# ECOLOGY OF MEDIUM AND SMALL SIZED CARNIVORES IN SARISKA TIGER RESERVE, RAJASTHAN, INDIA

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**January-2011**

*Dedicated To*

*My Parents*

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# Certificate

This is to certify that the thesis of Ms. Shilpi Gupta entitled **"Ecology of medium and small sized carnivores in Sariska, Rajasthan, India"** is an original piece of work submitted to Saurashtra University, Rajkot (Gujarat) for the award of the **Doctor of Philosophy in Wildlife Science.**

Ms. Shilpi Gupta has put more than five term of research work embodied in this thesis under our guidance and supervision. This work presented in this thesis has not been submitted for any degree of any other University or Institution.

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# CONTENTS

**Acknowledgements**

**Contents** **i- iv**

**List of Tables** **v-vi**

**List of Figures** **vii-ix**

**List of Plates** **x**

**List of Appendices** **xi**

**Summary** **xii-xvii**

**CHAPTER 1 INTRODUCTION**

1.1 Background **1-4**

1.2 Literature Review **4 - 12**

1.3 Objectives **12**

1.4 Study Period **13**

1.5 Study Animals

1.5.1 Striped hyena (*Hyaena hyaena*) **13**

1.5.2 Jungle cat (*Felis chaus*) **14**

1.5.3 Jackal (*Canis aureus*) **14-15**

1.5.4 Ratel (*Mellivora capensis*) **15-16**

1.5.5 Common palm civet (*Paradoxurus hermaphrodites*) **16-17**

1.5.6 Small Indian civet (*Viverricula indica)* **17**

1.5.7 Common grey mongoose (*Herpestes edwardsii)* **18**

1.5.8 Ruddy mongoose (*Herpestes smithii)* **18-19**

1.6 Organization of thesis **19**

**CHAPTER 2 STUDY AREA**


2.1 General, location and topography **23**

2.2 Climate **24**

2.3 History and archaeological richness **24**

2.4 Major vegetation types

2.4.1 *Anogessius pendula* forest **25**

2.4.2 *Boswellia* forest **26**

2.4.3 *Acacia catechu* forest **26**

2.4.4 Miscellaneous forest **26-27**

2.5 Fauna **27**

2.6 Human settlements **28**

2.7 Tourism **28**

2.9 Intensive study area (ISA) **29**


**CHAPTER 3 POPULATION ESTIMATION**


3.1 Introduction **33 - 35**

3.2 Methods **35 - 43**

3.2.1 Sampling design for camera trap and track plots **35 - 36**

3.2.1 a) Analytical methods for the species where individual recognition is possible (striped hyena) **36-37**

3.2.1 b) Analytical methods for species abundance where individual recognition is not possible (jackal, jungle cat, civets, ratel and mongoose) **40 - 43**

3.3 Results **43- 57**

3.3a) Estimation of striped hyena population using capture-recapture analysis **43 - 49**

3.3b) Estimation of occupancy and abundances (camera trap) **50 - 52**

3.3b).1 Jungle cat **50**

3.3b).2 Jackal **50**

3.3b).3 Ratel **50**

3.3b).4 Palm civet **51**

3.3b).5 Small Indian civet **51**

3.3b).6 Common grey mongoose **51**

3.3b).7 Ruddy mongoose **52**

3.3c) Estimation of occupancy and abundance (track plots) **52- 54**

3.3c).1 Jungle cat **52**

3.3c).2 Jackal **53**

3.3c).3 Ratel **53**

3.3c).4 Civets **53**

3.3c).5 Mongoose **54**

3.3d) Estimation of abundance and occupancy of study animals (comparison between camera trap and track plots) **54**

