RANGING PATTERNS AND HABITAT USE OF RE-INTRODUCED GAUR (*Bos gaurus gaurus*) IN BANDHAVGARH TIGER RESERVE, MADHYA PRADESH.

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BY

B. Navaneethan

Supervisor

Dr. K. Sankar, Senior Professor

Department of Habitat Ecology

Wildlife Institute of India, Dehra Dun, Uttarakhand

Co-Supervisor

Shri. Qamar Qureshi, Senior Professor

Department of Landscape Level Planning and Managment

Wildlife Institute of India, Dehra Dun, Uttarakhand

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Wildlife Institute of India

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भारतीय वन्यजीव संस्थान
Wildlife Institute of India

Certificate

This is to certify that the thesis entitled "**Ranging patterns and habitat use of re-introduced gaur *(Bos gaurus gaurus)* in Bandhavgarh Tiger Reserve, Madhya Pradesh" in the Wildlife Institute of India, Dehra Dun**" submitted for the award of degree of **Doctor of Philosophy** in Wildlife Science to Saurashtra University, Rajkot is a record of original and independent research work carried out by **Mr. B. Navaneethan** under our guidance. No part of this thesis has been submitted to any other university or institution for the award of any degree and it fulfills all the requirements laid down by Saurashtra University.

Dr. K. Sankar
(Supervisor)
Professor and Scientist 'G'
Department of Habitat Ecology
Wildlife Institute of India
Dehra Dun, Uttarakhand, India

Shri. Qamar Qureshi
(Co-supervisor)
Professor and Scientist 'G'
Department of Landscape Ecology
Wildlife Institute of India
Dehra Dun, Uttarakhand, India

पत्रपेटी सं0 18, चन्द्रबनी, देहरादून – 248 001, उत्तराखण्ड, भारत
Post Box No. 18, Chandrabani, Dehradun – 248 001, Uttarakhand, INDIA
ई.पी.ए.बी.एक्स : +91-135-2640111 से 2640115 फैक्स : 0135-2640117, तार : WILDLIFE
EPABX : +91-135-2640111 to 2640115; Fax : 0135-2640117; GRAM : WILDLIFE
ई–मेल / E-mail: wii@wii.gov.in

Saurashtra University, Rajkot

Office of the Saurashtra
University, University Road,
Rajkot – 360 005
Gujarat (INDIA)

Re-Accredited Grade "B" by NAAC
[CGPA 2.93]

Phone: +91 281 2578501

Fax: + 91 281 2586983

CERTIFICATE FOR PRE PH.D. PRESENTATION

This is to certify that **Mr. B. Navaneethan (Regd. No. 4879, 01.01.2012)** has made Pre Ph.D. presentation as per UGC Guide Line "University Grant Commission (Minimum Standard and Procedure for award of Ph.D. Degree) Regulation–2009" and Saurashtra University Ordinance for Ph.D. Programme (O.Ph.D. 6.2), on the research work entitled **"Ranging patterns and habitat use of re-introduced gaur *(Bos gaurus gaurus)* in Bandhavgarh Tiger Reserve, Madhya Pradesh"** in the **Wildlife Institute of India, Dehra Dun,** Research Centre of Saurashtra University, Rajkot, on **3rd July 2014** before all faculty members and students of the Department for getting feedback and comments.

I also certify that the research work was appreciated by all who remain present and there was no comments made for this research work/comments made are incorporated in the thesis.

Place: **Dehradun**

Guide : **Dr. K. Sankar**

Date: **3rd July 2014**

Department/College:

Wildlife Institute of India
Chandrabani, Dehradun – 248 001
(Uttarakhand)

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Bandhavgarh Tiger Reserve (BTR), situated in Central India, supported a small population of gaur (38 individuals) till 1995. This gaur population became locally extinct in 1998, and the reason for the same is attributed to disruption of the migratory corridor between the forests of Bandhavgarh and Ghunghuti and Amarkantak. Even after the local extinction of gaur, BTR continued to be an excellent habitat for gaur and hence it was decided to reintroduce gaur in BTR as it would be a major conservation initiative for this endangered species.

The present study on reintroduced gaur was carried out from March 2011 to February 2013 covering all seasons in a year, summer (March - June), monsoon (July - October) and winter (November - February) in Bandhavgarh Tiger Reserve, Madhya Pradesh, Central India, to study the ranging pattern and habitat use.

The capture and translocation of 50 (14 male and 36 female) gaur from Kanha Tiger Reserve (KTR) to Bandhavgarh Tiger Reserve (BTR) was done in two phases *i.e.* phase I during January 2011 (n=19) and phase II, during March 2012 (n=31). Of these, individuals 27 gaur were fitted with radio collars. Two types of radio collars were used on gaur *i.e.* GPS/ SATELLITE/VHF and Very High Frequency-VHF. A hand held multichannel receiver along with uni-directional hand-held 3-element "Yagi" antenna and "H" type antenna were used to track the radio collared animals.

The study on ranging pattern of gaur was based on regular tracking of radio-collared (n=27) individuals. The radio-collared gaur was monitored periodically through

ground tracking, using "triangulation" and "homing in" techniques. A total of 18, 932 location were collected from all the radio collared individuals. Twelve to fifteen locations, per radio-collared individual in a week with "biologically independent" locations *i.e.* 06.00 hrs interval between consecutive locations of the same animal was collected on foot and from vehicle from March 2011 to February 2013. The location were obtained from 06.00 hrs to 18.00 hrs in all season *i.e.* summer, monsoon and winter. During the study period, two radio collared (GF5 and GF7) female gaur died naturally. Eight (GF1, GF8, GF10, GF14, GM1, GM3, GM5 and GM10) collars were dropped by animals and one VHF (GF9) collar ceased functioning. Two males, GM3 and GM10 collars were dropped due to territorial fight.

The obtained gaur radio collared locations were plotted in Arc GIS 9.2. Minimum Convex Polygon (MCP) and Fixed Kernel Density estimator (FKD) methods were used to estimate the home range size. To remove the effect of exploratory movements and outlying fixes, 95% and 50% FKD were computed. Mann-Whitney-Wilcoxon test and Kruskal-Wallis test were used to test the significance of difference between the home range size, age and sex classes gaur. To estimate the home range of each gaur individual in different season, data were grouped to understand the home range size of different demography classes. To understand the overall as well as seasonal ranging patterns, 100% MCP method was used. To estimate gaur home range in the study area, locations obtained from GPS and VHF collars (n=18, 932) were used.

A total of four different herds were identified during the study period. The individual gaur herd was identified based on the radio collared animals in each gaur herd. Month wise data was used to study the home range stabilization of herds.

To find out the seasonal movement pattern, data collected from 25 radio-collared (6 males and 19 females) gaur were used. Minimum of two locations per radio-collared gaur were collected in a day, which covers 24 hour cycle. To detect the initial daily movement patterns and monthly movement, two-year daily time-series model was used for each gender (male and female). Home Range Tools in Arc GIS 9.3 were used to estimate the gaur movement parameters including movement length l (*i.e.* distance moved in meters).

The minimum number needed to calculate the overall home range size of reintroduced gaur in Bandhavgarh reached an asymptode at 122 fixes (95% CI 111-133; range: 80-188). The average home range of reintroduced gaur reached an asymptote after exploring minimum of 154 km^2 (range: 71 Km^2 - 279 Km^2) within 143 days (range: 120 - 163 days). Locations of 25 radio-collared individuals were used to analyze the stabilization of home range. It was observed that the batch I (n=12) gaur home range exploration was gradual in the new environment and batch II (n=15) gaur home range exploration was unstable for three months.

The estimated overall 100 % MCP, 95 % FKD and 50 % FKD (core area) home range of reintroduced gaur was 405.2 Km^2, 146.9 Km^2 and 37.8 Km^2 respectively. It was observed that with 100 % MCP of all the demography classes of gaur, 22 gaur had a home range of more than 100 Km^2. Among these individuals, all the three adult males,

three adult female (GF14, GF31 and GF36) and two sub adult females (GF6 and GF9) had larger home range *i.e.* 200 Km^2. The overall home range of different demography classes (AM- Adult Male; SAM- Sub Adult Male; AF- Adult Female; SAF- Sub Adult Female) was estimated using 100 % MCP. The average home range size of AM (n = 3) was 250.2 ± 10.5 (SE) Km^2, SAM (n = 3) 124.6 ± 26.9 (SE) Km^2, AF (n =6) 188.6 ± 33.1 (SE) Km^2 and SAF (n = 13) 148.3 ± 14.7 (SE) Km^2.

Of the 19 gaur individuals reintroduced in 2011, it was observed that they formed two different herds *i.e.* Seven (H-1) and 13 (H-2), and both had were compresed with mixed age-sex class individuals. The suplimentation of 31 gaur in 2012, resulted in formation of four new gaur herds. A total of six different (two pre-existing and four new) gaur herds were observed during the entire summer 2012, and subsequently in early monsoon two gaur herds (H-5 with H-1and H-6 with H-2) joined with the prexisting herds. A total of four different gaur herds were observed consistantly till winter 2012.

Gaur were reintroduced in batches, in which the batch I gaur initially explored larger area (254.4 Km^2). The addition of 31 gaur during March 2012 resulted in overall home range exploration from 254.4 Km^2 in 2011 to 384.4 Km^2 in 2012. It was observed that the overall mean daily distance moved by reintroduced gaur in summer was 1.74 ± 1.17 (SE) Km, in monsoon it was 1.97 ± 1.65 (SE) Km and in winter it was 1.71 ± 1.68 (SE) Km.

The average time taken to establish the home range size of gaur varied among the age and sex classes due to intra specific competition. The observed large overall home range size of reintroduced gaur in the present study may be attributed to the availability

of wide spread natural mineral licks, adequate food and water along with availability of different vegetation types in the study area.

Both habitat use and habitat availability were assessed for individual radio-collared gaur locations in the study area. The analysis of gaur habitat use data was limited to seven different vegetation classes such as agriculture, bamboo forest, grassland, open mixed forest, mixed forest, sal forest and riparian forest within the study area comprising 1614.0 km^2. To assess the habitat use pattern of reintroduced gaur in Bandhavgarh, locations of individual radio collared gaur (n=27) were obtained from March 2011 to February 2013. The collected gaur locations (n=18,932) were plotted on the classified LISS-III imagery of Bandhavgarh. I used second-order resource selection function to determine the habitat selection of reintroduced gaur. Third-order resource selection was determined by using discrete-choice analysis at the home-range level. I used Resource Selection program for Windows to conduct the compositional analysis. I estimated the season wise habitat use by reintroduced gaur, using compositional analysis and also computed overall habitat use of gaur across gender to understand is there any specialization in habitat use. The utilized and availability data of habitats was evaluated using Bonferroni simultaneous confidence interval for males (n=6) because of inadequate number of samples to perform compositional analysis.

To evaluate the resource use of reintroduced gaur, the overall individual gaur home ranges were plotted on the study area map with 3 Km^2 grids using Hawths tool in Arc GIS 9.3. To evaluate the vegetation characteristic features in gaur home ranges in the study area, a total of 483 vegetation plots were laid in different seasons (summer,

monsoon and winter) during 2011-2013. In total, 363 vegetation plots were laid in all gaur utilized locations in order to evaluate the habitat use patterns and to obtain information on habitat availability, random vegetation plots (n=120) were laid within the home range of gaur. Parameters were enumerated in all vegetation plots such as tree density in 10 m circular plot, shrub density in 5 m circular plot and percentage availability of ground cover (grass, herb, bare soil, leaf litter and rock) in 1m plot by line intercept method. Based on the information extracted from each 3 Km^2 grid, 3^{rd} order resource selection (resource selection of individual gaur within its home range) by the reintroduced gaur was estimated using Generalized Linear Mixed effect Model (GLMM). All the resource parameters (habitat variables, topographical, hydrological, vegetation characteristics, anthropogenic pressure and predator response) were chosen as fixed effects and gaur locations were chosen as the random effect for GLMM models. I standardized the variables to z-scores to provide equal weightage in multiple regression analyses. To determine the best fit model of resource selection of prior models, I developed a global model including the selected variables. The best fit model was ranked smallest value by Akaike's Information Criterion (AIC) and considered competing low Delta AIC value (<5) from the top ranked model.

Gaur largely used mixed forest followed by bamboo and grassland, whereas sal forest and riparian forest were used according to their availability within their entire home range. A simplified matrix ranked the overall habitat use of reintroduced gaur in Bandhavgarh in the following order: bamboo forest > grassland > riparian> sal forest > mixed forest > open mixed forest > agriculture land. The habitat use of gaur in summer

was in the following order: grassland > sal forest > bamboo forest > riparian = open-mixed forest > mixed forest > agriculture land. The habitat use of gaur in monsoon was in the following order: bamboo forest > grassland > riparian > sal forest = mixed forest > open-mixed forest > agriculture land. The habitat use of gaur in winter was in the following order: bamboo forest > mixed forest > riparian = sal forest > grassland > open-mixed forest > agriculture land.

Overall, gaur males used grassland ($P < 0.001$) and bamboo forest ($P < 0.001$) more than their availability, whereas riparian ($P < 0.001$), sal forest ($P < 0.001$) and open-mixed forest ($P < 0.001$) were used according to their availabilities. Mixed forest ($P < 0.001$) and agriculture land ($P < 0.001$) were least utilized. The overall habitat use of gaur females was in the following order: bamboo forest > grassland > riparian > sal forest > mixed forest > open-mixed forest > agriculture land.

I evaluated 12 GLMM third order resource selection model for the reintroduced gaur in the study area. The reintroduced gaur intensively selected habitat variables such as mixed forest, bamboo, grassland, sal, riparian and open mixed forest with distance to village, tree density, weed abundance and grass cover which had positive influence in selection of resources, whereas the digital elevation model, distance to water and tree lopping had a negative influence on gaur with regard to habitat selection.

In Bandhavgarh Tiger Reserve, the mixed forest which is the dominated vegetation type constituted 43.8 % of the total area, but the use of bamboo forest followed by grassland by gaur showed higher ranking in habitat use. The preference of bamboo forest because of the availability of green shoots throughout the year and

grasslands which provide higher biomass of forbs and grasses, might have influenced the gaur to prefer these habitats. The significant avoidance of agriculture land ($p < 0.05$) and distance to village inside the Protected Area by reintroduced gaur had a strong influence and found to be an important factor in determining their resource selection.

Information on group size and age-sex composition of gaur was collected based on direct observation during March 2011 to February 2013 covering all seasons *viz* summer, monsoon and winter in the study area. In total, 50 gaur were re-introduced in Bandhavgarh Tiger Reserve (three adult males, 11 sub-adult males, 13 adult females, 21 sub-adult females, and two yearlings).

During the study period, the observed gaur group size of gaur varied from 2 to 24 individuals. The observed overall gaur mean group size (MGS) was 9.1 ± 1.6 (SE). The observed overall gaur typical group size (TGS) was 12.1. The overall MGS in summer was 8.6 ± 1.3 (SE), in monsoon it was 10.7 ± 2.8 and in winter it was 11.0 ± 2.9. In the overall composition of gaur groups, sub-adult females comprised large in numbers (n= 19) followed by adult females (n= 12), sub-adult males (n= 11), calf (n= 8), yearling or juveniles (n=7) and adult males (n= 3). In total, four mortalities were recorded during the study period, of which two gaur were predated by tiger and two radio collared gaur (GF5, GF7) died naturally. Two un-collared sub adult gaur females went missing and were never reported again. A total of 16 calves were born in Bandhavgarh during the study period. The maximum gaur calves were observed in winter (n=10) followed by summer (n= 5) and monsoon (n=1). During the study period (March 2011- Februaty 2013) the estimated overall growth of gaur population was 20 % and the mortality rate was 8 %.

During the study period two villages (Kallwah and Kumuruwah) from the core area were successfully relocated in June 2011 and subsequently gaur was found using the relocated sites in August 2011. This significantly provides vital space for the relocated gaur, which can set an example to expedite relocation of the remaining villages (n=13) from the core area. There is a need to implement a wide vaccination program (foot and mouth disease (FMD), rinderpest and anthrax) for the domestic livestock in and around the Tiger Reserve, to prevent the transmission of livestock diseases to gaur in the study area. Continues scientific monitoring is recommended for the reintroduced gaur population in Bandhavgarh Tiger Reserve for future periods.

Chapter I

Introduction

Chapter 1

INTRODUCTION

1.1. BACKGROUND

Large herbivores have ecological value as they have a major impact on the physical structure of habitats, rates of ecosystem processes and the diversity of communities as ecosystem landscapers (Gordon *et al.* 2004). The bovine are the most diverse group of ungulate species. Bovinae are phylogenetically relatively young group compared to other mammals and they are primarily old world in their distribution. The bovid family is commonly subdivided into eight subfamilies. The eight traditional subfamilies can be divided into two, the Boodontia (with the Bovinae as sole members) and the Aegodontia (composed of all other subfamilies).

Asia is the original habitat of the wild oxen and most of the present day species are distributed in this continent. Wild oxen of Europe and North America were almost completely eliminated in historical times and a few survivors are confined to the Zoological Parks and Protected Areas (Easa 1998). Gaur belongs to the group of wild oxen. These include the Asiatic buffalo, African buffalo, cattle and bison. The ancestors of the gaur evolved from Asia some 20 million years ago. The four genera (Asiatic buffalos (*Bubalus*), African buffalos (*Syncerus*), cattle (*Bos*) and Bison (*Bison*) have seven sub genera, nine species and 21 subspecies (Woodford 2000). The natural distribution of Bovini incorporates North America with the American bison (*Bison bison*), Europe with the European bison or wisent (*Bison bonasus*), and Africa with

African buffalo (*Syncerus caffer*). However most of the *Bos* species diversity is found in Asia: Kouprey (*Bos sauveli*; extinct), Gaur (*Bos gaurus*), Yak (*Bos grunniens*), Banteng (*Bos javanicus*), Water buffalo (*Bubalus bubalis*), Anoa (*Bos depressicornis*), Short-horned water buffalo (*Bos mephistopheles*), Tamaraw (*Bos mindorensis*) and Mountain anoa (*Bos quarlesi*).

Among three species of genus *Bos*, the Kouprey (*Bos sauveli*) is found in Cambodia, the Banteng (*Bos javanicus*) in Java, Borneo, Malaya and parts of Indochina and the gaur (*Bos gaurus*) from Malaya to India. The domestic cattle (*Bos taurus* and *Bos indicus*) and the yak (*Bos grunniens*) also belong to the this genus *Bos*. The genus *Bos*, contains several other species of wild cattle, all confined to the Oriental Region (Schaller 1967). Kouprey (*Bos sauveli*) of Cambodia, Banteng (*Bos banteng*) of Java, Borneo, Malaya and parts of Indochina, gaur (*Bos gaurus*) of India, Malaya and Indochina and the Gayal (*Bos frontalis*) of Assam and Burma are the wild cattle found in this part of the world (Woodford 2000).

1.2. STUDY SPECIES

1.2.1. Evolution and taxonomic status

Bovid are members of the subfamily Bovinae. The evolution of Bovids is dated back to lower Miocene period, almost 20 million years ago (Gentry 1992). The gaur is the member of subgenus *Bibos* with the Banteng and the Kouprey (*Bos sauveli*). Many subspecies of gaur have been described, but currently only three subspecies are recognized they are *Bos gaurus gaurus* occurs in India and Nepal; *Bos gaurus laosiensis*

ranges in Myanmar, Laos, Vietnam, Cambodia and Southern China and *Bos gaurus hubbacki* in Thailand and Malaysia (Gentry 1992). However further research is required to preciously determine the taxonomy of this species.

Classification

Phylum	: Chordata
Class	: Mammalia
Order	: Cetartiodactyla
Family	: Bovidae
Sub-family	: Bovinae
Genus	: *Bos*
Species	: *gaurus gaurus*
Common name	: Gaur

Gaur (*Bos gaurus*) commonly referred to as Indian bison or wild oxen, belongs to sub-family Bovinae (cloven-hoofed mammals) of the order Cetartiodactyla (includes whales and even toad ungulates). In South East Asia it is called as Sladang. Domestic inbreeding with cattle causes a hybrid called the Mithun, which is commonly found in North East India.

Three species of Gaur were recognized:

1. ***Bos gaurus gaurus*:** India, Nepal, and Bhutan

2. ***Bos gaurus readei*:** Myanmar (Burma), southern China, Lao PDR, Viet Nam, Cambodia and Thailand north of the Isthmus of Kra

3. ***Bos gaurus hubbacki*:** Thailand south of the Isthmus of Kra and in West Malaysia.

Srikosamatara and Suteethorn (1995) suggested from morphometric data that the Thailand and Indochina's *Bos gaurus readei* and Malaysia's *Bos gaurus hubbacki* are the same and may be called *Bos gaurus laosiensis*. However, recent advances in taxonomy of gaur suggest the presence of only two subspecies: *Bos gaurus gaurus* in India and Nepal and *Bos gaurus laosiensis* in the rest of the distribution range of the species. Specimens in north-eastern India may be intermediate forms between the subspecies (Choudhury 2002).

1.2.2. General description

Gaur is the tallest living oxen and the second heaviest. Gaur bulls weigh 600 to 1000 kg and stand 1.6 to 1.9 m of shoulder, whereas cows are about 10 cm shorter and weigh about 450 to 800 kg. Gaur are sexually dimorphic, both sexes have horns. In males the horns are larger especially at base with more outward swath and the curving is less at the tips. Adult males have pronounced muscular crest between shoulders and a large dewlap hanging between the forelegs and smaller one under the chin (Krishnan 1972). Adult bulls have a shiny black, short-haired pelage, except for white stockings, a gray boss between the horns, and rusty-colored hairs on the insides of the thighs and forelegs. Young bulls are dark brown like the cows. The horns of young bulls are smooth, yellow-orange in color and tipped with black, whereas the old bulls are corrugated a dull olive in color and sometimes frayed at the tips (Schaller 1967).

Cows are considerably smaller than the bulls and their dorsal ridges and dewlaps are not prominently developed. The pelage of cow is dark brown in color and the horns are thinner, upright and with a more inward curved than those of bulls. Juveniles are

brownish with spike horn. Young calves weigh about 43 kg have a light brown coat and lack the conspicuous white stockings, which do not appear until they change into a dark brown pelage at the age of about three months (Grzimek 2003, Wharton 1957) .

1.2.3. Geographical distribution

Gaur historically occurred throughout mainland of South and Southeast Asia and Sri Lanka (Duckworth *et al.* 2008). Gaur is currently distributed in India, Nepal, Bhutan, Bangladesh, Myanmar, Thailand, China, Laos, Cambodia, Vietnam and Malaysia (Ellerman and Morrison-Scott 1951, Corbett and Hill 1992).

India is having the highest gaur population than any other country in the world (Table 1.1). The current population status is unknown in most of the range countries and it is declining in all known distributional range countries (Schipper 2008). The population decline in Indochina, Myanmar and Malaysia is over 70% and the overall decline is considerably lower in India (Duckworth *et al.* 2008). Gaur population seems to be increasing in certain Protected Areas in India (Sankar *et al.* 2000). In India, gaur is found in 128 Protected Areas which cover only 26% of actual distribution area of gaur (Choudhury 2002).

Table 1.1. Current gaur *(Bos gaurus gaurus)* population in Asia based on published literature.

S. No.	Country	Population	Population trend	Source
1	India	12,000 - 22,000	Unknown	Ranjitsinh 1997
2	India	23,500	Declining	Sankar *et al.* 2000
3	India	23,000 - 34,000	Declining	Choudhury 2002
4	Nepal	250 – 350	Presently unknown	Duckworth *et al.* 2008
5	Bhutan	700 - 1,000	Declining	Duckworth and Hedges 1998
6	Bangladesh	Probably extinct	Unknown	Duckworth *et al.* 2008
7	Thailand	915	Unknown	Srikosamatara *et al.* 1995
8	Viet Nam	1000	Unknown	Byers *et al.* 1995
9	Malaysia	500	Declining	Read *et al.* 1994
10	Myanmar	100 – 200	Declining	Rabinowitz *et al.* 1995

Information on the distribution of Gaur is found in Gee (1964), Schaller (1967), Prater (1980), Mukherjee (1982), Ranjitsinh (1987), Sankar *et al.* (2000) Choudhury (2002) and Duckworth (2008). Gaur distribution maps were illustrated in Schaller (1967), Mukherjee (1982), Tikadar (1983) and Corbett and Hill (1992).

1.2.4. Conservation status

The red list of threatened (Duckworth *et al.* 2008) species categorizes gaur as a vulnerable species, and today it is found in 11 countries (Ashokkumar *et al.* 2010). The estimated population is around 13,000 to 30,000 with approximately 85% of population being present in India. Thus India is having the best chance for long-term conservation of this species (Ashokkumar *et al.* 2010). The populations in other countries are declining alarmingly. Gaur is listed in CITES Appendix-I, (CITES, 2003), which bans all international trade of gaur products. It is protected under Schedule I of Wildlife (Protection) Act 1972 of India (IUCN 2002).

1.2.5. Threats

Habitat loss has been largely responsible for the large scale decline of gaur range and it remains a major threat to gaur conservation in Asia (Choudhury 2002, Duckworth *et al.* 2008). The habitat degradation and fragmentation affect gaur population in two ways. They are i). The physical disturbance caused by people such as wood cutting and forest fire and ii). Loss of food availability due to extensive cattle grazing (Ashokkumar *et al.* 2010a). Poaching of gaur for meat and horns is one of the serious threats for gaur conservation (Ashokkumar *et al.*, 2010a).

The species is closely related to domestic livestock and is vulnerable to all the diseases that infect cattle. Epidemic diseases such as rinderpest causes a widespread death of gaur and this disease has been reported in Southern and Central India (Ranjitsinh 1997). Gaur has also been reported to die from foot and mouth disease (FMD) and anthrax (Ranjitsinh 1997). In 1968, hundreds of gaur died in Mudumalai-Bandipur of

South India due to rinderpest (Davidar 1997). The outbreak of rinderpest in Periyar Tiger Reserve was reported by Bansal and Joshi (1980).

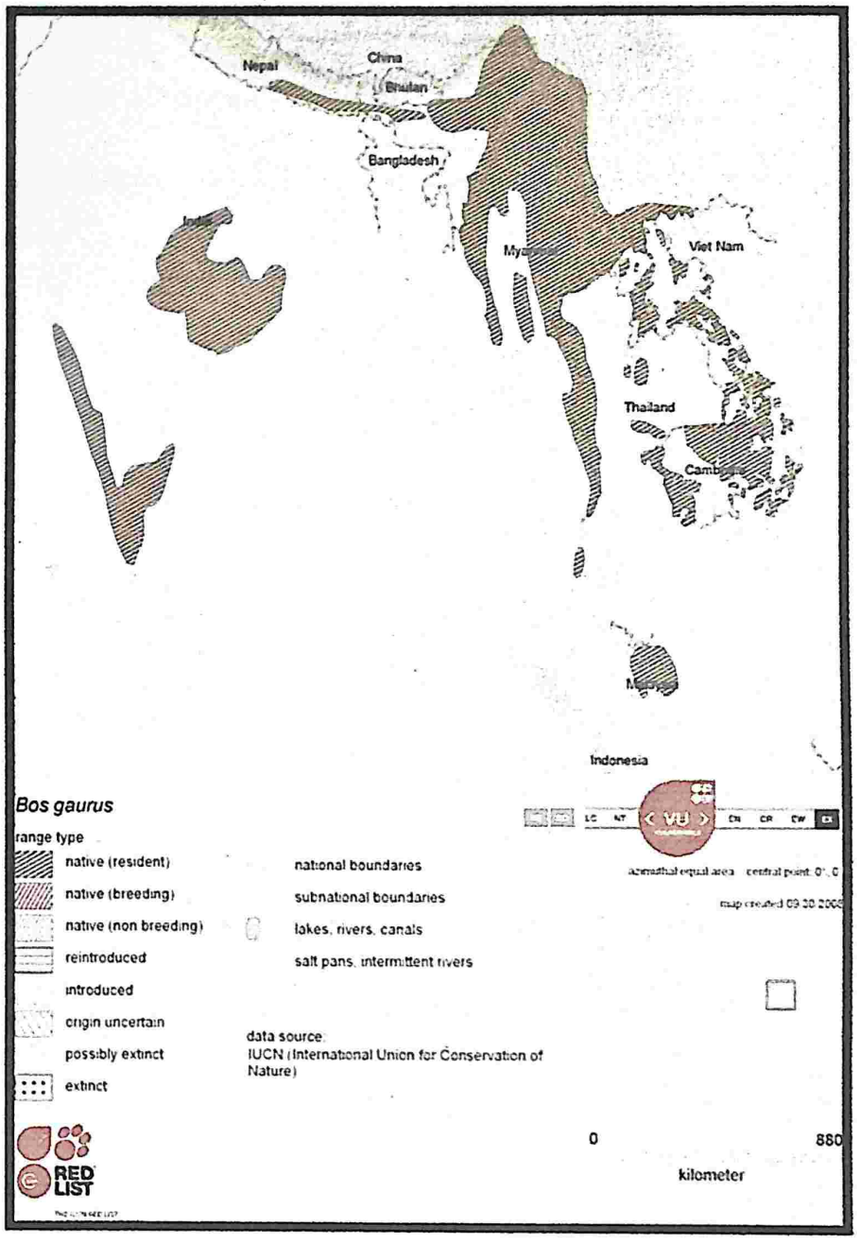
Straying into human habitations and damage to cardamom plantation by gaur is especially near smaller and fragmented habitats, led to gaur-human conflicts (Jayson 1999). The problem is more severe in highly fragmented North East India (WWF 2008) and in parts of Southern and Central India (Choudhury 2002).

1.3. STATUS AND DISTRIBUTION OF GAUR

1.3.1. Asia

Gaur is distributed in Bangladesh, Bhutan, Cambodia, China, India, Peninsular Malashiya, Myanmar, Nepal, Thailand and Vietnam. In India, Gaur is found in Central, Southern, Southwestern and Northeast regions (Choudhury 2002). The distribution of gaur in each country is fragmented (Figure 1.1).

Figure 1. 1. Present distribution range of gaur in South-East Asia (IUCN 2013).



Gaur is one of the charismatic mega fauna and it is one among the rapidly declining species. Gaur plays an important role in modifying their habitat by resetting succession of a forest habitat to grassland and spreading the propagules of numerous plants. Status and distribution of the sub species *Bos gaurus readei* and *Bos gaurus hubbacki* in Thailand have been investigated (Lekagul 1952, Suchart *et al.* 1976, Sayer

1981, Kutintara *et al.* 1982, Dobias 1982:1985, Supmee 1986, Sukavanich 1988, Nakhasathien 1989, Paliphod 1989, Climo 1990, Midas 1993). After a detail study on the status of different gaur subspecies in different ranges and its occurrence it was reviewed that no gaur sighting was reported outside Thailand's Protected Area (Srikosamatara *et al.* 1995).

In Vietnam, the species is distributed in Yok Don Nature Reserve, Huai Kha Khaeng Wildlife Sanctuary (Laurie *et al.* 1989, MacKinnon *et al.* 1989) and Nam Cat Tien National Park (Hoe and Quy 1991) and Green Forest and Nui Bi Doup (Canh 1995). However, there is no published information on the estimated population of gaur in any of these areas.

In China, late1980s, the species was extinct in Lancang County, and the remaining animals were split into two populations: Xishuangbanna–Simao and Cangyuan (Duckworth and Hedges 1998). According to Xiang and Santiapillai (1993) gaur was locally exterminated from Xishuangbanna, due to hunting. Only a remnant population is said to be crossing back and forth along the Chinese Myanmar border (Ma *et al.* 1994). The subspecies in Malaysia, *Bos Gaurus hubbacki* is reported to be on the increase till late 1990's (Khan 1973, Khan *et al.* 1982, Abidin *et al.* 1991).

In Cambodia, Gaur probably declined by 90% or more in the period from the late 1960s to the early 1990s, at which time it still remained widespread, outside the lower Mekong and Tonle Sap lowlands, although in generally low numbers (Heng Kimchhay *et al.* 1998, Daltry and Momberg 2000, Timmins and Ou 2001). By far the most substantial gaur population of the country remained in eastern Cambodia centered on Mondulkiri

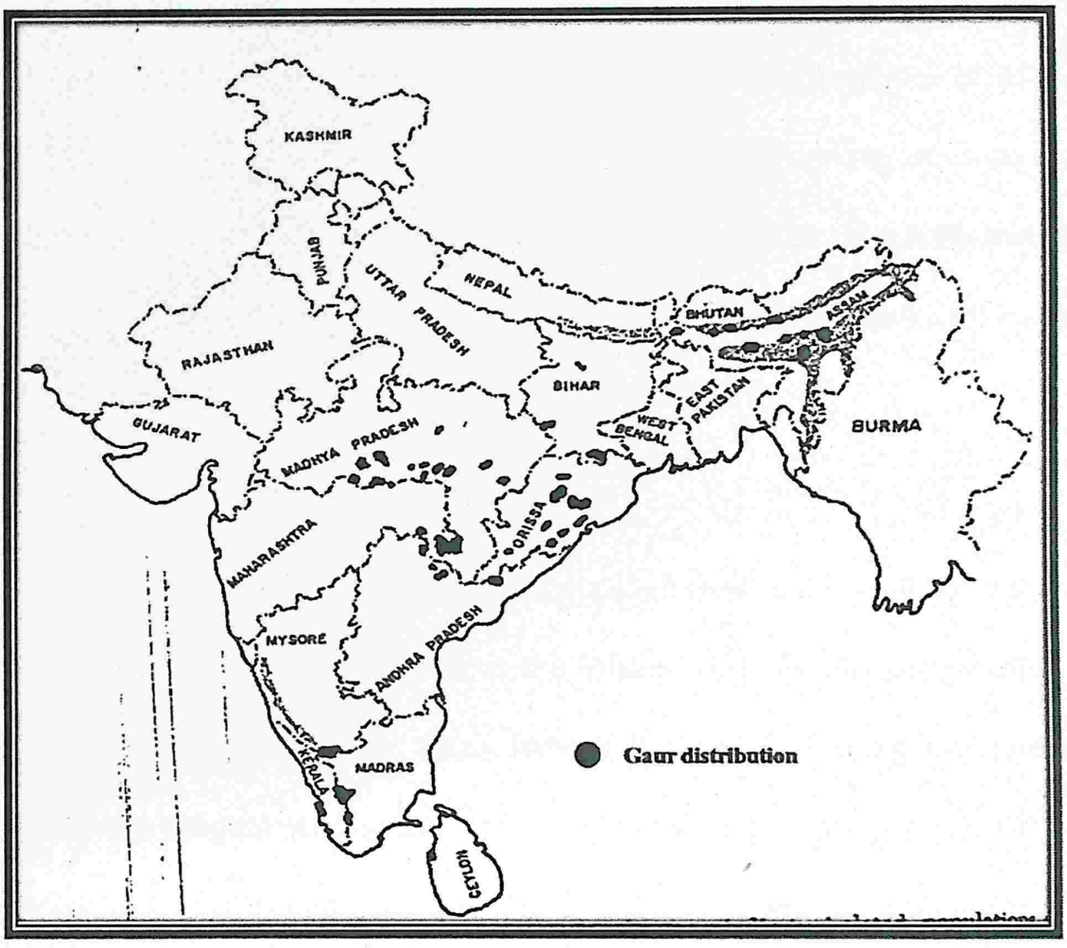
province, where in the late 1990s potentially several hundred to a thousand may have survived in a forested landscape of over 15,000 km² (Timmins and Ou 2001, Tordoff *et al.* 2005).

A few were thought still to occur in the Chittagong, Chittagong Hill Tracts, Sylhet, and Mymensingh areas in the early 1980s, but none had been seen in Pablakhali Wildlife Sanctuary in the Hill Tracts since the early 1970s (Khan 1985). Choudhury (2002) stated that gaur individuals from Mizoram and Tripura (India) still cross into Bangladesh, although the records on which this was based were not given. In Bhutan, gaur apparently persists all over the southern foot-hill zone, notably in Royal Manas National Park, Phipsoo Wildlife Sanctuary and Khaling Wildlife Sanctuary (Choudhury 2002).

1.3.2. India

Gaur is the largest living bovine confined to the oriental biogeography region and India supports 85% of its current global population (Ashokkumar *et al.* 2010a). Schaller (1967) gave a detailed account on the distribution of gaur in India mainly from information collected from various sources. In India, four major (Western Ghats, Central India, Eastern Ghats and North-East) and two minor (Bihar and West Bengal) "Gaur conservation areas" have been identified, reflecting the remaining distribution (Sankar *et al.* 2000, Choudhury 2002) (Figure 1.2). India has already lost one large bovid, the Banteng (*Bos javanicus*) which was once known to occur in North East India (Prater 1971, IUCN 1978).

Figure 1. 2. Past distribution ranges of gaur in India (Schaller 1967).



1.3.2.1. South Western India

The true home of gaur in India is the chain of undulating hills of the Western Ghats (Krishnan 1972). The Majestic gaur is found in Western Ghats including its southern ranges, Nilgiris, Anamalais and the Cardamom Hills and adjacent plateau (Ashokkumar 2004). On the eastern side of the peninsula, it is found in the Palani and Dindugal hills, the Shandamangalam ranges, the Shervaroys and some of the hill ranges near Vellore and the border of Karnataka. The species range extends from South Western Maharastra through Goa, Karnataka, Tamilanadu and Kerala. The gaur is now

discontinuously distributed in the region. The important gaur areas are Mudumalai and Anamalai in Tamil Nadu, Wayand, Periyar and Parambikulam in Kerala, Bandipur, Nagarhole and Bhadra in Karnataka, Molem in Goa and Radhanagari in Maharastra (Davidar 1986). This region harbors largest population of gaur than anywhere else in Asia (Choudhury 2002). The habitat type of this region consists of mainly tropical wet evergreen forest to scrub forest. The approximate population of the gaur in these areas is 9,000-12,000 within the available forest area of 1, 50,000 km^2.

1.3.2.2. North Eastern India

In Northeast the gaur is found in the Himalayan foot hills from the Narayani river through North Bengal to the Siang river, in the Mishmi Hills, Dapha Bum Range, Patkai Range, Naga Hills, Barail Range, Mizo Hills, hill tracts of Chittagong, Tripura and Manipur and the Meghalaya Plateau. The gaur is extinct in the plains of the Barak Valley; however it is still found in parts of the Terai, Duars and the Brahmaputra valley. The habitat in the Northeast is contiguous with that in Bhutan, Bangladesh, Myanmar and to some extent in Nepal. As in the other regions, the distribution is discontinuous and highly fragmented with at least 20 populations are already separated. The approximate gaur population in this area is 5000 to 8000 within the available gaur habitat of 54000 km^2. Information on population status from the states of Andhra Pradesh, Orissa and Northeast is limited (Choudhury 2002); there are demonstrably very few gaur in Kaziranga (Karanth and Nicholls 2000).

In recent years there are records of local extinction of gaur in Protected Areas *viz.* Bandavagarh National Park, in Madhy Pradesh, Thattakad Wildlife Sanctuary, in Kerala and Kanger Valley National park, in Chhattisgarh (Sankar *et al.* 2000).

1.3.2.3. Central Indian Landscape

In central India, the gaur extends from central parts of the Satpura Range to the Chotanagpur Plateau and then to the Northern ranges of the Eastern Ghats. Presently gaur confined to isolated patches due to habitat fragmentation and their number is dwindling in most of its ranges. Central India has the highest gaur habitat of the three regions, covering 83,000 km^2. The landscape holds approximately one fourth of the present population surviving in the country. In Madhya Pradesh, the gaur population is found in ten isolated districts (Table 1.2.), geographically isolated from one another (Lad *et al.* 1992).

Table 1. 2. Distribution of gaur in Madhya Pradesh Districts (Lad *et al.* 1992).

S. No.	Districts	Place
1	Sidhi	Sanjay National Park
2	Shahdol	Bandhavgarh National Park
3	Mandla	Kanha National Park
4	Seoni	Pench National Park
5	Bastar	Indravati/ Kanger National Park
6	Raipur	Barnavapara/ Udyanty Sanctuary
7	Bilaspur	Achanakmar Sanctuary
8	Raigarh	Badalkol/ Gomardha Sanctuary
9	Surguja	Tamorpingla/ Semarsot Sanctuary
10	Hoshangabad	Satpura/ Bori- Pachmari Sanctuary

Some important gaur areas are Melghat in Maharastra, Kanha, Satpura and Pench in Madhya Pradesh, Indravati in Chattishgarh, Palamau in Jharkhand and Simlipal in Orissa. The gaur density ± SE/ km² in the Central India landscape in 2011 was 3.47 ± 0.92/km^2 (Jhala *et al.* 2010).

Kanha National Park supports a good population of gaur and there has been substantial increase in numbers of gaur due to strict conservation measures applied ever

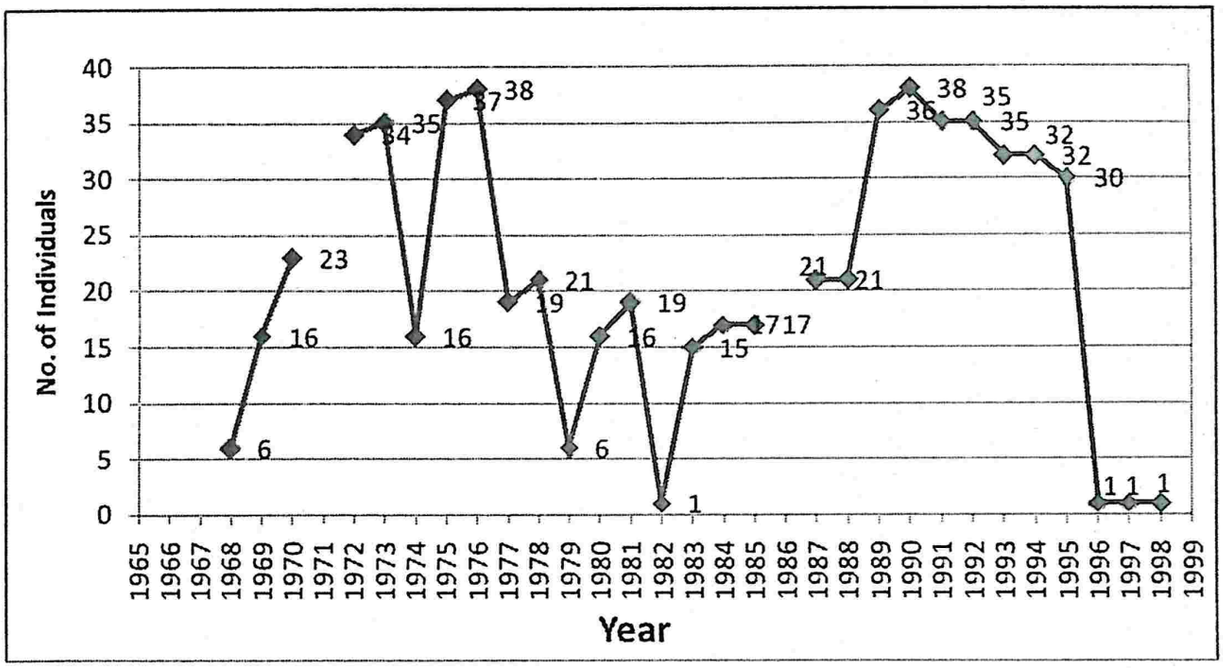
since the park was included under the Project Tiger (Belsare *et al.* 1984). A few herds are also seen in the Northern Andhra Pradesh, Bastar districts of Madhya Pradesh and adjoining Chanda district of Maharashtra and in Palmau and Singhbhum districts of Bihar. A few gaur were reported from Northern Bengal (Rao 1961). Parts of the Deccan Plateau between the Gawilgarh Hills and Northern Eastern Ghats also form some of its range. It is distributed in the states of Maharastra (northern and eastern areas), Andhra Pradesh (northern areas), Madhya Pradesh (mainly eastern and southern areas), Chhatishgarh, Jarkahnad, Bihar (South-Western corner), Uttar Pradesh (only in extreme South-Eastern areas) and Orissa.

Due to fragmentation of habitats and epidemics of rinderpest and foot and mouth diseases have adversely affected the population in the Central and Southern India (Stewart 1928, Ali 1927, Baker 1890, Bansal and Joshi 1980).

1.3.2.4. Bandhavgarh

The gaur was historically found in Bandhavgarh in small numbers. The small population of gaur is representative of the few herds surviving in the state north of river Narmada (Lad *et al.* 1992). According to the Management plan prepared by Sh. M. Dixit (1975), gaur was localized in the hilly tract around the Bandhavgarh fort. Gaur population of Bandhavgarh National Park was considered to be threatened (Sonakiya 1993). Estimated gaur population in Bandhavgarh from 1968 to 1998 is given in figure 1.3.

Figure 1. 3. Population estimation of gaur in Bandhavgarh.



** Population estimation for 1971 and 1986 are not avilable.

Gaur was usually seen in the Rajbahra, Bathan, Bhadrashila and Chakradhara areas of Tala Range, only in winter and summer. There is no definite information regarding where the species spent the rainy season. It was generally believed that they migrated to the Ghunghuti and Amarkantak areas (Southwest of Bandhavgarh) during the monsoon, but they were occasionally recorded within the extended park area (Kallwah and Magdhi ranges) during the rainy season as well. The 1988 monitoring program conducted by the forest department confirmed their presence in the Kaliwah/Magdhi area in the monsoon.

The information regarding mortality on gaur in Bandhavgarh is incomplete (lad *et al.* 1992) and the data was available only for certain period from 1974-1982 and 1988-1989 where in mortality of seven gaur were reported. Selective calf predation by tiger

and wild dog was largely responsible for the present status of gaur population in the park (lad *et al.* 1992). However, the animals did not return to their post-monsoon range in 1995. According to the management plan prepared by Prakasam (2006), the last gaur, a male, was seen in Bandhavgarh in 1998.

1.4. SIGNIFICANCE OF THE STUDY

1.4.1. Reintroduction

1.4.1.1. Plan preparation

As a part of active management and population building exercise, a proposal was prepared to re-introduce 20 gaur in Bandhavgarh Tiger Reserve from Kanha Tiger Reserve by Madhya Pradesh Forest Department in 2007. Subsequently Wildlife Institute of India performed Population Viability Analysis (PVA) and based on analysis it was proposed to re-introduce 50 gaur (Male : Female ratio was 1:3) so as to achieve the overall population growth rate of 5% along with probability of survival as 99% (Pabla *et al.* 2011). It was proposed to reintroduce 20 gaur (15 adult females and 5 adult males) in the 1st year and after careful monitoring of the initial population, the supplementation of 30 gaur to the population within two years, would be under taken to maintain a viable population of approximately 50 animals (Pabla *et al.* 2011).

1.4.1.2. Pre-preparation in Kanha Tiger Reserve

The Tiger Reserve comprises of core zone (940 km^2) and buffer zone of (1009 km^2) and Phen Wildlife Sanctuary, which joins with an area of 110 km^2, along with Kanha Tiger Reserve.

1.4.1.3. Enclosure

A holding Boma (enclosure for large herbivores; Swahili term, Mozambique) was designed at Kisli range in Kanha Tiger Reserve where the immobilized animal was released before eventually being loaded in the transport truck. The Boma was constructed of steel sections 2.5 m high by 3 m long made out of 50 mm x 75 mm x 3 mm rectangular hollow tubes. The Boma had three sliding gates 1.5 m wide sliding on a 3 m rail and 2.5 m high. The Boma had a loading ramp which was a 3 m section and made of solid pressed steel at 2.5 m height. The steel sections of the Boma beyond the sliding gate were covered using the agri-mesh all the way up to the entrance of the truck. Since gaur is forest dwelling animals, this was done to give them a sense of having a space to hide in. Branches with foliage were hung on the wires running across the Boma. The Boma was divided into two compartments using bamboo mats and sliding gate and provision was made for providing food, water and salt in the last compartment. A loading ramp was prepared which is a 3 m section, of solid pressed steel at 2.5 m height. The same specifications applied to the walkway of the other sections.

1.4.2. Transport truck and stretcher

1. Two mini transport trucks (TATA 407 four by four) were fabricated as recovery vehicles for carrying immobilized animals from the site of capture to the vehicle or the enclosure.
2. One heavy duty transport (TATA LPT 1615) truck was fabricated for the transport of animals by road from Kanha to Bandhavgarh Tiger Reserve.

