Subject: Response to RTI WLIOI/R/2018/50018 dated-13-June-2018
From: "Dr. Anju Baroth" <anju.baroth@wii.gov.in>
Date: 05-07-2018 12:26
To: <advocategauravkumarbansal@gmail.com>
CC: "'mpa'" <mpa@wii.gov.in>, "'G Muthu Veerappan'" <mv@wii.gov.in>

Sh. Bansal,

Response to your RTI **WLIOI/R/2018/50018** dated: 13-June-2018 is attached with this mail. Since the RTI portal supports the upload of files upto 1 MB size, the complete information requested by you is being sent to you by email with two attachments of size 3 MB (Full thesis) and 228 KB (Abstract). A screenshot of this email will be attached to the RTI portal for online disposal of your request.

If you are not satisfied with the aforesaid reply, you may file an appeal before the First Appellate Authority i.e, “Dr.V.B.Mathur, Director, Wildlife Institute of India, P.Box. # 18, Chandrabani, Dehradun – 248001, Ph. 0135-2646102, 2640910” within a period of one month.

Regards
Dr. Anju Baroth
NO & CPIO
Wildlife Institute of India
Dehradun

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ABSTRACT

1. One of the few mammals to have a near-global distribution, dogs (*Canis familiaris*) are an introduced mammalian predator. Dogs have contributed to 11 vertebrate extinctions and are a potential threat to 188 threatened species globally. This study investigates population sizes, ranging patterns, behavioural activity, and resource utilisation of free-ranging dogs in Thar landscape, Rajasthan.

2. Using double sampling framework, I calibrated effort-standardized counts (C) with mark-recapture based abundances ($\widehat{N}$) that was used to estimate dog abundances within human habitation. Landscape-scale dog abundance was estimated using vehicle transect based distance sampling. Home ranges of nine free-ranging dogs was determined using locations from radio-telemetry. Resource use was quantified as feeding durations on various food items based on continuous monitoring. Resource availability was quantified as wild prey and livestock carcass density using line transect based distance sampling.

3. The calibrated relationship [$N = (1.65 \pm 0.05_{SE})$ x C] estimated a total of $761 \pm 109_{SE}$ dogs in human habitation with the total number of dogs averaging at $1804 \pm 462_{SE}$ dogs in 1008 km^2 area. Home range (95% MCP) of free-ranging dogs averaged at $19.81 \pm 4.79_{SE}$ km^2 with no difference between males and females. Space-use was two-fold closer to enclosures (prime wildlife resource patches) and threefold closer to settlements (human-derived resource patches) than expected under random use.

4. Activity budget and temporal activity pattern obtained from 156-hours continuous monitoring per dog showed that dogs were crepuscular, mostly active during 0600-0900 and 1800-2100 hours, and resting for 75% of the day.

5. Prey densities (individuals/km^2) were estimated to be $7 \pm 1.22_{SE}$ chinkara, $0.46 \pm 0.23_{SE}$ nilgai, 4681 spiny tailed lizard and $2861 \pm 203_{SE}$ jird. Goat and sheep carcasses contributed most to the diet (54% feeding time) and were also most selected (Ivlev's index = 0.96_{goat} and 0.95_{sheep}) followed by predation on nilgai and chinkara. I estimated potential predation rates of chinkara and nilgai to be 9.67 and 10.95 dog^{-1} $year^{-1}$ respectively albite with a small sample.

6. **Synthesis and applications.** This study provides information on important aspects of

Attachments:

Screenshot_2018-06-30-05-03-21-113_com.google.android.apps.docs.png	228 KB
Final_thesis.pdf	3.1 MB

HAS CONSERVATION GONE TO THE DOGS?

Ecological aspects of free-ranging dogs in the Thar

Dissertation submitted to Saurashtra University, Rajkot in partial fulfillment of Master's Degree in Wildlife Science (June 2017)

By

Monisha S Mohandas

Supervisors

Yadvendradev V. Jhala, PhD

Qamar Qureshi, M.Phil

Sutirtha Dutta, PhD

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

Destroyed buildings can be rebuilt; destroyed works of art may possibly be replaced by new creations; but every animal and every flower which becomes extinct is lost forever in the most absolute of all deaths.

Joseph Wood Krutch

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ACKNOWLEDGEMENTS

June 19, 2015 my mom's first question to me when we visited Dehradun was "Do you think you will be able to study here for two years?" I looked at my mom and she looked back, and we both smiled. And now officially having completed my graduate degree, I have come a long way thanks to the people who have directly or indirectly helped me.

For the openness and support shown by my family in my interest and allowing me to pursue my own choices despite it being relatively different from the norm. Their emotional and moral support as well as guidance and humour have made me come this far and be what I am today. And Krish, for listening to my problems and giving me barking advice as well as lending a paw in times of need. I love you all. SYK!

On a formal note, I would like to thank the Director and Dean of Wildlife Institute of India (WII) for permitting me to pursue my Masters in WII and carry out this research study. I would like to extend my gratitude to the Rajasthan Forest Department for granting permission to carry out this study there and for arranging lady guards to accompany me during this study period. Additionally, Dr. Shrawan Rathore for helping me collar free-ranging dogs for this study. Our course director, Dr. Bivash Pandav and assistant course director, Dr. Gopi G.V. for patiently tolerating our lively behaviour and lending an ear when we needed it.

The main man behind the scenes of my work who stays at the shadows but his presence is always known, my supervisor, Dr. Y.V. Jhala. His ways of giving me a push but at the same time my independence in dealing with situations has allowed me to grow as a person during this period. His contagious passion and overflowing enthusiasm in the field has made me realize than fun finds you when you have the passion. I am deeply grateful to you Sir!

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I guess it is true when they say that the people you mingle with determine the atmosphere around you. I am glad to say that the people around me including my field assistants were amazingly helpful and hard workers. I am grateful to Tarun, my main field assistant who during the mark recapture process in settlements, handled the 101 personal questions each villager had about us and what we were doing while I photographed the dogs. Even the moments when he would tell stories and jokes just to keep us entertained during the 24-hours continuous monitoring on dogs. I would also like to thank Avinash, Rachana, Aaranya, Vijay, Ali, Amrit, Govind, Karan, Kojraj, Lal Singh, Musa, Pushpa Malik, Pushpa, Pushta, Saroj and Shambu for the assistance provided during the continuous monitoring.

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The researchers who made time for me when I had doubts about running analysis on my data, Ayan, Kausik, Ninad and Ujjwal. Those difficult made easy teachings made a significant impact. Thank you! I would also like to thank Vishnu, for the interesting papers shared and the quick tips on Microsoft Word.

And not forgetting, my batchmates of the 15th MSc Wildlife Science course, who have made my two years in WII memorable and dangerously fun and always had my back. Thanks a bunch guys! The good times we spent in the evenings having momos as a class and the midnight discussions will always be cherished. A special shout out to those who helped in those late nights, making dog collars.

Last but not least, the free-ranging dogs who were ever so photogenic and accepted me as part of their family, words are not enough to express my gratitude. Thank you for letting me in on your secret life.

Finally, I would like to acknowledge the CAMPA GIB species recovery project, for funding my research and the logistics support provided during this four months.

For all those who have not forgotten to follow their passion…

Monisha S Mohandas
20th June 2017

ABSTRACT

1. One of the few mammals to have a near-global distribution, dogs (*Canis familiaris*) are an introduced mammalian predator. Dogs have contributed to 11 vertebrate extinctions and are a potential threat to 188 threatened species globally. This study investigates population sizes, ranging patterns, behavioural activity, and resource utilisation of free-ranging dogs in Thar landscape, Rajasthan.

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6. **Synthesis and applications.** This study provides information on important aspects of free-ranging dog ecology and their impacts in Thar landscape. It provides the basis required for implementing dog control programs in the landscape focusing on the flagship and critically endangered great Indian Bustard *Ardeotis nigriceps*.

Keywords: activity pattern, Canis familiaris, double sampling, home range, population, predation rate

CHAPTER 1

INTRODUCTION

1.1 General Introduction

In today's world, a 14,000 years bond that has been maintained, if not strengthened by man in every generation, is now being put to the test. For the dog or for wildlife? *Man's best friend* are descendants of the charismatic grey wolf (Doherty et al. 2017), which was domesticated by man at least 14,000 years ago to save their lives and livestock from wolves itself (Frantz et al. 2016). 14,000 years later, dogs have invaded most parts of the world and expanded their niche with their abundance continually increasing (Lenth et al. 2008).

About 1 billion domestic dogs have been estimated worldwide, of which, this population is composed of pets, free-ranging and feral dogs (Gompper 2014). The term free-ranging dogs refer to dogs that are not owned by humans but depend on human derived food resources as well as occasionally on wild prey (Lenth et al. 2008, Vanak 2008). These include stray dogs and owned farm and pastoral companion dogs (Vanak 2008). However, feral dogs are considered to be wild and partially dependent of human derived food resources (Nesbitt 1975; Green and Gipson 1994).

Since free-ranging dogs have to survive on their own, they tend to kill livestock of villagers in the rural areas, go through garbage bins in urban, semi urban or rural areas and occasionally hunt wildlife as prey (Hughes and Macdonald 2013). This scenario provides a loss to villagers, increases disease transmissions, and causes free-ranging dogs to be a threat to wildlife (Hughes and Macdonald 2013; Belo et al. 2015).

According to the Living Planet Index (LPI) of 2016, about 10% of the decline in wildlife population globally is due to invasive/introduced species and disease transmissions (World Wide Fund for Nature, WWF 2016). Considering the fact, that dogs carry transmissible pathogens for diseases such as rabies and canine distemper virus, they can often decrease the population of native species of wildlife (Woodroffe 1999; Young et al. 2011; Vanak et al. 2007). Transmission of zoonotic diseases are very possible especially when these free-ranging dogs are found in close proximity to humans (Salb et al. 2008; Young et al. 2011).

1.2 Current situation with free-ranging dogs in Thar landscape

This is an emerging crisis in Thar landscape which is an important arid biodiversity area of India. The Thar landscape provides an appropriate platform to study this crisis because of the intersection between endangered native biodiversity and human dominance with the highest human density recorded across any desert. The landscape has a relatively large dog population that depends on village resources, tourist resorts, livestock, and native wildlife (Dutta pers. communication & Hiby *et al.* 2016). The large dog population in this landscape might be because of the additional availability of water via the Indira Gandhi canal and/or the alternative food availability aforementioned. This raises a conservation outcry as native species of Desert National Park (a protected area in Thar) are now introduced to a new competitor and/or predator. Thar, with its severe arid conditions that result in typically low ungulate and native predator densities, might not be able to sustain such additional pressure in terms of a non-native formidable predator.

To effectively understand and mitigate this crisis, it is imperative to study dog abundance, their impact on wildlife as well as factors affecting their numbers, distribution and behaviour in the wild. This is of pivotal importance because the Indian government has started implementing grassland recovery plans with emphasis on great Indian bustards as a flagship species and the Thar landscape holds the largest yet precariously surviving population of these critically endangered birds (Dutta et al. 2016). With the increase of free-ranging dogs and their partial dependence on wild diet, the naïve Great Indian bustards would most likely be under utmost threat from these formidable predators.

1.3 Current literature

1.3.1 Population Estimation

Studies have shown that free-ranging dogs, are known to have a negative impact on local people as well as native wildlife. These negative impacts can occur through different ways such as predation on wildlife (Ritchie et al. 2014), competition with native species (Vanak et al. 2014), disease transmission (Furtado et al. 2016) and hybridization (Bassi et al. 2017). To understand this, estimating the population of these dogs is the most crucial aspect.

Extensive empirical work has been conducted to estimate populations of species. This took a forward leap with the introduction of capture, mark and recapture technique introduced by Johannes Petersen in the 19th century. This technique was named the Lincoln-Petersen estimator and assumed that the study population is 'closed' whereby no births, deaths, immigration, and emigration has occurred during the mark recapture sampling. Mark recapture techniques on canids have used ear tags, radio collars, dyes, and physiological markers such as radioactive isotopes as means of marking individuals (Kruuk et al. 1980; Roemer et al. 1994; Hein and Andelt 1995; Schauster et al. 2002).

In India, the mark recapture technique has been used to estimate the population of free-ranging dogs. Currently, the closest literature available in India are Pal (2001) on the population ecology of free-ranging dogs in West Bengal, Punjabi et al. (2012) in suburban Mumbai and Hiby et al. (2011) in estimating dog population in Rajasthan. Pal (2001) explains that there was a seasonal variation in population density of 185 ± 19 dogs per km^2 and the sex ratio of 1.37:1, was skewed to males. Punjabi et al. (2012) used a mark-resight framework to estimate dog abundance and reported a total of 680.64 ± 34.06 dogs in Aarey Milk Colony, Mumbai which borders Sanjay Gandhi National Park while Hiby et al. (2011) estimated dog abundance using mark resight surveys in three cities in Rajasthan (36,580 dogs in Jaipur, 24,853 in Jodhpur and 2,962 in Jaisalmer) for the purpose of dog sterilization.

1.3.2 Ranging Patterns

Research on ranging patterns of canids in India has been going on since the early 1980s (Johnsingh 1981 on ecology and behaviour of dhole with reference to predator-prey relations; Venkataraman et al. 1995 on movement patterns of two dhole packs; Aiyadurai and Jhala 2006 on habitat use of golden jackals; Vanak and Gompper 2010 on spatial ecology of Indian foxes in a human-dominated dry grassland ecosystem). Understanding the ranging patterns of species is essential in determining their home ranges and territory as well as factors that affect their habitat selection.

Home ranges and territory size explains the functional role of a species and individuals in a system. Publications such as List and Macdonald (2003) and Jhala et al. (2009), have used radio telemetry to understand the home ranges of mammalian species while a publication has used GPS-collars to study the movement patterns of leopards in a human dominated landscape (Odden et al. 2014). Beside this, literature on the application of radio telemetry on free-ranging dogs to study ranging patterns in India is currently not present.

Though, across the globe, there have been many studies on free-ranging dog ecology. Research such as number of threatened species due to dogs as invasive (Bellard et al. 2016), ecology of feral dogs in Alabama (Scott and Causey 1973) and role of roads in facilitating dog access to primary habitats (Doherty et al. 2015) are a few of the publications present.

Understanding behaviour of a species provides intricate details on the ‘how’ and ‘why’ questions. Temporal activity pattern and time activity budget of a species answers such a question. It portrays information regarding the 24-hour cycle of an animal in terms of its activity and the average time spent in each activity. Such literature is extensively available in India especially for large carnivores, in understanding their movement patterns in accordance with prey (Johnsingh 1983; Karanth and Sunquist 2000; Majumder et al. 2011).

