areas and target management. Surface maps of habitat covariates were generated by kriging values (Baldwin et al. 2004) from sampled cells in program ArcMap (ESRI 1999-2008). Species' encounter rates during 2015-16 surveys were also mapped across cells. Cells were prioritized for conservation management based on the combined population status of great Indian bustard, chinkara and fox. We ranked the status of bustard as: 0 (not detected), 1 (secondary report), or 2 (sighting) and that of chinkara and fox as: 0 (1^{st}–2^{nd} quartiles of encounter rate), 1 (3^{rd} quartile of encounter rate), or 2 (4^{th} quartile of encounter rate). These ranks were weighted by species' endangerment level (3 for bustard, 1 for chinkara and 1 for desert fox) and summed to generate a conservation priority index. Based on this index, cells were classified as 'low' (1^{st}–2^{nd} quartiles of index), 'medium' (3^{rd} quartile) and 'high' (4^{th} quartile) priority to guide judicious investment of conservation efforts.

3.4.4. Community responses

To assess the social composition of villages, we scored communities and livelihoods on the basis of their dominance in a village (0: absent to 3: most dominant) and averaged the score across respondents. To estimate village-level livestock holdings, we converted livestock count reports into Animal Unit equivalents (cattle =1 AU, sheep and goat = 0.25 AU), and averaged the values across respondents. We estimated the proportion of respondents who reported occurrences of our focal species in their village areas, and mapped the detection/non-detection of these species at the village-level.

4. Results and Findings

4.1. Population status

Our extensive surveys covered 108 cells (15,552 km² area) along 1697 km transect in 2014, 77 cells (11,088 km² area) along 1246 km transect in 2015, and 120 cells (17,280 km²) along 2273 km transect in 2016 (figure 1). We intensively surveyed 7 cells (1,008 km² area) used by great Indian bustard along 725 km transect in 2015 and 755 km transect in 2016. Data generated from these surveys provided estimates of species' occupancy, density and abundance.

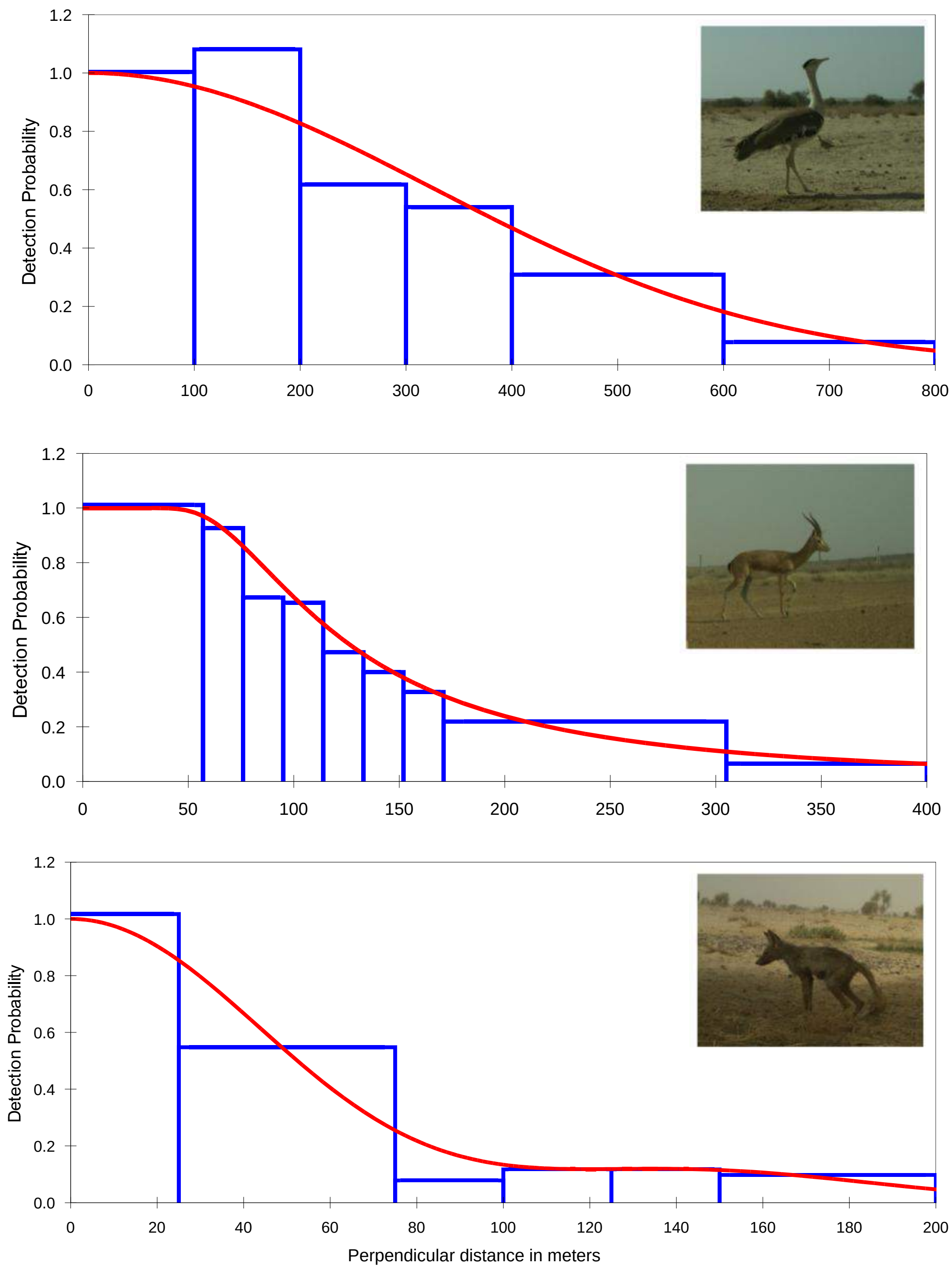
4.1.1. Great Indian Bustard

Surveys conducted during 2014, 2015 and 2016 surveys recorded minimum 38, 40 and 37 unique great Indian bustards respectively, comprising observations along transects and those en route or while returning from sampling cells. Extensive surveys during 2014-16 detected great Indian bustard in 11 cells or 8.4 % of sites (naïve occupancy). Probability of detecting at least one great Indian bustard in a used cell during an annual survey was $0.52 \pm 0.11_{SE}$. Detection corrected proportion of sites used by great Indian bustard during these years (asymptotic occupancy) was $0.11 \pm 0.03_{SE}$. Pooling extensive and intensive surveys in used cells during 2015-16, we detected 53 flocks with mean flock size of $1.90 \pm 0.19_{SE}$ individuals and encounter rate of 2.73 ± 0.59 individuals/100km. We fitted half-normal, hazard-rate and uniform detection models on distance data (truncated at 800m) of these observations. Although all models obtained similar support ($\Delta AIC<1$), based on model parsimony and goodness-of-fit, we selected the half-normal detection function ($\chi^2=0.95$, df=4, p=0.92). It estimated flock detection probability and effective strip width at $0.50 \pm 0.05_{SE}$ and $401 \pm 39_{SE}$ m**, respectively (figure 2). Pooling data from our dummy bird experiments in June 2014 and March 2016, we obtained a similar effective strip width of $402 \pm 34_{SE}$ m. Subsequently, density in **used cells** (not to be confused with landscape-level density) was estimated at $6.50 \pm 1.43_{SE}$ birds/100km². Landscape-scale abundance, estimated from the product of used area and density in used area, was $140 \pm 53_{SE}$ birds* (figure 3).

* This is statistically similar to the earlier estimate ($169 \pm 70_{SE}$ birds, see Dutta et al. 2015)
** This estimate differs from the past estimate (476±52m, see Dutta et al. 2015) as we have truncated the distance data from 1000m to 800m for obtaining better fit of detection function

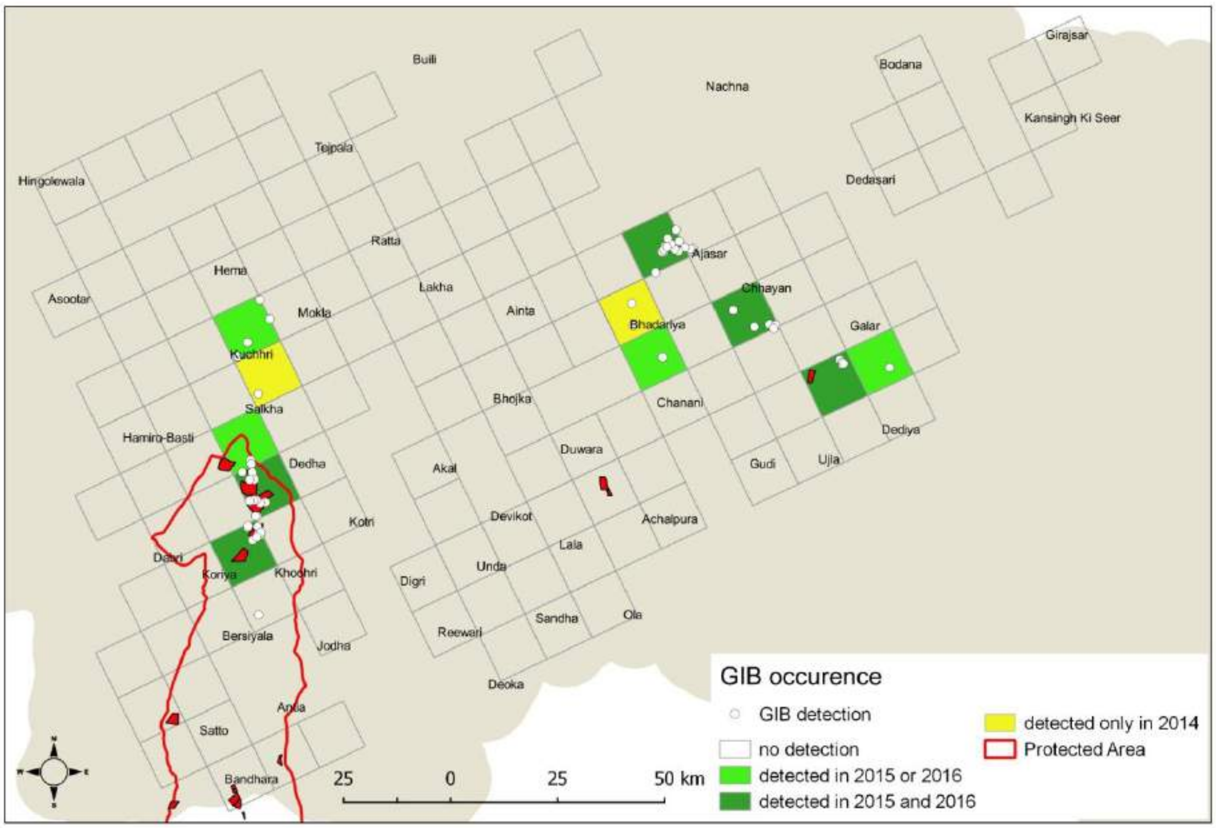
Note that this is the pooled estimate of 2015-16 as the time period is too short for any detectable change in populations of such slow life-history species.

Figure 2. Detection functions relating probability of detecting individual with perpendicular distance from transect for great Indian bustard, chinkara and fox in Thar landscape during 2014-15



Using our traditional approach, where we use encounter rate data only from extensive surveys which are randomly distributed across the landscape (details in section 3.4.1), density of great Indian bustard was estimated at 0.84 ± 0.38 birds/100 km² and landscape-scale abundance was found to be 166 ± 74 birds in 2016.

Figure 3. Great Indian bustard occurrence status in 144 km² cells based on surveys in Thar landscape (2014-2016)



4.1.2. Chinkara

Extensive survey in 2016 detected 504 chinkara herds at encounter rate of 21.74 ± 2.5$_{SE}$ herds/100km and mean herd size of 2.77 ± 0.11$_{SE}$ individuals. Hazard-rate detection function fitted the distance data (truncated at 400m) best (χ^2=4.67, df=6, p=0.59) that estimated herd effective strip width at 159 ± 9$_{SE}$ m (figure 2). Chinkara density was estimated at 188 ± 25$_{SE}$ animals/100km², yielding abundance estimates of 37,000 ±

* Our current approach of estimating great Indian bustard density/abundance is a refinement over the traditional approach (Dutta et al. 2015) and provides relatively precise and conservative estimate. We are further developing on this method using Density Surface Modeling approach (Buckland et al. 2015) to obtain more realistic and precise estimates for monitoring

4970SE in the landscape. Chinkara was detected in 78 % cells (naïve occupancy) as opposed to 91% cells in 2014-15 (figure 4).

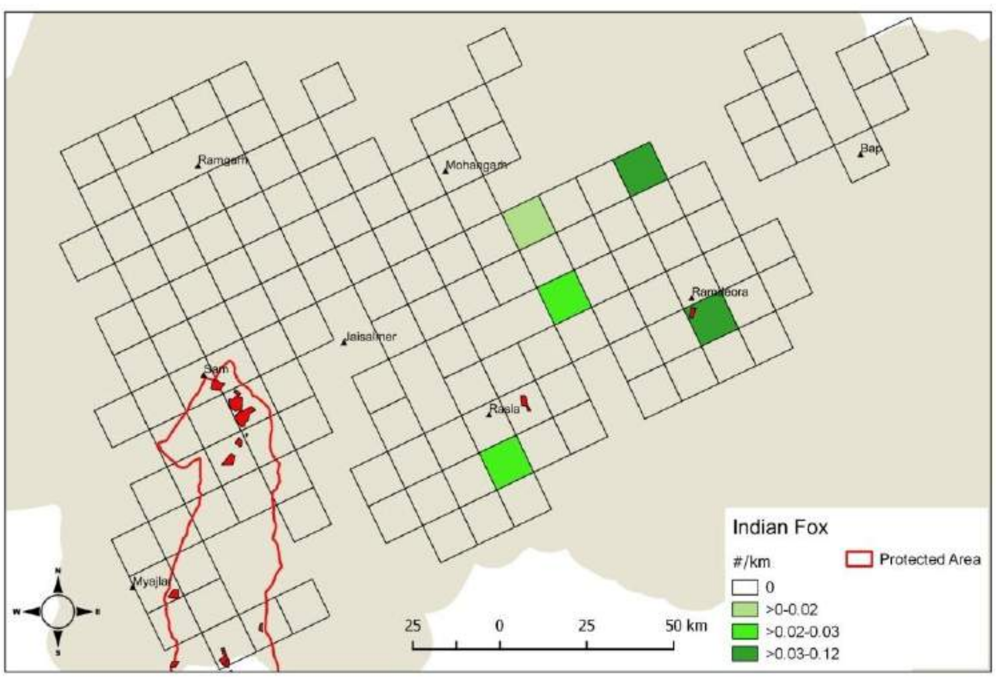
Figure 4. Chinkara encounter rates in 144 km² cells of Thar landscape (2015-2016)

4.1.3. Fox

Extensive survey in 2016 detected 39 desert fox and 7 Indian fox at encounter rates of 1.67 ± 0.33SE individuals/100km and 0.30 ± 0.15SE individuals/100km, respectively. Both species were observed mostly solitarily, yielding group size estimates of 1.13 ± 0.08SE individuals (desert fox) and 1 individual (Indian fox). Since these species have similar body size and behaviour, a common detection function was built. Half-normal detection function fitted the distance data best (χ^2=3.09, df=4, p=0.54) that estimated effective strip width at 66 ± 7SE m (figure 2). Species' densities were estimated at 14.35 ± 3.46SE desert fox/100km² and 2.28 ± 1.19SE Indian fox/100km². Accordingly, their abundances were estimated at 2830 ± 683SE (desert fox) and 450 ± 235SE (Indian fox) in the landscape. Desert fox was detected in 23 % sites (figure 5) and Indian fox was detected in 4% sites (naïve occupancy) (figure 6).

Figure 5. Desert Fox encounter rates in 144 km² cells of Thar landscape (2015-2016)

Figure 6. Indian Fox encounter rates in 144 km² cells of Thar landscape (2015-2016)



4.1.3. Other fauna

Extensive survey in 2016 also yielded sightings of nilgai (31 groups of 6.35 ± 1.16$_{SE}$ individuals at encounter rate of 8.71 ± 2.84$_{SE}$ individuals/100km) and pig *Sus scrofa* (9 groups of 6.78 ± 1.44$_{SE}$ individuals at encounter rate of 2.28 ± 0.99$_{SE}$ individuals/100km) (figure 7). Spiny-tailed lizard burrows were detected in 8.8 % plots. Sightings of domestic animals included 119 dogs (encounter rate 5.2 ± 1.0$_{SE}$ /100km), 11,297 cattle (493.7 ± 61.7$_{SE}$ /100km) and 50,571 sheep and goat (2203.8 ± 222.8$_{SE}$ /100km). Livestock was converted into Animal Units and their encounter rates were mapped to surrogate grazing intensity for identifying areas of high overlap between wild and domestic species (figure 8).

Figure 7. Nilgai (a) & pig (b) occurrence in 144 km² cells of Thar landscape (2015-2016)

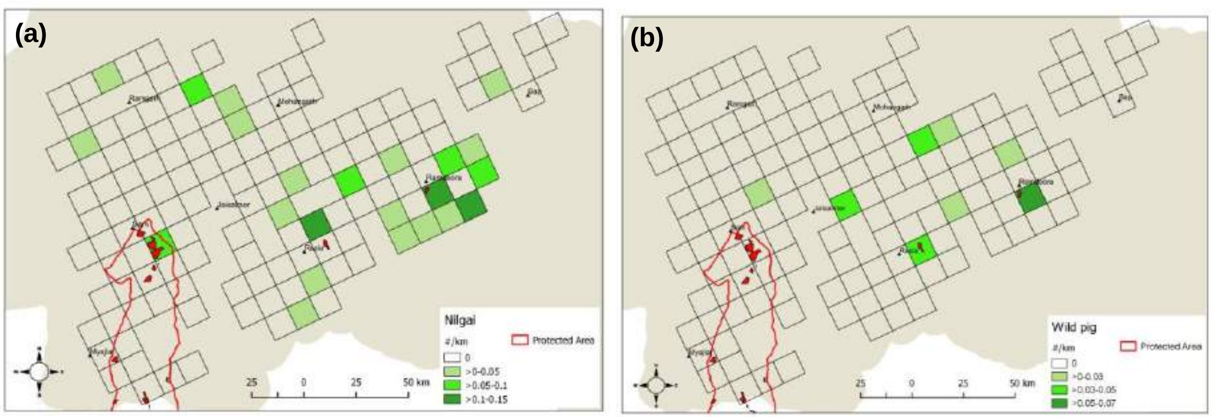
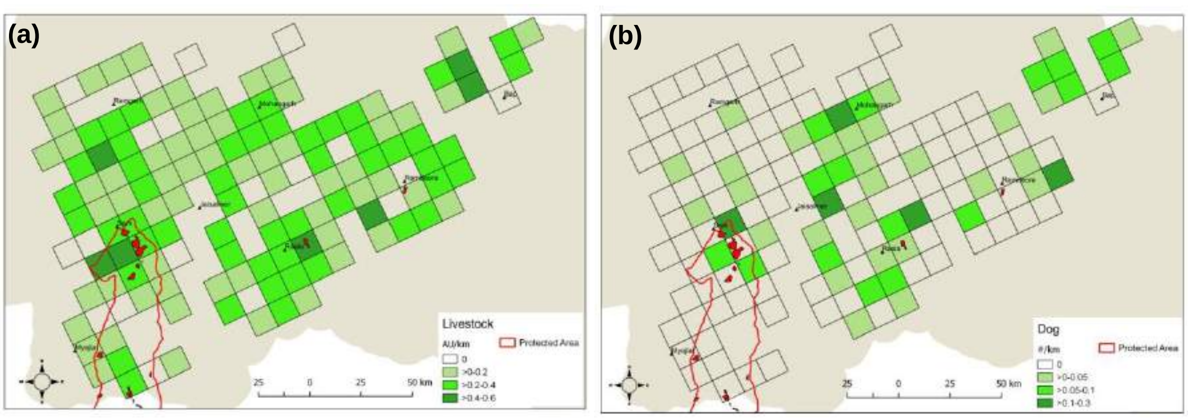


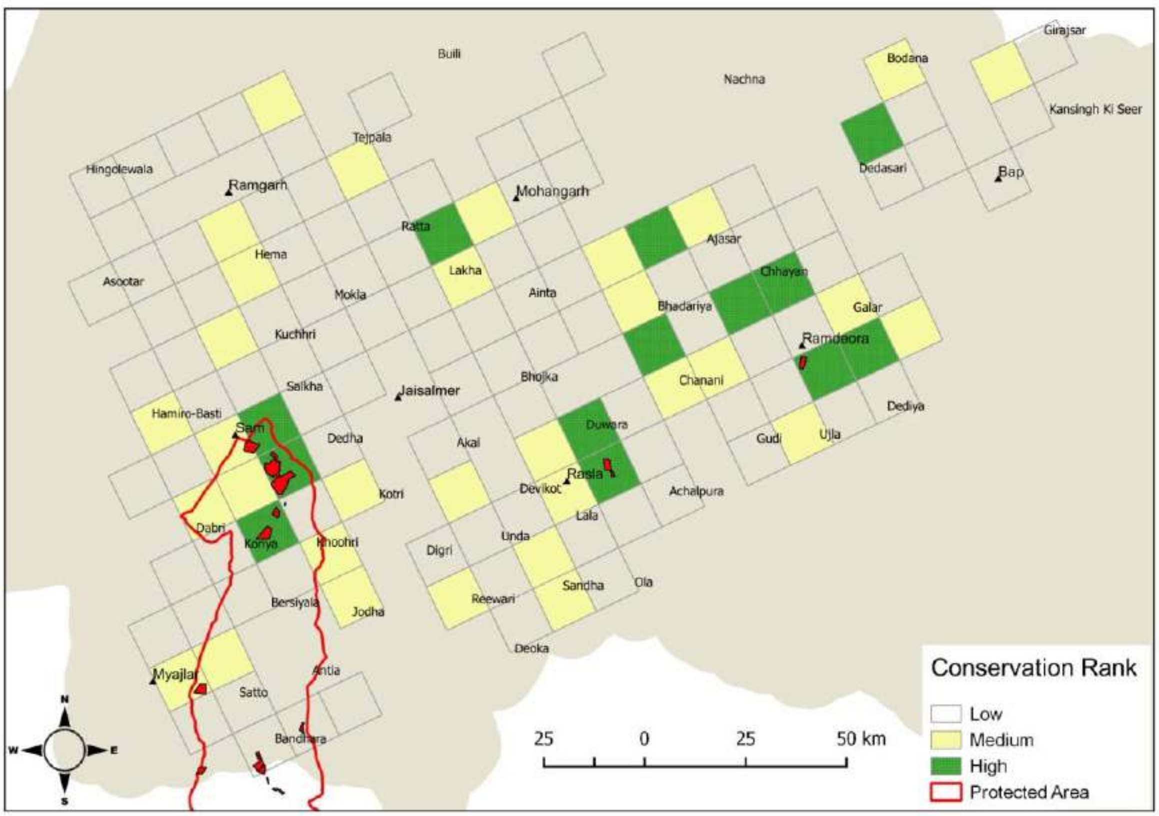
Figure 8. (a) Livestock and (b) dog detections rates in 144 km² cells of Thar landscape (2015-16)



4.1.4. Conservation Prioritization

Conservation priority index, generated from population status of key species in 144 km² cells, ranged between 0-10. On classifying this range into three ranks (low: 0-2, medium: 3-4, and high: 5-10), 11 % of sampled cells (13) were attributed high priority and 89 % cells were attributed low and medium priority for conservation (figure 9). Only 38 % (5 cells) of high priority cells had some fraction of area within protective enclosures owned by Forest Department (Sam, Sudasari, Gajaimata, Rasla, and Ramdeora). Whilst unprotected habitats adjoining villages Pithala and Kanoi-Salkha-Habur near Jaislamer, Nathoosar, Chanani, Ugras, Galar, Chhayan, Ajasar-Keroo and Bhadariya near Ramdeora, Mohangarh and Dhaleri also have high conservation value.

Figure 9. Conservation priority index of 144 km² cells in Thar landscape (2014-16)

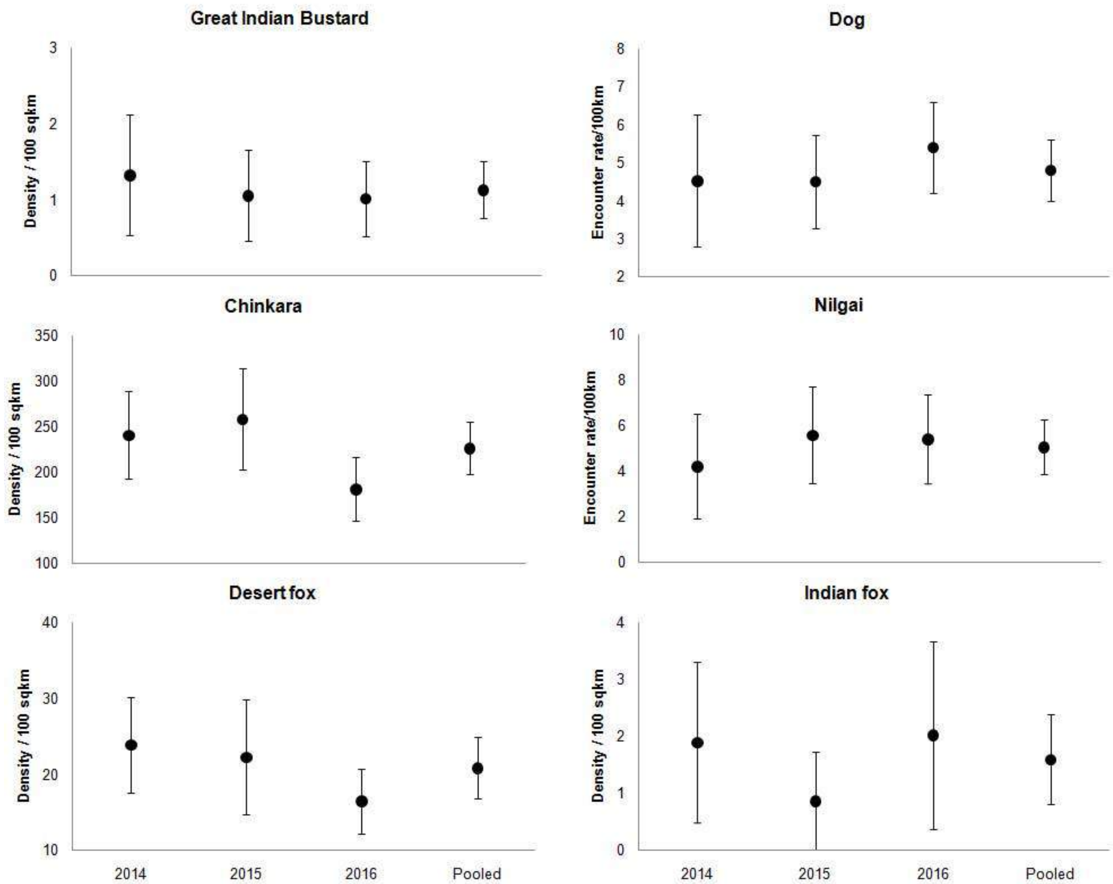


4.1.5. Species' population trends

Estimates of species' density/abundance from the past two surveys should not be used to infer future changes in population status because those surveys were treated as pilot implementation and were progressively refined to develop a logistically feasible yet robust monitoring protocol that is replicable in future. The important modifications made across survey-years are: a) progressively refining the 'potential bustard landscape' by removing 'non-habitat' areas as information on species' distribution and habitat became available from primary and secondary data. For instance, some Bishnoi-occupied agricultural areas in eastern part of Thar landscape, which are prime chinkara habitats, and some sandy areas in south-western part of Thar landscape, have been removed from 2016 sampling because they are not potential bustard habitats. b) Unlike the past two years, in 2016 survey, we used laser range-finders and compasses to improve the accuracy of distance measurements that allowed more reliable fitting of detection functions to sighting data. Although we found negligible difference in detection probability of great Indian bustard and fox between 2014-15 and 2016, there was some difference in detection probability of chinkara between these years, which may not reflect temporal difference in detectability *per se* but measurement errors in earlier surveys. We have now standardized these refinements so that species' status assessments in future become comparable to the current assessment.

For comparing current population status with that of past years, we used mean ± 1 SE species' encounter rates/100 km or density based on the current (most accurate estimate of) Effective Detection Width obtained from cells which have been consistently surveyed across years. This approach circumvents the issues of a) changing landscape and b) refinement of distance measurements with the assumption that detectability of average observer remained constant over years. We generated species' encounter rates and density estimates for preliminary population trend analysis from 2014-16 in this manner (fig 10 with table). The precision of our estimates (mean coefficient of variation in species' encounter rate across years) ranged from 19% (Chinkara) to 84% (Indian fox) across species. Since estimates from all three years (2014, 2015, 2016) were within one SE of each other, the populations were considered to be stable and a pooled robust estimate was obtained by combining data from all three years. These pooled estimates should be used for inferences and future comparisons. It is necessary to observe the population trajectories of these species over multiple assessment cycles for diagnosing population trends and their causal factors.

Figure 10. Species' population trends based on mean ± 1 SE encounter rates / 100 km and density / 100 sqkm from consistently sampled cells of Thar landscape across 2014-16. Same data in table format below.



Species	Measure	2014	2015	2016	Pooled
Great Indian bustard	Encounter rate	1.06 (0.63)	0.85 (0.48)	0.82 (0.39)	0.91 (0.29)
	Density	1.32 (0.79)	1.05 (0.6)	1.02 (0.49)	1.13 (0.38)
Chinkara	Encounter rate	76.52 (14.73)	82.11 (16.97)	57.72 (10.48)	72.12 (8.26)
	Density	240.63 (48.27)	258.21 (55.33)	181.51 (34.51)	226.79 (28.96)
Desert fox	Encounter rate	3.15 (0.76)	2.93 (0.95)	2.17 (0.52)	2.75 (0.44)
	Density	23.88 (6.27)	22.23 (7.54)	16.45 (4.33)	20.85 (3.99)
Indian fox	Encounter rate	0.25 (0.18)	0.11 (0.11)	0.27 (0.22)	0.21 (0.1)
	Density	1.9 (1.41)	0.86 (0.86)	2.02 (1.65)	1.59 (0.79)
Nilgai	Encounter rate	4.22 (2.28)	5.59 (2.11)	5.4 (1.95)	5.07 (1.22)
Dog	Encounter rate	4.52 (1.73)	4.51 (1.23)	5.41 (1.2)	4.81 (0.81)

4.2. Habitat status and use

Habitat characterization along transects during 2015-16 surveys showed that the sampled area was dominated by: a) flat followed by undulating terrain; b) soil followed by sand substrate; c) grassland/savanna followed by agriculture land-cover and shrubland; and d) predominantly short grass interspersed with shrubs and tall grass (vegetation structure). The woody vegetation was dominated by *Capparis* > *Calotropis* > *Aerva* > *Leptadenia* ~ *Zizyphus* > *Prosopis juliflora* > *Acacia* > *Prosopis cineraria* ~ *Salvadora* species, while the herbaceous vegetation was dominated by *Lasiurus* ~ *Dactyloctenium* > *Cenchrus* > 'Lana' (table 1).