3. A stretcher was specially designed for carrying immobilized animals from the site of capture to the mini transport truck.

1.4.3. Pre-preparation in Bandhavgarh Tiger Reserve

A suitable site with good vegetation cover and water was selected for the soft release of gaur at Beheraha in Bandhavagarh Tiger Reserve at the borders of Tala and Magdhi ranges. A 50 hectare carnivore proof enclosure with solar powered electric fence was prepared for the release of animals. A small area of 2.5 hectare was fenced inside the larger enclosure to facilitate closer observation of the animals during the initial few days. Details of the pre-preparation of gaur translocation in Kanha Tiger Reserve and Bandhavgarh Tiger Reserve are given in appendix I.

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1.5. REVIEW OF LITERATURE

1.5.1. Reintroduction

Reintroduction and translocation are both important tools for population and species management. Reintroduction may involve returning native species to localities where they had been lost, or called as "re-establishment" (Campbell *et al.* 2010). Translocation moves wild-caught animals from one natural location to another, while Reintroduction moves captive-born/ wild animals into their natural historical ranges (Kleiman 1989). An estimated 30,000 plants/ animals species are destroyed annually by tropical deforestation (Myers 1998). Many populations are getting extinct have so declined (Ceballos 2002), that nearly 3000 vertebrate taxa face extinction, and may only be saved through conservation breeding (Ebenhard 1995). Captive breeding,

reintroduction, and translocation programs are thus becoming increasingly important conservation tools (Griffith *et al.* 1989).

Two important obstacles to re-establishing the species are:

1) To understand the fundamental ecological requirements and life histories of species of concern (Sarrazin *et al.* 1996).

2) To identify appropriate areas for reintroduction or restoration, recognizing that degradation or modification can render native habitats unsuitable (Dobson *et al.* 1997 and Shugart *et al.* 2001).

Evolving reintroduction methodologies therefore demand greater scientific input. Conservation biology techniques, such as Population Habitat and Viability Assessment (PHVA) (Ellis *et al.* 1995), usually require detailed life history and habitat information. Unfortunately, such data do not exist for most species, particularly for the endangered taxa (Sarrazin *et al.* 1996), and the cost of collecting it by conventional methods can be prohibitive. Modeling is also useful for determining the most essential factors controlling an ecosystem (Levin 1992), and thus the amount of information that must be collected to understand the system. Together, remote sensing and modeling allow ecological issues to be examined over large areas and over long times, and thus may be crucial to the long-term success of reintroduction programs (Estes 2005).

Only a very few studies were done on wild animal reintroduction and restoration in the world. Reintroduction was done on wild animals, and also on captive-bred animals to the wild (Rob Laidlaw 2001) such as tiger (*Panthera tigress*) in India (Sankar *et al.* 2010, Ramesh *et al.* 2011) Grey wolf (*Canis lupus*), Arabian oryx (*Oryx leucoryx*) and

Black bear (*Ursus americanus*) in USA (Campbell *et al.* 2010), White Rhinoceros (*Ceratotherium simum*) in Botswana (Pitagano 2007), Elk (*Cervus canadensis*) in America (Schneider *et al.* 2006), Rein deer (*Rangifer tarandus)* in Finland (Kojola *et al.* 1998), America bison (*Bison bison*) in Canada (Kay *et al.* 2001), Asiatic wild ass (*Equus hemionus*) in Israel (Saltz *et al.* 1995) and One Horned Rhinoceros (*Rhinoceros unicornis*) in Nepal (Jnawali 1991). The first efforts to restore a sustainable population of elk in the eastern habitats was reported in 1913, and additional reintroduction efforts on this species were reported by Wisconsin (1995) and Missouri (2012).

Few studies are available in Indian Subcontinent on reintroduction of wild animal such as tiger (*Panthera tigress*) in Sariska Tiger Reserve, Western India (Sankar *et al.* 2010) and Panna Tiger Reserve, Central India (Ramesh *et al.* 2011), wild buffalo (*Bubalus bubalis arnee*) in Dibru - Saikhowa National Park, Assam (Ashraf and Sarkar 2011), One Horned Rhinoceros (*Rhinoceros unicornis*) in Dudhwa Tiger Reserve, Uttar Pradesh (Sinha *et al.* 2001, Pitlagano 2006) and Manas National Park, Assam (WTI 2011).

1.5.2. Gaur

Gaur *Bos gaurus* (H. Smith 1827) is the largest bovid confined to the oriental biogeographic region of the world. Gaur, the second largest animal in Peninsular India has been one of the least studied in all respects throughout its ranges (Schaller 1967, Krishnan 1972 and Choudhury, 2002). Approximately 85% of its current global population of gaur occurs in India (Duckworth *et al.* 2008). From its reported distribution in the past the species has experienced dramatic range reductions with present population

surviving in isolated forested patches. Information on its current distribution status in India was obtained through a questioner survey and literature reports (Choudhury 2002, Sankar *et al.* 2000). Little is known of the life history of Asia's largest Bovini species, gaur *Bos gaurus gaurus* (Schaller 1967).

Some historical information on gaur is reported by Brander (1923) and Finn (1929). Most of the available information on the species are annectodal observations (Cameron 1929, Brander 1935, Blackburn 1935, Morris 1937: 1954, Biddulph 1936, Mustill 1938, Russel 1938: 1940, Rynjah 1950, Hutton 1951). A few of the published notes dealt with observations on the morphology of gaur (Vairavel 1998). Piezy (1940) reported the distinction between Indian and Malayan gaur. Morris (1948) and Kurt (1974) briefly mentioned the disease aspects of gaur.

The status of gaur in Northeast India was reported by Choudhury (2002), Gupta and Mukherjee (1994) and Wegge (1976), while in central and southern India their status was reported in Basappanavar (1985), Davidar (1986), Dwivedi (1987), Imam (1985), Karanth (1986), Karanth and Sunquist (1992, 1995), Krishnan (1972, 1982), Raju and Heggde (1995), Raju *et al.* (1987), Rao (1991), Saharia (1982), Samant (1990), Sanzgiri (1995), Shahi (1977), Shukla (1994) and Shukla and Khare (1998) Vairavel (1998) and Sankar *et al.* (2001). Interesting information on albino gaur was reported by Williams (1969), Davidar (1970) and Ajith *et al.* (1998).

The biology and ecology of gaur in different Protected Areas was investigated by Pasha *et al.* (2002), Kannan (2001), Chetri (2006) and Gad and Shyama (2009). Till date, only three detailed long-term studies were undertaken on gaur in India by Vairavel

(1998) in Parambikulam Wildlife Sanctuary, Kerala, Sankar *et al.* (2000) in Pench Tiger Reserve, Madhya Pradesh and Ashokkumar (2004) in Mudumalai Tiger Reserve, Tamil Nadu. In addition, two ecological studies were carried out in other countries *i.e.* Conry (1989) investigated home range and habitat utilization of gaur in Malaysia. Prayurasiddhi (1997) attempted a comparative study on gaur and banteng (*Bos javanicus*) in Thailand in which the population, feeding ecology of these species were investigated. Ahrestani *et al.* (2011) studied the life-history traits of gaur in Mysore Zoo. Age and sex determination of gaur is reported in captivity by Ahrestani and Prins (2011). Two short term studies on the activity pattern and feeding behavior of gaur were studied, by Moorthy (1989) in Kodaikanal Hills and Prabhakar (1992) in Indira Gandhi National Park.

1.6. JUSTIFICATION OF THE STUDY

Since the gaur population was extinct locally from Bandhavgarh Tiger Reserve it is essential to monitor and study the relevant ecological aspects and enhance the long-term survival of the species that will address the important aspects like food habits, ranging, movement, dispersal pattern, habitat utilization and home range size of the reintroduced animals. Therefore the outcome of this study will be immensely helpful for the park management to conserve this endangered species.

1.7. OBJECTIVES

1. To study the ranging patterns of re-introduced gaur in Bandhavgarh Tiger Reserve and
2. To study the habitat use of re-introduced gaur in Bandhavgarh Tiger Reserve.

1.8. STUDY PERIOD

The study was conducted from March 2011 to February 2013 covering all seasons in a year, summer (March - June), monsoon (July - October) and winter (November - February).

1.9. ORGANIZATION OF THESIS

The thesis is structured into six chapters, each chapter consisting of an introduction of the topic, review of literature, elaboration of methods and analysis used, results arrived at and discussion of the results and comparison with earlier studies.

Chapter 1: Deals with the study species gaur, reintroduction, scope of the study and objectives of the study.

Chapter 2: Describes the study area, Bandhavgarh Tiger Reserve, Madhya Pradesh.

Chapter 3: Deals with the ranging pattern, movement pattern and herd formation of the reintroduced animals.

Chapter 4: Describes the habitat use and resource selection of reintroduced animals.

Chapter 5: Group size and composition of reintroduced gaur.

Chapter 6: Conservation of reintroduced gaur population in Bandhavgarh Tiger Reserve.

Chapter II

Study Area

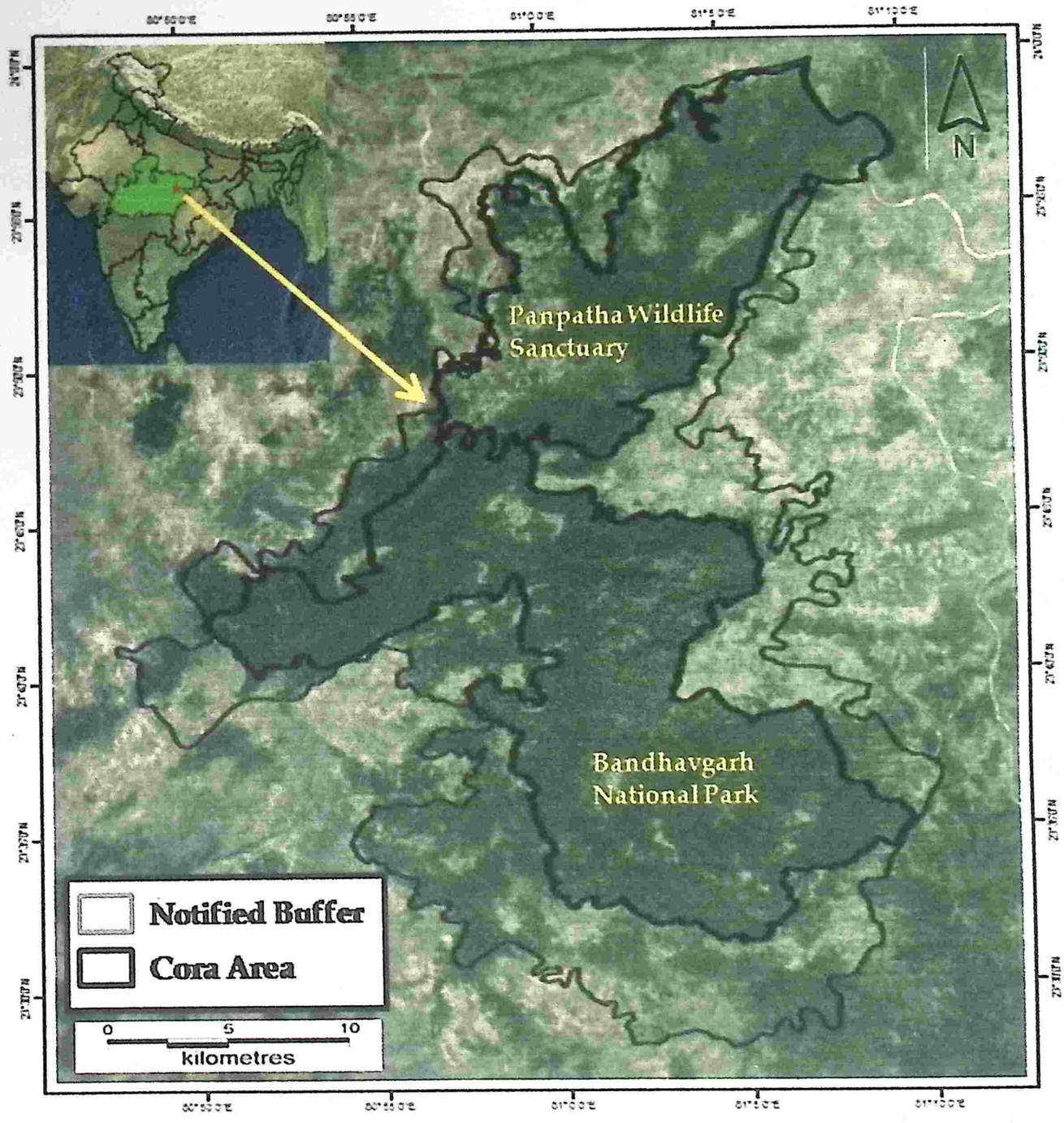
Chapter II

STUDY AREA

2.1. LOCATION

The survey was carried out in Bandhavgarh Tiger Reserve (BTR), which lies along the extreme north-eastern border of the Madhya Pradesh state and the northern flanks of the eastern Satpura Mountain range 23°30' to 23°46' N and 80°11' to 80°36' E (figure 2.1). The area of BTR is 716.46 Km^2, which includes the Bandhavgarh National Park (BTR) and Panpatha Wildlife Sanctuary (PWS) and the elevation of the park varies between 410 m (1,345 ft) and 810 m (2,657 ft). The total area of the BNP is 716.46 Km^2, out of which 521.30 Km^2 lies in the Umaria Forest Division and the remaining in Katni Forest Division. The PWS has an area of 264.28 Km^2 and it is connected to Sanjay Tiger Reserve towards the Eastern part of the park.

Figure 2. 1. Location of Bandhavgarh Tiger Reserve, Madhya Pradesh, Central India.



2.2. GENERAL INFORMATION

Bandhavgarh Tiger Reserve is a prominent Tiger Reserve in India. The rich flora supports an equally diverse fauna (Gopal 1991). Yet Bandhavgarh is a classic model of a habitat island (Sawarkar 1986). High density of tigers reaching almost saturation level for the area, tends to show 'spacing phenomenon' in the individuals and spreading towards buffer zone (Dwivedi 1987). Bandhavgarh is an important tiger conservation area of the country (Gruber *et al.* 1982, Panwar 1986). Bandhavgarh Tiger Reserve can be approached by road from both Umaria and Katni. Umaria (32 Km) is the nearest railway station and Jabalpur (191 Km) is the nearest airport.

2.3. HISTORICAL AND LEGAL STATUS

Bandhavgarh Tiger Reserve has a very old history, ruins of the bygone era are scattered all over the Tiger Reserve. No records however remain to show the construction of Bandhavgarh Fort. It is believed to be some 2000 years old and there are references to it in the ancient texts, the *Narad Panch Ratra* and the *Shiva Purana*. Bandhavgarh is named after Shri Lakshmana, the younger brother of Lord Rama, hero of the Hindu epic Valmiki Ramayana. It is said that while returning from Ayodhya after the coronation of Lord Rama, two monkey engineers Nala and Nil thought of presenting a tribute to lord hence they built Bandhavgarh fort. Later, Lord Rama handed over the fort to his brother Lakshamana (Tiwari 1998). Various dynasties have ruled the fort (Sharma 1994). During 300 A. D. several caves were developed in Bandhavgarh fort. Bhimsen was the prominent ruler during 300 A. D. In 1494 the King Baghel ruled Bandhavgarh.

Vikramaditya ruled from 1597 to 1624 A. D. in which, the habitation of Bandhavgarh fort started during 1617 A. D. On *Ramnavami Festival* and *Krishna Janmashtami* local people visit Bandhavadheesh temple.

The old park area was declared as reserved forest under 'Kanun Jungle' Riyasat Rewa during 1927 and restrictions on felling of certain species were also imposed. The new rule formed under 'The nistar grazing' related to reserved forest and A M Jungle in 1930. In 1959 the M.P. Govt. Act ended hunting and the area was declared as National Park on 23/3/1968 under M.P. Park Act 1955 (No. VII of 1955). Subsequently, Tala Reserved Forest was included in the National Park, (Notification No. 2977/x/68) (Sonakia 1993). The Governmet of Madhya Pradesh notified its intention to enlarge the park area as 448.842 Km^2 in 1982. Panpatha Wildlife Sanctuary (PWS) (Notified vide No. 2411/x-12/10-83 Dated 4/6/1983, with an area 245 Km^2 was later included and subsequently the entire area was declared as Bandhavgarh Tiger Reserve under Project Tiger in the year 1993.

2.4. CONSERVATION VALUES

Central Highlands of India are one of the most important habitats in the world for the conservation of the umbrella species and the endangered cat; the tiger (*Panthera tigris*). The Bandgavgarh TR has great significance in the context of conservation of avian fauna too, as it not only provides suitable habitat for the resident birds; but also provides wintering grounds for many waterfowl. Besides tiger and birds, the reserve harbors a wide range of faunal species, some of which figure prominently in the IUCN

Red List. These species include *Cuon alpinus, Vulpes benghalensis, Melursus ursinus, Lutra perspicillata, Panthera pardus,* and *Python molurus.* The presence of mosaics of meadows within the forest, being large expanses of herbage availability, also has a bearing on the concentration of herbivores. More than 250 species of birds and 36 species of mammals, 110 species of butterflies and several species of reptiles, arthropod and termites are present in the reserve. A total of 553 plant species belonging to 362 genera and 94 families were recorded in the reserve (Sonakiya 1993). The reserve is a rich locality for exploration of flora and it should prove an important landmark to botanists (Tiwari 1968).

2.5. TOPOGRAPHY AND GEOLOGY

Topographically, Bandhavgarh is extremely rugged with small hillocks. It is part of a larger plateau having a minimum height of 400 m and maximum altitude is 810 m above msl (mean sea level). The topography is rugged, interspersed with grassy swamps (Gopal 1991). The hill formations are bounded by Charanganga and Damna Rivers. The Sanctuary area is generally plain and some parts have undulating hillocks and the highest peak of the Sanctuary is 500 m above msl. The sandstone covers almost the entire Tiger Reserve and several faults occur in NE – SW and SW – SE sides (Sonakiya 1993).

Geology

The Bandhavgarh Tiger Reserve contains one of the oldest rocks in the world – the Gondwana rocks which spread over Umaria (Tiwari 1979, Singh 1986). The soft feldspathic sandstone of medium to coarse texture of Supra Bharakar is the main geological formation of the park. In this rock, rounded quartzite pebbles are embedded in

soft sandy matrix. The beds of rivers and nalas are sandy. The soil is brown red or gray in color (Sinha 1977). The sandstone has resulted in sandy soil, which is deep in the foothills (Gopal 1991).

2.6. PHYSICAL FEATURES

2.6.1. Soil

The various rock formations and local topography have played an important role in the formation of soil. Soil is derived from Gondwana sandstone and conglomerates are sandy loams. At few places where trap occurs, the percentage of sand is less and rich black soil or alluvial loam is found. Sandstone is formed due to deposition of secondary rocks. Major underlying rock formation of the area is sandstone and loams. Basic rocks give rise to black cotton soil on weathering, which are best suited for agriculture. Such soil are available, though restricted in extent in Badrehal, Pathari and other surrounding areas (Sonakiya 1993). The sub soil is usually unbroken and impervious. Sedimentary rocks are primarily responsible for the tropical dry deciduous type forest. The pH of the soil is 20 and the composition of the chloride is 13 (Roy *et al.* 1992). The soil is usually poor in nitrogen and organic matter and fairly rich in potash.

2.6.2. Terrain

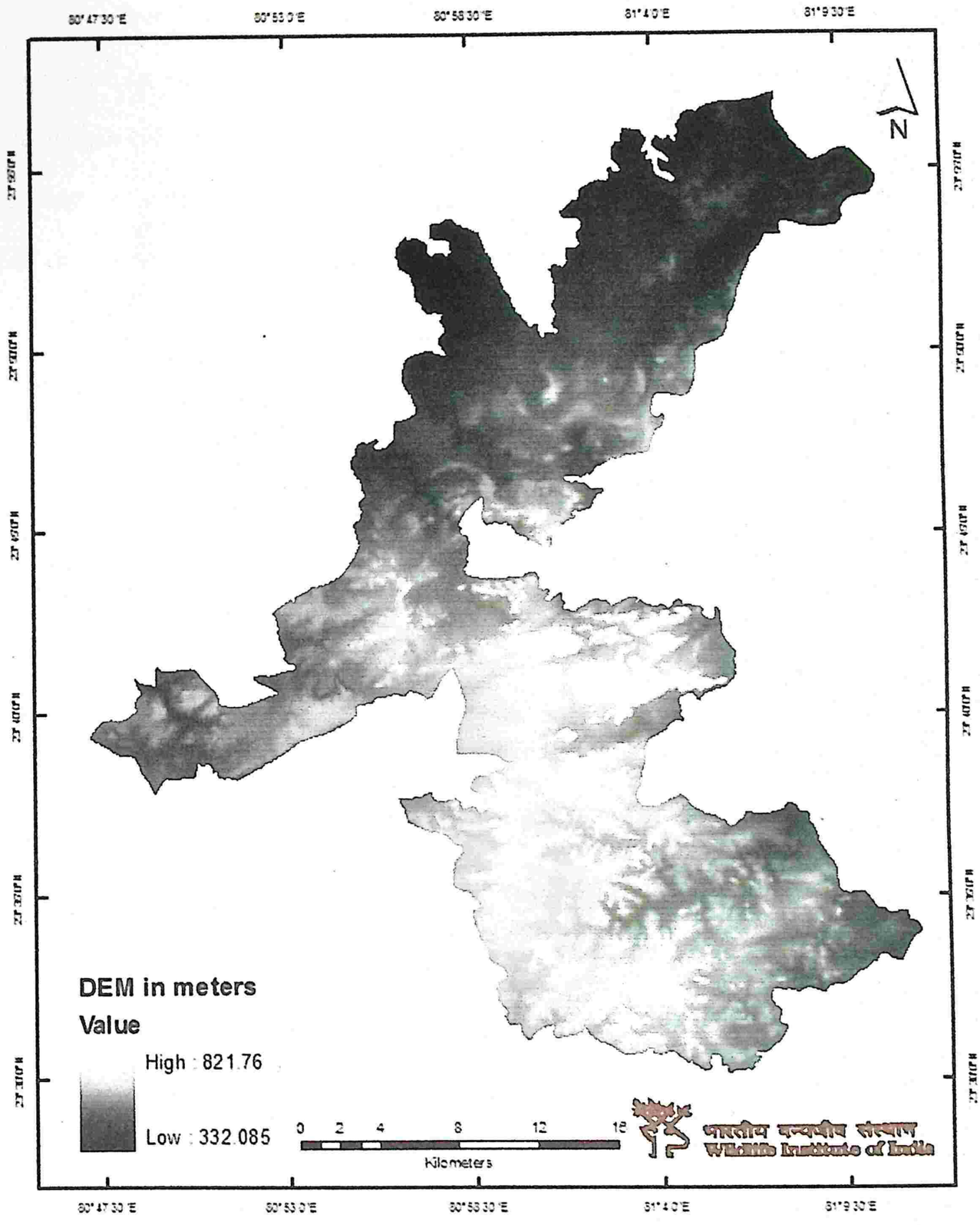
The terrain is of rocky hills rising sharply from the swampy and densely forested valley in the lowland. The finest of these hills is Bandhavgarh, merged with great cliffs and eroded rocks. The PWS is generally plain with few undulating hillocks in few parts.

The elevation in the Tiger Reserve varies from 440 m to 810 m from the msl, the higest elevation is Bandhavgarh fort at 810 m and in Sanctuary it is 500 m above msl. The hills have gradual to steep slopes with almost flat tops. The Park reflects Lithology and structure of Geological formation. Bandhavgarh Fort is flat topped, with gentle northerly slope corresponding to the lone dip of the Bandhavgarh sandstone beds. The park is surrounded by 32 hillocks.

2.6.3. Slope

The slope (figure 2.2) categories in Bandhavgarh TR have been identified into eight classes *viz*. 330-390 degrees, 390-450 degrees, 450-520 degrees, 520- 580 degrees, 580- 640 degrees, 640-700 degrees, 700- 760 degrees and 760- 820 degrees. Most of the protected area (PA) falls into flat to gentle slope (330- 640 degrees) class. Part of Tala range (reserved forests) has a rugged terrain with steep slopes (700- 820 degrees).

Figure 2. 2. Digital Elevation Model map of Bandhavgarh Tiger Reserve.

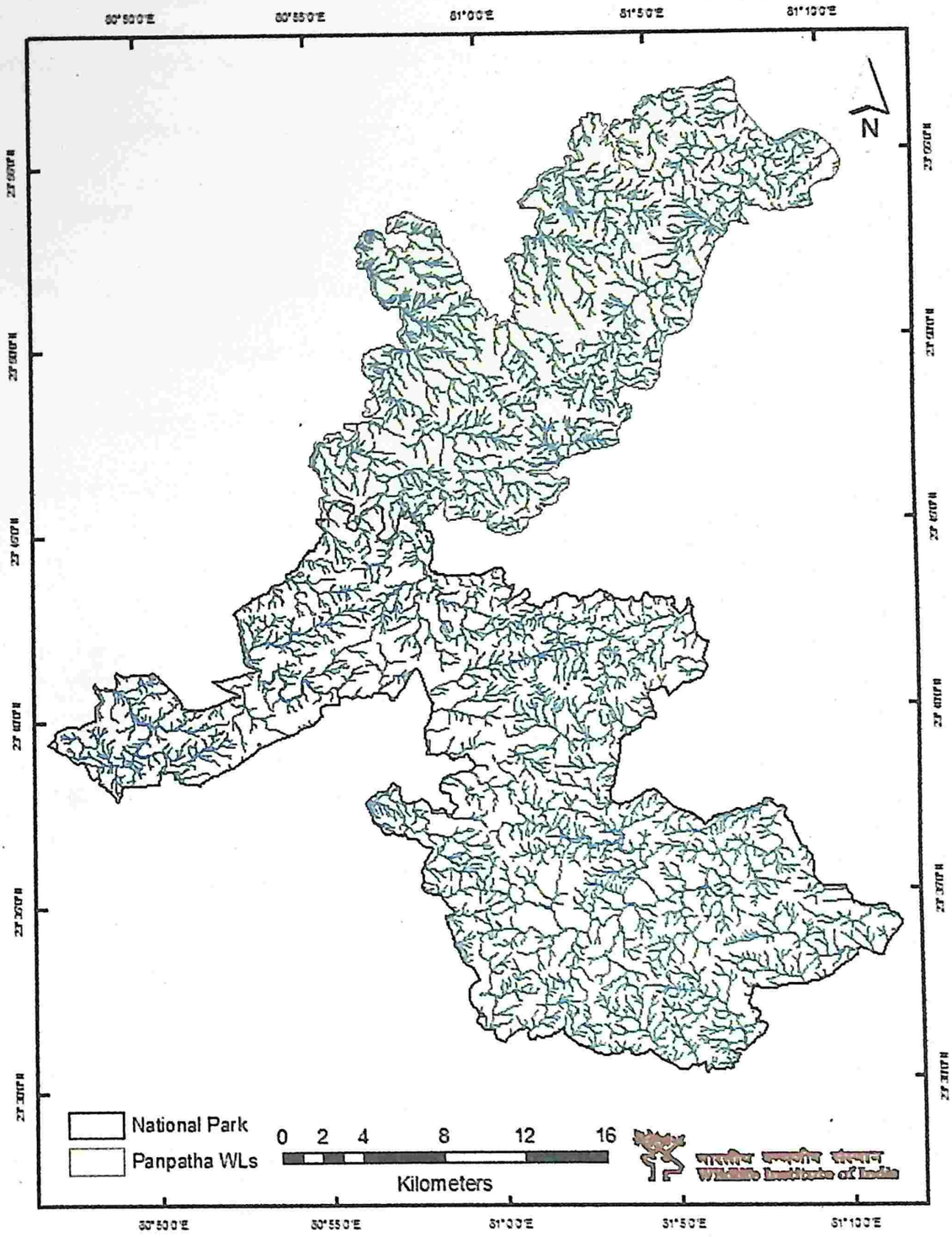


2.6.4. Drainage pattern and water availability

The Tiger Reserve has number of seasonal and perennial streams and nullas, but most of them are seasonal (Lad and Gopal 1992). Charanganga River originates from the Bandhavgarh Hills and flows through the human habitations outside the Tiger Reserve. The major perennial rivers are Umarar, Damar, Janad, Johila, Charanganga and seasonal nalas are Bhadar, Chachahi and Chamkuli. Son river flows in the north eastern direction along the boundary of Panpatha WLS. A large number of perennial springs originate on the slope of Bandhavgarh Fort (Pabla 1998). The Janad river runs year around and flows in North-East region of the park, which originates from Magdhi range and flows into Kallwah range and joins the Son river running along the buffer boundary. In Sanctuary area the main rivers are Halphal, Jaruwahi Nala and Bagaiha Nala.

The major artificial waterholes are Rajbehra dam, Devkanni talab, Andhri jeriya Hatwal, Bamera dam and Damdama talab. The seasonal waterholes include Jhurjura dam, Mahaman dam, Bhodha thalab, Charakava talab, Suka dam, Sukhi patiya, Bodaha, Akadava, Karkacha and Murdhuva. Water in the seasonal streams flow only during rainy season but water is available for wildlife in puddles throughout the year. These water resources become limited during summer. To combat this problem at several places the park management has constructed artificial water holes, in which the water is supplied with the help of tankers, solar pumps and hand pumps. The drainage pattern of the Tiger Reserve is shown in figure 2.3.

Figure 2. 3. Drainage pattern of Bandhavgarh Tiger Reserve.



2.6.5. Climate

The Tiger Reserve lies within the Tropical Zone characterized by a distinct winter (November-February), summer (March- June) monsoon (July- August) and post-monsoon (September-October).

2.6.5.1. Summer

The summer sets in the month of March and lasts till around mid June. The temperature of the area varies from 0^0C to 44^0C (figure 2.4). The summer is usually dry, but instances of rains, hailstorms and thunder do occur in the month of March and April. The relative humidity in the early afternoon is as low as 15-20%.

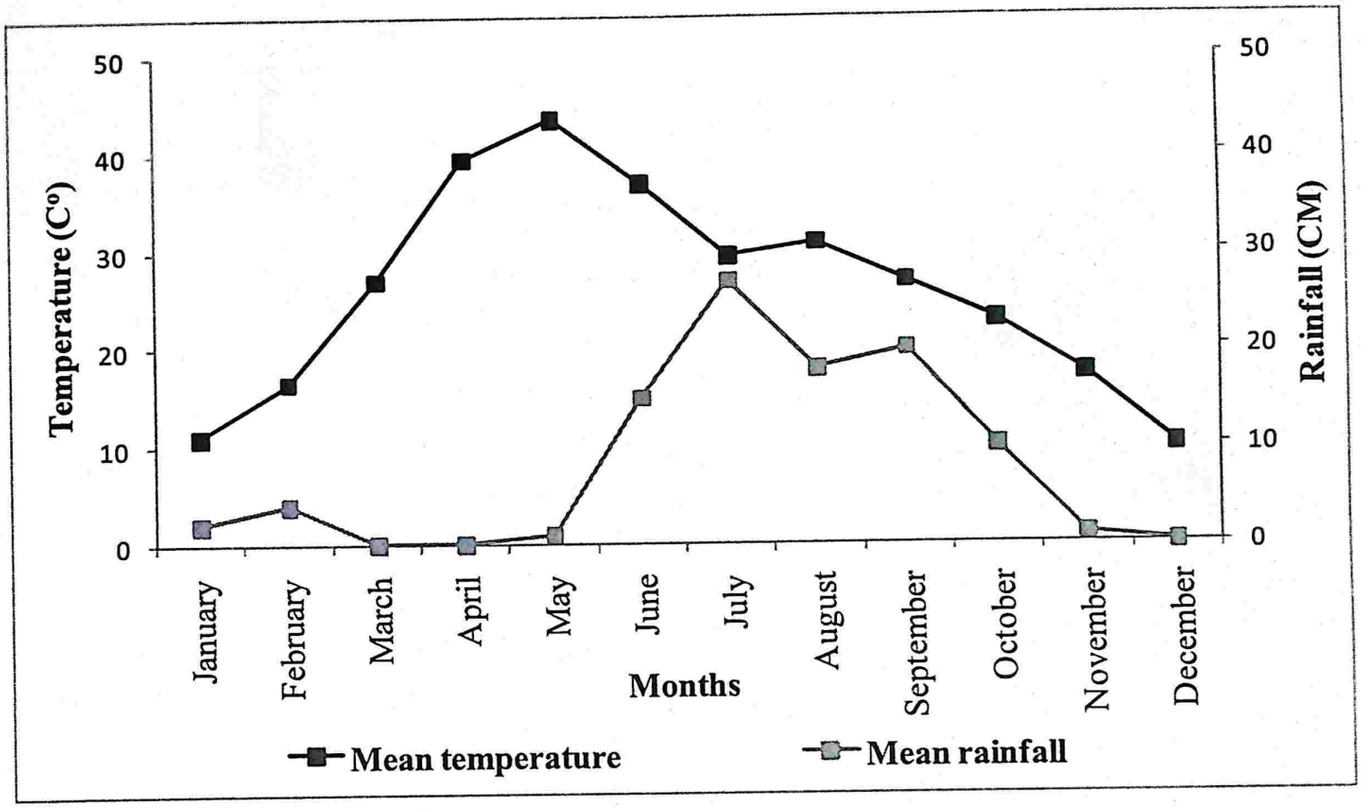
2.6.5.2. Monsoon

The advent of rainy season starts with pre-monsoon showers usually received in the second or third week of June, and regular onset takes place by the first week of July. About 70 percent of the precipitation is received from the South – West monsoon during the rainy season and about 20 percent comes from the North-East monsoon during the winter season (figure 2.4).

2.6.5.3. Winter

Winter starts from November and continues till the end of February. The coolest months are December and January. The average minimum temperature is 8.2 C. Frost is not common in the region, but relative humidity becomes very high during the night and the incidence of dew is heavy.

Figure 2. 4. Mean temperature and rainfall in Bandhavgarh Tiger Reserve, Central India. (January 2011 to December 2013).

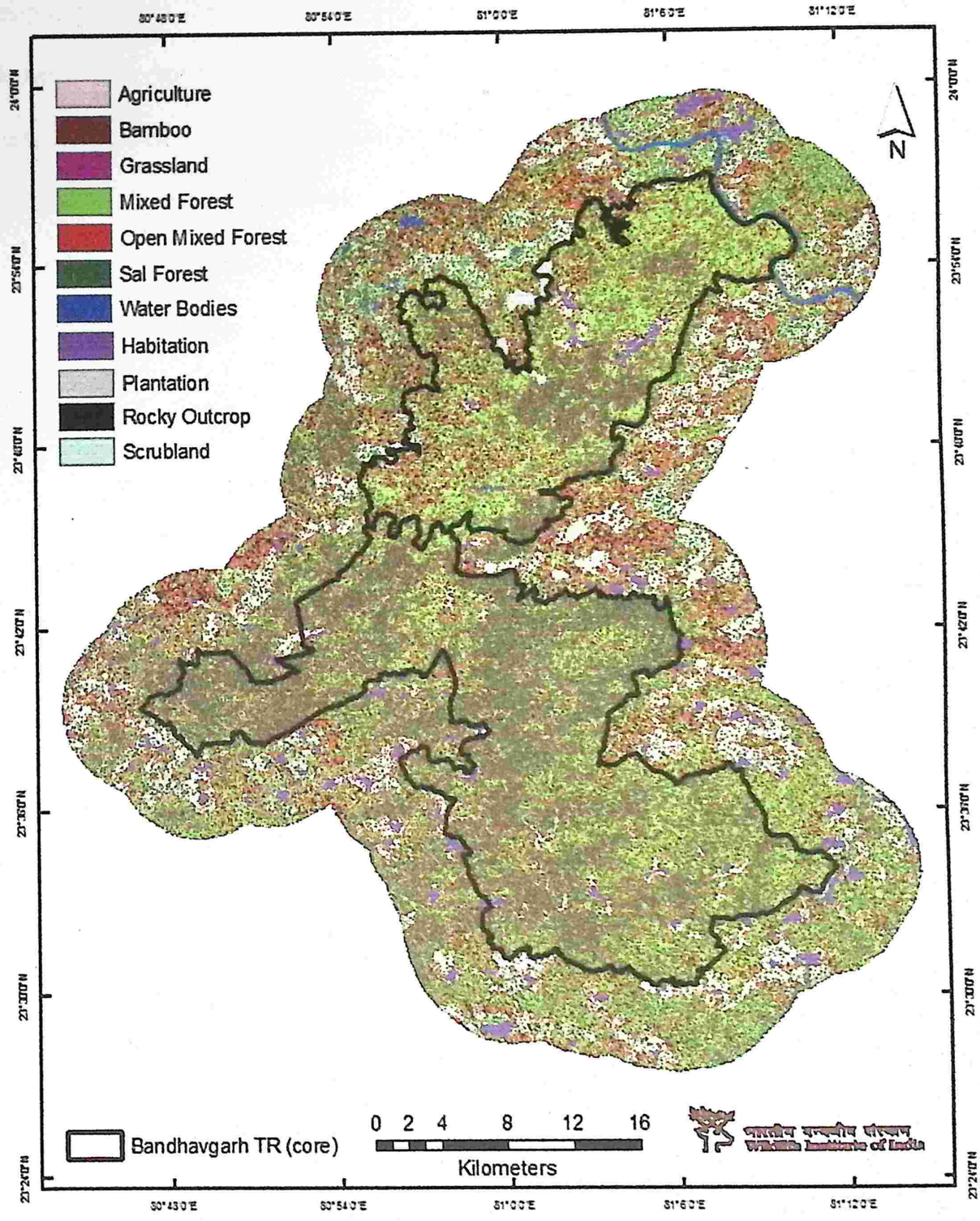


2.7. BIOLOGICAL ATTRIBUTES (FLORA AND FAUNA)

2.7.1. Flora

Vegetation of Bandhavgarh Tiger Reserve falls under five categories (Champion and Seth, 1968) such as Moist peninsular low level Sal forest ($3C/C_{2e}$), Northern dry mixed deciduous forest ($5B/C_2$), Dry deciduous scrub (DS_1), Dry grassland ($5/DS_4$) and West Gangetic moist mixed deciduous forest ($3C/C_{3a}$). The land use and land cover map of the Tiger Reserve is given in figure 2.5.

Figure 2. 5. Vegetation and land cover map of Bandhavgarh Tiger Reserve, Madhya Pradesh.



A) *Moist peninsular low level Sal forest ($3C/C_{2e}$)*

Sal typically forms a high forest in which it constitutes 60 - 80% of the top canopy, which is 25–40 m high. The undergrowth is abundant with the presence of climbers. The main associates are *Terminala tomentosa, Pterocarpus marsupium, Anogeisus latifolia, Madhuca indica, Emblica officinalis, Buchanania lanzan, Diospyros melanoxylan, Terminalia Chebula, Kydia calcina, Ougeinia oojenensis, Bridelia retusa, Bauhinia retusa* and *Phoenix acaulis.* Sixty percent of the Tiger Reserve area comprises of Sal forests and its associates.

B) *Northern dry mixed deciduous forest ($5B/C_2$)*

The upper canopy in this forest type is usually light, open and irregular, the trees having relatively short bole and poor form and a height rarely over 10 m. The canopy is made entirely of deciduous trees. The main species found are *Anogeissus pendula, Acacia catechu, Butea monosperma, Buchanania lanzan, Acacia leucophloea, Syzygum cumini, Mangifera indica, Aegle marmelos, Soymida febrifuga, Carissa fistula, Flacourtia indica, Capparis decidua, Aristida depressa, Cymbopogon martini, Heteropogon centortus, Dendrocalamus strictus* and *Themeda quadrivalvis.* The undergrowth is comprised of *Zizihpus mauritiana, Zizihpus oenopolia, Zizihpus nummularia, Carissa opaca, Holarrhena antidysenterica, Bauhinia vahlii, Aristida depressa, Cynodon dactylon* and *Cassia tora.*

C) *Dry deciduous scrub (DS_1)*

This forest type represents a degradation stage of the dry deciduous forest and has been brought into existence by adverse biotic factors like excessive grazing, looping,

felling and fires. In spite of sufficient rains, moisture retention is poor and the type has now become a stable edaphic climax. The crop is open with less tree cover. The main species found are *Butea monosperma, Diospyros melanoxylon, Cassia fistula, Aenogeissus latifolia* and the undergrowth is mainly compressed of *Woodfordia fruticosia* and *Flacortia indica.*

D) *Dry grassland (5/DS$_4$)*

The dry grassland is found where the site has been subjected to biotic pressure. The soil surface has medium size stones. Grasses grow up to 1 m tall. The dominant grasses are *Themeda quadrivalvis*, *Aristida adscensionis* and *Heteropogon contortus*.

E) *West Gangetic moist mixed deciduous forest (3C/C$_{3a}$)*

Many species growing in this forest type are common to the moist deciduous forests. The canopy is comparatively open allowing good percentage of grass and herb to grow. The main species found in this type are *Lagerstroemia parviflora, Anogeissus latifolia, Adina cordifolia, Terminalia chebula, Diospyros tomentosa, T. bellerica, Bauhinia retusa, Lannea coromandelica, Mitrayyna parvifolia, T. arjuna, Cassia fistula, Kydia calycina, Bauhinia racemosa, Emblica officinalis, B. variegata, Aegle marmelos, Grewia tiliaefolia, Erioloena hookeriana, Bridelia retusa, Casearia esculenta, Cleistanthus collinus, Gardenia turgida, G. latifollia, Holarrhena antidysenterica, Garuga pinnata, Buchanania lanzan, Butea monosperma, Helicteres isora, Colebrookia oppositifolia* and *Dendrocalamus strictus* (Lall 1988). Most of the moderately moist mixed deciduous forest in which Sal is scarce or absent appears to be the only serial in status and the indications are that once the progression has reached a point at which Sal

can obtain a rooting, it relatively quickly establishes its dominance and characteristics of the climax formation (Champion and Seth 1968). Bamboo occurs as undergrowth which are heavily browsed and become bushy. New culms of bamboo grow during November – December. These forests are highly prone to fire. The degraded forest conditions in Tala forest are attributed to relentless biotic pressure as the forest area is exposed to human interference from nearby villages (Lall 1988).

2.7.2. Fauna

The Tiger Reserve supports a fabulous assemblage of herbivores such as chital (*Axis axis),* sambar (*Rusa unicolor*) nilgai (*Boselaphus tragocamelus*), wild pig (*Sus scrofa*), barking deer (*Muntiacus muntjac*), four-horned antelope (*Tertracerus quadricornis*) and chinkara (*Gazella bennetti*). The arboreal mammals such as bonnet macaque (*Macaca radiata),* common langur (*Seminopithecus entellus),* and Indian giant squirrel (*Ratufa indica)* are found. The area supports a wide variety of large, medium and small sized carnivores such as tiger (*Panthera tigris*), leopard (*Panthera pardus*), dhole (*Cuon alpinus*), sloth bear (*Melursus ursinus*), jackal (*Canis aureus*), jungle cat (*Felis chaus*), rusty spotted cat (*Prionaillurus rubiginosus*), common palm civet (*Paradoxurus hermaphroditus*), small Indian civet (*Viverricula indica*), grey mongoose (*Herpestes erdwardsii*), ruddy mongoose (*Herpestes smithii*) and stripe necked mongoose (*Herpestes vitticollis*). Wolf (*Canis lupus*), striped hyena (*Hyaena hyaena*), and Indian fox (*Vulpes bengalensis*) occur on the fringes of the park.

The Indian porcupine (*Hystrix indica)*, blacknaped hare (*Lepus nigricollis*), flying squirrel (*Petaurista petaurista*), three stripped squirrel (*Funambulus palmarum*) and

Indian pangolin (*Manis crassicaudata*) also occur in Bandhavgarh Tiger Reaerve. Domestic livestock (cattle, buffalo and goat) occur in the village areas present inside the National Park and Sanctuary.

2.8. TOURISM

The park provides very good sighting opportunities of large cats (Tyabji 1991). The park remains open around nine and half months (mid of October -June) and tourists are allowed entry for four hous in the morning and three hours in the evening.

2.9. HUMAN SETTLEMENTS

There are 15 villages located inside the Tiger Reserve, of which seven are located in the notified Bandhavgarh National Park and eight are in Panpatha Wildlife Sancatury which are due for relocation. Some villagers work with the Forest Department as fire watchers, chokman, elephant caretakers and riders, grass cutters and as a part of anti-poaching team. Villagers largely depend on agricultural products and cultivate wheat, ragi, cauliflower, cabbage, beans and other vegetables. These cultivated vegetables are sold in the nearby weekly market. Large number of buffaloes and a few cows along with some goats are kept in the villages. The milk and dairy products are sold in the nearby towns. Of the seven villages inside the National Park, two villages, Kallwah and Kumarwah from Kallwah range were successfully relocated (figure 2.6) between 2011 and 2013 from the notified National Park area. At present there are 96 villages within a

five kilometer radius of the outer boundary of the Bandhavgarh Tiger Reserve. The total human population of these villages is estimated to be around 45,000 heads.

Figure 2. 6. Location of villages in core and buffer areas of Bandhavgarh Tiger Reserve.

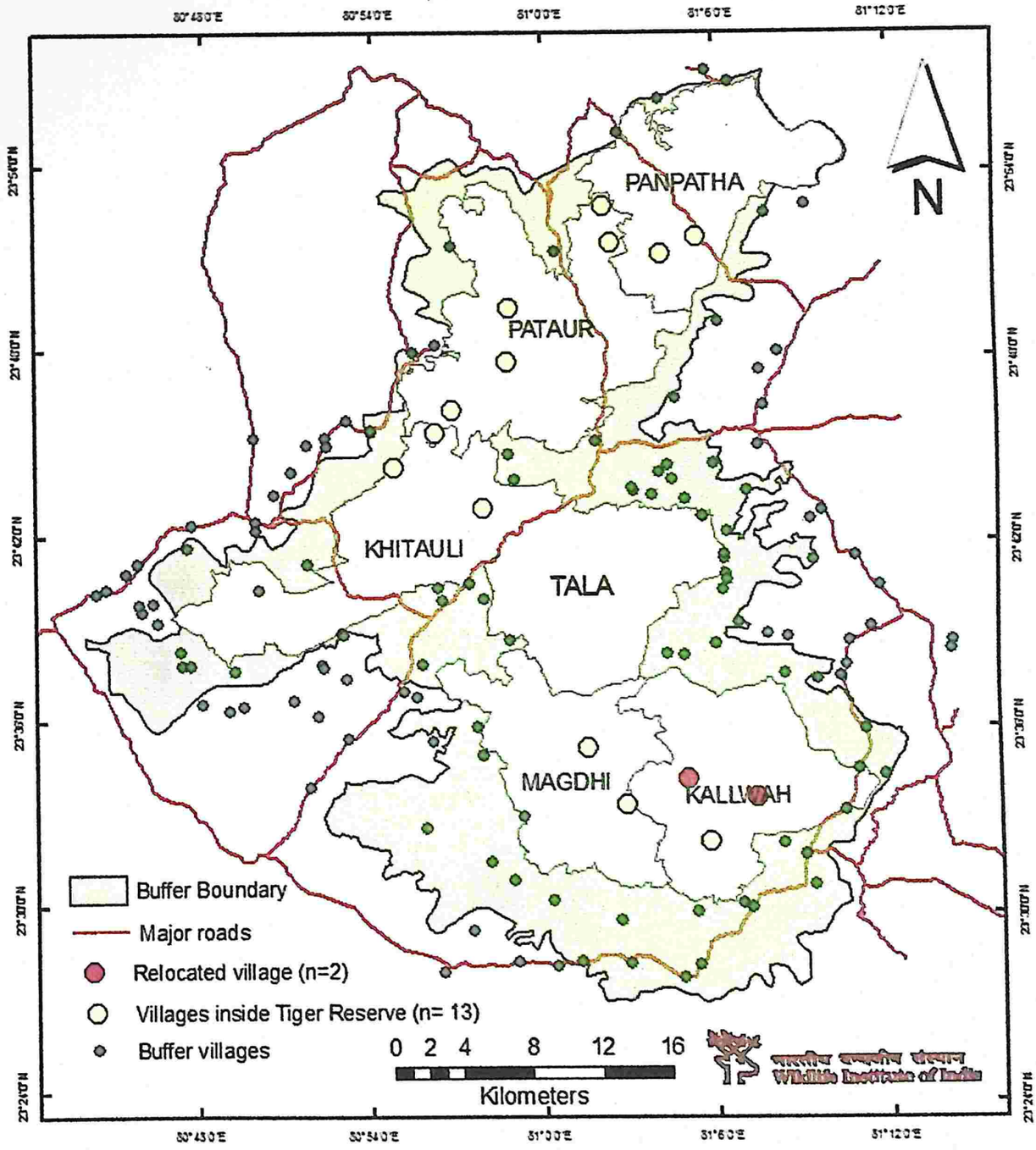


Plate 2.1. The Bandhavgarh Fort and adjoining vegetation types.