1.3.3 Resource Utilisation

Diet, most fundamental in understanding ecology of any species, is a primary resource governing all other attributes. Therefore, diet studies are imperative in understanding range-use, habitat-needs, predation effects and competition (Karanth and Sunquist 1995 on prey selection by tigers, leopards and dholes in tropical forests; Jethva and Jhala 2004 on food habits of Indian wolves in Gujarat by analyzing scats and monitoring radio-tagged wolves; Aiyadurai and Jhala 2006 on foraging and habitat use by golden jackals in Gujarat). However, in India, this study is only partially explored for free-ranging dogs (Vanak and Gompper 2009 looked at the dietary niche separation between free-ranging domestic dogs and Indian foxes and discovered that dogs survived largely on human-derived foods while

Home et al. 2017 explained that most small-bodied livestock was predated upon by dogs in the Upper Spiti landscape, Himachal Pradesh). Considering how free-ranging dogs have become inimical in India, there are limited studies on their impact on wildlife (but see Vanak et al. 2007; Bhardwaj and Dutta 2015).

1.4 Present Study

1.4.1 Broad Objective

The rationale behind this study is to understand the dependency of free-ranging dogs on anthropogenic resources and their impact on wildlife in Thar to create conservation awareness about the same and provide information relevant to their management.

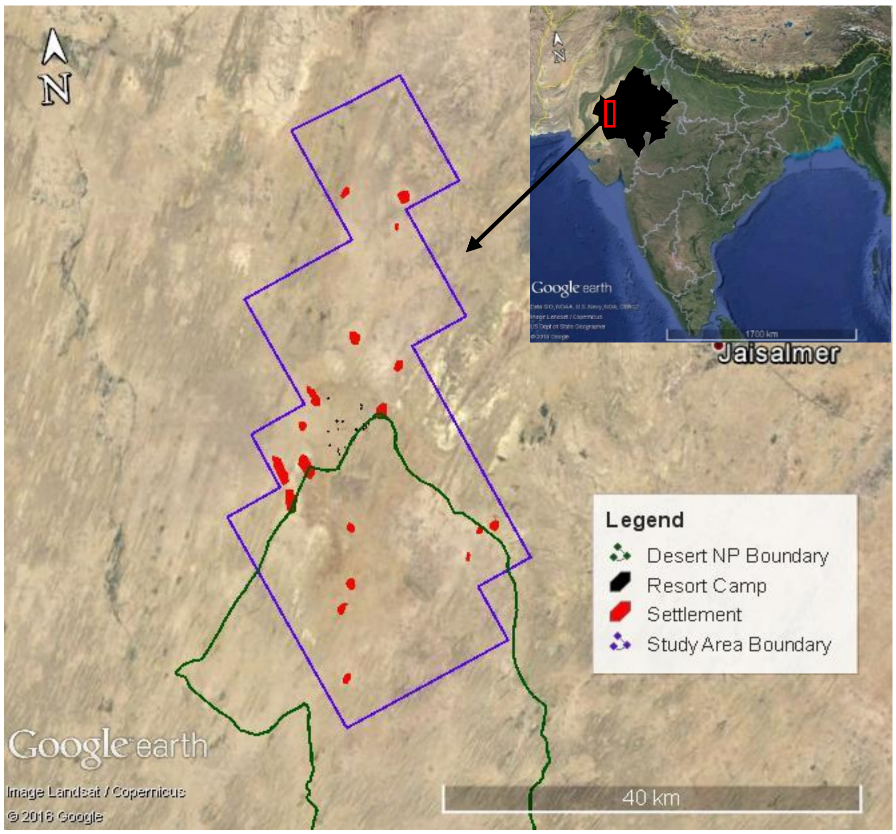
1.4.2 Main Objectives

- To assess the population status of dogs in the study area.
- To determine the ranging patterns of free-ranging dogs in Thar landscape.
- To assess temporal activity patterns of free-ranging dogs in Thar landscape.
- To obtain time activity budgets of free-ranging dogs in Thar landscape.
- To study the resource utilisation of free-ranging dogs in Thar landscape

CHAPTER 2

STUDY AREA

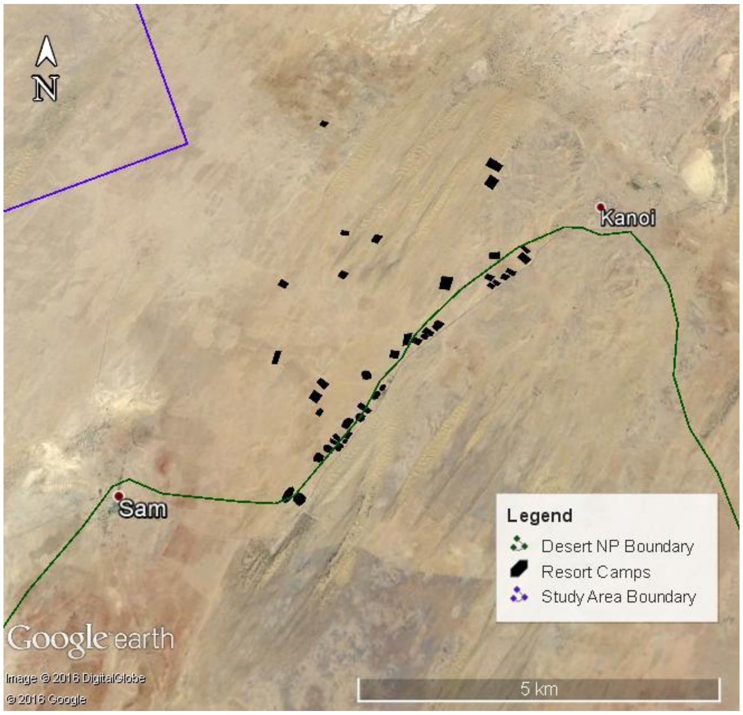
My study was conducted in Thar landscape, west of Rajasthan, India from December 2016 to April 2017 (**Map 1**).



Map 1. Study area map. The relative location of Rajasthan in India and the position of the study area in the state.

Thar landscape is under biogeographic zone 3 (Indian desert) per the classification provided by Rodgers et al. 2002. It is one of the most populated deserts in the world inhabited with 85 humans/km^2 (Rahmani 1989). My study area comprises of the northern part of Desert National Park (hereafter DNP) with 18 human settlements (7 within the NP and 11 at the periphery) and about 70 resort camps as well as the arid landscape outside the protected area.

My study area includes the tourism zone comprising of resort camps, wilderness and traditional agro-pastoral area since I expected dog densities to respond to tourism waste deposits. The resort camps providing concrete and tented accommodation are situated between Sam and Kanoi and only open during the tourist season which is November to February (**Map 2**). During this season, dogs are seen close by and feed on the leftovers thrown in dumps behind the resort camps. Hence, this area is considered an important stratum in my study area.



Map 2. The tourist area between Sam and Kanoi which is open from November to February only

DNP is the largest national park in India with an area of 3162 km^2 (Sharma et al. 2013). It was officially notified in 1980 and is part of the Thar landscape. It is situated in the state of Rajasthan extending over two districts, that of Jaisalmer and Barmer (Sharma et al. 2013).

The southern half of my study area (**Map 1**) is dotted with Dhanis where local pastoral communities stay in thatched huts through the year or on seasonal basis to graze their livestock in adjoining habitats. In the same area, the Forest Department has created enclosures for Great Indian Bustard conservation that harbours other wildlife. This combination, results in free-ranging dogs in biodiversity rich habitats whose impacts can be potentially detrimental to wildlife conservation.

My study area of about 1008 km^2, a typical desert landscape was chosen due to high records of Great Indian Bustards (*Ardeotis Nigriceps*) and native wildlife (Dutta et al. 2016, **Figure 1**). Some native wildlife which are potential prey for free-ranging dogs in this area are nilgai, chinkara, Indian fox, desert fox, desert cat, great Indian bustard, spiny-tailed lizard and Indian desert jird. Local people, although agnostic towards free-ranging dogs, occasionally feed them. The area is a mosaic of grassland, gravel and sand dune habitats interspersed with human habitation and agricultural patches providing an ideal setting for studying free-ranging dog ecology especially interactions between dogs and wildlife.

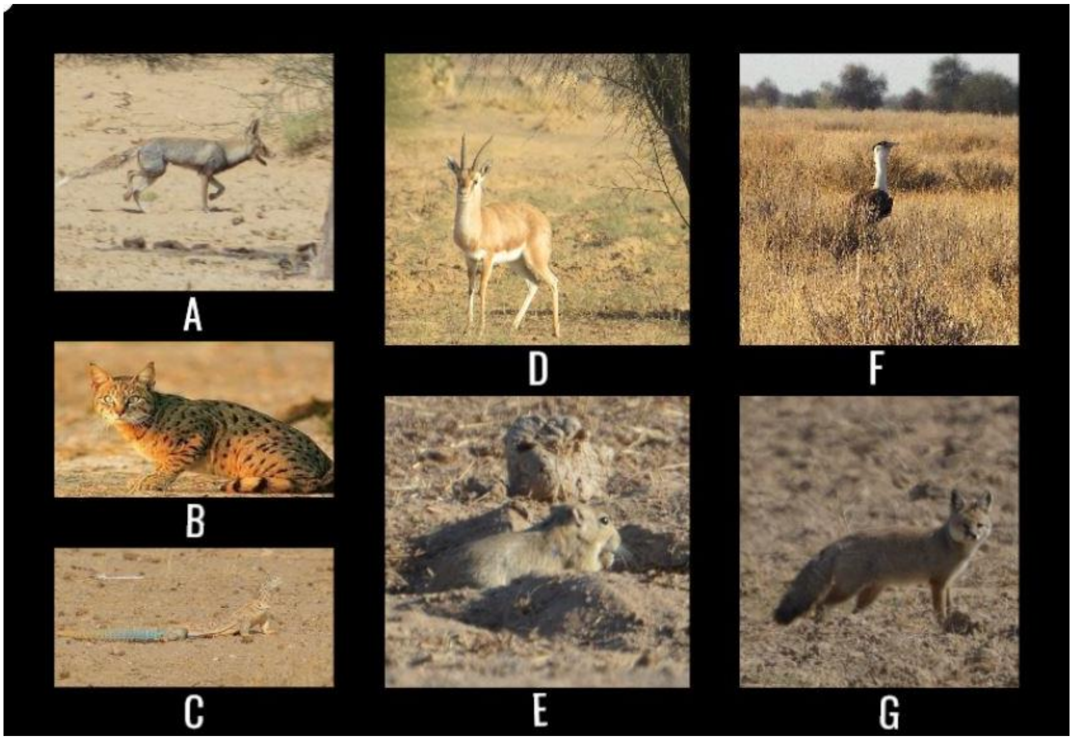


Figure 1. Some major wild fauna found in Thar landscape, Rajasthan. A. Desert fox (*Vulpes vulpes pusilla*), B. Desert cat (*Felis silvestris*) © Ramki Sreenivasan, C. Spiny tailed lizard (*Saara hardwickii*), D. Chinkara (*Gazella bennettii*), E. Indian desert jird (*Meriones hurrianae*), F. Great Indian Bustard (*Ardeotis Nigriceps*) and G. Indian fox (*Vulpes bengalensis*)

This landscape harbours grasslands dominated by *Lasiurus sindicus* and *Dactyloctenium sindicum*, scrublands dominated by *Zizyphus mauritiana, Capparis decidua, Haloxylon salicornicum* and *Crotolaria bhuria* shrubs as well as thorny scrubs (Dutta et al. 2016). Rainfall is minimal and infrequent with an average of 100-500 mm yearly that declines in an east to west gradient (Pandeya et al. 1977). During the summers (April to June), temperatures rise to ≥50˚C while in the winters (November to February) temperatures drop below 0˚C (Sikka 1997).

Figure 2. Topographical features in Thar landscape. A. Grasslands, B. Settlements, C. Sandy scrub, D. Agriculture, E. Sand dunes and F. Dhani

CHAPTER 3

METHODS

Ethics Statement

All permissions to carry out the research work were obtained from the Office of the Chief Wildlife Warden, Rajasthan State (Letter no: F3(02)/CWLW/2015/1/97, dated:23 November 2016) under provisions of the Wildlife (Protection) Act, 1972, Government of India. Permission for radio-collaring dogs were obtained from the office of the Deputy Conservator of Forest and Director, Desert National Park and carried out under the supervision of a veterinary official from Jodphur. The dissertation committee of Wildlife Institute of India which also considers the ethics of research methods approved the study.

3.1 Population Estimation

I estimated dog numbers in settlements and tourism area using a double sampling approach (Cochran 1977), where crude counts of dogs were calibrated with mark-recapture based abundance. I also estimated landscape-scale dog abundance using vehicle transect based distance sampling. While conducting count surveys, the sociodemographic (religion) and socio-economic factor (number of livestock holding) of settlements were recorded.

- **Field methods**

Dog Count Survey

To count dogs in human settlements, I mapped settlements in the study area via Google Earth and ground-truthed them using surveys. Eighteen settlements (consisting of at least 15 houses) were noted (see Chapter 2, **Map 1**). I, then created trails passing through the settlements using Google Earth (see Appendix, **Figure A1**). The putative trail length was 10km per 1km^2 settlement area. For the dog count survey, one observer walked through the settlements on the digitised trails and counted the number of dogs while recording their age (pup or adult) and gender with minimal deviation from the created path. These counts were done only once in all settlements within my study area. Although this approach did not account for imperfect detection, it generated a logistically easy index of abundance.

Mark-Recapture

To estimate detection-corrected abundance of dogs, I conducted mark recapture sampling in six settlements and the tourism resort area that were selected based on count surveys to represent the entire range of the population count spectrum (low to high dog counts). The six settlements were *Bida, Kuchhri, Lakhmanon ki basti*, *Neemba*, *Salkha* and *Sam* and the tourism area between Sam and Kanoi.

During the mark recapture sampling, my field assistant and I (navigator and observer) walked through the settlement on the same trail but maximized capture probability by intensively searching for dogs (deviating from the trails when required). For the tourism area, mark recapture sampling was conducted on a slow-moving vehicle (20km/h) with an open top. The left and right flank and the front side of each dog were photographed and its gender was recorded for identification. The images were captured using a Samsung SM101C smartphone with 10x optical zoom which had an installed OSM Tracker application (OSM Tracker, Hiby 2016) configured for the mark recapture sampling of dogs (see Appendix for details, **Figure A2**). Each session was of four occasions for all sites except for settlement, *Lakhmanon ki basti*, where sampling was done for three occasions due to issues with logistic constraints. The mark recapture and count surveys for Sam and Salkha were obtained from an earlier pilot survey conducted in September 2016 and reported in Hiby et al. (2016).