Table 1. Descriptive statistics of habitat covariates in 144 km² cells of Thar landscape (2015-2016)

Factor	Covariate	Measurement	Mean	SD
Terrain	Flat	Frequency of occurrence of the category in 100m radius plots, averaged across plots within cell	0.67	0.26
	Sloping		0.09	0.12
	Undulating		0.26	0.23
Substrate	Rocky/Gravel	Frequency of occurrence of the category in 100m radius plots, averaged across plots within cell	0.22	0.23
	Sand		0.36	0.31
	Soil		0.67	0.25
Land-cover	Barren	Frequency of occurrence of the category in 100m radius plots, , averaged across plots within cell	0.13	0.15
	Agriculture		0.34	0.27
	Grassland/Savanna		0.44	0.28
	Woodland		0.16	0.18
	Shrubland		0.25	0.22
Vegetation structure	Short grass (<30cm)	Percentage cover of vegetation type in 20m radius plots, averaged across plots within cell	22	12
	Tall grass (>30cm)		10	8
	Shrub (<2m)		13	8
	Tree (>2m)		6	5
Vegetation composition	*Capparis*	Frequency of occurrence (%) of dominant plant in 100m radius plot, averaged across plots within cell	0.40	0.27
	Calotropis		0.32	0.29
	Lasiurus		0.20	0.25
	Aerva		0.20	0.23
	Dactyloctenium		0.19	0.22
	Leptadenia		0.18	0.23
	Zizyphus		0.13	0.18
	Cenchrus		0.11	0.19
	Prosopis juliflora		0.10	0.17
	Acacia		0.09	0.14
	'Lana'		0.08	0.15
	Prosopis cinereria		0.05	0.08
	Salvadora		0.05	0.10
Human artifacts	Human incidence	Summed occurrence of settlement (weight 2) and hut (weight 1) in 500m radius	1.01	0.66
	Infrastructure intensity	Summed occurrence of power-lines, roads & wind-turbines in 500m radius	0.71	0.50

Among disturbance covariates, some forms of human presence (settlements or farm-huts) and infrastructure (metal roads, power-lines, and wind-turbines) were found within 500m radius of $54.1 \pm 26.9_{SD}$ % and $48.2 \pm 29.8_{SD}$ % of plots, respectively.

We modeled great Indian bustard occurrence on habitat covariates collected during 2014-15 surveys. There was some inter-correlation between the covariates that were considered potentially important for explaining bustard occurrence (table 2). Principal Component Analysis (PCA) on the terrain, substrate and land-cover covariates extracted three components, cumulatively explaining 77 % of information in the data. Of these, two components were considered important for great Indian bustard: one surrogated undulating, sandy (negative value) versus flat (positive value) topography and the other surrogated grassy (negative) versus woody (positive) cover (table 3). There were distinct gradients of these potentially important covariates across the landscape (figure 11).

Among the 15 alternate models postulated to explain great Indian bustard distribution, three models obtained maximum and comparable support from data ($\Delta AIC < 2$, table 4a). These models incorporated disturbances (human incidence, infrastructure intensity and grazing intensity) and protection (distance to enclosure) with or without topography and land-cover. Out of these, the model with least number of parameters was selected for inference. Parameter estimates of this model (*Hum+Inf+Grz+Dst-enc*) indicated that bustard occurrence was determined by protection (declined with distance from enclosure) and disturbance (detections decreased with human incidence and infrastructure intensity but secondary reports were not related to disturbances). There was a positive association between great Indian bustard and grazing intensity, likely due to similar resource requirements (productive grasslands) by both taxa (table 4b).

Table 2. Correlation between select habitat covariates in 144 km^2 cells of Thar landscape (2014-2015)

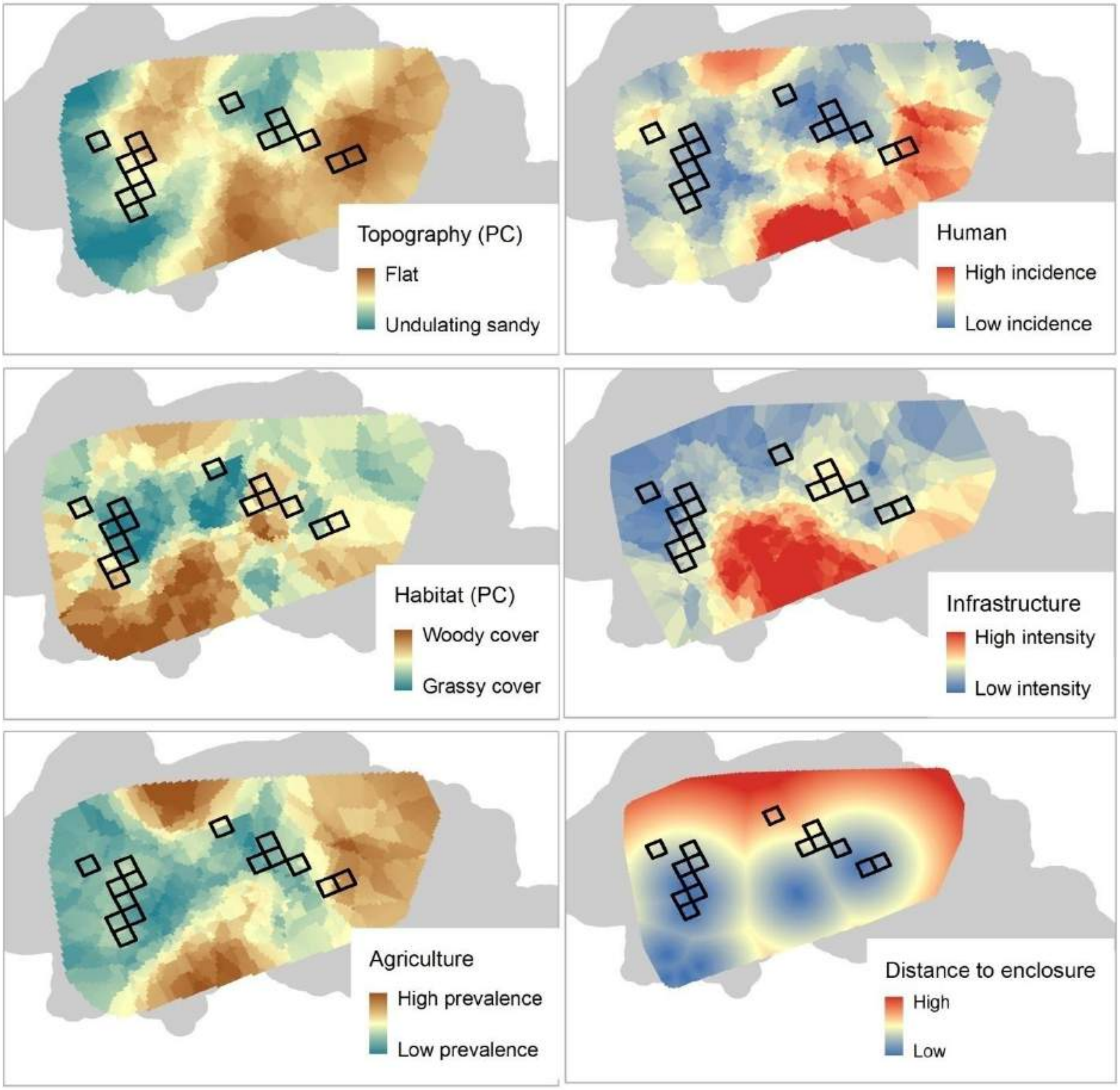
	Flat	Undl	RkGr	Sand	Agri	Grsl	Wood	HumI	InfI	GrzI	EncD
Flat		**-.88**	.04	**-.57**	**.39**	-.08	-.10	**.34**	.00	-.10	-.02
Undulating			-.02	**.55**	**-.38**	-.05	**.19**	**-.28**	-.07	.08	-.01
Rock/Gravel				**-.49**	**-.27**	-.05	.03	-.06	.17	-.06	**-.19**
Sand					**-.24**	.15	.00	**-.25**	**-.25**	-.04	.12
Agriculture						**-.31**	**-.31**	**.46**	.10	.00	**.24**
Grassland							**-.27**	**-.22**	-.11	.04	.17
Woodland								-.04	.18	.03	**-.23**
Human incidence									.14	.04	-.01
Infrastructure intensity										-.02	-.18
Grazing intensity											.11
Distance to enclosure											

Significant correlations ($p<0.05$) indicated in bold; strong correlations ($|r|>0.4$, $p<0.05$) shaded in grey

Table 3. Summary of Principal Component Analysis: covariate loadings, information explained, and ecological interpretation of extracted habitat components in Thar landscape (2014-2015)

Covariates	Principal Component 1	Principal Component 2	Principal Component 3
Flat	0.56		
Undulating	-0.55		
Rocky/ Gravel		0.67	
Sand	-0.47		
Agriculture		-0.41	
Grassland			-0.77
Woodland		0.44	0.43
Information explained	38%	21%	18%
Ecological interpretation	Undulating sand (-) vs. flat topography (+)	Agriculture (-) vs. rocky/gravely woodland (+)	Grass (-) vs. wood (+) cover

Figure 11. Important habitat gradients in Thar landscape (2014-2015), interpolated by kriging from covariates collected and analyzed at 144 km² cells



Open squares indicate cells where great Indian bustard was detected during surveys

Table 4. (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 (2014-2015)

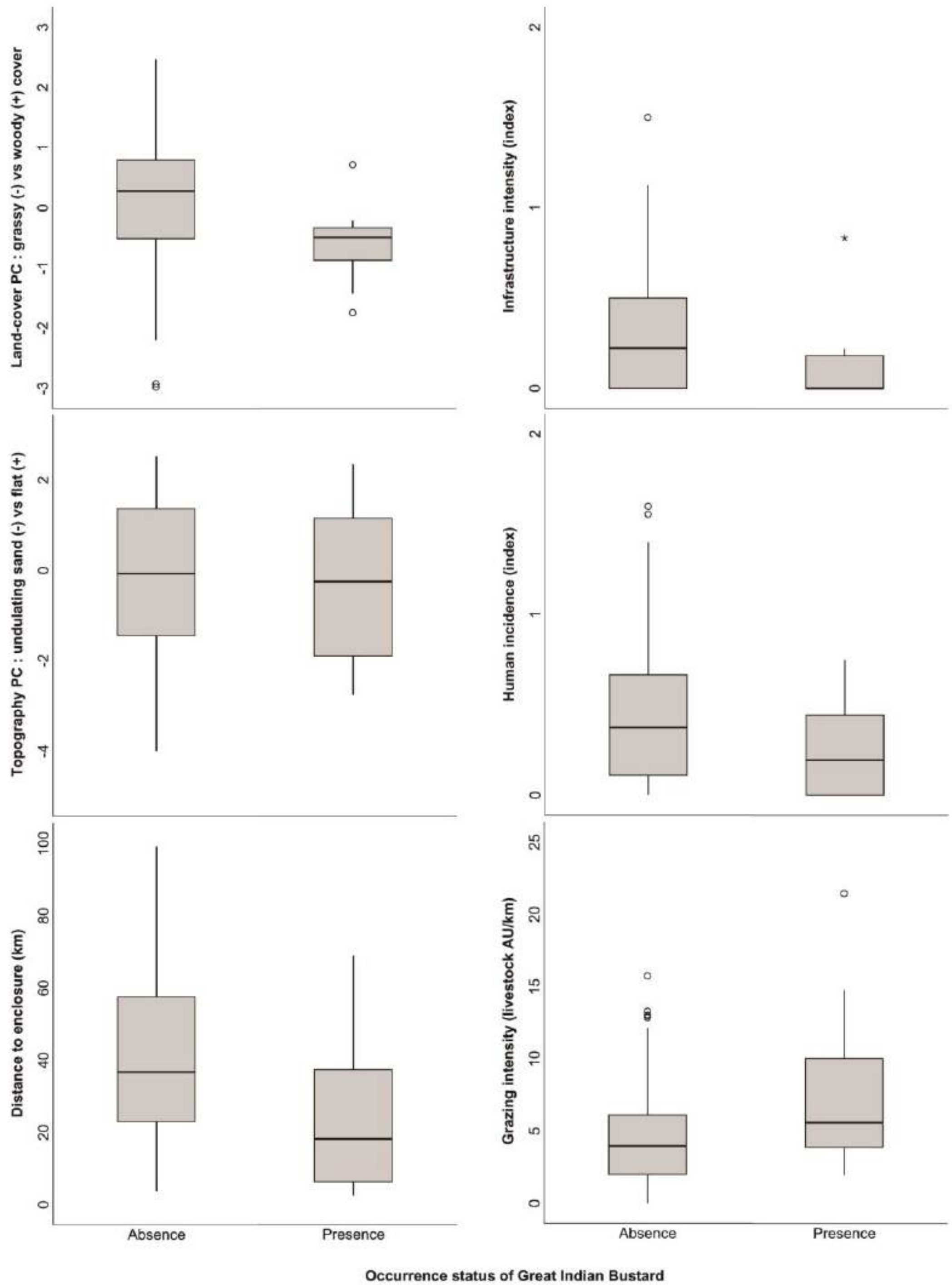
(a) Model	ΔAIC	AIC	Deviance	K	GOF-p	R^2	CC %
PC-top + Hum + Inf + Grz + Dst-enc	**0.00**	**162.51**	**138.51**	**12**	**0.95**	**0.44**	**75**
Hum + Inf + Grz + Dst-enc	**0.97**	**163.48**	**143.48**	**10**	**0.96**	**0.41**	**73**
PC-hab + PC-top + Hum + Inf + Grz +Dst-enc	**1.68**	**164.19**	**136.19**	**14**	**0.57**	**0.46**	**76**
PC-hab + Hum + Inf + Grz +Dst-enc	2.60	165.11	141.11	12	0.64	0.43	73
PC-top + Hum + Inf + Grz	11.50	174.01	154.01	10	0.86	0.33	71
Hum + Inf + Grz	11.69	174.20	158.20	8	0.87	0.30	71
PC-hab + PC-top + Hum + Inf + Grz	13.77	176.28	152.28	12	0.86	0.35	72
PC-hab + Hum + Inf + Grz	13.92	176.43	156.43	10	0.85	0.31	71
PC-hab + PC-top + Dst-enc	23.92	186.43	170.43	8	0.64	0.19	67
PC-hab + Dst-enc	24.52	187.03	175.03	6	0.51	0.14	67
PC-top + Dst-enc	25.70	188.21	176.21	6	0.49	0.13	68
Dst-encl	26.35	188.86	180.86	4	0.35	0.08	68
PC-hab + PC-top	29.68	192.19	180.19	6	0.64	0.10	68
PC-top	30.28	192.79	184.79	4	0.47	0.05	68
PC-hab	30.31	192.82	184.82	4	0.65	0.05	68

(b)	Primary data		Secondary data	
Covariate	$\hat{\beta}$	SE	$\hat{\beta}$	SE
Dst-encl	-0.062	0.022	-0.017	0.012
Hum	-3.223	1.519	0.641	0.598
Infra	-3.969	1.610	-0.444	0.801
Grz	0.218	0.064	0.181	0.057

Covariates
PC-top: undulating-sand (-) vs. flat (+) topography [Principal component]
PC-hab: grassy (-) vs. woody (+) land-cover [Principal component]
Dst-encl: Mean distance to protected enclosures (km)
Hum: Human incidence in 100m radius along transect
Infra: Infrastructure intensity in 100m radius along transect
Grz: Livestock encounter rate in Animal Units/km

Abbreviation: AIC (Akaike Information Criteria); K (parameters); GOF-p (Pearson χ2 p-value as a measure of model goodness-of-fit); R^2 (Nagelkerke's coefficient of determination); CC (Correct classification rate)

Figure 12. Box and whisker plots showing distribution of habitat covariates against occurrence status of great Indian bustard (absence vs. detection) in 144-km² cells of Thar landscape (2014-2015)



Occurrence of great Indian bustard and livestock grazing is highly correlated since both prefer similar habitat

4.3. Community responses

Our community survey data (n=342 respondents from 193 villages) showed that Rajputs were the most common community (present in 62% villages) followed by Meghwal (49%) > Muslim (34%) > Bheel (20%) > Suthar (8%) > Bishnoi (5%) > Joginath (4%) > others (individually present in <3% villages) (Figure 13). Agriculture (dominance score = 2.14 ± 0.08) followed by pastoralism (1.26 ± 0.09) were the major livelihoods, while 1.5% of respondents depended on tourism (Figure 14). Average village livestock holding was reported at 2416 ± 295 Animal Units (Figure 15). Great Indian bustard was reported from 38% of villages at present as opposed to 54% of villages 10 years back (Figure 16). Chinkara, fox and crane were reported from 89%, 83% and 76% villages, respectively (Figures 17 - 19).

Figure 13. Community composition across sampled villages in Thar landscape (2016)

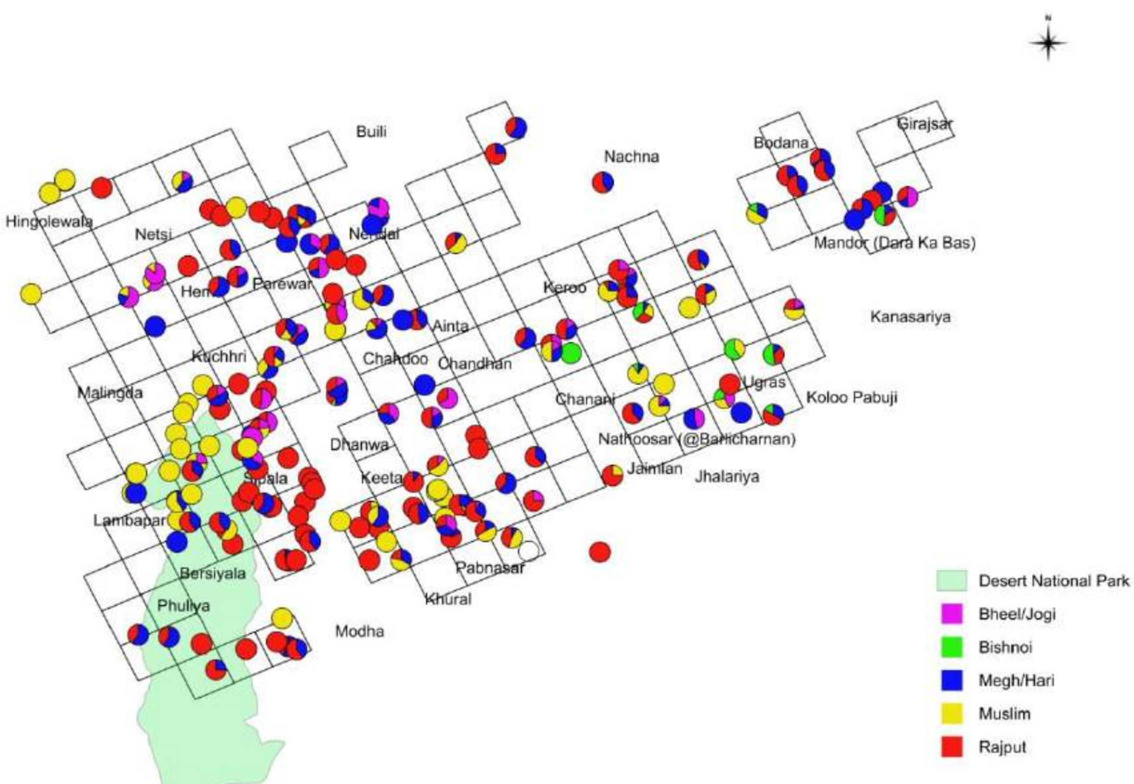


Figure 14. Distribution of major livelihoods across sampled villages in Thar landscape (2016)

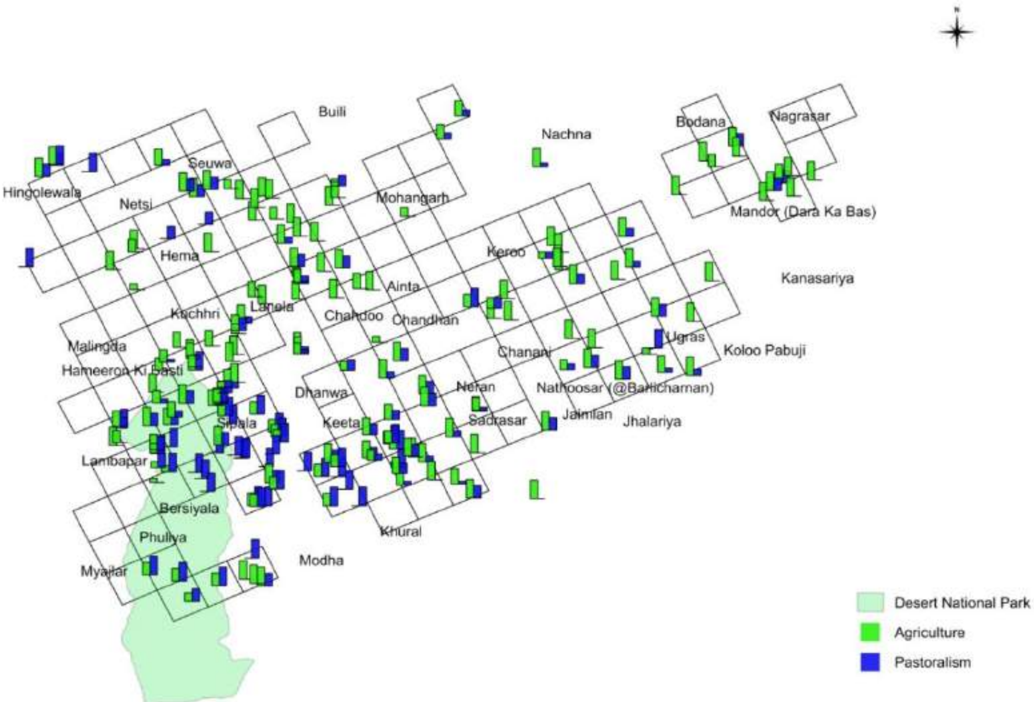


Figure 15. Distribution of village livestock holdings (Animal Unit classes) across sampled villages in Thar landscape (2016)

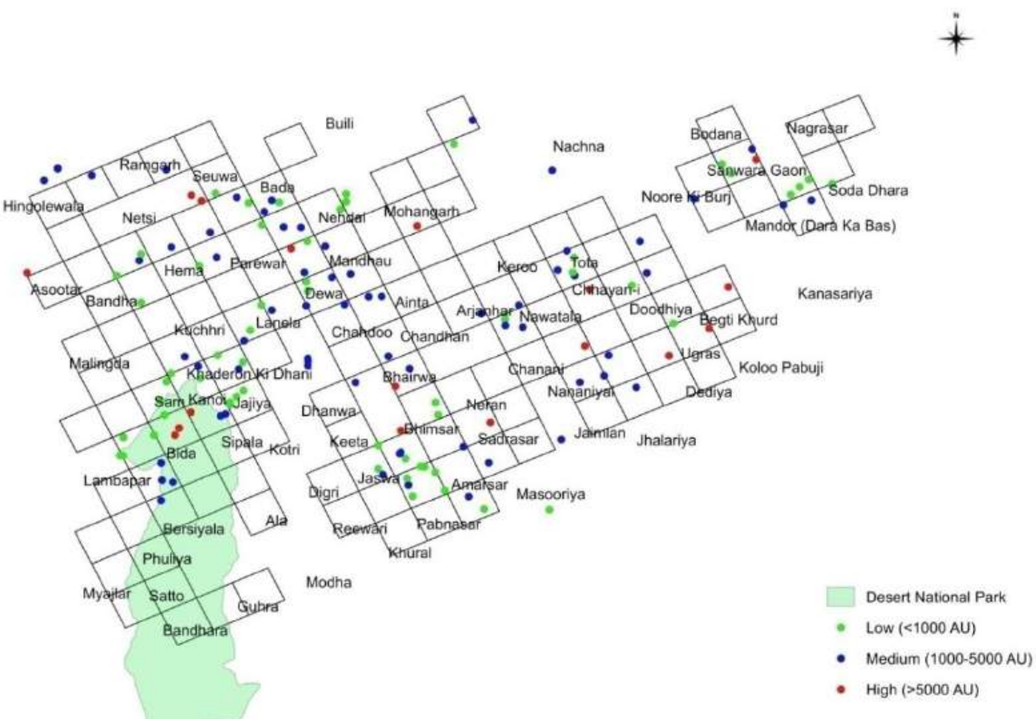


Figure 16. Occurrence, non-occurrence and local extinction (occurred in past but currently absent) reports of great Indian bustard across sampled village areas in Thar landscape (2016)

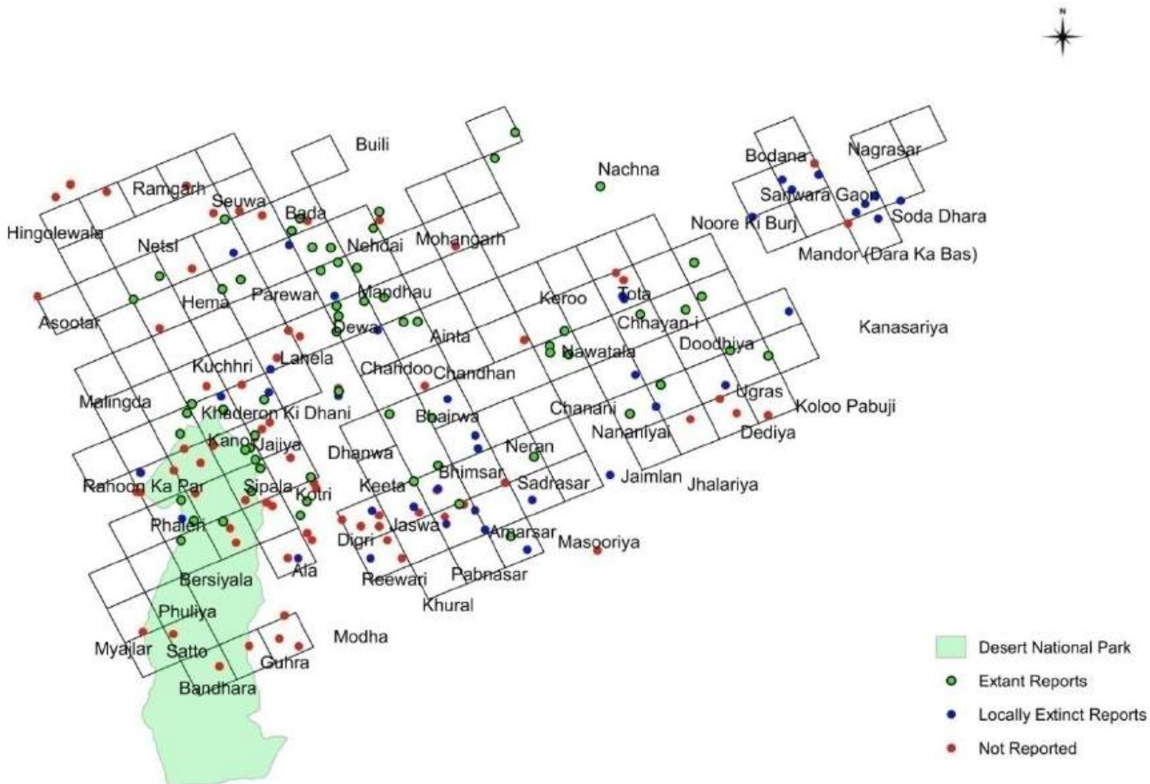


Figure 17. Reports of chinkara occurrence across sampled village areas in Thar landscape (2016)

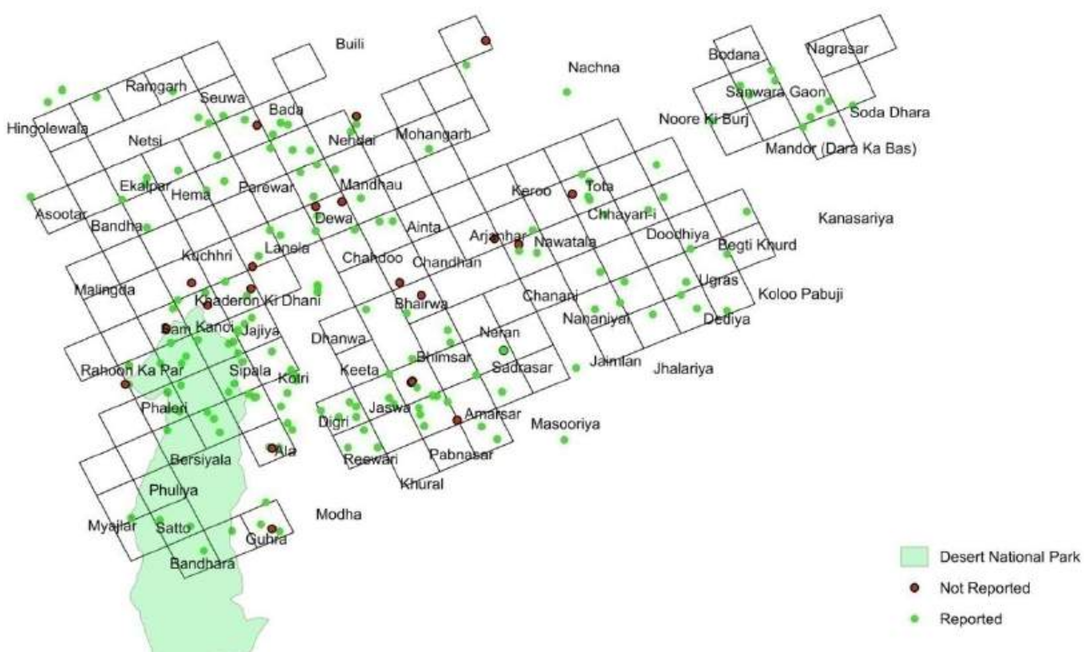


Figure 18. Reports of desert fox occurrence across sampled village areas in Thar landscape (2016)

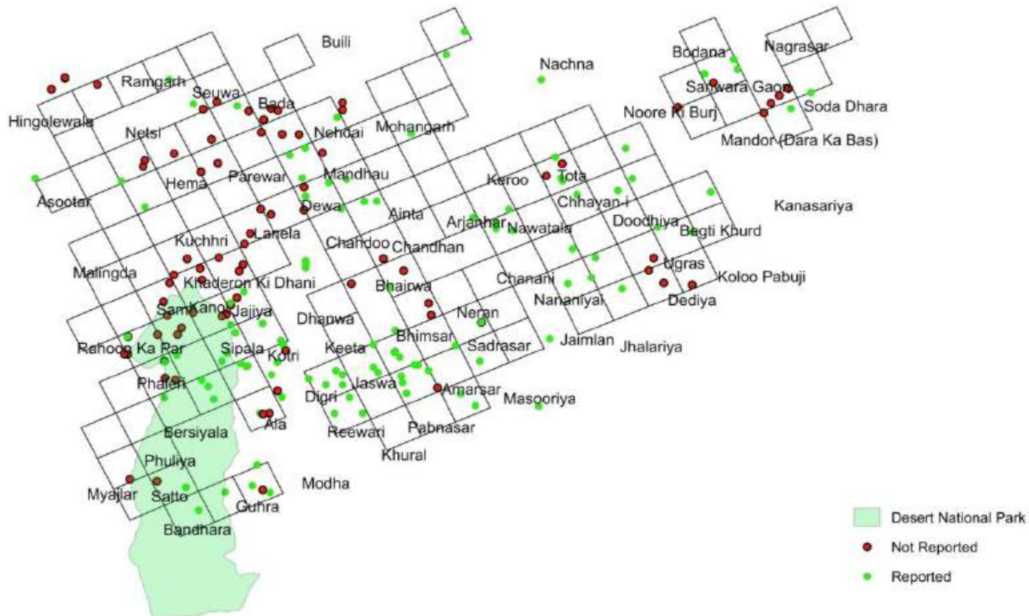
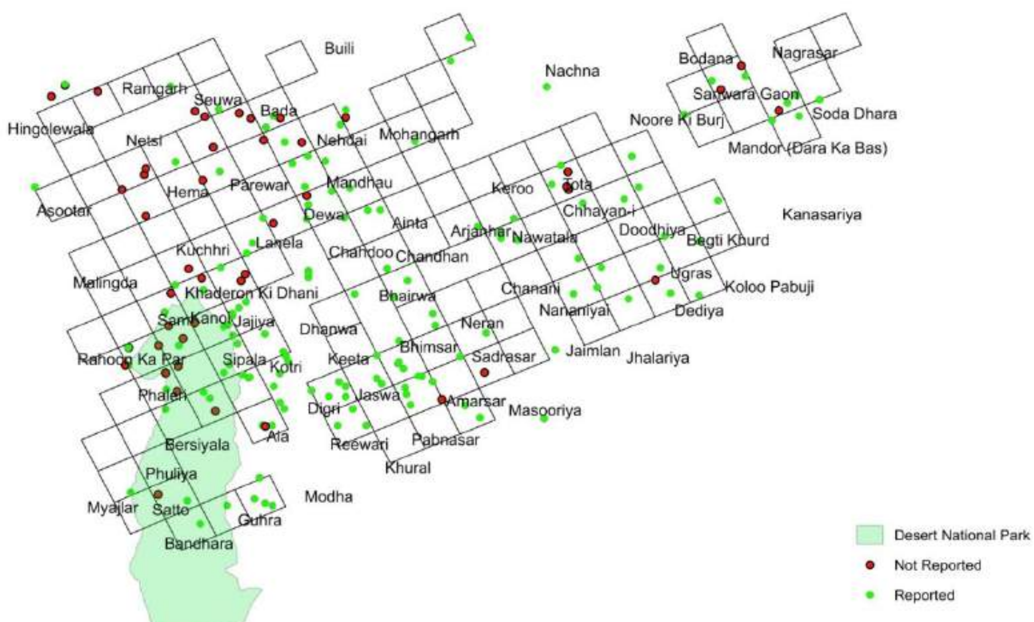


Figure 19. Reports of crane occurrence across sampled village areas in Thar landscape (2016)



5. Discussion

By adopting a standardized, spatially representative sampling and analysis design that accounts for imperfect detectability, we have generated robust population parameter estimates for the critically endangered great Indian bustard and its associated chinkara and desert fox in 20,000 km² potential bustard habitat of Thar landscape. During the three initial survey years (2014-16), we have tried and tested various modifications over our basic sampling and analytical designs. This year's protocol is more refined than our earlier years on two fronts: a) the use of tools such as range-finders and compasses for accurate measurement of distance of observation that allows more reliable estimation of detectability, and hence, density/abundance. b) Assessment of great Indian bustard density/abundance follows a two-phase sampling, where extensive surveys across the landscape generates information on proportion of cells used by the species, and intensive surveys generates information on density in used cells, together providing abundance estimate in the landscape. For comparison with past estimates, we have also reported the density/abundance estimated using the traditional approach.