Plate 2.2. Grassland and mixed forest.

Plate 2.3. Sal forest.

Plate 2.4. Mixed forest.

Plate 2.5. Relocated village site (Kumuruwah).

Chapter III

Ranging pattern of reintroduced gaur

Chapter III

RANGING PATTERN OF REINTRODUCED GAUR

3.1. INTRODUCTION

3.1.1. Reintroduction

Reintroduction is the release of captive animals into wild areas where they occurred in the past, and where they have significantly declined or even extirpated in historical times (Jungius 1985, Kleiman 1989). Reintroduction of threatened or endangered species tend to fail more often (Griffith *et al.* 1989). To improve the rate of success, the International Union for the Conservation of Nature and Natural Resources (IUCN) has recommended a four-phase reintroduction schedule:

(1) A feasibility study to determine likelihood of success,

(2) A preparation phase for selecting animals and release sites,

(3) The release phase including selection of date and time for release, and

(4) Post-release monitoring that evaluates the success of the release. It also recommends arrangement steps for enhancing the success of current and future reintroductions (IUCN 1987).

While more attention has been devoted to the first three phases, post-release monitoring has often been neglected (Ralls *et al.* 1992). The success of a reintroduction depends on the ranging size, habitat use, reproductive success and adaptation of the

population to the natural habitat (Ballou and Ralls 1982, Griffith *et al.* 1989). Thus, monitoring program should concentrate/focus on survival and breeding success of individuals by age and sex classes, and the intrinsic and extrinsic variables that may affect them in the environment (Scott and Carpenter 1987). The current chapter deals with overall ranging pattern, home range stabilization, herd formation and movement pattern of the reintroduced gaur population in Bandhavgarh Tiger Reserve, Central India.

3.2. REVIEW OF LITERATURE

3.2.1. Radio telemetry

Radio telemetry was introduced in late 1960's and since then it has become one of the most important methods to study animal's ranging, dispersal, resource utilization and activity patterns (Cochran and Lord 1963, White and Garrott 1990, Priede and Swift 1992, Samuel and Fuller 1996). Radio telemetry as a tool used for wildlife research has proven to be very effective in understanding the secretive lives of the animals being studied (Shanker *et al.* 2003). Although the new technique provided completely new insights into many aspects of wildlife ecology, it remained labor intensive and was often compromised by environmental and logistic constraints (Mech and Barber 2002).

After the advent of VHF telemetry first of the advancements was the use of satellites to locate animals, which allowed remote tracking of tagged wildlife animals over long distances. The use of satellite telemetry started in 1970's on elk (*Cervus elaphus*) in Wyoming (Craighead *et al.* 1972). In 1978 the Argos satellite system became available for civilian use and soon allowed the remote tracking of tagged wildlife over

large distances (Taylor 1986, Fancy *et al.* 1988). With the reduction in size and weight of the satellite transmitters or platform terminal transmitters (PTTs) the technology has been largely used in small mammals and birds (Fuller *et al.* 1995). The GPS collar was first used in wildlife tracking in 1994 (Rodgers 2001) and monitoring of animals was easier and more reliable in radio tracking using GPS technology (Blake *et al.* 2001). The GPS-GSM technology has been introduced recently (Sundell *et al.* 2006, Moe *et al.* 2007, Rahim and Owen-Smith 2007).

Mech (1983) as a part of field techniques introduced radio-telemetry to India in 1976 and 1980 under the support of Project Tiger. In 1983, radio-telemetry study was carried out in India on gharial (*Gavialis gangeticus*), where 12 individuals were tagged and tracked successfully (Singh 1985). This study was carried out in the Crocodile Research Center of the Wildlife Institute of India (WII), and then based at Hyderabad. Further this technique was used in Indian Flying Fox (*Pteropus giganteus*) in 1985; with six individuals were radio-tagged (Goyal and Sale 1989). Among the large mammals, Asiatic Elephant was first to be radio-collared, in Mudumalai Tiger Reserve in 1985 (Desai 1991), and tiger (*Panthera tigress*) in Nagarhole National Park in 1990 (Karanth and Sanquist 2000). Among birds the first satellite telemetry study undertaken was during 1993-1994 on Eurasian Cranes (*Grus grus*) in Keoladeo National Park, Bharatpur (Higuchi *et al.* 1994).

3.2.2. Ranging pattern

Information on ranging pattern of animals helps in understanding the natural environments, mammals especially the gregarious ones often respond to climatic changes

by altering the herd size and switching over habitats (McNaughton 1985). The technique involved in term "radio tracking" is to refer an animal located with the help of a transmitting device attached to it when animals are tracked to detect radio signals transmitted from the equipment attached to the animal body (Sivakumar and Habib 2010). The studies on the home range in various wildlife species suggest that, the size of the home range are directly related to its body size and weight (Lindstedt *et al.* 1986, Swihart *et al.* 1988, Schoener 1968, Turner *et al.* 1969). The social structures and behavioral pattern of the animal species have also some effects on the home range size (Gittleman and Harvey 1982, Lindstedt *et al.* 1986).

3.2.3. Home range

"One may wonder whether it is worthwhile to attempt to measure anything as indefinite and variable as home range" (Stickel 1954). "Home range" referred to an individual or a group of animals will have an area that it habitually uses but does not necessarily defend (White and Garrott 1990). Home range has been measured in a myriad of ways i.e bounded areas or polygons (Mohr and Stumpf 1966). Burt (1943) described home range as the area traversed by an individual in its normal activities, including protection, feeding, mating, caring for young and other life history requisites. The concept of home range has been challenged because of difficulties in quantification and calculation (White and Garrott 1990, Millspaugh and Marzluff 2001). The size of an animal's home range give an indication of the availability of essential resource, restrictions imposed by the respective conservation areas or and other artificial barriers and the degree of disturbance to which the animal is exposed (Hitchins 1969, Whyte

1996). The distribution and home range size of the animal is influenced by an interaction of factors, which include topography, elevation, soil type, amount of rainfall, human interference and factors like availability of food, forage quality and metabolic requirements (Laurie 1978-1982, Pomeroy and Service 1992, Bailey and Provenza 2008).

Since its conception, home range has been a major focus and useful tool in animal ecology. Widely, home range is considered as second order spatial scale of selection (Johnson 1980). Between second order selection and patch selection (third order selection) there is a dynamic category termed the core area (Kaufman 1962). Core areas are often employed in space-use to emphasize sections of a home range where an animal supposedly concentrates its time spent *i.e.* areas of intense use (Samuel *et al.* 1985, Seaman and Powell 1990). There are exceptions of being larger core areas in the home range size in dry season than the wet season (Viljoen 1989, Shannon *et al.* 2006). Mega-herbivores to maximize their food resource intake, have to move from one area to another within the landscape (Prins and Van Langevelde, 2008).

Few studies on radio telemetry on ungulates are available in Indian subcontinent. Sankar (1994) reported radio-telemetry studies on sympatric herbivores, chital (*Axis axis*), sambar (*Rusa unicolor*) nilgai (*Boselaphus tragocamelus*) in Sariska Tiger Reserve, Western India. Among the radio-telemetry studies on mega herbivores, Indian elephant (*Elephant maximus*) was studied by Desai (1991) in Mudumalai Tiger Reserve, Johnsingh and Sale (1989) and Khan (2004) in Rajaji National Park, Sukumar *et al.* (2003) in Buxa Tiger Reserve and Venkataraman *et al.* (2005) in West Bengal and gaur (*Bos gaurus gaurus*) in Pench Tiger Reserve, Central Indian Landscape (Sankar *et al.*

2000). Study by Shah and Goyal (1993) on wild ass (*Equus hemionus*) in Little Rana of Kutch, Bhatnagar (1997) on Himalayan ibex (*Capra ibex*) in Pin Valley National Park and Chauhan and Barwal (2010) on wild pig (*Sus scrofa*) in Ranthambore National Park are the other related telemetry studies on ungulates.

3.2.4. Gaur

In the mid-1900's most of the source population of gaur were secure because of the remote and isolated nature of their habitat (Hubback 1937, Foenander 1952).Very few studies reported the trend in population of gaur based on the long-term and systematic monitoring. Weigum (1972) reported gaur herd range as 13 km^2 in Taman Nagara National Park, Malaysia. Conry (1989) estimated home range of gaur yearling males, yearling females and adult males in Malaysia to be as 29.9 km^2 and 52.1 km^2 and 137.3 km^2 respectively. The estimated composite (one adult male one adult female and one sub adult male) home range of gaur in Pench Tiger Reserve was 175 km^2 (Sankar *et al.* 2000). Physiographical features, temperature and rainfall fluctuations played important roles in determining the home range sizes of gaur in Pench Tiger Reserve, Madhya Pradesh (Sankar *et al.* 2000). Prayurasiddhi (1997) attempted a comparative study on gaur and banteng (*Bos javanicus*) in Thailand in which the population and feeding ecology of these species were investigated. Among the wild bovids, gaur is one of the most wide-ranging species showing seasonal and local movements between foraging sites (Schaller 1967), but very limited information exists on its ranging pattern belonging to different age sex classes.

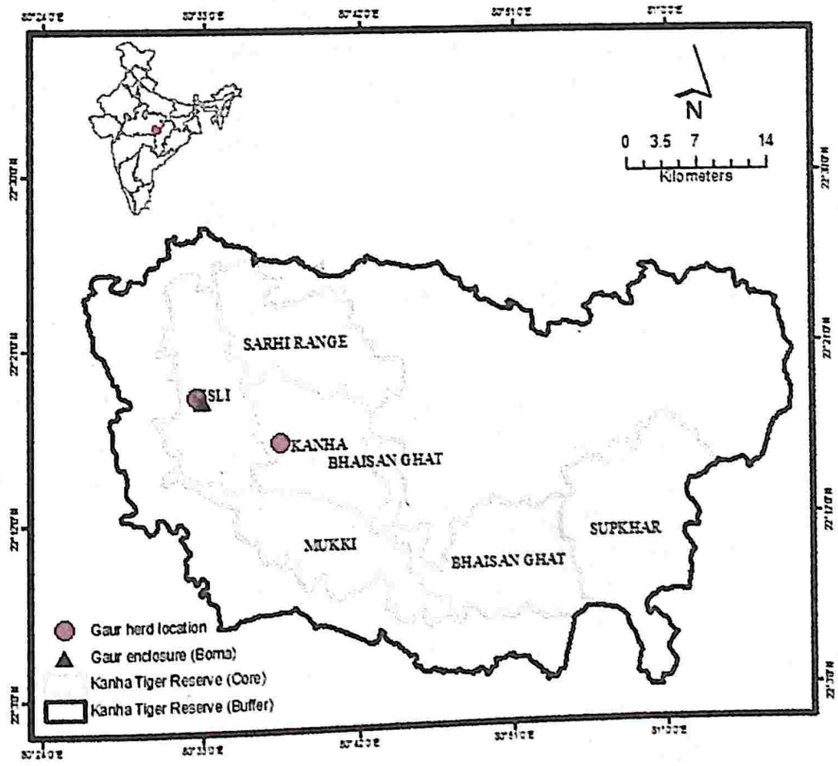
3.3. METHODS

3.3.1. Capture and translocation of gaur

The capture and translocation of 50 (14 male and 36 female) gaur from Kanha Tiger Reserve (KTR) to Bandhavgarh Tiger Reserve (BTR) was done in two phases *i.e.* phase I during January 2011 (n=19) and phase II, during March 2012 (n=31). Individuals were selected from different herds from Kisli and Kanha ranges in KTR (figure 3.1). Details of all the translocated gaur is given as appendix II.

In phase I, 19 individuals, were captured and translocated between 21 January and 27 January 2011. Of these, 12 animals were fitted with radio collars. Details on phase I (will be pronounced as batch I) radio collared animals (ID, capture site, demography class, collar details and approximate age in years) are given in table 3.1.A.

Figure 3. 1. Gaur capture locations in Kanha Tiger Reserve, (Range: Kanha and Kisli).



3.3.2. Operation details

Nine trained captive elephants were used for the search operations. Once the gaur herd was located, the size, composition, terrain conditions for darting and the distance from the road were considered prior to the actual operation. Darting of the animal was done from elephant back. Gaur were tranquilized using Etorphine hydrochloride (Captivion, Wildlife Pharmaceuticals (Pty) Ltd., 9.8 mg/ml) mixed with 18 azaperone (Stressnil, Janssen Pharmaceutica NV, 40 mg/ml) and was remotely injected employing 3.0 ml nylon darts using a Dan Inject projector (model JM). The animal was left undisturbed till it reached a condition safe for handling. After ensuring that the animal had been sedated sufficiently so that it was safe to handle it, the animal was immediately blindfolded and maintained in sternal recumbency. Proper positioning of the tranquilized animal was maintained. After ensuring the physiological parameters were stable, the animal was weighed, and body measurements were taken, including total body length, shoulder height, chest girth, tail length and horn length.

Selected animals were fitted with radio-collars. The immobilized animal was shifted onto the stretcher and loaded onto the small vehicle for taking it to the boma or directly loaded onto the transport truck. All the animals captured at Kisli range were brought to the boma, whereas the animals captured at Kanha range were directly shifted into the transport truck. Once the loading of animals into the truck the journey *via* road, covering the distance of 250 Km almost took 8 hours to reach Bandhavgarh. The journey was commenced in the late evening to avoid any human and vehicular disturbance and to reach the release site during the early morning hours. Special care was taken to maintain

a uniform speed during the journey, with the speed adjusted according to the local road conditions. The animals were monitored at every one hour interval throughout the journey. Details of gaur translocation are given in appendix III.

The same capture technique and transportation procedure was followed for the second phase of gaur in March 2012. In the second phase, 31 gaur (9 males and 22 females) were captured between 3 March 2012 and 11 March 2012 and translocated to Bandhavgarh. Details on phase II (will be pronounced as batch II) radio collared animals (ID, capture range, demography class collar details and approximate age in years) are given in table 3.1.B. These animals were selected from different herds in Kisli and Kanha ranges in KTR.

Table 3. 1. A. Details of gaur radio-collaring in Kanha Tiger Reserve, Madhya Pradesh, during January 2011.

Gaur ID	Range/ Site	Demography class	Collar type	Approximate age in years
GF1	Kisli / 1	SAF	VHF	3 - 4
GF3	Kisli / 1	SAF	VHF	3 - 4
GF5	Kisli / 1	AF	VHF	6 - 7
GF6	Kanha / 2	SAF	VHF	4
GF7	Kanha / 2	SAF	VHF	4 - 4.5
GF8	Kanha / 2	SAF	VHF	4 - 4.5
GF9	Kanha / 2	SAF	VHF	4 - 5.5
GF10	Kanha / 2	AF	VHF	5 - 6
GF14	Kanha / 2	AF	VHF	5 - 6
GM1	Kisli / 1	SAM	VHF	3 - 4
GM3	Kisli / 1	AM	GPS/Satellite/VHF	5 - 6
GM5	Kanha / 2	AM	GPS/Satellite/VHF	6 - 7

GF-Gaur Female; GM-Gaur Male.

SAF- Sub Adult Female; SAM- Sub Adult Male; AF- Adult Female; AM- Adult Male.

Table 3. 1. B. Details of gaur radio-collaring in Kanha Tiger Reserve, Madhya Pradesh, during March 2012.

Gaur ID	Range/ Site	Demography class	Collar type	Approximate age in years
GF 19	Kanha / 2	SAF	VHF	4 - 4.5
GF20	Kanha / 2	SAF	VHF	4 - 4.5
GF22	Kanha / 2	SAF	VHF	4 - 4.5
GF27	Kisli / 1	SAF	VHF	4 - 4.5
GF28	Kisli / 1	SAF	VHF	4 - 4.5
GF31	Kisli / 1	AF	GPS/Satellite/VHF	8 - 8.5
GF32	Kisli / 1	SAF	VHF	4.5 - 5
GF33	Kisli / 1	SAF	VHF	3.5 - 4.5
GF35	Kisli / 1	AF	GPS/Satellite/VHF	6 - 6.5
GF36	Kisli / 1	AF	VHF	5 - 5.5
GF37	Kisli / 1	SAF	VHF	5 - 5.5
GF40	Kisli / 1	AF	GPS/Satellite/VHF	4.5 - 5
GM7	Kanha / 2	SAM	VHF	4 - 4.5
GM10	Kisli / 1	AM	GPS/Satellite/VHF	6.5 - 7
GM12	Kisli/ 1	SAM	VHF	4 - 4.5

GF- Gaur Female; GM-Gaur Male.

SAF- Sub Adult Female; SAM- Sub Adult Male; AF- Adult Female; AM- Adult Male.

3.3.3. Radio collar

I used radio collars with mortality sensors (TELONICS, United State of America). Two types of radio collars were used on gaur (GPS/ SATELLITE/VHF and Very High Frequency-VHF). The first batch GPS (n=2) collars were programmed to receive locations every day initially for three months and subsequently on every third day to maximize the collar life. In the first batch, I used break away collars (appendix III: picture 10). In 2012 the GPS (n=4) collars were programmed to receive locations every day. TELONICS made TR-4 receiver along with uni-directional hand-held 3-element "Yagi" antenna and "H" type antenna were used to track the radio collared animals.

3.3.4. Radio tracking of gaur

Study on ranging pattern of gaur was based on regular tracking of radio-collared (n=27) individuals. The radio-collared gaur was monitored periodically through ground tracking, using "triangulation" and "homing in" techniques (White and Garrot 1990). Triangulation is the process of estimating the location and is largely depends upon radio signals, by taking bearings (Mech 1963) from three fixes with the directions of the signals (Kenward 1987). Homing in is done by ground tracking, the VHF transmitters that emit radio signals of the collar over a long distance depending on the habitat and terrain in which the animals can be located visually (Kenward 1987). Details of locations collected for each radio-collared gaur *i.e.* seasonally and overall, using "triangulation" and "homing in" techniques are given in table 3.1.C.

Table 3. 1. C. Details of locations collected for each radio-collared gaur in different season (summer, monsoon, winter) in Bandhavgarh Tiger Reserve (2011 and 2012).

Gaur ID	2011			2012			Locations			
	S	M	W	S	M	W	Triangulation	Homing in	GPS/ Satellite	Total
GF1	304	255	223	80	59	89	124	886	--	1010
GF3	291	235	264	80	59	74	104	899	--	1003
GF5	70	--	--	--	--	--	7	63	--	70
GF6	313	237	247	79	54	71	103	898	--	1001
GF7	126	--	--	--	--	--	15	111	--	126
GF8	165	183	243	74	49	67	79	702	--	781
GF9	271	194	215	80	51	55	89	777	--	866
GF10	323	241	257	59	52	49	151	830	--	981
GF14	301	213	166	58	51	69	104	754	--	858
GM1	301	207	248	43	51	67	154	763	--	917
GM3*	651	592	331	48	51	74	203	906	638	1747
GM5*	597	589	367	71	54	81	175	863	721	1759
GF 19	--	--	--	97	89	86	41	231	--	272
GF20	--	--	--	93	84	95	36	236	--	272
GF22	--	--	--	79	68	59	54	152	--	206
GF27	--	--	--	79	70	58	21	186	--	207
GF28	--	--	--	96	78	79	33	220	--	253
GF31*	--	--	--	541	652	582	19	302	1454	1775
GF32	--	--	--	79	68	59	27	179	--	206
GF33	--	--	--	85	76	59	20	200	--	220
GF35*	--	--	--	625	583	493	14	261	1426	1701
GF36	--	--	--	91	67	81	31	208	--	239
GF37	--	--	--	79	68	59	54	152	--	206
GF40*	--	--	--	591	569	461	19	281	1321	1621
GM7	--	--	--	79	68	59	41	165	--	206
GM10	--	--	--	73	81	72	54	172	--	226
GM12	--	--	--	83	61	59	34	169	--	203

GF-Gaur Female; GM-Gaur Male.

S- Summer; M-Monsoon; W-Winter; * GPS/Satellite collar.

3.3.5. Data collection

Twelve to fifteen locations, per radio-collared individual in a week with "biologically independent" locations *i.e.* 6 hour interval between consecutive locations of the same animal as defined by Dolev *et al.* (2002) was collected on foot and from vehicle from March 2011 to February 2013. The locations were obtained during 0600 hrs to 1800 hrs in all seasons, summer, monsoon and winter.

Two radio collared gaur females (GF5 and GF7) of batch I died naturally during the study period. The satellite data up-link for two GPS collars (GM3 and GM5), which was fitted in 2011 in adult males stopped functioning, in August 2011 and October 2011 respectively. Thereafter the gaur GM3 and GM5, were tracked by VHF signals (ground tracking). Eight (GF1, GF8, GF10, GF14, GM1, GM3, GM5 and GM10) collars were dropped by animals and one VHF (GF9) collar stopped functioning. Two males GM3 and GM10 collars were dropped in a territorial fight. The gaur individuals, which dropped their collars, were subsequently identified in field based on their body size, structure, horn length, horn curve and the size of bos as described by Ahrestani and Prins (2011).

3.3.6. Data analysis

Each radio collared gaur location was obtained with the help of Global Positioning System (GPS) and latter plotted in ArcGIS 9.2 (ESRI 2006). I used two non-parametric home range estimaters, such as Minimum Convex Polygon (MCP) (Mohr 1947) and Fixed Kernel Method (FKD) (Worton 1989) estimate home range size. The 100% MCP is most widely used method (Harris *et al.* 1990). Home ranges calculated with the MCP used either 100% of locations (to allow comparisons with other studies) or

95% of locations, in which the most peripheral points (outliers) were excluded. As pointed out by White and Garrot (1990) using outliers can greatly overestimate home range size, including parts that were never visited by the individuals. To remove the effect of exploratory movements and outlying fixes, I computed 95% and 50% fixed kernel as described by Kernohan *et al.* (2001). The fixed kernel density estimator is rated as one of the most robust and least biased estimator of home range considering its performance with small sample sizes, auto-correlated data, and shape of underlying utilization distribution, outlier data and comparability between different studies (Jaremovic and Croft 1987, Kernohan *et al.* 2001, Worton 1995). Percent overlap between adjacent male home range and female home range was computed as the average proportion of overlap between male and female home ranges (Kernohan *et al.* 2001, Mizutani and Jewell 1998). I used t-tests (Zar 2010) to test the significance of difference in home range sizes between batches, Mann-Whitney-Wilcoxon test and Kruskal Wallis test (Zar 2010) to test the significance difference in home range size between gaur age and sex classes also gender across season.

3.3.7. Core area of activity

The smoothing parameter of the 95% fixed kernel density estimator was chosen using the Least Square Cross Validation (LSCV) procedure (Kernohan *et al.* 2001, Silverman 1986). I defined the 95% isopleth of the utilization distribution as the animal's home range, the 50% isopleth as the "core area" (CA). Program CALHOME (Kie 1994) and ArcGIS 9.2 (ESRI 2006) with Hawth's tool and Home Range Tool (Rodgers and Kie 2010) was used to estimate gaur home ranges using different methods.

I estimated home range of each gaur individual in different seasons and the data were grouped to understand the home range size of different demography classes. I used 100% MCP method to understand their overall as well as seasonal ranging patterns. Locations obtained from GPS and VHF collars (n=18, 932) were used to estimate gaur home range in the study area.

3.3.8. Herd formation

Total of four different herds were identified during the study period. I identified the individual gaur herd based on the radio collared animals in each gaur herd. Since, gaur are herd living animal (Schaller 1967), the home range size of different herds was estimated using 100% MCP method to understand their seasonal ranging pattern for both the years. Percent overlap between adjacent herds was computed as the average proportion of overlap between two herds (Kernohan *et al.* 2001, Mizutani and Jewell 1998). For the identified herds minimum of one location per day was collected throughout the study period across seasons. Month wise data was used to study the home range stabilization of herds. Adult males were not considered in herd home range stabilization, because of their fluctuation in movment, solitariness and has the tendency of moving from one herd to another (Schaller 1967).

3.3.9. Movement pattern

The study of animal movement pattern allows ecologists to determine the distribution of species both in space and time, and the factors that influence their movements in different environments (Pinaud 2008). The identification of temporal thresholds or shifts in animal movement informs ecologists of changes in an animals

behaviour, which contributes to an understanding of species responses in different environments. To measure the site fidelity of radio collared gaur, I determined by measuring the straight line distance between consecutive daily locations (Rabinowitz 1990). The daily distance travelled represents a short-term measure or indicator of the space required by the animals, reflecting the use of surroundings (Blake *et al.* 2001). Minimum of two locations per radio-collared gaur were collected in a day, which covers 24 hour cycle. To keep the uniformity, I used only the first recorded location of each day of the sequence for the analysis. This distance would naturally be a gross underestimate considering non-linear movements of gaur moved within home range. To find the seasonal movement pattern, I used data collected from 25 radio-collared (6 males and 19 females) gaur. To detect the initial daily movement patterns and monthly movement, I ran a two-year daily time-series model (Birkett *et al.* 2010) for each gender (male and female).

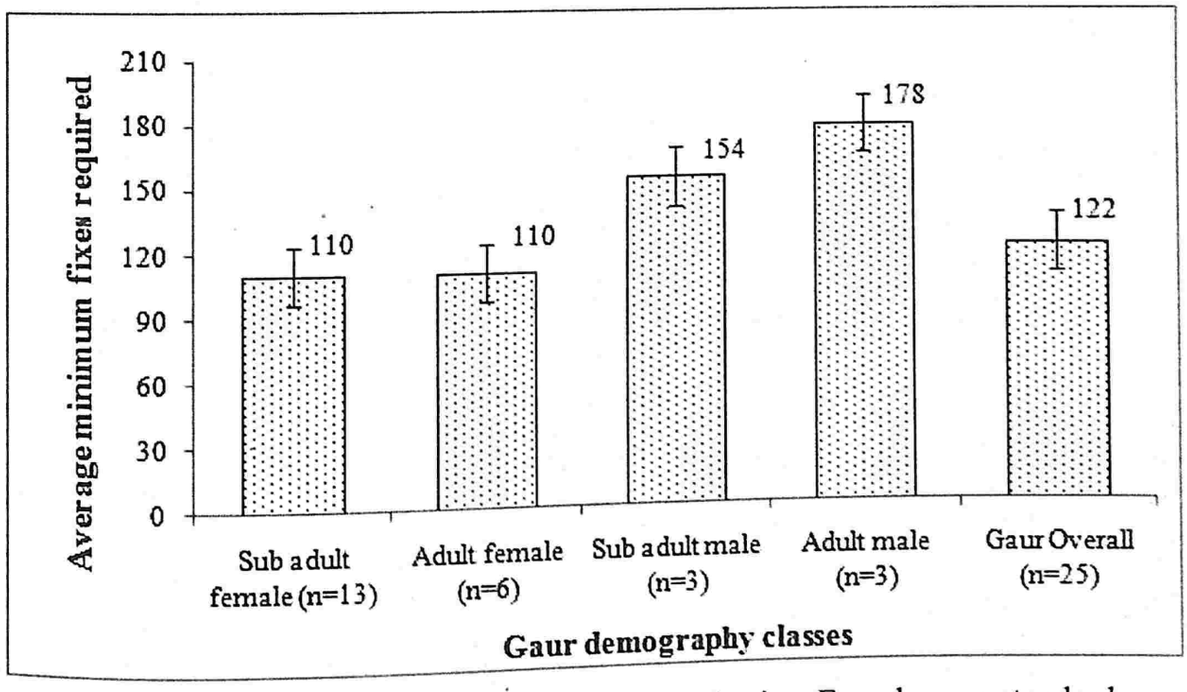
Of the total 21,012 gaur locations recorded during the entire study period 18,403 locations were used for movement pattern analysis and the remaining locations were dropped from the analysis because of multiple locations obtained in a day. The radio-collared animals were tracked in all three seasons, in both the years (2011-2012). All gaur latitude–longitude locations were projected into UTM 1983 (Zone 44, WGS84 datum). I used Home Range Tools (HRT: Rodgers and Kie 2010) in ArcGIS 9.3 for ESRI (Environmental Systems Research Institute, USA) to estimate gaur movement parameters including movement length l (*i.e.* distance moved in meters).

3. 4. RESULTS

3.4.1. Sample size adequacy for home range estimation

The minimum number needed to calculate overall home range size of reintroduced gaur in Bandhavgarh reached asymptode at 122 fixes (95% CI 111-133; range: 80-188) (figure 3.2). Males required more fixes to calculate home range size than females. Especially adult males (n=3) required more number of fixes to calculate home range size and reached an asymptote at 178 fixes (range: 168-188). The sub adult male (n=3) home range reached an asymptote at 154 fixes (range: 145-160). In contrast, the female home range size reached an asymptote at 110 fixes (adults (n=4) range: 83-126 and sub adult (n=13) range: 80-130). One hundred percent MCP method was used to calculate the overall home range size of gaur and the average number of fixes ploted for different age and sex classes of gaur is given in figure 3.6.

Figure 3. 2. Average minimum number of fixes required to estimate home range of gaur.

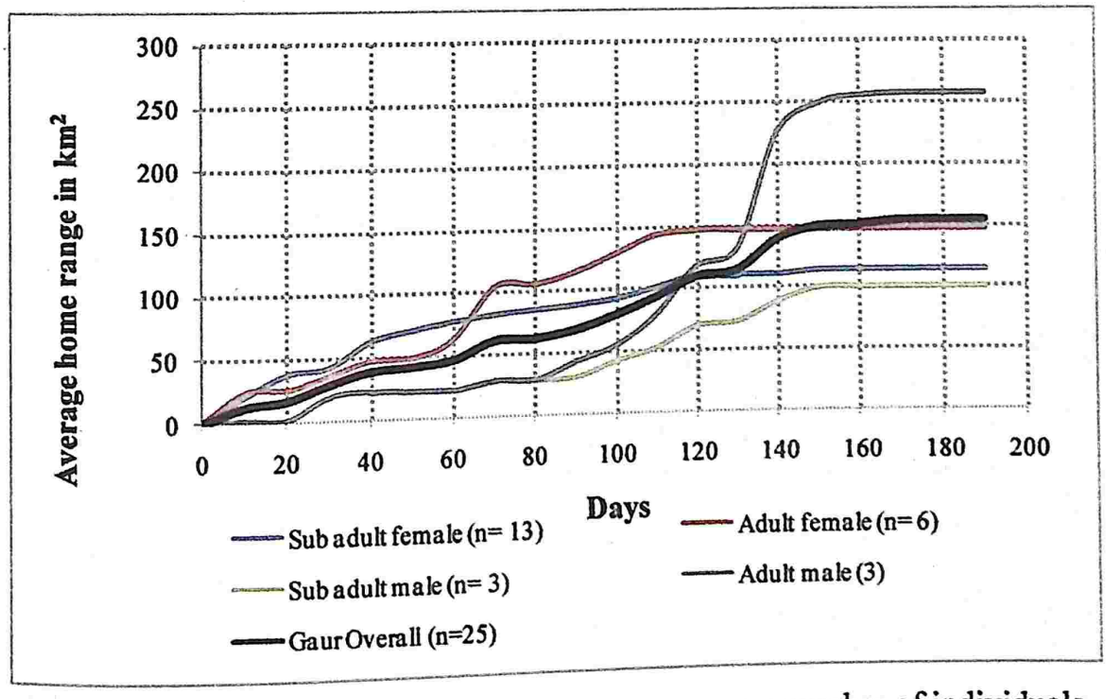


n = sample size; Error bars as standard errors

3.4.2. Home range stabilization curve

The average home range of reintroduced gaur reached an asymptote after exploring minimum of 154 km^2 (range: 71 Km^2 - 279 Km^2) within 143 days (range: 120 - 163 days). An average adult male explored larger area and the home range reached an asymptote on 257 Km^2 within 141 days. Average sub adult males home range reached an asymptote in 100 Km^2 within 163 days. In case of females, adult female average home range reached an asymptote in 149 Km^2, whereas average sub adult female home range reached an asymptote in 111 Km^2. Both the age class of females took an average of 120 days to establish their home range size. The cumulative curves plotted with 100% MCP home range size versus number of days are given in figure 3.3.

Figure 3. 3. Cumulative curves of average home range areas for overall and different demography classes of gaur plotted against number of days.



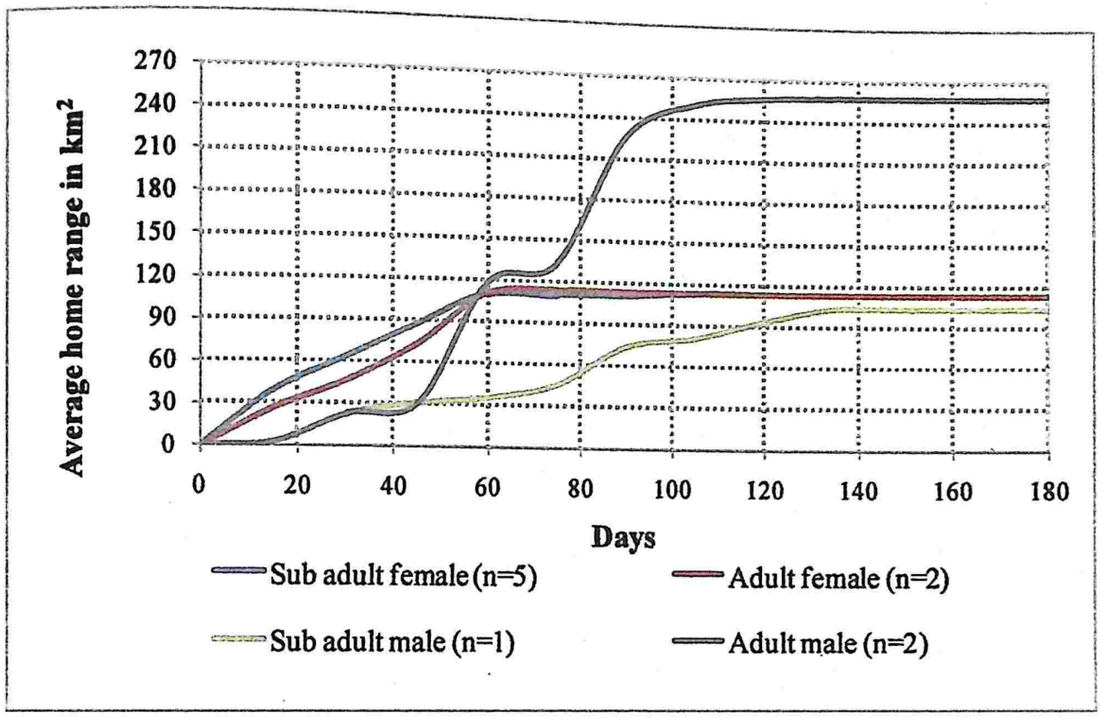
n= number of individuals

3.4.3. Batch wise home range stabilization

Locations of 25 radio-collared individuals were used to analyze the stabilization of home range. It was observed that the batch I (n=12) gaur home range exploration was gradual. Sub-adult females (n=5) and adult females (n=2) settled in new habitat over a period of 60 days, and the home range curve reached an asymptode in 110 Km^2. Adult male (n=2) and sub adult male (n=1) settled in the new environment within 105 and 135 days respectively. Home range curve reached an asymptode after exploring larger area of 257 Km^2 for adult male and 100 Km^2 for sub adult male (figure 3.4).

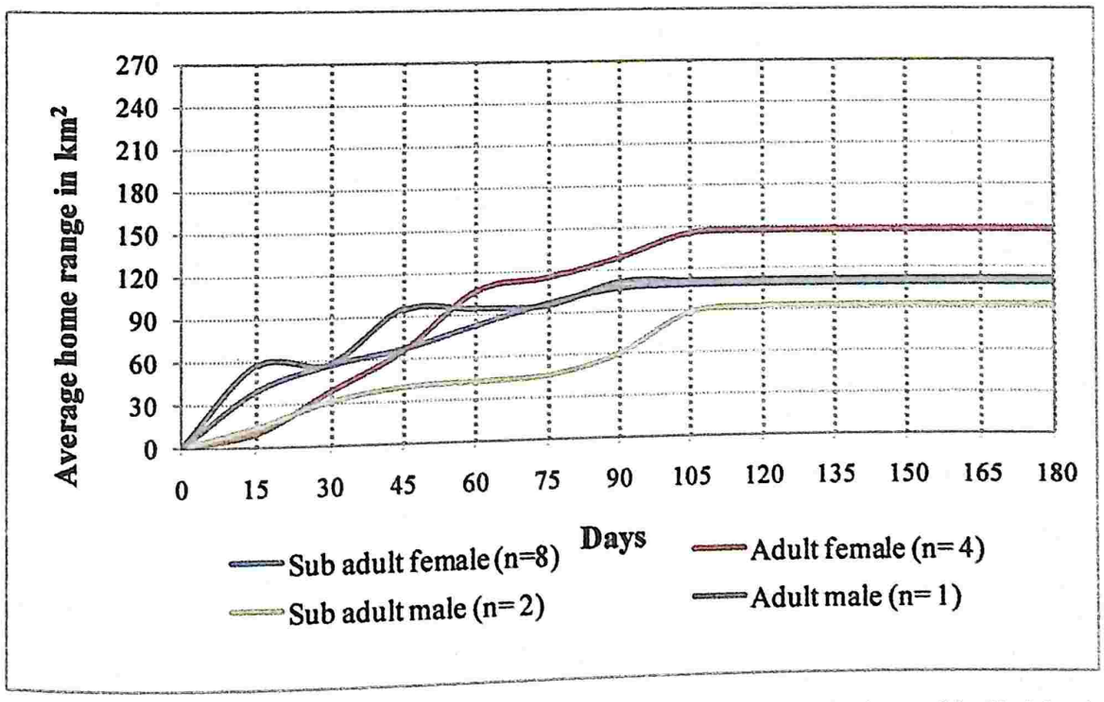
It was observed that the batch II (n=15) gaur home range exploration was unstable in the new habitat for 90 days. All the age and sex class individuals got settled in the new habitat between 90 and 105 days (figure 3.5).

Figure 3. 4. Stabilization of home range for male and female gaur in Bandhavgarh Tiger Reserve (Batch I - 2011).



n= number of individuals

Figure 3. 5. Stabilization of home range for male and female gaur in Bandhavgarh Tiger Reserve (Batch II - 2012).



n= number of individuals

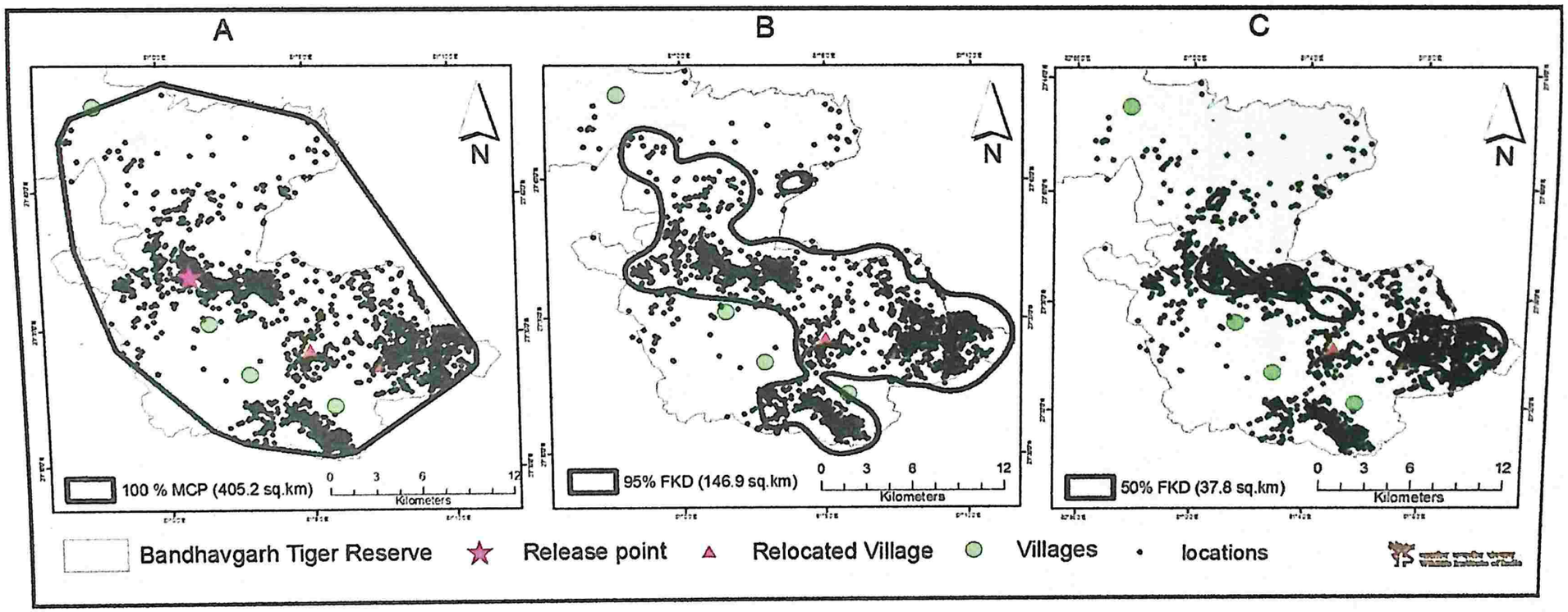
3.4.4. Estimation of home range of gaur in Bandhavgarh Tiger Reserve

3.4.4.1. Overall home range of reintroduced gaur

The overall 100 % MCP, home range of reintroduced gaur was 405.2 Km^2 (figure 3.6). The estimated 95 % FKD home ranges was 146.9 Km^2. The estimated 50 % FKD home range, which was considered as the core-area activity within the entire home range was 37.8 Km^2.

Figure 3. 6. Estimated overall home range of reintroduced gaur using different methods,

(A) 100% Minimum Convex Polygon- MCP; (B) 95 % Fixed Kernel Density and (C) 50% Fixed Kernel Density.



3.4.4.2. Home range size of individual radio collared gaur

Using all locations of an individual (MCP 100%) the estimated average overall home range of reintroduced gaur was 160.3 ± 13.3 (SE) Km^2 (range: 71 Km^2 to 279 Km^2; 95 % CI – 186.4 Km^2 to 134.6 Km^2) (table 3.2). The intensity by which each animal used its home range was calculated with different methods using MCP 95 % and 50% and Kernel (FKD 95% and 50 %) (table 3.2). It was observed that with 100 % MCP of all the demography classes of gaur, 22 gaur had a home range of more than 100 Km^2. Among these individuals, all the three adult males, three adult females (GF14, GF31 and GF36) and two sub adult females (GF6 and GF9) had larger home range *i.e.* 200 Km^2 (table 3.2).

The overall home range of different demography classes (AM- Adult Male; SAM- Sub Adult Male; AF- Adult Female; SAF- Sub Adult Female) was calculated using 100 % MCP. The average home range size of AM (n = 3) was 250.2 ± 10.5 (SE) Km^2, SAM (n = 3) 124.6 ± 26.9 (SE) Km^2, AF (n =6) 188.6 ± 33.1 (SE) Km^2 and SAF (n = 13) 148.3 ± 14.7 (SE) Km^2 (table 3.3 and figure 3.7.A). Two gaur females (GF5 and GF7) that died during the study period were not included in the home range analysis. The home range estimated with 50% FKD, which was the core area within the home range for AM, SAM, AF and SAF was 18.3 ± 1.3 (SE) Km^2, 16.8 ± 0.6 (SE) Km^2 16.9 ± 2.3 (SE) Km^2 and 19 ± 1.7 (SE) Km^2 respectively (table 3.3 and figure 3.7.B).

Table 3. 2. Estimated overall home range size (Km^2) of individual radio collared gaur in Bandhavgarh Tiger Reserve (2011 - 2012).

Individuals	Demography class	Number of locations obtained	Minimum Convex Polygon (Km^2)			Fixed Kernel Density (Km^2)	
			100%	95%	50%	95%	50%
GM3	AM	1747	261.2	221.3	126.3	96	17
GM5	AM	1759	260	124.6	65.7	119	21
GM10	AM	226	229.5	103.1	24.3	136	17
GM1	SAM	917	173.6	81.5	42.1	89	16
GM7	SAM	206	81.1	68.1	17.5	50.6	18
GM12	SAM	203	117.5	109.1	53.8	35.6	16.5
GF5*	AF	70	34.3	23.4	13.1	34	5
GF10	AF	981	173	84.3	44.2	90	16
GF14	AF	858	231.3	89.1	17.6	77	9
GF31	AF	1775	279	191.6	94.8	100.1	21.9
GF35	AF	1701	103.2	46.8	18.1	40.3	14.3
GF36	AF	239	258.9	244.5	18.3	109.2	25
GF40	AF	1621	86.6	63.2	11.8	42.8	15.7
GF1	SAF	1010	173.3	80.2	43.3	86	15
GF3	SAF	1003	173.1	80.2	43.3	89	16
GF6	SAF	1001	234	89.5	17.7	78	14
GF7*	SAF	126	111	104.3	5.9	71	7
GF8	SAF	781	187.7	118.2	97.2	119	23
GF9	SAF	866	230.8	80.6	17.2	71	8
GF19	SAF	272	113	104.6	50.1	66.5	26.1
GF20	SAF	272	170	159.5	53.2	82.4	30.8
GF22	SAF	206	164.4	77.4	15.3	74.5	23.8
GF27	SAF	207	71	44.93	9.23	38	22.5
GF28	SAF	253	85.5	73.6	16.2	59.2	23.1
GF32	SAF	206	101	52.5	12.1	37.9	15.5
GF33	SAF	220	103.2	97.4	19.3	40.3	14.3
GF37	SAF	206	121.1	46.2	11.9	64	15.2

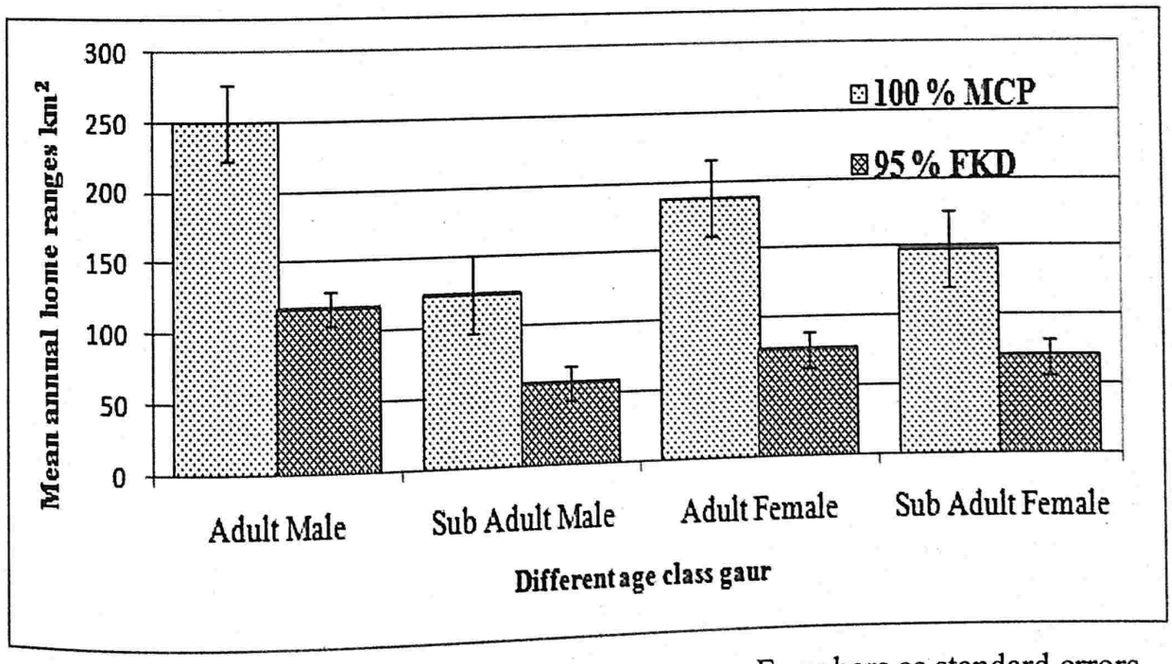
GM-Gaur Male; GF-Gaur Female; AM-Adult Male; SAM- Sub Adult Male; AF-Adult Female; SAF-Sub Adult Female; *Animal dead during the sampling period

Table 3. 3. Estimated mean overall home range size (Km^2) of different demography classes of gaur in Bandhavgarh Tiger Reserve (2011-2012).