Vehicle Transect

To estimate landscape-scale dog abundance using distance sampling, the entire study area was divided into 28 grids, each of 6 x 6 km using ArcGIS 9.3 (ESRI). Each grid, had a random point and I digitised transects on Google Earth passing through the random point by following visible dirt trails (see Appendix, **Figure A3**). The length of each transect was 8.14 ± 0.07 km and if a settlement was present the transect passed through it. During vehicle transect exercise, species, count, perpendicular distance and GPS locations were recorded using handheld LASER rangefinder (make:Bushnell), magnetic compass (SUUNTO see through) and GPS Garmin etrex30 (Appendix, **Figure A4**). Each transect was surveyed through twice on a slow-moving vehicle (speed ≤20 km/h), once each in winter (January-February 2017) and summer (March 2017).

- **Analytical methods**

Mark Recapture

For mark recapture based abundance estimation, I identified individual dogs from the photographs using gender, pelage patterns and natural markings (like scars, wounds and ear-cuts) (see Appendix, **Figure A5**). I removed duplication of same individuals (if any) within a session. The first session was compared with the next session and individuals that were detected in both sessions were given the same identity code (ID). The process was repeated for subsequent sessions. A detection history '1 0' X-matrix was generated for each site (Otis et al. 1978). The entire mark recapture process for six settlements and tourism area was completed within two months.

I tested for population closure using Pradel models, where an unconstrained model with survival (phi), recruitment (f) and recapture parameter estimates was compared with a constrained model where phi and f were fixed at 1 and 0 respectively to assume no loss or gain. I considered the population closed if the constraint model found more support than the unconstrained model in terms of AIC and likelihood ratio test (Cooch and White 2009).

For closed population abundance estimation, I modeled detection parameters as constant (null model: M_0), time-variant (M_t), variable between individuals (M_h) and variable with time and individual (M_{th}) using Huggins model in Program Mark (White and Burnham 1999). The behaviour model, M_b was not run because we did not physically capture dogs for marking. Hence, we did not expect a behavioural response of trap shyness and trap happiness by dogs during recaptures. However, time model, M_t was tested because the capture probability of dogs in the settlements partially depended on their movements away from settlements to food resource areas such as tourism areas and carcass sites within the day. Heterogeneity model, M_h with 2 mixtures was tested with an assumption that there might be a difference in behavioural or personality between individual dogs. I diagnosed model parameters for convergence issues and removed models with convergence errors from candidate set. I ranked remaining models using AICc scores and selected the least AICc model for inferring. If two models had similar support (ΔAICc<2), then I used the simpler model for inference.

Dog Count Survey

To calibrate the relationship of counts with abundance, $\widehat{N}$ (obtained from mark-recapture analysis), dog abundance was modeled with count in the six settlements using linear regression in R version 3.3.1 software (R Core Team). Dog abundances in the remaining 12 villages were then predicted by fitting counts to the calibrated equation. For tourism area, I computed the ratio of count to $\widehat{N}$ in one block and used that ratio to correct counts into abundance in other two tourism blocks. Standard errors in predicted abundance was generated by bootstrapping.

Vehicle Transect

Vehicle transect data consisting of dog sightings, spatial location, angle and distance was analysed in Distance 7.0 software (Thomas et al. 2010) to estimate density of free-ranging dogs in a landscape-scale. I fitted half-normal, uniform and hazard rate models with cosine, hermite polynomial and simple polynomial series expansion and estimated effective strip width and density based on the model with least AIC and satisfactory goodness of fit following Buckland et al. (2015).

3.2 Ranging Patterns

I constructed a home range map using minimum convex polygon and fixed kernel densities. I obtained GPS locations through radio-telemetry data of five dogs and using commercial vehicle tracking satellite tags on four dogs.

- **Field methods**

To capture and radio-collar free-ranging dogs, baits (using carcasses from natural-mortalities) and track-and-dart techniques were used. Some dogs (n=3) were trapped on a carcass using soft-padded foot-hold traps. Upon being trapped, a gas-powered dart delivery system was used. Other dogs (n=6) were darted directly by following them on foot or a 4-wheel drive. Telonics MOD 400 VHF radio transmitter collars were then placed on the captured free-ranging dogs (N=9, 5 Males, 4 Females) in Desert National Park. These collars weighed on an average of 400g (~1-2% of the dog's weight).

Although, one male dog's transmitter was removed by a villager, 25 days after collaring it, 26 locations were obtained prior to the collar being removed and thus data was still used for computing ranging patterns.

Table 1. Details of the dogs collared in the wild (inside Desert National Park)

S. No	Collaring Batch	Sex	Individual Names	Details
1.	First	Female	WII-6	Mother with 5 pups. In a pack with WII-5 and WII-9.
2.	First	Male	WII-5	In a pack with WII-6 and WII-9.
3.	First	Male	WII-7	Slightly more tolerant towards humans compared to the rest
4.	First	Male	WII-8	The individual whose VHF collar was removed after 25 days by a villager and died on 16th February 2017.
5.	First	Male	WII-9	In a pack with WII-5 and WII-6 but seen alone too.
6.	Second	Female	WII-1	Mother with 4 pups
7.	Second	Female	WII-2	Mother with 3 pups
8.	Second	Female	WII-3	Mother with 4 pups
9.	Second	Male	WII-4	Seen alone or sometimes with a brown female dog

Each radio-collared dog was located by actual sighting and homing in (White and Garrott 1990) systematically across different times of the day from vehicle using either a three element Yagi or H antenna with a handheld receiver (Habit model HR 2600/ Telonics TR-

4). The activity of the dog, GPS location, associated individuals and time were recorded daily for each individual.

Commercial vehicle tracking satellite tags (make: SPOT Trace) (weighing ~88 g) were placed on 4 collared individuals in addition to the MOD 400 collar to provide remotely accessible location data at a very fine resolution (5-minute interval). The SPOT data were downloaded from the website: https://login.findmespot.com/spot-main-web/auth/login.html.

- **Analytical methods**

All data explorations were done using MS Excel 2016 (Microsoft Inc.).

Minimum Convex Polygons (MCP) were created for each dog from the GPS locations using ArcGIS 9.3 (ESRI) and Biotas 2.0α (Ecological Software Solutions LLC).

Home ranges were estimated using area accumulation plots wherein 20% - 100% MCP were digitised (Harris et al. 1990). The point after which the area enclosed reached an asymptote despite an increase in MCP percentage, was taken as the home range.

I, also, used fixed kernel estimators in Hawths Tools (White and Garrott 1990) in ArcGIS 9.3 (ESRI). For each dog, kernel home range areas corresponding to 15%-95% contours or isopleths were derived and the mean proportion of area enclosed by isopleths relative to the maximum (95% contour area) was plotted. The isopleth corresponding to inflection point in the graph where home range area increased rapidly or exponentially indicated the area. I compared the distances of nearest enclosure and settlement to dog radio-locations with 1000 random points in the combined dog MCP area, using frequency distribution and t-test.

3.3 Resource Utilisation

From 24-hour continuous monitoring data, I constructed an activity pattern and time budget. I used Ivlev's Index to understand prey preference by free-ranging dogs and computed the number of chinkara and nilgai kills annually by dogs found in the wild in my intensive study area.

- **Field methods**

Behaviour

Initially, I followed four radio-collared dogs on foot and/or four-wheel drive to understand the starve-feed cycles, distinguish between predation and scavenging events and develop a behaviour sampling protocol (**Table 2**).

Table 2. The total time spent continuously monitoring each dog.

Individual Names	Total time spent on continuously monitoring dogs (hours)
WII-6	216
WII-5	156
WII-7	156
WII-9	156
WII-2	96

Hence, a total of 876 hours of continuous monitoring data was recorded during the study period. Data collected were time, belly score, activity, GPS location, presence and interaction of associated individuals, presence and interaction of prey (goats, sheep, chinkara and nilgai), presence and interaction of competitors (wild pig and vultures) and presence and interaction of humans (see Appendix, **Figure A6**).

During the study, dogs were kept in view or within 50 to 150 meters from the observer's, day and night. Prior to continuous monitoring, we habituated the dogs to our presence and the usage of flashlight at night for two weeks. The dogs were tolerant to our presence within 50m without any obvious alteration in their behaviour. At night, a flashlight was used at every 10 minute intervals to confirm dog location apart from radio signals. All predation and scavenging events by dogs were recorded during continuous monitoring. The behavioural states and events were also recorded to assess temporal activity pattern and time activity budget (**Table 3**).

Table 3. Definition of different key activities used in the study for assessing time activity budgets in free-ranging dogs (modified after Schaller 1972, Creel and Creel 2002).

States	Definition
Alert	Either standing on fours or sitting on twos or all down while scanning the surroundings and being alert. Face muscles are tight, mouth is closed and ears cocked up.
Feeding	Feeding on carcass (predated or scavenged) gauged by direct observations. Includes drinking (lapping) of water.
Grooming	Scratching ears and nose, licking genitals and other parts of the body and using plants or other materials as a means of cleaning themselves.
Interaction	When two dogs are seen in close proximity (touching) with each other. For instance, suckling, licking, sniffing, playing and aggression.
Hunting	The act of predation which comprises of stalking, chasing, actual act of bringing down prey (usually done when there are two dogs for large mammals but for small animals only one individual is present). Includes, digging to get Spiny tailed lizard and Desert jird out from their burrow.
Moving	Travelling from one point to another alone or with the presence of associative individuals or pups. Face is open mouthed with relaxed muscles and is usually silent.
Resting	Sitting or lying in a relaxed posture with the head pointing downwards and the mouth either loosely closed or lower jaw drooping. Also, lying flat on one side with flank, head and legs resting on the ground.
Wallowing	Cooling the body by sitting or lying in water or mud for a period of time.

Events	Definition
Barking	Vocalisation with slightly raised muzzles and includes growling, howling, whimpering and barking.
Excretion / Scent Marking	Stopping at intervals while moving and urinating while standing with hind limb up (characteristic of dominant male canids) or by squatting (both males and females) and defecating.
Sniffing	The nose is pointed towards the ground while moving or when stationary.
Regurgitate	Contents from the stomach is removed via the mouth.

Resource Quantification

To quantify resources available for free-ranging dogs in this area, I estimated prey and carcass density by using the following methods:

i) Based on GPS locations obtained from collared dogs, a 100% MCP was created with a 2km buffer around it. In the first method, this area was divided into 94 grids of 1km x 1km and in each grid, a diagonal 1km line transect was laid (see Appendix, **Figure A7**). Two observers walked on the 1km line transect. While the first observer, upon encountering wild prey, recorded the species, count, transect bearing, animal bearing, distance and GPS location, the second counted and recorded the number of active jird and spiny tailed lizard burrows in the first 500m x 2m belt of the transect (see Appendix, **Figure A8**).

ii) To estimate the number of available carcasses, a route of 127km was digitised on Google Earth (see Appendix, **Figure A9**). The route was sampled at 16 day intervals, recording carcass of cow, nilgai, chinkara, goat and sheep, the condition of carcass (fresh, partially eaten, completely eaten), presence of scavengers, GPS location, closest distance from the route and approximate size of the carcass (see Appendix, **Figure A10**). Carcasses that were previously recorded were not noted down in subsequent surveys.

- **Analytical methods**

Behaviour

Behavioural data of 876 hours collected during 24-hour continuous monitoring sessions was used to understand temporal activity pattern. I divided the time of the day into eight periods of three hours each and calculated proportional time spent on these activities for each period. Mean and standard error of proportion time spent on activities was estimated across dogs. I calculated the average of total time spent for each activity by free-ranging dogs, by dividing the time spent for each activity per dog, by the total hours of observation for each dog to obtain a time activity budget. A graph depicting the type of prey (livestock carcass and wild prey) and the quantity fed upon by dogs in both seasons was generated.

Resource Quantification

Wild prey (chinkara and nilgai) data was analysed using Distance 7.0 software (Thomas et al. 2010) by fitting half normal, uniform and hazard rate models with cosine, hermite polynomial and simple polynomial series expansion to distance data and estimating effective strip width and density based on the least AIC model with satisfactory goodness of fit. Since spiny tailed lizards live solitarily, the number of active burrows accounts for the number of individuals following Dutta and Jhala (2007). Density of jird was calculated from burrow counts using the calibration model developed by Ramesh (2011).

Carcass density was computed using Distance 7.0 (Thomas et al. 2010) based on relative size (>50kg was categorised as big (cattle and nilgai) and <50kg as small (chinkara, goat and sheep)) and based on each route and its replicate (N=4). From the prey items fed by free-ranging dogs during the 24-hour continuous monitoring, the amount utilised by free-ranging dogs from what was available was derived. Since there were no actual weights of prey eaten by dogs, which was difficult to enumerate in field, time spent on carcasses were taken as surrogates of biomass consumed. With the data obtained, Ivlev's index was used to understand the preference of prey items by free-ranging dogs in Thar landscape, Rajasthan. The biomass of wild prey was based on Dutta (unpublished data), Ramesh (2011) and Menon (2014).

Predation rate

Predation rates of chinkara and nilgai were obtained from continuous monitoring data and expressed as numbers killed/days observed for each dog. This rate was averaged across all monitored dogs. The number of dogs found in the intensive study area of 94km^2 (see Chapter 4, section 4.3), was multiplied with the number of kills per dog in a year to determine the average number of chinkara and nilgai individuals that are potentially predated annually.

Data was processed using MS Excel 2016 (Microsoft Inc.) and the softwares specified above.

CHAPTER 4

RESULTS

4.1 Population Estimation

- **Dog abundance in settlements and tourism area**

I estimated mark recapture based dog abundance in four settlements (Bida, Kuchhri, Lakmanon and Neemba) and the tourism area. I used the results on dog abundance of two additional settlements (Sam and Salkha) from Hiby et al. 2016. Closure test using Pradel models indicated that all four settlements were closed populations **(Table 4)**.

Table 4. Models for closure test in four settlements in Thar landscape, Rajasthan with their corresponding number of parameters (K), AICc values, difference in AICc values between the jth model and the model with the lowest AICc value (ΔAICc) and deviance.

Settlement	Model Name	K	AICc	ΔAICc	Deviance
Bida	{phi(1) f(0)}	1	83.99	0	9.12
	{phi(.) f(.)}	2	85.81	1.82	8.73
Lakmanon	{phi(1) f(0)}	1	64.11	0	15.39
	{phi(.) f(.)}	3	68.22	4.11	14.69
Kuchhri	{phi(1) f(0)}	2	279.30	0	44.62
	{phi(.) f(.)}	4	281.60	2.30	42.66
Neemba	{phi(1) f(0)}	1	385.56	0	20.84
	{phi(.) f(.)}	3	388.05	2.49	19.21

phi – survival parameter
f – recruitment parameter
(1) – present
(.) – constant
(0) – absent

Heterogeneity models for all four settlements did not converge and were removed from model comparison. Null model (M_0) found maximum support for Bida and Kuchhri while, time model (M_t) found maximum support for Neemba (**Table 5**). For, Lakmanon time (M_t) and null model found equal support (ΔAICc =0.04) and I selected the M_0 model (**Table 5**).