Comments on the population enumeration technique

Thar landscape extends over a vast area with little barrier to bird/animal movements, thereby rendering total population counts impractical and unreliable. Comparing great Indian bustard numbers observed in conventional surveys to that reported by local informants, Rahmani (1986) speculated that only 10-20 % of population might be detectable. This impeded earlier efforts of assessing their population status with confidence. Similarly, our extensive surveys detected 45_{Mean} % of the minimum number of birds present in seven intensively sampled cells (2015) that can be considered as a crude approximation of the proportion of birds in a cell detectable during conventional survey. Moreover, encounter rates of birds on repeated surveys within 18 days varied between 80-173 % among seven cells (2014). These facts emphasize that conventional counts miss substantial proportion of birds. Our approach of estimating effective detection widths from dummy (2014 and 2016) and actual birds (2015-16), that were found to be exactly same, circumvents this problem and allows detection-corrected density/abundance to be estimated from a sample of sites. Selection of sites following random sampling design allows unbiased extrapolation of this sample statistic to population density/abundance estimate. However, for great Indian bustard, precision of estimate in this framework is relatively poor, as can be expected for a species with tiny population and patchy distribution across large area. Implementing two phase sampling that makes use of intensive data from sites used by species and pooling samples from both years have provided more precise estimate than earlier years (Dutta et al. 2014, Dutta et al. 2015). We are in the process of further improving the precision of density/abundance estimate by using Density Surface Modeling, which is a model-based approach in contrast to our current design based approach (Buckland et al. 2015). This approach models species' counts in transect segments, after correcting for imperfect detection, with habitat covariates (remotely sensed), and the model is used to predict spatially explicit density/abundance from spatial covariate layers. Abundance can be summed over the target area, and the precision of estimate is typically high because spatial variability in species' distribution has been explicitly accounted. However, we highlight that different assessment methods - one-phase sampling based distance analysis (following Dutta et al. 2015), two-phase sampling based occupancy and distance analysis (this report), and density surface modeling (in preparation) - have provided converging abundance estimates of around 140-200 (mean) birds, wherein, the two-phase sampling based abundance (140 $\pm$ 53 birds) is the most conservative estimate.

For the purpose of monitoring, we recommend replicating our intensive surveys on a seasonal basis in cells with high conservation value / bustard usage that would allow reliable inferences on local population trend and seasonality. A complete two-phase sampling, spanning summer (Marh-April) and winter (October-December) seasons can be conducted once in 2-4 years to detect changes in overall population status. As explained earlier, the current species' density/abundance estimates should not be compared to that reported in Dutta et al. (2014) since we have refined the expanse of potential habitat and method during the latter surveys. The pooled estimates reported in section 4.1.5 should be used as baseline for inferences on population trends as data from multiple assessment cycles become available in future.

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, numbers and area of use have seemingly declined in these three decades. Rahmani (1986) reported great Indian bustard sightings in/around Bap, Sam-Sudasari, Khuri-Tejsi, Khinya, Rasla and Sankara; whereas, we detected the species in/around Sam-Sudasari, Salkha, Ramdeora-Bhadariya-Ajasar-Loharki. Typical number of birds seen by respondents in their localities has also reduced from earlier times. Local peoples' responses to our questionnaires indicated decline of occurrence reports from 54% to 38% through last ten years. Local extinction reports were concentrated around Phalodi-Bap (north-east Thar) and Reewari-Bhimsar-Rasla-Sadrasar (south-central Thar) areas that corroborated our field observations.

Our results on species-habitat relationships indicated that disturbance was the prime factor influencing distribution in this region. Great Indian bustard did not use areas with high incidence of humans or infrastructure. Their occurrence also depended on protection and declined with distance from protected enclosures. The positive relationship between great Indian bustard and grazing intensity was an effect of correlation and not causation, since both taxa prefer similar habitat characteristics; productive grasslands (figure 9). Hence, reduction of anthropogenic pressures in great Indian bustard occupied cells by creating enclosures and/or providing alternate arrangements to local communities should be the priority conservation action. This proposition is supported by observations of great Indian bustards frequently using and breeding in Ramdeora, new enclosures in Sudasari and Chowani after anthropogenic disturbances have been excluded from this site through chain-link-fencing. It was also found that 75 % of priority conservation cells occurred outside of Desert National Park (figure 7). Although some of these areas benefit from protection by Bishnoi community

(Bap-Ramdeora area) and inviolate space created for defense activities (Pokhran-Bhadariya-Loharki area), majority are threatened by hunting, development projects (e.g., wind power generation), and over-extraction of resources (e.g., livestock overgrazing). The cells of high conservation value should not have further infrastructural (power-lines, wind-turbines, buildings etc.) or agricultural development that can act as barriers to bird movements between them. The recent (late 2013) installation of wind-turbines and high tension power-lines between Sam-Sudasiri and Salkha areas is a severe threat to the survival of great Indian bustard population as they increase the risk of electrocution and fatal collisions of the locally migrating birds in western Thar. Thar landscape has already lost great Indian bustard from Mokla grasslands following the installation of wind-turbines and high tension power-lines between near Mokla in early 2011. At least five instances of great Indian bustard mortality through collision with power-lines associated with wind-turbines have been reported from Kachchh and Solapur districts in the last decade. If the priority conservation cells are to be developed, it should be bustard-friendly such as underground power-lines and organic, rainfed cultivation of food crops. The recent deliberations and decision that no more over-head power-lines and wind turbines will be installed in the priority great Indian bustard habitats will greatly benefit the species.

However, these regulations need to be carefully enforced as the community responses to our questionnaires suggested general lack of support for bustard conservation and the possibility of antagonistic reactions. Effective conservation in Thar would require a multi-pronged approach that involves multiple stakeholders: Forest Department, Indian Army, local communities and research/conservation agencies. Apart from protecting key breeding areas as enclosures, conservation funds should be utilized on activities to maintain anthropogenic pressures below species' tolerance threshold by involving communities in participatory-planning that balances conservation and livelihood concerns. This includes activities such as regulated ecotourism that can improve the local economy, mitigation of infrastructural development, and bustard-friendly agro-pastoral practices (Dutta et al. 2013).

Since great Indian bustard usage is spread across large expanse of Thar, comprehensive insights into their ranging patterns are required for fine-tuning these conservation actions. Currently, two distinct population clusters are noticeable – one in western Thar extending from Chowani in south to Habur in north, and another in eastern Thar, in/around Pokhran Field Firing Range. Secondary occurrence reports of great Indian bustard from Bada-Nehdai-Dewa-Mandhau-Ainta villages in northern Thar indicate possible connectivity between these western and eastern populations. But the actual corridors can only be determined through biotelemetry studies.

Key recommendations

The great Indian bustard population and habitats are declining drastically across its distribution range. Thar landscape is the only remaining habitat supporting a viable (and the largest) breeding population in 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) in early 1980s. 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 small proportion of the priority conservation areas in Thar. Therefore, we recommend rationalizing the Park boundary with the objectives of: a) notifying the northern Sam-Sudasari area (500 km^2) as National Park with **voluntary** relocation of villages; b) selectively declaring areas in priority conservation cells as Community/Conservation Reserves where human landuses can be regulated (e.g, habitats near Kanoi-Salkha-Habur, Nathoosar, Chanani, Ugras, Galar, Chhayan, Ajasar-Keroo, Bhadariya, Mohangarh and Dhaleri); and c) notifying areas equal to the denotified Park area (2600 km^2) as PA in the relatively less populated Shahgarh Bulge.

In terms of management activities, we recommend:

a) Consolidating existing enclosures in bustard breeding areas using predator-proof chain-link fences (in Sam, Sudasari, Gajaimata, Rasla and Ramdeora).

b) Removing feral dogs, pigs and other nest predators (foxes, mongoose and monitor lizards) from breeding enclosures (~25 km² cumulative area) to improve nesting success and chick survival of great Indian bustard.

c) Transferring lands in priority conservation cells (e.g, habitats near Kanoi-Salkha-Habur, Nathoosar, Chanani, Ugras, Galar, Chhayan, Ajasar-Keroo, Bhadariya, Mohangarh and Dhaleri) to Forest Department for creating new protective enclosures.

d) Mitigating the ill-effects of wind-turbines and overhead power-lines in priority conservation cells, particularly the great Indian bustard ranging arc between Sudasari-Sam-Salkha-Mokla-Mohangarh-Bhadariya-Ajasar-Ramdeora (figure 3) to reduce obstruction to local bird movements. New power-lines should be made underground and existing ones should be marked with Bird Flappers/Diverters to make them visible and minimize collision risk (Silva et al. 2014).

d) Smart and intensive patrolling to generate management information and control poaching. This entails recruiting more staff, building their capacity through tools and training, and providing performance based incentives.

e) Targeted research on great Indian bustard to characterize threats spatio-temporally, understand landscape use patterns using satellite telemetry, and objective monitoring of their population status by involving research organizations.

f) Involving local people in conservation by addressing their livelihood concerns (e.g., regulated ecotourism), and encouraging them to monitor bustard occurrence and report illicit activities using rewards and incentives. Baseline information on community composition, livelihoods and village livestock holdings, generated from our questionnaires can aide in designing such outreach programs.

The key to conserve this vital yet neglected landscape is a combination of stringent protection measures, scientific habitat management, sensible landuse planning, and provisioning of basic amenities and livelihood options to local people (e.g., regulated ecotourism) in the priority conservation areas.

Well-intended but ill-informed management practices in Thar should be discontinued, such as (top) plantation of tree/shrub species that are detrimental to native wildlife, particularly great Indian bustard, and (bottom) water provisioning in enclosures that attract undesired species such as livestock, pigs, and Indian fox and increase nest predation of bustard.

Free-ranging dogs, which depend on human-based resources as well as hunt wild prey such as chinkara, fox, ground-dwelling birds, and lizards, are a major emerging threat to native wildlife in Thar. Their population and resources need to be urgently managed/controlled.

Great Indian bustard habitats in Thar are regarded as unproductive 'wastelands' and allocated for wind and solar power projects. Touted as 'green energy', these projects add to the existing power-lines and cause bird mortality through collision. These projects should not be allowed in priority bustard habitats.

Regulated livestock grazing is beneficial to grassland structure and quality, and is compatible with bustard conservation. But, current livestock densities are higher than ecological carrying capacities, depleting food and cover for wildlife. Forest Department have established grazing-free enclosures as "maternity wards" for bustard. Existing barbed-wire fencing around enclosures is ineffective in controlling grazing and should be upgraded to chain-link-fencing. To induce the benevolent effects of regulated livestock grazing on grassland and bustard, enclosures should be made seasonally inviolate by excluding grazing only during growing season.

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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 / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	

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)					3 dominant plants (100m radius)	*Sandha* Pr (10m radius)	Human structure (100m radius)
							Short grass/ herb(<30cm)	Tall grass (>30cm)	Shrub (<2m)	Tree (>2m)	Crop (name)			
				F / S / U (M / V)	R / G / S / s	B / A / G / W / S							1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W / S							1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W / S							1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W / S							1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W / S							1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W / S							1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W / S							1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W / S							1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W / S							1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W / S							1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W / S							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) / **G** (grassland) / **W** (woodland) / **S** (scrubland)
Human structure – **S** (settlement) / **H** (farm hut) / **R** (metal road) / **E** (electricity lines) / **W** (wind turbine) / **P** (water-source)
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 name	GPS location	3 most dominant castes in village	Major livelihoods in village	How many livestock in village?		What do you see around your village?	GIB around your village 10 years back?
				Sheep & goat	Cattle & buffalo		
						Chinkara / Nilgai / Fox (D/I) / Crane (D/C) / GIB	
						Chinkara / Nilgai / Fox (D/I) / Crane (D/C) / GIB	
						Chinkara / Nilgai / Fox (D/I) / Crane (D/C) / GIB	
						Chinkara / Nilgai / Fox (D/I) / Crane (D/C) / GIB	
						Chinkara / Nilgai / Fox (D/I) / Crane (D/C) / GIB	
						Chinkara / Nilgai / Fox (D/I) / Crane (D/C) / GIB	
						Chinkara / Nilgai / Fox (D/I) / Crane (D/C) / GIB	
						Chinkara / Nilgai / Fox (D/I) / Crane (D/C) / GIB	

Rajasthan
Forest Department

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

Status of Great Indian Bustard and Associated Fauna in Thar

Survey Report 2014 & 2015

Wildlife Institute of India
&
Rajasthan Forest Department

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Executive Summary

Arid ecosystems of India support unique biodiversity and traditional agro-pastoral livelihoods. But, they are highly threatened due to land-use mismanagement and neglect of conservation policies. The Critically Endangered great Indian bustard (GIB) acts as a flagship and indicator of this ecosystem, for which the Government is planning conservation actions that will also benefit the 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 context remain poorly understood.

This study assessed the status of GIB, chinkara and fox alongside their habitat and anthropogenic pressures across ~20,000 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 $16 \pm 3_{SD}$ km transects to record species' detections, habitat characteristics in sampling plots, and secondary information on species' occurrence. Multiple teams comprising field biologists and Forest Department staff simultaneously and rapidly sampled 108 cells along 1697 km transects in March 2014 and 77 cells along 1246 km transects in March 2015. Species' detection data were analyzed in Occupancy and Distance Sampling framework to estimate proportion of sites used and density/abundance of key species.

Our key findings were that GIB used $18 \pm 6_{SE}$ % of sites, although secondary information obtained from local community using questionnaires indicated usage in 34 % of sites. Bird density was estimated at $0.86 \pm 0.35_{SE}$ /100 km^2, yielding abundance estimates of $133 \pm 55_{SE}$ in the sampled cells (15,552 km^2) and $169 \pm 70_{SE}$ birds in Thar landscape (19,728 km^2 area). During the survey, ~38 (2014) and ~40 (2015) individual birds were detected. Bustard-habitat relationships, assessed using multinomial logistic regression, showed that disturbances and level of protection influenced distribution in this landscape. Chinkara used $92 \pm 3_{SE}$ % of sites at overall density of $375 \pm 41_{SE}$ animals/100 km^2 and abundance of $73{,}976 \pm 8145_{SE}$ in the landscape. Desert and Indian fox used $60 \pm 7_{SE}$ % of sites, at densities of $24.07 \pm 5.02_{SE}$ desert fox/100 km^2 and $1.23 \pm 0.68_{SE}$ Indian fox/100 km^2, and abundances of $4{,}749 \pm 989_{SE}$ desert fox and $243 \pm 135_{SE}$ Indian fox in the landscape. Nineteen percent of sampled cells were found to be of high conservation value, out of which, 75 % cells were outside Protected Area. Although some of them benefit from community or Army protection, majority are threatened by hunting and unplanned landuses.

This study provides robust abundance estimates of key species in Thar. It also provides spatially-explicit information on species' distribution and ecological parameters to guide site-specific management and policy. Thar supports the largest global population of GIB and offers the best hope for its survival. This survey captured snapshots of GIB distribution that needs to be augmented with landscape-scale seasonal use information using satellite telemetry to prioritize areas for conservation investment.

1. Introduction

The great Indian bustard (*Ardeotis nigriceps*) is Critically Endangered (IUCN 2011) with less than 300 birds left. Rajasthan State in India holds the largest population and prime hope for saving the species (Dutta et al. 2011). As the range States across the country are developing species' recovery plans (Dutta et al. 2013), baseline information on current distribution, abundance and habitat relationships are scanty. Such information are essential for conservation planning and subsequently 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 study was aimed at generating information on population and habitat status of these species for the crucial bustard landscape of western Rajasthan.

Great Indian Bustard are cryptic and vagile birds occupying large landscapes without distinct boundaries that make complete enumeration of population impractical and unreliable. Their population status has to be estimated using robust sampling and analytical methods that can be replicated, incorporate imperfect detection, and allow statistical extrapolation of estimates to non-sampled areas. However, the extreme rarity of bustards makes precise estimation of population abundance difficult and logistically demanding. Through repeated surveys during March 2014 and 2015, we have attempted to develop a protocol for monitoring the population status of great Indian bustard and associated wildlife in Thar and other bustard landscapes across the country.

Our survey covered the potential great Indian bustard habitat in Jaisalmer and Jodhpur districts, Rajasthan (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).

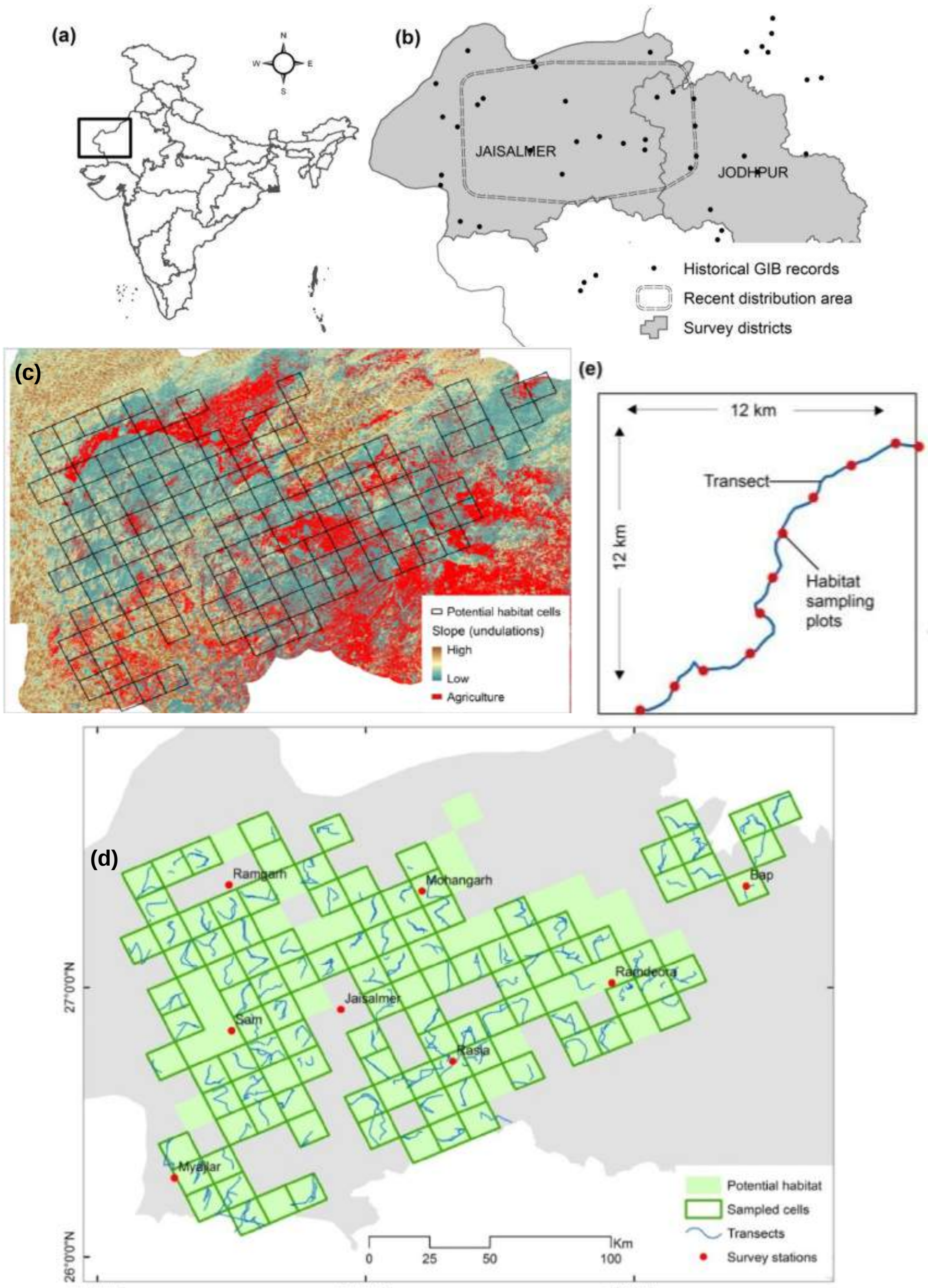
2. Thar landscape

The potential great Indian bustard landscape in Thar was identified in a stepwise manner. Past records (post 1950s) of great Indian bustard in western Rajasthan were collated (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, extensive sand dunes, built-up and intensive agriculture areas were considered unsuitable based on prior knowledge (Dutta 2012). These areas were identified from the combination of land-cover maps procured from NRSC (ISRO), Digital Elevation Model and night-light layers in GIS domain, Google Earth imageries, and extensive ground validation surveys during 2014-2015. The remaining landscape, an area of 20,000 km^2, was considered potentially habitable for great Indian bustard and subjected to sampling (figure 1).

The study area falls in Desert Biogeographic Zone (Rodgers et al. 2002) with arid (Jodhpur) to superarid (Jaisalmer and Bikaner) 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 Thorny Scrub, characterized by open woodlot dominated by *Prosopis cineraria*, *Salvadora persica* and exotic *Acacia tortilis* trees, scrubland dominated by *Capparis decidua*, *Zizyphus mauritiana*, *Salvadora oleoidis*, *Calligonum polygonoides*, *Leptadenia pyrotechnica*, *Aerva pseudotomentosa*, *Haloxylon salicornicum* and *Crotolaria bhuria* shrubs, and grasslands dominated by *Lasiurus sindicus* and *Dactyloctenium sindicum*. Notable fauna, apart from the ones mentioned before, include mammals like 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 that 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 km²) has been declared as Desert National Park (Wildlife Sanctuary), 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 (2014-2015): location of study area (a); delineation of bustard landscape from existing information on species' occurrence (b), remotely sensed habitat information and reconnaissance surveys (c); distribution of transects in 144 km² cells overlaid on potential habitat (d); and habitat sampling plots at 2 km interval on transect (e)



3. Methods

3.1. Organization of survey

The potential great Indian bustard landscape in Thar was divided into seven sampling blocks which were simultaneously surveyed by 18 teams during March 22-26, 2014 and by 17 teams during March 21-25, 2015. This enabled us to cover such large expanse within brief time period in order to minimize bird/animal movements between survey areas. The sampling blocks were named after their respective field-stations, as: a) Ramgarh, b) Mohangarh, c) Bap, d) Ramdeora, e) Rasla, f) Myajlar, and g) Sam-Sudasari. Two-three teams operated for four-five days in each of these blocks. 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 many years of field experience on wildlife surveys. Team members were trained through workshops and field exercises on a standardized data collection protocol for two days prior to block surveys. Data collected by different teams were collated after the completion of surveys and analyzed.

3.2. Sampling design

Species and habitat status were assessed using extensive vehicle transects in a systematic sampling design. A grid of 137* cells, each 144 km^2 in size (12 km x 12 km), were overlaid on the potential great Indian bustard habitat (covering 19,728 km^2) and realized on ground by handheld GPS units and Google Earth imageries. Subsequently, 108* cells were randomly selected for sampling in 2014, out of which 77 cells were resampled in 2015. Cells were surveyed along dirt trails of $16.2_{Mean} \pm 3.4_{SD}$ km length (single continuous or two broken transects) from a slow moving (10-20 km/hr) vehicle on each occasion. Surveys were conducted in early morning (0600-1000) and late afternoon (1600-1900), when bird/animal activity was highest. This sampling scheme was chosen to optimize 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 ≥70 % area) and logistic constraints (six days, eight hours/day and 18 teams were feasible).

* Earlier, 25,500 km^2 area was considered potentially suitable and 177 grid-cells were overlaid, out of which, 118 cells were sampled (Dutta et al 2014). Subsequently, as more refined information on habitat and species' distribution became available in 2015, 40 of these cells, inclusive of 10 sampled cells, were considered unsuitable and dropped from sampling/analysis

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 disturbances (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/scrubland/woodland), 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 structure 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. These covariates were 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. Vegetation composition was recorded (only during 2015) as three dominant plant taxa within 100m radius of the point. Presence of human structures (settlement/farm-hut/metal-road/power-lines/wind-turbine/water-source) was recorded within 100-m radius (2014) and 500-m radius (2015) of the point. Status of spiny-tailed lizard, another key associate of bustard with a relatively small activity range (Dutta and Jhala 2014), was recorded as occurrence of their burrow(s) within 10 m radius of the point.

3.3.3. Secondary information

Secondary information on bustard and associated species were collected from $3.04_{Mean} \pm 1.81_{SD}$ respondents/cell in 2014 and opportunistically in 2015, preferably from adults and agro-pastoralists with local knowledge (datasheet in appendix 3).

3.4. Data analysis

3.4.1 Population status

Density/abundance and (as a cheaper alternative) occupancy/use are commonly used parameters to assess population status. Species' density was estimated using Distance sampling and analysis in program DISTANCE (Thomas et al. 2010). This technique modeled the declining probability of detecting individual(s) with distance from transect, 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 averaged across cells) into density estimate ($\overline{D}$) (demonstrated in the footnote, also see Buckland et al. 2001). Subsequently, species' abundances in sampled cells and potential landscape were estimated by multiplying the density estimate with the respective areas. Great Indian bustard sightings on extensive surveys were inadequate for robust estimation of detectability. To circumvent this issue, we had earlier developed detection function using dummy birds in blind tests (Dutta et al. 2014). In 2015, we intensively sampled seven randomly selected cells used by great Indian bustard following similar protocol as our extensive survey. The only difference was that multiple teams simultaneously surveyed different portions of these cells on two occasions. This increased the sightings, allowing direct estimation of detectability from actual bird sightings. For each species, effective strip width was estimated by pooling observations across years since detectability was unlikely to differ annually. We tested for difference in species' encounter rates between years, and since there was no statistical difference (see Results), we obtained pooled density estimate using data from both years. This was also ecologically reasonable since the time-frame was too short for any detectable change in the species' populations. For feral dogs and livestock, mean ± SE of encounter rates across cells were estimated.

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

The proportion of sites used by a species (i.e., its asymptotic occupancy integrated over time, see Efford and Dawson 2012) was estimated using Occupancy analysis in program PRESENCE (Mackenzie et al. 2006). This technique accounts for the probability of missing species present at a site by using detection data from repeated surveys at sites, thereby yielding more accurate estimates of occupancy. We treated the combined length of transects in a cell as a site/plot, and generated detection/non-detection matrix from species' sightings within 2 km transect-segments across two years (spatio-temporal replicates). This was used to estimate asymptotic occupancy following the traditional model of Mackenzie et al (2003) that assumes constant detection probability (across replicates) and occupancy (across sites)*. For spiny-tailed lizard, we used burrow detection in 10 m radius plots to estimate occupancy.

3.4.2. Habitat status and use

Habitat characteristics of a cell were summarized from covariate data collected at $15_{Mean} \pm 5_{SD}$ sampling plots along extensive transects in two years. a) For categorical covariates (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., flat-undulating mix), otherwise '0'. These values were averaged across plots to generate an index of prevalence for each terrain type. b) For interval covariates (vegetations structure), mid-values of class-intervals were averaged across plots. c) Vegetation composition was characterized from the frequency of occurrence (%) of dominant plant taxa across plots. c) Disturbance covariates were grouped into: infrastructure intensity – measured as summed occurrence of metal road, power lines and wind turbines; and human incidence – 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. Mean ± SE estimates of covariates were computed across sampled cells to describe landscape characteristics.

Great Indian bustard occurrence pattern was examined by modeling its presence (sighting or confirmed signage) and secondary report vs. absence (reference category)

* The alternate formulation of Hines et al. (2010) that accounts for spatial correlation of detections was not used since the detections were based on spatial and temporal surveys for estimating "use"

on potential habitat covariates at the cell-level using multinomial logistic regression in program SPSS (Quinn and Keough 2002). Among the covariates collected, the following were selected as potentially important for explaining bustard occurrence based on our ecological understanding: 1) flat or 2) undulating [terrain]; 3) grassland, 4) woodland or 5) agriculture [land-cover]; 6) rock/gravel or 7) sand [substrate]; 8) human incidence in 100m , 9) infrastructure intensity in 100m, and 10) grazing intensity (livestock encounter rate Animal Units/km) [disturbances]; and 11) mean distance to enclosure [protection]. Some of the covariates were inter-correlated (see Results), which could complicate interpretations of regression parameters (Graham 2003). After inspecting the data, Principal Component Analysis (Quinn and Keough 2002) was carried out on terrain, substrate and land-cover covariates in program SPSS that extracted synthetic components to surrogate prominent and independent habitat gradients. A global model incorporating the habitat components, disturbance and protection covariates and its ecologically meaningful subset models were built. These models were compared using Information Theoretic approach (Burnham and Anderson 2002) and goodness-of-fit statistic (R^2) to draw inferences on factors influencing bustard distribution.