Demography class	Number of collared animals	Number of locations obtained	100% MCP* $Km^2 \pm SE$	95 % FKD* $Km^2 \pm SE$	50% FKD (core area) $Km^2 \pm SE$
Adult Male	3	3353	250.2 ± 10.5	117 ± 11.5	18.3 ± 1.3
Sub Adult Male	3	1326	124.6 ± 26.9	58.4 ± 15.9	16.8 ± 0.6
Adult Female	6	7145	188.6 ± 33.1	76.5 ± 11.9	16.9 ± 2.3
Sub Adult Female	13	6629	148.3 ± 14.7	69.6 ± 6.3	19 ± 1.7

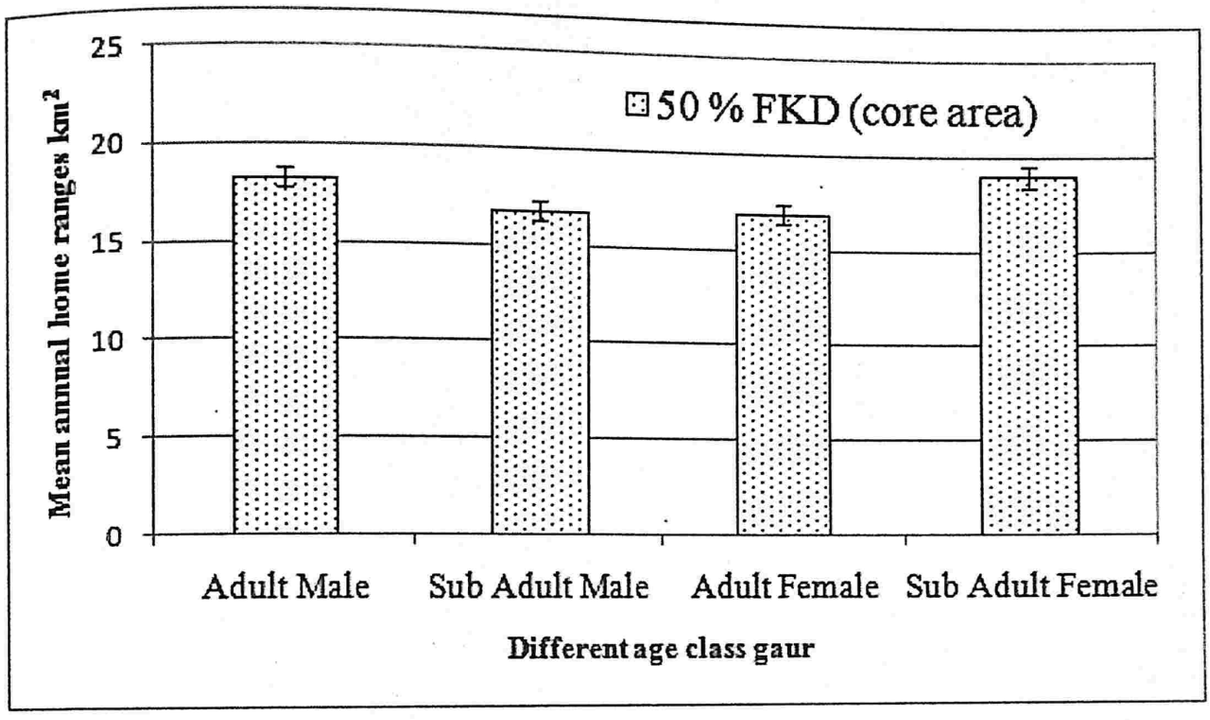
MCP - Minimum Convex Polygon; FKD - Fixed Kernel Density; * Home range in Km^2
SE - Standard Error

Figure 3. 7. A. Mean overall home range size of different demography classes of gaur in Bandhavagrh Tiger Reserve.



Error bars as standard errors

Figure 3. 7. B. Mean core areas of different demography classes of gaur as determined by 50 % Fixed Kernel Density estimator (2011-2012).



Error bars as standerd errors

3.4.4.3. Season wise home range of gaur

The estimated mean summer home range with 100 % MCP for AM was 147.3 ± 13.6 (SE) Km^2, for SAM it was 109 ± 9.3 (SE) Km^2, for AF it was 102 ± 5.4 (SE) Km^2 and for SAF it was 103 ± 5.9 (SE) Km^2 (table 3.4). The estimated mean monsoon home range was 173 ± 19.2 (SE) Km^2; 161.1 ± 7.1 (SE) Km^2; 136.8 ± 4.1 (SE) Km^2 and 142 ± 4.5 (SE) Km^2 for AM, SAM, AF and SAF respectively. The mean winter home range was 160.2 ± 24.1 (SE) Km^2 , 97.2 ± 7.2 (SE) Km^2, 126.4± 11.1(SE) Km^2 and 123.4 ± 5.2 (SE) Km^2 for AM, SAM, AF and SAF respectively (table 3.4).

The estimated mean home range with 95 % FKD for AM was 90.5 ± 12.5 (SE) Km^2, SAM 54.3 ± 3.6 (SE) Km^2, AF 67.9 ± 11.8 (SE) Km^2 and for SAF it was 56.8 ± 4.4 (SE) Km^2. The estimated mean monsoon home range was 98 ± 10 (SE) Km^2, 70.6 ± 3 (SE) Km^2, 69.8 ± 2.9 (SE) Km^2 and 68.8 ± 2.5 (SE) Km^2 for AM, SAM, AF and SAF respectively. The estimated mean winter home range was 95.5 ± 31.5 (SE) Km^2 , 48 ± 10.3 (SE) Km^2, 49 ± 6.9(SE) Km^2 and 54 ± 4.8 (SE) Km^2 for AM, SAM, AF and SAF respectively (table 3.4). The estimated mean core area of activity with 50 % FKD for AM was 24.2 ± 14.2 (SE) Km^2, SAM 14.2 ± 3.1 (SE) Km^2, AF 19.3 ± 4.9 (SE) Km^2 and for SAF it was 14.9 ± 2.3 (SE) Km^2. The estimated mean monsoon home range was 27.5 ± 9.4 (SE) Km^2, 18.2 ± 5 (SE) Km^2, 22.1 ± 8.2 (SE) Km^2 and 19.5 ± 4.6 (SE) Km^2 for AM, SAM, AF and SAF respectively. The mean winter home range was 23.1 ± 5.9 (SE) Km^2, 11.3 ± 3.9 (SE) Km^2, 15.8 ± 3(SE) Km^2 and 13.2 ± 2.8 (SE) km^2 for AM, SAM, AF and SAF respectively (table 3.4).

Table 3. 4. Estimated mean seasonal home range size (Km^2) of different demography classes of gaur in Bandhavgarh Tiger Reserve (2011-2013).

Demography class	Season	Number of radio-collared individuals	Number of locations obtained	Mean 100% MCP* Km^2 ± SE	Mean 95 % FKD* Km^2 ± SE	50 % FKD* (CA) Km^2 ± SE
Adult Male (AM)	summer	2	821	147.3 ± 13.6	90.5 ± 12.5	24.2 ± 14.2
	monsoon	2	729	173 ± 19.2	98 ± 10	27.5 ± 9.4
	winter	2	659	160.2 ± 24.1	95.5 ± 31.5	23.1 ± 5.9
Sub Adult Male (SAM)	summer	4	1021	109 ± 9.3	54.3 ± 3.6	14.2 ± 3.1
	monsoon	4	839	161.1 ± 7.1	70.6 ± 3	18.2 ± 5
	winter	4	745	97.2 ± 7.2	48 ± 10.3	11.3± 3.9
Adult Female (AF)	summer	7	1625	102 ± 5.4	67.9 ± 11.8	19.3 ± 4.9
	monsoon	6	983	136.8 ± 4.1	69.8 ± 2.9	22.1 ± 8.2
	winter	6	1013	126.4 ± 11.1	49 ± 6.9	15.8 ± 3
Sub Adult Female (SAF)	summer	14	2003	103 ± 5.9	56.8 ± 4.4	14.9 ± 2.3
	monsoon	13	1562	142 ± 4.5	68.8 ± 2.5	19.5 ± 4.6
	winter	13	1403	123.4 ± 5.2	54 ± 4.8	13.2 ± 2.8

MCP - Minimum Convex Polygon; FKD - Fixed Kernel Density; FKD (CA) – Fixed Kernel Density (Core Area);
* Home range in km^2; CA- Core Area; SE- Standerd Error.

3.4.5. Herd formation of gaur and their home range

Batch-1

Of the 19 gaur individuals reintroduced in 2011, it was observed that they formed two different gaur herds i.e H-1(n=7) and H-2 (n=13), and both had a mixed age and sex class individuals (table 3.5). However, none of the males were associated with H-I in the first year (table 3.5). H-1 moved towards northern side of the National Park initially and ranged over 108.5 Km^2 in the month of May and subsequently its home range size dropped to 12.7 Km^2 in the month of November (table 3.6). The H-2, which was associated with all the males (n=5), moved towards the southern part of the National Park and gradually explored larger area i.e 43.4 km^2 in the month of August and subsequently its home range reduced to 9.2 Km^2 in the month of November (table 3.6).

The month wise utilization area of two herds is given in the table 3.6. Month wise home range stabilization curve for both the herds is given in figure 3.8.

Table 3. 5. Details of two gaur herds and their demography classes in Bandhavgarh Tiger Reserve in 2011.

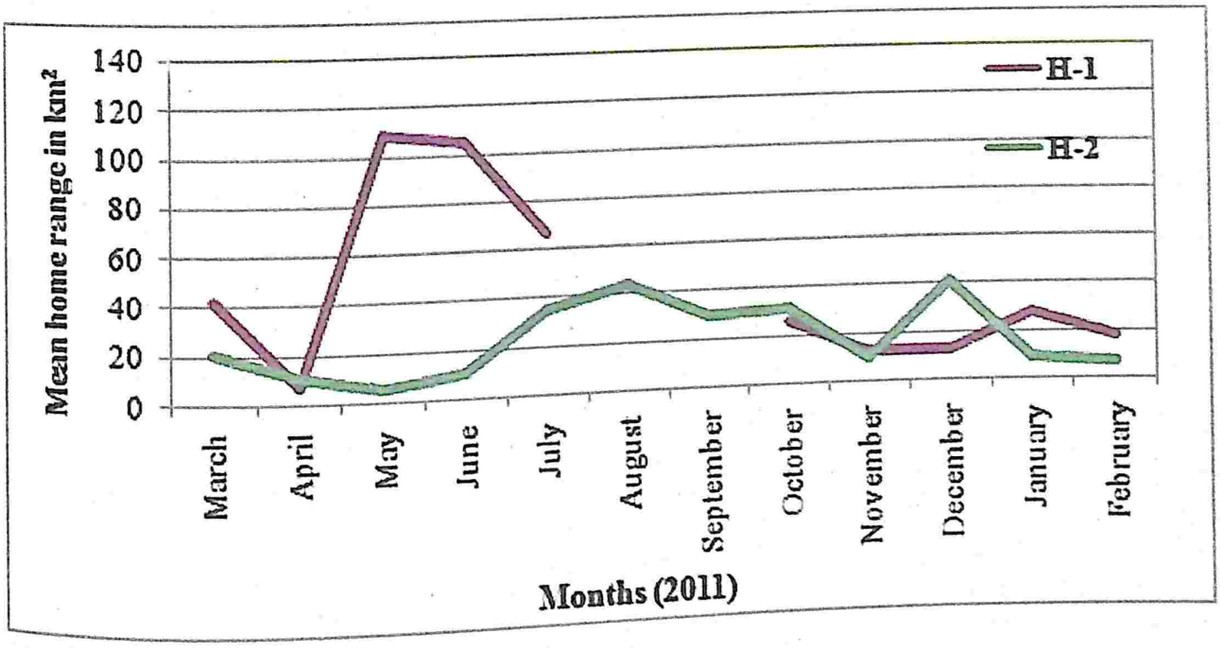
Herd	1	2
Number of Individuals	7	13
Adult male	--	2
Sub adult male	--	2
Adult female	2	5
Sub adult female	3	2
Yearling	1	2
Calf	1	--

Table 3. 6. Month wise utilized area of two gaur herds in Bandhavgarh Tiger Reserve in 2011.

Months	H-1*	H-2*
March	41.8	20.1
April	7.4	10.6
May	108.5	5.6
June	104.3	10.6
July	66.0	34.9
August	--	43.4
September	--	29.1
October	26.2	30.8
November	12.7	9.2
December	11.9	20.6
January	17.8	9.0
February	17.9	7.4

H- Herd; * Home range in Km^2; -- Data not collected

Figure 3. 8. Month wise area utilization curve of two gaur herds in Bandhavgarh Tiger Reserve in 2011.



3.4.5.1. Seasonal home range of gaur herds I and II in Bandhavgarh Tiger Reserve in 2011.

Using 100 % MCP the seasonal and annual home range of herd I (H-1) and herd II (H-2) was calculated. The estimated summer home range was 114.2 Km^2 and 173.4 Km^2 for H-I and H-2 respectively. The monsoon home range for H-1 and H-2 was 66.0 Km^2 and 112.9 Km^2 respectively. The winter home range for H-I and H-2 was 66.8 Km^2 and 101.3 Km^2 respectively (table 3.7 and figure 3.9). The estimated home range with 95 % FKD for H-1 and H-II in summer was 58.6 Km^2 and 106.2 Km^2 respectively. The monsoon home range for H-1 and H-2 was 43.2 Km^2 and 57.6 Km^2 respectively. The winter home range for H-I and H-2 was 46.3 Km^2 and 92.6 Km^2 respectively (table 3.7). The estimated home range with 50 % FKD for H-1 and H-II in summer was 11.0 Km^2 and 14.2 Km^2 respectively. The monsoon home range for H-1 and H-2 was 8.9 Km^2 and 21.8 Km^2 respectively. The winter home range for H-I and H-2 was 9.3 Km^2 and 23.1 Km^2 respectively (table 3.7).

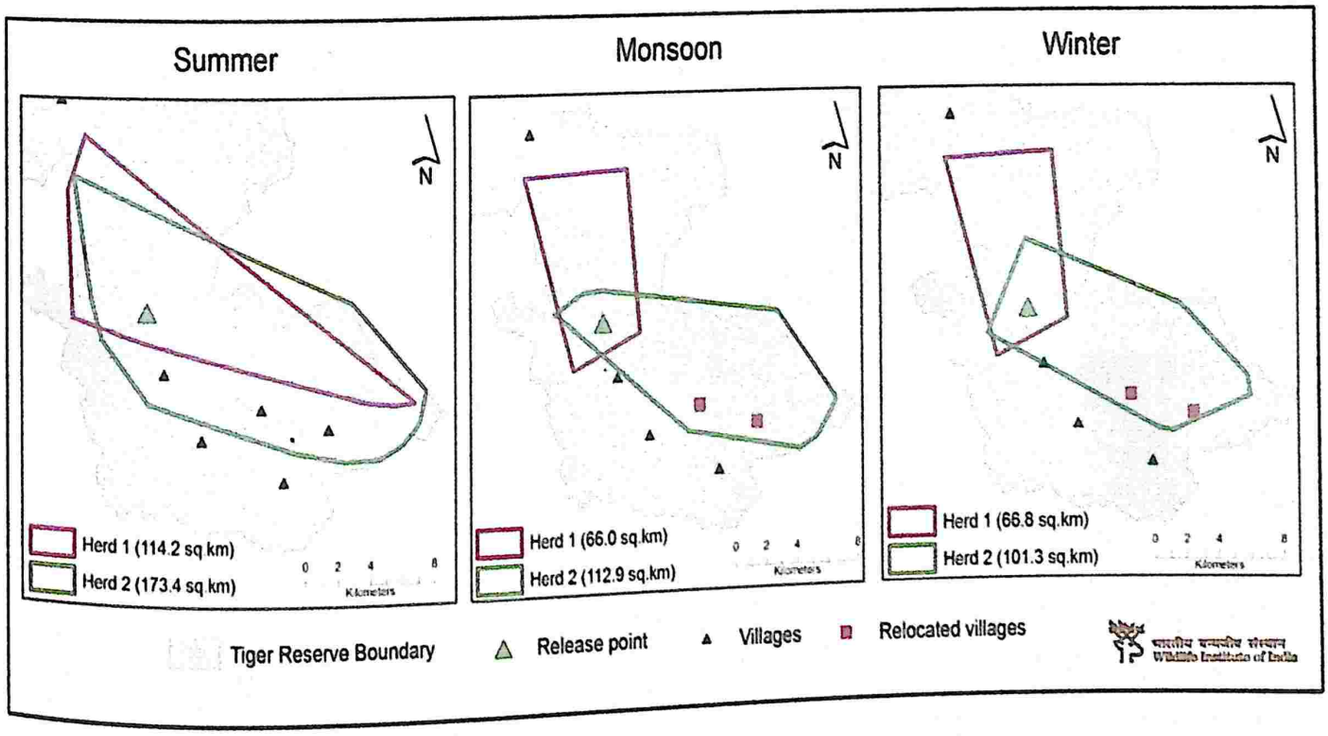
Table 3. 7. Estimated seasonal home range of two gaur herds in Bandhavgarh Tiger Reserve in 2011.

Methods	100 % MCP		95 % FKD		50 % FKD (CA)	
Herd	1	2	1	2	1	2
Summer*	114.2	173.4	58.6	106.2	11	14.2
Monsoon*	66.0	112.9	43.4	57.6	8.9	21.8
Winter*	66.8	101.3	46.3	92.6	9.3	23.1

MCP - Minimum convex polygon; FKD - Fixed Kernel Density;

FKD (CA) – Fixed Kernel Density (Core Area); * Home range in Km^2.

Figure 3. 9. Season wise home range and home range overlap between two gaur herds in Bandhavgarh Tiger Reserve (2011) using 100 % minimum convex polygon method.



Batch II

The suplimentation of 31 gaur in 2012, resulted in formation of four new gaur herds. A total of six different (two pre-existing and four new) gaur herds were observed during the entire summer 2012, and subsequently in early monsoon two gaur herds (H-5 with H-1and H-6 with H-2) joined with the prexisting herds. A total of four different gaur herds were observed consistantly till winter 2012. The month wise utilization area of different gaur herds is given in table 3.8. The month wise home range stabilization curve for diffrent gaur herds is given in figure 3.10.

It was observed that the established H-1 (2011) gaur herd was joined by individuals from H-5 in early monsoon 2012. After the addition of few more individuals to H-1, there was an increase in the home range from 10.6 Km^2 to 34.9 Km^2 in the month of July and subsequently their home range was reduced to 9.2 Km^2 in the month of November 2012 (table 3.9). H-2 (2011) gaur herd was also joined by individuals from H-6 in the early monsoon 2012 which resulted in increase of home range from 9.8 Km^2 to 42.9 Km^2 in the month of July and subsequently their home range was reduced to 11.2 Km^2 in the month of December 2012 (table 3.9).

It was observed that H-3 gaur herd had 15 individuals, gradually increased their home range and explored larger area of about 41.5 Km^2 in the month of July and subsequently their home range was reduced to 7.7 Km^2 in the month of December 2012. H-4 gaur herd had six individuals, explored larger area of 127.6 Km^2 in the month of May and subsequently their home range was reduced to 16.5 Km^2 in the month of October 2012.

Table 3. 8. Details of different gaur herds and their demography classes in Bandhavgarh Tiger Reserve in 2012.

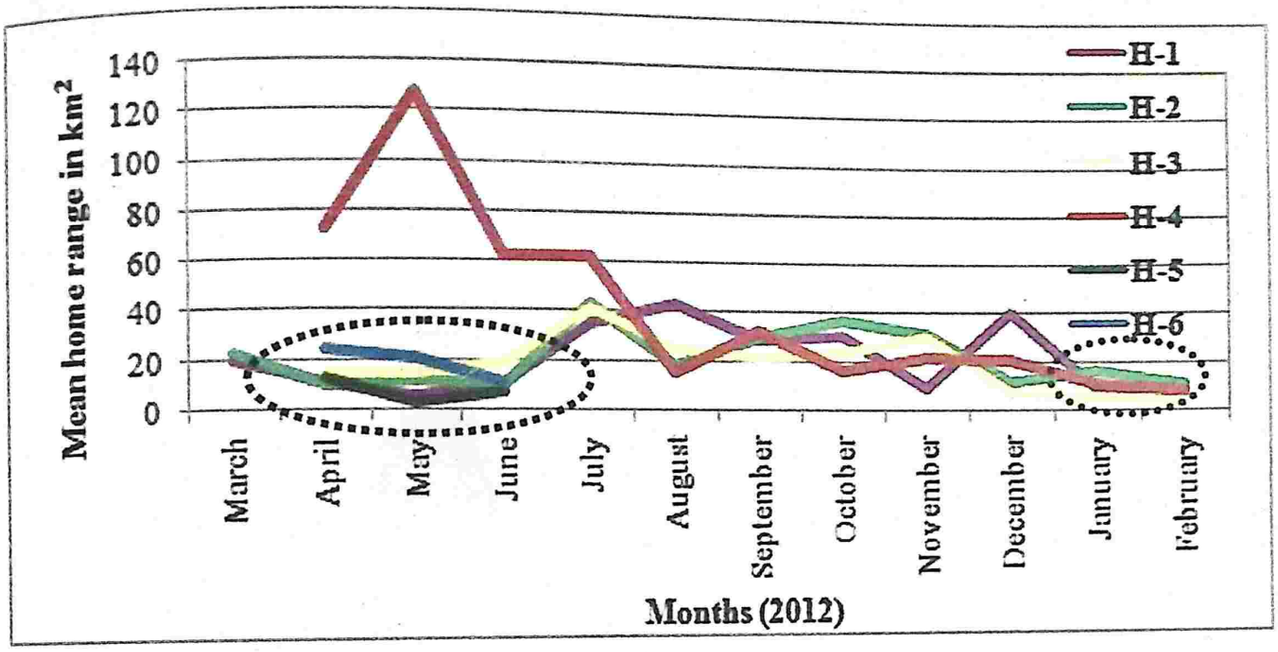
Herd	1	2	3	4
Number of Individuals	14	22	15	6
Adult male	1	1	1	--
Sub adult male	2	4	3	1
Adult female	3	7	3	1
Sub adult female	6	4	5	3
Yearling	1	2	2	--
calf	1	4	1	1

Table 3. 9. Month wise utilized area of different gaur herds in Bandhavgarh Tiger Reserve in 2012.

Months	H-1*	H-2*	H-3*	H-4*	H-5*	H-6*
March	20.1	22.6	--	--	--	--
April	10.6	9.8	14.4	72.7	12.7	24.3
May	5.6	11.2	14.2	127.6	2.9	20.8
June	10.6	9.8	19.2	62.1	7.2	11.3
July	34.9	42.9	41.5	61.8	--	--
August	43.4	17.9	25.4	16.0	--	--
September	29.1	29.7	19.4	33.0	--	--
October	30.8	36.6	23.2	16.5	--	--
November	9.2	31.1	31.1	22.2	--	--
December	20.6	11.2	7.7	21.3	--	--
January	9.0	15.9	6.0	11.5	--	--
February	7.4	10.8	3.8	8.5	--	--

H- Herd; * Home range in Km^2; -- Data not collected

Figure 3. 10. Month wise area utilization curve of different gaur herds in Bandhavgarh Tiger Reserve in 2012.



3.4.5.2. Seasonal home range of different gaur herds in 2012

Using 100 % MCP the seasonal home range of different gaur herds was calculated. The summer home range varied from 35.1 Km^2 to 273.8 Km^2 for six different gaur herds. The estimated monsoon home range for four gaur herds was 98.5 Km^2, 58.6 Km^2, 76.1 Km^2 and 92.5 Km^2 for H-1, H-2, H-3 and H-4 respectively, whereas in winter the estimated home range for the same four gaur herds was 50.7 Km^2, 32.3 Km^2, 60.0 Km^2 respectively (table 3.10 and figure 3.11). With 95% FKD the estimated summer home range for six different gaur herds varied from 24.6 Km^2 to 127 Km^2. The estimated monsoon home range for four gaur herds was 79.7 Km^2, 43.9 Km^2, 74.1 Km^2 and 73.8 Km^2 for H-1, H-2, H-3 and H-4 respectively, whereas in winter the estimated home for

the same herds range was 57.1 Km^2, 23.5 Km^2, 43.5 Km^2 and 22.5 Km^2 respectively (table 3.10). With 50 % FKD the estimated summer home range for six different gaur herds varied from 14.7 Km^2 to 8.8 Km^2. The monsoon home range for four gaur herds was 11.6 Km^2, 18.0 Km^2, 18.2 Km^2 and 11.2 Km^2 for H-1, H-2, H-3 and H-4 respectively, whereas in winter the estimated home range for the same gaur herds was 10.5 Km^2, 7.3 Km^2, 7.4 Km^2 and 5.9 Km^2 respectively (table 3.10).

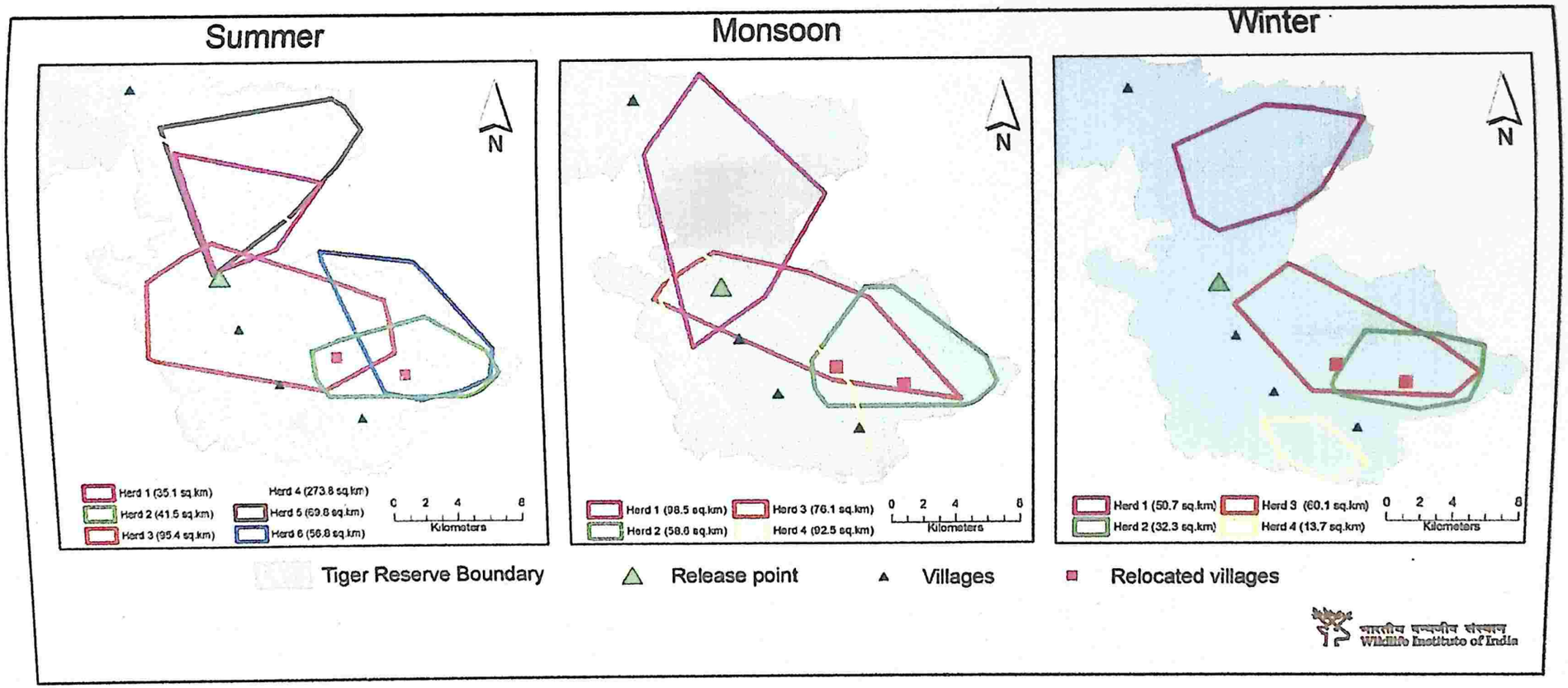
Table 3. 10. Estimated seasonal home range of different gaur herds in Bandhavgarh Tiger Reserve in 2012.

Herd	Number of individuals in herd	100 % MCP *			95 % FKD *			50 % FKD (CA)*		
		Summer	Monsoon	Winter	Summer	Monsoon	Winter	Summer	Monsoon	Winter
1	6	35.1	98.5	50.7	24.2	79.7	57.1	13.3	11.6	10.5
2	22	41.5	58.6	32.3	34.3	43.9	23.5	8.9	18.0	7.3
3	16	95.4	76.1	60.1	56.9	74.1	43.5	12.4	18.0	7.4
4	5	273.8	92.5	13.7	127.0	73.8	22.5	14.7	11.2	5.9
5	4	69.8	Joined Herd 1		40.0	Joined Herd 1		8.8	Joined Herd 1	
6	6	56.8	Joined Herd 2		59.5	Joined Herd 2		9.3	Joined Herd 2	

MCP-Minimum convex polygon; FKD-Fixed kernel Density; FKD (CA)-Fixed Kernel Density (Core Area);

* Home range in Km^2

Figure 3. 11. Season wise home range and home range overlap between different gaur herds in Bandhavgarh Tiger Reserve (2012), using 100 % minimum convex polygon method.



3.4.6. Movement pattern of reintroduced gaur

3.4.6.1. Overall dispersal

Nineteen gaur that were introduced in 2011 January, initially explored larger area (254.4 km^2) by moving towards northern and southern directions of the Tiger Reserve (figure 3.12.A). On few occasions, males and females remained solitary from the herd for a week. A high overlap (70.3 %) was observed between gaur males and females in summer 2011. In late summer 2011 two villages namely Kallwah and Kumuruvaha were relocated from the core area of the Tiger Reserve. Gaur avoided the relocated village sites initially in monsoon and subsequently started using the relocated sites in winter. The addition of 31 gaur re-introduced during March 2012 resulted in overall home range exploration from 254.4 Km^2 in 2011 to 384.4 Km^2 in 2012 (figure 3.13).

Figure 3. 12. Area used by reintroduced gaur in 2011 (A) and 2012 (B) in Bandhavgarh Tiger Reserve.

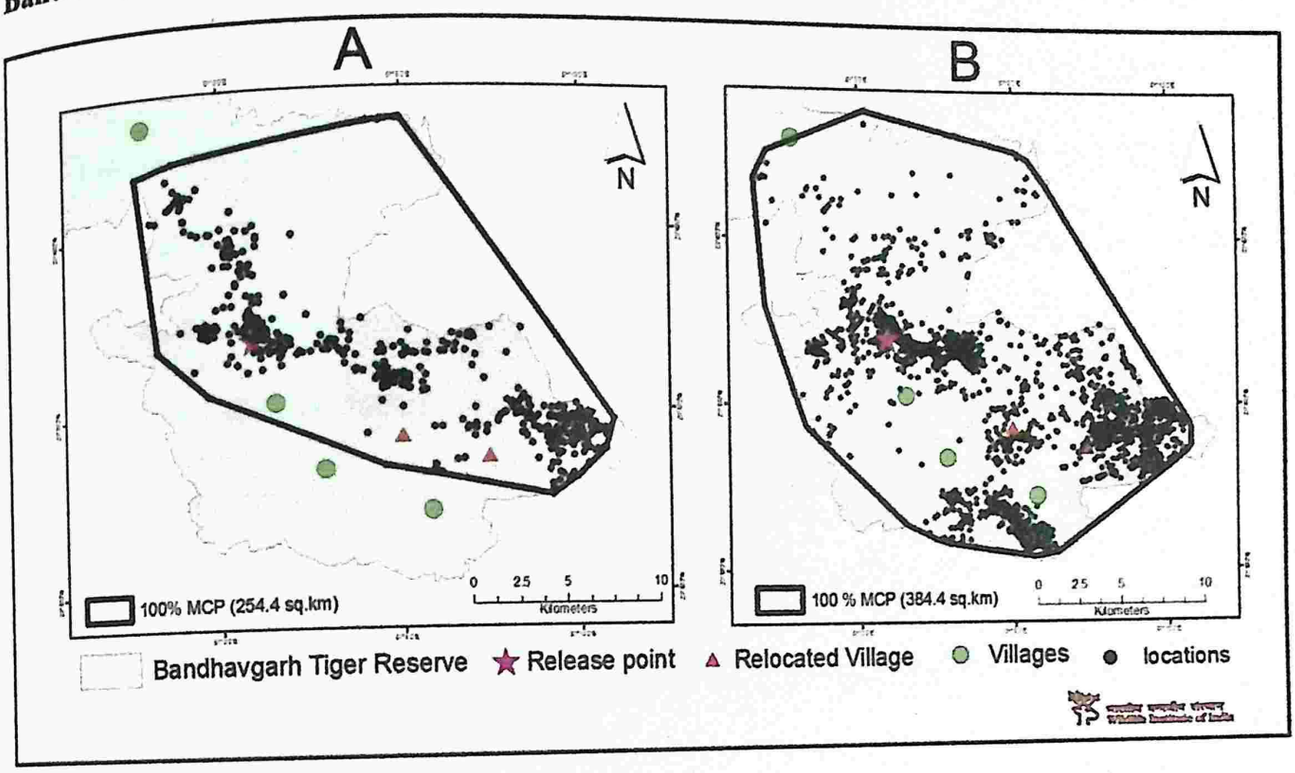
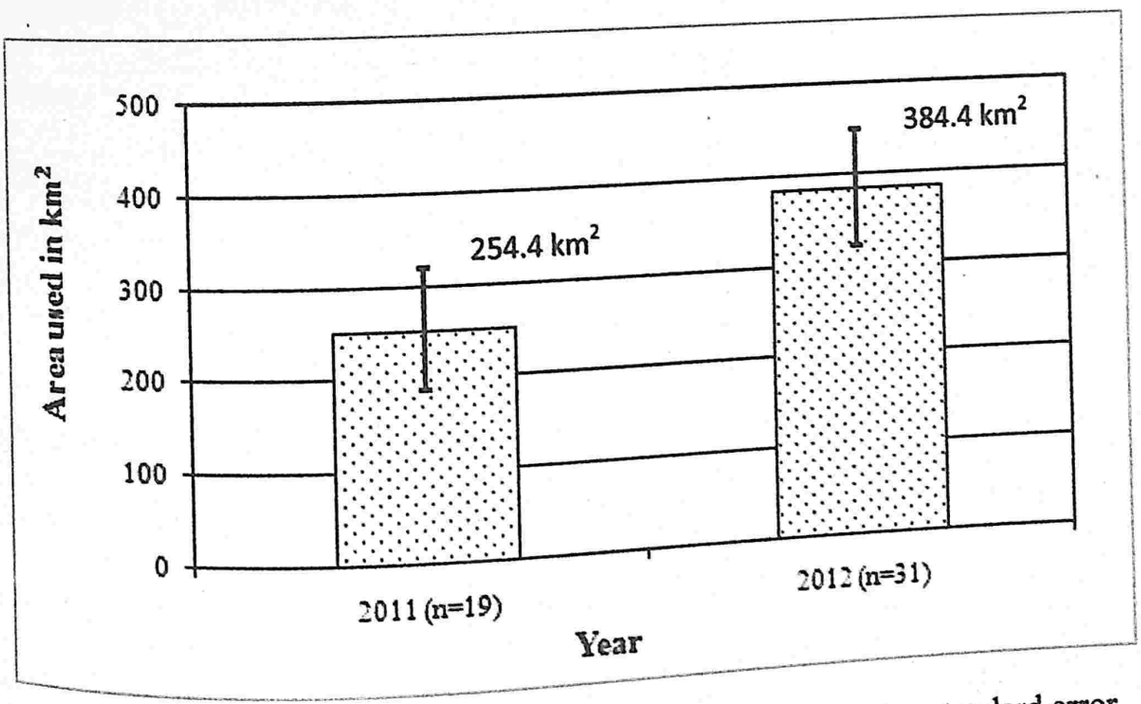


Figure 3. 13. Mean home range size of reintroduced gaur in 2011 and 2012 in Bandhavgarh Tiger Reserve.



n= number of individuals; Error bars are standard error

3.4.6.2. Demography classes

It was observed that the overall mean daily distance moved by reintroduced gaur (males (n=6) and females (n=19) (adult and sub adult)) in summer was 1.74 ± 1.17 (SE) Km, in monsoon it was 1.97 ± 1.65 (SE) Km and in winter it was 1.71 ± 1.68 (SE) Km. The observed mean movement for females (adult and sub adult) in summer was 1.83 ± 1.23 (SE) Km, in monsoon it was 1.94 ± 1.64 (SE) Km and in winter it was 1.56 ± 1.47 (SE) Km. The observed mean movement for males (adult and sub adult) in summer was 1.66 ± 1.11 (SE) Km, in monsoon it was 2.00 ± 1.75 (SE) Km and in winter it was 1.89 ± 1.14 (SE) Km (table 3.11).

Table 3. 11. Estimated distance moved by reintroduced gaur in different seasons in Bandhavgarh Tiger Reserve (2011-2013).

Season	Overall (Km ± SE)	Female (Km ± SE)	Male (Km ± SE)
Summer	1.74 ± 1.17	1.83 ± 1.23	1.66 ± 1.11
Monsoon	1.97 ± 1.65	1.94 ± 1.64	2.00 ± 1.75
Winter	1.71 ± 1.68	1.56 ± 1.47	1.89 ± 1.14

Km = Kilometer; SE = Standard Error

The adult male GM5 was observed to travel long distance, up to 19 Km on a single day (May 2011). It was observed that large proportion of this movement was in night hours. Two females GF9 and GF36 occasionally travelled large distances 11 Km and 14 Km in a day (including dawn and dusk) during summer (May 2011) and Monsoon (July 2012). The observed distance travelled by gaur herds, H-II (12 individuals) and H-4 (6 individuals) was 9 Km and 7 Km in summer 2011 and summer 2012 respectively.

3.4.6.2. Year wise

In summer of 2011, the estimated mean distance travelled by female gaur (n=7) was 1.37 ± 1.02 (SE) Km, in monsoon it was 1.77 ± 1.22 (SE) Km and in winter it was 1.42 ± 1.02 (SE) Km. The observed mean distance travelled by male gaur (n=3) in summer was 1.11 ± 0.79 (SE) Km, in monsoon it was 1.60 ± 1.12 (SE) Km and in winter it was 2.07 ± 1.39 (SE) Km (table 3.12).

In summer of 2012, the estimated mean distance travelled by female gaur (n=19) was 1.83 ± 0.88 (SE) Km, in monsoon it was 2.07 ± 1.35 (SE) Km and in winter it was 1.56 ± 1.49 (SE) Km. The observed mean distance travelled by male gaur (n=6) in summer was 1.66 ± 0.97 (SE) Km, in monsoon it was 2.00 ± 1.37 (SE) Km and in winter it was 1.89 ± 1.49 (SE) Km (table 3.12). The mean month wise movement of male and female gaur for each year, 2011and 2012 is given in figure 3.14 and figure 3.15.

Table 3. 12. Seasonal movement pattern of reintroduced gaur in Bandhavgarh Tiger Reserve (2011 and 2012).

	2011		2012	
Season	**Females** (Km ± SE)	**Males** (Km ± SE)	**Females** (Km ± SE)	**Males** (Km ± SE)
Summer	1.37 ± 1.02	1.11 ± 0.79	1.83 ± 0.88	1.66 ± 0.97
Monsoon	1.77 ± 1.22	1.60 ± 1.12	2.07 ± 1.35	2.00 ± 1.37
Winter	1.42 ± 1.02	2.07 ± 1.39	1.56 ± 1.49	1.89 ± 1.49
Overall	1.52 ± 1.08	1.59 ± 1.10	1.82 ± 1.24	1.85 ± 1.27

Km = Kilometer; SE = Standard Error

Figure 3. 14. Mean month wise movement pattern of male gaur in Bandhavgarh Tiger Reserve (2011 and 2012).

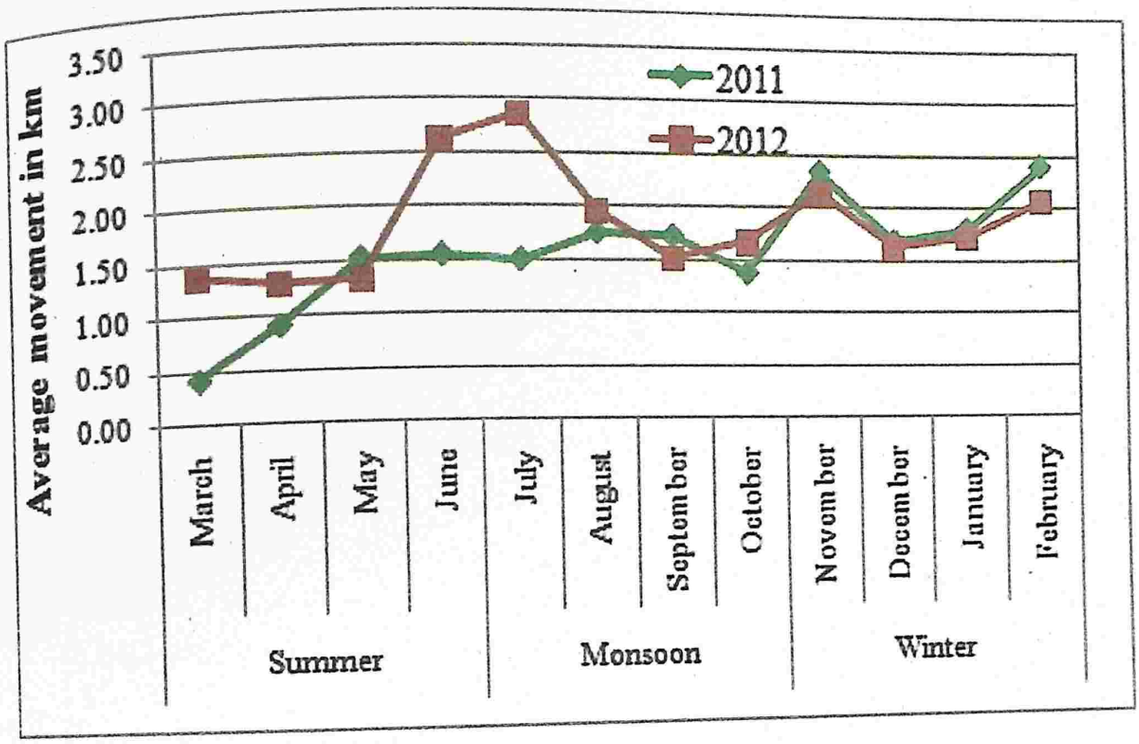
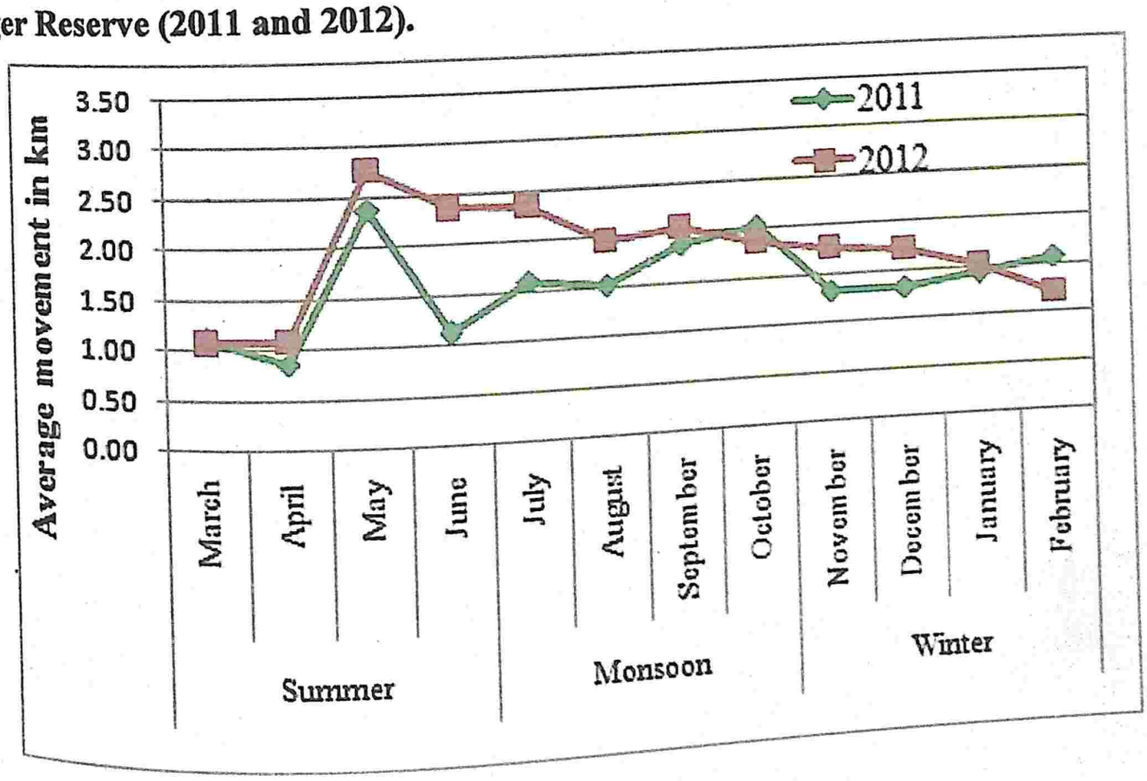


Figure 3. 15. Mean month wise movement pattern of female gaur in Bandhavgarh Tiger Reserve (2011 and 2012).



3.5 DISCUSSION

3.5.1. Overall home range of gaur

Gaur is one of the largest wild cattle occurring widely from mainland South Asia through South East Asia. Little information is available on the ranging pattern of the species. This is the first study on reintroduction and subsequent monitoring of the species. It is essential to get minimum number of fixes to calculate animal true home range size (Harris *et al.* 1990). In the present study, the minimum number of fixes (n=122) needed to calculate the reintroduced gaur home range size varied between demography classes.

In the present study, the reintroduced gaur home range size reached asymptote at 154 Km^2 and varied between age and sex classes. In general, range size of mammals is directly proportional to its body size (Harestad and Bunnell, 1979) and gaur are no exception. The average time taken to establish the home range size (12 individuals range variation: 110 Km^2 to 260 Km^2) of batch I gaur in terms of days varied among the age and sex classes. Less intra specific competation among the age and sex classes of gaur in Bandhavgarh might have allowed them to establish their home ranges. In case of batch II gaur, to establish the home range size (15 individuals range variation: 71 Km^2 to 279 Km^2) in Bandhavgarh in terms of days did not show difference between different age and sex classes. This may be attributed to the intra specific competition between gaur individuals of batch I and batch II in Bandhavgarh for the available resources. Similar findings were reported in batch wise (in different year) reintroduction studies on white

rhinoceros in Moremi Game Reserve, Botswana (Pitagano 2007) and elk in Kentuck, United States (Schneider *et al.* 2006).

In the present study, the home range size of gaur was estimated with different estimators, such as MCP (100%, 95%) and FKD (95% and 50%). The MCP area and shape is influenced by outlying fixes, and hence it may include large unused areas causing an overestimation of home range size (Harris *et al.* 1990). Despite its limitations the MCP was the method of choice in the past and was recommended by IUCN in 1994 (Burgman and Fox 2003), as hence this method was chosen to draw comparisons of present study with previous studies on the species.