Table 5. Models for closure test in four settlements in Thar landscape, Rajasthan with their corresponding number of parameters (K), AICc values, difference in AICc values between the jth model and the model with the lowest AICc value (ΔAICc) and deviance.

Settlement	Model Name	K	AICc	ΔAICc	Deviance
Bida	Mo	1	83.95	0	70.47
	Mt	4	90.30	6.35	70.20
Lakmanon	Mt	3	64.01	0	72.24
	Mo	1	64.05	0.04	76.73
Kuchhri	Mo	1	204.40	0	323.04
	Mt	3	207.27	2.87	321.79
Neemba	Mt	4	378.31	0	476.88
	Mo	1	385.55	7.24	490.25

Salkha had the highest dog abundance, $\widehat{N}$ with 125 $\pm$ 8.75 individuals while Bida had the lowest dog abundance with a $\widehat{N}$ of 16 $\pm$ 0.54 individuals (**Table 6**). During dog count survey, number of dogs recorded for Salkha was 76, Sam was 65, Neemba was 48, Kuchhri was 36, followed by Bida and Lakmanon at 16 and 12 respectively.

Table 6. Number of dogs counted within a settlement and the estimated population size ($\widehat{N}$) of dogs for six settlements in Thar lansdscape, Rajasthan with standard errors (SE).

Settlement	Count	M_{t+1}	$\widehat{N}$	SE
Bida	16	16	16	0.54
Kuchhri	36	52	60	3.88
Lakmanon	12	16	18	1.68
Neemba	48	71	74	2.03
Salkha	76	103	125	8.75
Sam	65	82	115	10.35

- **Estimated population size with dog counts**

When population size was plotted against dog counts, the abundance of dogs increased linearly with an increase in count (N=6, y=1.65x, R^2=0.99, $p<0.05$, **Figure 3**). The intercept was forced at the origin for Figure 3 because y-intercept was insignificant (encompassing zero) indicating that when no dogs were counted the dog abundance was a negative value. Using the equation, y=1.65x, the dog population was modelled for all settlements in my study area (**Table 7**).

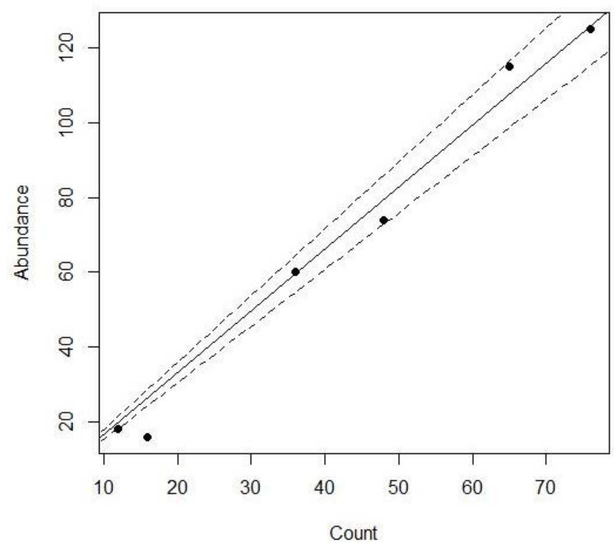


Figure 3. Estimated population size ($\hat{N}$) of dogs plotted against dog counts in six settlements.

Table 7. Predicted population of dogs in 12 settlements with respective standard errors (SE).

Settlement	Count	Predicted $\hat{N}$	SE
Balanio Ki Dhani	3	5	0.02
Ganga	12	20	0.08
Ghuriya	22	36	0.14
Ishaniyon Ki Basti	16	26	0.10
Jamra	6	10	0.04
Kangar Ki Dhani	2	3	0.01
Kanoi	71	117	0.45
Keshovon Ki Basti	23	38	0.14
Lolai	6	10	0.04
Loonoon Ki Basti	0	0	0
Rojani Ki Basti	4	7	0.03
Sagroan Ki Basti	1	2	0.01

Closure test using Pradel model indicate that tourism area block 1 was an open population. For tourism area, I estimated the initial population size and superpopulation using POPAN model in program Mark (White and Burnham 1999) was used to estimate the initial population or the super-population. The best model assumed a time constant survival parameter, zero probability of entering the population from the super-population (surrounding wild and settlement area) and time-constant recapture parameter (**Table 8**). The initial population size which was same as the superpopulation size was estimated at 44 $\pm$ 3.86 individuals. On an independent count survey in tourism area block 1, I counted 10 dogs and computed count abundance ratio of 4.40. Using this ratio, I corrected counts in the entire tourism area (block 1, block 2 and block 3) to abundance estimate of 79 $\pm$ 6.95 dogs.

Table 8. Models for population estimation of dogs in tourism area in Thar landscape, Rajasthan with their corresponding number of parameters (K), AICc values, difference in AICc values between jth model and the model with the lowest AICc value (ΔAICc) and deviance.

Model Name	K	AICc	ΔAICc	Deviance
{Popan (phi=(.) pent=0 N0=(.)}	3	164.34	0	0
{Popan (phi=(.) pent=(.) N0=(.)}	3	26986.86	26822.52	26803.11

phi – survival parameter
pent – probability of entry
N0 – initial population size
(.) – constant
(0) – absent

- **Socio-demographic and socio-economic factors with dog abundance**

Dog abundance was not affected by religion (Hindu and Muslim) of settlements (t-stat=0.106, df=7, p>0.05, **Table 9**). Moreover, there was no correlation between livestock holding on dog abundance (R=0.10, N=15, p>0.05).

Table 9. Mean dog abundance in settlements based on the majority ethnic group with respective standard errors (SE).

Religion of settlements	Mean dog abundance/household	SE
Hindu	0.13	0.05
Muslim	0.14	0.04

- **Dog Density in study area**

The dog density was also estimated in the larger landscape inclusive of wilderness habitats and areas without settlements and tourism between January to March 2017. Half normal-cosine adjustment model was selected based on least AICc score and satisfactory goodness fit (χ^2 =0.46, df=3, p=0.93) with an effective strip width of 85.78 $\pm$ 6.40 meters (see Appendix, **Figure A11**). Dog density of 1.79 individuals per km^2 was estimated from January to March 2017, yielding an abundance estimate of 1804 dogs in my study area (**Table 10**). Since, there was no difference in detection function between seasons, I pooled both seasons to estimate detection function more robustly and precisely. 28% of the dog observations in winter were of pups while in summer it was 16% indicating that there were 0.12 dogs less in summer per dog observed in winter.

Table 10. Number of dogs (N), density (individual/km^2) (D), encounter rate (DS) and cluster size (ES) with standard errors in Thar landscape based on season.

Season	Parameters	Estimate	SE
Winter	N	2265	634.89
	D	2.25	0.63
	DS	1.46	0.38
	ES	1.53	0.16
Summer	N	1381	517.64
	D	1.37	0.51
	DS	0.87	0.31
	ES	1.57	0.16
Winter and Summer	N	1804	461.76
	D	1.79	0.46
	DS	1.16	0.31

4.2 Ranging Patterns

- **Home range of free-ranging dogs**

The average home range size (95% MCP) irrespective of sex-classes for nine collared dogs were 19.81 ± 4.79 km^2 in Thar landscape, Rajasthan. Meanwhile, for 95% KDE it was 31.89 ± 3.03 km^2 and for 85% KDE it was 18.67 ± 4.82 km^2. The average home range size of male dogs was 20.24 ± 5.94 km^2 (N=5) while for females it was 19.26 ± 8.85 km^2 (N=4). Home range size was similar between male and female dogs. The average area of overlap between males was 49.60 ± 7.58 % while between females it was 42.92 ± 15.63 %.

Table 11. Number of GPS location, 95% MCP, 95% KDE, 85% KDE for each radio-collared dog.

Individual	Number of GPS locations	95% MCP (km^2)	95% KDE (km^2)	85% KDE (km^2)
WII-1	2578	9.85	24	15
WII-2	2364	10.65	26	16
WII-3	2680	45.82	47	22
WII-4	2887	38.41	38	20
WII-5	91	21.93	36	24
WII-6	104	10.73	27	16
WII-7	105	2.68	18	10
WII-8	26	13.54	31	20
WII-9	82	24.65	40	25

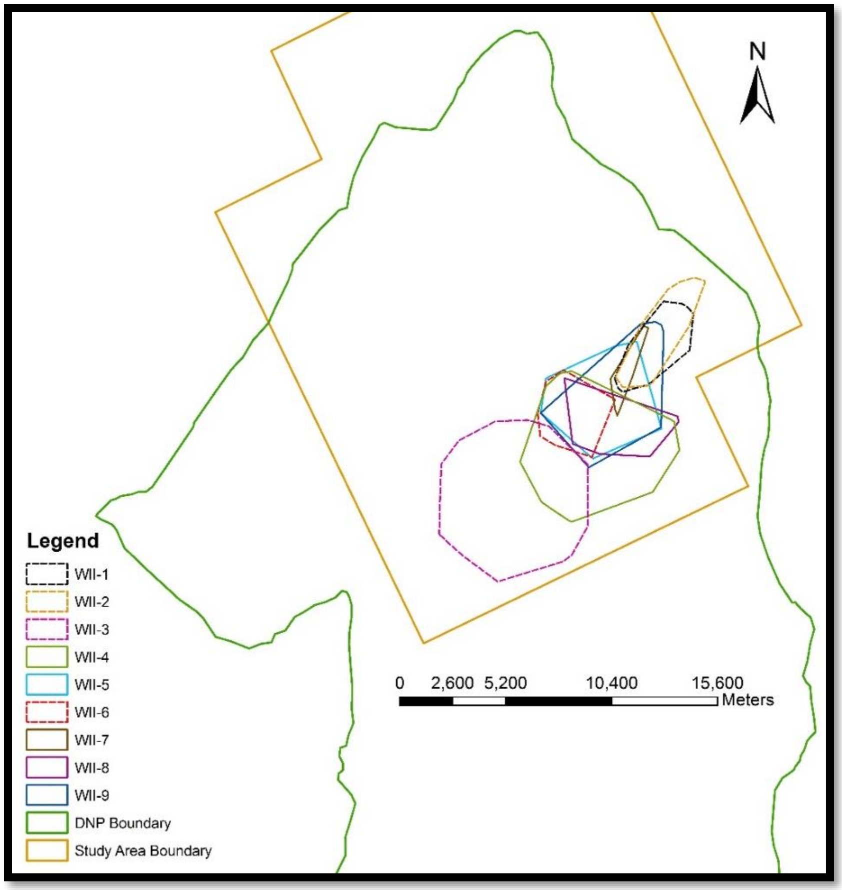


Figure 4. 95% MCP home ranges (km^2) of free-ranging dogs in Thar landscape, Rajasthan from January to April 2017. The home ranges indicated by dotted lines refer to females while the solid lines refer to males.

Kernel home range analysis shows that beyond 85% fixed kernel, the isopleth area increment was exponential indicating the latter to be caused by exploratory forays and movements outside the usual ranges of the individual (**Figure 5**). Hence, 85% was used to indicate home range of dogs in Thar landscape, Rajasthan. The average area for males was 19.80 ± 2.65 km^2 **(Figure 6**) while for female dogs it was 17.25 ± 1.60 km^2 (**Figure 7**).

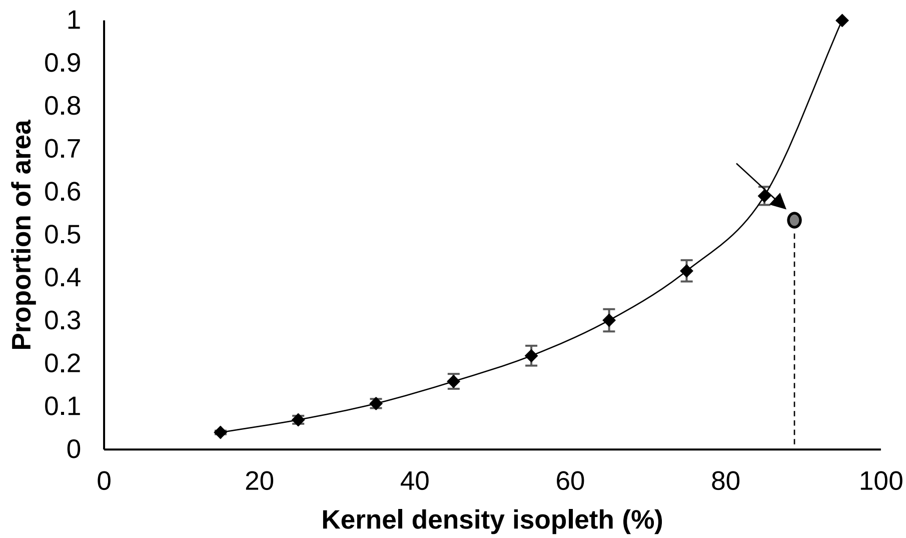


Figure 5. Proportion of home range area of free-ranging dogs against different kernel density isopleths with respective standard errors.