3.4.3. Spatially explicit information on ecological parameters

Spatially explicit information on species and habitat status help prioritize conservation areas and target management. Surface maps of habitat covariates were generated by kriging values (Baldwin et al. 2004) from sampled cells in program ArcMap (ESRI 1999-2008). Species' encounter rates were also mapped across cells. Cells were prioritized for conservation management based on the combined population status of great Indian bustard, chinkara and fox. We ranked the status of bustard as: 0 (not detected), 1 (secondary report), or 2 (sighting) and that of chinkara and fox as: 0 (1^{st}–2^{nd} quartiles of encounter rate), 1 (3^{rd} quartile of encounter rate), or 2 (4^{th} quartile of encounter rate). These ranks were weighted by species' endangerment level (3 for bustard, 2 for chinkara and 1 for fox) and summed to generate a conservation priority index. Based on this index, cells were classified as 'low' (1^{st}–2^{nd} quartiles of index), 'medium' (3^{rd} quartile) and 'high' (4^{th} quartile) priority to guide judicious investment of conservation efforts.

4. Results and Findings

4.1. Population status

Total 108 cells covering 15,552 km^2 area was surveyed along 1697 km transect in 2014. Out of these, 77 cells covering 11,088 km^2 area was resurveyed along 1246 km transect in 2015 (figure 1). Data generated from these surveys provided estimates of species' occupancy, density and abundance.

4.1.1. Great Indian Bustard

Surveys conducted during 22–26 March, 2014 and 21-25 March, 2015 recorded minimum 34-43 and 38-42 unique great Indian bustards (encompassing errors due to double counting) respectively, comprising observations along transects and those enroute or while returning from sampling cells. Twelve flocks were detected on extensive transects (2014-2015) at encounter rate of $0.41 \pm 0.16_{SE}$ flocks/100km. There was no statistical difference between the encounter rates of 2014 (0.35, $0\text{-}0.80_{95\%CI}$ flocks/100km) and 2015 (0.50, $0\text{-}1.00_{95\%CI}$ flocks/100km). Supplementing this data with intensive transects in used cells yielded a total of 33 flocks. Flock size estimated from extensive and intensive transects was $1.97 \pm 0.19_{SE}$ individuals. All detection models tested on distance data pooled from extensive and intensive transects (half-normal, hazard-rate and uniform functions) obtained similar support (ΔAIC<1). Based on the least number of model parameters and the highest goodness-of-fit, we selected the half-normal detection function (χ^2=0.92, df=2, p=0.63). It estimated flock detection probability and effective strip width at $0.48 \pm 0.05_{SE}$ and $476 \pm 52_{SE}$ m, respectively (figure 2). Our detectability experiment based on dummy birds in 2014 returned a similar effective strip width of $423 \pm 120_{SE}$ m. Incorporation of detection probability in bustard encounter rates on extensive transects returned density estimate of $0.86 \pm 0.35_{SE}$ birds/100km^2 and abundance estimate of $133 \pm 55_{SE}$ in sampled cells (15,552 km^2). Extrapolation of this density to the potential landscape area (19,728 km^2) yielded estimate of $169 \pm 70_{SE}$ birds*. Great Indian bustard was detected in 9 cells or 8.3 % of sites (naïve occupancy). The probability of detecting at least one bustard along 2 km transect-segment was 0.04 ± 0.01. Detection corrected proportion of sites used by great

* This is statistically similar to the earlier estimate (Dutta et al. 2014) but should be treated as more robust since it is based on larger sample size considering similar abundance between years

Indian bustard (asymptotic occupancy) during two years was estimated at 0.18 ± 0.06. Supplementing this with interviews of local people (bird records in last 3 months) and our auxiliary surveys (February-June 2014 & 2015) indicated some level of great Indian bustard usage in 38 (34 %) sampled cells (figure 3).

4.1.2. Chinkara

During extensive surveys of 2014-2015, 887 chinkara herds were detected at encounter rate of 30.17 ± 2.79_{SE} herds/100km and herd size of 2.92 ± 0.11_{SE} individuals. There was no statistical difference between encounter rates of 2014 (30.5, $23.0\text{-}38.0_{95\%CI}$ herds/100km) and 2015 (29.7, $21.8\text{-}37.7_{95\%CI}$ herds/100km). Hazard-rate detection function fitted the distance data best (χ^2=7.23, df=5, p=0.20) that estimated herd detection probability and effective strip width at 0.10 ± 0.006_{SE} and 117 ± 5_{SE} m, respectively (figure 2). Chinkara density was estimated at 375 ± 41_{SE} animals/100km^2, yielding abundance estimates of 58,317 ± 6421_{SE} in sampled cells and 73,976 ± 8145_{SE} in the landscape. Chinkara was detected in 91 % cells (naïve occupancy) (figure 4). The probability of detecting a chinkara along 2 km transect-segment was 0.32 ± 0.01_{SE}. Detection-corrected proportion of sites used by chinkara was estimated at 0.92 ± 0.03_{SE}.

4.1.3. Fox

During extensive surveys of 2014-2015, 101 desert fox and 6 Indian fox were detected along transects at encounter rates of 3.42 ± 0.53_{SE} individuals/100km and 0.18 ± 0.09_{SE} individuals/100km, respectively. There was no statistical difference between the encounter rates of 2014 (3.99, $2.62–5.36_{95\%CI}$ [desert fox] and 0.23, $0\text{-}0.46_{95\%CI}$ [Indian fox]) and 2015 (2.62, $1.14\text{-}4.10_{95\%CI}$ [desert fox] and 0.11, $0\text{-}0.34_{95\%CI}$ [Indian fox]). Both species were observed mostly solitarily (12 % sightings were in pairs), yielding group size estimate of 1.14 ± 0.04_{SE} individuals. Since these species have similar body size and behaviour, a common detection function was built. Hazard-rate detection function fitted the distance data best (χ^2=4.13, df=4, p=0.39) that estimated detection probability and effective strip width at 0.16 ± 0.02_{SE} and 71 ± 10_{SE} m, respectively (figure 2). Species' densities were estimated at 24.07 ± 5.02_{SE} desert fox/100km^2 and 1.23 ± 0.68_{SE} Indian fox/100km². Accordingly, their abundances were estimated at 3743 ± 780_{SE} (desert fox) and 192 ± 106_{SE} (Indian fox) in the sampled cells, while 4749 ± 989_{SE} (desert fox) and 243 ± 135_{SE} (Indian fox) in the landscape area. Fox (pooling both species) was detected in 43 % of transects (naïve occupancy) (figure 5). The probability of detecting fox on a 2km transect-segment was 0.09 ± 0.01_{SE}. Detection-corrected proportion of sites used was estimated at 0.60 ± 0.07_{SE}.

Figure 2. Detection functions relating probability of detecting individual with perpendicular distance from transect for great Indian bustard, chinkara and fox in Thar landscape during 2014-15

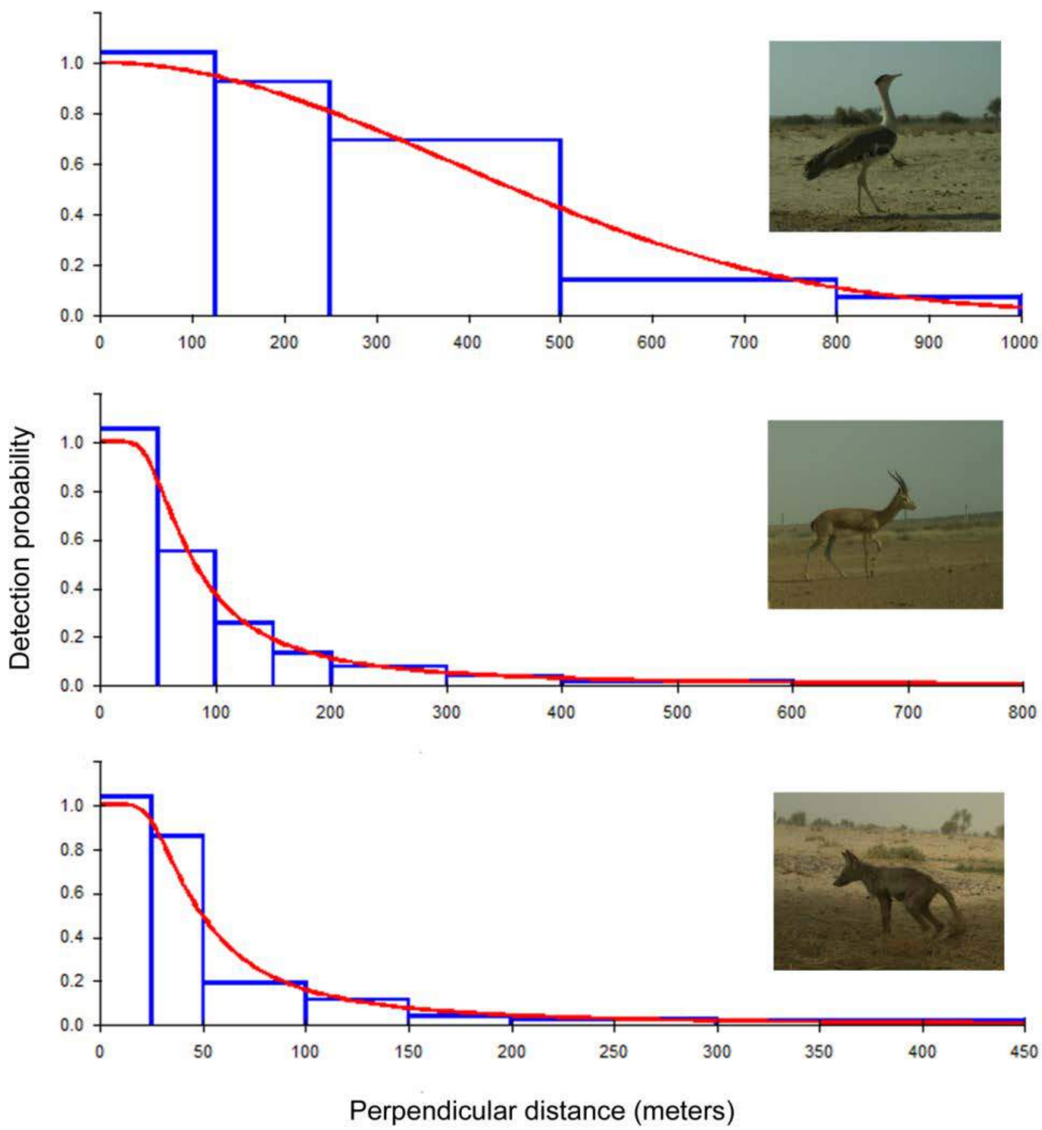


Figure 3. Great Indian bustard occurrence status in 144 km² cells based on surveys (primary data) and reports by local people (secondary data) in Thar landscape (2014-2015)

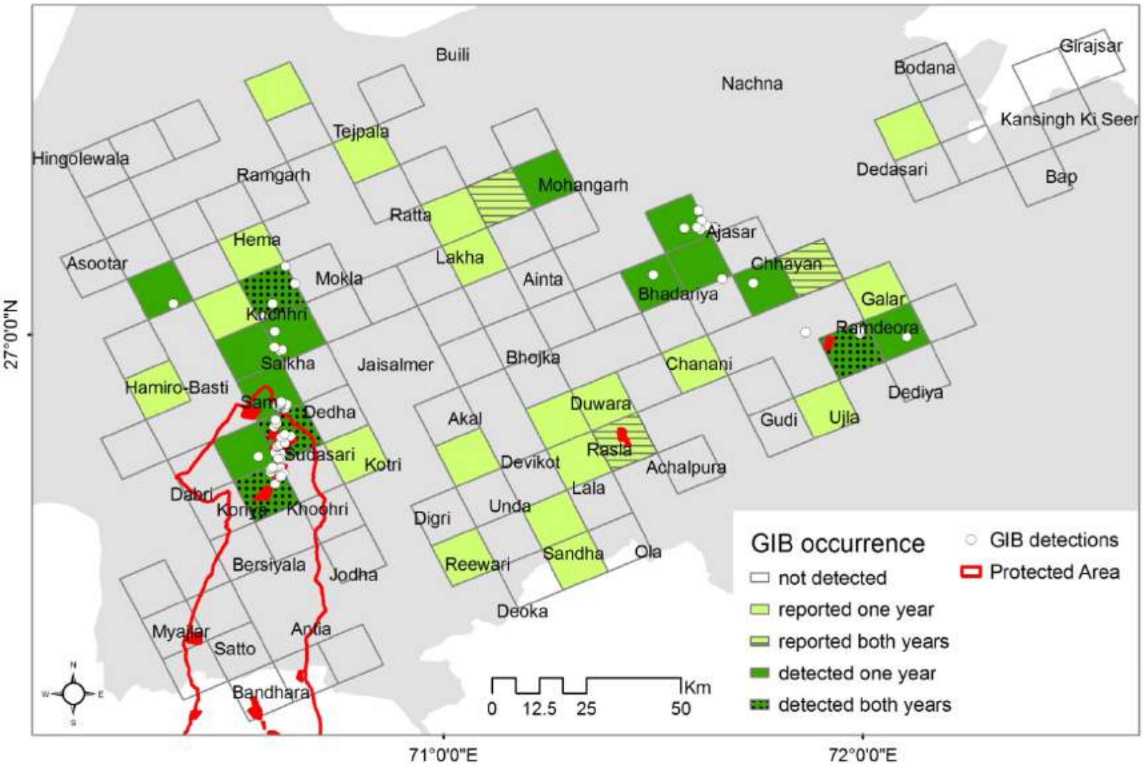


Figure 4. Chinkara encounter rates in 144 km² cells of Thar landscape (2014-2015)

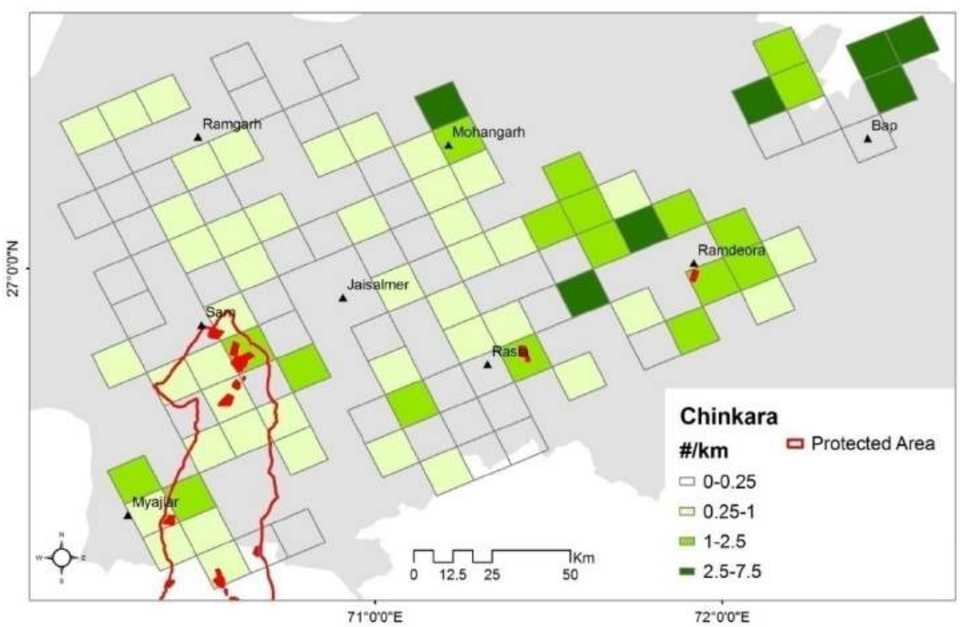
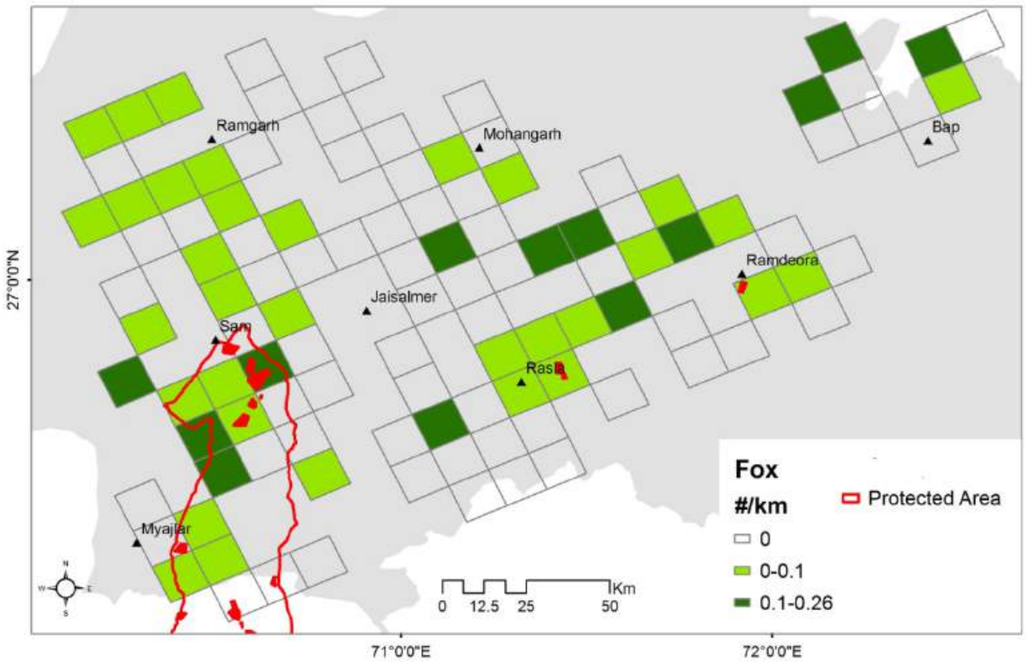


Figure 5. Fox encounter rates in 144 km² cells of Thar landscape (2014-2015)



4.1.3. Other fauna

Our extensive surveys of 2014-2015 also yielded sightings of nilgai (26 groups of 4.79 ± 0.96_{SE} individuals at encounter rate of 3.84 ± 1.25_{SE} individuals/100km) and pig *Sus scrofa* (4 groups of 9.50 ± 3.14_{SE} individuals at encounter rate of 1.15 ± 0.77_{SE} individuals/100km) (figure 5). Spiny-tailed lizard burrows were detected in 7.6 ± 1.2_{SE} % plots. Sightings of domestic animals included 121 dogs (encounter rate 4.12 ± 0.92_{SE} /100km), 11,753 cattle (371.94 ± 52.08_{SE} /100km) and 42,015 sheep and goat (1300.04 ± 105.94_{SE} /100km). Livestock was converted into Animal Units and their encounter rates were mapped to surrogate grazing intensity for identifying areas of high overlap between wild and domestic species (figure 6).

4.1.4. Conservation Prioritization

Conservation priority index, generated from population status of key species in 144 km² cells, ranged between 0-12. On classifying this range into three ranks (low: 0-3, medium: 3-6, and high: 6-12), 19 % of sampled cells (20) were attributed high priority and 81 % cells (88) were attributed low and medium priority for conservation (figure 7).

Only 25 % (5 cells) of high priority cells had some fraction of area within protective enclosures owned by Forest Department (Sam, Sudasari, Gajaimata, Rasla, and Ramdeora). Whilst unprotected habitats adjoining villages Pithala and Kanoi-Salkha-Habur near Jaislamer, Nathoosar, Chanani, Ugras, Galar, Chhayan, Ajasar-Keroo and Bhadariya near Ramdeora, Mohangarh and Dhaleri also have high conservation value.

Figure 5. Other ungulate (nilgai & pig) occurrence in 144 km² cells of Thar landscape (2014-2015)

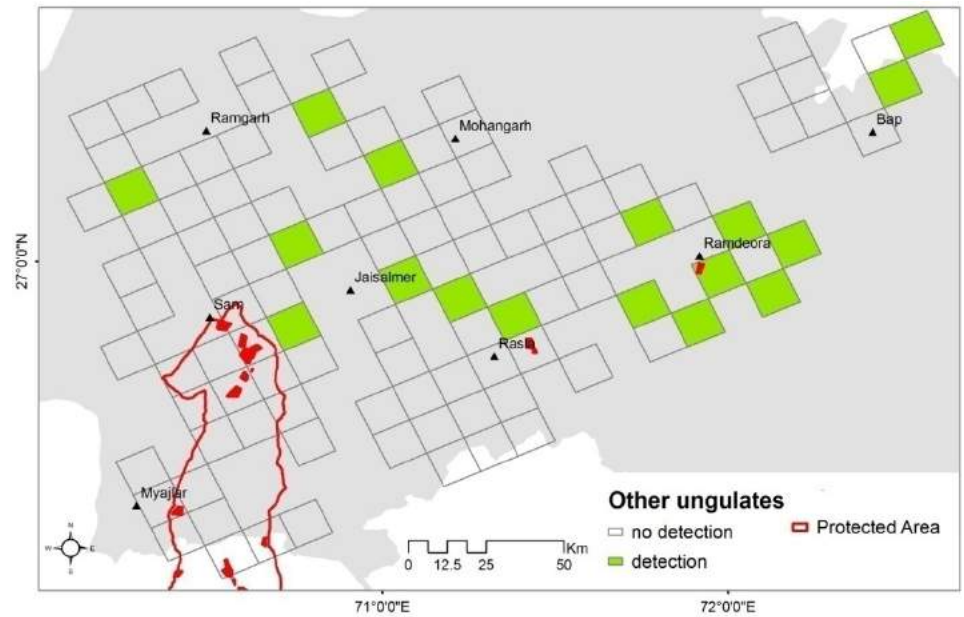


Figure 6. (a) Livestock and (b) dog detections rates in 144 km² cells of Thar landscape (2014-15)

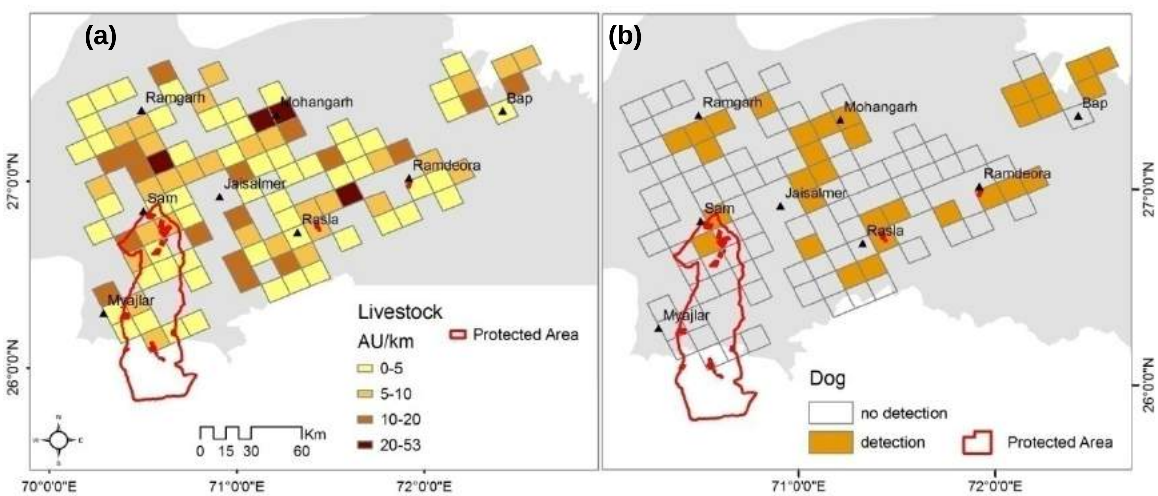
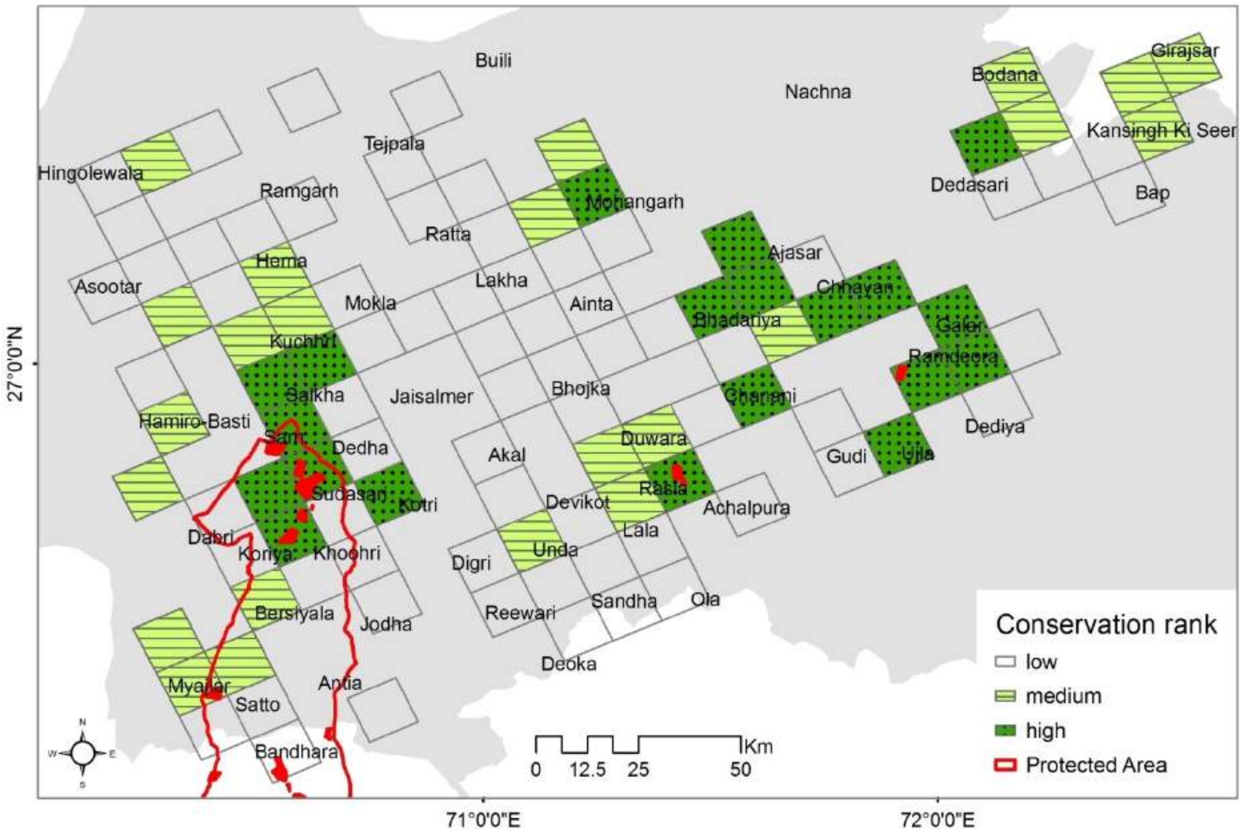


Figure 7. Conservation priority index of 144 km² cells in Thar landscape (2014-15)



4.2. Habitat status and use

Habitat characterization along transects showed that the sampled area was dominated by: a) flat followed by undulating terrain; b) soil followed by sand substrate; c) scrub/wood- land followed by grassland and agriculture land-cover; and d) relatively even mix of short grass, shrubs and tall grass (vegetation structure). The woody vegetation was dominated by *Capparis* > *Calotropis* > *Leptadenia* > *Aerva* ~ *Zizyphus* > *Acacia* ~ *Prosopis cineraria* ~ *Prosopis juliflora* species, while the herbaceous vegetation was dominated by *Lasiurus* ~ *Dactyloctenium* (table 1). Among disturbance covariates, some forms of human presence (settlements or farm-huts) and infrastructure (metal roads, power-lines, and wind-turbines) were found within 500m radius of 52.4 ± 3.1 % and 49.2 ± 3.4 % of plots, respectively.

Table 1. Descriptive statistics of habitat covariates in 144 km² cells of Thar landscape (2014-2015)

Factor	Covariate	Measurement	Mean	SE	Median
Terrain	Flat	Prevalence of a category in 100m radius plot, scored as 0 (absent)-1 (dominant) and averaged across plots within cell [index]	0.49	0.02	0.50
	Sloping		0.08	0.01	0.04
	Undulating		0.27	0.02	0.22
Substrate	Rocky/Gravel	Frequency of occurrence of the category in 100m radius plots within cell [proportion]	0.18	0.02	0.13
	Sand		0.33	0.03	0.26
	Soil		0.50	0.02	0.50
Land-cover	Barren	Frequency of occurrence of the category in 100m radius plots within cell (sum > 1 due to co-dominant categories)	0.12	0.01	0.06
	Agriculture		0.28	0.02	0.26
	Grassland		0.33	0.02	0.30
	Woodland		0.19	0.02	0.16
	Scrubland		0.19	0.02	0.13
Vegetation structure	Short grass (<30cm)	Percentage cover of vegetation type in 20m radius plots within cell	15.23	0.86	13.05
	Tall grass (>30cm)		10.16	0.79	7.59
	Shrub (<2m)		12.10	0.70	9.94
	Tree (>2m)		6.57	0.43	5.55
Vegetation composition	*Capparis*	Frequency of occurrence (%) of dominant plant in 100m radius plot within cell [dominance index]	0.43	0.03	0.44
	Calotropis		0.31	0.03	0.25
	Leptadenia		0.22	0.03	0.11
	Aerva		0.17	0.03	0.00
	Lasiurus		0.17	0.03	0.00
	Dactyloctenium		0.16	0.03	0.00
	Zizyphus		0.15	0.02	0.07
	Acacia		0.11	0.02	0.00
	Prosopis cineraria		0.11	0.02	0.00
	Prosopis juliflora		0.10	0.02	0.00
	Zygophyllum		0.08	0.02	0.00
	Salvadora		0.08	0.02	0.00
	Calligonum		0.04	0.01	0.00
Human artifacts	Human incidence	Summed occurrence of settlement (weight 2) and hut (weight 1) in 100m radius [index]	0.46	0.04	0.40
		Summed occurrence of settlement (weight 2) and hut (weight 1) in 500m radius [index]	0.96	0.07	0.83
	Infrastructure intensity	Summed occurrence of power-lines, roads & wind-turbines in 100m radius [index]	0.30	0.03	0.20
		Summed occurrence of power-lines, roads & wind-turbines in 500m radius [index]	0.74	0.06	0.63
	Water	Occurrence of water in 100m radius [proportion]	0.06	0.01	0.00

There was some inter-correlation between the covariates that were considered potentially important for explaining bustard occurrence (table 2). Principal Component Analysis (PCA) on the terrain, substrate and land-cover covariates extracted three components, cumulatively explaining 77 % of information in the data. Of these, two components were considered important for great Indian bustard: one surrogated undulating, sandy (negative value) versus flat (positive value) topography and the other surrogated grassy (negative) versus woody (positive) cover (table 3). There were distinct gradients of these potentially important covariates across the landscape (figure 8).