The estimated overall home range size of reintroduced gaur during the present study was found much larger (405.2 Km^2) as compared to the study conducted at Pench Tiger Reserve, Central India (175 Km^2) by Sankar *et al.* (2000), which is not a reintroduced study (table 3.13). This high overall home range of gaur in Bandhavgarh is attributed to the initial explorations to new habitats after reintroduction. The initial exploration of gaur with larger areas (405.2 Km^2) and latter adapting to the smaller habitats (37.8 Km^2) as observed in Bandhavgarh is in accordance with other reintroduction studies on herbivores such as elk, one horned rhinocerus, rein deer and wild ass (Schneider *et al.* 2006, Pitagano 2007, Kojola *et al.* 1995, Saltz and Rubenstein 1995).

The average home range size of individual gaur recorded in Bandhavgarh using 100% MCP was 160.3 ± 13.3 (SE) Km^2 which was varied between individuals. Between age and sex class individuals there were not varied significantly (Kruskal Wallis test =

5.53, df = 3, P > 0.05). The observed variation in the home range size of individual gaur in Bandhavgarh might be due to availability of different habitat types. The average home range size of batch I (186.9 ± 18.8 (SE) Km^2) and batch II (139 ± 17.2 (SE) Km^2) gaur were not varied significantly (t = 1.870, df = 26, p > 0.05, two tailed). The larger home range size in 2011 (batch I) may be attributed to less intra specific competition between individuals for available space and resources. The supplementation of 31 gaur individuals in 2012 (batch II) resulted in the high intra specific competition between the existing gaur population and the new stock in Bandhavgarh. Difference in home range size in batch wise reintroduction was reported in the reintroduction studies on elk (Schneider *et al.* 2006) and white rhinocerous (Pitagano 2007).

In the present study, the observed average overall home range size of adult gaur male was large (250.2 ± 10.5 (SE) Km^2) as compared to sub adult gaur male (124.6 ± 26.9 (SE) Km^2) (Mann-Whitney U test, U = 6, p = 0.125). The adult gaur males utilized larger areas and stayed solitary on many occasions (n= 236), and also had the tendency to move from one herd to another in search of females within the area. This finding was also supported by Corny (1989) and Sankar *et al.* (2000) using radio-telemetry studies on gaur (table 3.13) and without radio telemetry studies on gaur by Schaller (1967), Vairavel (1998), Easa (1998) Jayson (1999), Choudhary (2002) and Ashokkumar *et al.* (2004). Adult gaur male have the tendency of ranging larger areas in search of female, being solitary in nature (Schaller 1967). The observed small home range size in sub adult male gaur may be attributed to their sub-dominance nature and their conflicts with dominate males in Bandhavgarh.

The observed average overall home range size of adult gaur female was larger (188.6 ± 33.1 (SE) Km^2) as compared to sub adult gaur female (148.3 ± 14.7 (SE) Km^2) (Mann-Whitney U test, U = 20, p = 0.04). The gaur female home range size as recorded in the present study was not comparable with other studies on gaur elsewhere (table 3.13). The observed large home range of adult gaur females may be attributed to their inherent behavior in leading the herd while exploring areas. Usually in large mammals, the home range size does not vary between sub adult female those were associated with adult female (Harestad and Bunnell 1979).

Table 3. 13. Gaur home ranges as reported by different studies, using 100% MCP.

Study area	Number of radio collars	Habitat	Overall home range (Km^2)	Adult male (Km^2 ± SE)	Sub adult male (Km^2 ± SE)	Adult female (Km^2 ± SE)	Sub adult female (Km^2 ± SE)	Authors
Bandhavgarh TR, Central India	27	Dry Deciduous forest	405 .2	250 ± 10.5	123.6 ± 26.7	166.2 ± 35.6	145.4 ± 13.8	Present study
Pench TR, Central India	3	Dry Deciduous forest	175	150	--	75	--	Sankar *et al.* 2000
Lepar Valley, Pahang, Malaysia	5	Tropical Evergreen forest	--	137.3	29. 9	--	52.1	Corny, 1989

Km- Kilometer; SE- Standard Error

Range overlap between gaur males and females *i.e.* 87.6 % in the present study indicates the competition for different resources in the habitat. Similar results were

discussed by Schaller (1967), Corny (1989) and Sankar *et al.* (2000). In mammals, especially the mega herbivores it is expected that males often have large range that overlap with the range of females to maximize their reproductive success by mating with as many females as possible (Leuthold 1977, Nelson 1995, Bond and Wolff 1999).

Initially the reintroduced gaur moved out of Tiger Reserve on few occasions (n=21), and this might be due to exploration of new habitats, presence of larger predators and anthropogenic disturbance in the study area. Similar findings were reported on other reintroduction studies on mega herbivores (Jnawali and Wegga 1991, Kojola *et al.* 1995, Schneider *et al.* 2006, Pitagano 2007).

3.5.2. Season wise home range of different age and sex classes of gaur

In the present study, the estimated mean home range size of adult gaur male had no significant difference across seasons (Kruskal Wallis test = 2.11 df = 2, $p > 0.05$). The reported adult gaur male home range size (100% MCP) in Pench Tiger Reserve was 12.6 Km^2 and 7 .6 Km^2 in summer and monsoon respectively (Sankar *et al.* 2000). The estimated mean home range size of sub adult gaur male differed significantly across seasons (Kruskal Wallis test = 18.92, df = 2, $p < 0.05$). The estimated mean home range size of adult gaur female had marginal significant difference across seasons (Kruskal Wallis test = 6. 03, df = 2, $p < 0.05$). The reported adult gaur female home range size (100% MCP) in Pench Tiger Reserve was 7.2 Km^2 and 13.8 Km^2 in summer and monsoon respectively (Sankar *et al.* 2000). The mean home range size of sub adult

female in Bandhavgarh significantly differed across seasons (Kruskal Wallis test = 6.20, $df = 2, p < 0.05$).

The observed larger home range size for different age and sex classes of gaur during monsoon and winter (table 3.4) as observed in the present study may be attributed to the availability of wide spread natural mineral licks, adequate food and water along with availability of different vegetation types in the study area. The observed smaller home range of gaur males and females in summer and monsoon in Pench Tiger Reserve was attributed to the availability of food resources and water throughout the year (Sankar *et al.* 2000). As the nutritive value of plants changes considerably during the winter and summer, the home range size of individuals should vary during this period (Deinum 1984).

3.5.3. Herd formation of gaur and their home range

Of the 19 gaur individuals translocated in 2011, formation of two different herds H-1 and H-2, in which the season wise home range size for both the gaur herds varied. The estimated large home range size (114.2 Km^2 and 173.4 Km^2) and the high overlap in their home range (95.2 %) in summer 2011 may be attributed to initial response of reintroduction and less intra specific competition between reintroduced gaur in Bandhavgarh. Two villages *viz.* Kallwah and Kummuruvah from gaur occupied range were relocated in late summer 2011 (figure 3.9). It was observed that the reintroduced gaur started using the relocated site in winter 2011. This may be attributed to less home range overlap between two gaur herds in monsoon (26.3 %) and winter (33.1 %). Among

the 19 individuals reintroduced in 2011, three gaur died naturally and three calves were born and hence the total population was maintained as 19 individuals.

Formation of different herds (n=4) was observed after the supplementation of more individuals (n=31) in summer 2012. It was observed that there was high overlap (93.6%) between six gaur herds for establishing their territory during summer 2012 and no bonding of individuals observed between the existing gaur herds and the newly introduced stock in summer 2012. The high range overlap observed was attributed to the intra specific competition between individuals in the new habitat, dominance nature of individuals, and predator's presence in the study area.

In early monsoon, interaction and congregation between gaur herds were observed. The home range size increased within gaur herds since the joining of new individuals, H-5 to H-1 and H-6 to H-2. The considerable increase in home range size may be attributed to fulfill their requirements for the available food, shelter and mate. Similar observations were reported on mega-herbivores such as elephants in Kenya (Poole 2011) and giraffe in Zambia (Bercovitch and Berry 2012). Gradual decrease in range overlap observed between individual gaur herds in monsoon (53.6 %) and winter (24.1 %) may be attributed to the settlement in new habitat by establishing their home ranges. Prior to this study, the only other investigation of the home range in gaur herd in Malaysia was that of Weigum in 1960s, where Kula Tahan herd ranged over 13 km^2. The gaur herd home range size as recorded in the present study was not comparable because of different techniques used by Weigum (1960) in which he tracked the herd animals using visual observations and fresh spoor marks, and hence he may not have documented continues monitoring of the gaur herd.

In Bandhavgarh, the gaur herd size varied from six to 22 individuals and all the gaur herds had compressed of mixed age class individuals. The overall ranging size varied among gaur herds in Bandhavgarh. In mammals, formation of herds decreases the risk of predation on individual animals (Kenward 1978, Pulliam and Caraco 1984, Lima 1995 a,b, Krause and Ruxton 2002, Uetz *et al.* 2002). Very less is known about group size formation and predation risk on mega-herbivores (Messier and Barrette 1985, Fitzgibbon 1990, Creel and Creel 2002, Goldspink *et al.* 2002, Hebblewhite and Pletscher 2002).

3.5.4. Movement pattern of reintroduced gaur

The overall home range size by reintroduced gaur varied across two years (2011 and 2012). It was observed that the reintroduced gaur used similar areas where the presence of gaur had been reported earlier in Bandhavgarh by Lad and Gopal (1992). The larger (384.4 Km^2) home range size of gaur in 2012 compared to initial home range in 2011 (254.4 Km^2), may be attributed to the intra specific competition between reintroduced gaur in Bandhavgarh. Similar observations was reported in other reintroduction studies, *viz.* one horned rhinoceros (Jnawali and Wegga 1991) in Nepal, rein deer (Kojola *et al.* 1995) in Finland and elk (Schneider *et al.* 2006) in America.

Mega herbivores have larger movement within home range than smaller herbivores (Mech 1983) because the need of higher amount of energy and consequently in order to find enough food to satisfy their needs (Mcnab 1963). Among the ungulates gaur is known to be one of the most wide ranging animals and shows seasonal and local movements between foraging sites (Schaller 1967).

In the present study, the average overall daily movements of reintroduced gaur across seasons differed significantly (Kruskal Wallis test = 17.79, df = 2, $p < 0.05$). The movement pattern of males and females did not differ significantly across different seasons ($F = 3.353$, df = 2, $p > 0.05$). The gaur were reintroduced in two batches (n=19 and n=31) in different years (2011 and 2012) in which, the significant difference was observed in their movement pattern (Kruskal Wallis test = 81.7, df = 1, $p < 0.05$). The significant movement in different seasons may be attributed to the availability of food, water, cover and mineral licks in different vegetation types in Bandhavgarh.

The adult gaur male (GM5) moved larger distance *i.e.* 19 Km in the present study which was similar to as reported by Corny (1989) in Lepar valley, Malaysia. Adult male gaur has the tendency of moving solitarily over a long distance in search of females (Schaller 1967, Sankar *et al.* 2000). Two gaur females (GF9 and GF36) occasionally moved long distances (11Km and 14 Km). The sub adult gaur female GF9 travelled 11Km in a day during summer 2011 when the gaur was initially released in the wild and when it got separated from the herd. In case of adult gaur female GF36 it travelled 14 Km in a day during July 2012 when the female lost her new born calf (15 days old) due to predation. Dunbar (1912) reported in Central Africa that a wounded elephant cow travelled 95 km in one day.

In the present study, the observed larger distance travelled by two different gaur herds (9 Km and 7 Km) in summer in different years (2011 and 2012) may be attributed to exploration of new areas soon after reintroduction.

Plate 3. 1. Radio tracking of gaur in Bandhavgarh Tiger Reserve.

Plate 3. 2. A herd of gaur in Bandhavgarh Tiger Reserve.

Chapter IV

Habitat use and Resource Selection of reintroduced gaur

Chapter IV

HABITAT USE AND RESOURCE SELECTION OF REINTRODUCED GAUR

4.1. INTRODUCTION

Habitat ecology is fundamentally concerned with understanding the relationships between organisms and their environment (Baker 1978). The lack of information on the habitat ecology and the resource selection of animals can be a serious impediment in the conservation management of the species and landscapes (Apps *et al.* 2001, Lyons *et al.* 2003). In mammals, the concept of habitat has been defined as the resources and conditions present in an area that produce occupancy which includes the survival and reproduction of a species (Fryxell and Sinclair 1988, Hall *et al.* 1997, White *et al.* 1997, Bowyer *et al.* 1998). Among large herbivores, the habitat selection depends upon various factors, such as availability and quality of forage site (Klein 1970, Skoglund 1980, Bowyer 1986, Albon and Langvatn 1992, Cameron *et al.* 1993), mineral requirements (Belovsky and Jordan 1981), climatic factors such as wind (Miller *et al.* 1985, Ion and Kershaw 1989), parasite avoidance (Duncan 1983), predation (Bergerud *et al.* 1984, Festa-Bianchet 1988, Bleich *et al.* 1997), inter specific competition (Caro and Stoner 2003, Vanam and Gomper 2009) and food supply (Sinclair 1975, White 1978).

However, the habitat selection by mega herbivores is associated with the abundance food resources (Duncan 1983, McNaughton 1984, 1988, Murden and Risenhoover 1993). The habitat selection affects individual fitness, and the resource selection is a multilevel and hierarchical process in response to various environmental

factors, starting from the geographic range of a species till the selection of particular elements within the territory of the species (Johnson 1980, Hall *et al.* 1997, Manly *et al.* 2002).

Most of the habitat distraction and habitat loss to the species in the globe is mainly due to habitat fragmentation (Erickson *et al.* 1998, Morrison *et al.* 2001). As the habitat fragmentation occurs, it affects the distribution of species and leads to species extension from the area (Griffith *et al.* 1989, Wolf *et al.* 1996, Fischer and Lindenmayer 2000). As translocation is one of the major management options for restoration and conservation of species (IUCN 1998), in which the species has been extirpated from the area (Fischer and Lindenmayer, 2000). The restoration of animals is considered to be a success if it results in a self sustaining population (Griffith *et al.* 1989). Understanding the scale in which the environment context influences habitat selection and the resource of the reintroduced population is essential (Matson *et al.* 2004).

There are several factors that influence translocation success, including the number of animals released (Griffith *et al.* 1989, Wolf *et al.* 1996, Fischer and Lindenmayer, 2000, Matson *et al.* 2004), the habitat quality of the release area and the location of the release area in relation to the historical range of the species (Griffith *et al.* 1989, Wolf *et al.* 1996). The information on habitat use and resource selection may provide better understanding of the species in the environment (Anderson *et al.* 2005). This information is useful to get an idea on maximum space use of animals in an area, where the prime habitats are shrinking due to fragmentation and degradation (Vairavel 1998). Selection of seasonal habitat in mega herbivores between different habitat types

(Bell 1971, McNaughton 1987) to fulfill their need has been well documented (Fuller 1960, Shackleton 1968, Shult 1972, Duncan 1975, Oven-Smith 1979, Krasinska *et al.* 1987).

4.2. LITERATURE REVIEW

Resource selection by animals is a hierarchical process of behavioral responses to particular environmental characteristics (Horne e*t al.* 2008). Mammals, especially the gregarious ones often respond to climatic changes and the resultant change in the habitat by altering herd size and pattern of habitat utilization (McNaughton 1985). Johnson (1980) defined habitat selection as a process in which an animal actually chooses the habitats, and use of habitat is said to be selective if habitat are used according to their availability. Analysis of habitat selection has been a common and important aspect of wildlife science (Alldredge and Ratti 1986). Information on food, water availability and food quality could yield a wealth of information on the status and trend of the animals' environment (Senft *et al.* 1987). Herbivores are known to favor habitat types or vegetation communities where they can maximize their nutrient intakes (Westoby 1974, Owen-Smith and Novellie 1982, Owen-Smith 1985). Dinerstein (1979) reported that the changes in the plant distribution and phenology affected ungulate food habits, energy budget, movement and seasonal distribution in Nepal. Seasonal movements of large herbivores between different habitat types have also been well studied (Bell 1971, McNaughton 1987, Van Beest *et al.* 2013). Seasonal habitat selection has been reported in several species (Shackleton 1968, Shult 1972, Duncan 1975, Oven-Smith 1979,

Krasinska *et al.* 1987, Dinerstein 2003) and it is an important consequence in ecology and conservation management (White *et al.* 2010)

Knowledge of the habitat selection of reintroduced species is crucial to the successful re-establishment of viable populations and effective conservation decision making (Yan *et al.* 2013). Therefore, in-depth investigation on the habitat selection of reintroduced species becomes crucial for making decisions about conservation and management planning (Seddon *et al.* 2007). The reintroduction of species is assumed to be more successful when they are less affected by human disturbance and have adapted to more suitable habitat (Oakleaf *et al.* 2006, Kiwan *et al.* 2008).

Schaller (1967) evaluated the vegetation maps of India with regard to distribution of gaur and concluded that the species is largely confined to evergreen, semi-evergreen, and moist deciduous forests but it also occurred in dry deciduous forests and thorn forests. Information on habitat use and resource selection of gaur was reported in a few Protected Areas in its entire distribution range. In Malaysia, Weigum (1972) observed that the abundance of grass, forbs and several browse species in agricultural lands are the most important factors influenced gaur distribution. Conry (1989) reported that gaur mostly preferred agricultural patches in Malaysia. In Western Ghats Landscape, India, Vairavel (1998) reported that gaur mostly preferred grassland. Imam and Kushwaha (2012) reported that gaur was largely found in mixed forest in Maharashtra. In Central Indian landscape (Pench Tiger Reserve), Sankar *et al.* (2000) reported that gaur largely used teak forest and miscellaneous forest, whereas Paliwal and Mathur (2012) reported that gaur in Tadoba-Andhari Tiger Reserve showed positive association with open forest.

Conry (1983) and Sankar *et al.* (2000) reported the habitat use of gaur based on radio-telemetry studies. In order to study the habitat use and resource selection of reintroduced gaur in Bandhavgarh, data on 27 radio-collared individuals was collected from March 2011 to February 2013 respectively.

4.3. METHODOLOGY

4.3.1. Habitat use

Both habitat use and habitat availability were assessed for individual radio-collared gaur locations in the study area (table 3.1.C chapter III). Second-order (selection of home ranges within a geographic range) and third-order (selection of habitats within established home ranges) resource selection functions (Johnson 1980) were used to evaluate the habitat preference use of reintroduced gaur. A multispectral (LANDSAT 7 ETM+), high-resolution (30 m) satellite imagery from the Global Land Cover Facility (GLCF) was used to generate the landuse/ landcover (LULC) map of the study area (figure 4.1). The overall habitat was classed into 11 different vegetation classes *viz* agriculture, bamboo forest, grassland, open-mixed forest, mixed forest, sal forest, riparian forest, habitation, plantation, rocky outcrop and scrubland.

1. **Agriculture land:** This is represented by irrigation and rain fed lands in Bandhavgarh, which breaks the connectivity between forest patches. The main crop includes wheat, corn flour, mustard and edible vegetables.

2. **Bamboo Forest:** The dense bamboo distribution occurs mainly in the National Park and also occurs in Panpatha WS. Some bamboo patch areas also occur along with mixed-

forest in the National Park. Due to strict protection measures and ban in forestry operations, the natural regeneration of bamboo occurs in all areas (Gopal 1989).

3. **Grassland:** Grassland patches occur in the valleys and along the streams (nalas) and also near the villages. The major grass species includes *Bothriochoa odorata*, *Chrysopongen fulous*, *Digitaria sanguinalis*, *Cynodon dactylon*, *Dichanthium annulatum*, *Saccharum spontaneum* and *Vetiveria zizanoides*.

4. **Open-Mixed Forest:** This occurs in patches near to the villages. The major tree species includes *Anogeissus pendula, Acacia catechu, Butea monosperma, Acacia leucophloea, Soymida febrifuga, Careya arborea, Maduca indica, Ziziphus xylopyrus,* and *Capparis deciduas*. The major shrub species found are *Holarrhena antidysenterica, Mimosa hamata* and *Woodfordia floribunda* and major climbers are *Bauhinia vahlii* and *Butea superb*. The major grass species are *Aristida depressa, Cymbopogon martini, Heteropogon centortus* and *Themeda quadrivalvis*.

5. **Mixed Forest:** This is distributed throughout the park and provides good canopy cover to the animals. Few patches of mixed forest also occur in riparian areas, where alluvial black clayey soil is present especially in Kallwah range. The major tree species includes *Anogeissus latifolia, Acacia catechu, Dendrocalamus strictus, Holarrhena antidysenterica, Terminalia tomentosa, Emblica officinalis, Pterocarpus marsupium, Lagerstroemia parviflora, Terminalia chebula, Kydia calycina, Salmalia malabarica, Dispyros melanoxylon* and *Ziziphus mauritiana*.

6. **Sal Forest:** Sal (*Shorea robusta*) patches in Bandhavgarh constitute 60 to 90 % of the top canopy. The associated species are *Anogeisus latifolia, Buchanania lanzan,*

Diospyros melanoxylan, Emblica officinalis, Kydia calcina, Madhuca indica and *T. arjun.*

7. **Riparian Forest**: This type is restricted to perennial and semi perennial rivers and streams. The canopy is dominated by species like *Dendrocalamus strictus, Ficus bengalensis, Ziziphus mauritiana, Butea monosperma, Syzygium cuminii and T. arjuna.*

8. **Habitation:** This is found in buffer area of Bandhavgarh TR, where livestock grazing is observed.

9. **Plantation:** Very few patches of plantation are found in buffer areas with species like *Shorea robusta, Dendrocalamus strictus* and *Tectona grandis*.

10. **Rocky Outcrop:** This is found in Bandhavgarh Fort and other hilly areas in the Sanctuary.

11. **Scrubland:** This is found in the fringes of National Park and in Sanctuary area in association with *Acacia catechu* and *Lantana camara*.

The analysis of gaur habitat use data was limited to seven different vegetation classes such as agriculture, bamboo forest, grassland, open mixed forest, mixed forest, sal forest and riparian forest within the study area comprising 1614.0 km^2 (table 4.1). The vegetation classes such as habitation, plantation, rocky outcrop and scrubland were dropped from the habitat use analysis since they are found in buffer area of the Tiger Reserve and falls outside the intensive area, used by gaur during the study period.

The Minimum Convex Polygon (MCP) home range estimates were used to describe the outer limits of each radio collared gaur movements. The 100 % MCP annual home range of individual radio collared gaur for the years 2011 and 2012 is given in

figure 4.2 and 4.3 respectively. To evaluate habitat use pattern of reintroduced gaur in Bandhavgarh, locations of individual radio collared gaur (n=27) were obtained for the years March 2011 to February 2013 which are spaced throughout the study area at different time intervals. The collected gaur locations (n=18,932) were plotted on the classified LISS-III imagery of Bandhavgarh.

Habitat use of reintroduced gaur in Bandhavgarh was estimated as the percent number of locations recorded in each habitat type as determined by Aebischer *et al.* (1993), White and Garrot (1990). The habitat availability for gaur in each gaur MCP home range, and the proportion of radio locations from radio collared gaur within each habitat type were calculated using the program Arc GIS 9.3 (ESRI 2006).

4.3.2. Compositional analysis

I used second-order resource selection function (Aebischer *et al.* 1993) to determine the habitat selection of reintroduced gaur, by plotting a minimum convex polygon around the 100% MCP home range of all the radio collared gaur. Compositional analysis (Aebischer *et al.* 1993) was followed to determine the habitat selection of reintroduced gaur, but with a modification that I assigned values based on the utilization distribution (UD) as described by Millspaugh *et al.* (2006). Use of each gaur individual was defined as the number of locations obtained in each land cover types (Millspaugh *et al.* 2006). Third-order resource selection was determined by using discrete-choice analysis (Cooper and Millspaugh 1999, 2001) at the home-range level. I used Resource Selection program for Windows (RSW; Leban 1999) to conduct the compositional analysis.

I estimated the season wise habitat use by reintroduced gaur, using compositional analysis (Aebischer *et al.* 1993), to understand whether any significant difference observed in habitat use across seasons. I also computed overall habitat use of gaur across gender to understand is there any specialization in habitat use. The utilized and availability data of habitats was evaluated using Bonferroni simultaneous confidence interval (New *et al.* 1974) for males because of inadequate number of samples (n=6) to perform compositional analysis (Aebischer *et al.* 1993).

Figure 4. 1. Landuse and landcover map of Bandhavgarh Tiger Reserve with 5 km buffer.

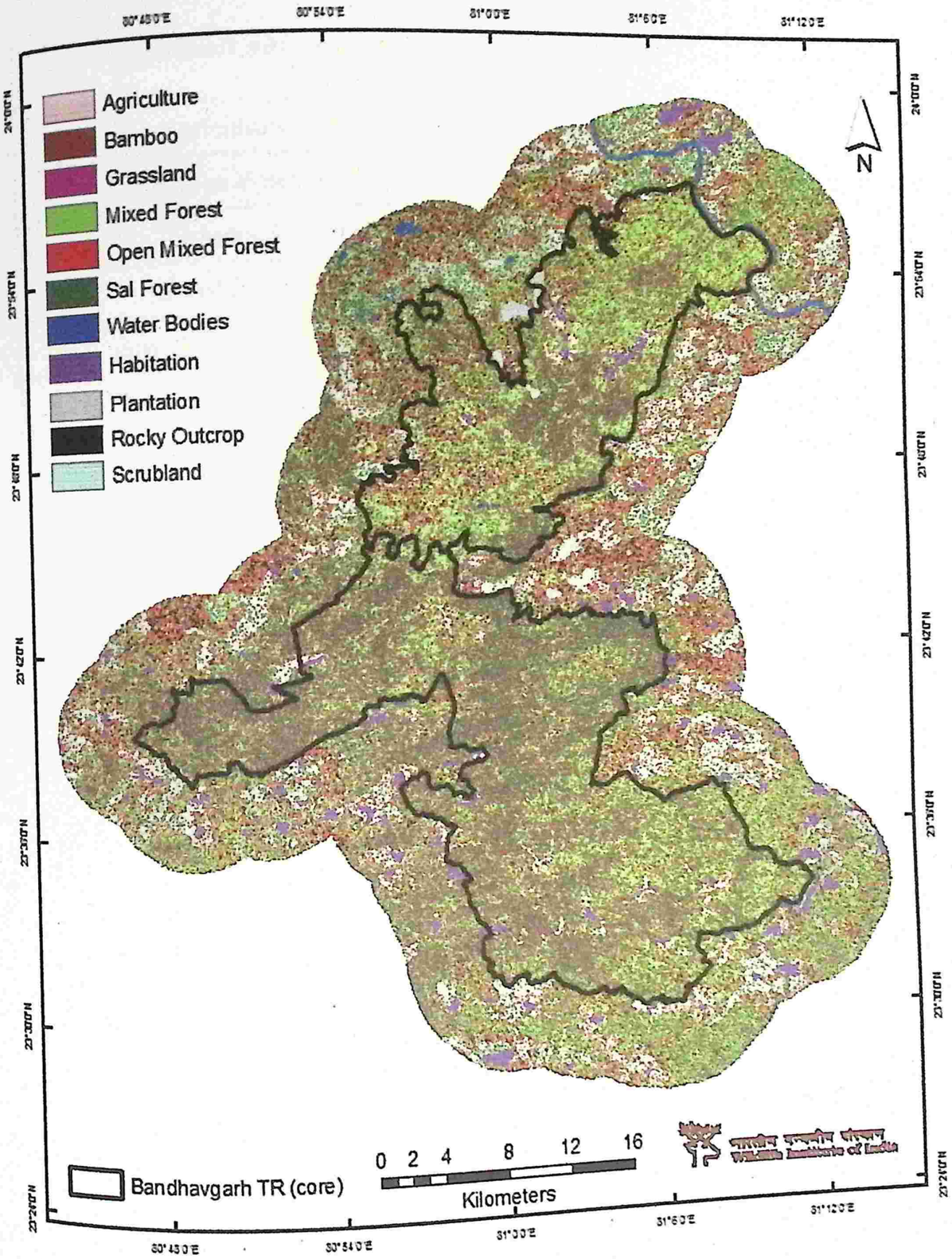


Table 4. 1. Available vegetation and land cover classes in Bandhavgarh Tiger Reserve.

Vegetation/Land cover type	Area (Km^2)	Percentage
Agriculture (Agr)	69.2	4.3
Bamboo Forest (Bam)	221.9	13.7
Grassland (Gra)	115.3	7.1
Mixed Forest (Mix)	706.9	43.8
Open-Mixed Forest (OMF)	196.4	12.2
Sal Forest (Sal)	231.1	14.3
Water Body (Riv)	73.2	4.5
	1614.0	100.0

Figure 4. 2. Home range of reintroduced gaur in Bandhavgrah Tiger Reserve (2011) as determined by Minimum Convex Polygon method (100% MCP).

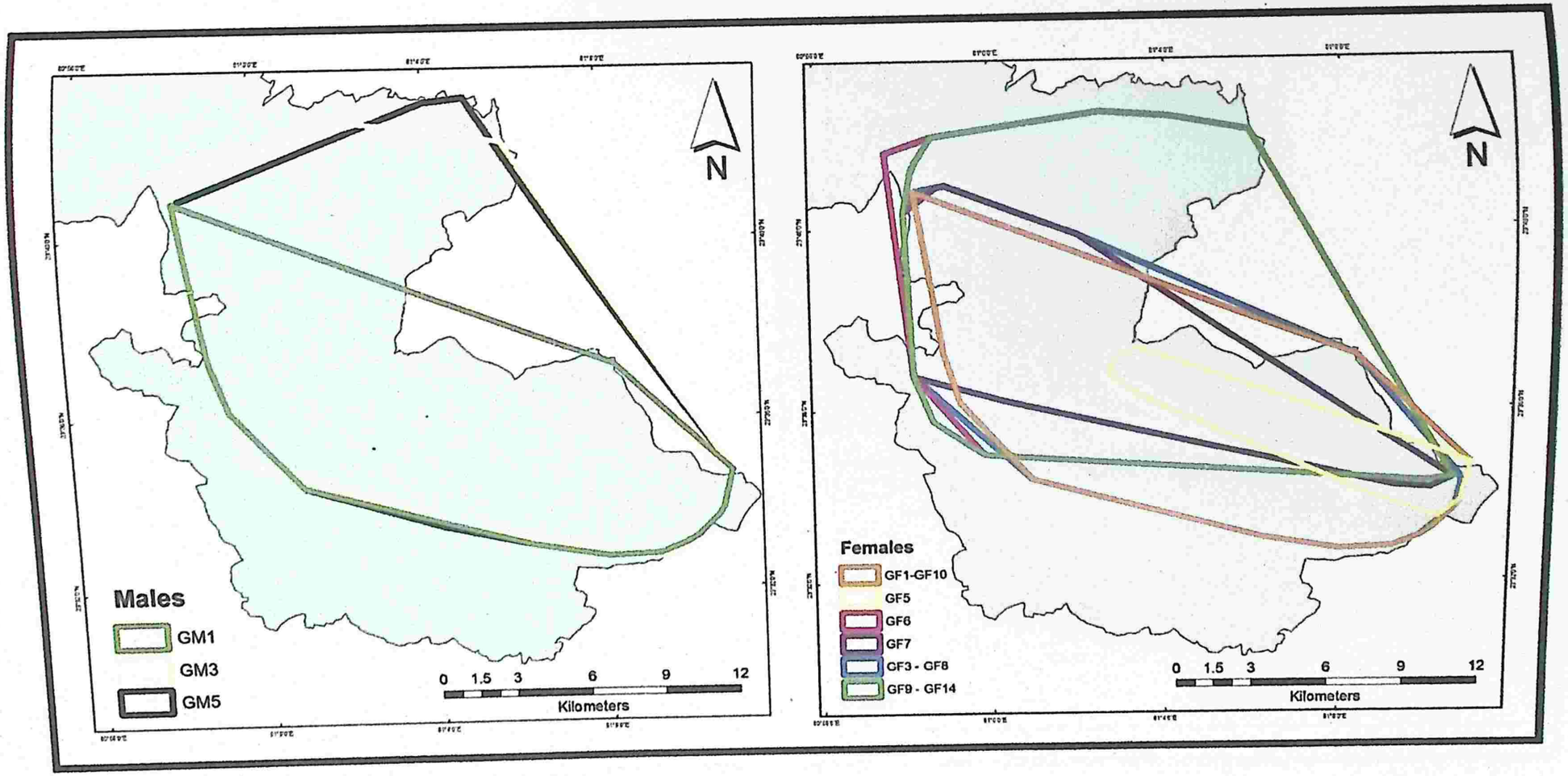
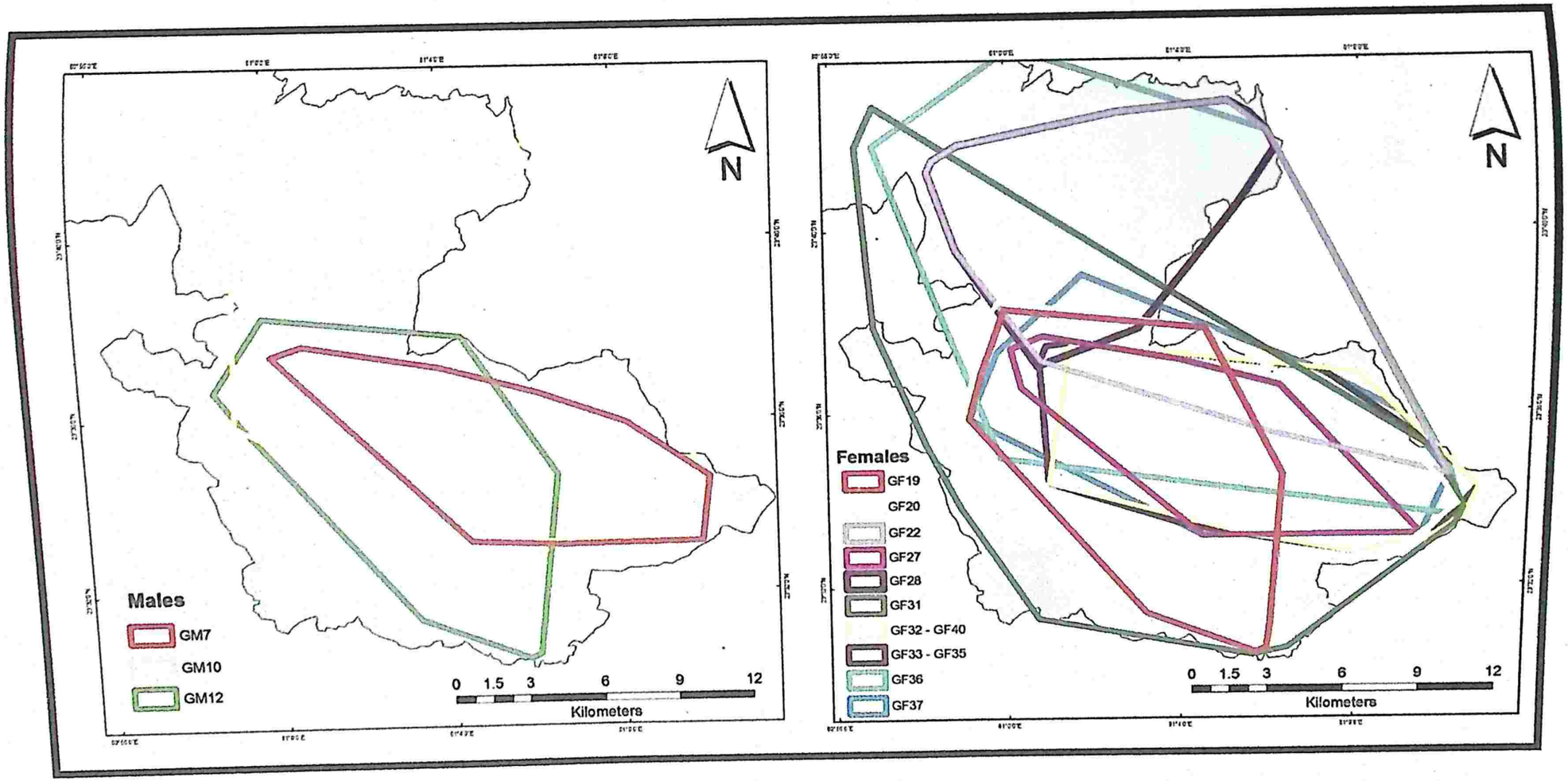


Figure 4. 3. Home range of reintroduced gaur in Bandhavgrah Tiger Reserve (2012) as determined by Minimum Convex Polygon method (100% MCP).



4.3.3. Resource use

4.3.3.1. Habitat characteristics

To evaluate the resource use of reintroduced gaur the overall individual gaur home range was plotted on the study area map having 3 Km^2 grids using Hawths tool in Arc GIS 9.3 (figure 4.4). Habitat classes (agriculture, bamboo forest, grassland, mixed forest, open mixed forest and riparian forest) were categorized by LULC map of Bandhavgargh Tiger Reserve (figure 4.1). Distance to saltlick area was calculated from each 3 Km^2 grid as the Euclidean distance in Arc GIS 9.3 (ESRI 2006). Normalized Difference Vegetation Index (NDVI) data was used to evaluate vegetation response and to determine changes in vegetation cover over time in the study area which was calculated for each 3 Km^2 grid.

4.3.3.2. Vegetation characteristic features

To evaluate the vegetation characteristic features in gaur home range in the study area, a total of 483 vegetation plots were laid across different seasons (summer, monsoon and winter) during 2011 and 2012. To obtain information on habitat use, total of 363 vegetation plots were laid in all gaur utilized locations. Additional parameters were enumerated in all vegetation plots such as tree density in 10 m circular plot, shrub density in 5 m circular plot and percentage availability of ground cover (grass, herb, bare soil, leaf litter and rock) in 1m plot by line intercept method (LI) (Canfield 1941). To obtain information on habitat availability for gaur, random vegetation plots (n=120), as described above were laid in gaur home range during 2011-2012 and parameters such as tree densityin 10 m, shrub density in 5 m circular plot and percentage of ground cover by

LI method (Canfield 1941) were enumerated in each vegetation plot. Using these vegetation plot data I extracted the density of tree, shrub, canopy cover and ground layer (grass, herb, bare soil, leaf litter and rock) for each grid.

4.3.3.3. Hydrological data

From the existing data on rivers (seasonal and perennial) and waterhole (natural and artificial), the distance to water from each gaur location was calculated as the Euclidean distance of the centroid of each 3 Km^2 grid cell to the nearest water source in Arc GIS 9.3 (ESRI 2006). The artificial water holes and perennial rivers were assumed to carry water throughout the year, whereas the natural water holes and seasonal rivers were assumed to have water only during monsoon and winter.

4.3.3.4. Topography

A 30 m resolution Shuttle Radar Topography Mission (SRTM) elevation model (Jarvis *et al.* 2008) was used to represent the surface elevation across Bandhavgarh TR, which ranges from 320 m to 811 m. The mean elevation (Ele) for each 3 Km^2 grid cell was extracted in Spatial Analyst tool in Arc GIS 9.3 (ESRI 2006) and used for analyses.

4.3.3.5. Anthropogenic pressure

To assess the anthropogenic pressure in gaur home range, Euclidean distances to the nearest human settlements (core area villages) and roads were calculated in Arc GIS 9.3 (ESRI 2006) for each 3 Km^2 grid cell. The percentage wood cutting, lopping, grazing, grass cutting and weed abundance in 10 m circular plot were quantified and percentage of each variable was enumerated for each 3 Km^2 grid cell. To study the predator response by

tiger, tiger scats (n= 398) and kill (n= 199) location was collected from the study area during March 2011 to February 2013 and the encounter rate was extracted from each 3 Km^2 grid cell.

4.3.3.6. Data analysis

Based on the information extracted from each grid (table 4.2) the 3rd order resource selection (Johnson 1980) by the reintroduced gaur was evaluated. The 3rd order resource selection (resource selection of individual gaur within its home range) by the reintroduced gaur was estimated using Generalized Linear Mixed effect Model (GLMM). All the resource parameters (habitat variables, topographical, hydrological, vegetation characteristics, anthropogenic pressure and predator response) were chosen as fixed effects and gaur locations were chosen as the random effect for GLMM models.

4.3.3.7. Correlations between environmental variables

To evaluate the correlation structure between the environmental variables used in the analyses, I calculated Spearman correlation coefficients between each pair of environmental variables that were chosen as the random effect for GLMM models. The correlation between all (n= 26) the variables where generally low, where only few (n= 14) variables were selected for modeling the habitat (table 4.3).

4.3.3.8. Gaur location data

Data on gaur habitat use was obtained from 27 radio collars (21 females and 6 males; Chapter III, table 3.1.C) deployed on reintroduced gaur. The two year data (March 2011– February 2013) resulted in collection of 18,932 gaur locations. Although

the collars provided locations of individual gaur, in order to analyze data on a population level (combining all the individuals), I used type II design as described by Manly *et al.* (1993).

4.3.3.9. Model selection

To model the habitat use of reintroduced gaur in Bandhavgarh, I standardized the variables to z-scores to provide equal weightage in multiple regression analyses (Zar 2010). I used SPSS (version 17.0 INC, Chicago, USA) to study the generalized linear-mixed-effect models (GLMM), which is applied on habitat studies of wildlife (Mladenoff *et al.* 1999). I used the value of each utilization distribution grid cell (n=189) (figure 4.4) as the response variable in the model and digital elevation model, distance to water, distance to village, grass cover, tree percentage, tree lopping percentage, weed and tiger presence as fixed effects with individual gaur as a dependent variable on the intercept to account variation among reintroduced gaur.

To determine the best fit model of resource selection (Burnham and Anderson 2002), from the list (table 4.4) of prior models, I developed a global model including the selected variables. The best fit model was ranked smallest value by Akaike's Information Criterion (AIC) (Akaike 1973) and considered competing low Delta AIC value (<5) from the top ranked model (Rotenberry *et al.* 2006). This avoids over fitting while retaining most information regarding habitat selection models (Calenge *et al.* 2008).

Table 4. 2. List of variables used in generalized linear model analysis.

Variables	Variables type	Source
Habitat	Agriculture	Land use and land cover from Landset -7 - ETM + data (source: Panna Lal 2007)
	Bamboo Forest	
	Grassland	
	Mixed Forest	
	Open Mixed Forest	
	Sal Forest	
	Water body	
	Distance to Saltlick	Field data
	NDVI	Wildlife Institute of India (source: Panna Lal 2007)
Topographical	Dem	Wildlife Institute of India (source: Panna Lal 2007)
Hydrological	Distance to water	
Vegetation information	Grass	Vegetation plot data (2011-2013)
	Herb	
	Litter	
	Bare soil	
	Rock	
	Tree percentage	
	Shrub percentage	
Anthropogenic	Distance to road	Wildlife Institute of India (source: Panna Lal 2007)
	Distance to village	
	Tree cutting percentage	Vegetation plot data (2011-2013)
	Tree lopping percentage	
	Livestock dung percentage	
	Grass grazing by livestock	
	Weeds	
Predator presence	Tiger scat	Field data (February 2011- March 2013)

Figure 4. 4. Overall gaur home range plotted in 3 Km^2 grids over Bandhavgarh Tiger Reserve.

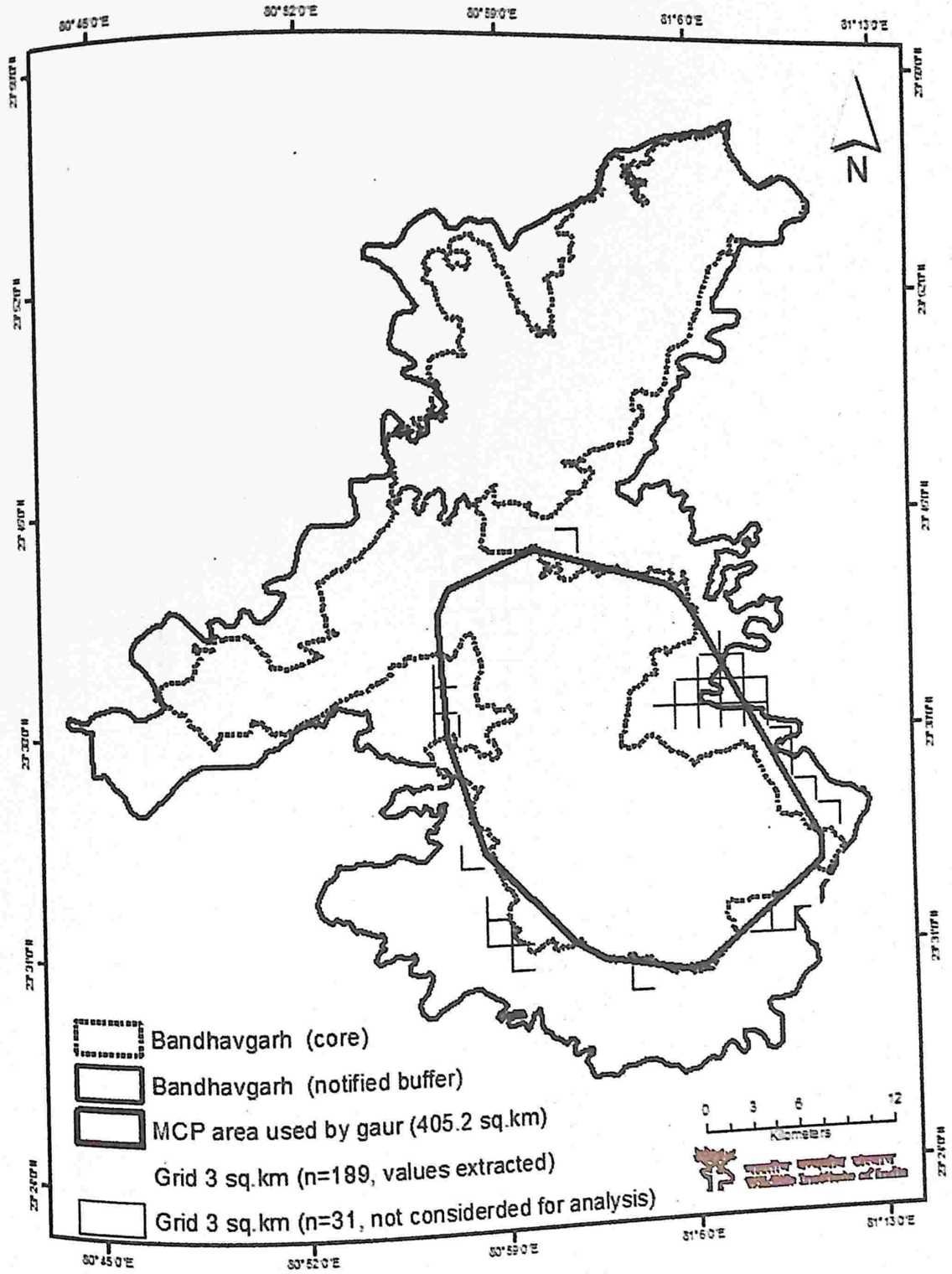


Table 4. 3. Correlation between the environmental variables used in the analysis. Values depict the Pearson correlation coefficients.