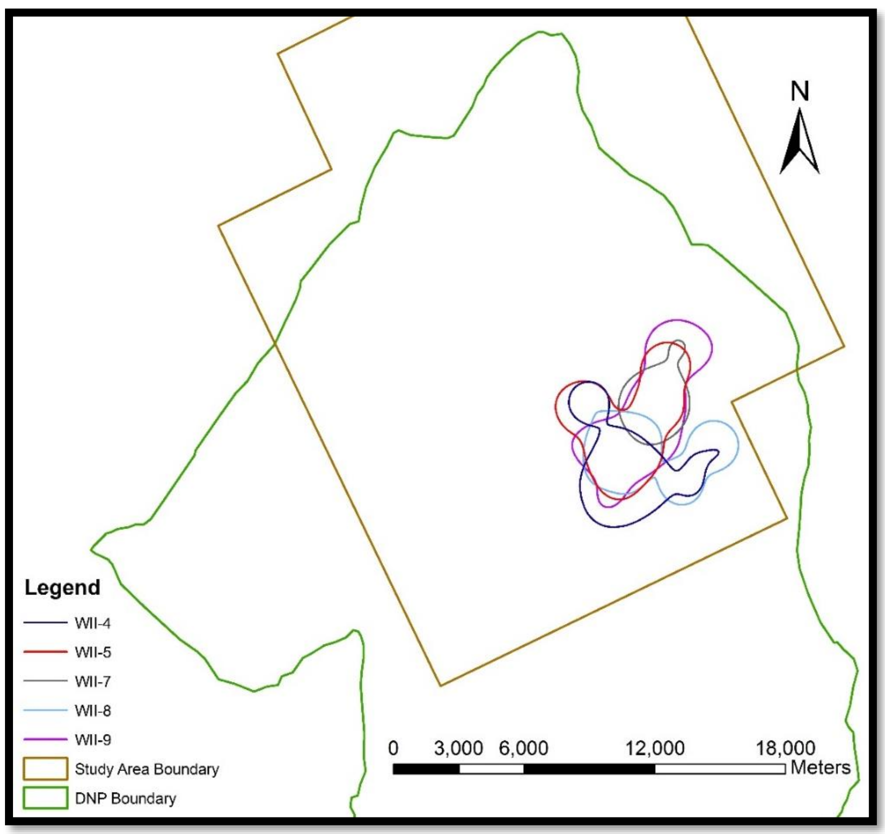


Figure 6. 85% fixed kernels showing home range (km^2) of male radio-collared dogs in Thar landscape, Rajasthan from January to April 2017.

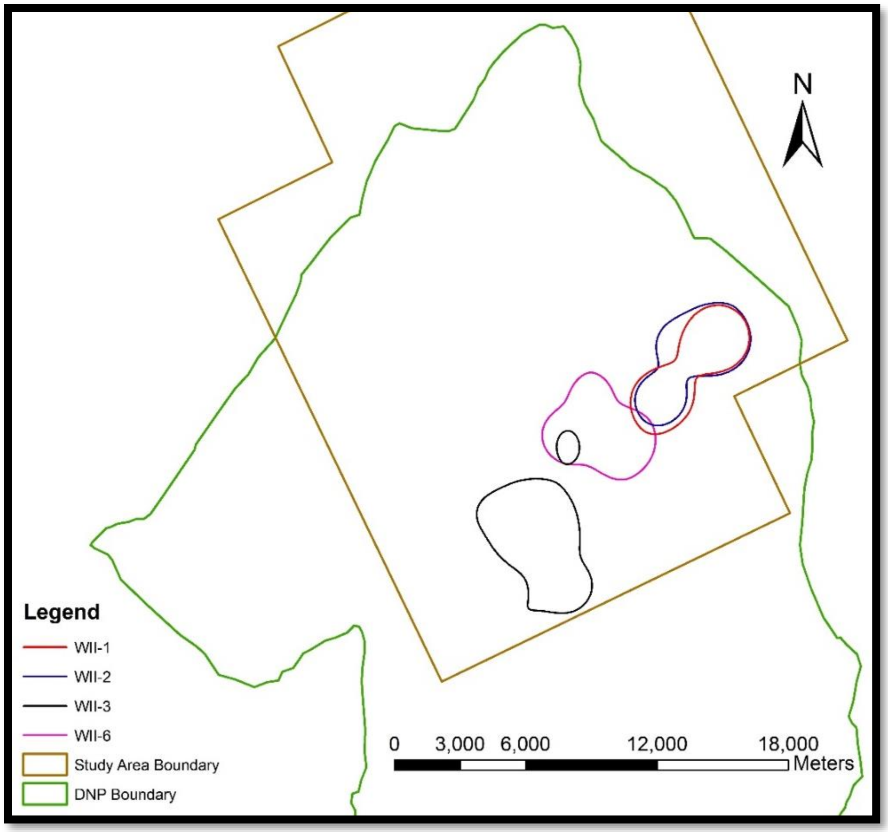


Figure 7. 85% fixed kernels showing female home range (km^2) of radio-collared dogs in Thar landscape, Rajasthan from January to April 2017.

- **Distance of home range to nearest enclosure and settlement**

Dogs were two-fold closer to enclosures (x=746 m, CI=16, n=11083) and three-fold closer to settlement (x=599 m, CI=14) than random locations (distance to enclosure = 1699 m, CI=101, n=1000 and distance to settlement = 1828, CI=65) (**Figure 8** and **Figure 9**).

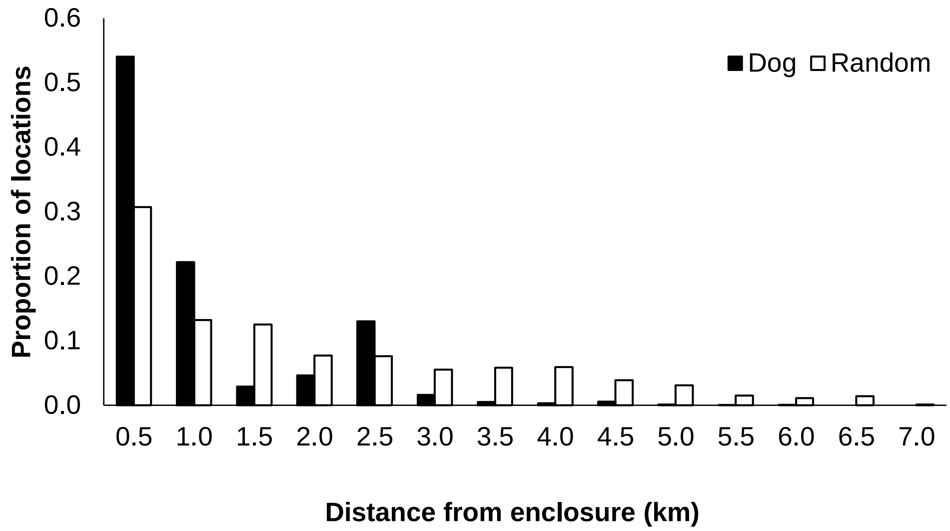


Figure 8. Proportion of dog and random locations with distance from enclosure.

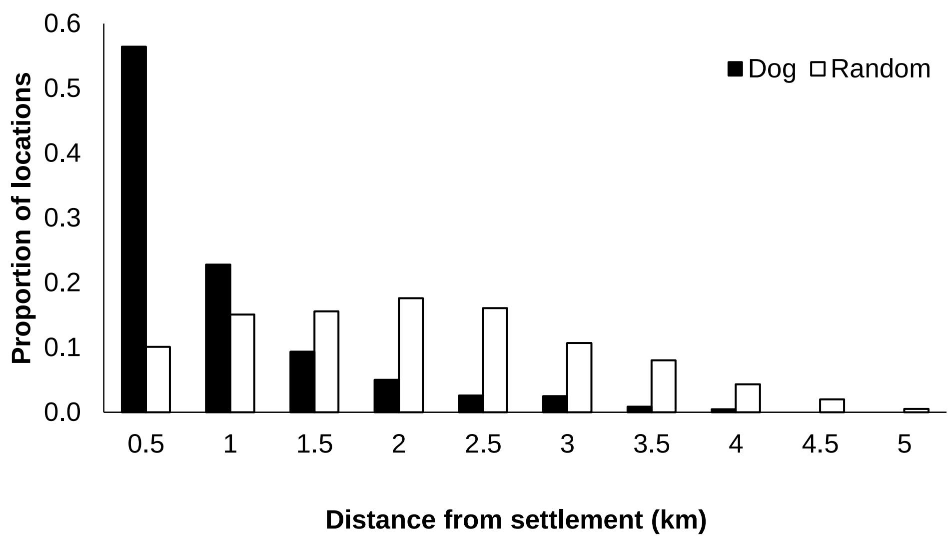


Figure 9. Proportion of dog and random locations with distance from settlement

4.3 Resource Utilisation

- **Time Activity Budget**

Free-ranging dogs spent 75% of the day resting followed by 11% moving, 10% being alert, 2% for feeding and the remaining 2% in other activities such as social interaction, hunting and auto-grooming (**Figure 10**).

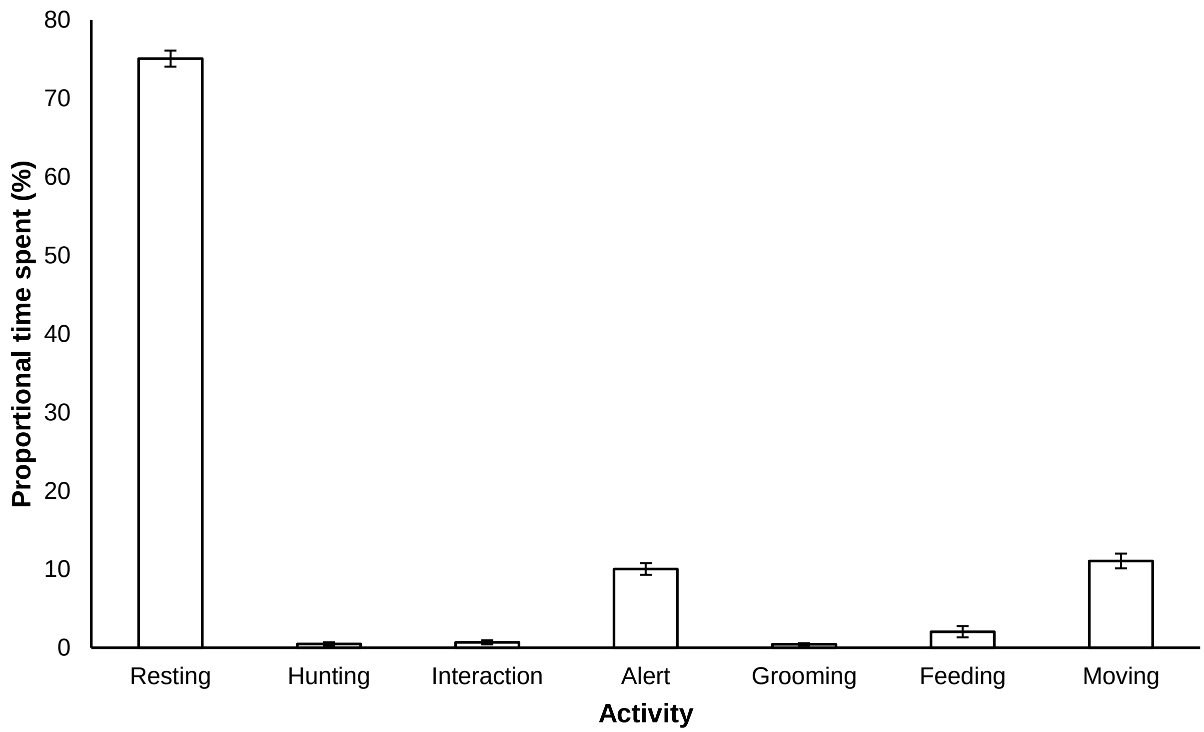


Figure 10. Time activity budget of free-ranging dogs from 24-hour continuous monitoring in Thar landscape, Rajasthan. The error bars represent standard errors with dogs as samples.

- **Temporal Activity Pattern**

A temporal activity pattern was generated based on 4 key behavioural states (**Figure 11**). Free-ranging dogs are crepuscular showing maximum activity during 0600-0900 hours and 1800-2100 hours when time allocation to resting was minimal. Dogs were observed resting in mid-day (0900-1800 hours) and mid-night (2100-0300 hours). Movements peaked between 0300-0600 hours and 1800-2100 hours. Feeding mostly occurred between 0600-0900 hours and 1800-2100 hours. Dogs were more alert in the early morning between 0600-0900 hours and became less alert in the afternoon and evening.

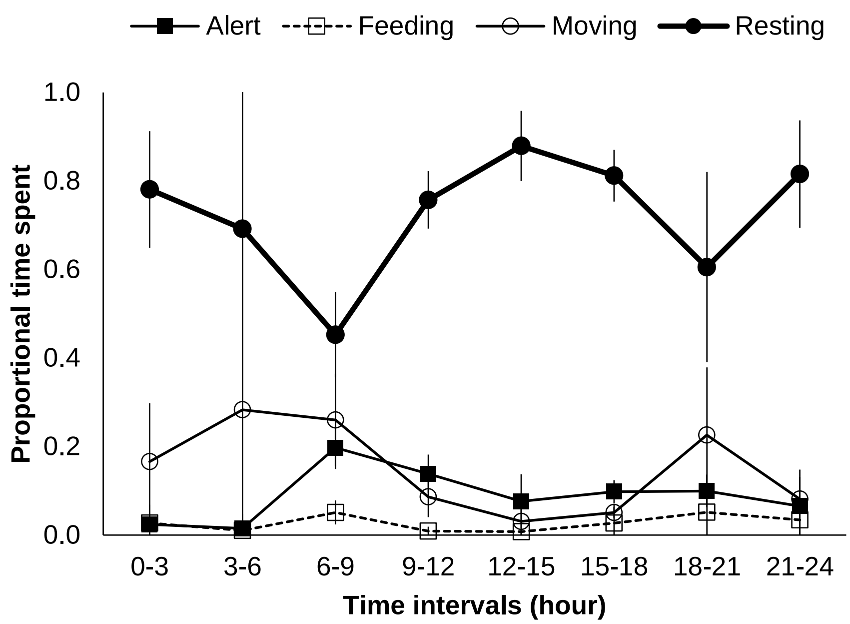


Figure 11. Temporal activity pattern of free-ranging dogs obtained from 24-hour continuous monitoring in Thar landscape, Rajasthan. The error bars represent standard errors with dogs as samples

Wild Prey Density

Analysis of detection data for chinkara showed support for uniform model with cosine adjustment. The model had satisfactory goodness of fit ($\chi^2 = 0.65$, df= 5, $p_{chinkara} = 0.99$) (**Table 12** and see Appendix, **Figure A12**). Due to small sample size of nilgai individuals, uniform model found maximum support ($\chi^2 = 0.18$, df= 2, $p_{nilgai} = 0.91$) (**Table 12** and see Appendix, **Figure A13**). **Table 13** shows the herbivore biomass per km^2 of wild prey (chinkara, jird, nilgai and spiny-tailed lizard). Spiny tailed lizard density was estimated at 4680.85 individuals per km^2. Density of jird burrows was estimated at 25925.53 per km^2 which yielded individual density estimates of 2860.66 per km^2.

Table 12. The effective strip width (ESW) (m), number of individuals (N), density (D) (individual/km^2), cluster size (ES) and encounter rates (DS) of the best model relating detections versus distance classes with respective standard errors for chinkara and nilgai.

Species	Parameters	Estimate	SE
Chinkara	ESW	180.16	12.14
	N	660	114.95
	D	7.02	1.22
	ES	2.17	0.21
	DS	3.24	0.47
Nilgai	ESW	357.76	0*
	N	43	21.64
	D	0.46	0.23
	ES	2.91	0.88
	DS	0.16	0.06

* effective strip width is equivalent to maximum width in a uniform model. Estimated with certainty.