Table 2. Correlation between select habitat covariates in 144 km² cells of Thar landscape (2014-2015)

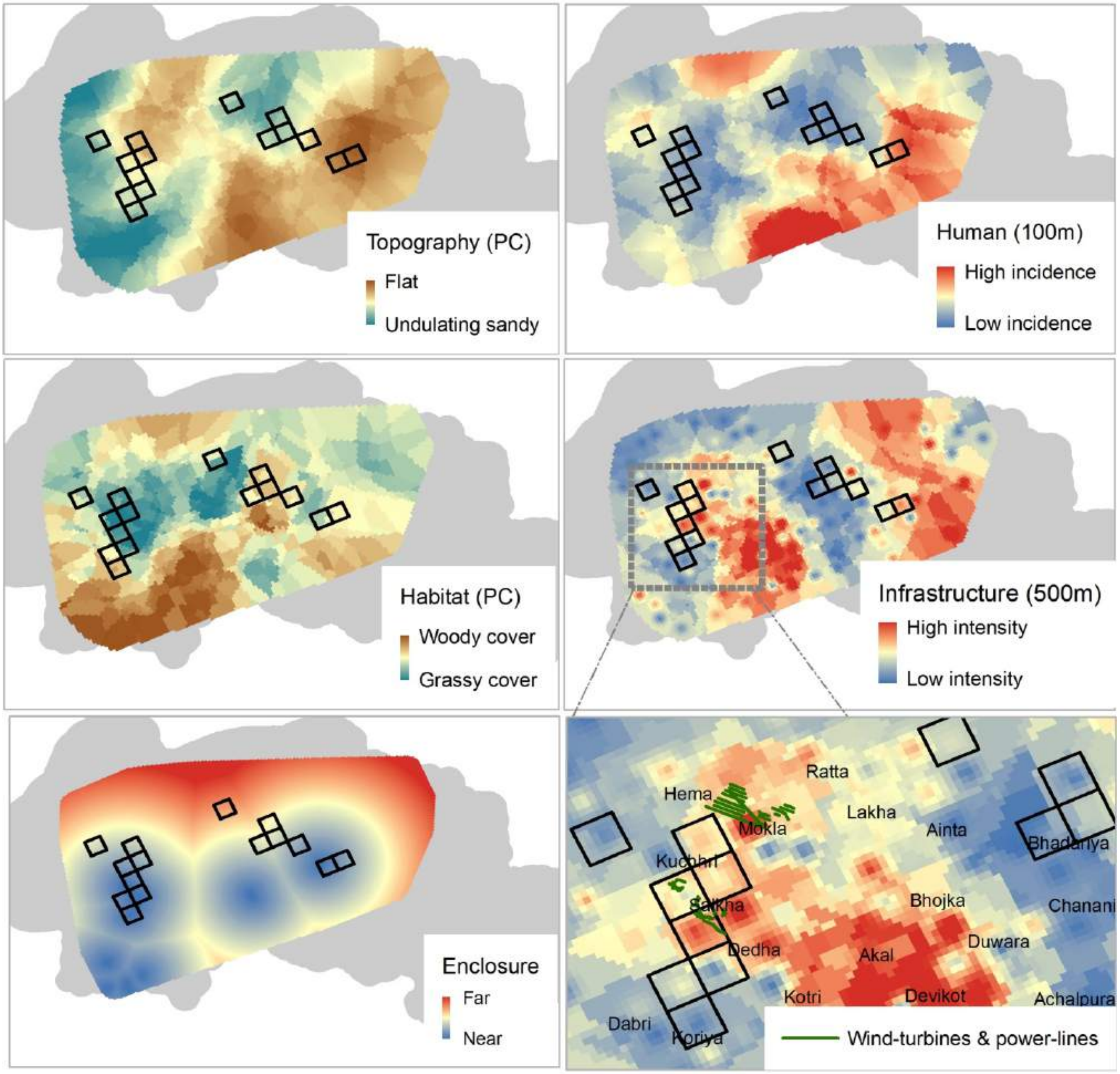
	Flat	Undl	RkGr	Sand	Agri	Grsl	Wood	HumI	InfI	GrzI	EncD
Flat		**-.88**	.04	**-.57**	**.39**	-.08	-.10	**.34**	.00	-.10	-.02
Undulating			-.02	**.55**	**-.38**	-.05	**.19**	**-.28**	-.07	.08	-.01
Rock/Gravel				**-.49**	**-.27**	-.05	.03	-.06	.17	-.06	**-.19**
Sand					**-.24**	.15	.00	**-.25**	**-.25**	-.04	.12
Agriculture						**-.31**	**-.31**	**.46**	.10	.00	**.24**
Grassland							**-.27**	**-.22**	-.11	.04	.17
Woodland								-.04	.18	.03	**-.23**
Human incidence									.14	.04	-.01
Infrastructure intensity										-.02	-.18
Grazing intensity											.11
Distance to enclosure											

Significant correlations ($p<0.05$) indicated in bold; strong correlations ($|r|>0.4$, $p<0.05$) shaded in grey

Table 3. Summary of Principal Component Analysis: covariate loadings, information explained, and ecological interpretation of extracted habitat components in Thar landscape (2014-2015)

Covariates	Principal Component 1	Principal Component 2	Principal Component 3
Flat	0.56		
Undulating	-0.55		
Rocky/ Gravel		0.67	
Sand	-0.47		
Agriculture		-0.41	
Grassland			-0.77
Woodland		0.44	0.43
Information explained (%)	38	21	18
Ecological interpretation	Undulating sand (-) vs. flat topography (+)	Agriculture (-) vs. rocky/gravely woodland (+)	Grass (-) vs. wood (+) cover

Figure 8. Important habitat gradients in Thar landscape (2014-2015), interpolated by kriging from covariates collected and analyzed at 144 km² cells



1. Open squares indicate cells where great Indian bustard was detected during surveys

2. Note the high concentration of infrastructure between western and eastern Thar landscape that forms a potential barrier to bird movements, increases the chance of bird mortality through collisions with power-lines, and endangers the long-term persistence of great Indian bustard

Among the 15 alternate models postulated to explain great Indian bustard distribution, three models obtained maximum and comparable support from data (ΔAIC < 2, table 4a). These models incorporated disturbances (human incidence, infrastructure intensity and grazing intensity) and protection (distance to enclosure) with or without topography and land-cover. Out of these, the model with least number of parameters was selected for inference. Parameter estimates of this model (*Hum+Inf+Grz+Dst-enc*) indicated that bustard occurrence was determined by protection (declined with distance from enclosure) and disturbance (detections decreased with human incidence and infrastructure intensity but secondary reports were not related to disturbances). There was a positive association between great Indian bustard and grazing intensity, likely due to similar resource requirements (productive grasslands) by both taxa (table 4b).

Table 4. (a) Alternate hypotheses explaining distribution of great Indian bustard in 144 km^2 cells of Thar landscape, and (b) influence of important covariates on species' occurrence (primary & secondary data) analyzed using multinomial logistic regression (2014-2015)

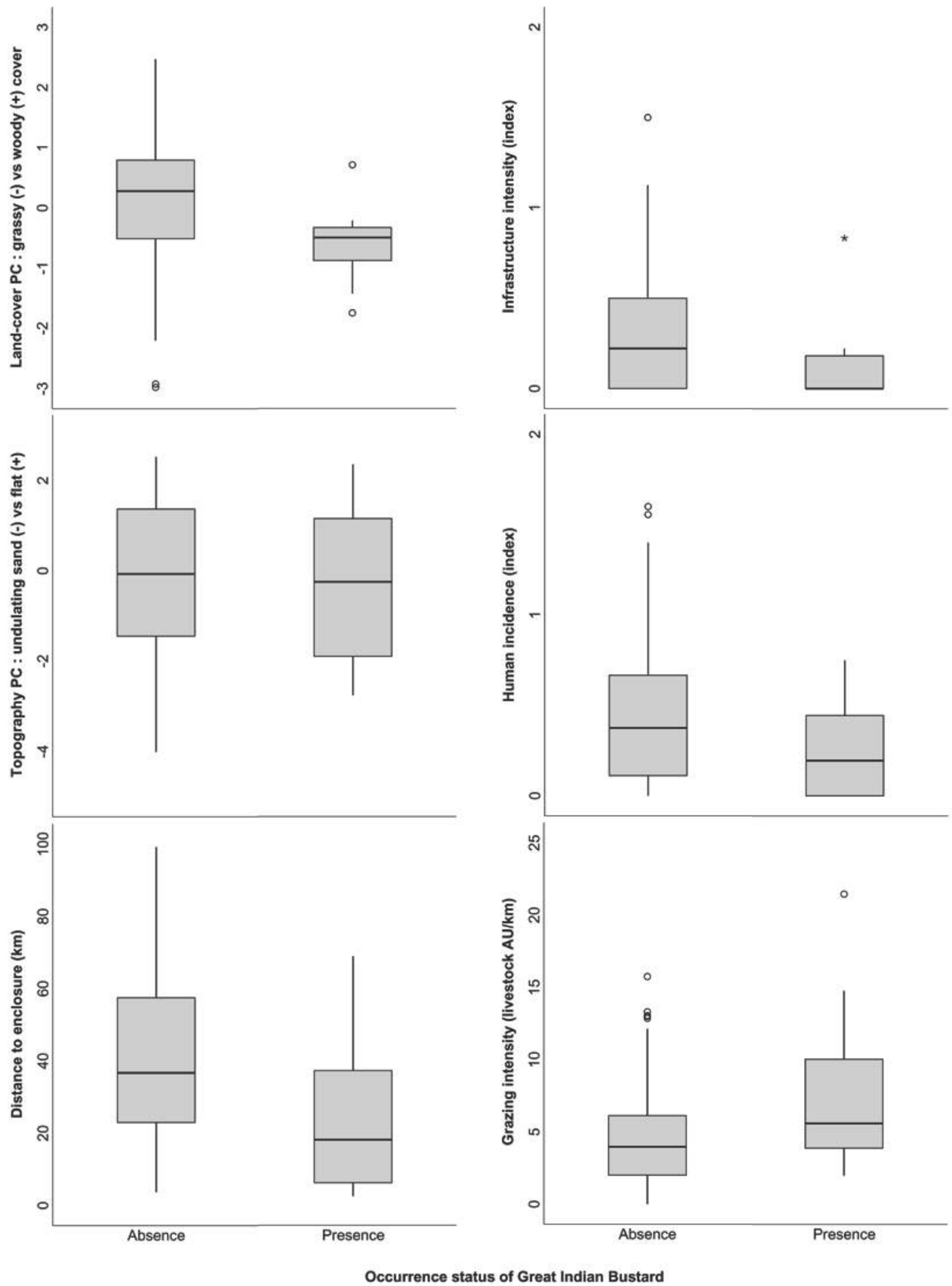
(a) Model	ΔAIC	AIC	Deviance	K	GOF-p	R^2	CC %
PC-top + Hum + Inf + Grz + Dst-enc	**0.00**	**162.51**	**138.51**	**12**	**0.95**	**0.44**	**75**
Hum + Inf + Grz + Dst-enc	**0.97**	**163.48**	**143.48**	**10**	**0.96**	**0.41**	**73**
PC-hab + PC-top + Hum + Inf + Grz +Dst-enc	**1.68**	**164.19**	**136.19**	**14**	**0.57**	**0.46**	**76**
PC-hab + Hum + Inf + Grz +Dst-enc	2.60	165.11	141.11	12	0.64	0.43	73
PC-top + Hum + Inf + Grz	11.50	174.01	154.01	10	0.86	0.33	71
Hum + Inf + Grz	11.69	174.20	158.20	8	0.87	0.30	71
PC-hab + PC-top + Hum + Inf + Grz	13.77	176.28	152.28	12	0.86	0.35	72
PC-hab + Hum + Inf + Grz	13.92	176.43	156.43	10	0.85	0.31	71
PC-hab + PC-top + Dst-enc	23.92	186.43	170.43	8	0.64	0.19	67
PC-hab + Dst-enc	24.52	187.03	175.03	6	0.51	0.14	67
PC-top + Dst-enc	25.70	188.21	176.21	6	0.49	0.13	68
Dst-encl	26.35	188.86	180.86	4	0.35	0.08	68
PC-hab + PC-top	29.68	192.19	180.19	6	0.64	0.10	68
PC-top	30.28	192.79	184.79	4	0.47	0.05	68
PC-hab	30.31	192.82	184.82	4	0.65	0.05	68

(b)	Primary data		Secondary data	
Covariate	$\hat{\beta}$	SE	$\hat{\beta}$	SE
Dst-encl	-0.062	0.022	-0.017	0.012
Hum	-3.223	1.519	0.641	0.598
Infra	-3.969	1.610	-0.444	0.801
Grz	0.218	0.064	0.181	0.057

Covariates
PC-top: undulating-sand (-) vs. flat (+) topography [Principal component]
PC-hab: grassy (-) vs. woody (+) land-cover [Principal component]
Dst-encl: Mean distance to protected enclosures (km)
Hum: Human incidence in 100m radius along transect
Infra: Infrastructure intensity in 100m radius along transect
Grz: Livestock encounter rate in Animal Units/km

Abbreviation: AIC (Akaike Information Criteria); K (parameters); GOF-p (Pearson χ2 p-value as a measure of model goodness-of-fit); R^2 (Nagelkerke's coefficient of determination); CC (Correct classification rate)

Figure 9. Box and whisker plots showing distribution of habitat covariates against occurrence status of great Indian bustard (absence vs. detection) in 144-km^2 cells of Thar landscape (2014-2015)



Occurrence of great Indian bustard and livestock grazing is highly correlated since both prefer similar habitat

5. Discussion

By adopting a standardized, spatially representative sampling and analysis design that accounts for imperfect detectability, we have generated robust population parameter estimates for the critically endangered great Indian bustard and its associated chinkara and desert fox in 20,000 km^2 potential bustard habitat of Thar landscape. These estimates are based on pooled data of March 2014 and 2015 since the time period is too short for any change in population that is also empirically evident from the similarity of encounter rates between years. Therefore, the pooled density/abundance should be considered as more robust than the earlier one (Dutta et al. 2014) because of larger sample size. Since these species are specialized to arid ecosystems, and critically depends on the Thar landscape, our estimates form the crucial baseline information to aide their conservation management.

Comments on the population enumeration technique

Thar landscape extends over a vast area with little barrier to bird/animal movements, thereby rendering total population counts impractical and unreliable. Comparing great Indian bustard numbers observed in conventional surveys to that reported by local informants, Rahmani (1986) speculated that only 10-20 % of population might be detectable. This impeded earlier efforts of assessing their population status with confidence. Similarly, our extensive surveys detected 45_{Mean} % of the minimum number of birds present in seven intensively sampled cells (2015) that can be considered as a crude approximation of the proportion of birds in a cell detectable during conventional survey. Moreover, encounter rates of birds on repeated surveys within 18 days varied between 80-173 % among seven cells (2014). These facts emphasize that conventional counts miss substantial proportion of birds that can vary between sites. Our approach of estimating effective detection widths from dummy (2014) and actual birds (2015), that were found to be statistically similar, circumvents this problem and provides a robust framework to assess density/abundance from a sample of sites. Selection of sites following random sampling design allows unbiased extrapolation of this sample statistic into population density/abundance estimate.

The precision of our estimate is relatively poor, as can be expected for a species with extremely small population and patchy distribution across large landscape. Nonetheless, pooling samples from both years provided more precise estimate than the earlier one (Dutta et al. 2014). Precision of abundance estimate can be improved by using individual recognition (possibly by tagging birds and/or through molecular tools) based capture-recapture analysis at small spatial scales. A pilot study on this line is being carried out by the authors in Sam-Sudasari area. For the purpose of monitoring, we recommend replicating our surveys on an annual basis in cells with high conservation value that would allow reliable inferences on population trend. We caution readers against comparing the current abundance estimates (but not density estimates) of associated species to that reported in Dutta et al. (2014), since we have refined the expanse of potential bustard habitat during the latter survey.

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, numbers and area of use have seemingly declined in these three decades. Rahmani (1986) reported great Indian bustard sightings in/around Bap, Sam-Sudasari, Khuri-Tejsi, Khinya, Rasla and Sankara; whereas, we detected the species in/around Sam-Sudasari, Salkha, Ramdeora-Bhadariya-Ajasar-Loharki. Typical number of birds seen by respondents in their localities has also reduced from earlier times.

Our results on species-habitat relationships indicated that disturbance was the prime factor influencing distribution in this region. Great Indian bustard did not use areas with high incidence of humans or infrastructure. Their occurrence also depended on protection and declined with distance from protected enclosures. The positive relationship between great Indian bustard and grazing intensity was an effect of correlation and not causation, since both taxa prefer similar habitat characteristics; productive grasslands (figure 9). Hence, reduction of anthropogenic pressures in great Indian bustard occupied cells by creating enclosures and/or providing alternate arrangements to local communities should be the priority conservation action. This proposition is supported by observations of great Indian bustards frequently using and breeding in Ramdeora enclosure after anthropogenic disturbances have been excluded from this site through fencing. It was also found that 75 % of priority conservation cells occurred outside of Desert National Park (figure 7). Although some of these areas benefit from protection by Bishnoi community (Bap-Ramdeora area) and inviolate space created for defense activities (Pokhran-Bhadariya-Loharki area), majority are threatened by hunting, development projects (e.g., wind power generation), and over-extraction of resources (e.g., livestock overgrazing). The cells of high conservation value should not have further infrastructural (power-lines, wind-turbines, buildings etc.) or agricultural development that can act as barriers to bird movements between them. The recent (2013) installation of wind-turbines and high tension power-lines between Sam-Sudasiri and Salkha areas is a severe threat to the persistence of great Indian bustard population as they increase the risk of electrocution and fatal collisions of the locally migrating birds. Thar landscape has already lost great Indian bustard from Mokla grasslands following the installation of wind-turbines and high tension power-lines therein in 2011. At least five instances of great Indian bustard mortality due to collision with power-lines have been reported from Kachchh and Solapur districts in the last decade. If the priority conservation cells are to be developed, it should be bustard-friendly such as underground power-lines and rainfed, organic cultivation of food crops.

However, these regulations need to be carefully enforced as the community responses to our questionnaires suggested general lack of support for bustard conservation and the possibility of antagonistic reactions. Effective conservation in Thar would require a multi-pronged approach that involves multiple stakeholders: Forest Department, Indian Army, local communities and research/conservation agencies. Apart from protecting key breeding areas as enclosures, conservation funds should be utilized on activities to maintain anthropogenic pressures below species' tolerance threshold by involving communities in participatory-planning that balances conservation and livelihood concerns. This includes activities such as regulated ecotourism that can improve the local economy, mitigation of infrastructural development, and bustard-friendly agro-pastoral practices (Dutta et al. 2013). Since great Indian bustard usage is spread across

~7,000 km^2 expanse, comprehensive insights into their ranging patterns, using biotelemetry based research, are required for fine-tuning these conservation actions.

Key recommendations

The great Indian bustard population and habitats are declining drastically across its distribution range. Thar landscape is the only remaining habitat supporting a viable (and the largest) breeding population in 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) in early 1980s. 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 Park boundary with the objectives of: a) notifying the northern Sam-Sudasari area (500 km^2) as National Park with appropriate relocation of villages; b) selectively declaring areas in priority conservation cells as Community/Conservation Reserves where human landuses can be regulated (e.g, habitats near Kanoi-Salkha-Habur, Nathoosar, Chanani, Ugras, Galar, Chhayan, Ajasar-Keroo, Bhadariya, Mohangarh and Dhaleri); and c) notifying areas equal to the denotified Park area (2600 km^2) as PA in the relatively less populated Shahgarh Bulge. This process has been initiated and will balance conservation and livelihoods by providing local people with basic amenities, gaining their support for conservation, and deterring commercial misuse of this landmass which is a hot spot for desert biodiversity.

In terms of management activities, we recommend:

a) Consolidating existing enclosures in bustard breeding areas using predator-proof chain-link fences (in Sam, Sudasari, Gajaimata, Rasla and Ramdeora).

b) Removing feral dogs, pigs and other nest predators (foxes, mongoose and monitor lizards) from breeding enclosures (~25 km^2 cumulative area) to improve nesting success and chick survival of great Indian bustard.

c) Transferring lands in priority conservation cells (e.g, habitats near Kanoi-Salkha-Habur, Nathoosar, Chanani, Ugras, Galar, Chhayan, Ajasar-Keroo, Bhadariya, Mohangarh and Dhaleri) to Forest Department for creating new protective enclosures.

d) Mitigating the ill-effects of wind-turbines and overhead power-lines in priority conservation cells, particularly the great Indian bustard ranging arc between Sudasari-Sam-Salkha-Mokla-Mohangarh-Bhadariya-Ajasar-Ramdeora (figure 8) to reduce obstruction to local bird movements. New power-lines should be made underground and existing ones should be marked with Bird Flappers/Diverters to make them visible and minimize collision risk (Silva et al. 2014).

d) Smart and intensive patrolling to generate management information and control poaching. This entails recruiting more staff, building their capacity through tools and training, and providing performance based incentives.

e) Targeted research on great Indian bustard to characterize threats spatio-temporally, understand landscape use patterns using satellite telemetry, and objective monitoring of their population status by involving research organizations.

f) Involving local people in conservation by addressing their livelihood concerns (e.g., regulated ecotourism), and encouraging them to monitor bustard occurrence and report illicit activities using rewards and incentives.

The key to conserve this vital yet neglected landscape is a combination of stringent protection measures, scientific habitat management, sensible landuse planning, and provisioning of basic amenities and livelihood options to local people (e.g., regulated ecotourism) in the priority conservation areas.

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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 / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	

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)					3 dominant plants (100m radius)	*Sandha* Pr (10m radius)	Human structure (100m radius)
							Short grass/ herb(<30cm)	Tall grass (>30cm)	Shrub (<2m)	Tree (>2m)	Crop (name)			
				F / S / U (M / V)	R / G / S / s	B / A / G / W / S							1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W / S							1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W / S							1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W / S							1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W / S							1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W / S							1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W / S							1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W / S							1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W / S							1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W / S							1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W / S							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) / **G** (grassland) / **W** (woodland) / **S** (scrubland)
Human structure – **S** (settlement) / **H** (farm hut) / **R** (metal road) / **E** (electricity lines) / **W** (wind turbine) / **P** (water-source)
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

Status and Trend of

GREAT INDIAN BUSTARD

Associated Wildlife and Threats in Thar

SURVEY REPORT
2017-18

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

Status and trend of Great Indian Bustard, Associated Wildlife and Threats in Thar

2017–18

Wildlife Institute of India,

Dehradun Rajasthan Forest

Department, Jaipur

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Executive Summary

Arid ecosystems of India support unique biodiversity and traditional agro-pastoral livelihoods. However, these habitats are highly threatened due to their historical marginalization in conservation planning and large-scale land-use changes. The Critically Endangered great Indian bustard *Ardeotis nigriceps* acts as a flagship and indicator of this ecosystem, and is the focus of current conservation efforts implemented by the Government to protect these ecosystems. Persistence of this species critically depends on Thar landscape, where ~75 % of the global population resides. Since 2014, Wildlife Institute of India and Rajasthan Forest Department are conducting joint surveys to understand the current status, distribution patterns, and local contexts of key conservation-dependent species in Thar, for developing scientific management plan. This report contains findings of the 2017 survey, and focuses on recent spatio-temporal trends in the population of key species, habitat and threats.

This study assessed the status of native and conservation-dependent species such as great Indian bustard, chinkara and fox, non-native and/or 'problem' species such as free-ranging dogs, wild pig and nilgai alongside their habitat and anthropogenic pressures across 19,728 km² of potential bustard landscape in Thar spanning Jaisalmer, Jodhpur and small parts of Bikaner and Barmer districts of Rajasthan. Systematic surveys were conducted in 144 km² cells from slow-moving vehicle along $29.2 \pm 8.0_{SD}$ km transects to record species' detections, habitat characteristics in sampling plots, and secondary information on species' occurrences. Multiple teams comprising field biologists and Forest Department staff simultaneously and rapidly sampled 121 cells along 3,529 km transects (extensive surveys) with additional 635 km transects in five great Indian bustard occupied cells (intensive surveys). Extensive surveys provided information on bustard occurrence across the landscape and intensive surveys provided information on bustard density in occupied cells. Additionally, extensive surveys provided information on abundance of associated species. Great Indian bustard and other key species' detection data were analyzed in Occupancy and Distance Sampling framework to estimate proportion of sites occupied and density/abundance.

During the last four surveys, 38 (2014), 40 (2015), 37 (2016) and 37 (2017) great Indian bustards were detected. Their detection/non-detection in 2-km transect segments (spatial surveys) across cells (2017) showed that $6.7 \pm 2.9_{SE}$ % of sites were occupied (naive occupancy 5%). Bird density was estimated at $0.48 \pm 0.10_{SE}$ /100 km² across all sites and $7.49 \pm 1.63_{SE}$ /100 km² in used sites (cells where at least one bird was detected during 2017). Abundance was estimated at $95 \pm 21_{SE}$ individuals in the 19728 km² landscape, pooling data across 2016-17. The current abundance estimate was lower than the past estimate ($140 \pm 53_{SE}$ in 2015-16); this could be partly due to inadequate intensive surveys in high-density sites within Pokhran Field Firing Range. Hence, Wildlife Institute of India's great Indian bustard conservation project team conducted follow-up distance based line transect surveys in the subset of landscape where the species is distributed (western Thar: 4068 km² area, and Pokhran Field Firing Range: 5184 km² area) in March–April 2018, to refine the past estimate. Based on these surveys, abundance was estimated at $128 \pm 19_{SE}$ individuals in 9252 km² great Indian bustard distribution area in Thar. Additional ancillary information based on power-line carcass surveys (2 mortalities in 20 km high-tension power-lines surveyed seven times) indicated that about 18 birds were expected to have died because of the 152 km high-tension lines distributed across bustard occupied sites.

Chinkara density was estimated at 205 ± 14_{SE} animals/100 km^2, yielding abundance of 40,442 ± 2811_{SE} in 19,728 km^2 landscape (2017). Desert fox density was estimated at 15.03 ± 2.39_{SE} /100km^2, and abundance of 2965 ± 471_{SE} individuals in 19,728 km^2 landscape.

Our threat surveys showed an expansion of human artifacts across survey years, wherein the proportion of sampling plots with water source, power-lines, farm-huts and wind turbines had increased annually by 0.12, 0.09. 0.07, and 0.03, respectively, over the last three years. Correspondingly, population of free-ranging dogs showed a remarkable expansion over these years, wherein the proportion of sites occupied increased from 0.15 ± 0.04_{SE} (2014) to 0.61 ± 0.09_{SE} (2017), and their encounter rate increased from 4.32 ± 1.77_{SE} to 23.11 ± 9.39_{SE} /100km in sites that were monitored across all years.

Our study provides robust abundance estimates of key native / conservation dependent as well as non-native / 'problem' species in Thar. It provides recent trends of species' distribution and abundance vis-à-vis habitat and threat intensity across space and time, to alarm managers about the changing dimensions of Thar landscape and guide site-specific management and policy. The expansion of power-lines and the expected mortality rate of bustards is unsustainable given that this population cannot sustain human-induced death of >2 birds/yr (see Dutta *et al.* 2011).

Thar supports the largest global population of great Indian bustard and offers the best hope for its persistence. This survey captured snapshots of great Indian bustard distribution that needs to be augmented with satellite telemetry based information on seasonal landscape use to mitigate threats. Based on results and field knowledge, we strongly recommend: a) expeditiously mitigating power-lines by undergrounding all lines within high priority areas (this is the only foolproof measure for conserving the great Indian bustard), and marking lines with bird diverters in medium priority areas, b) improving great Indian bustard recruitment in existing enclosures using predator-proof-fences and nest-predator removal, c) creating more enclosures or conservation/community reserves in priority conservation cells, d) smart and intensive patrolling to control poaching and generate management information, e) targeted research to understand local ecology of great Indian bustard, characterize threats, and ranging patterns, f) balancing local livelihood concerns with conservation goals through social research and incentivized bustard-friendly land-uses, and g) engaging local communities to monitor and protect wildlife through outreach and incentive programs.

1. Introduction

The great Indian bustard (*Ardeotis nigriceps*) is Critically Endangered (IUCN 2011) with less than 300 birds left, largely in India. Rajasthan holds the largest population and prime hope for saving the species (Dutta et al. 2011). As the range States across the country are implementing recovery plans for great Indian bustard (Dutta et al. 2013), information on current status and recent trends of their population, habitat characteristics, and threats are scanty. Such information are essential for conservation planning and subsequently assessing the effectiveness of management actions. Great Indian bustard inhabit open, arid &semi-arid 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 study was aimed at generating information on population and habitat status of these species for the crucial bustard landscape of western Rajasthan.

Great Indian bustard are cryptic and vagile birds occupying large landscapes without distinct boundaries that make complete enumeration of population impractical and unreliable. Their population status has to be estimated using robust sampling and analytical methods that incorporate imperfect detection, allow statistical extrapolation of estimates to non-sampled areas, and are replicable. However, the extreme rarity of bustards makes precise estimation of population abundance difficult and logistically demanding. Through repeated surveys from March 2014 to 2016, we have attempted to develop a protocol for monitoring the population status of great Indian bustard and associated wildlife in Thar and other bustard landscapes across the country, and conducted a survey following this approach in March 2017.

Our survey covered the potential great Indian bustard habitat in Jaisalmer and parts of Jodhpur, Bikaner and Barmer districts, Rajasthan (hereafter, Thar landscape). Ground data was collected by researchers, volunteers and Forest Department staff who were trained through workshops and field exercises prior to the survey. This report provides robust abundance estimates of the aforementioned species, recent population trends, along with spatially explicit information on the status and trends of key ecological parameters (habitat and anthropogenic threats) to guide managers in implementing *in-situ* management actions as prescribed by the bustard recovery plans (Dutta et al. 2013).

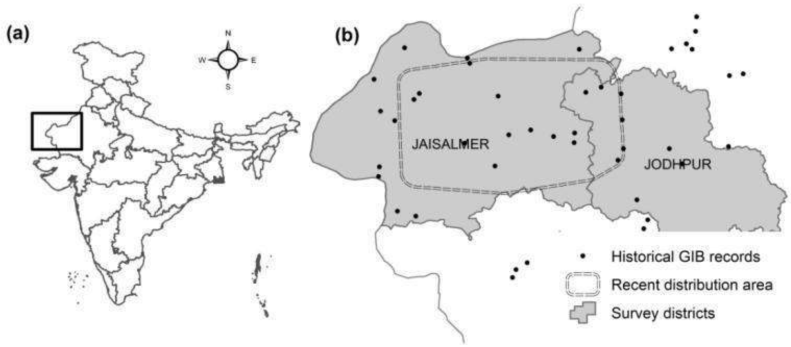
2. Thar landscape

We identified the potential great Indian bustard landscape in Thar in a stepwise manner during the past surveys. Recent historical records (post 1950s) of great Indian bustard in western Rajasthan were collated (Rahmani 1986; Rahmani and Manakadan 1990) and the broad distribution area was delineated that was further streamlined using recent information on species' absence from some historically occupied sites (sources: Rajasthan Forest Department, Ranjitsinh and Jhala 2010). Herein, extensive sand dunes, built-up and intensive agriculture areas were considered unsuitable based on prior knowledge (Dutta 2012). These areas were identified from the combination of land-cover maps procured from NRSC (ISRO), Digital Elevation Model and night-light layers in GIS domain, Google Earth imageries, and extensive ground validation surveys during 2014-2015. The remaining landscape, an area of 19,728 km^2, was considered potentially habitable for great Indian bustard and subjected to sampling (figure 1).

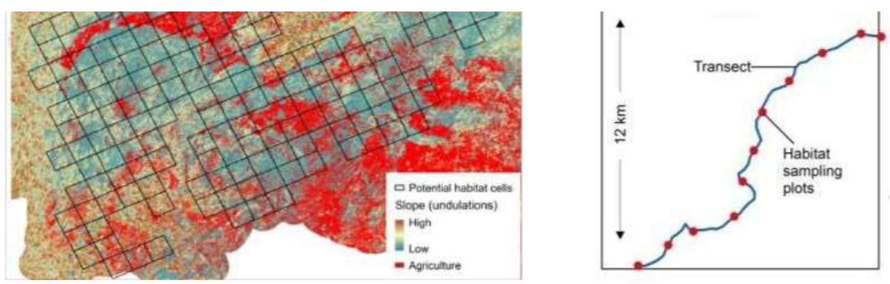
The study area falls in Desert Biogeographic Zone (Rodgers et al. 2002) with arid (Jodhpur) to superarid (Jaisalmer and Bikaner) conditions. Rainfall is scarce and erratic, at mean annual quanta of 100-500 mm that decreases from east to west (Pandeya et al. 1977). The climate is characterized by very hot summer (temperature rising up to 50°C), relatively cold winter (temperature dropping below 0°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 Thorny Scrub, characterized by open woodlot dominated by *Prosopis cineraria*, *Salvadora persica* and exotic *Acacia tortilis* trees, scrubland dominated by *Capparis decidua*, *Zizyphus mauritiana*, *Salvadora oleoidis*, *Calligonum polygonoides*, *Leptadenia pyrotechnica, Aerva pseudotomentosa*, *Haloxylon salicornicum* and *Crotolaria bhuria* shrubs, and grasslands dominated by *Lasiurus sindicus* and *Dactyloctenium sindicum*. Notable fauna, apart from the ones mentioned before, include mammals like desert cat *Felis silvestris*, birds like Macqueen's bustard *Chlamydotis macqueenii* (not available during survey period), cream-coloured courser *Cursorius cursor*, sandgrouses *Pterocles* spp., larks, and several raptors.