Variables	*Sal forest*	*Mixed forest*	*Bamboo forest*	*Grassland*	Riparian forest	Open Mixed Forest	Digital elevation model	Distance to water	Distance to village	Grass cover	% tree	% tree lopping	% weed	Tiger presence
Sal forest	*1*	*.060*	*.870***	*.490***	-.303**	-.260**	.389**	-.090	.004	-.049	.128	.321**	-.285**	-.120
Mixed forest	.060	1	.287**	.694**	.721**	.568**	.036	-.049	-.126	.116	.013	.050	-.144	.075
Bamboo forest	.870**	.287**	1	.746**	-.197*	-.208**	.355**	-.059	-.176*	.036	.087	.237**	-.260**	-.078
Grassland	.490**	.694**	.746**	1	.138	.039	.238**	-.059	-.186*	.120	-.028	.079	-.216**	.058
Riparian forest	-.303**	.721**	-.197*	.138	1	.896**	-.097	-.078	-.029	.110	.023	.005	.005	.051
Open Mixed Forest	-.260**	.568**	-.208**	.039	.896**	1	-.041	-.081	-.040	.089	-.010	.011	-.042	.071
Digital elevation model	.389**	.036	.355**	.238**	-.097	-.041	1	-.044	.071	-.125	.168*	.154	-.167*	.095
Distance to water	-.090	-.049	-.059	-.059	-.078	-.081	-.044	1	.078	.059	-.039	.039	.038	.011
Distance to village	.004	-.126	-.176*	-.186*	-.029	-.040	.071	.078	1	-.125	.058	.095	-.071	-.098
Grass cover	-.049	.116	.036	.120	.110	.089	-.125	.059	-.125	1	-.384**	-.026	.036	.031
% tree	.128	.013	.087	-.028	.023	-.010	.168*	-.039	.058	-.384**	1	.215**	-.036	-.067
% tree lopping	.321**	.050	.237**	.079	.005	.011	.154	.039	.095	-.026	.215**	1	-.488**	-.014
% weed	-.285**	-.144	-.260**	-.216**	.005	-.042	-.167*	.038	-.071	.036	-.036	-.488**	1	-.051
Tiger presence	-.120	.075	-.078	.058	.051	.071	.095	.011	-.098	.031	-.067	-.014	-.051	1

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

Table 4. 4. Resource selection of reintroduced gaur using Generalized Linear Mixed Model (GLMM) analysis in Bandhavgarh Tiger Reserve (2011-2013).

Model	Model structure in GLMM	Hypothesis of the model for Reintroduced gaur
1	(sal+ mix+ bam+ grass+ rip+ dist.vil)	Habitat + Disturbance (Habitat use varied in avoidance of village)
2	(sal+ mix+ bam+ grass+ rip+ dist.wat)	Habitat (Habitat use closely related to water with their habitat)
3	(sal+ mix+ bam+ grass+ rip+ dist.wat+ dist.vil)	Habitat + Disturbance (Habitat use varied by avoiding the village closely related to presence of water)
4	(sal+ mix+ bam+ grass+ rip+ dist.wat+ tre.den+ tre.lop)	Habitat + Vegetation+ Disturbance (Habitat use varied by distance to water along with tree percentage and disturbance (tree lopping))
5	(sal+ mix+ bam+ grass+ rip+ omf+ dist.wat+ dem+ dist.vil)	Habitat + Terrain + Disturbance (Habitat use varied across terrain along with distance to village and water and influence of open mixed forest)
6	(sal+ mix+ bam+ grass+ rip+ gra.cov+ tre.den+ tre.lop+ weed)	Habitat + Vegetation+ Disturbance (Habitat use varied by grass cover along with the tree percentage and disturbance (tree lopping, presence of weed))
7	(sal+ mix+ bam+ grass+ rip+ dist.wat+ dist.vil+ tre.den+ tre.lop)	Habitat + Disturbance (Habitat use varied by distance to village and water along with the tree percentage and disturbance (tree lopping))

8	*(sal+ mix+ bam+ grass+ rip+ gras.cov+ dist.wat+ tre.den+ dist.vil+ tre.lop)*	Habitat + Vegetation + Disturbance (Habitat use varied by grass cover, distance to village and water along with tree percentage and disturbance (tree lopping))
9	(sal+ mix+ bam+ grass+ rip+ dist.wat+ dem+ tre.den+ dist.vil+ tre.lop+ weed)	Habitat + Terrain + Vegetation + Disturbance (Habitat use varied by terrain distance to village and water, along with tree percentage and disturbance (tree lopping and weed))
10	(sal+ mix+ bam+ grass+ rip+ omf+ dist.wat+ dem+ dist.vil+ tre.den+ tre.lop+ weed)	Habitat + Terrain + Disturbance (Habitat use varied by open mixed forest, terrain along with distance to village and water with the presence of tree percentage and disturbance (tree lopping and weed))
11	(sal+ mix+ bam+ grass+ rip+ omf+ dist.wat+ dem+ tre.den+ gras.cov+ dist.vil+ tre.lop+ weed)	Habitat + Terrain + Vegetation + Disturbance (Habitat use varied across open mixed forest, terrain along with grass cover and disturbance (tree lopping and weed))
12	(sal+ mix+ bam+ grass+ rip+ omf+ dist.wat+ dem+ tre.den +gras.cov + dist.vil+ tre.lop+ weed+ tiger)	Habitat + terrain+ Vegetation + Disturbance+ Predator Habitat use varied across terrain, tree percentage, distance to water and village and disturbance (tree lopping, weed) along with the presence of tiger
13	(sal+ mix+ bam+ grass+ rip +dem)	Habitat + Terrain Habitat use varied across different terrain

sal-sal forest; **mix**-mixed forest; **bam**-bamboo forest; **grass**-grassland; **rip**-riparian forest; **omf**-open mixed forest; **dem**-digital elevation model; **dist.wat**-distance to water; **dist.vil**-distance to village; **gras.cov**-grass cover; **tre.den**-tree density; **tre.lop**-tree lopping; **tiger**-scat and kill encounter rate.

4.4. RESULTS

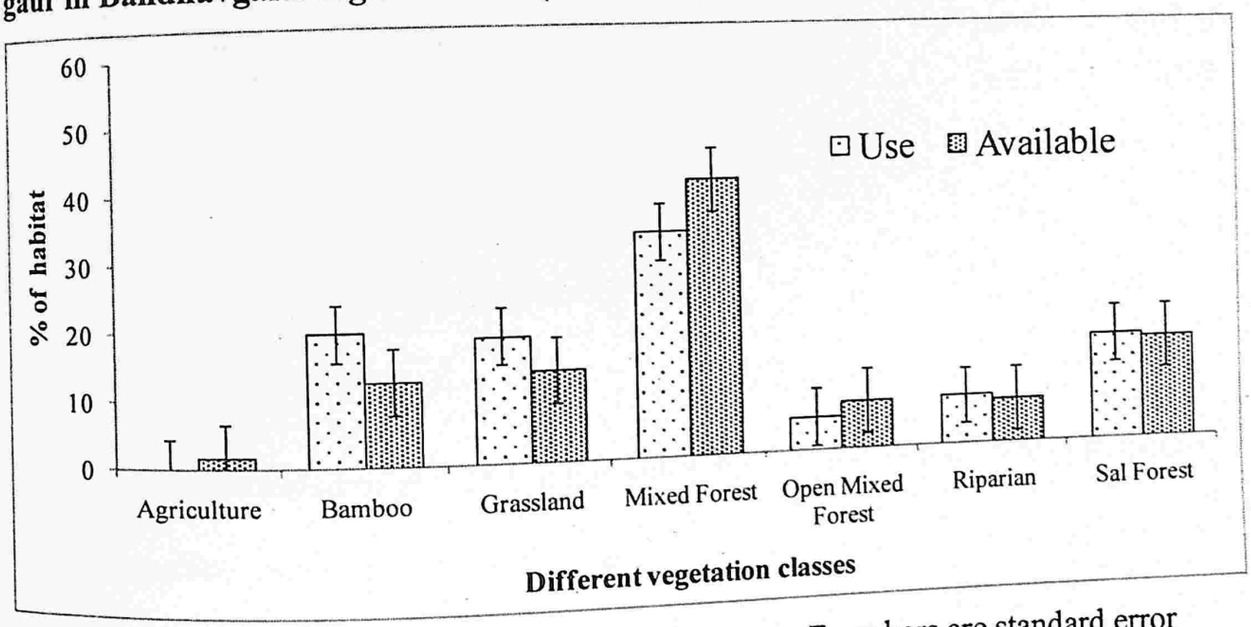
4.4.1. Habitat use

4.4.1.1. Overall habitat use by reintroduced gaur in Bandhavgarh

Compositional analysis

Gaur largely used mixed forest followed by bamboo and grassland whereas sal forest and riparian forests were used according to its availability within their entire home range (figure 4.5).

Figure 4. 5. Use and availability of different vegetation types by the reintroduced gaur in Bandhavgarh Tiger Reserve (2011-2013).



Error bars are standard error

I transferred the available (total study area joining all the MCP) habitat compositions and utilized (kernel utilization distribution of each animal) habitat compositions to log-ratios y_0 and y using the proportion of Sal forest as the dominant habitat and then the difference $d = y - y_0$ was calculated (table 4.5). The residual matrix R_1

is the matrix of mean-corrected sums of square and cross products calculated from *d*; R_2 is the matrix of raw sums of squares and cross-products calculated from *d* as follows:

R_1	330.316	11.1245	-18.4499	35.1498	148.6066	77.5395
	11.1245	5.428	3.4568	3.8646	5.9364	4.1602
	-18.4499	3.4568	8.1029	-0.007	-13.2603	-1.0771
	35.1498	3.8646	-0.007	8.7294	17.5249	20.0296
	148.6066	5.9364	-13.2603	17.5249	107.5666	27.1598
	77.5395	4.1602	-1.0771	20.0296	27.1598	70.881
R_2	1226.481	-48.3431	-54.0654	72.4576	200.8236	33.5228
	-48.3431	9.3742	5.8201	1.3889	2.4713	7.0811
	-54.0654	5.8201	9.5184	-1.4897	-15.3356	0.6722
	72.4576	1.3889	-1.4897	10.2826	19.6988	18.1971
	200.8236	2.4713	-15.3356	19.6988	110.6091	24.595
	33.5228	7.0811	0.6722	18.1971	24.595	73.0429

Then, $\lambda = R_1 / R_2$

$R_1 = 10507064.1699$

$R_2 = 169872472.7866$

$= 10507064.1699/169872472.7866$

$\lambda = 0.0619$

The comparasion of $\chi^2 = 75.1$ value with 6 degrees of freedom, yielded P- value < 0.001. Inspection of *d* (table 4.5) showed that its distribution is not multivariate normal, however the level of significance obtained by randomization was $P < 0.001$. This clearly showed that the habitat used by reintroduced gaur in Bandhavgarh was non-random.

To rank the habitat types in order of use, a matrix of mean and standard error of all the habitat types (Agr, Bam, Gras, Mix, OMF, Rip, and Sal) was calculated for each radio collared gaur (n=27) and the significance of the ratio was assessed by randomization tests (table 4.6).

Table 4. 5. Log-ratios of utilized habitat (y) and differences in log-ratios of utilized habitat ($d = y - y_0$) used to evaluate gaur habitat use based on kernel home ranges of each radio-collared gaur data with availability in the total study area of Bandhavgarh Tiger Reserve.

	Log-ratios utilized habitat (y)						Difference in log-ratios ($d = y - y_0$) *					
Individual Gaur	**Agr/Sal**	**Bam/Sal**	**Gras/Sal**	**Mix/Sal**	**OMF/Sal**	**Rip/Sal**	**Agr/Sal**	**Bam/Sal**	**Gras/Sal**	**Mix/Sal**	**OMF/Sal**	**Rip/Sal**
1	-1.7746	0.1026	-0.1385	1.3071	-0.5842	-0.7533	-7.4903	0.816	0.7881	-0.0899	-0.6192	-0.1475
2	-1.7886	0.0969	-0.144	1.3018	-0.5687	-0.7533	-7.4809	0.8063	0.7918	-0.0848	-0.7671	-0.0847
3	-9.5067	-0.4708	1.1992	0.523	-9.5067	-2.7738	5.5252	0.7005	-1.509	0.793	8.6089	1.2671
4	-3.1772	-0.2427	-0.6819	0.4104	-1.2584	-1.5952	-1.383	0.2422	0.0928	-0.4584	0.2728	-0.057
5	-3.4064	-0.4567	0.3183	-0.9168	-2.3041	-10.2414	1.2788	0.542	0.2081	1.71	1.063	8.2508
6	-1.8271	0.0314	-0.2581	1.1633	-0.7067	-0.8753	-2.8958	0.8769	0.6885	-0.0159	-0.4753	-0.1944
7	-2.998	-0.2367	-0.6462	0.4647	-1.2244	-1.5442	-2.2806	0.31	0.2428	-0.1131	0.4411	0.1368
8	-1.7639	0.0966	-0.1264	1.3057	-0.6729	-0.7819	-7.4905	0.8172	0.5789	-0.0833	-0.6299	0.0507
9	-3.3893	-0.2424	-0.663	0.449	-1.2461	-1.5546	-0.7632	0.1977	0.1126	-0.5898	0.4468	-0.1243
10	-1.7894	0.0968	-0.1724	1.301	-0.5935	-0.7541	-7.519	0.7695	0.7278	-0.1324	-0.6534	-0.2211
11	-2.8227	-0.2012	-0.4402	0.8324	-0.9545	-1.2021	-7.0554	0.2909	0.2924	-0.4692	0.1531	-0.143
12	-1.9808	-0.0418	-0.3562	1.0931	-0.7879	-0.943	-2.6233	1.0079	1.0413	0.204	-0.5316	-0.0209
13	-1.9062	-0.1547	0.1879	1.3636	-0.3293	-0.1797	-8.0282	-0.6302	-0.204	-0.8416	-1.0037	-1.732
14	-1.7052	-0.1539	0.1581	1.3688	-0.4089	-0.2552	-8.2394	-0.4797	-0.2941	-0.81	-0.682	-0.8273
15	-1.881	0.2384	0.4659	1.3102	0.2553	-0.333	-8.1592	-0.476	-0.6645	-1.1026	-1.8402	-0.7939
16	-1.8816	-0.2942	-0.0564	1.2056	-0.534	-0.4569	-7.4094	0.8685	0.7244	-0.1639	-0.0264	0.6161
17	-4.5589	-0.5904	-0.3478	0.4922	-0.5042	-0.8021	-5.2601	0.5667	-0.4293	0.2774	-0.8199	-1.2463
18	-1.7275	-0.1937	0.1093	1.2862	-0.4507	-0.3355	-8.0069	-0.2225	-0.4329	-0.2832	-2.527	0.1269
19	-1.2551	-0.0278	0.163	1.5278	-0.4314	-0.3408	-8.3673	0.3481	0.4861	-0.8561	-2.4343	-0.644
20	-1.5008	-0.2965	-0.0822	1.2442	-0.6801	-0.5094	-8.366	0.4607	-0.0747	-0.7285	-2.43	-0.2273
21	-1.1408	-0.0803	0.1144	1.5009	-0.5084	-0.4013	-8.4445	0.4754	0.5849	-0.9273	-2.6971	-0.1072
22	-3.197	-0.6059	-0.4059	0.5104	-0.8639	-1.0257	-6.768	0.3628	0.1262	-0.2167	-0.1613	0.268
23	-1.7254	-0.073	0.134	1.3721	-0.3917	-0.3008	-7.8783	0.2061	0.1633	-0.5734	-0.8716	0.0914
24	-1.8103	-0.3373	-0.0669	1.0931	-0.5031	-0.4786	-7.538	0.7181	0.7269	0.0333	-0.2456	0.2935
25	-1.524	-0.0548	0.1333	1.4069	-0.5223	-0.3796	-7.8112	0.4987	0.4209	-0.2028	-0.1018	0.1482
26	-2.2965	-0.3248	-0.2488	0.9268	-0.7992	-0.6919	-7.1701	0.5951	0.6832	-0.008	0.258	0.5446
27	-2.0247	-0.4122	-0.0926	1.1031	-0.6732	-0.5044	-7.9271	-0.3464	0.3098	-0.7426	-0.7898	-0.3436

Agr-Agriculture; Bam-Bamboo Forest; **Gras**-Grassland; **Mix**- Mixed Forest; **OMF**-Open Mixed Forest; **Rip**-Riparian Forest; **Sal**-Sal Forest.

*The log-ratios describing availability (y_0), calculated by dividing the proportions of different vegetation types (Agr, Bam, Gra, Mix, OMP, Rip) in the total study area by that of sal forest.

Table 4. 6. Ranking matrix of means and standard errors obtained by averaging each habitat type for all the radio collared gaur in Bandhavgarh Tiger Reserve.

Resource	Agr*	Bam*	Gra*	Mix*	OMF*	Rip*	Sal*
Agr *		-6.1435 ± 0 .6683	-5.9902 ± 0.7312	-5.5213 ± 0.6187	-5.4255 ± 0.4476	-5.9419 ± 0.594	-5.7612 ± 0.686
Bam*	6.1435 ± 0.6683		0.1533 ± 0.0971	0.6221 ± 0.0957	0.718 ± 0.3795	0.2016 ± 0.3193	0.3823 ± 0.0879
Gra*	5.9902 ± 0.7312	-0.1533 ± 0.0971		0.4688 ± 0.1549	0.5646 ± 0.4501	0.0482 ± 0.3448	0.229 ± 0.1074
Mix*	5.5213 ± 0.6187	-0.6221 ± 0.0957	-0.4688 ± 0.1549		0.0958 ± 0.3402	-0.4206 ± 0.2537	-0.2398 ± 0.1115
OMF*	5.4255 ± 0.4476	-0.718 ± 0.3795	-0.5646 ± 0.4501	-0.0958 ± 0.3402		-0.5164 ± 0.4244	-0.3357 ± 0.3914
Rip*	5.9419 ± 0.594	-0.2016 ± 0.3193	-0.0482 ± 0.3448	0.4206 ± 0.2537	0.5164 ± 0.4244		0.1807 ± 0.3297
Sal*	5.7612 ± 0.686	-0.3823 ± 0.0879	-0.229 ± 0.1074	0.2398 ± 0.1115	0.3357 ± 0.3914	-0.1807 ± 0.3297	

Agr-Agriculture; Bam-Bamboo Forest; Gras-Grassland; Mix- Mixed Forest; OMF-Open Mixed Forest; Rip-Riparian Forest; Sal-Sal Forest; *Means ± SE.

A simplified matrix (table 4.7) ranked overall habitat use of reintroduced gaur in Bandhavgarh TR in the following order: bamboo forest > grassland > riparian> sal forest > mixed forest > open mixed forest > agriculture land ($\chi^2 = 75.1$, df = 6, $P < 0.001$). There was no detectable difference in use of the two top-ranking habitats (bamboo forest, grassland), but each showed significantly greater use than the remaining habitat types. The implication is that rank 4 and 3 are inter changeable (riparian and sal), but that there is a clear split between them and the lower ranks.

Table 4. 7. Simplified ranking matrix of reintroduced gaur in Bandhavgarh Tiger Reserve, based on comparing the UD of radio collared locations for each gaur in each vegetation class with proportion to total available habitat classes. Each mean element in the matrix was replaced by its sign A (-3) represents significant deviation from random at $p < 0.05$.

Resource	Agriculture	Bamboo forest	Grassland	Mixed forest	Open mixed forest	Riparian	Sal forest	Rank
Agriculture		-3	-3	-3	-3	-3	-3	0
Bamboo forest	3		1	3	1	1	3	6
Grassland	3	-1		3	1	1	3	5
Mixed forest	3	-3	-3		1	-1	-3	2
Open mixed forest	3	-1	-1	-1		-1	-1	1
Riparian	3	-1	-1	1	1		1	4
Sal forest	3	-3	-3	3	1	-1		3

4.4.1.2. Seasonal habitat use of reintroduced gaur in Bandhavgarh Tiger Reserve

In summer and monsoon gaur largely used grassland and riparian forest and in winter bamboo forest was largely used followed by mixed forest, whereas the sal forest was used according to its availability in all the seasons within their entire home range (figure 4.6). The habitat use of gaur in summer was in the following order: grassland > sal forest > bamboo forest > riparian = open-mixed forest > mixed forest > agriculture land (χ^2 = 148.4, df = 6, P-value < 0.001) (table 4.8.A). The habitat use of gaur in monsoon was in the following order: bamboo forest > grassland > riparian > sal forest = mixed forest > open-mixed forest > agriculture land (χ^2 = 158.2, df = 6, P < 0.001) (table 4.8.B). The habitat use of gaur in winter was in the following order: bamboo forest > mixed forest > riparian = sal forest > grassland > open-mixed forest > agriculture land (χ^2 = 136.1, df = 6, P < 0.001) (table 4.8.C).

Figure 4. 6. Use and availability of different vegetation types by the reintroduced gaur across seasons in Bandhavgarh Tiger Reserve (2011-2013).

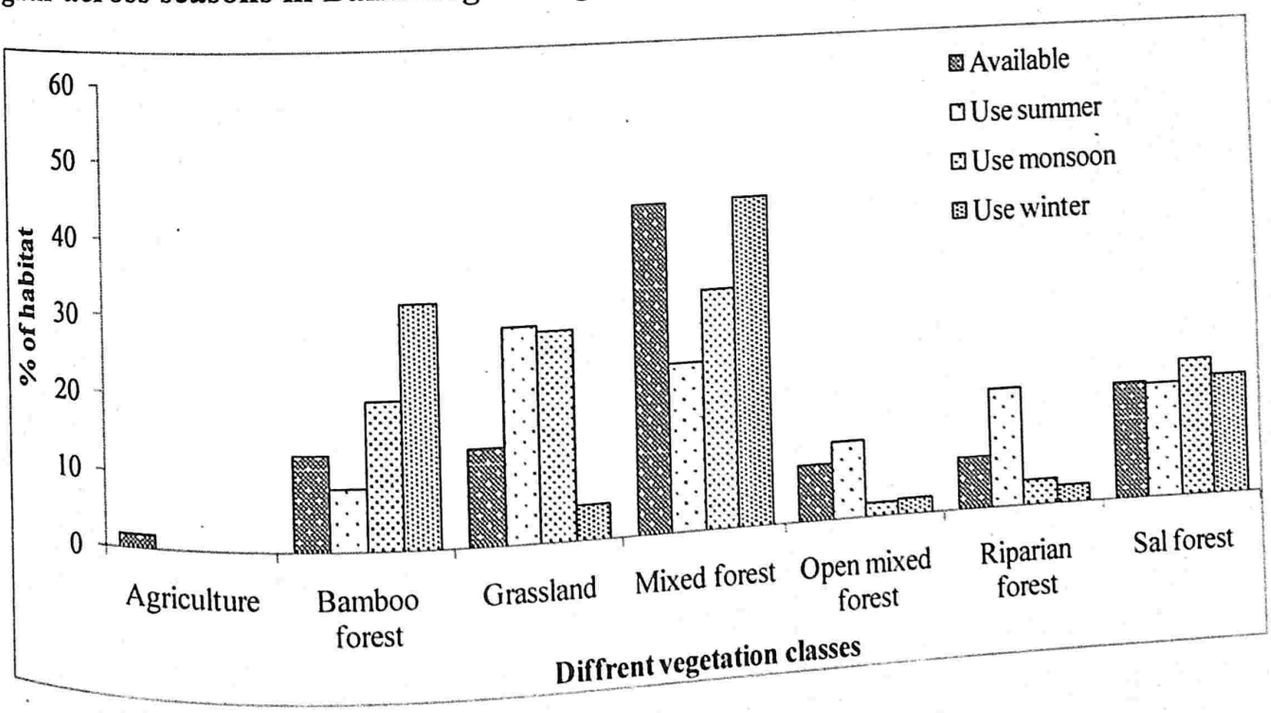


Table 4. 8. Simplified ranking matrix of reintroduced gaur in Bandhavgarh Tiger Reserve, based on comparing the UD of radio collared locations for each gaur in each vegetation class with proportion to total available habitat classes. Each mean element in the matrix was replaced by its sign (-3) represents significant deviation from random at $p < 0.05$.

A. Summer

Resource	Agriculture	Bamboo forest	Grassland	Mixed forest	Open mixed forest	Riparian	Sal forest	Rank
Agriculture		-3	-3	-3	-1	-1	-3	0
Bamboo forest	3		-3	3	3	3	-3	4
Grassland	3	3		3	3	3	3	6
Mixed forest	3	-3	-3		3	-1	-3	1
Open mixed forest	1	-3	-3	-3		1	-3	2
Riparian	1	-3	1	-1	1		-3	3
Sal forest	3	3	-3	3	3	3		5

B. Monsoon

Resource	Agriculture	Bamboo forest	Grassland	Mixed forest	Open mixed forest	Riparian	Sal forest	Rank
Agriculture		-3	-1	-1	-1	-1	-1	0
Bamboo forest	3		3	3	3	3	3	6
Grassland	1	-3		3	3	1	1	5
Mixed forest	1	-3	-3		1	-1	-3	2
Open mixed forest	1	-3	-3	-1		-3	-3	1
Riparian	1	-3	1	1	3		-1	4
Sal forest	1	-3	-1	3	3	1		3

C. Winter

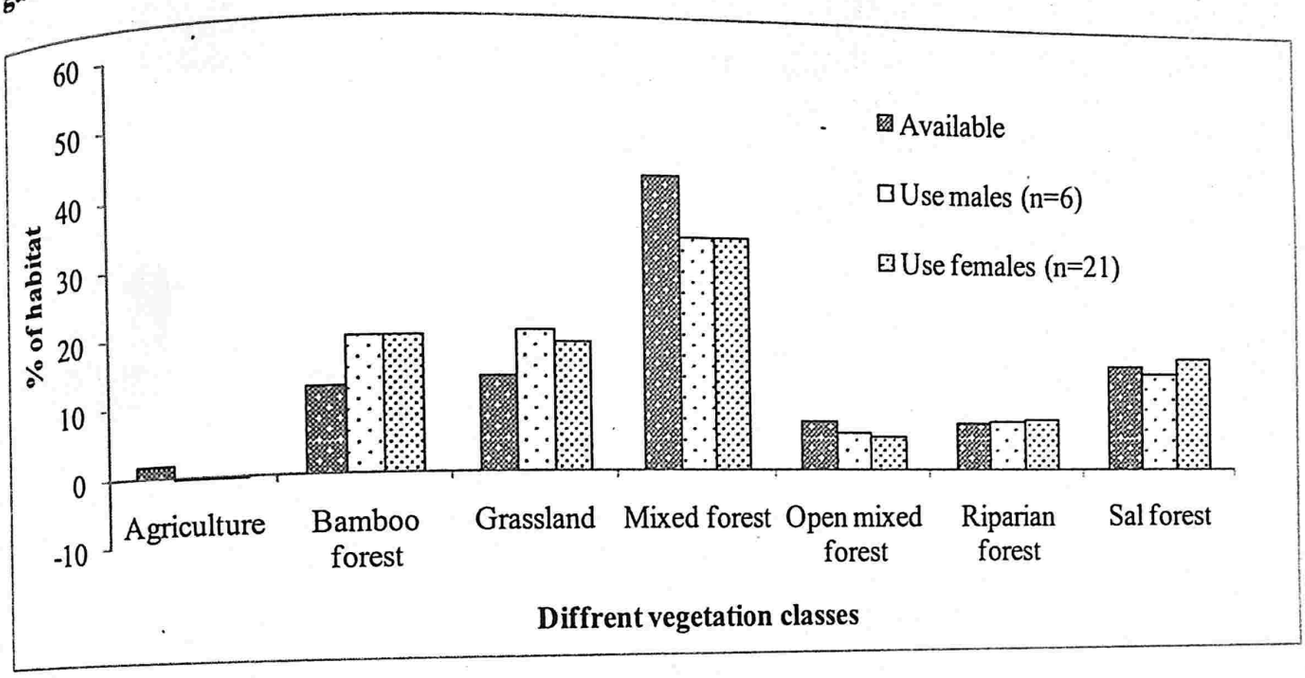
Resource	Agriculture	Bamboo forest	Grassland	Mixed forest	Open mixed forest	Riparian	Sal forest	Rank
Agriculture		-3	-3	-3	3	-3	-3	1
Bamboo forest	3		3	3	3	3	3	6
Grassland	3	-3		-1	3	-1	-1	2
Mixed forest	3	-3	1		3	1	1	5
Open mixed forest	-3	-3	-3	-3		-3	-3	0
Riparian	3	-3	1	-1	3		1	4
Sal forest	3	-3	1	-1	3	-1		3

4.4.1.3. Habitat use of males and females in Bandhavgarh Tiger Reserve

Gaur males and females largely used bamboo forest and grassland, whereas the sal forest, riparian forest and open-mixed forest were used according to its availability within their home range (figure 4.7). Overall, gaur males used grassland ($P < 0.001$) and bamboo forest ($P < 0.001$) more than their availability, whereas riparian ($P < 0.001$), sal forest ($P < 0.001$) and open-mixed forest ($P < 0.001$) were used according to their availabilities. Mixed forest ($P < 0.001$) and agriculture land ($P < 0.001$) were least preferred ($\chi^2 = 84.3$, $df = 6$, $P < 0.001$). The index of selection in the habitat use by gaur male was ranked as: grassland > bamboo forest > riparian = sal forest = open-mixed forest = mixed forest > agriculture land (table 4.9).

In order to assess the habitat use of reintroduced gaur females (n=21), comparison of utilized and availability data was evaluated using compositional analysis. The habitat use of gaur females was in the following order: bamboo forest > grassland > riparian > sal forest > mixed forest > open-mixed forest > agriculture land ($\chi^2 = 53.1$, $df = 6$, $P < 0.001$) (table 4.10).

Figure 4. 7. Use and availability of different vegetation types by the reintroduced gaur males and females in Bandhavgarh Tiger Reserve (2011-2013).



n= number of individuals.

Table 4. 9. Preference of different vegetation classes by gaur males in Bandhavgarh Tiger Reserve as shown by Bonferroni simultaneous confidence interval analysis.

Vegetation classes	Proportion		Proportion available	Preference	Significance
	Lower	Upper			
Agriculture	0	0.0176	0.019	Used less than availability	
Bamboo forest	0.1518	0.2384	0.1265	Used more than availability	(P < 0.001)
Grassland	0.1569	0.2445	0.1207	Used more than availability	(P < 0.001)
Mixed forest	0.2792	0.382	0.4443	Used less than availability	(P < 0.05)
Open mixed forest	0.0297	0.0793	0.0711	Used in proportion to availability	
Riparian	0.0418	0.0974	0.0706	Used in proportion to availability	
Sal forest	0.1034	0.1796	0.1478	Used in proportion to availability	

Table 4. 10. Simplified ranking matrix of reintroduced gaur females in Bandhavgarh Tiger Reserve, based on comparing the UD of radio collared locations for each gaur in each vegetation class with proportion to total available habitat classes. Each mean element in the matrix was replaced by its sign (-3) represents significant deviation from random at $p < 0.05$.

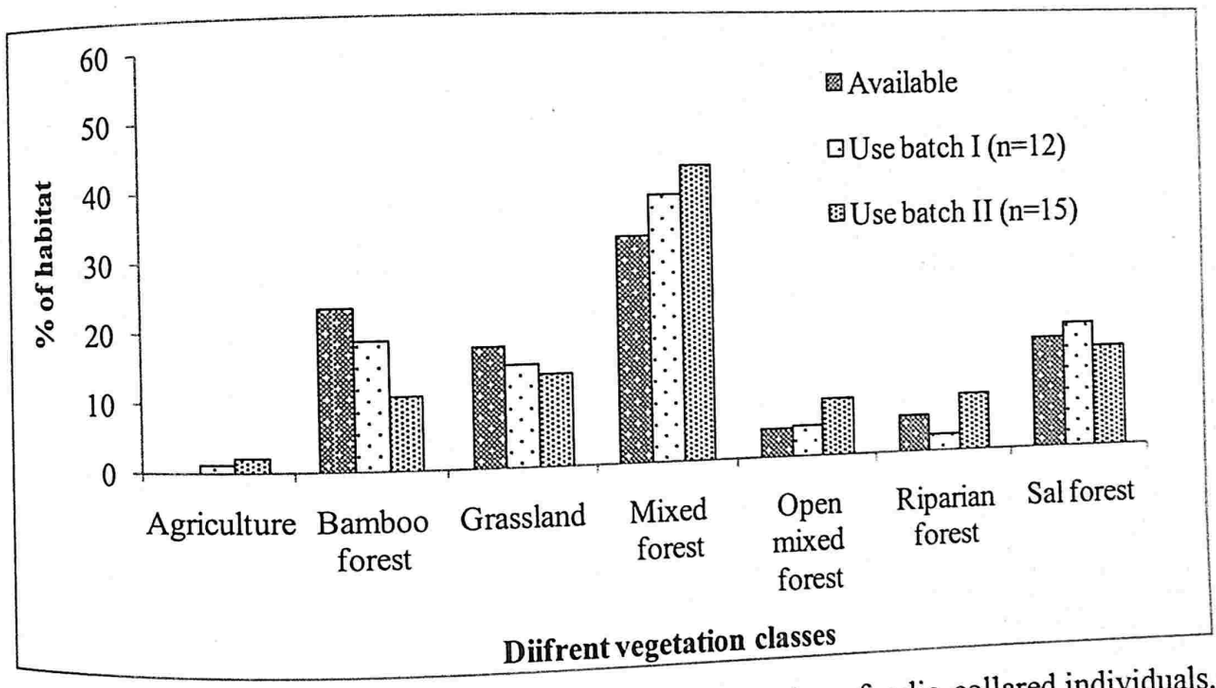
Resource	Agriculture	Bamboo forest	Grassland	Mixed forest	Open mixed forest	Riparian	Sal forest	Rank
Agriculture		-3	-3	-3	-3	-3	-3	0
Bamboo forest	3		1	3	1	1	3	6
Grassland	3	-1		3	1	1	1	5
Mixed forest	3	-3	-3		1	-1	-3	2
Open mixed forest	3	-1	-1	-1		-1	-1	1
Riparian	3	-1	-1	1	1		1	4
Sal forest	3	-3	-1	3	1	-1		3

4.4.1.4. Habitat use of gaur batch wise (Batch I and Batch II)

The reintroduced gaur in batch-I, largely used mixed forest followed by sal forest whereas the gaur in batch-II largely used mixed forest followed by open mixed forest within their entire home range (figure 4.8). Compositional analysis was performed for both the reintroduced gaur batches. In order to rank the habitat classes according to the order of use, a matrix of the mean and standard error (SE) of seven habitats was calculated for radio collared gaur, batch wise (individuals: 12 in batch-I and 15 in batch-II). Results of compositional analysis showed that the overall habitat use of reintroduced

gaur in 2011 was in the following order: bamboo forest > grassland = sal forest > riparian = mixed forest > open-mixed forest > agriculture land ($\chi^2 = 88.5$, df = 6, $P < 0.001$) (table 4.11). The overall habitat use of reintroduced gaur in 2012 was in the following order: bamboo forest > grassland > riparian = sal forest = open- mixed forest > mixed forest > agriculture land ($\chi^2 = 92.6$, df= 6, $P < 0.001$) (table 4.12).

Figure 4. 8. Use and availability of different vegetation types by the reintroduced gaur in Bandhavgarh Tiger Reserve during 2011 and 2012.



n = number of radio-collared individuals.

Table 4. 11. Simplified ranking matrix of reintroduced gaur in 2011, based on comparing the UD of radio collared locations of radio-collared gaur (n=12) in each vegetation class with proportion to total available habitat classes (n=7). Each mean element in the matrix was replaced by its sign (-3) represents significant deviation from random at $p < 0.05$.

Resource	Agriculture	Bamboo forest	Grassland	Mixed forest	Open mixed forest	Riparian	Sal forest	Rank
Agriculture		-3	-3	-3	1	-3	-3	1
Bamboo forest	3		3	3	3	3	3	6
Grassland	3	-3		3	3	3	3	5
Mixed forest	3	-3	-3		3	1	-1	3
Open mixed forest	-1	-3	-3	-3		-3	-3	0
Riparian	3	-3	-3	-1	3		-3	2
Sal forest	3	-3	-3	1	3	3		4

Table 4. 12. Simplified ranking matrix of reintroduced gaur in 2012, based on comparing the UD of radio collared locations of radio-collared gaur (n=15) in each vegetation class with proportion to total available habitat classes (n=7). Each mean element in the matrix was replaced by its sign (-3) represents significant deviation from random at $p < 0.05$.

Resource	Agriculture	Bamboo forest	Grassland	Mixed forest	Open mixed forest	Riparian	Sal forest	Rank
Agriculture		-3	-3	-3	-3	-3	-3	0
Bamboo forest	3		3	3	3	3	3	6
Grassland	3	-3		3	3	1	1	5
Mixed forest	3	-3	-3		3	-3	-3	2
Open mixed forest	3	-3	-3	-3		-3	-3	1
Riparian	3	-3	-1	3	3		1	4
Sal forest	3	-3	-1	3	3	-1		3

4.4.2. Resource selection

I evaluated 12 GLMM third order resource selection model for the reintroduced gaur in the study area. The top ranked model was observed to be the habitat variables with distance to village, based on the lowest AIC value (427.99) (table 4.13). Model with habitat variables + distance to water + distance to village + tree percentage + tree lopping was second ranked (AIC = 428.32) (table 4.15). The model with habitat variables and distance to water + distance to village and the terrain with the presence of open-mixed of forest was marginally selected in the habitat (AIC = 431.52). Habitat variables along with terrain did not play any significant role in the habitat selection of reintroduced gaur. The reintroduced gaur intensively selected the habitat (mixed forest, bamboo, grassland, sal, riparian and open mixed forest) with distance to village, tree density, weed abundance and grass cover which had positive influence in selection of resources, whereas the digital elevation model, distance to water and tree lopping had a negative influence with regard to habitat selection (table 4.14).

Table 4. 13. Generalized linear-mixed models for resource selection by reintroduced gaur in Bandhavgarh, based on Akaike's Information Criterion (AIC).

Model number	Models in GLMM	K	AIC	Delta AIC
1	(sal+ mix+ bam+ grass+ rip+ dist.vil)	6	427.99	0*
7	(sal+ mix+ bam+ grass+ rip+ dist.wat+ dist.vil+ tre.den+ tre.lop)	9	428.32	0.33*
3	(sal+ mix+ bam+ grass+ rip+ dist.wat+ dist.vil)	7	428.52	0.53*
8	(sal+ mix+ bam+ grass+ rip+ gras.cov+ dist.wat+ tre.den+ dist.vil+ tre.lop)	10	430.28	2.29*
9	(sal+ mix+ bam+ grass+ rip+ dist.wat+ dem+ tre.den+ dist.vil+ tre.lop+ weed)	11	431.16	3.17*
5	(sal+ mix+ bam+ grass+ rip+ omf+ dist.wat+ dem + dist.vil)	9	431.52	3.53*
10	(sal+ mix+ bam+ grass+ rip+ omf+ dist.wat+ dem+ dist.vil+ tre.den+ tre.lop+ weed)	12	433.15	5.16
11	(sal+ mix+ bam+ grass+ rip+ omf+ dist.wat+ dem+ tre.den+ gras.cov+ dist.vil+ tre.lop+ weed)	13	435.15	7.16
2	(sal+ mix+ bam+ grass+ rip+ dist.wat)	6	436.16	8.17
4	(sal+ mix+ bam+ grass+ rip+ dist.wat+ tre.den+ tre.lop)	8	436.19	8.2
13	(sal+ mix+ bam+ grass+ rip +dem)	6	436.34	8.35
12	(sal+ mix+ bam+ grass+ rip+ omf+ dist.wat+ dem+ tre.den +gras.cov + dist.vil+ tre.lop+ weed+ tiger)	14	437.12	9.13
6	(sal+ mix+ bam+ grass+ rip+ gra.cov+ tre.den+ tre.lop+ weed)	9	438.94	10.95

K- number of parameters; **AIC**- Akaike's Information Criterion; **sal**-sal forest; **mix**-mixed forest; **bam**-bamboo forest; **grass**-grassland; **rip**-riparian forest; **omf**-open mixed forest; **dem**-digital elevation model; **dist.wat**-distance to water; **dist.vil**-distance to village; **gras.cov**-grass cover; **tre.den**-tree density; **tre.lop**-tree lopping; **tiger**-scat and kill encounter rate;

* - selected model based on low Delta AIC value (<5) (Rotenberry *et al.* 2006).

Table 4. 14. Model averaged and parameters estimated β coefficient values for the top models of resource selection by reintroduced gaur in Bandhavgarh.

S. No	Parameter	Abbreviation	Beta coefficient	SE	95 % Confidence Interval	
					Lower CI	Upper CI
1	Mixed	mix	0.495	0.214	0.251	1.008
2	Bamboo	bam	0.487	0.252	0.044	0.990
3	Grassland	grass	0.382	0.198	0.006	0.767
4	Distance to village	dist.vil	0.285	0.015	0.107	0.462
6	Tree density	tre.den	0.146	0.038	0.020	0.294
5	Sal	sal	0.126	0.195	0.056	0.709
7	Riparian	rip	0.037	0.166	0.003	0.289
8	Weed	weed	0.005	0.015	-0.024	0.034
9	Grass cover	gras.cov	0.003	0.013	-0.024	0.029
10	Open Mixed Forest	omf	0.002	0.028	-0.054	0.056
11	DEM	dem	-0.026	0.026	-0.077	0.025
12	Distance to water	dist.wat	-0.072	0.015	-0.197	0.146
13	Tree loping	tre.lop	-0.078	0.041	-0.158	0.002

4.5. DISCUSSION

4.5.1. Habitat use

The ultimate measure and the success of reintroducing animals in which the establishment of self-sustaining populations in the new habitat and the response to the environmental factors play a key factor (Scott and Carpenter 1987, Seddon 2005). To study animal's natural habitat selection, where radio-telemetry provides significant data on which the space use of animals can be studied better (Aebischer *et al.* 1993). In the present study, the gaur habitat use was evaluated using radio telemetry. The resource selection analysis was done by a second order compositional analysis (Vanak and Gompper 2010) and also related to rank based method (Johnson 1980). Though the habitat use of gaur was reported in a few Protected Areas in its distribution range (Weigum 1972, Conry 1989, Vairavel 1998, Sankar *et al.* 2000) the present study gave more detailed account on their habitat preference.

In Bandhavgarh Tiger Reserve, the mixed forest which is the dominated vegetation type constituted 43.8 % of the total area but the use of bamboo forest followed by grassland by gaur showed higher ranking in habitat use. The reintroduced gaur preferred bamboo forest because of the availability of green shoots throughout the year in the study area. Also the bamboo forest provides better shelter/resting areas as compared to other available habitat types in Bandhavgarh. Grasslands provide much higher biomass of forbs and grasses (Song and Li 1994) and hence it might have influenced gaur to prefer grasslands in the study area. In general, herbivores select grassland where there can forage freely in large number (Treydte *et al.* 2013). Whereas in Chihao region, China, the

reintroduced Eld's deer selected shrubs, because of the grassland habitat were mostly distributed (Yan *et al.* 2013).

Gaur in Parambikulam National Park largely used grasslands as compared to other available habitats (Vairavel 1998). In Pench Tiger Reserve the use of teak dominant forest and miscellaneous forest by gaur was significantly higher than other habitat types (Sankar *et al.* 2000). Free-ranging large herbivores have to make many foraging decisions at different resolution levels (Senft *et al.* 1987, Stuth 1991) resulting in a foraging strategy that meets the specific nutrient and energy requirements of large herbivores that ultimately determines differential habitat selection by them.

Gaur used sal forest and riparian forest according to their availability and this is attributed to the distribution and availability of these habitats in study area. The observed less habitat use of open- mixed forest by gaur in Bandhavgarh may be attributed to lack of food resources and water availability in this habitat. In general, mega herbivores avoid the habitat that does not have good forage with nutrition level (Roever *et al.*2013). Agricultural land was least used by gaur because of anthropogenic disturbance in Bandhavgarh. Whereas Conry (1989) reported that gaur in Leper valley Malaysia, largely used secondary forest habitats and agriculture lands.

In the present study, the use of different habitat types by gaur did not vary much across seasons, although the grassland in summer and bamboo forest in monsoon and winter were preferred. Gaur is a generalist feeder but prefers to browse in dry season and predominantly graze in monsoon and winter (Schaller 1967, Vairavel 1998, Sankar *et al.* 2000, Ashokkumar *et al.* 2010). Schaller (1967) observed that gaur frequently moved to

meadows and the low-lying forested areas during most part of the year except monsoon when the animals moved up and dispersed into the hills. Lad (1992) reported that gaur moved to higher elevations during monsoon so as to escape the flies which are abundant during the rainy season in the grasslands and low-lying areas of the forest. Gaur in Pench Tiger Reserve showed similar results as that of to Schaller's observation in Kanha Tiger Reserve regarding the use of forested areas by gaur across seasons (Sankar *et al.* 2000). Use of different habitat types across seasons by European Bison as per availability of food plants has been reported (Gill 1967, Krasinski *et al.* 1987, Krasinski and Krasinska 1992). Forest meadows were preferred by American bison (Shackleton 1968). The mega-herbivores show high selectivity of habitat and food species across seasons (McNaughton and Georgiadis 1986). Though there was high range overlap (87.6 %) observed between males and females in the batch I and batch II reintroduced gaur population, the use of habitat did not vary significantly amongst them and the reason for the same is attributed to the wide spread availability of habitat types and availability of food plants, in Bandhavgarh.

4.5.2. Resource selection of gaur

Understanding and accurately predicting the spatial patterns of habitat use by animals is important for ecological research, biodiversity conservation and ecosystem management. However, this understanding is complicated by the effects of spatial scale, because the scale of analysis affects the quantification of species–environment relationships (De Knegt *et al.* 2011). It is essential to understand the factors that influence resource selection of reintroduced animals, in the new habitat in which it may provide

important conservation aspect in relationship with the species and environment (Conard 2009). It is a known fact that gaur being an herbivore is an important member of food chain and ultimately an indicator of ecosystem quality (Schaller 1967). Habitat depletion is one of the important factors, resulting in isolated gaur population (Imam and Kushwaha 2012).

In the present study, the significant avoidance of agriculture land ($p < 0.05$) and distance to village inside the Protected Area by reintroduced gaur had a strong influence and found to be an important factor in determining their resource selection. Mega herbivores avoid the human dominated areas in their habitat selection (Harris *et al.* 2008, Roever *et al.* 2013). Generally, herbivores avoid or less prefer human dominated area because of less forage availability (Rowland *et al.* 2000, McCorquodale 2003, Anderson *et al.* 2005). The disturbance to the natural habitat by human activity is one of the major factors responsible for decline of wildlife populations and the deterioration of their natural habitats (Vitousek *et al.* 1997). As the present finding in which the reintroduced gaur significantly avoided the village areas in the habitat selection was similar to that which has been reported in reintroduced Eld's deer in Datian Reserve, China (Song and Li 1994, Zeng *et al.* 2005), mega herbivores in savanna landscape, Africa (Schielly *et al.* 2009) and ungulates in Central Africa (Evans 2008).

The pattern of resource selection of reintroduced gaur, next to the prior model (table 4.15; model 7 and 3) determined the preference for water and tree percentage and avoidance for lopped areas. The mammalian species distribution is determined by the presence of water in deciduous forest (Schaller 1972, Kruuk 1972). Large herbivores need to drink water every day (Van Aarde *et al.* 2008). Early naturalists also reported that

gaur is an obligatory feeder which needs to drink water every day (Brander 1923, Hubback 1937, Schaller 1967, Conry 1989). Gaur in Parambikulam National Park was observed drinking water even in noon hours (Vairavel 1998). Most of the forest patches which are used by gaur in the present study, had perennial rivers (chakardara, damnar, sukipatiya-jurna, badbada, akadava-chachai, magdhi, janad, cheachpur, kumuruva), and artificial water holes built in the form of check dams (rajbehra, jhurjur, devkanni, kalleah, kumuruvaha boda, sharadhadra, mahaman, beheraha, dudhighati, kallwah, bedhria) by the park management. In the present study, it was found that during daytime the presence of gaur was close to water sources. Thus, the wide spread of water source and the presence of gaur are closely associated in the study area. The result of the present study confirm findings of an earlier report in study area, in which feeding sites of gaur were located within a radius of 3 to 4 Km from water source (Lad and Gopal 1992).

Gaur significantly avoided lopped areas during the present study. *Shorea robusta, Anogessus latifolia, Buchanania lanzan, Butea monosperma, Chlorozylon swetiena, Terminalia chebula, Ziziphus mauritiana* and *Dendro calamus strictus* were lopped inside the Tiger Reserve by villagers for various purposes (fuel, timber, house construction and as livestock fodder) to fulfill their regular needs. All these species were utilized by reintroduced gaur in Bandhavgarh (Sankar *et al.* 2013). Wild animals are sensitive to their habitat selection (Arroyo and Razin 2006), where the impact of human disturbance changes behavior and adaptation of the species which leads in shift towards areas containing less disturbance and less human interaction (LaGory 1987, Trombulak and Frissell 2000). The continuous anthropogenic pressure in the study area may create disturbance to the habitat and affects the gaur movement patterns.