Table 13. Herbivore biomass, density and biomass density of chinkara, jird, nilgai and spiny-tailed lizard.

Herbivore	Biomass (kg)	Density (individual/km^2)	Biomass density (kg/ km^2)
Chinkara	19	7.02	133.38
Jird	0.075	2860.66	214.55
Nilgai	110	0.46	50.6
Spiny-tailed lizard	0.225	4680.85	1053.19

- **Carcass Density**

Free-ranging dogs feed on carcasses for 51% of the feeding time from February to April 2017. Carcass densities decreased with days (N=4, R^2=0.86, p<0.05) showing a decrease in carcasses from winter through summer (**Figure 12**). Best model relating carcass detection and distance classes was selected based on satisfactory goodness of fit and least AICc score as a half-normal cosine (χ^2 = 0.67, df= 3, p = 0.88). There was no difference in detection function of carcasses in terms of size, thus, I pooled all carcass types to estimate detection function more robustly and precisely (**Table 14** and see Appendix, **Figure A14**).

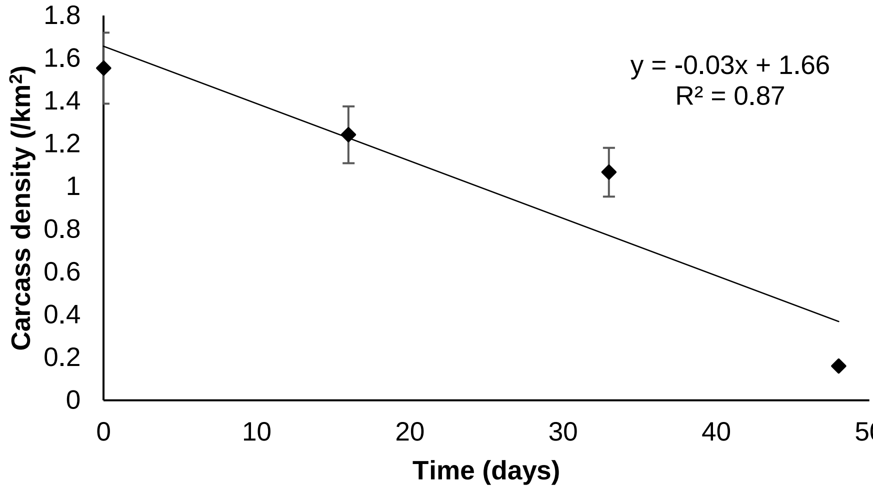


Figure 12. Carcass density of prey plotted against time with the line equation and coefficient R^2 value and respective standard errors in Thar landscape, Rajasthan.

Table 14. The effective strip width (ESW) (m), density (D) (individual/km^2) and number of carcasses (N) from March to April 2017 with respective standard errors.

Parameters	Estimate	SE
ESW	19.83	3.06
D	1.29	0.44
N	121	41.06

- **Food preference**

Livestock carcasses were fed upon more compared to wild prey in winters while in summer, more wild prey was fed upon (**Figure 13**). Ivlev's index computed on proportion time spent on different food items and their density in the wild, showed that the most preferred prey item was goat (0.96), followed by sheep (0.95), nilgai (0.46), chinkara (0.25) and cattle (0.12) (**Figure 14**). On the other hand, spiny-tailed lizard (-0.64) was not preferred.

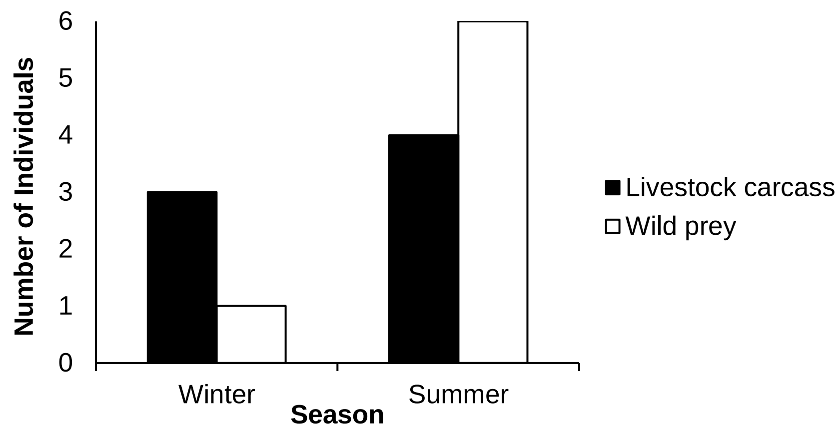


Figure 13. Comparing the number of livestock carcasses and wild prey fed upon in winter and summer for free-ranging dogs.

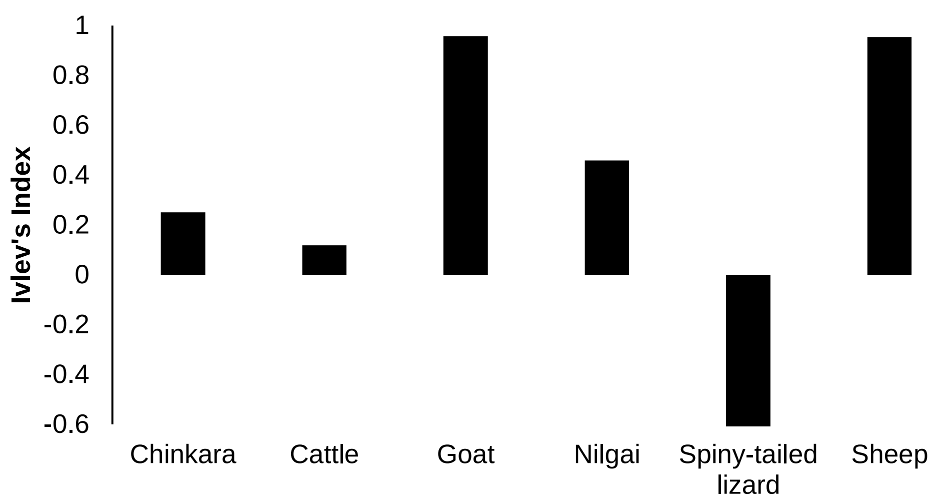


Figure 14. Ivlev's selectivity index for different prey items of free-ranging dogs in Thar landscape, Rajasthan.

- **Predation rate**

The average number of kills of chinkara and nilgai per day among the radio-collared dogs were 0.05 and 0.09 individuals respectively. In my intensive study area of 94km^2, there are about 21 dogs in total including the eight radio-collared ones. Continuous monitoring and *ad libitum* observations indicated that typical group size of dogs hunting nilgai and chinkara were 3 and 2 respectively. Predation rates of chinkara and nilgai extrapolated to these hunting dog packs indicated that 203.07 chinkara and 235.83 nilgai individuals were at potential risk from dog predation annually.

CHAPTER 5

DISCUSSION

5.1 Studying free-ranging dogs in Thar landscape

In my study, I developed a double sampling based approach to calculate dog abundance. This approach can be used to rapidly assess dog numbers for establishing baselines and monitor effectiveness of population management measures in and around Desert National Park. I explored the spatial distribution of free-ranging dogs inside Desert National Park looking at their home ranges to discern their space pattern usage. Lastly, I assessed the interactions of a sample of free-ranging dogs with potential prey, competitors and conspecifics to comprehend their potential impacts on wildlife.

5.2 Population Estimation

A double sampling method is a practical technique used in field by incorporating two methods that are an index to abundance (Eberhardt and Simmons 1987). Using double sampling approach that calibrates effort-standardized counts with mark recapture based abundances, I estimated 682 (SE=0.05) dogs in 18 settlements distributed across 1008 km^2 landscape in Thar. Double sampling approach was introduced by Neyman (1938) and applied to assess population status of several species such as white-tailed deer (Ryel 1971) and nesting birds (Bart and Earnst 2001)**.** This approach is ideal for cases where within a short time frame, and an extensive area to cover a cost effective and logistically as well as scientifically robust method is required. In our case, use of double sampling approach allowed dog population to be estimated at a reasonably large scale with confidence and less funds. I estimated that mark recapture in all settlements would cost 193250 INR (3004 USD) as compared to 107142.50 INR (1665 USD) in the current assessment framework (see Appendix, **Table A1** and **Table A2**). Also, the residual standard error of predicted dog numbers in six settlements where actual dog numbers were also available was 6.31, indicating that abundance could be estimated with reasonable confidence using this approach at large scales.

Since dog counts are sensitive to survey efforts, with counts increasing asymptotically with efforts, efforts should be standardized across villages, such as 10 km per km^2 village area in our case. If efforts are not standardized across villages, then count-abundance relationship would be weak and confounded with detectability and unequal survey efforts. For future studies on dogs in this landscape, since villages are similar in structure and hence detection process of dogs should be similar, I recommend counting dogs in all settlements in one occasion with a minimal survey effort of 10 km per km^2 village area, and predicting dog numbers based on my calibration model (Population size=1.65 (SE=0.05) * dog counts). However, for other landscapes with different settlement structure and hence different detection process, this model should not be transferred, rather a locally suited calibration model should be developed from a subset of doubly sampled settlements.

Implemented at large scales, this approach can generate baselines that can be monitored over years to understand dog demography, assess if management measures such as sterilization programs are being effective in reducing population size, and importantly, understanding factors influencing dog abundance patterns such as resource availability and social tolerance. In this landscape, dog abundance in Hindu dominated settlements were similar to those in Muslim dominated settlements. Moreover, there was no correlation between settlement livestock holding on dog abundance. This may be because dog population is not limited by livestock availability inside settlements as dogs can range widely to access food. Another possibility is that livestock count obtained for each settlement through questionnaires may not be depicting the true abundance of livestock, and needs to be verified with actual livestock censuses in villages by survey teams.

Dog densities in winter was much higher than that in summer. A possible explanation is vehicle transects based distance sampling in winter were conducted from January to February which coincided with the birth of pups increasing the number of dogs in the landscape but this only explains about 12% of the increase in dog abundance during winter as shown in the findings. The proportion of pups seen in winter were much higher than summer due to pup mortality. Another explanation would be that higher per-capita food resources in tourism areas in winter encouraged dogs to locally immigrate and the pleasant ambient weather in winter increased dog activity, hence more use of the landscape (Ables 1969; Kavanau and Ramos 1972; Scott and Causey 1973; Geffen and Macdonald 1993). This means that we might have underestimated the dog abundance in summer because of inactive dogs that are resting.

5.3 Ranging Patterns

Home range size for both male and female dogs averaged at 19.81 ± 4.79 km^2. As the metabolic needs of a carnivore increases, so does its home range size (Gittleman and Harvey 1982). Food and water availability do have a strong influence on a carnivore's home range. Carnivores' home ranges depend on the distribution of their prey allowing them to have higher hunting success and prevent shortage of food (Frame et al. 1979). For free-ranging dogs in Thar landscape, enclosures set up by the Forest Department has a higher wild prey density (chinkara and nilgai) than surrounding unprotected areas. Probably because of such high resources inside enclosures, home ranges of all dogs usually encompassed these enclosures. Livestock carcasses, a frequent food source for free-ranging dogs were dumped in open areas by people living in Dhanis. These carcasses were dispersed across the study area such that they were not a predictable resource and had to be actively searched by dogs. However, the open areas used for carcass dumping were frequently near enclosures.

In terms of the high variability in home range size of dogs, it was noticed that home ranges of individuals that were much larger (WII-3 and WII-4), although encompassing part of the enclosures, they were the furthest from enclosures compared to other dogs. This is a possible explanation that the home ranges were much larger to encompass a part of the enclosure. Being a semi-arid state, water is a critical-resource for the animals (Gittleman and Harvey 1982). Waterholes in enclosures and water tanks in Dhanis were a crucial resource for these dogs as they mostly drank after feeding which was once a day.

The enclosures set up by the Forest Department were accessible to dogs and aided the dogs in their hunting prowess. The dogs usually got inside enclosures via 1) holes on the fence that were cut by people living in Dhanis to allow their livestock to forage in enclosures and

2) by digging the ground below the fence and squeezing through. During hunting, dogs used the enclosure fence as a physical barrier for wild prey. Hunting in packs, they would drive their prey towards the fence and before their prey can cross over, they would attack the rear to paralyse the prey and then aim for the neck followed by evisceration. This hunting strategy by dogs is similar to most canids such as dholes, Indian wolves and African wild dogs (Jhala 1993; Creel and Creel 2002).

Based on *ad libitum* observations and continuous monitoring, it was observed that lactating females used Dhanis as a refuge for their pups. The potential reason could be because of secure water source, shelter and occasional human-derived food resources that can improve pup recruitment. Studies have shown that lactating female wolves and foxes drink water more often and therefore, their denning sites are always less than 2km from a water source (Jhala et al. 2003; Maurya 2012). In account of this fact, all Dhanis had a personal water tank which was accessible by these dogs.

From continuous monitoring, observations showed that dogs did not only depend on Dhani's as a water source, but they used Dhani's as a resource hold. Multiple Dhani owners, were of the notion that they owned the same dog and that their dogs did not harm wildlife but protected their poultry from other dogs and thus, fed these dogs. Yet, our radio-telemetry data indicated otherwise showing that these dogs moved from Dhani to Dhani after staying for several days and did indeed hunt wild prey. On top of this, the dogs obtained free food from Dhani owners. This indicates that free-ranging dogs are closer to both wild resources as well as human derived resources, thus, utilizing the rural and wild niches to the fullest.

5.4 Resource Utilisation

To delve into the behavioural ecology of a species, causes an explosion of questions that requires extensive research and large sample sizes. Nevertheless, it is this first step which is crucial to perceive a species and its surroundings for the purpose of management and conservation of that very species and the ecosystem itself (Caro 2007).

To understand the behaviour of free-ranging dogs, I investigated the activity budget and temporal activity pattern of radio-collared dogs. Free-ranging dogs spent most of their day resting (~75%) which is normal in carnivores (usually canids and felids) for them to digest rich protein diet and conserve energy (Zepelin and Rechtschaffen 1974). I found that there was no difference between the proportion of time spent in different activities between males and females. However, proportion of time spent in various activities differed considerably with time of day. Like other large canids such as dholes (*Cuon alpinus)* and coyotes *(Canis latrans)*, free-ranging dogs too were crepuscular with activity peaking during 0600-0900 hours and 1800-2100 hours. Free-ranging dogs moved both during the day and the night for hunting and/or searching for prey carcasses to feed on (Johnsingh 1982; Andelt 1985).