Thar is the most populated desert, inhabited by 85 persons/km^2 that 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 (Wildlife Sanctuary), which is not inviolate and includes 73 villages (Rahmani 1989). As a result of such human dependence and governmental policies of diverting this landscape to renewable energy production, we are noticing an expansion of human artifacts in this landscape that may potentially impact the native wildlife, and were monitored as part of this survey.

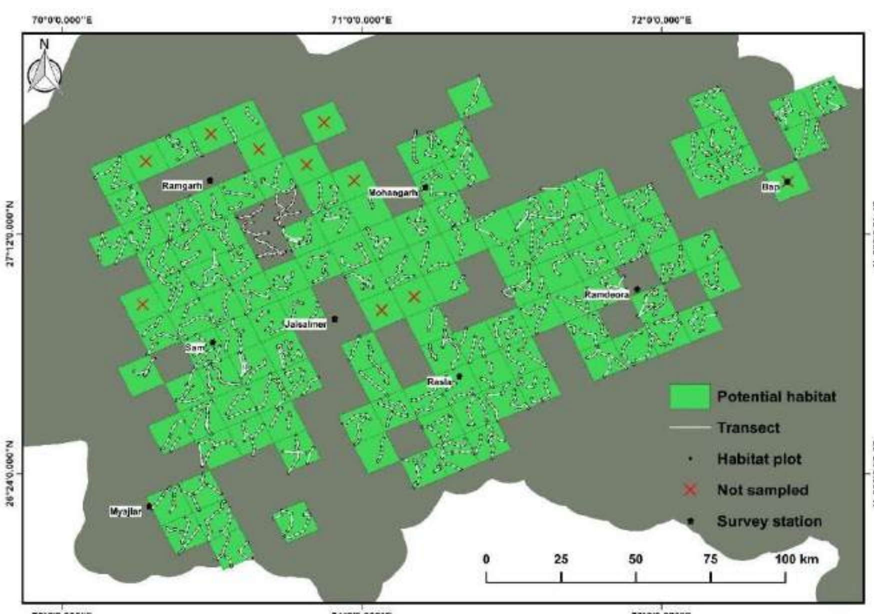
Figure 1 Sampling design for great Indian bustard population and habitat assessment in Thar landscape (2014-2016): location of study area (a); delineation of bustard landscape from existing information on species' occurrence (b), remotely sensed habitat information and reconnaissance surveys (c); distribution of transects in 144 km² cells overlaid on potential habitat (d); and habitat sampling plots at 2 km interval on transect (e)



(c)



(d)



3. Methods

3.1. Organization of survey

The potential great Indian bustard landscape in Thar was divided into seven sampling blocks (Ramgarh, Mohangarh, Bap, Ramdeora, Rasla, Myajlar, and Sam-Sudasari) which were simultaneously surveyed by 52 teams during March 18-23, 2017. Similar exercise was carried out in the past with the help of 18 teams during March 22-26, 2014, 17 teams during March 21-25, 2015, and 40 teams during March 15-19, 2016. Each sampling block was surveyed by separate teams, enabling us to cover such large expanse within brief time period in order to minimize bird/animal movements between survey areas. Each team comprised of a researcher/volunteer, one Forest Department guard adept with the locality, and one rugged-terrain vehicle. Field activities in a sampling block were supervised by a research biologist from the Wildlife Institute of India with several years of field experience on wildlife surveys. Team members were trained through workshops and rigorous field exercises on a standardized data collection protocol for two days prior to block surveys. Data collected by teams were collated after the completion of surveys and analyzed.

3.2. Sampling design

Species and habitat status were assessed using vehicle transects in a systematic sampling design. A grid of 137* cells, each 144 km^2 (12 km x 12 km) in dimension, were overlaid on the landscape of interest (19,728 km^2 area) and realized on ground by handheld GPS units and Google Earth imageries. Sampling was carried out in two phases: extensive surveys at first, where we randomly sampled 121 cells in 2017. Cells were surveyed along dirt trails of $29.2 \pm 8.0_{SD}$ km length (two or three transects) from a slow moving (10-20 km/hr) vehicle. Surveys were conducted in early morning (0600-1000) and late afternoon (1600-1900), when bird/animal activity was highest. This sampling scheme was chosen to optimize our target of ≥70 % area coverage and logistic constraints (man-power, six days, eight hours/day) (details in Dutta et al. 2014). Secondly, intensive surveys were conducted, wherein cells occupied by great Indian bustard (during the extensive survey) were intensively sampled along multiple transects of $14.6 \pm 6.6_{SD}$ km length, totaling to $127 \pm 13.5_{SD}$ km efforts in a cell, following similar protocol as above. Intensive surveys provided more robust and spatially representative estimate of great Indian bustard population status in occupied areas.

3.3. Data collection

3.3.1. Species' information

Data on great Indian bustard, key associated species (desert fox, Indian fox, chinkara, nilgai *Boselaphus tragocamelus* and pig), and biotic disturbances (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 collected. Perpendicular distance was measured from the distance and angle of sighting, using a Bushnell/Hawke Laser Range-finders and Suunto Compass, respectively, when animals were sighted along roughly linear segments of the transect, or as the closest approach distance (Hiby and Krishna 2004) when animals were sighted around curving path. 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). Dominant land-cover type barren/agriculture/grassland/shrubland/ woodland), 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 structure 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. These covariates were 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. Vegetation composition was recorded as three dominant plant taxa within 100m radius of the point. Presence of human structures (settlement/farm-hut/metal-road/power-lines/wind-turbine/water- source) was recorded within 500-m radius of the point. Status of spiny-tailed lizard, another key associate of bustard with a relatively small activity range (Dutta and Jhala 2014), was recorded as occurrence of their burrow(s) within 10 m radius of the point.

3.3.3. Community surveys

Community surveys were conducted in 99 randomly selected villages, by opportunistically interviewing 131 residents (appendix 3). Village-level information on reports of bustard (present and ten years back) and associated species' (chinkara, fox, nilgai and crane) occurrences in village areas were collected.

3.4. Data analysis

3.4.1 Population status

Occupancy and density/abundance are commonly used parameters to assess population status.

We estimated occupancy or proportion of cells occupied by great Indian bustard from extensive survey data using dynamic/multi-season occupancy modes (Mackenzie et al. 2006). This approach corrects for the probability of missing species at a site during a season/year using detection data from repeated surveys, and can estimate occupancy (probability of patch occupied), colonization (probability of an unoccupied patch being occupied in next time period) and extinction (probability of an occupied patch being unoccupied) probabilities. We used species' sightings in 2 km transect segments to generate detection/non-detection matrix (spatial surveys) for sampled cells across survey years 2014, 2015, 2016 and 2017 (primary seasons). We fitted dynamic occupancy models that assumed a) occupancy to be constant across years $psi(.)$ or varying between years, because of b) constant extinction $ext(.)$ and colonization $col(.)$ probabilities or c) temporally varying extinction $ext(t)$ and colonization $col(t)$ probabilities, while assuming detection probability to be d) constant across sites and surveys $p(.)$ or e) varying between years $p(t)$ (MacKenzie et al. 2006). We compared these models using Information Theoretic approach Burnham and Anderson (2002), and derived year-wise occupancy estimates from the least AICc (Akaike 1974) model in R (R Core Team 2017).

Species' density was estimated using Distance analysis in program DISTANCE (Thomas et al. 2010). This approach models the declining probability of detecting individual(s) along increasing distances from transect, wherefrom effective detection/strip width ($\overline{ESW}$) and effective sample area ($\overline{ESA}$) are derived. This metric is used to convert encounter rate into density estimate ($\bar{D}$) (demonstrated in the footnote, also see Buckland et al. 2001). Since extensive transects were random samples, species' abundance was estimated as the product of density and landscape area. We used this framework to assess population size of chinkara and desert fox. For other species, we provided mean ± SE estimates of encounter rates.

However, great Indian bustard sightings were too few and spatially clustered for robust modeling of detection function and for obtaining an unbiased, precise estimation of density/abundance in this framework. To circumvent this issue, we supplemented extensive surveys with intensive surveys in sites where great Indian bustard was detected (known occupancy). Thereafter, landscape-scale abundance was estimated by pooling extensive and intensive survey data to model detection function, compute density at each cell, and estimate the landscape-scale density/abundance as the average of cell-wise (replicates) densities in program DISTANCE. Since, we could not intensively sample the Pokhran Field Firing Range due to access issues in 2017 survey, Wildlife Institute of India's Great Indian Bustard Conservation Project team conducted follow-up distance based line transect surveys in the subset of landscape where the species is distributed (western Thar: 4068 km^2 area, and Pokhran Field Firing Range: 5184 km^2 area) in March–April 2018, to refine the past estimate in a similar analytical framework.

Our current estimation of great Indian bustard numbers is a refinement over our earlier approach (2014-15 assessment, see Dutta et al. 2015), where information on density came only from extensive surveys. We expect our current estimation to be less biased since information on density from intensive and spatially exhaustive sampling will be more representative.

3.4.2. Habitat status and use

Habitat characteristics of a cell were summarized from covariate data collected at $16.5_{Mean} \pm 4_{SD}$ sampling plots along extensive transects of 2017. a) For categorical covariates (land-cover and substrate types), frequency of occurrence of each category was estimated. b) For interval covariates (vegetation structure), mid-values of class-intervals were averaged across plots. c) Vegetation composition was quantified as the mean dominance score of plant taxa across plots (dominant: 3 – not dominant: 1). c) Disturbance covariates were quantified as frequency occurrence of settlement, farm hut, metal road, power lines, wind turbines, solar plant and water body. Thereafter, these values were averaged across plots to generate disturbance indices for each cell. Mean $\pm$ SE estimates of covariates were computed across sampled cells to describe landscape characteristics.

3.4.3. Spatial and temporal trends of species, habitat and threats

We generated spatially explicit information on status and trend of species, habitat, and threats to understand how the landscape is changing and to aid managers in targeting conservation actions. We estimated species' encounter rates across years using data from cells that were sampled across all years, for meaningful comparison. We mapped current encounter rates of focal species along with their recent trends, by estimating the linear regression slope of encounter rates across years in a cell, to depict temporal change rate at the site-level. We generated surface maps of habitat covariates from their mean values in sampled cells. All mapping was carried out in program ArcMap (ESRI 1999-2008). Finally, we assessed the temporal trend in habitat and threat variables, by estimating the annual frequency occurrence of various threats (e.g., farm hut and power lines), proportional cover of land-cover types (e.g., agriculture and grassland) and percentage ground cover of vegetation structure (e.g., short grass and tall grass), and computing their temporal change rates, as above .

3.4.4. Community responses

We estimated the proportion of respondents who reported occurrences of the focal species in their village areas, and generated occurrence maps based on secondary reports. We also mapped the areas where great Indian bustard was reported to be present 10 years back but was currently absent (i.e., locally extinct) at the village-level. We compared the mean and 95% confidence interval of intensity and trend of power- lines between great Indian bustard occupied, unoccupied, and locally extinct sites to test the effect of power- lines on bird distribution and extinction risk.

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

4. Results

4.1. Population status

Our extensive surveys covered 121 cells (17,424 km² area) along 3,529 km transect in 2017, with additional 635 km transects in six great Indian bustard occupied cells (figure 1). Data generated from these surveys provided estimates of species' occupancy, density and abundance. In the past, we sampled 108 cells along 1,697 km transect in 2014, 77 cells along 1,246 km transect in 2015, and 120 cells along 2,273 km transect in 2016.

4.1.1. Great Indian Bustard

Surveys conducted during 2014, 2015, 2016 and 2017 recorded minimum 38, 40, 37 and 37 unique great Indian bustards respectively, comprising observations along transects and those *en route* sampling cells. Extensive surveys during 2017 detected great Indian bustard in six cells or 5 % of sites (naïve occupancy). Probability of detecting great Indian bustard in a 2 km trail segment (if present in the cell) was estimated at 0.09 ± 0.03_{SE}; showing that the probability of detecting the species if present in a site was ~0.8 on average. Correcting for such imperfect detection, proportion of sites occupied by great Indian bustard was estimated at 6.7 ± 2.9_{SE} % of sites in 2017. Pooling extensive and intensive surveys of 2016-17, we detected 65 flocks with mean flock size of 1.63 ± 0.11_{SE} individuals. Distance data of these observations was best explained by uniform detection function with cosine series expansion (least AICc value; goodness of fit: $\chi 2=0.65$, df=5, p=0.99). This model estimated effective strip width at 401 ± 26_{SE} m (figure 2), based on which, great Indian bustard density was estimated at 0.48 ± 0.10_{SE} birds/100km² for all cells and 7.49 ± 1.63_{SE} birds/100km² in occupied cells (fig 3). Landscape-scale abundance was estimated at 95_{Mean} ± 21_{SE} individuals (table 1). Our traditional approach, where great Indian bustard encounter rate was computed only from extensive surveys of 2017, yielded abundance estimate of 135 birds.

Follow-up survey (2018) results

Follow-up surveys conducted in December – January 2017 in western Thar: 4068 km² area, and March – April 2018 in Pokhran Field Firing Range: 5184 km² area, to refine the past estimate involved 3052 km search efforts, yielding 35 detections. Distance data was best explained by uniform detection function (X^2 = 1.53, df=4, p=0.82), and effective strip width was estimated to be 447 ± 48_{SE} m. Bird density of the entire area (9252 km²) was estimated to be 1.4 ± 0.20 (1.0 – $1.9_{\ 95\%\ CI}$) birds/100 km², yielding abundance estimate of 128 ± 19_{SE} individuals.

4.1.2. Chinkara

Extensive survey in 2017 yielded detection of 1036 chinkara herds at encounter rate of 29 + 2.3_{SE} herds/100km and mean herd size of 2.49 ± 0.07_{SE} individuals. Distance data of these observations was best explained by hazard-rate detection function with simple polynomial series expansion (truncated at 420m) (least AICc and GOF-p=0.99) that estimated herd effective strip width at 169 ± 7_{SE} m (figure x). Chinkara density was estimated at 205 + 14_{SE} animals/100km², yielding abundance estimates of 40,442 ± 2810_{SE} animals in the landscape (table 1).

4.1.3. Desert fox

Extensive survey in 2017 yielded detection of 77 desert fox at encounter rate of 2.15 ± 0.26_{SE} individuals/100km, and group size of 1.09 ± 0.04_{SE} individuals. Distance data of these observations (truncated at 228 m) was best explained by half-normal detection function with cosine series expansion (least AICc and GOF-p: 0.91) that estimated effective strip width at 82 ± 9_{SE} m (figure x). Desert fox density was estimated at 15.03 ± 2.39_{SE} individuals/100km², yielding abundance of 2965 ± 471_{SE} animals in the landscape (table 1).

* Detectability experiments using dummy birds (June 2014 and March 2016) yielded a similar effective strip width of 402 ± 34_{SE} m.

4.1.4. Other fauna

Extensive survey in 2017 also yielded sightings of Indian fox (encounter rate 0.22 ± 0.08_{SE} animals/100km), nilgai (3.93 ± 1.11_{SE} animals/100km), wild pig (1.98 ± 0.75_{SE} animals/100km), and domestic livestock (484.49 ± 62.84_{SE} cattle/100km and 2065.83 ± 138.8_{SE} sheep-goat/100km) (table 3). Spiny-tailed lizard burrows were detected in 8.2 ± 1.5 % plots.

Table 1 Population status of Great Indian Bustard and associated native fauna of Thar landscape during 2017

Species	*Trn*	*Eff*	*Obs*	$\hat{E}SW$	$\hat{D}$ (# km^{-2})	$\hat{\psi}$	$\hat{\psi}.A$	$\hat{N}$
Great Indian Bustard (2016-17) *A. nigriceps*	575 158*	7493 1846*	65	401 (24)	0.005 (0.001) 0.075 (0.016)*	0.067 (0.029)	1322	95 (21) 97 (48)*
Chinkara (2017) *G. bennettii*	293	3583	1036	169 (7)	2.05 (0.14)	0.89 (0.04)	15625	40442 (2810)
Desert fox (2017) *V. vulpes pussilla?*	293	3583	77	82 (9)	0.150 (0.024)	0.68 (0.13)	13415	2965 (471)

Trn = Number of transects/trails sampled

Eff = Total length of transects/trails, or efforts in kilometers

Obs = Number of individuals detected on transects/trails

$\hat{E}$= Mean (SE) Effective Strip Width in meters, indicating the distance from the transect within which you effectively detect birds (see ref)

$\hat{D}$ = Mean (SE) density of birds in numbers km^{-2}, representative of the entire Thar landscape.

$\hat{N}$ = Mean (SE) Number of individuals in the landscape (19,728 km^2) or abundance

$\hat{\psi}$ = Mean (SE) occupancy probability, or proportion of cells (144 km^2) occupied by the species, correcting for imperfect detection

$\hat{p}$ = Mean (SE) species detection probability, or the probability of detecting the species in a survey if it is present in the cell

S = Naïve occupancy, or proportion of cells (144 km^2) where the species was detected

$\hat{\psi}.A$ = Occupied area, estimated as the product of landscape area (19,728 km^2) and occupancy probability

Values marked as (*) are representative of six cells that were occupied by great Indian bustard

Figure 2 Detection function (probability of detecting an animal along perpendicular distance from transect) of Great Indian Bustard (top), Chinkara (center) and Fox (bottom) in Thar landscape during 2017

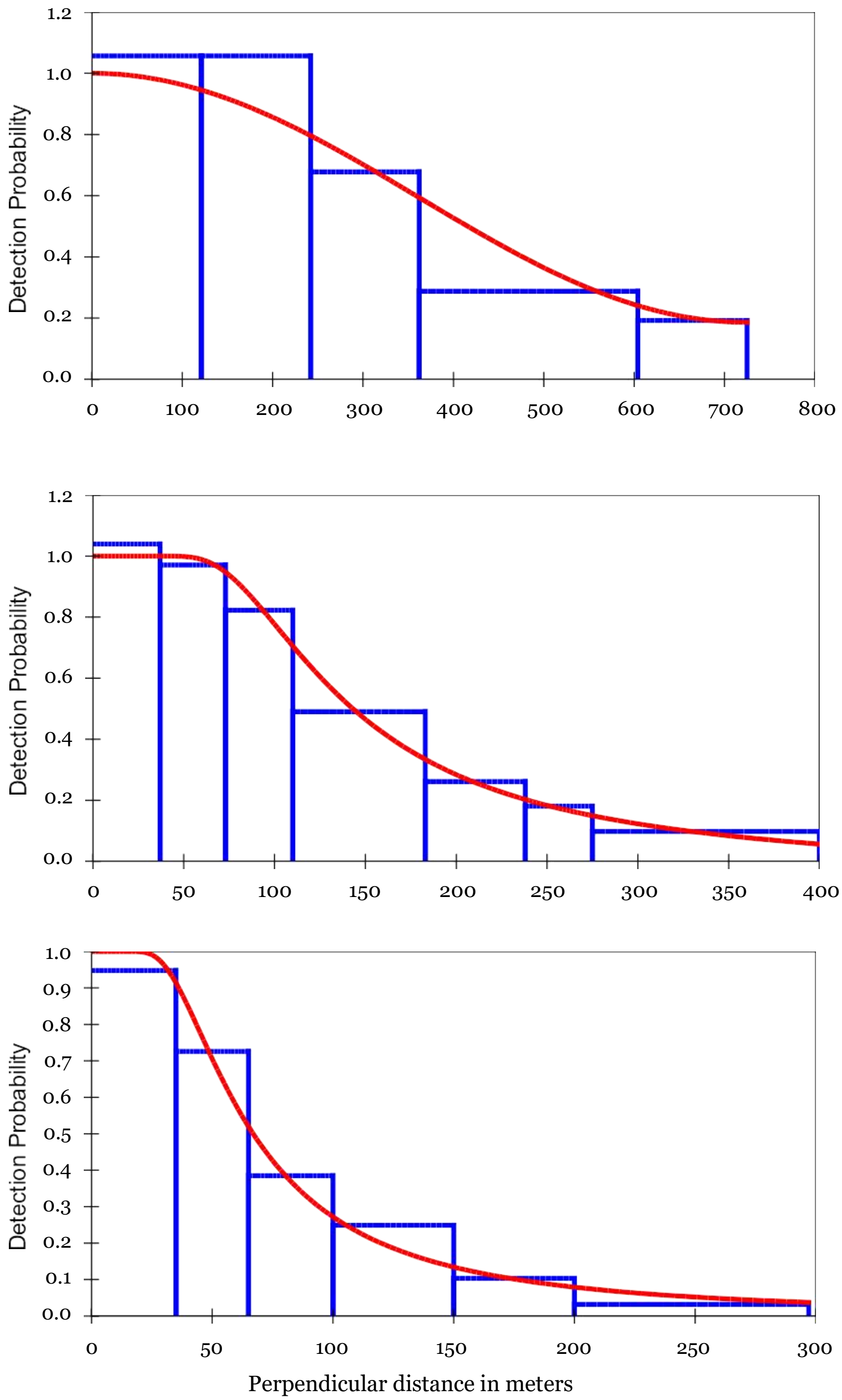


Figure 3 Status (2017) and trend (2014–2017) of Great Indian Bustard in Thar landscape

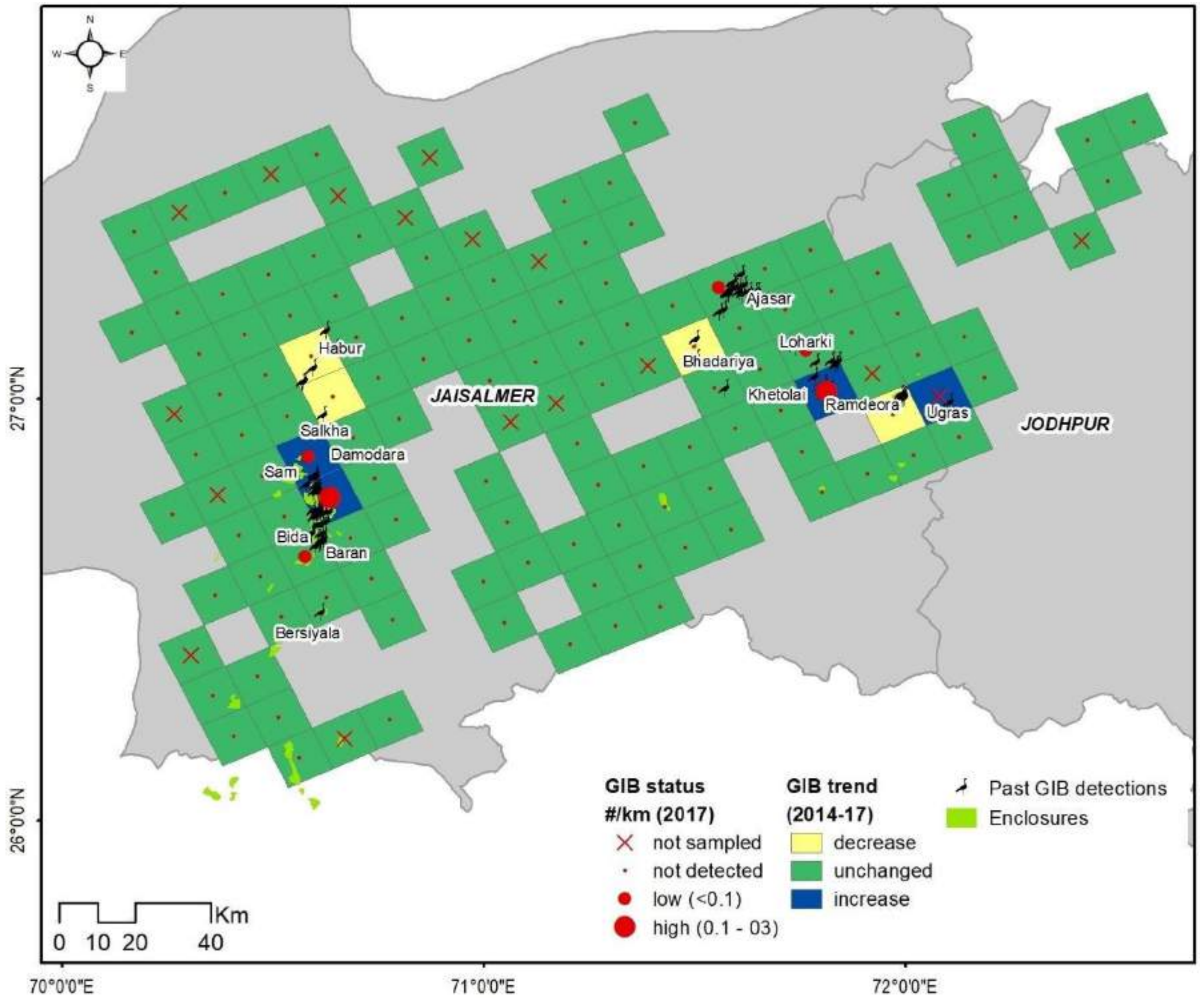


Figure 4 Status (2017) and trend (2014–2017) of Chinkara (top) and Desert fox (bottom) in Thar landscape

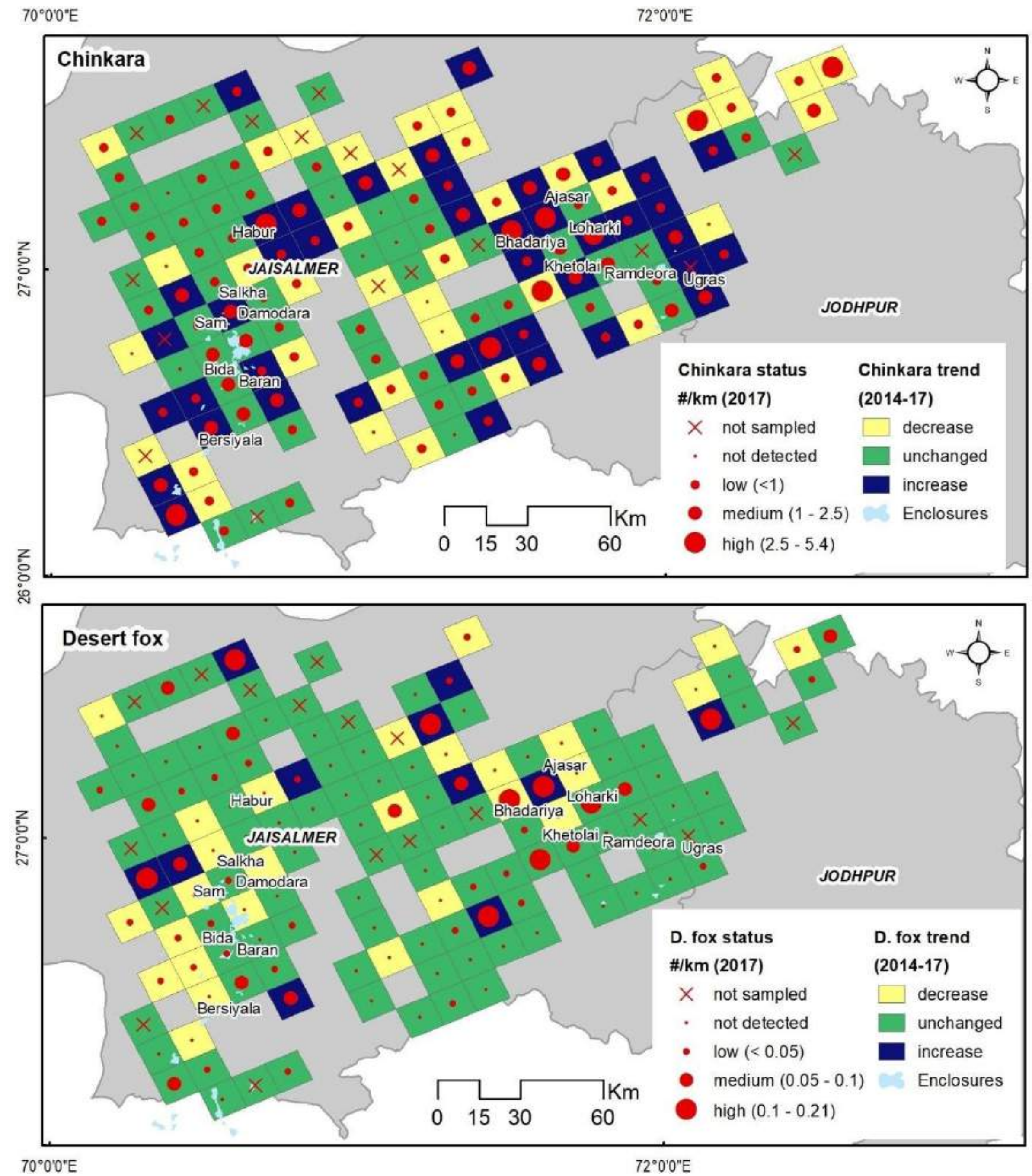
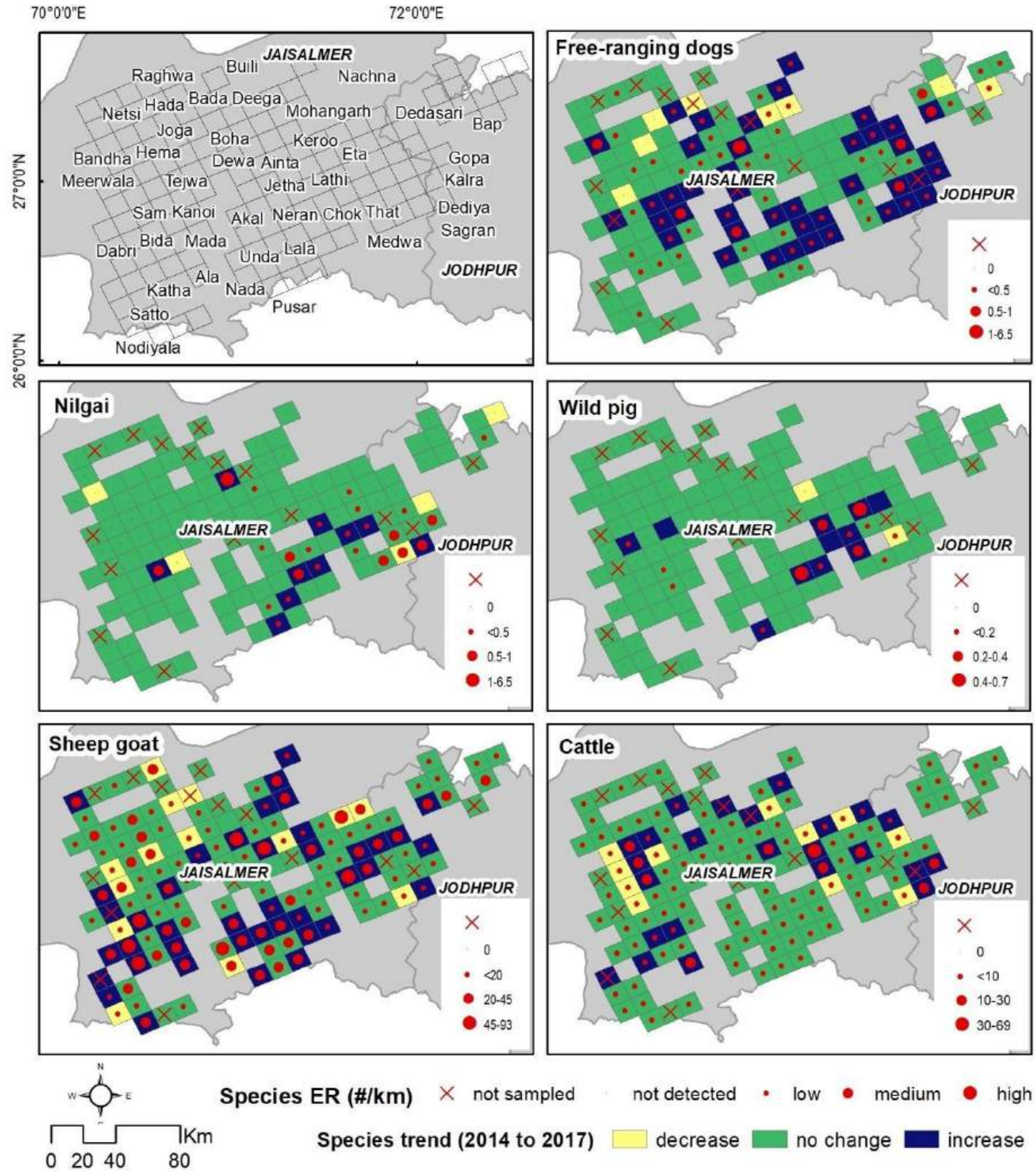