It is a well known fact that the presence or absence of a species in a particular habitat may indicate the richness of the area (Zarri *et al.* 2008). The presence of weed (*lantana camara, Xanthium strumarium, Cassia tora, Parthenium hysterophorus* and *Sida acuta*) result in depletion of available food plants of gaur in the study area. Similar findings were reported from Mudumalai (Ashokkumar *et al.* 2012). The presence of weed species reduces the growth of tall grasses in forest area (Subramanian *et al.* 2001).

It is necessary to understand the selection of habitat and survival of the reintroduced population in human dominated landscape (Sanderson *et al.* 2002, Armstrong and Seddon 2008). Village relocation plays a major role in reducing the anthropogenic pressures on the forest area and is highly beneficial to wild animals (Karant and Karant 2007).

During the study period two villages (Kallwah and Kumuruwah) from the core area were successfully relocated in June 2011 and subsequently gaur was found using the relocated sites in August 2011. This significantly provides vital space for the relocated gaur, which can set an example to expedite relocation of the remaining villages (n=13) from the core area. Ecologically, reducing the anthropogenic pressure from the forest areas provide ample space for animals to fulfill their regular needs (Frid and Dill 2002). Resources (water and forage) play a key role in determining the habitat overlap between gaur and livestock where both the species co-exist (Sankar *et al.* 2000). Gaur are highly susceptible to transmission of infections from domestic livestock (Vairavel 1998), and there are many records of populations of gaur succumbing to epidemics of foot and mouth disease (FMD), rinderpest and anthrax in various parts of its distributional range (Schaller 1967, Sankar *et al.* 2000, Ashokkumar 2010a). At present there are 13 villages

inside the Tiger Reserve and 96 villages in the periphery of 5 Km radius from the Park boundary. The estimated livestock population is 6000 inside the Tiger Reserve, whereas more than 1, 00,000 livestock are found in the peripheral areas. There is a need to implement a wide vaccination program (foot and mouth disease (FMD), rinderpest and anthrax) for the domestic livestock in and around the Tiger Reserve, to prevent the transmission of livestock diseases to gaur in the study area.

Chapter V

Group size and composition of reintroduced gaur

CHAPTER V

GROUP SIZE AND COMPOSITION OF REINTRODUCED GAUR

5.1. INTRODUCTION

Understanding behavioral and demographic aspects of wild animals facilitates population monitoring and effective conservation planning (Caughley 1977, Khan *et al.* 1995). Most of the mammalian species often live in groups, the size of which constitutes the simplest and most basic elements of their social organization (Eisenberg 1966, Crook *et al.* 1976). Group size varies widely within and between species (Altman 1974, Geist 1974, Jarman 1974, Clutton-Brock and Harvey 1977, Rodman 1981). Herbivores commonly experience considerable seasonal, climatic and spatial variations in resource availability in arid and semi-arid tropical environments (Illius and O'Connor 2000). Ungulate group sizes tend to be larger in open habitats than in habitats with relatively dense vegetation which serves as cover (Lagory 1986), reflecting varied anti-predator strategies in different habitat types (Hamilton 1971, Estes 1974, Hirth 1977). This variation needs to be explained if it is to be considered as a part of the species adaptation to its environment (Southwell 1984). Minimizing predation risk is arguably the most general and important benefit in group formation and cooperative defense (Pulliam and Caraco 1984, Krause and Ruxton 2002), especially in large herbivores such as bovids and cervids (Jarman 1974, Kaufmann 1974, Hirth 1977, Brashares and Arcese 2002). The distribution of group sizes in a population can be viewed as the outcome of decisions

made by multiple individuals evaluating the benefits and costs of being in groups of different sizes (Alexander 1974, Pulliam and Caraco 1984).

5.2. REVIEW OF LITERATURE

Group size is generally considered as a fundamental attribute of the social organization of many ungulates (Jarman 1974, Clutton-Brock and Harvey 1978, Shankar Raman 1997). The main cost of grouping in mega herbivores is generally considered to be feeding competition (Terborgh and Janson 1986). Animals in groups may have to forage over larger areas and spend more time in search of food than solitary animals (Wrangham *et al.* 1993). Jarman (1974) reported that food quality, abundance, and dispersion varies with cover density and may at least partially influence the group size of herbivores. Understanding the population trend in wild ungulates and their group composition, becomes crucial in changing habitat structure, resource abundance and distribution (Lott 1991, Brashares and Arcese 2002, Alexander 1974, Pulliam and Caraco 1984). Studying the group size in mega herbivores influence the shape and magnitude of the relationship between group sizes (Wrangham *et al.* 1993).

Very few studies have reported the trend in gaur population based on long-term and systematic monitoring in its entire distribution range. Most of the available information on the group size and composition of gaur are limited to Protected Areas (PAs) (Ashokkumar 2004). Except a few long term ecological studies on gaur population in Parambikulam, Pench and Mudumalai (Vairavel 1998, Sankar *et al.* 2000, Ashokkumar 2010), no detailed study on gaur group size and population structure has

been reported in India. However, several short observations on group size and sex ratios of gaur were available from PAs such as Kanha Tiger Reserve (Schaller 1967, Belsare *et al.* 1984), Palamu Reserved Forest (Sahai 1977), Gorumara Wildlife Sanctuary (Guin and Pal 1980), Periyar Tiger Reserve (Nair *et al.* 1985), Pench Bison Wildlife Sanctuary (Dwivedi and Shukla 1988), Berijam Reserve (Moorthy 1989), Indira Gandhi National Park (Prabakar 1992), Shevaroy Hills (Kannan 2001), Mudumalai Tiger Reserve (Kumar *et al.* 2004, Ashokkumar *et al.* 2010b, Ramesh *et al.* 2012), Parsa Wildlife Reserve (Chetri 2006), and in Trishna Wildlife Sanctuary (Dasguptha *et al.* 2008). Lad and Gopal (1992) reported the status of gaur in Bandhavgarh Tiger Reserve before the local extermination.

5.3. METHODOLOGY

Information on group size and age-sex composition of gaur was collected based on direct observation during March 2011 to February 2013 covering all seasons *viz* summer, monsoon and winter in the study area. In total, 50 gaur were re-introduced in Bandhavgarh Tiger Reserve (three adult males, 11 sub-adult males, 13 adult females, 21 sub-adult females, and two female yearlings). Details of age and sex composition of gaur selected for translocation in Kanha Tiger Reserve, Madhya Pradesh are given in table 5.1. The reintroduced gaur was classified based on the criteria mentioned below following Schaller (1967) and Krishnan (1972).

1. **Adult Male (AM)** – Sooty black in colour, enlarged dewlap, well diverged and fully converged tip of horn, prominent dorsal ridge and rotary movement of hump while walking (> 5 years)
2. **Sub Adult Male (SAM)** – Black or brownish black in colour, prominent dewlap, the diverged horn about to converge.
3. **Adult Female (AF)** – Dark brown and closer to black in colour, non-prominent dewlap, less diverged but not converged horn, less prominent dorsal ridge.
4. **Sub Adult Female (SAF)** - Brownish black in colour (more black in thoracic portion and more brownish colour in the rump portion), dewlap absent and less diverged but not converged horn.
5. **Yearling (YR) or Juveniles (JU)** – Brownish in colour with dagger like spike horn (approximately 20 to 25 cm in length in both sexes).
6. **Calf (CA)** – Golden brownish in colour and can pass through between the legs of its mother (less than three months old and approximately 1 m in height) in both sexes. Lack of conspicuous white stockings.

No gaur calf was selected for translocation from Kanha to Bandhavgarh. Each gaur group after re-introduction was distinguished based on the radio-collar individuals. All the identified gaur groups were considered for group composition analyses, where mean group size (MGS) and typical group size (TGS) was computed across seasons in different years following Jarman (1974) and Barrette (1991). TGS is an animal centred measure of group size, reflecting the experience of an average individual in a group and the MGS is the observer-centred estimates of group size. The solitary gaur was not considered for

calculating mean group size. The adult female: adult male ratio and calf: adult female ratio was calculated following Schaller (1967).

Table 5. 1. Details of age and sex classes of gaur selected for translocation from Kanha Tiger Reserve, Madhya Pradesh.

Gaur age and sex class	Number of individuals
Adult Male (AM)	3
Sub-adult Male (SAM)	11
Adult Female (AF)	13
Sub-adult Female (SAF)	21
Yearling (YE) or Juveniles (JU)	2
Calf (CA)	0
Total	50

5.4. RESULTS

5.4.1. Group size

During the study period, the observed gaur group size varied from 2 to 24 individuals. The observed overall gaur mean group size (MGS) was 9.1 ± 1.6 (SE). The annual MGS of gaur in 2011 was 7.3 ± 0.8 (SE) and in 2012 it was 10.3 ± 2.6 (SE). The overall MGS of gaur in summer was 8.6 ± 1.3 (SE), in monsoon it was 10.7 ± 2.8 (SE) and in winter it was 11.0 ± 2.9 (SE). In 2011, MGS of gaur in summer was 9.5 ± 0.8 (SE) in monsoon it was 7.6 ± 1.4 (SE) and in winter it was 5.3 ± 1.2 (SE). In 2012, MGS of gaur in summer was 8.3 ± 1.7 (SE), in monsoon it was 14 ± 3.8 (SE) and in winter it was 15 ± 3.7 (SE) (table 5.2).

The observed overall gaur typical group size (TGS) was 12.1, in 2011 it was 8.9 and in 2012 it was 13.3. The overall, TGS of gaur in summer was 10.1, in monsoon it was 15.2 and in winter it was 15.7. In 2011, TGS of gaur in summer was 10.1, in monsoon it was 8.8 and in winter it was 9.1. In 2012, TGS of gaur in summer was 5.62, in monsoon it was 17.1 and in winter it was 17.3 (table 5.2). More solitary individuals were observed in males (11%) than females (2%).

Table 5. 2. Mean group size (SE) and typical group size of reintroduced gaur across seasons in Bandhavgarh Tiger Reserve (2011-2013).

Season	2011		2012		Overall	
	MGS ± SE	TGS	MGS ± SE	TGS	MGS ± SE	TGS
Summer	9.5 ± 0.8	10.1	8.3 ± 1.7	5.62	8.6 ± 1.3	10.1
Monsoon	7.6 ± 1.4	8.8	14 ± 3.8	17.1	10.7 ± 2.8	15.2
Winter	5.3 ± 1.2	9.1	15 ± 3.7	17.3	11.1 ± 2.9	15.7
Overall	7.3 ± 0.8	8.9	10.3 ± 2.6	13.3	9.1 ± 1.6	12.1

MGS - Mean Group Size; TGS - Typical Group Size; SE - Standard Error.

5.4.2. Overall gaur composition

In the overall composition of gaur groups, sub-adult females comprised large in numbers (n= 19) followed by adult females (n= 12), sub-adult males (n= 11), calf (n= 8), yearling or juveniles (n=7) and adult males (n= 3) (table 5.3).

Table 5. 3. Age and sex classes of reintroduced gaur from Kanha Tiger Reserve (2011-12) and the change in composition of age and sex classes at the end of study period in Bandhavgarh Tiger Reserve (2013).

Age and sex class	Number of reintroduced gaur from Kanha (2011-2012)	Present gaur individuals under different age and sex classes in Bandhavgarh (February 2013)
Adult Male (AM)	3	3
Sub-adult Male (SAM)	11	11
Adult Female (AF)	13	12
Sub-adult Female (SAF)	21	19
Juveniles (JU)	2	7
Calf (CA)	--	8
Total	50	60

5.4.3. Overall sex ratio

The estimated overall gaur sex ratio (adult male: adult female) was 1: 4, the sub adult male: sub adult female ratio was 1: 1.7 and the adult female: calf ratio was 1: 1.5 (table 5.4).

Table 5. 4. Sex ratio of reintroduced gaur in Bandhavgarh during the study period (2011-2013).

Sex ratio of gaur during the reintroduction (2011-2012)		Present gaur sex ratio in Bandhavgarh (February 2013)	
adult (male : female)	1 : 4.3	adult (male : female)	1 : 4
sub adult (male : female)	1 : 1.9	sub adult (male : female)	1 : 1.7
		female : calf	1 : 1.5

5.4.4. Mortality and natality in the reintroduced gaur population

In total four mortalities were recorded during the study period, of which two gaur (one sub adult female, one calf) were predated by tiger and two radio collared gaur (GF5, GF7) died naturally. Two un-collared sub adult gaur females went missing (on 27th March 2011 and 22nd April 2012) and were never reported again.

A total of 16 calves were born in Bandhavgarh during the study period. The maximum gaur calves were observed in winter (n=10) followed by summer (n= 5) and monsoon (n=1). The relationship between mean monthly temperature and number of gaur calves born showed an increase in number of gaur calves during low temperature period (figure 5.1). The number of gaur calf births month wise along with the mean rainfall (2011-2013) indicated an increase in number of gaur calves after the onset of monsoon (figure 5.2).

Figure 5. 1. Mean temperature and number of gaur calves born in Bandhavgarh Tiger Reserve (2011-2013).

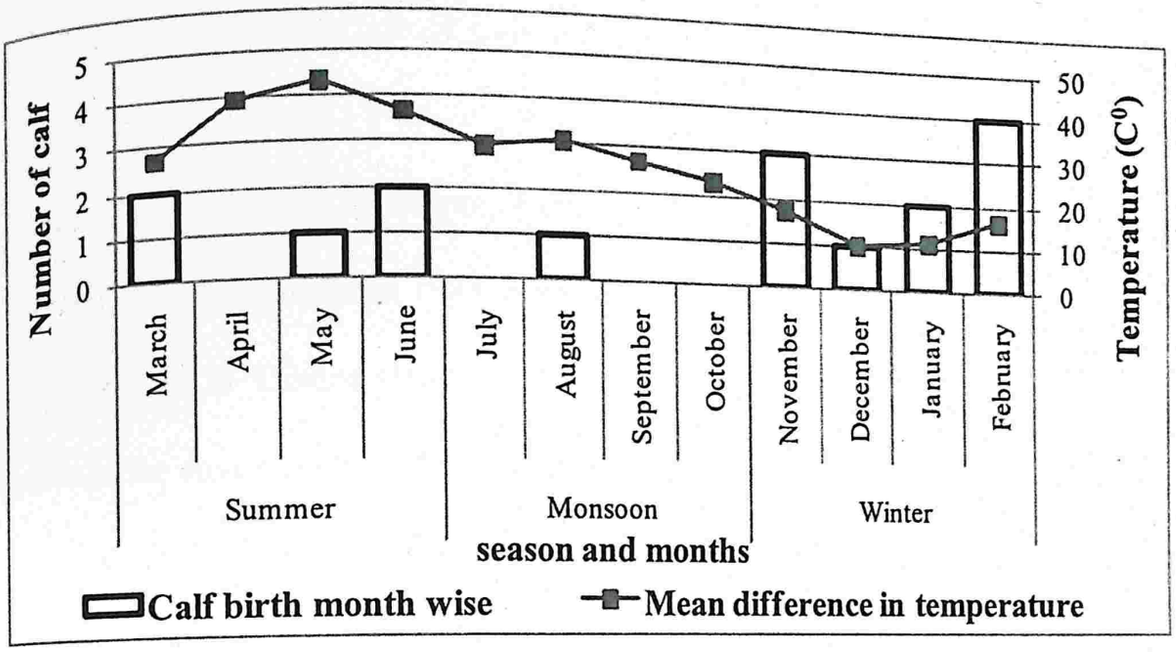
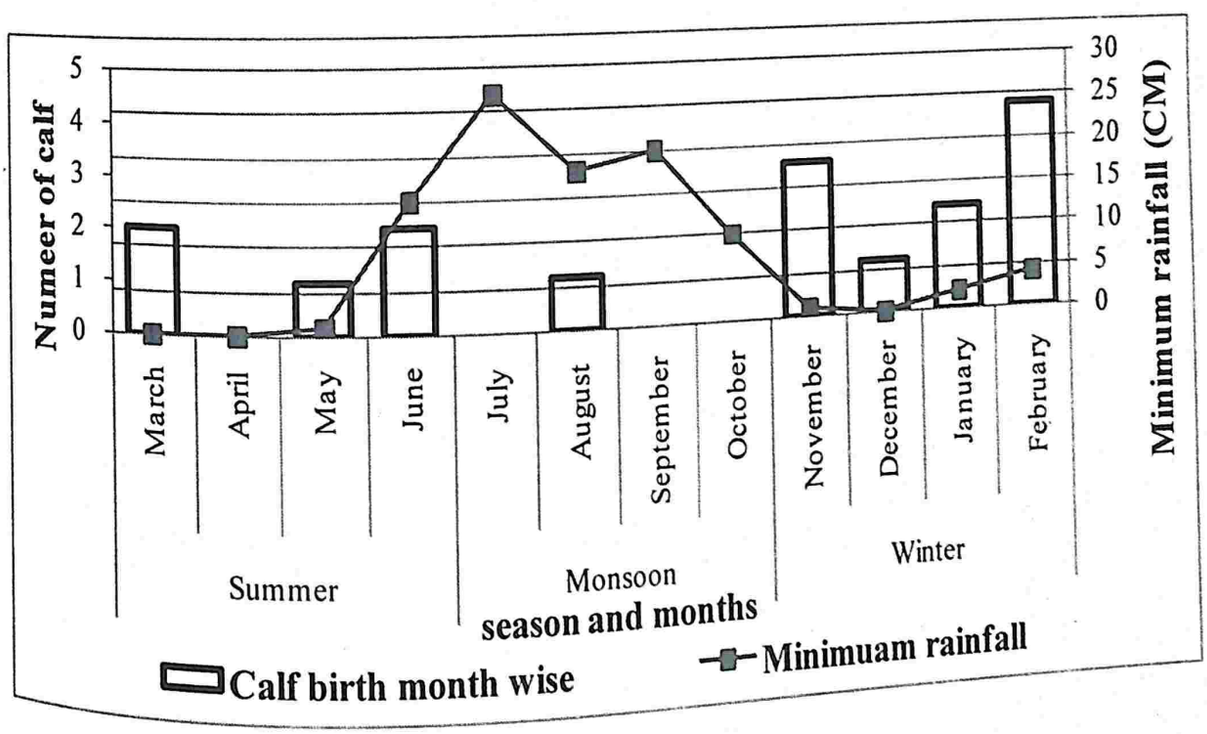


Figure 5. 2. Mean monthly rainfall and number of gaur calves born in Bandhavgarh Tiger Reserve (2011-2013).



5.5. DISCUSSION

Gaur is a social animal with a fluid group structure (Brander 1923, Schaller 1967). The reported group size of gaur in the present study was similar to as reported in Parambikulam and Pench (Vairavel 1998, Sankar *et al.* 2000) and lower than as reported in Mudumalai, Nagarhole, Bandipur, Kanha and Jaldapara (Ramesh *et al.* 2012, Karanth and Sunquist 1992, Johnsingh 1983, Schaller 1967, Bhattacharya *et al.* 1997) and higher than as reported in Trishna (Dasgupta *et al.* 2008) (table 3.5). Group size is an optical response to the environment where the ecological factors may influence the species Mean Group Size (MGS) (Jarman 1974, Shankar Raman 1997). In the present study, the observed overall MGS of gaur was higher in monsoon and winter and this may be attributed to better quality of vegetation available during these seasons in the study area. Similar observations were reported in Mudumalai, (Ashokkumar 2010b, Ramesh *et al.* 2012), Pench (Sankar *et al.* 2000) and Trishna (Dasgupta *et al.* 2008). In summer, gaur in the study area was observed in smaller groups (8.6 ± 1.3 SE) which may be due to availability of food resources in patches and due to which they were forced to form smaller groups. By living in small herds, grazing ungulates may get access to extra resources that cannot sustain larger herds (Lagory 1986, Shanker Raman 1997, Marino and Baldi 2014).

Sub-adult gaur females had maximum influence on the total population followed by adult gaur females and sub-adult gaur males in Bandhavgarh which was similar to that as reported in European bison (Krasinski 1978). More sub adult individuals in the reintroduced population are vital for maintaining the long term reproductive success

(Saltz and Rubenstein 1995). No bachelor group was observed in the present gaur population in the study area which was similar to that as reported on gaur in Parambikulam Tiger Reserve, Kerala (Vairavel 1998) and also in European bison (Krasinska and Krasinska 1995). In large herbivores, males have the tendency to move from one herd to another herd as part of their mating strategy (McHugh 1972, Clutton-Brock 1982) and their nature of dominance over other individuals in the population may result in solitary nature of adult gaur. Similar findings on gaur were reported in India (Schaller 1967, Vairavel 1998), Malaysia (Conry 1989) and also in American and European bison (McHugh 1972, Green and Rothstein 1991).

Adult female gaur at the time of calving was observed solitary (n=34) in the study area which was similar to the findings as reported on gaur in India, such as Kanha, Palamu, Parambikulam and Pench (Schaller 1967, Sahai 1972, Vairavel 1998, Sankar *et al.* 2000), and in American bison (Rutberg 1986). It is possible that the inability to move fast with the group along with a dependent calf causes the mother to remain solitary in the nature.

The forage production and the breeding cycle between most ungulates are closely associated with rainfall in the tropical climate areas (Phillipson 1975, Eltringham 1979). The pregnant females require additional nutrition during pregnant and lactating period (Sadlier 1967). Breeding period of gaur varied considerably in its distribution range across different seasons (Brander 1923). During the present study, 62.5 % of new born calves were observed in winter, which was similar to the observation made by Stebbing (1911) and Sanderson (1912) on gaur in Central Indian landscape. As reported by

Brander (1923) and Schaller (1967) the peak calving period of gaur occurred during December and January. Bhattacharya *et al.* (1997) in Jaldapara reported that new born gaur calves was observed during November and December. In Parambikulam Tiger Reserve the peak calving period of gaur was observed in second wet season (September to December) (Vairavel 1998), where as in Mudumalai Tiger Reserve (Kumar *et al.* 2004 and Ramesh *et al.* 2012) and Pench Tiger Reserve, (Sankar *et al.* 2000) gaur calves were observed throughout the year which is attributed to the resource availability for gaur thought the year.

During the study period of two years (2011-2013) in Bandhavgarh Tiger Reserve, the estimated overall growth of gaur population was 20% and the mortality rate was 8 %. The success of a species reintroduction cannot be assessed until the growth rate has reached to obtain sustainable population (Riney 1964, Phillips 1997). Continues monitoring is recommended for the reintroduced gaur population in Bandhavgarh Tiger Reserve to evaluate the growth rate and mortality for future periods.

Table 5. 5. Mean group size (MGS ± SE) and group size range of gaur as reported from different Protected Areas in India.

Protected Areas	Overall (MGS ± SE)	Summer (MGS ± SE)	Monsoon (MGS ± SE)	Winter (MGS ± SE)	Group size range
Bandhavgarh *	9.1 ± 1.6	8.6 ± 1.3	10.7 ± 2.8	11.1 ± 2.9	1-24
Mudumalai [1]	7.5 ± 0.4	6.9 ± 0.7	8.4 ± 0.7	7.2 ± 0.7	1-42
Mudumalai [2]	9.8 ± 7.6	8.7 ± 6.2	10.1 ± 8.1	10.2 ± 7.9	1-26
Trishna [3]	5.9 ± 2.9	3.1 ± 0.5	--	4.6 ± 0.2	2-14
Mudumalai [4]	8.1 ± 0.6	--	--	--	1-47
Bhadra [5]	2.3 ± --	--	--	--	--
Pench [6]	4.2 ± 0.1	3.9 ± 0.1	4.62 ± 0.2	5.66 ± 0.4	1-19
Parambikulam [7]	6 ± --	5.4 ± --	5.9 ± --	6.9 ± --	1-19
Nagarahole [8]	6.9 ± --	--	--	--	1-47
Palamu [9]	5 to 7	--	--	--	2-27
Kanha [10]	8.8 ± 0.7	--	--	--	1-40

* Present study; [1] Ramesh *et al.* 2012; [2] Ashokkumar *et al.* 2010; [3] Dasgupta *et al.* 2008; [4] Kumar *et al.* 2004; [5] Jathanna *et al.* 2003; [6] Sankar *et al.* 2000; [7] Vairavel 1998; [8] Karanth and Sunquist 1992; [9]Sahai 1977; [10] Schaller 1967.

MGS - Mean Group Size; **SE** - Standard Error; -- Information not available.

Chapter VI

Conservation of reintroduced gaur population in Bandhavgarh Tiger Reserve

Chapter VI

CONSERVATION OF REINTRODUCED GAUR POPULATION IN BANDHAVGARH TIGER RESERVE

The known extinction of gaur from three protected areas in India (Thattakad Wildlife Sanctuary, Kerala; Bhandhavgarh Tiger Reserve and Kanger Valley National Park, Madhya Pradesh) in the last two decades is a testimony to the fact this species is losing ground very fast and urgent measures are required to stem the process. Therefore, conservation needs active programs like reintroduction and reestablishment of important species in the areas where they have been recently lost, with or without habitat related interventions. Hence, the gaur reintroduction program in Bandhavgarh Tiger Reserve was an important need and attempt to establish a gaur population in an area which was once part of its historical range, but become locally extirpated in recent past. Thereby, the present study justifies an important rather successful ecological step towards the conservation of this large bovid.

The present study has drawn the first time information on ranging pattern of gaur (n=27) and their degree of preferences towards different vegetation types in different seasons, which will be very useful for the park administration for effective conservation of this endangered species including habitat intervention, if needed.

During the study period two (kumuruva and kallwah) villages from Kallwah Range were relocated outside the Protected Area. Gaur have been observed to use these

relocated village sites intensively. Hence creation of such additional habitat space is vital for gaur conservation, by relocating the remaining 13 villages from the Tiger Reserve.

Since gaur are highly susceptible to some cattle diseases there is a need to implement a wide vaccination programme and making it regular for the domestic livestock in and around Protected Areas (core and buffer) of Bandhavgarh Tiger Reserve to prevent the livestock transmitting diseases to gaur.

Cutting and lopping of food plants species and collection of *Madhuca indica* flower and *Phyllanthus emblica* fruit, inside the buffer area should be restricted through efficient patrolling. Removal of weeds (*Lantana camara, Cassia tora, parthenium hysterophorus* and *Xanthium strumarium*) from the gaur home range areas to improve the forage quality is recommended. It is important to strengthen the corridors from Bandhavgarh Tiger Reserve to Sanjay Tiger Reserve and Amarkantak Wildlife Sanctuary to conserve the existing small gaur population in Bandhavgarh Tiger Reserve.

A long term study on the ecological aspects such as ranging pattern, habitat use, food habits and predation of the reintroduced gaur in Bandhavgarh Tiger Reserve will be crucial for the conservation and management of this endangered bovid. With an increase in the population of gaur in Bandhavgarh Tiger Reserve since their reintroduction it is recommended to collar few more individuals and monitor them for further periods.

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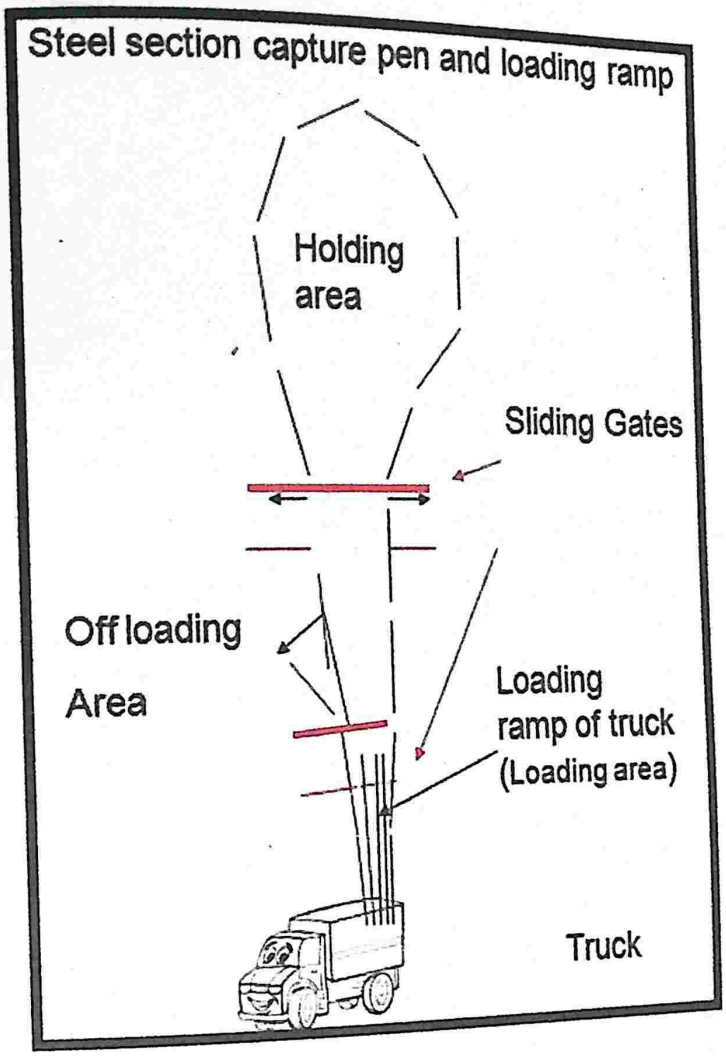
Appendix

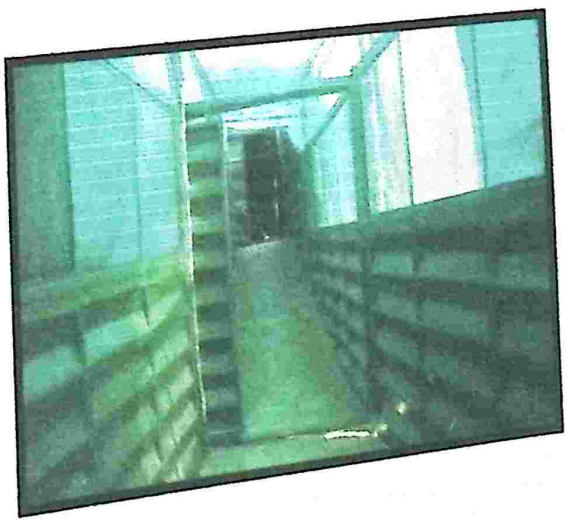
Appendix I: Details of preparation for gaur translocation in Kanha Tiger Reserve and Bandhavgarh Tiger Reserve.

A. Construction of Boma in Kanha Tiger Reserve



B. Holding Area

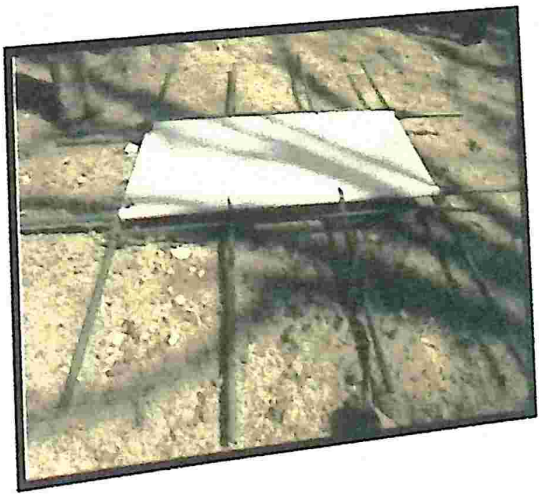
C. Loading area



D. Heavy duty transport truck (TATA LPT 1615)

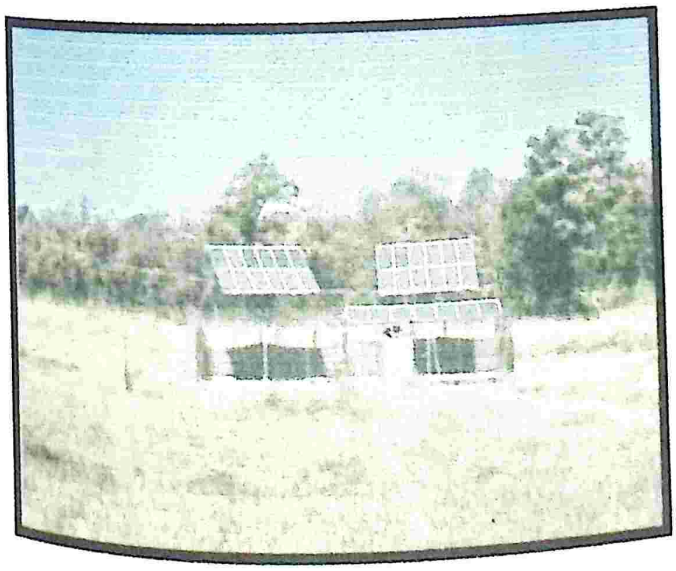
E. Mini transportation truck (TATA 407)

F. Stretcher design



G. Preparation of larger enclosure in Bandhavgarh Tiger Reserve

H. Solar powered fence in Bandhavgarh



I. Releasing ramp in Bandhavgarh

Appendix II: Capture details of reintroduced gaur in Bandhavgarh Tiger Reserve. (2011-2012).

Animal ID						Approximate		Body Measurements (CM)			Horn spread (CM)			
KTR	BTR	Date of Capture and release	Capture Range	Radio collar	Sex	Age	Weight	Nose tip to tail	Neck girth	Hind limb length	U	M	B	Remarks
G1	GF1	20/1/2011	Kisli	Yes	Female	3 - 4	400	236	70	178	31	49	19	Translocated to BTR
G2**	GF2	20/1/2011	Kisli	No	Female	3 - 4	400	--	--	--	--	--	--	Died (aspiration pneumonia)
G3	GM1	20/1/2011	Kisli	Yes	Male	3 - 4	350	--	--	--	--	--	--	Translocated to BTR
G4	GF3	20/1/2011	Kisli	Yes	Female	3 - 4	300-350	340	74	174	41	43	24	Translocated to BTR
G5	GM2	20/1/2011	Kisli	No	Male	3 - 4	300-350	240	75	174	45	46	22	Translocated to BTR
G6*	GF4	21/2/2011	Kisli	No	Female	5 - 6	600	--	--	--	--	--	--	Released after capture (Animal seen with calf)
G7	GM3	21/2/2011	Kisli	Yes	Male	4 - 5	500	260	82	184	38	58	28	Translocated to BTR
G8	GF5	23/1/2011	Kisli	No	Female	6 - 7	600	215	90	184	--	--	--	Translocated to BTR
G9	GM4	23/1/2011	Kisli	No	Male	18months	150	137	54	--	18	--	18	Translocated to BTR
G10	GF6	24/1/2011	Kanha	Yes	Female	4	400-450	180	84	180	42	48	22	Translocated to BTR
G11	GF7	24/1/2011	Kanha	Yes	Female	4 - 4.5	400-450	252	84	--	48	45	--	Translocated to BTR
G12	GF8	24/1/2011	Kanha	Yes	Female	4 - 4.5	400	138	92	--	42	44	23	Translocated to BTR
G13	GF9	24/1/2011	Kanha	Yes	Female	5 - 5.5	400	267	84	--	42	55	23	Translocated to BTR
G14	GF10	25/1/2011	Kanha	Yes	Female	5 - 6	500	--	86	178	38	40	22	Translocated to BTR
G15	GF11	25/1/2012	Kanha	No	Female	6 - 7	550	268	80	180	--	58	--	Translocated to BTR

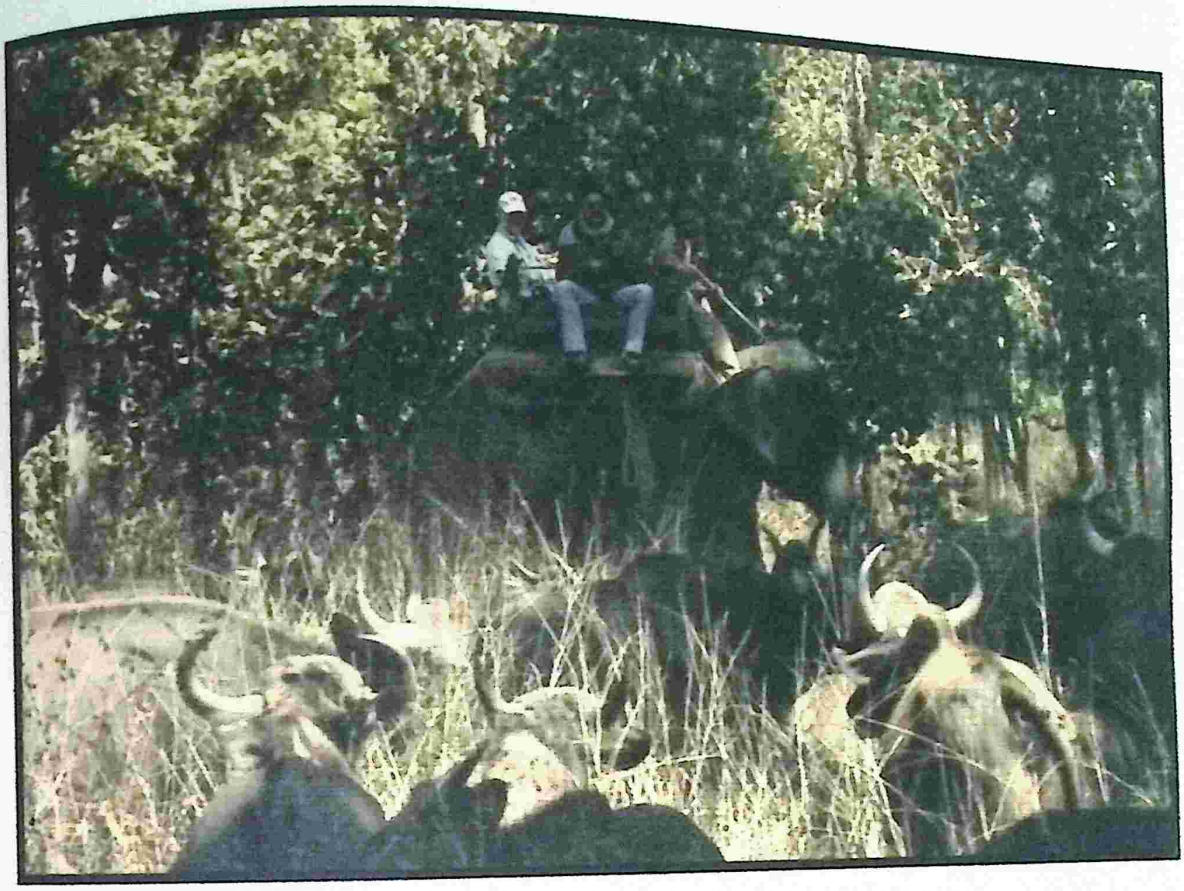
G16	*GF12*	*25/1/2013*	*Kanha*	*No*	*Female*	18 months	150-200	140	64	130	30	18	--	Translocated to BTR
*G17**		*25/1/2014*	*Kanha*	No	Female	6 - 7	600	--	--	--	--	--	--	Immobilized for loading onto container
G18	GF13	*27/1/2011*	Kanha	No	Female	3 - 3.5	300-350	235	86	169	48	48	24	Translocated to BTR
G19	GF14	27/1/2011	Kanha	Yes	Female	5 - 6	500	47	84	180	57	26	--	Translocated to BTR
G20	GF15	27/1/2011	Kanha	No	Female	2.5 - 3	200	46	63	172	40	18	--	Translocated to BTR
G21	GF16	27/1/2011	Kanha	No	Female	2.5	200	--	--	--	--	--	--	Translocated to BTR
G22	GM5	27/1/2011	Kanha	Yes	Male	6 - 7	600	268	103	180	68	29	--	Translocated to BTR
G1	GF19	3/3/2012	Kanha	Yes	Female	3	350-370	--	72	74	47	52	30	Translocated to BTR
G2	GF20	3/3/2012	Kanha	Yes	Female	3 - 4	350-400	--	--	--	--	--	--	Translocated to BTR
G3	GF21	3/3/2012	Kanha	No	Female	4	350	--	--	--	--	--	--	Translocated to BTR
G4	GM6	3/3/2012	Kanha	No	Male	1.5 - 2.5	250-300	161	--	170	26	62	58	Translocated to BTR
G5	GM7	4/3/2012	Kanha	Yes	Male	2 - 3	300	198	70	--	47	53	26	Translocated to BTR
G6	GM8	4/3/2012	Kanha	No	Male	2	200-220	199	--	140	39	41	21	Translocated to BTR
G7	GF22	4/3/2012	Kanha	Yes	Female	2-2.5	250-300	172	--	--	39	41	21	Translocated to BTR
G8	GF23	4/3/2012	Kanha	No	Female	2	175-200	204	73	--	34	40	28	Translocated to BTR
G9	GF24	5/3/2012	Kisli	No	Female	2 – 3	250-300	209	--	--	--	--	--	Translocated to BTR
G10	GF25	5/3/2012	Kisli	No	Female	2	200-225	207	67	--	29	--	--	Translocated to BTR
G11	GF26	5/3/2012	Kisli	No	Female	2	250-300	208	67	--	35	41	23	Translocated to BTR
G12	GF27	5/3/2012	Kisli	Yes	Female	4 - 5	350	211	92	--	58	68	24	Translocated to BTR

G13	GM9	5/3/2012	Kisli	No	Male	2	200	196	66	105	34	37	22	Translocated to BTR
G14	GM10	5/3/2012	Kisli	Yes	Male	5- 6	600-700	221	107	88	56	75	41	Translocated to BTR
G15	GF28	6/3/2012	Kisli	Yes	Female	3.5	235-350	228	76	--	26	50	38	Translocated to BTR
G16	GM11	6/3/2012	Kisli	No	Male	2-2.5	250-275	200	60	154	28	52	50	Translocated to BTR
G17	GF29	6/3/2012	Kisli	No	Female	2	195-220	193	62	--	28	39	40	Translocated to BTR
G18	GF30	6/3/2012	Kisli	No	Female	2	175-190	192	66	--	36	33	24	Translocated to BTR
G19	GF31	6/3/2012	Kisli	Yes	Female	7.5 - 8	500	250	--	--	29	57	29	Translocated to BTR
G20	GM12	6/3/2012	Kisli	Yes	Male	4.5 - 5	425	235	84	160	38	52	53	Translocated to BTR
G21	GM13	7/3/2012	Kisli	No	Male	2.5	225-250	145	68	140	28	40	44	Translocated to BTR
G22	GF32	7/3/2012	Kisli	Yes	Female	3 - 4	375-400	201	70	155	34	45	39	Translocated to BTR
G23	GF33	7/3/2012	Kisli	Yes	Female	3- 3.5	250	206	72	--	46	40	36	Translocated to BTR
G24	GF34	7/3/2012	Kisli	No	Female	2 - 3	200	192	68	--	35	39	26	Translocated to BTR
G25	GF35	7/3/2012	Kisli	Yes	Female	6	475-500	273	85	--	31	33	28	Translocated to BTR
G26	GF36	7/3/2012	Kisli	Yes	Female	6	500	275	76	--	42	55	37	Translocated to BTR
G27	GF37	11/3/2012	Kisli	Yes	Female	5.5 - 6	500	255	76	--	34	46	35	Translocated to BTR
G28	GF38	11/3/2012	Kisli	No	Female	Not estimated	500-600	250	82	--	50	57	29	Translocated to BTR
G29	GF39	11/3/2012	Kisli	No	Female	2 - 3	--	--	--	--	--	--	--	Translocated to BTR
G30	GF40	11/3/2012	Kisli	Yes	Female	6	550-600	263	82	--	23	54	32	Translocated to BTR
G31	GM14	11/3/2012	Kisli	No	Male	2 - 2.5	200	150	--	--	29	25	20	Translocated to BTR

** Animal dead; * Animals not transported; U-Upper; M-Middle; B-Base.

Appendix III: Details of gaur translocation in Kanha Tiger Reserve (2011-2012).

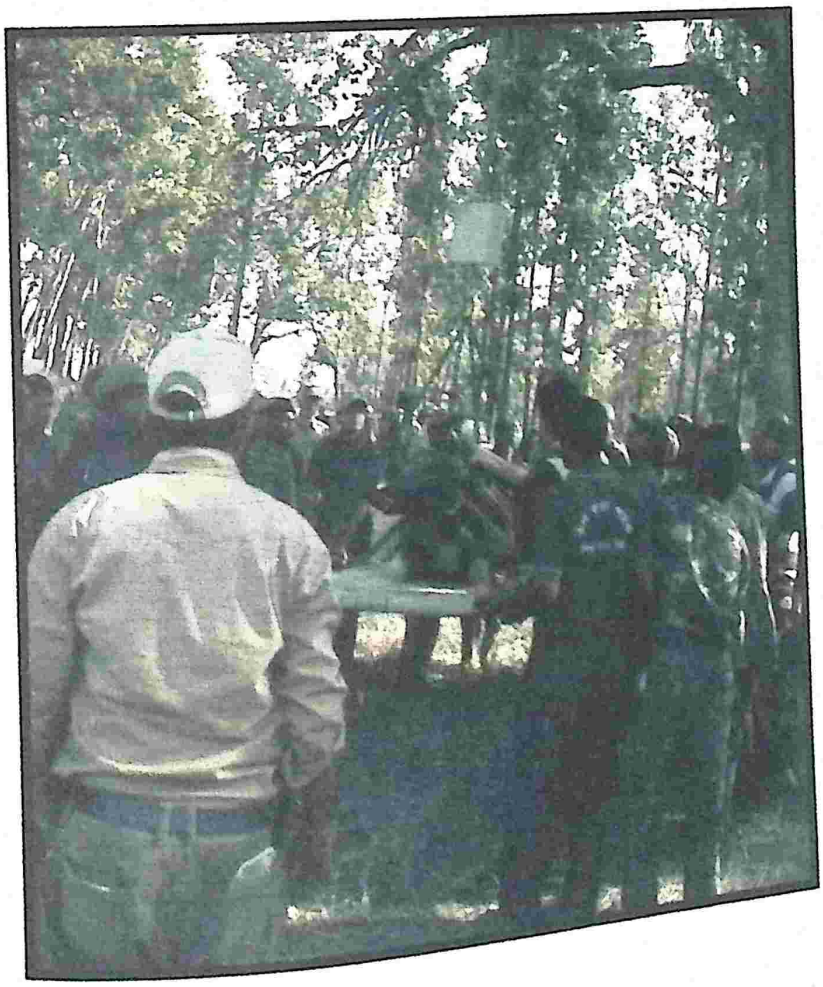
Picture 1. Selection of gaur from the herd in Kanha Tiger Reserve.



Picture 2. Gaur darting form elephant back in Kanha Tiger Reserve.

Picture 3. Gaur shifting into a small truck (recovery vehicle) in Kanha Tiger Reserve.

Picture 4. Weighing of the gaur in Kanha Tiger Reserve.



Picture 5. Fitting of radio collar on gaur in Kanha Tiger Reserve.