Free-ranging dogs were mostly alert at the peak feeding time. A*d libitum* observations and continuous day-night monitoring indicated that such alertness was probably to prevent kleptoparasitism from other scavengers such as ravens (*Corvus corax*), Egyptian vultures (*Neophron percnopterus*), Cinereous vulture (*Aegypius monachus*) and wild pigs (*Sus scrofa*). Our observations on interactions between dogs and wildlife showed 1.9 interactions with competitors per dog day, and 50% of these occasions involved aggressive response of free-ranging dogs and flight response of kleptoparasites. This observation is in concurrence with studies on other canids, such as Gorman et al. 1998 showing that African wild dogs are vulnerable to kleptoparasitism; Caro and Stoner 2003 showing that kleptoparasitism increases time cost for carnivores; and Stahler et al. 2006 showing that wolves in Yellow National Park lose significant amounts of biomass from their kill to scavengers.

Results of resource use-availability analysis showed that, free-ranging dogs preferred carcasses (sheep and goat) more than hunting wild prey (nilgai and chinkara). That is why feeding on livestock was documented only as scavenging events on carcasses, and no active predation was observed. This is probably because of the availability of carcasses as free meals, which does not require dogs to spend extra cost (time and energy) to hunt (Stephens and Krebs 1986). According to optimal foraging theory (MacArthur and Pianka 1966), predators tend to maximize their net rate of food intake while foraging, and to do so, benefits and cost are weighed. Thus, feeding on carcasses maximizes the net rate of food intake by free-ranging dogs (cost is the search time) as compared to wild prey (cost is the search time and handling time). However, it was seen that in summer, dogs fed more on wild prey than livestock carcasses. The probable explanation is that carcass densities were decreasing in summer as shown in my findings which made dogs hunt wild prey. Dogs did not show preference towards spiny-tailed lizard and jird probably because the energy to dig them out of their burrows was too costly compared to the energetic gains from consuming these small animals.

Moreover, chinkara and nilgai density within a 94km^2 area was 7.02 ± 1.22 and 0.46 ± 0.23 individuals/km^2 respectively which was considerably high compared to the report by Dutta et al. (2016) which estimated density for chinkara and encounter rate for nilgai in the larger Thar landscape as 1.88 ± 0.25 individuals/km^2 and 0.09 ± 0.03 individuals/km respectively. The high densities of chinkara and nilgai are because of the five enclosures that are a part of this 94km^2 area. These enclosures have higher densities of the mentioned species than other open areas in the landscape.

The total herbivore biomass in the intensive study area is 1451.72 kg/km^2. This area has one of the lowest estimates of herbivore biomass in the country as studies show that Mudumalai Tiger Reserve had an estimate of 2117.15 kg/km^2 (Venkataraman 1995), Kanha including domestic prey had 2450 kg/km^2 (Schaller 1967) and Bandipur National Park had 3320 kg/km^2 (Johnsingh 1982). Ranthambore Tiger Reserve and Gir National Park, despite being a semi-arid region, the biomass density was 6263 and 1646 kg/km^2 respectively (Bagchi et al. 2004; Khan 1997). However, comparing my study area to that of deserts around the world, Thar landscape has a higher herbivore biomass density. Namib desert has a herbivore biomass density of 520kg/km^2 while the Kalahari desert is 439kg/km^2 based on large herbivores only (Williamson and Williamson 1981; Southgate et al. 1996). A probable reason that Thar is higher compared to Namib and Kalahari desert is that underground dwellers mainly jird and spiny tailed lizard contributed the most while for the other two deserts, rodents and reptiles were not a part of the herbivore biomass density estimate.

To synthesise the outcomes of my study, I calculated predation rates on chinkara, a native conservation-dependent species within my intensive study area of $94km^2$. Based on the five collared dogs, the number of chinkara individuals that are at potential risk from predation per dog year is 9.67. Continuous monitoring and *ad libitum* observations indicated that there were another 13 dogs that lived within the $94km^2$ area apart from the ones radio-collared by us and also, typically a pack of two dogs hunted chinkara. Therefore, predation rates of chinkara extrapolated to a total of 21 dogs indicated 203.07 chinkara individuals were at potential risk from dog predation in a year, which is a substantial 31% of the chinkara population. However, this data is based on a small sample size which can be augmented through longer continuous monitoring sessions.

5.5 Methodological issues and study limitations

Closed mark recapture models assume closure of population to gains (births and immigration) and losses (deaths and emigration) of individuals (Otis et al. 1978). In this study, mark recapture surveys in a settlement were completed within 7 days. This time window was short enough to assume minimal chance of death and pups were not considered as they might be born within the sampling period. However, the possibility of local emigration and immigration to and from adjacent settlements could not be negated as home range diameter of dogs (mean = 5 km for 9 collared dogs) exceeded the distance between adjacent settlements. Therefore, I performed formal test for closure using Pradel models (Cooch and White 2009). Results of closure test indicated that dog populations in all sampled villages were closed population.

However, the tourism area was an open population, where individuals left the initial population linearly with time, and no new individual entered the population. This pattern was perhaps because tourism intensity, and hence, food resources in tourism resorts, declined from early to late January, and visitation of dogs from adjacent settlements reduced with time. Thus, the population available in each count was a subset of the superpopulation, and count to abundance ratio of tourism area was much smaller than other settlements. Hence, I estimated dog abundance in tourism area separately from villages, by correcting counts in the entire tourism area by the ratio of count to superpopulation abundance (in this case, the initial population size) in a subset of the tourism area – the western tourism block. Since the superpopulation was not restricted to one tourism block although the counts in one survey were, my assessment of dog abundance in the tourism area could be overbiased. A better approach would be to estimate dog abundance for the entire tourism area by mark recapture approach that was not possible due to logistic constraints of this study.

Detection probability of dogs estimated by our models did not vary with time or in response to prior capture in most settlements. This was expected because dogs were not physically captured or baited that could change their behavior, and surveys were done by the same observers under similar conditions (time and weather) and following a standard protocol. However, in one settlement, Neemba, there was community interference which prevented us from completing the second survey, because of which the time model (M_t) found more support unlike the other settlements. As expected, this model estimated much lower recapture probability in the second occasion compared to the other occasions.

It should be noted that the detection probability estimated by mark recapture models in this study is a confounding effect of local availability (probability of presence within settlement) and detection probability (probability of detection if presence within settlement). Given our intensive search during mark recapture surveys within a settlement, I speculate that dogs were missed during a survey mostly because of their foraging bouts away from the settlement, i.e., local unavailability, rather than non-detection *per se*. In vehicle transect based distance sampling for assessing landscape scale dog abundance, majority of detections were obtained from settlements. There was visible difference in density and also detectability within and outside settlements, and for more robust density estimation, ideally, these differences should be partitioned in multicovariate detection and density surface modeling framework (Miller et al. 2013).

Chapter 6

CONCLUSION

My study shows that free-ranging dogs act as the apex predator in the Thar landscape. Compared to other apex predators, they occur at much higher densities, to the tune of 1.79 ± 0.46 individuals per km^2, resulting in 1804 dogs in $1008km^2$. The double sampling method used in this study was statistically robust and logistically cost-effective as well as feasible (R^2=0.99). For future studies in this landscape, the calibrated model (Population size = (1.65 ± 0.05) * dog counts) can be used to estimate dog abundances.

Dogs in this landscape, not only used Dhani's as a water source but also as a resource hold. The free-ranging dogs, apart from staying near Dhani's and obtaining food from them, used Dhani's as a hotspot for hunting wild prey. Thus, both wild and human derived resources were used to the fullest.

The wild resources that dogs hunted were chinkara, nilgai and spiny-tailed lizards. Dogs selected livestock (goat and sheep) carcasses more than wild prey. Among 21 free-ranging dogs in the intensive study area, the potential predation rates of chinkara are 203 individuals in a year which is 31% of the chinkara population.

Thar landscape has a higher herbivore biomass density than other deserts. This is probably because underground dwellers were a part of this estimate while for Kalahari and Namib desert only mammalian herbivores biomass density was estimated.

Impacts of free-ranging dogs on wildlife including predation and competitive interactions are substantial and needs to be managed. Management solutions such as a sustained sterilization program at settlement level, constant removal of dogs from enclosures, and predator-proofing of enclosures must be enforced to resolve the growing free-ranging dog crisis in this landscape. This step can help in bridging the gap between conservation agencies and local communities, who want the dogs in their settlement to be relocated (based on personal observations and communications).

This thesis is only the first step in a long-term goal of free-ranging dog management in India. There are many further aspects and questions that should be answered in the future for better understanding of free-ranging dog ecology. This is an imperative step to curb the free-ranging dog issue which is affecting conservation efforts for our native wildlife.

After all, at the end of the day, we humans, can make changes in our environment for the better, we can save many of these extraordinary, highly evolved species, if we only stop to think and act on it in time.

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APPENDIX

Figure A1. Trails digitized using Google Earth to carry out dog count surveys within human settlement areas in Thar desert

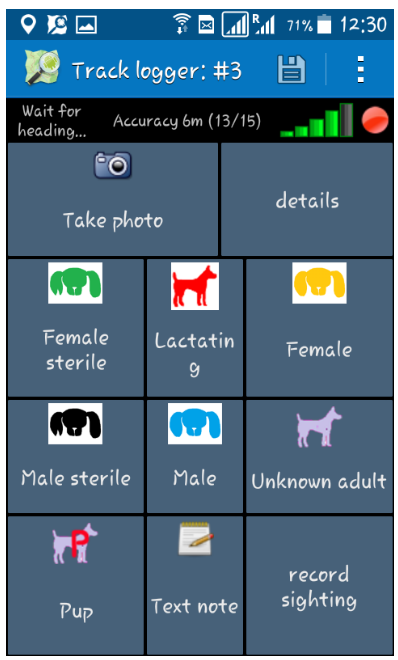

Figure A2. The OSM tracker app used in the smartphone for mark recapture survey of dogs within human settlements and tourism areas in Thar desert.

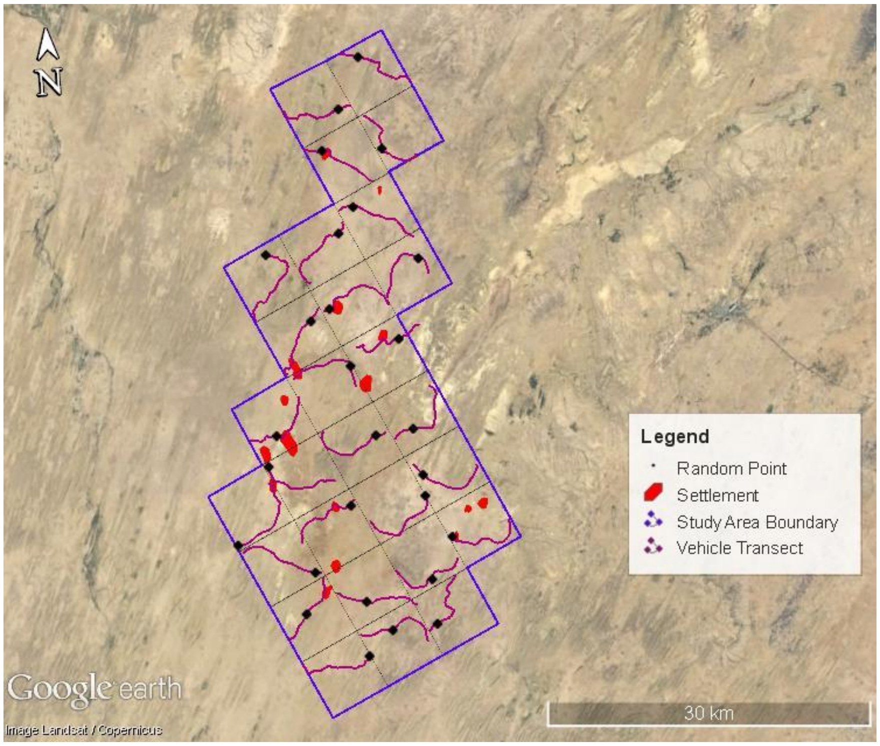

Figure A3. Vehicle transect created using Google Earth based on a random point generated in a 6km x 6km grid using ArcGIS within the intensive study area of Thar desert

Group Name: ____________________ **Date:** ______________ **Start Time:** _____________ **End Time:** ___ __________

Begin GPS Lat: ___________________(N), **Long:** ____________ (E) **End GPS Lat:** _______ ________(N), **Long:** ______ _________(E)

Transect ID: ______________________ **Total Length:** ______ km **Weather Condition: Cloudy / Clear Sky / Rain**

Seg No.	GPS Coordinates	Animal Species	Total Number	Total					Transect Bearing	Sighting Distance and Angle		GPS Location
				M	F	SM	SF	Young		*Animal Bearing	Distance	

M- male, F- female, SM - sub adult male, SF - sub adult female

Figure A4. Data collection sheet used for vehicle transects in study area.

Figure A5. Three photographs showing the same dog due to similar individual markings on the face and limbs.