Figure 5 Status (2017) and trend (2014–2017) of non-native / domestic species in Thar landscape



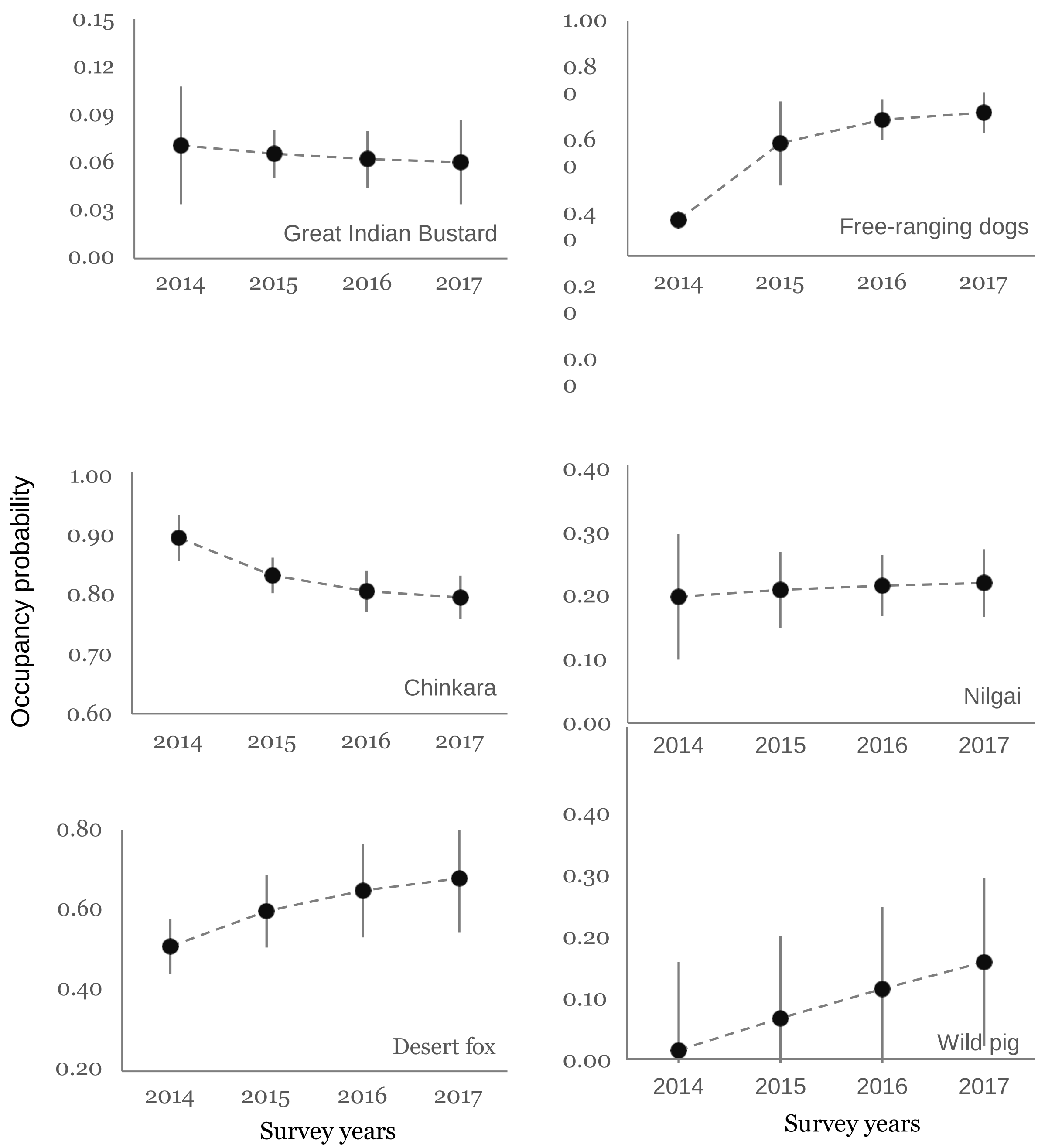
4.1.5. Species' population trends

For meaningful comparison of population trends for our focal species, we computed mean ± 1 SE animal encounter rates/100 km across cells, which were surveyed in all years (table 2). Additionally, annual occupancy estimates were derived from our dynamic occupancy models to infer trends (figure z). These results showed a rapid increase of free-ranging dogs, an increasing trend of sheep and goat, and a non-significant but declining trend of great Indian bustard that needs to be ascertained in subsequent surveys.

Table 2 Species' population trend across years (2014–2017) in Thar landscape, estimated as mean (SE) number of animals 100km^{-1}. For each species, encounter rates have been computed for all cells sampled in a year (first row) and the subset of cells sampled in all years (same cells)

Species	Sample	2014	2015	2016	2017
Great Indian Bustard	All cells	0.82 (0.32)		0.59 (0.2)	
	Same cells	1 (0.41)		0.83 (0.3)	
Chinkara	All cells	83.44 (11.98)	85.58 (14.94)	60.71 (7.44)	80.75 (8.8)
	Same cells	78.72 (15.31)	85.48 (17.6)	59.93 (10.86)	79.37 (12.78)
Desert fox	All cells	3.56 (0.61)	2.64 (0.81)	1.87 (0.38)	2.76 (0.4)
	Same cells	3.29 (0.79)	3.06 (0.98)	2.27 (0.54)	2.64 (0.52)
Indian fox	All cells	0.21 (0.12)	0.1 (0.1)	0.29 (0.15)	0.22 (0.08)
	Same cells	0.26 (0.19)	0.12 (0.12)	0.28 (0.22)	0.18 (0.09)
Dog	All cells	3.47 (1.15)	5 (1.22)	5.08 (0.92)	18.6 (5.44)
	Same cells	4.32 (1.77)	4.59 (1.28)	5.46 (1.24)	23.11 (9.39)
Nilgai	All cells	3.07 (1.42)	4.88 (1.8)	9.28 (3.15)	3.93 (1.11)
	Same cells	4.41 (2.38)	5.06 (2.08)	5.63 (2.03)	5.42 (1.8)
Wild pig	All cells	0.85 (0.85)	1.28 (0.91)	2.33 (0.93)	1.98 (0.75)
	Same cells	1.45 (1.45)	0.89 (0.89)	2.92 (1.35)	2.26 (1.22)
Cattle	All cells	217.5 (32.18)	687.9 (194.62)	465.09 (67.15)	484.49 (62.84)
	Same cells	237.79 (43.93)	558.58 (166.01)	450.43 (83.28)	469.53 (101.8)
Sheep goat	All cells	1252.6 (124.76)	1539.42 (209.83)	2187.03 (228.66)	2065.83 (138.8)
	Same cells	1389.71 (165.7)	1622.77 (248.21)	2146.63 (291.9)	1868.28 (137.6)

Figure 6 Species' distribution trend across years (2014–17) in Thar landscape, estimated as mean ± 1 SE proportion of sites occupied using dynamic occupancy models, for native / 'important' (left) and non-native / 'problem' species (right)



4.1.6. Habitat status and trends

Habitat characterization along transects during 2017 survey showed that the landscape was dominated by: a) flat followed by undulating terrain; b) soil followed by sand substrate; c) grassland/savanna followed by agriculture and shrubland land-cover; and d) short grass and crops interspersed with tall grass and shrub as the vegetation cover. Woody vegetation was dominated by *Capparis* > *Calotropis* > *Leptadenia* > *Aerva* > *Zizyphus* > *Calligonum* > *Crotolaria* in the shrub layer, and *Acacia* > *Prosopis cineraria* ~ *Salvadora* in the tree layer (table 3). Whilst the herbaceous vegetation was dominated by *Dactyloctenium* > *Lasiurus* (grasses) and *Fagonia* > *Haloxylon* (herbs). Among human artifacts (threats), power-lines were most common followed by water sources and farm huts.

Table 3 Descriptive statistics of habitat covariates in 144 km^2 cells of Thar landscape (2017)

Feature	Unit	Habitat variable	Mean (SE)
Disturbances	Occurrence probability (500-m radius plot)	Power-lines	0.42 (0.03)
		Water body	0.39 (0.02)
		Hut	0.36 (0.02)
		Settlement	0.25 (0.02)
		Metal road	0.14 (0.01)
		Wind turbines	0.13 (0.02)
		Solar plant	0.02 (0.01)
Landcover	Proportional cover	Grassland	0.36 (0.02)
		Agriculture	0.26 (0.02)
		Shrubland	0.19 (0.02)
		Barren	0.13 (0.02)
		Woodland	0.06 (0.01)
Substrate	Proportional cover	Soil	0.78 (0.03)
		Sand	0.11 (0.02)
		Gravel	0.07 (0.02)
		Rocky	0.04 (0.01)
Terrain	Proportional cover	Flat	0.53 (0.02)
		Undulating	0.14 (0.02)
		Sloping	0.1 (0.01)
Vegetation composition (dominance score 1-3)	Grass	*Dactyloctenium*	0.91 (0.07)
		Lasiurus	0.45 (0.05)
	Herb	*Fagonia*	0.3 (0.03)
		Haloxylon	0.17 (0.03)
		Senia	0.16 (0.03)
	Shrub	*Capparis*	0.71 (0.05)
		Calotropis	0.59 (0.06)
		Leptadenia	0.44 (0.04)
		Aerva	0.39 (0.05)
		Zizyphus	0.26 (0.04)
		Calligonum	0.13 (0.03)
		Crotolaria	0.1 (0.02)
	Tree	*Acacia*	0.21 (0.03)
		Prosopis cineraria	0.09 (0.01)
Vegetation stratification	Ground cover (%)	Crop cover	26.02 (2.22)
		Short grass	20.91 (1.31)
		Tall grass	12.28 (0.9)
		Shrub	10.12 (0.7)
		Tree	5.61 (0.44)

We also observed sharp increase in the proportion of sampling plots with human artifacts, especially water sources, power-lines, farm-huts and wind-turbines across the survey years. However, land-cover composition and vegetation stratification did not show any discernible trend over the years. The rapid expansion of the above-mentioned human artifacts is concerning as they have far-reaching ecological consequences. Expansion of water sources and human presence may be the reason behind the expansion of 'undesirable' species such as free-ranging dogs in this landscape. Whilst, power-lines can have strong negative impacts on bustard by reducing their numbers through collision related mortality. Our ancillary surveys of power-lines for bird carcasses (2 mortalities in 20 km high-tension power-lines surveyed seven times) indicate that about 18 birds have likely died because of the 152 km unmitigated high-tension lines that are present in bustard occupied sites. Analyzing great Indian bustard occupancy and local extinction, based on secondary reports, against the current status and recent trend of putative habitat variables indicated higher trend of power-line intensity in extinct cells compared to occupied cells, and significantly positive trend of power-line incidence in occupied cells (table) that was a significant conservation concern, given the high mortality rate due to power-lines.

4.1.7. Secondary reports

Information provided by agro-pastoralists about the past and present occurrences of great Indian bustard and current occurrence of associated species were used to estimate the proportion of village areas where the occurrence of a particular species was confirmed by at least one respondent. Results indicated that great Indian bustard distribution was more widespread 10 years back ($25 \pm 5_{SE}$ % village-areas) than present ($16 \pm 4_{SE}$ %). The species was not reported from 64% of village areas, and in last ten years, 19% of village areas lost the species, whereas, 11% of village areas were newly occupied / colonized. Among the most commonly reported species were, chinkara (92%) > fox (78.1%) > spiny-tailed lizard (75%) > nilgai (66%) > crane (41%). Jackal, which is rare (if at all present) in the area was reported very less (6.8% village-areas), indicating the authenticity of the reports.

Figure 7 Spatial gradients of key putative factors influencing Great Indian Bustard distribution: (clockwise) terrain flatness, grassland cover, settlements and power-lines

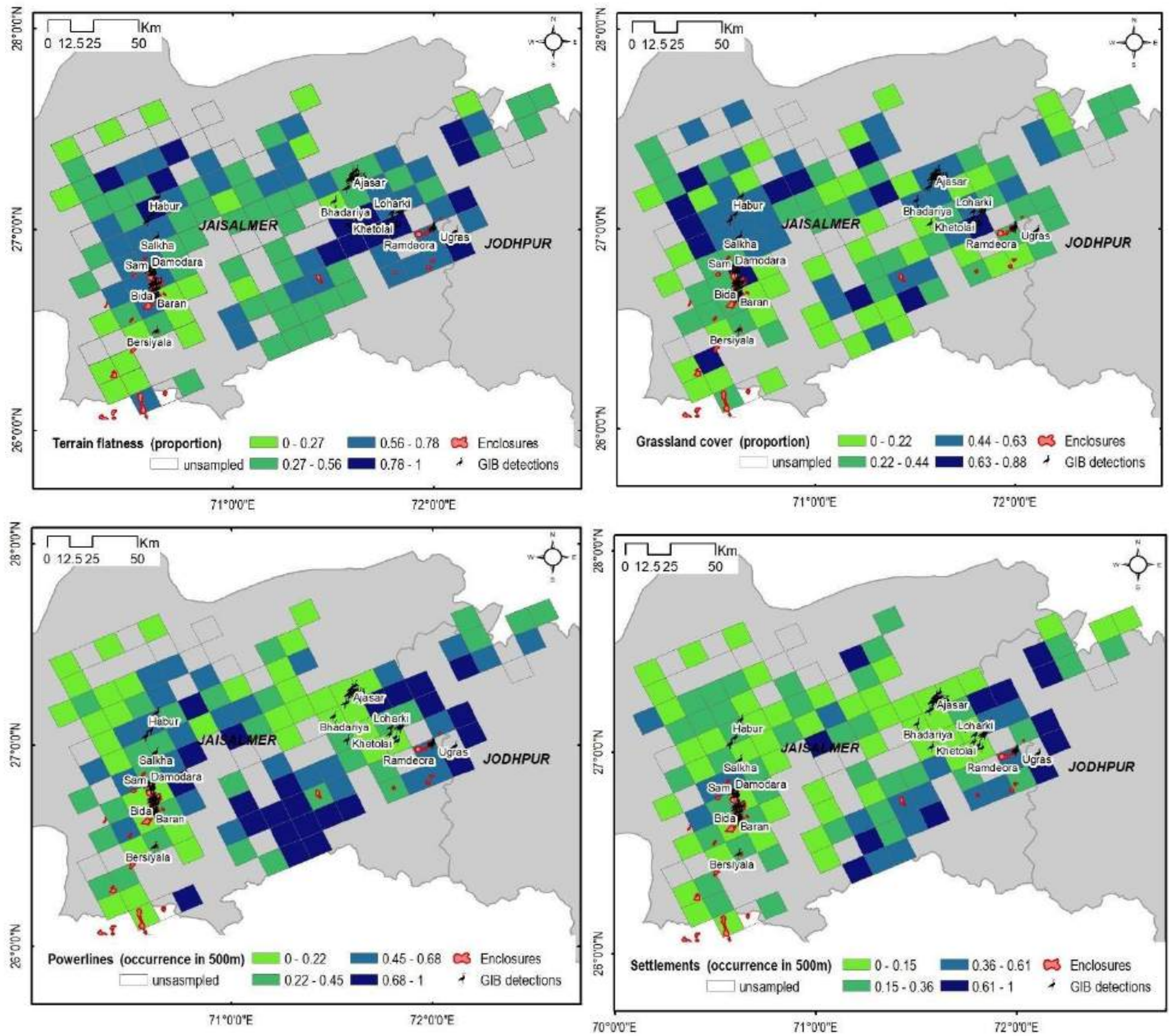


Figure 8 Occurrence probability of human artifacts in sampling plots across Thar landscape from 2015 to 2017. Error bars are 1 SE across 144-km² cells, and values in parentheses are regression slopes against years that are indicative of temporal trends. Also shown are land-cover and vegetation structure variables that, expectedly, do not show strong temporal trends

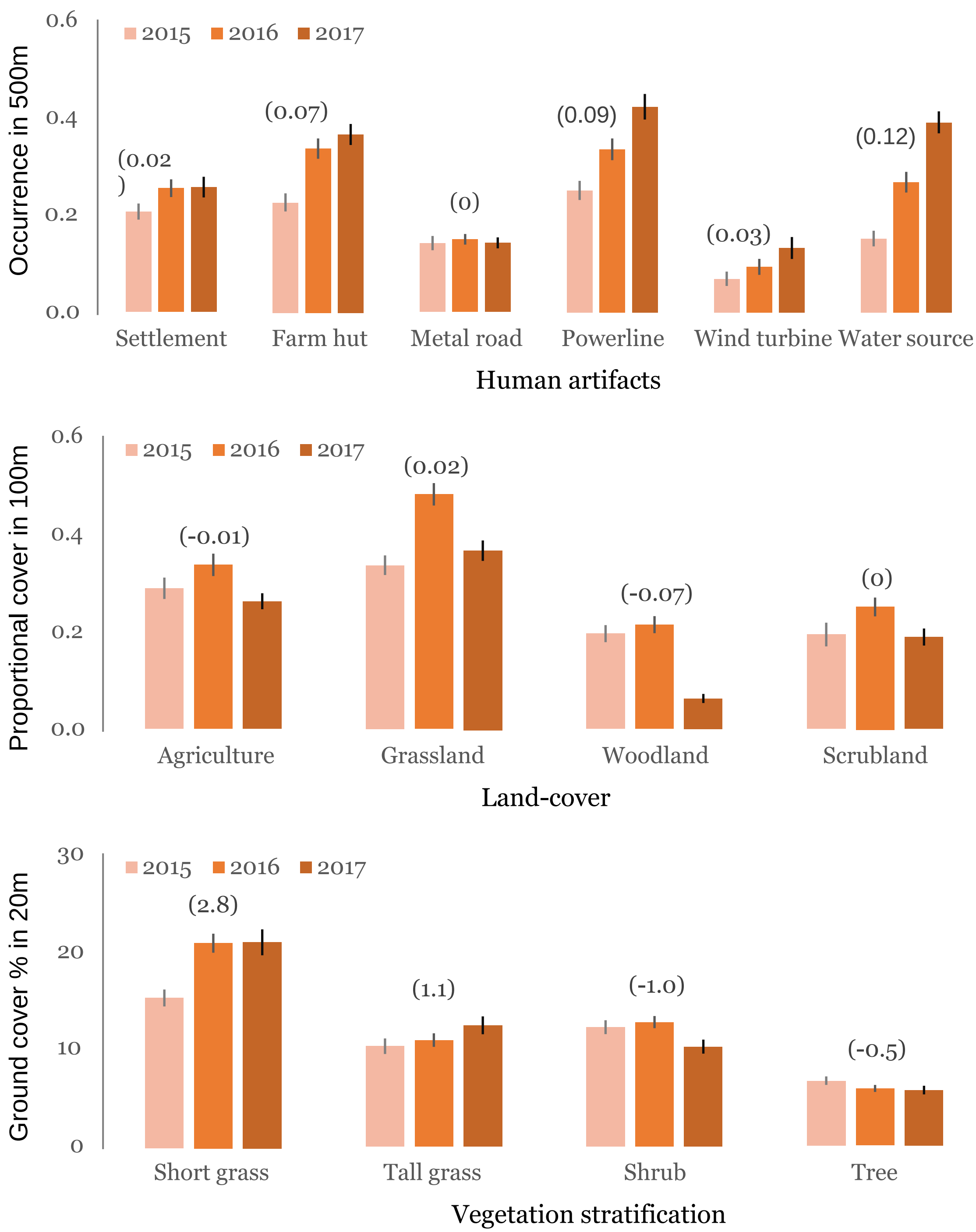


Figure 9 Great Indian Bustard distribution and local extinction in the past decade (based on secondary reports) and from 2014-15 to 2016-17 (based on occupancy surveys) overlaid on the occurrence (2016) and recent trend (2015-17) of power-line expansion across Thar landscape

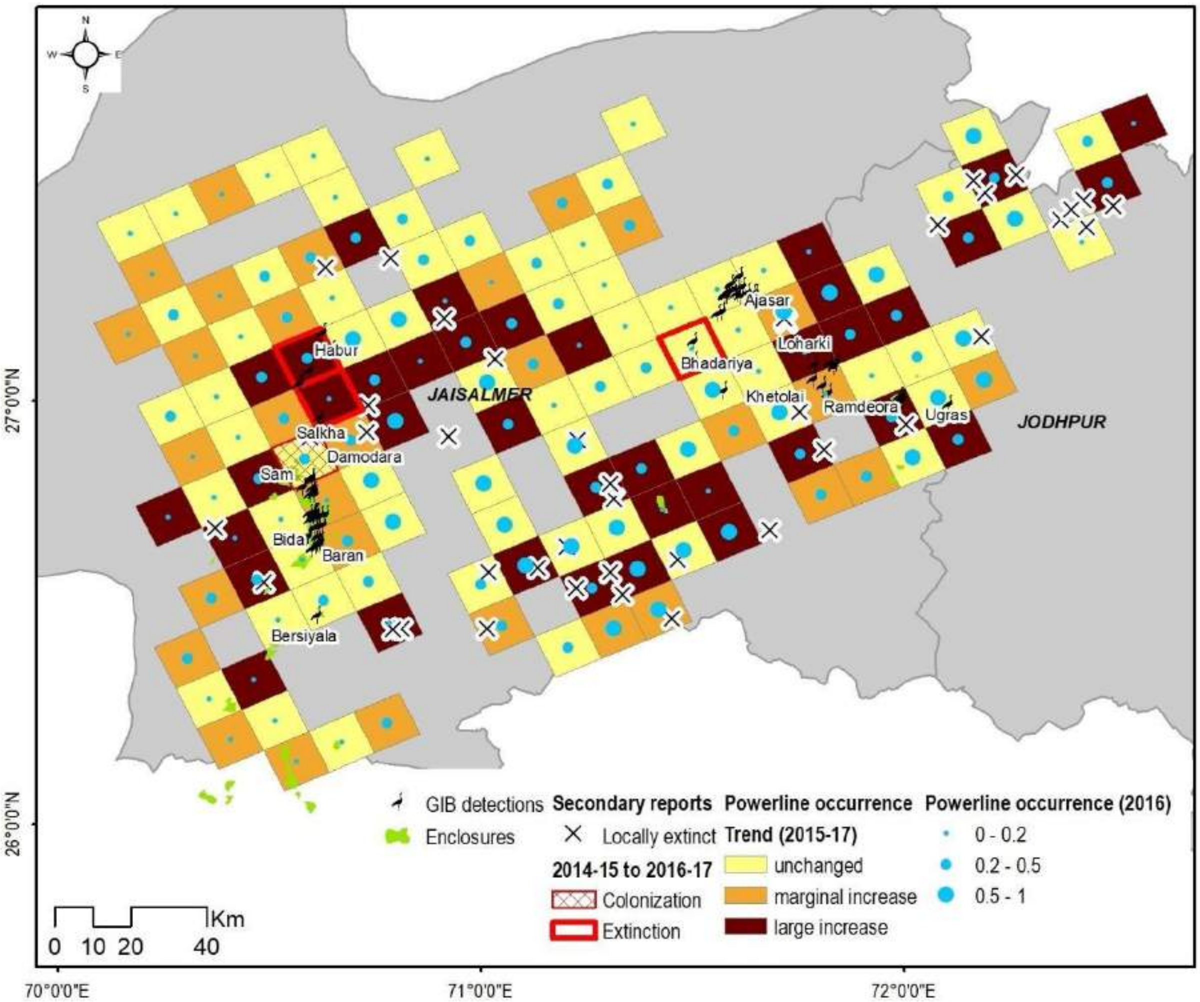
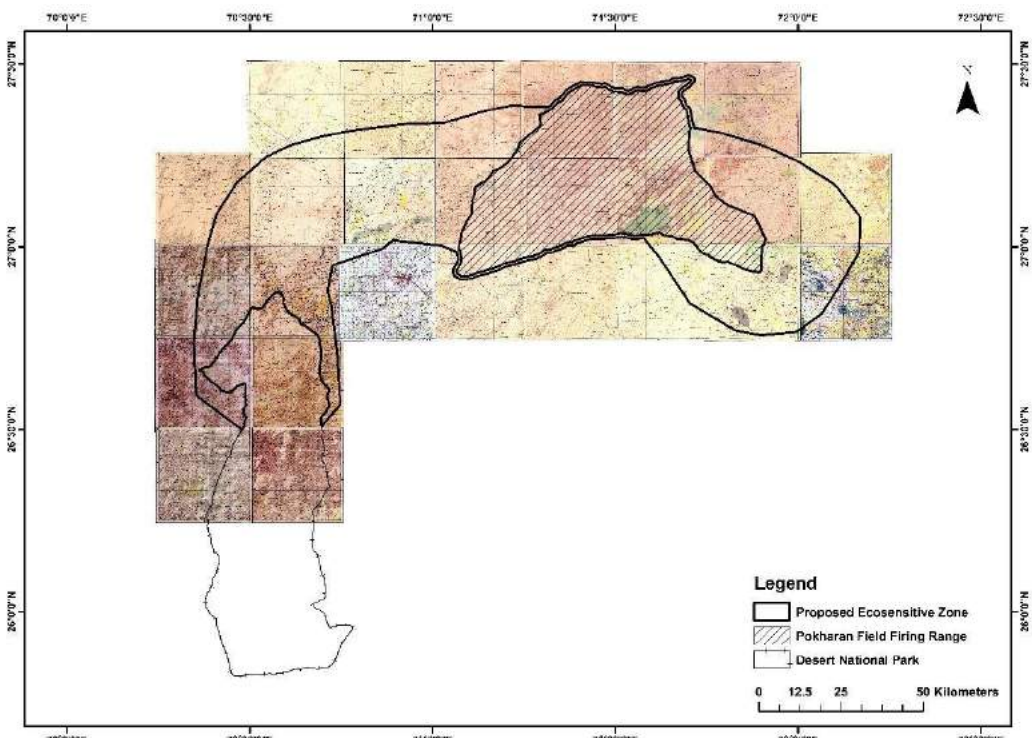


Table 4 Mean (95% CI) of current status and recent trend of putative habitat variables in 144 km² cells where great Indian bustard currently occurs (occupied), occurred 10 years back but not now (extinct) and never occurred (unoccupied) in Thar landscape, based on secondary reports during 2016-17 surveys

	Variables	Measurement	Extinct	Occupied	Unoccupied
Current status	Flatness	Frequency occurrence (proportion) in sampling plots	0.58 (0.5–0.66)	0.56 (0.47–0.64)	0.46 (0.37–0.55)
	Agriculture		0.28 (0.21–0.36)	0.25 (0.19–0.31)	0.22 (0.17–0.28)
	Grassland		0.36 (0.27–0.45)	0.38 (0.3–0.46)	0.31 (0.23–0.4)
	Settlement		0.32 (0.22–0.42)	0.24 (0.18–0.31)	0.22 (0.15–0.28)
	Power-lines		**0.53 (0.41–0.65)**	0.4 (0.31–0.49)	0.4 (0.3–0.5)
	Wind turbines		0.19 (0.07–0.31)	0.11 (0.04–0.18)	0.11 (0.03–0.19)
Rate of change	Settlement	Proportional change per year during 2015–2017	-0.02 (-0.11–0.08)	0.01 (-0.04–0.07)	-0.02 (-0.09–0.04)
	Power-lines		0 (-0.08–0.08)	**0.06 (0.01–0.1)**	0.02 (-0.03–0.07)
	Wind turbines		0.02 (-0.04–0.07)	0.01 (-0.01–0.04)	0.02 (-0.02–0.06)

Figure 10 Proposed ecosensitive zone to conserve great Indian bustard and associated fauna and habitat of Thar landscape



5. Discussion and recommendations

This report is an outcome of the long-term annual collaborative surveys of Wildlife Institute of India and Rajasthan Forest Department to monitor the population status of the critically endangered great Indian bustard and its associated fauna, habitat and threats in 19,728 km^2 potential bustard habitat of Thar landscape. This exercise follows a standardized, spatially representative sampling and analytical design that accounts for imperfect species' detection, thereby allowing robust spatio-temporal comparisons. During three initial survey years (2014-16), we have tried and tested various modifications over our basic sampling and analytical designs. The key refinement is a two-phase sampling to assess great Indian bustard abundance, wherein, extensive surveys across the landscape generates information on proportion of cells occupied by the species, and intensive surveys generates information on density in occupied cells, together providing abundance estimate in the landscape. For comparison with past estimates, we have reported the density/abundance estimated using the traditional approach; however, our current approach yields more realistic estimate.

Comments on the population enumeration technique

Thar landscape extends over a vast area with little barrier to bird/animal movements, thereby rendering total population counts impractical and unreliable. Comparing great Indian bustard numbers observed in conventional surveys to that reported by local informants, Rahmani (1986) speculated that only 10–20 % of population might be detectable. This impeded earlier efforts of assessing their population status with confidence, which we circumvent using line transect distance sampling approach. To obtain unbiased abundance estimate of an area, line transects should be randomly placed with respect to (1) animals and (2) the general habitat that can influence animal density gradient. For logistical practicality without violating the first assumption, we laid our transects on dirt and cross-country tracks, to which great Indian bustard did not show avoidance/preference, according to earlier studies (Dutta 2012) and absence of evasive movements in our long-term distance data. To adhere to the second assumption, we estimated animal density by sampling occupied cells in a spatially intensive and representative manner. This refinement generated more realistic population estimate than the earlier (2014-15) exercise. Our approach involves modeling of detection function using distance data of observations. We demonstrated that the effective detection widths based on actual bird detections (2014–17) matched very closely with that based on dummy birds (2014 and 2016). Hence, we recommend using dummy birds in blind trials to correct for imperfect detection when actual observations in a survey are inadequate. Our earlier exercise (2014-15) also lacked precision for great Indian bustard population estimation, as can be expected for a species with tiny population and patchy distribution across large area. Implementing two phase sampling that makes use of intensive data from sites used by species and pooling samples from consecutive years (without much difference in encounter rates) have provided reasonable precision in the current exercise.