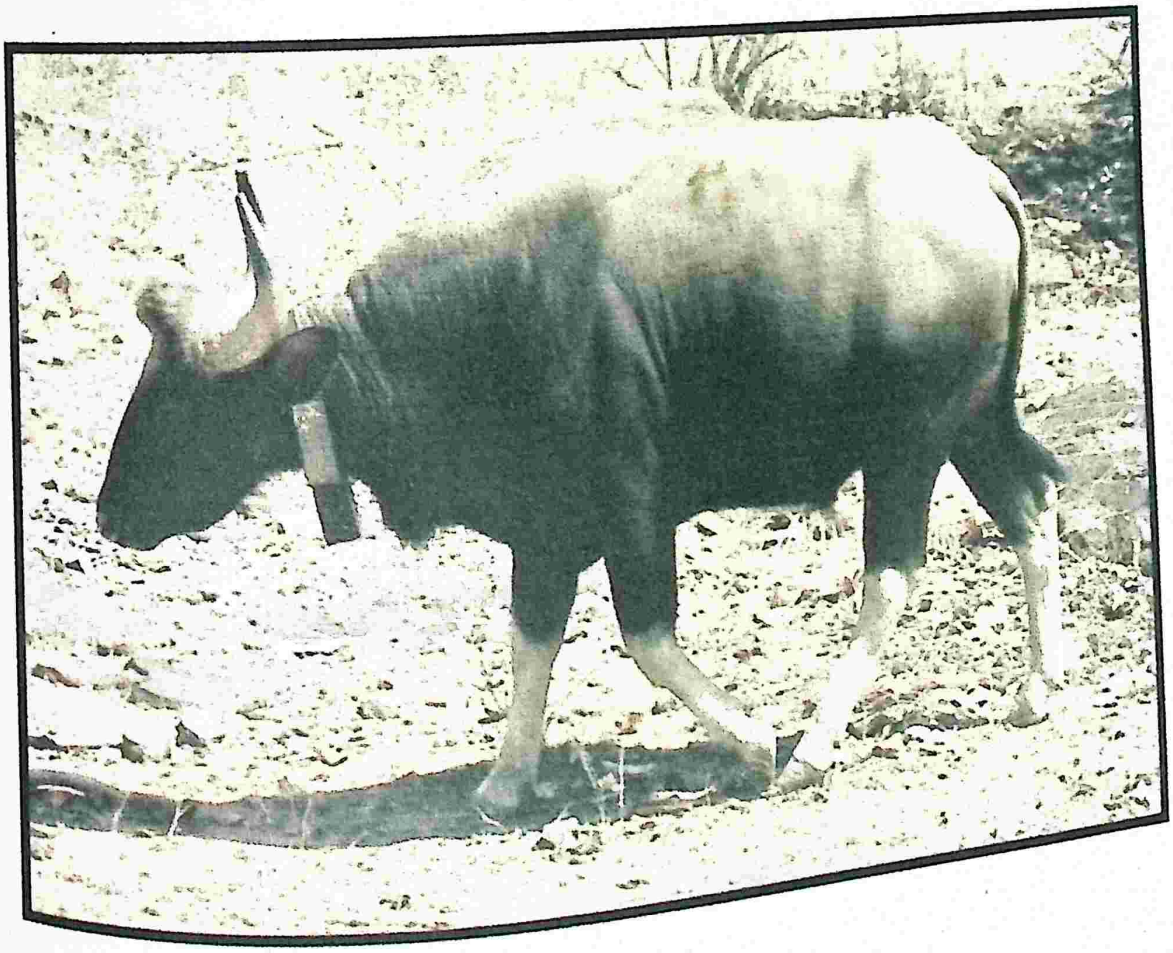
Picture 6: Shifting the gaur into the large truck for transportation.

Picture 7: Transportation of gaur from Kanha Tiger Reserve to Bandhavgarh Tiger Reserve by road.

Picture 8: Soft release of gaur in Bandhavgarh Tiger Reserve.

Picture 9: A herd of reintroduced gaur inside the enclosure in Bandhavgarh Tiger Reserve

Picture 10: Reintroduced gaur with detachable radio-collar.



Research Article

Home range, habitat use and food habits of re-introduced gaur (*Bos gaurus gaurus*) in Bandhavgarh Tiger Reserve, Central India.

K. Sankar[1*], H. S. Pabla[2], C. K. Patil[3], Parag Nigam[1], Qamar Qureshi[1], B. Navaneethan[1], Manas Manjreakar[1], Preeti S. Virkar[1] and Krishnendu Mondal[1].

[1] Wildlife Institute of India, Dehradun, India; [2]Former Principal Chief Conservator of Forest and Chief Wildlife Warden, Government of Madhya Pradesh; [3] Former Field Director, Bandhavgarh Tiger Reserve, Madhya Pradesh.

* Corresponding Author: K. Sankar: sankark@wii.gov.in

bstract:

ur, which became locally extinct before 1995 in Bandhavgarh Tiger Reserve (BTR), Central India, is an endangered animal per Schedule – I of e Indian Wildlife Protection Act (1972). A re-introduction program was therefore created to rebuild the gaur population in BTR, both to enhance e long-term survival of the species and to restore natural biodiversity. After re-introduction, the home range, habitat use and food habits of gaur os *gaurus gaurus*) were studied in BTR, India, from January 2011 to January 2012. Nineteen gaurs (five males - three radio-collared and 14 males - nine radio-collared) were re-introduced from Kanha Tiger Reserve to Bandhavgarh Tiger Reserve in January 2011. The reintroduced urs were monitored periodically through ground tracking and satellite GPS fixes. The mean annual group size of gaur was estimated at 7.3 ± 76 (SE). The overall estimated summer, monsoon and winter home ranges of gaur were 290 km^2, 137 km^2 and 155 km^2 (Minimum Convex olygon) respectively. The overall individual male home ranges varied from 135 to 142 km^2, and overall individual female home ranges varied from 2 to 169 km^2. Radio collared locations were plotted on a classified (LISS III) habitat map of Bandhavgarh Tiger Reserve to evaluate the habitat use nd availability in each season. Habitat preference was computed using Bonferroni confidence interval method, compositional analysis and Ivlev's dex. In summer, gaur largely preferred grassland (P<0.0001), whereas in monsoon and winter, gaur preferred bamboo mixed forest (P<0.0001). aur avoided open mixed forest (P<0.0001) and agricultural land in all three seasons. Data on food habits were collected through opportunistic ightings. In total, gaur fed on 68 plant species. The present study has reported first-time information on ranging patterns of reintroduced gaur nd their degree of preferences for different vegetation and terrain types across seasons, which will be very useful to the park administration for uture conservation of this endangered species and for habitat intervention.

ey words: Reintroduction, gaur *(Bos gaurus gaurus)*, home range, habitat use, food habits, Bandhavgarh Tiger Reserve.

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Introduction

Gaur (*Bos gaurus gaurus*), family Bovidae, is one of the large wild ungulates of Asian jungles. Gaur is an endangered animal per Schedule – I of the Indian Wildlife Protection Act (1972). It is included in Appendix I of the Conservation on International trade in Endangered Species of Wild Fauna and Flora (CITES) and categorized as Vulnerable by the International Union for Conservation of Nature and Natural Resources (IUCN). Gaur is the tallest living ox [1], and one of the four heaviest land mammals (elephant, rhino and wild buffalo are the other three). Adult gaur bulls weigh 600-940 kg and stand 1.6 to 1.9 m at shoulder [2]. The adult cows are about 10 cm shorter in height [3] and weigh about one fourth less than the adult males [4]. Formerly gaur were distributed throughout the forested tracts of India and South Nepal, east to Vietnam and south to Malaya [5]. According to Ranjitsinh [6] the estimated population of gaur in India is between 12,000 and 21,000. Sankar et al. [7] estimated the gaur population in India to be approximately 23,500. Presently gaur occur in 101 existing and 27 proposed Protected Areas (PA's) of India covering 15 states. Tropical Moist Deciduous and Tropical Dry Deciduous forests are the dominant vegetation types within the present distribution limits of gaur [7].

The gaur population in India co-occurs with elephants (*Elephas maximus*) throughout its present distributional range, except in the Central Indian highlands, where elephants have become extinct [8]. Presently gaur are distributed in more or less isolated pockets, largely corresponding to the major mountain systems of the Western Ghats, the Central Indian highlands and the North-Eastern Himalayas, including the hills south of Brahmaputra. As ecosystem landscapers, gaur play an important role in the moist and dry deciduous forests in India, as they have a major impact on the physical structure of habitats, rates of ecosystem processes and the diversity of communities [9]. Also, mega-herbivores like gaur are important modifiers of ecosystem structure and function because they can trigger trophic cascades [10-11], increase spatial heterogeneity, accelerate successional processes [12] and influence nutrient cycling and primary productivity [13].

The last small population of gaur (30 to 32 individuals) migrated out of the Bandhavgarh Tiger Reserve (BTR) in 1995. This population was considered to be the only population north of the Narmada River, in Central India. The local extinction of gaur from the park also resulted in loss of biodiversity and decline in tourist numbers in the park [14]. Since BTR also has a considerable population of tigers (n~50), it was important to have gaur in the park as a prey species of tiger [14].

For the last two decades, captive breeding, reintroduction and translocation programs have become increasingly important conservation tools [15-16], although there are two important obstacles to re-establishing species: first, understanding the fundamental ecological requirements and life histories of species of concern [17], and second, identifying appropriate areas for reintroduction or restoration, given that degradation or modification can render native habitats unsuitable [18-19]. A study [20] showed that young rhino males do not adapt quickly to a new environment and hence are susceptible to high mortality, whereas adult and near adult males and females adapt faster. Another factor in the success of reintroductions is whether animals remain where they are released [21]. There are few reintroductions of mega-herbivores and herbivores reported, *viz.*, reintroduction of bison (*Bison bison*) into the rocky mountain parks of Canada [22], elk (*Cervus canadensis*) in America [23], reindeer (*Rangifer tarandus*) in Finland [24], white rhinoceros (*Ceratotherium simum*) in Botswana [25] and Asiatic One-horned Rhinoceros (*Rhinoceros unicornis*) in Dudhwa Tiger Reserve, Uttar Pradesh [26].

The re-introduction program to re-build the gaur population in Bandhavgarh Tiger Reserve (BTR) translocated and reintroduced an initial population of 20 animals, with subsequent supplementation of 30 more animals; the sex ratio was 60% females and 40% males. The simulations of gaur population viability analysis (PVA) showed that the probability of survival of reintroduced gaur in BTR is 0.9400

(0.023 SE). This program is the first successful mass trans-location of gaur in its entire distributional range. Following re-introduction of gaur in BTR, the present study was conducted from January 2011 to January 2012 with the following objectives: a) to estimate the home ranges of gaur in different seasons, b) to understand the habitat use and habitat preference of gaur in different seasons and c) to estimate the food habits of gaur.

Methods

Study area

Bandhavgarh Tiger Reserve lies on the extreme north-eastern border of the Madhya Pradesh state and the northern flanks of the eastern Satpura Mountain range (23°30' 08" to 23°47'05" N and 80°11'43" to 80°47'05" E). BTR consists of two conservation units: Bandhavgarh National Park (442.842 km^2) and the Panpatha Wildlife Sanctuary (245.842 km^2). The altitude of the park varies between 410 m and 811 m. The terrain is of rocky hills rising sharply from the swampy and densely forested valley in the low land. BTR lies within the tropical zone, having three distinct seasons. The area is characterized by well-defined winter (November-February), summer (March- June) and monsoon-post monsoon (July- October). During the study period, the lowest temperature reported was 2.2 °C in winter, and the highest was 44 °C in summer. Average rainfall is 1,173 mm, most of which occurs during the monsoon [27].

Vegetation of BTR falls under five categories [28]: moist peninsular low level sal (*Shorea robusta*) forest ($3C/C_{2e}$), northern dry mixed deciduous forest ($5B/C_2$), dry deciduous scrub (DS_1), dry grassland ($5/DS_4$) and West Gangetic moist mixed deciduous forest ($3C/C_{3a}$). Wild herbivores found are chital (*Axis axis)*, sambar (*Rusa unicolor)*, barking deer (*Muntiacus muntjak)*, nilgai *(Boselaphus tragocamelus)* and chinkara (*Gazella bennettii)*; large carnivores are tiger *(Panthera tigris)* leopard *(Panthera pardus*) and dhole (*Cuon alpinus*). The scavengers/ omnivores consist of striped hyena *(Hyaena hyaena)*, golden jackal (*Canis aureus*), wild pig *(Sus scrofa)* and sloth bear *(Melursus ursinus)*. Other small carnivores such as jungle cat (*Felis chaus*), rattle (*Mellivora capensis*), common mongoose *(Herpestes edwardsi*), ruddy mongoose (*H. smithi*), palm civet (*Paradoxurus hermaphroditus*) and small Indian civet (*Viverricula indica*) are also found. Primates such as common langur *(Semnopithecus entellus)* and rhesus monkey *(Macaca mulatta)*, and rodents/lagomorphs such as porcupine (*Hystrix indica)* and rufous-tailed hare *(Lepus nigricollis ruficaudatus)* occur in the park.

There are 15 villages (with human population of 6160 and livestock population of 11042) located inside the Tiger Reserve, of which seven are located in National Park and are due for relocation. Large numbers of domestic buffaloes (*Bubalus bubalis*) and a few domestic brahmini cattle (*Bos indicus*) are kept in the villages.

Capture and translocation of gaur

The action plan was prepared by the Madhya Pradesh Forest Department which envisaged capture and reintroduction of 20 gaur (15 adult females and 5 adult males) from KTR to BTR, Madhya Pradesh. It was proposed that after careful monitoring of the initial reintroduced stock, reintroduction of 30 more gaur to Bandhavgarh would be undertaken within two years to maintain a viable population of approximately 50+ animals [14].

Nineteen gaur, five males (three sub adults, two adults) and 14 females (one yearling, six sub adults, seven adults) were captured from KTR between 21st January and 27th January 2011 and re-introduced into BTR. Of these, 12 animals were fitted with radio collars: two adult males with GPS/satellite collars

and 10 individuals with VHF collars (one male and nine females). A holding Boma (enclosure for large herbivores; *Swahili* term, Mozambique) was designed at KTR where the immobilized animal would be released before eventually being loaded in the transport truck. The Boma was constructed of steel sections 2.5 m high by 3 m long made out of 50 mm x 75 mm x 3 mm rectangular hollow tubes. The Boma had three sliding gates 1.5 m wide and 2.5 m high sliding on a 3 m rail. The Boma had a loading ramp, which was a 3 m section made of solid pressed steel at 2.5 m height. The steel sections of the Boma beyond the sliding gate were covered with agri-mesh all the way up to the entrance of the truck. Since gaur are forest dwelling animals, this was done to give them a sense of having a space to hide in. Branches with foliage were hung on the wires running across the Boma. The Boma was divided into two compartments using bamboo mats and sliding gate, providing food, water and salt in the last compartment. Transport trucks and containers were designed according to the animals' needs. A stretcher was specially designed for carrying immobilized animals from the site of capture to the vehicle. A suitable site with good vegetation, cover and water was selected for the soft release of gaur at the borders of Tala and Magdhi ranges at BTR. The reintroduced gaur were released in a power-fenced 50 hectare plot in BTR. On 20th March 2011 the reintroduced gaur were released into the wild.

Home range

The radio-collared gaurs were monitored periodically through ground tracking, using "homing in" and "triangulation" techniques [29-31]. The satellite data up-link in both the satellite collars ceased functioning, one in August 2011 and the other in October 2011. Thereafter the gaur were tracked by VHF signals (ground tracking). The Minimum Convex Polygon (MCP) technique was used to determine the home-ranges of the gaur [32-34]. The interpretation and comparison of home-range size were measured by 100% MCP. The use of MCP was justified because of the sample size in a one year study period, and the temporally clustered nature of fixes that resulted in autocorrelation of results [35]. Accurate analyses using Fixed Kernel methods would not be suitable with this data set because they generally require larger samples with a more even distribution of the locations to maintain accuracy [36]. Minimum Convex Polygon (MCP) technique is one of the oldest techniques for home range estimation, comparable among species globally, and its inclusion as one or more methods of range calculation is therefore valuable [32-34]. Program CALHOME [37] and ArcGIS 9.2 (ESRI 2006) were used to estimate the home ranges of gaur. Home ranges of each individual in different seasons were estimated in the present study. Since gaur is a group living animal, the home ranges were also grouped by males and females to understand their overall seasonal home ranges.

Habitat use

All the radio telemetry locations from 12 radio-collared gaur were analyzed to evaluate the habitat use patterns. Season-wise gaur locations were plotted on the classified Landsat ETM+ imagery of BTR. On each collared location, the major vegetation and terrain type were recorded. Seven vegetation types were classified from Landsat ETM+ imagery: sal (*Shorea robusta*) forest, bamboo forest, open mixed forest, mixed forest, riparian forest, grassland and agriculture land [38]. Three major terrain types were categorised in the study area, *viz.*, flat, gentle slope and steep slope. Habitat use by gaur was estimated as the percent of locations found in each vegetation and terrain type. The 100% MCP home range represents the total area within which an animal has the opportunity to choose different vegetation types. Therefore, the availability of different vegetation types (percentage area) to a gaur was computed within its 100% MCP home range in a GIS domain [39]. Subsequently, habitat use (vegetation and terrain) of gaur in each season was computed using Bonferroni simultaneous confidence intervals and

Chi-square test [40], and the result was further validated by the preference rank of different vegetation types through compositional analysis [38] and Ivlev's electivity Index [41]. The analytical methods (Bonferroni simultaneous confidence intervals and compositional analysis) were conducted using the program RSW (Resource Selection Analysis Software for Windows) [42]. Each gaur was considered as a sample for statistical analysis [43].

Food habits

Data on food habits of gaur were collected by opportunistic sightings in all seasons whenever the animals were located using radio-telemetry. After direct observation through binoculars (8 X 40), on-site inspections were made to identify the food plants and parts eaten by gaur in the field. Total time spent for recording food habits data was 146 hrs in summer, 139 hrs in monsoon and 161 hrs in winter.

Results

Group size and composition

The group size of gaur varied from 1 to 19 individuals. The two gaur bulls (GM3 and GM5) were found solitary on many occasions (n=138) in all seasons (summer, monsoon and winter) and would join the family groups for a span of 10-15 days. The mean annual group size of gaur was estimated as 7.3 ± 0.8 (SE). The mean group size of gaur in summer was 9.5 ± 0.8 (SE), in monsoon 7.6 ± 1.4 (SE) and in winter 5.3 ± 1.2 (SE).

Home range of gaur

In total, 3972 locations of radio collared gaur were obtained, of which 1579 locations were males and 2393 locations were females (March 2011 to January 2012). The number of radio collared locations obtained and home ranges of individual gaur are given in Appendix 1. The month-wise utilized area (in km^2) by the gaur is given in Fig. 1.

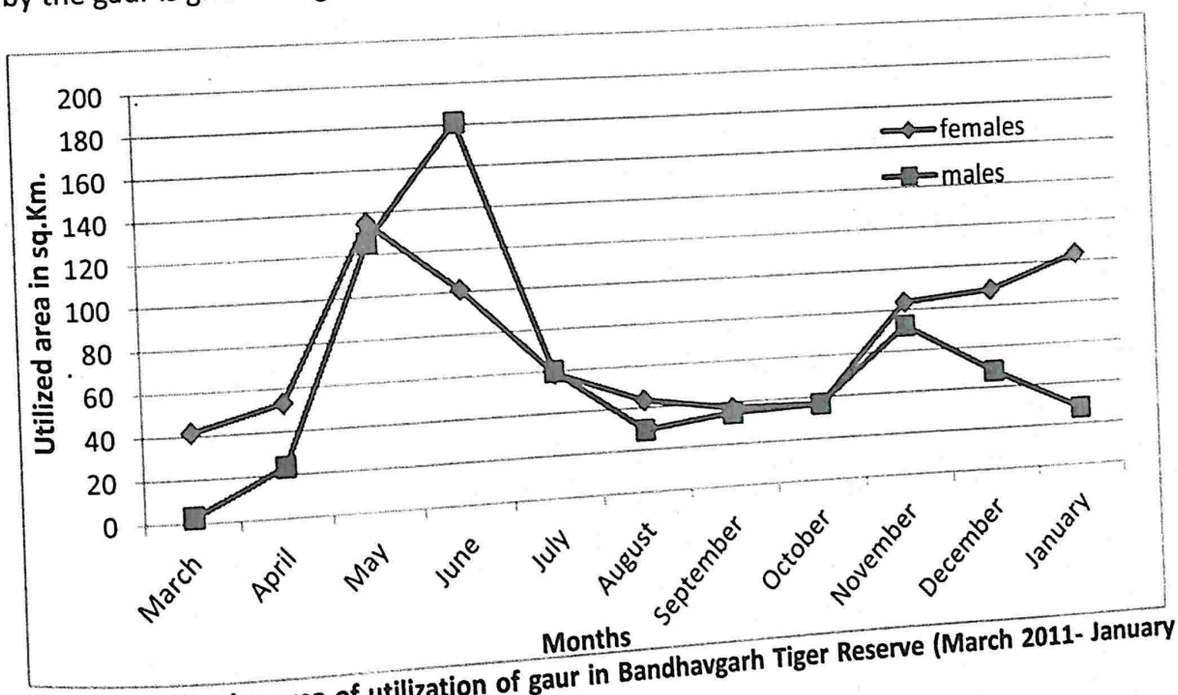

Fig. 1. Month-wise area of utilization of gaur in Bandhavgarh Tiger Reserve (March 2011- January 2012).

The estimated summer, monsoon and winter home ranges of the gaur were 290 km^2, 137.1 km^2 and 155 km^2 respectively. The overall home ranges of the males and females during the study period (March 2011 to January 2012) were 255 km^2 and 200 km^2, respectively, and the home-range overlap was 186 km^2 (Fig. 2). The summer (March 2011-June 2011) home ranges for males (n= 559) and females (n= 1338) were 231 km^2 and 161 km^2, respectively. In monsoon and post-monsoon (July 2011 to October 2011) the home ranges of males (n= 607) and females (n= 828) were 111 km^2 and 136 km^2 respectively. In winter (November 2011 to January 2012) the home ranges of males (n= 227) and females (n= 413) were 98 km^2 and 152 km^2 respectively (Fig. 3). The overall individual male home ranges varied from 135 to 142 km^2 and overall individual female home ranges varied from 32 to 169 km^2.

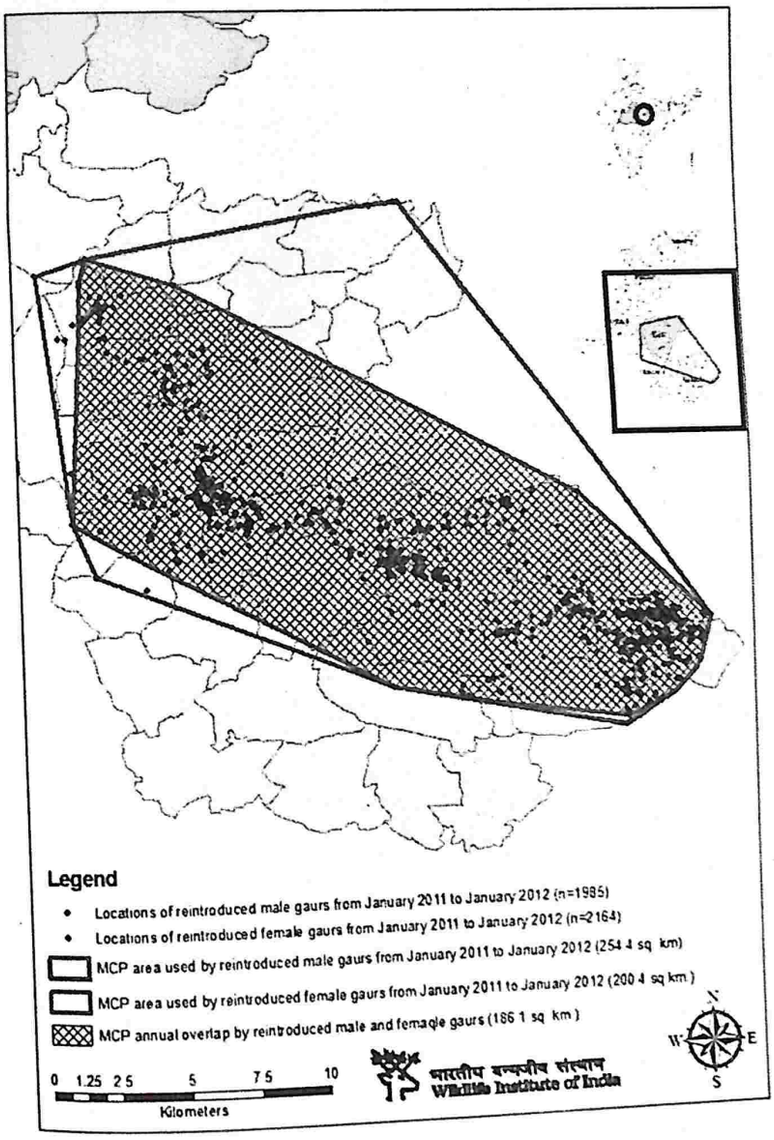

Fig.2. Overall home range of male and female gaur and their area of overlap in Bandhavgarh Tiger Reserve (March 2011- January 2012).

Natality and Mortality

There were four births during the study period, of which three calves survived. In total four animals died, of which two were collared females that died naturally. A sub-adult female was killed by a tiger on 4th June 2011. An un-collared female went missing from the park on 27th March 2011.

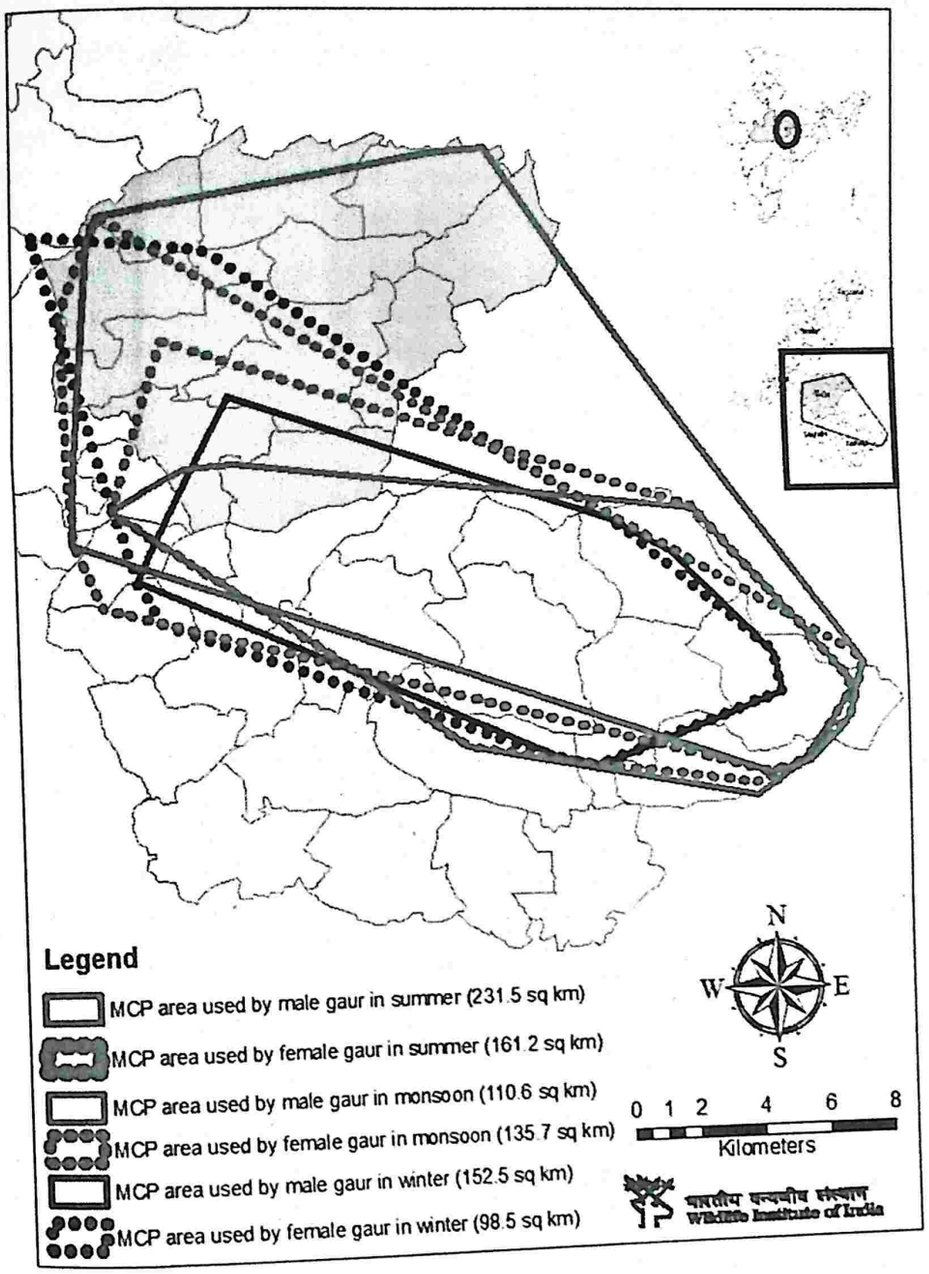

Fig. 3. Locations and home range of gaur season-wise (summer, monsoon and winter) in Bandhavgarh Tiger Reserve.

Habitat use by gaur

In summer, gaur used grassland ($P<0.001$) and sal forest ($P<0.001$) habitats more than their is availability; mixed forest ($P<0.001$), open mixed forest ($P<0.001$) and agricultural land ($P<0.001$) were less used than their availability; bamboo forest and riverine forest were used in proportion to their availability ($X^2=62.6731$, df= 6, $P<0.0001$, $\lambda= 0.0054$; Bonferroni simultaneous confidence intervals and Chi-square test) (Appendix 2). The summer habitat preference of gaur was in the following order: grassland> sal forest> bamboo forest> riparian forest> mixed forest> agricultural land> open mixed forest. In monsoon, gaur used bamboo forest ($P<0.001$) more than its availability; mixed forest ($P<0.001$), open mixed forest

($P<0.001$) and agricultural ($P<0.001$) land less than their availability; grassland, sal forest and riparian forest were used in proportion to their availability ($X^2=54.2351$, df= 6, $P<0.0001$, $\lambda= 0.028$; Bonferroni simultaneous confidence intervals and Chi-square test) (Appendix 2). The monsoon habitat preference of the gaur was in the following order: bamboo forest >grassland> sal forest> mixed forest> riparian forest> open mixed forest> agricultural land. In winter, gaur used bamboo forest ($P<0.001$) more than its availability; grassland ($P<0.001$), sal forest ($P<0.001$), open mixed forest ($P<0.001$) and agricultural land less than their availability; mixed forest and riparian forest were used in proportion to their availability ($X^2=33.0898$, df= 6, $P<0.0001$, $\lambda= 0.016$; Bonferroni simultaneous confidence intervals and Chi-square test) (Appendix 2). The winter habitat preference of gaur was in the following order: bamboo forest> mixed forest> riparian forest> sal forest> grassland> open mixed forest> agricultural land. Ivlev's electivity Index provided identical results as compositional analysis for ranking of preference of different habitats by gaur in BTR (Appendix 3).

Gaur mostly used flat terrain (65%) compared to gentle slope (28%) and steep slope (7%). The use of undulating terrain by gaur increased in monsoon and winter compared to summer. The use of terrain with a gentle slope went up from 25% in summer to 45% in winter. Gaur used flat terrain mostly in summer (71%) followed by monsoon (63%) and winter (51%). The steep slope was used by gaur mostly in monsoon (12%) followed by winter (4%) and summer (4%).

Food habits

In total 68 plant species were consumed by gaur (Appendix 4). Among the food plants eaten the number of tree species were maximum (n=28) followed by grass (n=21), herbs (n=10), shrubs (n=6) and climbers (n=3). The number of tree species in the diet of gaur was considerably higher in summer (n=22) than in monsoon (n=11) and winter (n=9). On the other hand, the number of grass species consumed by gaur was higher in monsoon (n=14) than in summer (n=10) and winter (n=9). Five incidences of de-barking of sal (*Shorea robusta*) and three incidences of de-barking of mahuwa (*Madhuca indica*) by the gaur were recorded in peak summer.

Discussion

The group size of gaur may range from 1 to 16 animals [1, 7, 44-46] and occasionally up to 40 individuals [47-48]. In Pench Tiger Reserve the observed mean group size of gaur was highest in winter (5.6 ± 0.42), followed by monsoon (4.6 ± 0.29) and summer (3.9 ± 0.14), and significant differences in the group sizes between summer and monsoon were reported [7]. In Mudumalai Tiger Reserve, the overall mean group size of gaur was 9.8 ± 7.6, while in dry season it was 8.7 ± 6.2 and in wet season it was 10.2 ± 7.9 [49]. In Parambikulam Wildlife Sanctuary the mean group size of gaur was 6.0 [50]. In the present study there was no significant difference observed in the gaur group size in different seasons. Hence, it can be assumed that different seasons played a negligible role in determining group size of gaur in BTR.

It was observed that the relocated gaur initially (March 2011 to June 2011) utilized an area of 290 km^2 after their reintroduction, and subsequently their ranges were reduced to 160 km^2 after exploration of new areas. In Pench Tiger Reserve, the home range of male gaur was 12.6 km^2 and 7.6 km^2 in summer and monsoon respectively, while in the present study, the home ranges of male gaur were much larger. The home ranges of female gaur in Pench Tiger Reserve were 7.2 km^2 and 13.8 km^2 in summer and monsoon respectively, while in the present study, the home ranges of female gaurs were much higher. The observed smaller home ranges of gaur males and females in all seasons in Pench Tiger Reserve may be attributed to the availability of food resources and water through the year [7]. In BTR, gaur were found to utilize grasslands more during summer and bamboo forest more in monsoon and winter. Gaur

is a generalist feeder but prefers to browse in dry season and predominantly graze in monsoon [49]. Riparian forest was used by the gaur according to its availability in all the seasons, because a number of perennial streams and artificial waterholes are found in riparian forests which serve as the major source of water in the Park. Open mixed forest was avoided by gaur in all seasons, as it lacks food resources and water. Agricultural land was avoided by gaur in all seasons because of anthropogenic disturbance. In Kanha Tiger Reserve gaur frequently used the meadows and low-lying areas during most part of the year except monsoon, when the animals moved up and dispersed into the hills [47]. In Bandhavgarh also the gaur used areas with steep slope more in monsoon than in summer and winter.

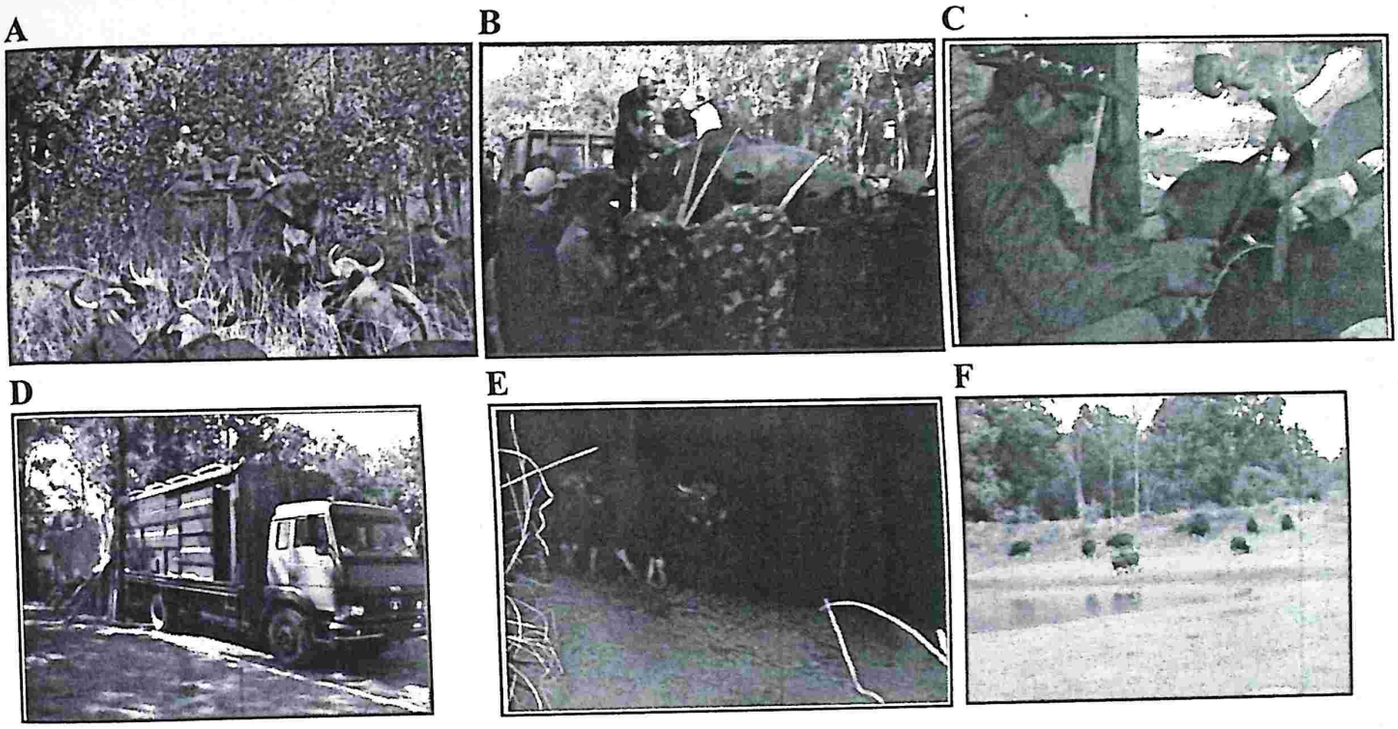

Fig. 4. A: Gaur Capture in Kanha Tiger Reserve; B: Gaur shifting into a small truck in Kanha Tiger Reserve; C: Fitting of radio-collar on gaur at Kanha Tiger Reserve.; D: Truck used to transport gaur from Kanha TR to Bandhavgarh TR.; E: Gaur released in an enclosure at Bandhavgarh Tiger Reserve; F: A herd of free ranging gaur in Bandhavgarh TR. PHOTO CREDITS – By Authors

Gaur have been reported to feed on the bark of trees such as *Adina cordifolia* and *Tectona grandis* in many areas throughout central India [47, 51]. In dry seasons, a high fibrous diet increases digestive efficiency by increasing the retention time of food in the gut [52] and also by increasing the turnover rate of the rumen content [53]. Incidences of de-barking of trees by gaur were rare in BTR, perhaps because even in summer considerable green foliage (trees/shrubs/bamboo) is available in the park.

Village relocation plays a major role in reducing the anthropogenic pressures on the forest area and is highly beneficial to wild animals [54]. In BTR there are 15 villages with large livestock populations located inside the National Park. Two villages in Kallwah range (Kallwah and Kumuruwah) from the National Park were successfully relocated in June 2011, which can set an example to expedite relocation of the remaining villages. Since August 2011, gaurs have been observed using these relocated village sites and hence creation of more such vacated habitats is vital for conservation of this species. Gaur are highly susceptible to transmission of infections from domestic livestock, and there are many records of populations of gaur succumbing to epidemics of foot and mouth disease (FMD), rinderpest and anthrax

in various parts of its distributional range [55]. There is a need to implement a wide vaccination program for the domestic livestock in and around BTR, to prevent the transmission of livestock diseases to gaur.

Implications for Conservation

The known extinction of gaur from three protected areas in India (Thattakad Wildlife Sanctuary, Kerala; Bhandhavgarh Tiger Reserve and Kanger Valley National Park, Madhya Pradesh) in the last two decades shows that this species is losing ground very fast and urgent measures are required to stem the process. Therefore, conservation requires active programs like reintroduction and reestablishment of important species in the areas where they have been recently lost, with or without habitat related interventions. Hence, the gaur reintroduction program in Bandhavgarh Tiger Reserve is an important attempt to re-establish a gaur population in an area that was once part of its historical range, from which it was locally extirpated in the recent past (Fig. 4). The present study takes a successful step towards the conservation of this large bovid, providing first-time information on ranging patterns of gaur and their degree of preferences for different vegetation and terrain types in different seasons. Such information will be very useful to the park administration for conservation of this endangered species and for habitat intervention, if needed. Per the proposed supplementation plan, 31 more gaur (nine males and 22 females) were reintroduced in BTR during March 2012 to establish a viable population of 50 animals.

A long-term study on ecological aspects such as ranging pattern, habitat use, food habits and predation of the reintroduced gaur in BTR will be crucial for the conservation and management of this endangered bovid. Also, the protocol prepared for gaur capture, chemical immobilization and transportation [14] will be highly useful for managers and conservationists in planning and execution of similar reintroduction program of mega-herbivores in their entire distributional range.

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Appendix 1. Home ranges of individual gaur in different seasons (summer, monsoon and winter) in Bandhavgarh Tiger Reserve.

Gaur ID	Summer		Monsoon		Winter	
	Home range (km^2)	Number of locations	Home range (km^2)	Number of locations	Home range (km^2)	Number of locations
GF1	44.5	196	108.7	207	83.4	81
GF3	44.5	194	108.7	207	95.9	81
GF5	33.1	119	xx	-	-	-
GF6	110.4	106	^^	-	45.8	86
GF7	106.5	106	xx	-	-	-
GF8	106.5	164	108.7	207	95.9	81
GF9	110.6	139	^^	-	^^	-
GF10	44.5	178	108.7	207	95.9	84
GF14	123.6	136	^^	-	^^	-
GM1	44.5	196	108.7	207	95.9	81
GM3	45.2	196	108.7	207	87.7	79
GM5	231.5	167	110.6	193	95.3	67

Note: GF= Gaur female; GM= Gaur male; 'xx'= animal dead; '^^'= animal was kept inside enclosure.

Appendix 2. Preference of different vegetation types by gaur in Bandhavgarh Tiger Reserve as shown by Bonferroni simultaneous confidence interval analysis.

Habitat types	Proportion use		Proportion available	Preference	Significance
	Lower limit	Upper limit			
Summer					
Agriculture land	0.0000	0.0112	0.0148	Used less than availability	
Bamboo forest	0.1412	0.1996	0.1852	Used in proportion to availability	
Grassland	0.3573	0.4332	0.0935	Used more than availability	P < 0.0001
Mixed forest	0.1406	0.1989	0.4535	Used less than availability	P < 0.0001
Open mixed forest	0.0087	0.0301	0.0659	Used less than availability	P < 0.0001
Riparian forest	0.0079	0.0287	0.0278	Used in proportion to availability	
Sal forest	0.1893	0.2537	0.1582	Used more than availability	P < 0.0001
Monsoon					
Agriculture land	0.0000	0.0000	0.0134	Used less than availability	
Bamboo forest	0.3525	0.4523	0.1758	Used more than availability	P < 0.0001
Grassland	0.0757	0.1386	0.0942	Used in proportion to availability	

Mixed forest	0.2556	0.3490	0.4745	Used less than availability	P < 0.0001
Open mixed forest	0.0000	0.0000	0.0557	Used less than availability	P < 0.0001
Riparian forest	0.0087	0.0401	0.0398	Used in proportion to availability	
Sal forest	0.1261	0.2014	0.1466	Used in proportion to availability	
Winter					
Agriculture land	0.0000	0.0000	0.0142	Used less than availability	
Bamboo forest	0.3201	0.4117	0.2035	Used more than availability	P < 0.0001
Grassland	0.0094	0.0386	0.0976	Used less than availability	P < 0.0001
Mixed forest	0.4248	0.5198	0.4314	Used in proportion to availability	
Open mixed forest	0.0000	0.0000	0.0494	Avoided	P < 0.0001
Riparian forest	0.0062	0.0323	0.0245	Used in proportion to availability	
Sal forest	0.0878	0.1493	0.1795	Avoided	P < 0.05

Appendix 3. Preference of different habitat types by reintroduced gaur in Bandhavgarh Tiger Reserve as shown by Ivlev's Selectivity Index analysis.

	Summer			Monsoon			Winter		
	Use	Availability	Ivlev's Index	Use	Availability	Ivlev's Index	Use	Availability	Ivlev's Index
Agriculture land	6.55	17.61	-0.45778	0	9.37	-1	0	11.39	-1
Bamboo forest	204.44	221.76	-0.04064	281.68	123.09	0.391803	292.71	162.77	0.285281
Grassland	474.29	111.39	0.619622	75.03	63.94	0.064482	19.2	78.09	-0.6053
Mixed forest	208.73	540.06	-0.45218	211.6	332.2	-0.22177	377.87	345.09	0.045341
Open mixed forest	23.26	78.53	-0.54258	0	38.96	-1	0	39.49	-1
Riparian forest	21.92	33.06	-0.20262	17.08	27.87	-0.24004	15.38	15.57	-0.11989
Sal forest	265.8	188.38	0.170461	114.61	102.61	0.055244	94.86	143.59	-0.20436

Appendix: 4. Food plants and parts eaten by gaur in Bandhavgarh Tiger Reserve (January 2011 to January 2012).

Family	Species	Parts eaten	Season
Trees			
Rutaceae	*Aegle marmelos*	Le	S
Leguminoseae	*Albizzia procera*	Le	S
Combretaceae	*Anogessus latifolia*	Le	S
Leguminoseae	*Bauhinia Racemosa*	Le	S
Burseraceae	*Boswellia serrata*	Le	M, W
Euphorbiaceae	*Bredelia retusa*	Le	S
Anacardiaceae	*Buchanania lanzan*	Le	M
Leguminoseae	*Butea monosperma*	Le	S, M, W
Meliaceae	*Chlorozylon swetiena*	Le	W
Fabaceae	*Cassia fistula*	Le	M
Poaceae	*Dendro calamus strictus*	Le	S, M, W
Ebenaceae	*Diospyros melanoxylon*	Le	S, M
Moraceae	*Ficus hispida*	Le	S
Bixaceae	*Flacourtia ramontchi*	Le	S, M
Tiliaceae	*Grewia tiliifolia*	Le	S
Apocynaceae	*Holarrhena antidysenterica*	Le	S
Sapotaceae	*Madhuca indica*	Le, Fu, Fl	S, M, W
Rubiaceae	*Mitragyna parviflora*	Le	S
Euphorbiaceae	*Phyllanthus emblica*	Le, Fu	S
Dipterocarpaceae	*Shorea robusta*	Le, Br	S, M, W
Myrtaceae	*Syzygium cumini*	Le, Fu	S, M
Combretaceae	*Terminalia chebula*	Le	W

Family	Species	Parts eaten	Season
Combretaceae	*Terminalia arjuna*	Le, Br	S
Combretaceae	*Terminalia tomentosa*	Le	S
Labiateae	*Vitex sps.*	Le	S
Apocynaceae	*Wrightia tinttoria*	Le	W
Rhamnaceae	*Zizyphus mauritiana*	Le, Fu, Br	S, M, W
Rhamnaceae	*Zizyphus xylopyra*	Le, Fu	S
Shrubs			
Colchicaceae	*Gloriosa sps.*	Le	M, W
Verbinaceae	*Lantana camara*	Le	S, M
Fabaceae	*Mimosa hamata*	Le	M
Arecaceae	*Phoenix acaulis*	Le	S
Rubiaceae	*Randia dumetorum*	Le	S
Lytharaceae	*Woodfordia floribunda*	Le	S, M, W
Herbs			
Asparagaceae	*Asparagas racemosus*	Sh	S
Cyperaceae	*Bulbostylis barbata*	Sh	M, W
Leguminoseae	*Cassia tora*	Sh	S, M
Cyperaceae	*Cyperus sps.*	Sh	M, W
Leguminosae	*Desmodium heterocarpus*	Sh	M, W
Fabaceae / Leguminosae	*Desmodium pulchellum*	Sh	M, W
Euphorbiaceae	*Euphorbia hirta*	Sh	S
Lamiaceae	*Leucas aspera*	Sh	M
Lamiaceae	*Leucas biflora*	Sh	M, W
Lamiaceae	*Ocimum tenuiflorum*	Sh	M
Grasses			
Amaranthaceae	*Achyranthes aspera*	Sh	M, W
Poaceae	*Andropogon sps.*	Sh	S

Family	Species	Parts eaten	Season
Poaceae	*Apluda mutica*	Sh	S
Poaceae	*Aristida sps.*	Sh	S
Poaceae	*Chloris dolichostachya*	Sh	S, M, W
Poaceae	*Cynodon dactylon*	Sh	S, M, W
Poaceae	*Dicanthium sps.*	Sh	S
Poaceae	*Digitaria setigera*	Sh	M, W
Poaceae	*Eragrostis tenella*	Sh	M
Poaceae	*Heteropogon contortus*	Sh	M, W
Poaceae	*Lipocarpha chinensis*	Sh	M
Cyperaceae	*Oplismenus sps.*	Sh	S
Poaceae	*Paspalidium flavidum*	Sh	M
Poaceae	*Saccharum spontaneum*	Sh	M, W
Poaceae	*Setaria glauca*	Sh	M
Poaceae	*Seteria pumila*	Sh	M
Poaceae	*Sorghum halepense*	Sh	S
Poaceae	*Sporobolous pulchelus*	Sh	W
Poaceae	*Themeda triandra*	Sh	S, M, W
Gramineae	*Thysanolaena maxima*	Sh	M
Poaceae	*Vetiveria zizanioides*	Sh	S, M, W
Climbers			
Rhamnaceae	*Zizyphus oenopila*	Le, Br	W
leguminoseae	*Butea supreba*	Le, Br	W
Fabaceae	*Bauhinia vahlii*	Le, Br	S, M, W

Le-Leaves; Br-Bark; Fr- fruits; Fl- Flowers; Sh- Shoot; S -Summer; M - Monsoon; W – Winter.