Start Date: **End Date:** **Weather:**

Observer: **Individual Name:**

Time	GPS Location	Activity	Associated Individuals					Prey					Competitor					Humans				Remarks
			IC Time	OC Time	Resp-Obs_dog	Resp-Ass_Ind	Desc	IC Time	OC Time	Resp-Obs_dog	Resp-Prey	Sps	IC Time	OC Time	Resp-Obs_dog	Resp-Comp	Sps	IC Time	OC Time	Resp-Obs_dog	Resp-Humans	

* IC refers to in contact
* OC refers to out of contact
* Obs refers to observed
* Desc refers to description of associated individual

*Sps refers to species

Figure A6. Data collection sheet used for 24-hour continuous monitoring of radio-collared dogs in Thar landscape

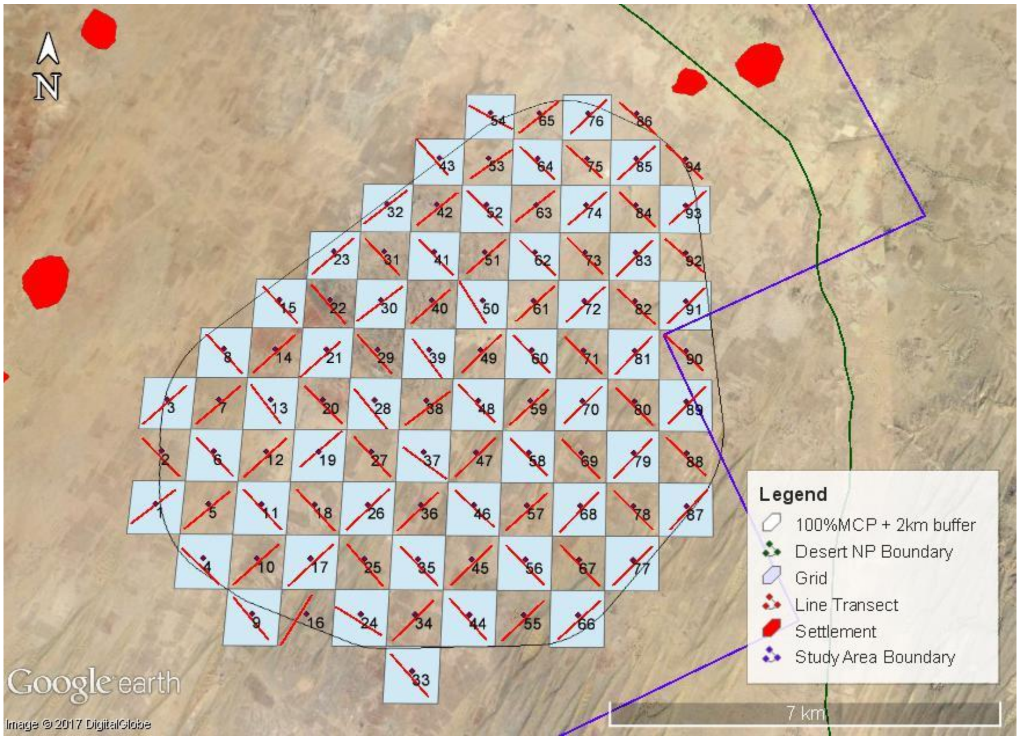

Figure A7. Ninety-four grids of 1km x 1km with a 1km line transect within each grid for sampling prey in the intensive study area of Thar desert

Transect ID: _________ **Observer:** __________________________ **Date:** _____________________ **Time:** _________________ – __________________

Weather: Clear / Cloudy / Rainy **Bearing:** ______________ **Effort:** __________ **(km)**

Segment (500 m)	Latitude dd.ddddd	Longitude dd.ddddd	Species	Number	Sighting distance (m)	Sighting angle	Proj. Sp. Latitude dd.ddddd	Proj. Sp. Longitude dd.ddddd	Remarks	Spiny-tailed lizard burrows in 500 x 2 sqm	Jird burrows in 500 x 2 sqm

Track ID:

Figure A8. Data collection sheet used in line transects for estimating density of wild prey within home range and 2km buffer of radio-collared dogs

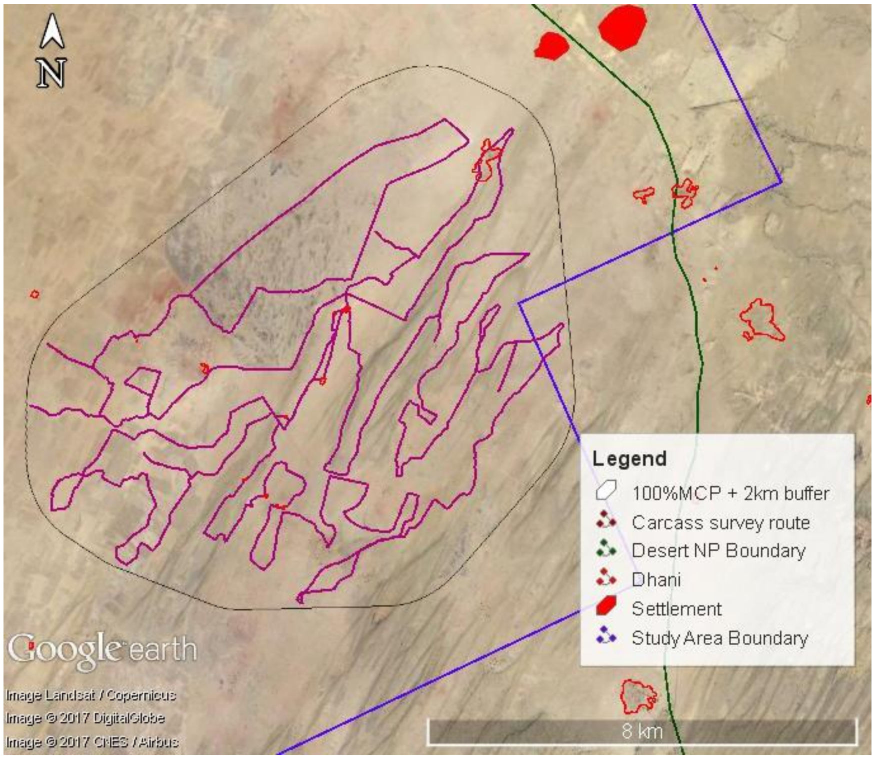

Figure A9. Vehicle transects to quantify carcass density within home range and 2km buffer of radio-collared dogs

Observer: ____________________ Date: ______________________ Start GPS Location: ____________________ N ____________________ E

Start Time: __________________ Sector: Wild End GPS Location: ____________________ N ____________________ E

End Time: ____________________ Length of trail: __________ km Weather: Clear sky / Sunny / Breezy / Rain / Cloudy

No.	Species				Condition of carcass			GPS Coordinates	Approx size	Scavengers present?	Closest app dist from route	Picture No.
	Cow	Goat	Sheep	Others	Fresh	Partially eaten	Completely eaten					

Figure A10. Data collection sheet used during the carcass survey

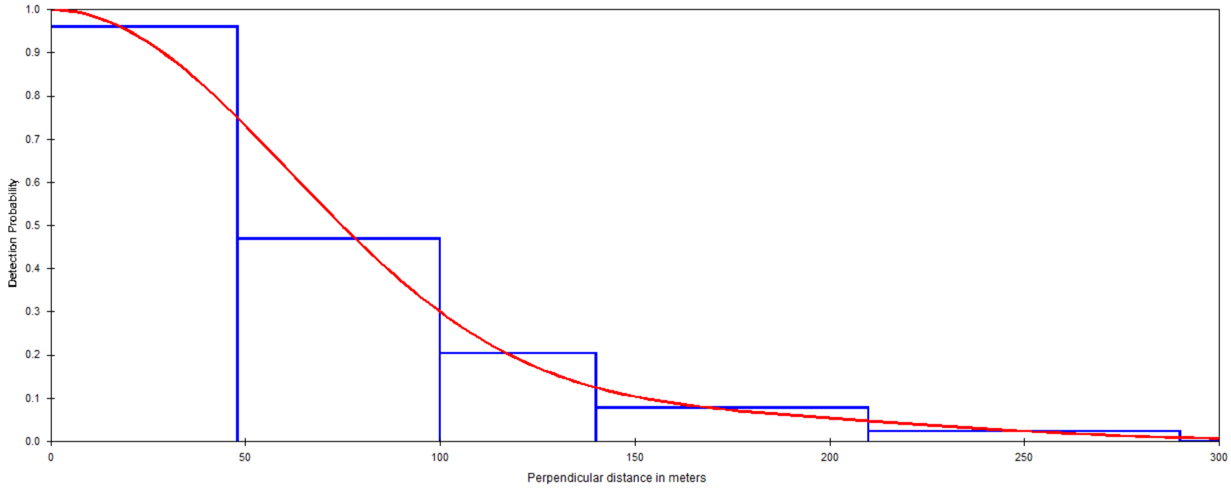

Figure A11. Model fit curve graph for dog density in study area.

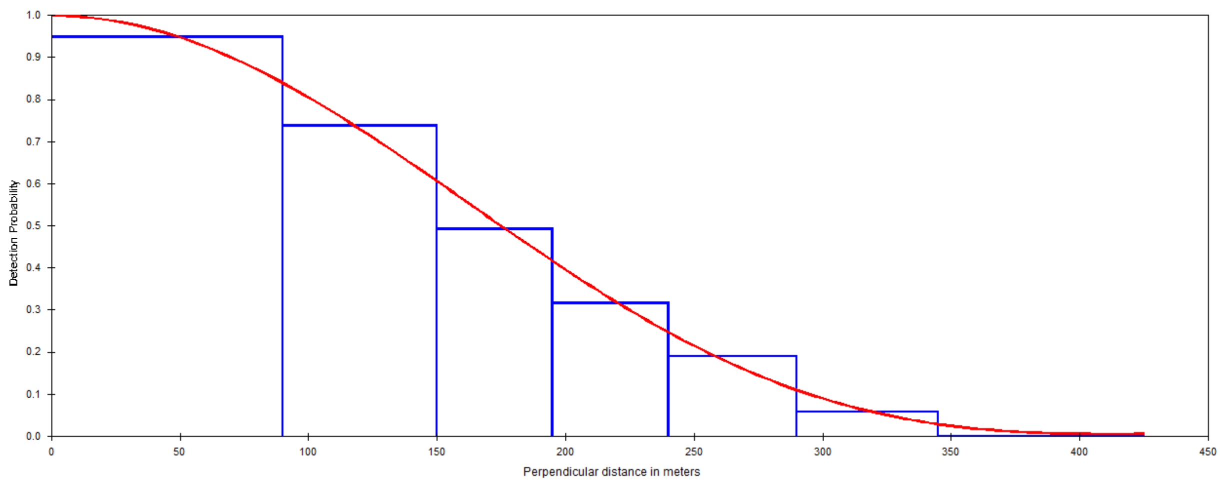

Figure A12. Model fit curve graph for chinkara in intensive study area.

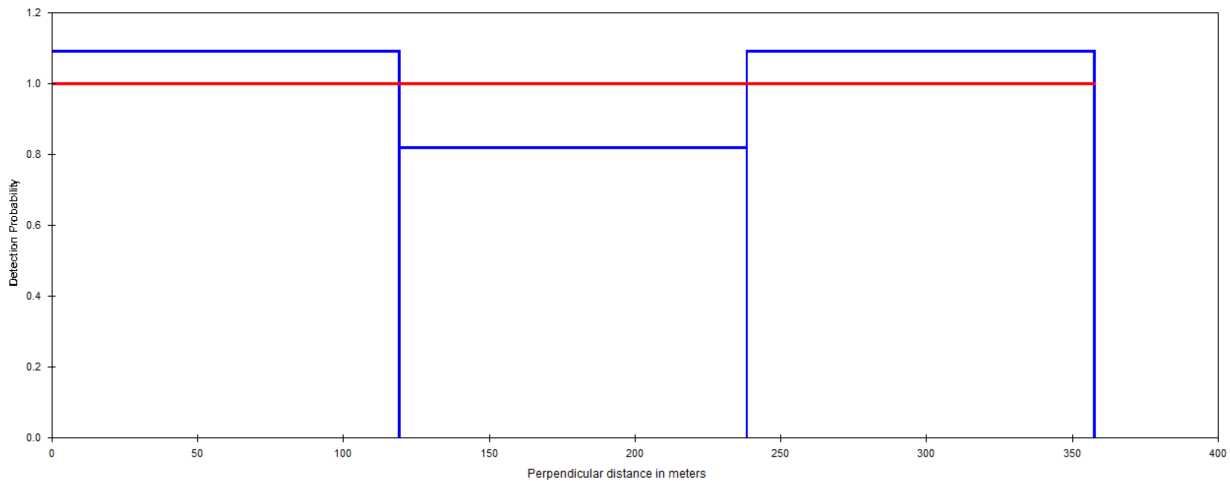

Figure A13. Model fit curve graph for nilgai in intensive study area.

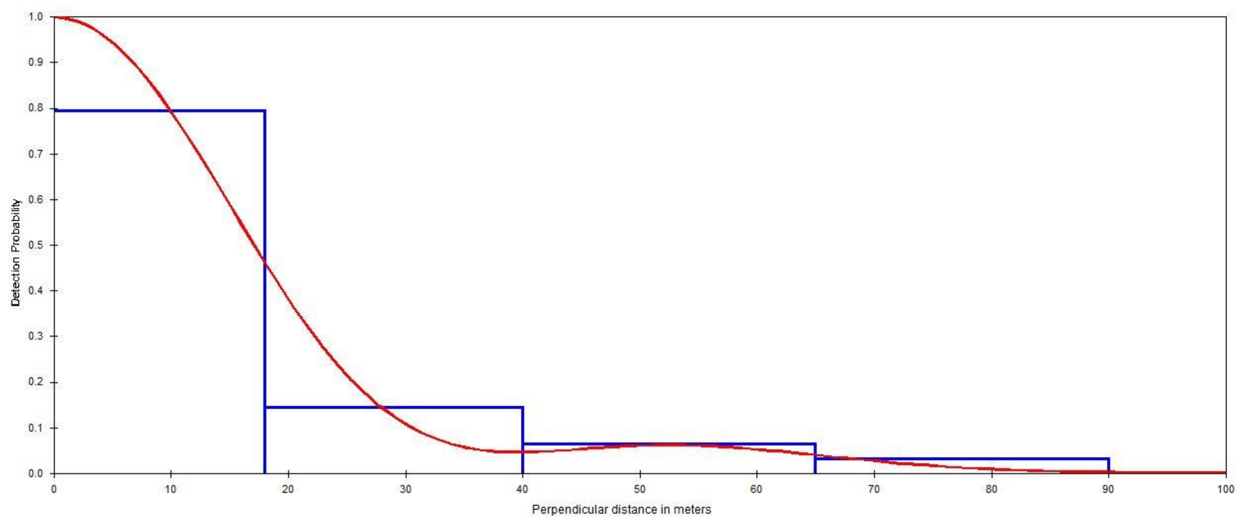

Figure A14. Model fit curve graph for carcasses in intensive study area.

Table A1. Total cost spent for mark recapture in all locations without a double sampling approach.

Type of cost	Amount (INR)	Quantity	Days	Number of locations	Total (INR)
Vehicle rent	1100	1	4	21	92 400
Fuel	65	6.5 litres	4	21	35 490
Labour	270	2	4	21	45 360
Equipment	20 000	1	4	21	20 000
				GRAND TOTAL:	**193 250**

Table A2. Total cost spent in using double sampling approach

Type of cost	Amount (INR)	Quantity	Days	Number of locations	Purpose	Total (INR)
Vehicle rent	1100	1	1	21	CS	23 100
Fuel	65	6.5 litres	1	21	CS	8 872.50
Labour	270	1	1	21	CS	5 670
Vehicle rent	1100	1	4	6	CMR	26 400
Fuel	65	6.5 litres	4	6	CMR	10 140
Labour	270	2	4	6	CMR	12 960
Equipment	20 000	1	4	6	CMR	20 000
				GRAND TOTAL:		**107 142.50**

CS- count survey
CMR- capture mark recapture

Plate 1. Radio-collaring free-ranging dogs in Thar landscape, Rajasthan

Plate 2. Homing in on one of the radio-collared dogs using a three-element Yagi antenna with a handheld receiver (Habit model HR 2600)

Plate 3. Walking line transects of 1km each for prey assessment in intensive study area.