For the purpose of monitoring, we recommend replicating our intensive surveys on a seasonal basis in great Indian bustard used areas in west (Chawani–Habur) and east (Bhadaria–Ajasar–Pokhran) Thar landscape that would allow reliable inferences on local population trend and seasonality. A complete landscape-scale survey, spanning summer (March-April) and winter (October-December) seasons can be conducted once every 2-4 years to detect changes in overall population status. Finally, the current species' density/abundance estimates should not be compared to that reported in Dutta et al. (2014, 2015) because of our methodological refinements. Instead, encounter rates based on consistently sampled cells should be used for inferences on temporal species' trends.

Is there a decline in population?

Although our estimate based on 2017 surveys (95 ± 21 individuals) indicated a decline in Great Indian Bustard numbers, inadequate sampling of the species' prime habitat – Pokhran Field Firing Range, could have biased the estimate. Our follow-up surveys, where the Great Indian Bustard Conservation Project team surveyed western Thar landscape and Pokhran Field Firing Range, yielded more refined estimate of 128 ± 19 individuals. Although we cannot infer trend in the population in a meaningful way because of the poor precision of the past (2014–16) estimates, managers should take cognizance of the mounting evidence of powerline mortalities in this landscape. Our carcass surveys covering 80 km low and high tension powerlines across ~4000 sqkm area on six occasions spread over a year estimated ~18 Great Indian Bustard deaths, based on three recorded mortalities (two during and one outside surveys). Although the initial years of monitoring shows a stable population of Great Indian Bustard in Thar, such high human- induced mortality rate is unsustainable for a long lived species; would eventually lead to their decline, and is necessary to be mitigated in an expeditious manner.

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, numbers and area of use have seemingly declined in these three decades. Typical number of birds seen by respondents in their localities has also reduced from earlier times. Local peoples' responses to our questionnaires indicated that great Indian bustard distribution was more widespread ten years back than it is currently. Local extinction reports were concentrated around Phalodi-Bap (north-east Thar) and Reewari-Bhimsar-Rasla-Sadrasar (south-central Thar) areas that corroborated our field observations.

Our earlier results on species-habitat relationships (Dutta *et al* 2016) indicated that disturbance was the prime factor influencing distribution in this region. Great Indian bustard did not use areas with high incidence of humans or infrastructure. Their occurrence also depended on protection and declined with distance from protected enclosures. Hence, reduction of anthropogenic pressures in great Indian bustard occupied cells by creating enclosures and/or providing alternate arrangements to local communities should be the priority conservation action. The recent (late 2013) installation of wind-turbines and high tension power-lines between Sam-Sudasiri and Salkha areas is a severe threat to the survival of great Indian bustard population as they increase the risk of electrocution and fatal collisions of the locally migrating birds in western Thar. Thar landscape has already lost great Indian bustard from Mokla grasslands following the installation of wind-turbines and high tension power-lines between near Mokla in early 2011. At least three instances of great Indian bustard mortality through collision with power-lines associated with wind-turbines have been reported from our power-line surveys and anecdotal evidence in Thar in the last year, and it is estimated that about 18 birds may die each year due to power-lines. Recent deliberations and decision that no more over-head power-lines and wind turbines should be installed in the priority great Indian bustard habitat, and existing power-lines will be mitigated, will greatly benefit the species. Based on our long-term understanding of this landscape, an eco-sensitive zone boundary has been proposed (fig 10) to facilitate this process. However, these actions need to be expeditiously implemented as the current level of power-line mortality is too high for this small population to sustain, and the increasing trend of power-lines in great Indian bustard occupied cells is particularly concerning in this context.

Effective conservation in Thar would require a multi-pronged approach that includes the Forest Department, Indian Army, local communities and research/conservation agencies. Apart from protecting key breeding areas as enclosures, conservation funds should be utilized on activities to maintain anthropogenic pressures below species' tolerance threshold by involving communities in participatory-planning that balances conservation and livelihood concerns. This includes activities such as regulated ecotourism that can improve the local economy, mitigation of infrastructural development, and bustard-friendly agro- pastoral practices (Dutta et al. 2013).

Since great Indian bustard usage is spread across large expanse of Thar, comprehensive insights into their ranging patterns are required for fine-tuning these conservation actions. Currently, two distinct population clusters are noticeable – one in western Thar extending from Chowani in south to Habur in north, and another in eastern Thar, in/around Pokhran Field Firing Range. Secondary occurrence reports of great Indian bustard from Bada-Nehdai-Dewa-Mandhau-Ainta villages in northern Thar indicate possible connectivity between these western and eastern populations. However, the actual corridors can only be determined through biotelemetry studies, and although capturing of a few birds involve an element of risk, this risk is unavoidable to conserve the species as a whole.

Key recommendations

The great Indian bustard population and habitats are declining drastically across its distribution range. Thar landscape is the only remaining habitat supporting a viable (and the largest) breeding population but is also experiencing a rapid increase in anthropogenic disturbances in terms of human presence in remote interiors, power-lines, wind turbines, and water provisioning – all of which are detrimental to the persistence of great Indian bustard. To recover great Indian bustard population by restoring habitats in this landscape, we recommend:

a) Consolidating existing enclosures where bustard breeds using predator-proof chain-link fences (in Sam, Sudasari, Gajaimata, Rasla and Ramdeora) as the current fencing is inadequate to keep predators away in most cases.

b) Active management of free-ranging dogs, pigs and native nest predators (foxes, mongoose and monitor lizards) from breeding enclosures (~25 km^2 cumulative area) to improve nesting success and chick survival of great Indian bustard, by routine translocation of these predators outside the enclosures, and the use of nest repellents (Pavlovian experiments) using dummy eggs. This management is unlikely to affect the population of these predators as the area of intervention is miniscule in comparison to their ubiquitous distribution.

c) Mitigating ill-effects of wind-turbines and overhead power-lines in priority conservation cells, particularly the great Indian bustard ranging arc between Sudasari-Sam-Salkha-Mokla-Mohangarh-Bhadariya- Ajasar-Ramdeora (figure x) to reduce obstruction to local bird movements. New power-lines should be made underground and existing ones should be marked with Bird Flappers/Diverters to make them visible and minimize collision risk (Silva et al. 2014). WII has already supplied pilot diverters, which have been installed in select lines by power agencies (Suzlon and RVPNL). Similar products need to be imported or locally made and deployed on priority power-lines across the eco-sensitive zone (fig 10) in an expeditious manner by power/energy agencies.

d) Transferring lands in priority conservation cells (e.g, habitats near Kanoi-Salkha-Habur, Nathoosar, Chanani, Ugras, Galar, Chhayan, Ajasar-Keroo, Bhadariya, Mohangarh and Dhaleri) to Forest Department for creating new protective enclosures, and where this strategy is unfeasible or undesirable, conservation areas can be jointly managed by local communities and Forest Department.

e) Adaptive management of breeding enclosures to accommodate the critical foraging needs of bustard during the nesting phase, apart from protection to nests/chicks. To achieve this objective, dietary supplementation by cultivating ~10% of enclosure area in patches of ~1 ha with local food crops can be planned. Enclosures can be seasonally opened to livestock grazing (October through March), not exceeding ecological carrying capacity of 10 Animal Units / km^2 (1 Animal Unit is equivalent to one adult female cow and 4 sheep and goat), so that the benevolent effects of livestock grazing on vegetation structure and the availability of dung beetles (an important food for bustard) are maintained. This management is ideal for older enclosures such as Sudasari and not in more recent enclosures which are recovering from the impacts of excessive grazing.

f) Smart and intensive patrolling to generate management information and control poaching. This entails recruiting more staff, building their capacity through tools and training, and providing performance based incentives.

g) Targeted research on great Indian bustard to characterize threats spatio-temporally, understand landscape use patterns using biotelemetry, and objective monitoring of their population status by involving research organizations.

h) Involving local people in conservation by addressing their livelihood concerns (e.g., regulated ecotourism), and encouraging them to monitor bustard occurrence and report illicit activities using rewards and incentives. A coordinated outreach program must be implemented that understands the needs and concerns of local people in the great Indian bustard conservation area (fig 10), sensitize them on desert/grassland conservation in general and the need of conserving great Indian bustard in particular, and provide alternate livelihood solutions that are socio-ecologically compatible. Baseline information on community composition, livelihoods and village livestock holdings, generated from our questionnaires (Dutta et al. 2016) can aide in designing such outreach programs.

i) Conducting regular outreach programs with other stakeholders such as Indian Army personnel and energy sector to sensitize them on the need and required actions for bustard conservation.

Conclusion:

The key to conserve this vital landscape is to implement a combination of stringent protection measures to control poaching, expeditious mitigation of infrastructure such as power-lines, and disallowing detrimental infrastructure in the larger great Indian bustard conservation area, but provisioning of basic amenities and livelihood options to local people (e.g., regulated ecotourism), and scientific habitat management of breeding enclosures. These recommended actions needs to be collaboratively implemented by Rajasthan Forest Department, Wildlife Institute of India and partner conservation agencies.

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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 / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	
						F / S / U (M / V)	R / G / S / s	B / A / G / W / S	

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 (100 m radius)	Substrate (100 m radius)	Land-cover (100 m radius)	Vegetation composition (% area in 20m radius)					3 dominant plants (100m radius)	*Sandha* Pr (10m radius)	Human structure (100m radius)
							Short grass/ herb(<30 cm)	Tall grass (>30cm)	Shrub (<2 m)	Tree (>2 m)	Crop (name)			
				F / S / U (M / V)	R / G / S / s	B / A / G / W / S							1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W / S							1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W / S							1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W / S							1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W / S							1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W / S							1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W / S							1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W / S							1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W / S							1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W / S							1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W / S							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) / **G** (grassland) / **W** (woodland) / **S** (scrubland)
Human structure – **S** (settlement) / **H** (farm hut) / **R** (metal road) / **E** (electricity lines) / **W** (wind turbine) / **P** (water-source)

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	Q2. When & where was the last that you have	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

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

POWER-LINE MITIGATION

TO CONSERVE BUSTARDS

Citation: Wildlife Institute of India 2018 Power-Line Mitigation Measures. Second edition (2020)

Cover photo of dead male Great Indian Bustard due to power-line in Jaisalmer : Bipin C.M.

HARMONIZING POWER SECTOR WITH BUSTARD CONSERVATION

The Great Indian Bustard (GIB) is a critically endangered species of bird, with 128(± 19) individuals remaining in the world. The GIB resides in the grasslands of India with the current majority of its population in Jaisalmer district of Rajasthan. There are several threats that are inching the bustard closer to extinction, however, powerlines seem to be the most significant.

EVIDENCE OF IMPACT

a) Bustards are prone to collision

Bustards have wide sideways vision to maximize predator detection, at the cost of narrow frontal vision. Because of this, and a habit of scanning the ground while flying, they cannot detect power-lines ahead of them, from far. Being heavy fliers, they fail to manoeuvre across power lines within close distances. The combination of these traits make them vulnerable to collision with power-lines. As a result, they collide with power lines and die from the impact, injuries/trauma or electrocution (Martin and Shaw 2010).

b) Evidence of bustard mortality due to power lines

Worldwide, studies have shown high mortality rates of several bustard species because of power-line collision. For example, 30% of Denham's bustards (Neotis denhami) die annually from power-line collisions in South Africa (Shaw 2009, Jenkins et al. 2010). In Spain, 8.5 km stretch of power-line killed a minimum of 25 Great Bustards in one year (JC Alonso pers. obs.). A review (Mahood et al 2017/18) of nine studies covering six bustard species from different parts of the world estimated 7 detected bustard mortalities per 10 km power-line per year. This factor causes 4 - 7% mortality of Great Bustard in areas with low power line density (Martin 2008) and 13% mortality in areas with high power line density (Alonso 2007).

c) Evidence of Great Indian Bustard collisions with power lines in India

Surveys conducted by Wildlife Institute of India (WII) in Thar covering 80 km of power lines repeated 7 times over a year found 289 carcasses of around 40 species including the Great Indian Bustard (GIB). **The study detected 8 carcasses/10 km for high tension and 6 carcasses/10 km for low tension power-lines**. Correcting these mortalities for the proportion of carcasses that are decomposed before survey or are missed during survey, mortality rate was estimated to be ~6 bird/km/month(high-tension lines), ~3 bird/km/month low-tension lines), and ~84,000 bird per year within 4200 sqkm area in and around Desert National Park. In terms of GIB, 6 mortality were recorded from 2017-2020, all due to high tension transmission lines - some of them connected to wind turbines.

Extrapolating these mortalities to the priority bustard habitat, intersected by ~150 km high tension lines, amounts to about **16 GIB deaths per year** from a population of about 128 ± 19 individuals in Thar. **Such high mortality rate is unsustainable for the species and a sure cause of extinction.** WII also tagged ten Great Indian Bustard on pilot basis in Rajasthan, Gujarat and Maharashtra, out of which two died from power line collision, corroborating the above findings.

d) Impact of power line collision on bustard population

Bustards are long-lived birds where adults have high annual survival probability (Palacín *et al* 2012). However, the excessive mortality due to power-lines are unsustainable and cause population declines or even extinction (Martin 2007). Power-line mortality can also disrupt important biological processes. Palacín et al (2012) shows that in a Great Bustard population in Spain, where migratory individuals suffered significant power-line mortality, the proportion of sedentary individuals increased over years against the reduction of migratory individuals. Here, power lines have reduced the propensity of a species to migrate, and can result in the loss of such intricate behaviors.

SOLUTIONS

e) No Power-line zones

Crucial breeding habitats of bustards have to be made free of overhead power-lines. Conservation of bustard is not possible in areas with power-lines which sooner or later kill the bird. Existing power-lines in such important habitats have to be moved underground or redesigned. No new power-lines should be permitted in such areas.

f) Mitigation of threat

Mitigation measures are available to reduce power-line mortality, such as under-grounding of cables and fitting overhead wires with bird diverters. Bird mortality and crossing rate through wires reduce, if lines are marked with diverters compared to unmitigated segments. While under-grounding of cables eliminates bird mortality, marking power line can reduce mortality by 10 % (Barrientos et al 2012) to 78 % (Barrientos et al 2011), depending on area and species, but not eliminate mortality.

IMPORTANCE OF TELEMETRY IN POWER-LINE MITIGATION

Great Indian Bustards range over large human-dominated landscapes that are facing rapid development and expansion of power-lines. Curtailing all infrastructural development across these large areas is impracticable and calls for prioritization of areas where these infrastructure should be avoided or mitigated. Use of bio-telemetry to understand GIB habitat can aide in this process, by generating fine-scale information on the birds' movement patterns that can overlaid on existing and proposed power-line maps to identify segments for mitigation measures. Thus, telemetry supplemented with bird surveys provide a powerful tool to prioritize habitats for infrastructure mitigation in particular, and conservation management in the wake of development.

Wildlife Institute of India demonstrated the potential of this tool for GIB conservation, by tagging two juvenile birds in Kachchh, Gujarat and 5 adult birds in Thar, Rajasthan using solar powered GPS tags that weighed <1% of the bird's body weight. These tags haveprovided information on bird movements for >1 year (May 2017 onwards) and have also provided evidence of one bird mortality from collision with 33 kV power-line near Lala Bustard Sanctuary. Movement data obtained from tagged birds was overlaid on habitat and infrastructure maps to identify critical areas for mitigating power-lines (see figure 1). However, individuals vary in their movement patterns and more birds need to be tagged across bustard landscapes (Thar, Rajasthan and Kutch, Gujarat) to draw population-level inferences and achieve best conservation results with finite resources and bring about a harmony between development and conservation needs of the country.

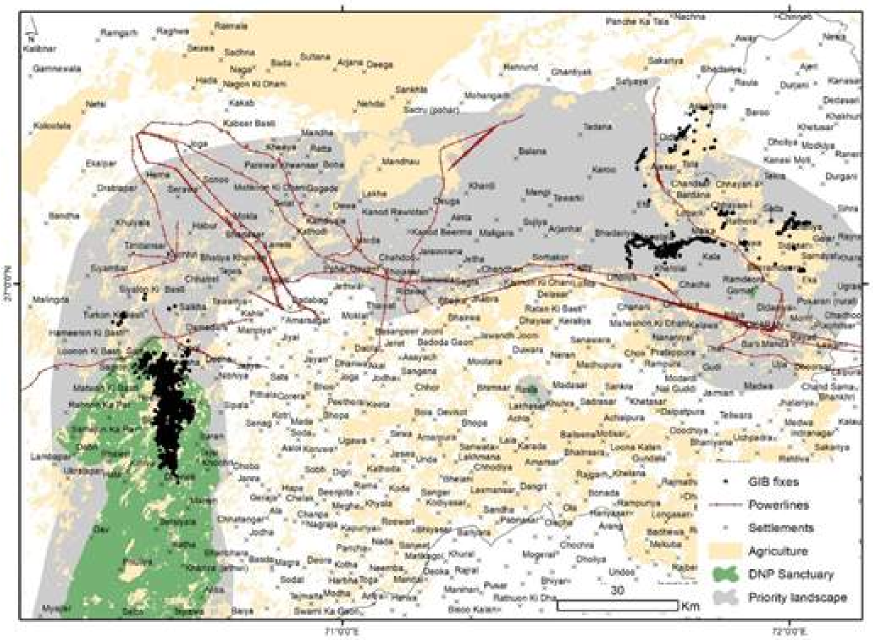
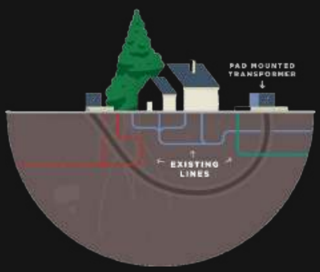


Figure 1 : Movement of tagged Great Indian Bustard overlaid on network of power lines and critical areas for mitigating power-lines (red lines).

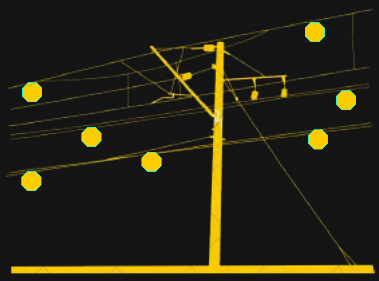
SOLUTIONS

This crisis can be mitigated as follows:

Avoid/divert any high tension power line from priority Great Indian Bustard habitat. (Figure 2a & 2b).



Undergrounding of <66kv wires of most risky power-lines in priority GIB habitat.



Retrofitting of existing overhead wires with bird diverters (details of diverter makes and costs, and installation design in figure 3).

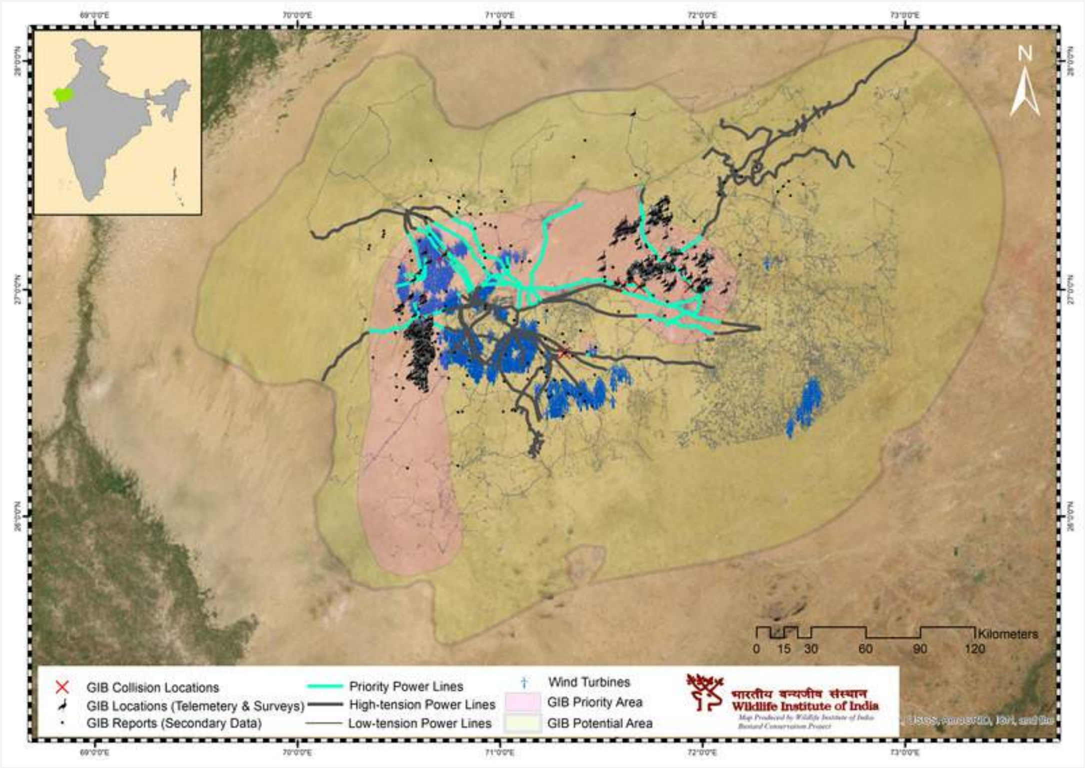


Figure 2a - Map showing Great Indian Bustard distribution, power-lines and wind turbines in Thar,Rajasthan

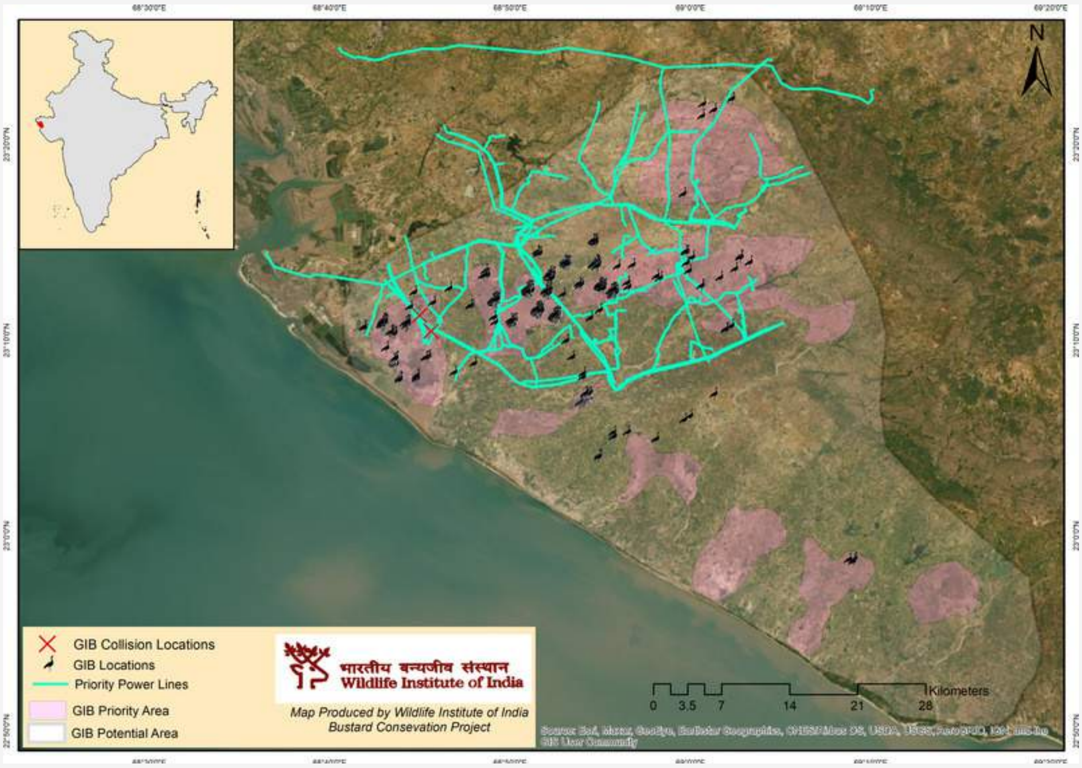


Figure 2b - Map showing Great Indian Bustard distribution and power-line in Abdasa, Kutch, Gujarat

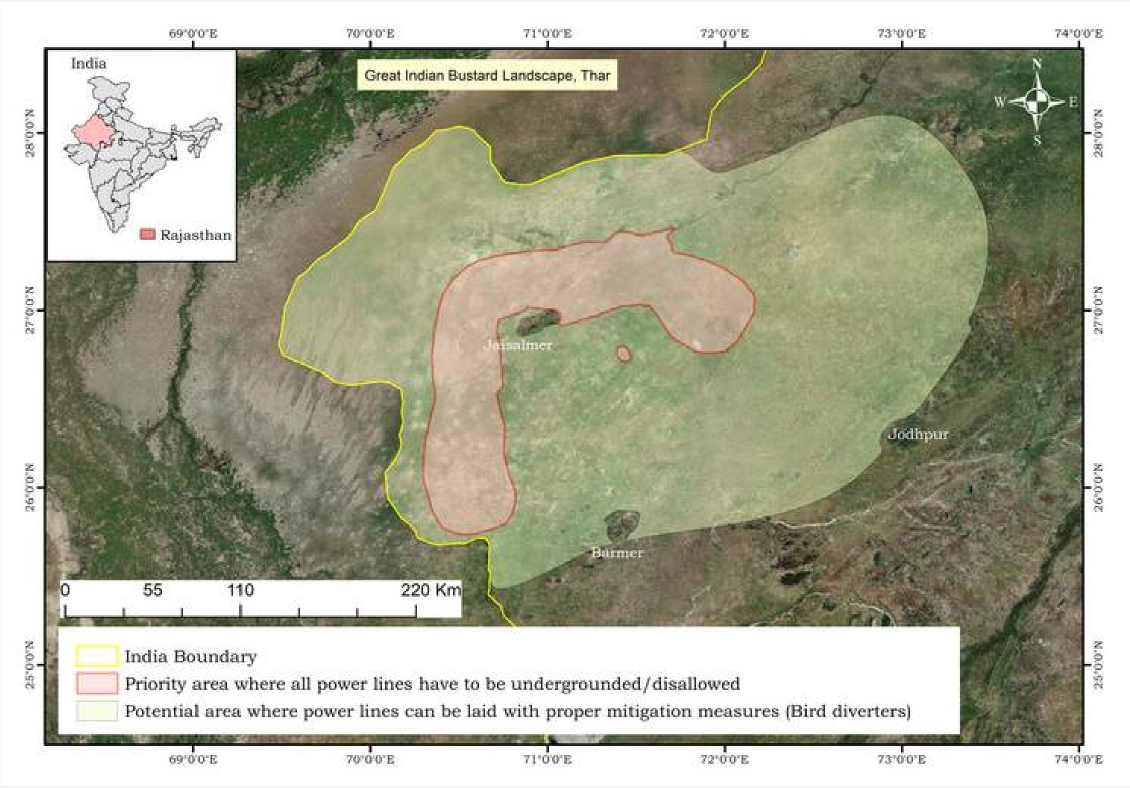


Figure 3a. Great Indian Bustard landscape in Rajasthan delineating the priority and potential areas for power-line mitigation.

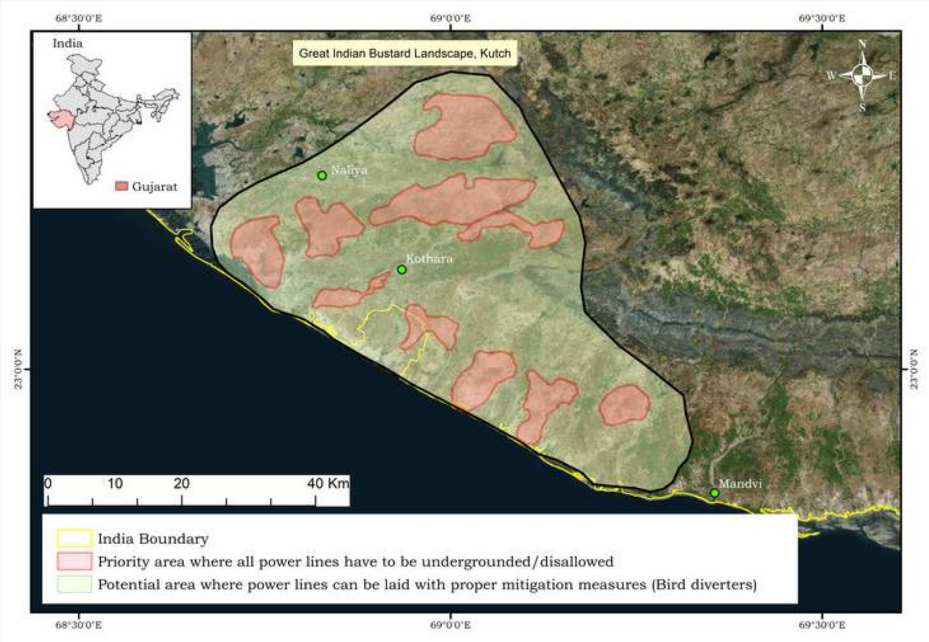
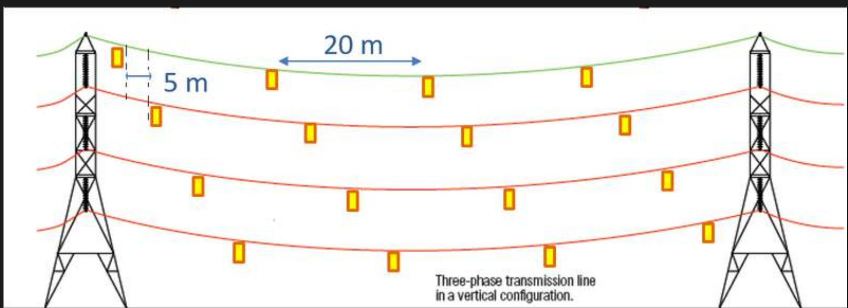
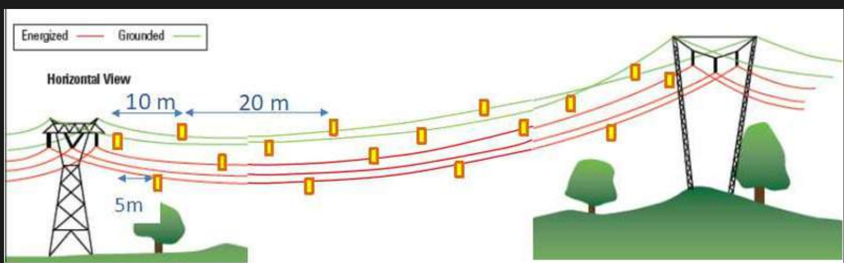


Figure 3b. Great Indian Bustard landscape in Gujarat delineating the priority and potential areas for power line mitigation.

Figure 4 : Details of diverter makes and costs, and installation design





Cost calculations:
Central 70% marking
~ 1 diverter/4m line
~4500 INR/unit + shipping charges (import)
~ 1000 INR /unit (local)

Installation

Marking earth wire with 1 diverter at every 10m, and marking conductors with 1 diverter at 15 m in a staggered way, such that power-line as a whole has at least 1 diverter every 5-6 m.

UNLESS POWER-LINES MORTALITY IS MITIGATED URGENTLY, EXTINCTION OF GIB IS CERTAIN.

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Photo Credits

Graphic image of flying GIB through power-lines - Devesh Gadhavi

Dead GIB due to electrocution in Maharashtra - Devesh Gadhavi

Network of power-line and windmill - Tanya Gupta

Tagged GIB in Gujarat - Devesh Gadhavi

Red Eléctrica de España

Designed by: Tanya Gupta

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