3.4 Discussions **58- 62**

**CHAPTER 4 PREY ABUNDANCE AND FOOD HABITS**

4.1 Introduction **63- 65**

4.2 Methods **65-68**

4.2 a) Estimation of prey populations **65- 66**

4.2a) 1.Ungulates and ground birds **65**

4.2a) 2. Rodents **65- 66**

4.2 b) Food habits **66- 68**

4.3 c) Niche and dietary overlap between species **68**

4.3 Results **69- 84**

4.3a) Estimation of prey density **69- 73**

4.3a) 1. Density of ungulates and ground birds **69- 71**

4.3a) 2. Density of rodents **71- 73**

4.3b) Food habits **73- 82**

4.3b) 1. Food habits of striped hyena **73-77**

4.3b) 2. Food habits of jackal **78- 80**

4.3b) 3. Food habits of jungle cat **80- 82**

4.3c) Niche and dietary overlap between species **83- 84**

4.4 Discussions **83- 91**

**CHAPTER 5 HABITAT MODELLING**

5.1 Introduction **92- 94**

5.2 Methods **94- 99**

5.2.1 Species studied **94**

5.2.2 Presence and absence data **94**

5.2.3 Spatial data and digitization **94- 95**

5.2.4. Probabilistic model **96- 97**

5.2.4.1 Logistic Regression **98- 99**

5.3 Results **99- 111**

5.3.1 Habitat suitability model for striped hyena **99 -100**

5.3.2 Habitat suitability model for jungle cat **101 -102**

5.3.3 Habitat suitability model for jackal **103**

5.3.4 Habitat suitability model for ratel **104**

5.3.5 Habitat suitability model for palm civet **104 -105**

5.3.6 Habitat suitability model for small Indian civet **105**

5.3.7 Habitat suitability model for common grey mongoose **105**

5.3.8 Habitat suitability model for ruddy mongoose **106**

5.4 Discussions **112 -125**

References and Appendices **126 –155**

## LIST OF TABLES

**Table 3.1** An example capture matrix for all species detections…….**42**

**Table 3.2** Model selection criteria for individual hyena identified based on right flank…**45**

**Table 3.3** Density estimates of striped hyena from camera trap during summer (2008-2009) in Sariska Tiger Reserve..……..**48**

**Table 3.4** Density estimates of striped hyena from camera trap during winter (2007-2009) in Sariska Tiger Reserve……**48**

**Table 3.6** Abundance estimation of small carnivores from camera trap data based on Royle-Nichols Induced heterogeneity model during summer (2008-2009) in Sariska Tiger Reserve…….**55**

**Table 3.7** Abundance estimation of small carnivores from camera trap data based on Royle-Nichols Induced heterogeneity model during winter (2007-2009) in Sariska Tiger Reserve…….....**55**

**Table 3.8** Abundance estimation of small carnivores from track plot data based on Royle-Nichols Induced heterogeneity model during summer (2008-2009) in Sariska Tiger Reserve……**56**

**Table 3.9** Abundance estimation of small carnivores from track plot data based on Royle-Nichols Induced heterogeneity model during winter (2007-2009) in Sariska Tiger Reserve……..**56**

**Table 3.10** Abundance estimation of small carnivores in summer (2008-2009) using camera trap and track plot method…….**57**

**Table 3.11** Abundance estimation of small carnivores in winter (2007-2009) using camera trap and track plot method…….**57**

**Table 4.1** Density of potential prey species during winter and summer (2007-2009) in Sariska Tiger Reserve……**71**

**Table 4.2** Overall density estimates of rodent species during November 2007- June 2009 in Sariska Tiger Reserve……**74**

**Table 4.3** Density estimates of rodent species captured during winter (2007-2009) in Sariska Tiger Reserve…….**74**

**Table 4.4** Density estimates of rodent species captured during summer (2008-2009) in Sariska Tiger Reserve……**75**

**Table 4.5** Weight and body measurements of rodent species captured in both seasons in Sariska Tiger Reserve……**75**

**Table 4.6** Diet composition of striped hyena in summer and winter (2007-2009) in Sariska Tiger Reserve……**77**

**Table 4.7** Diet composition of golden jackal in summer and winter (2007-2009) in Sariska Tiger Reserve……**79**

**Table 4.8** Diet composition of jungle cat in summer and winter (2007-2009) in Sariska Tiger Reserve……**82**

**Table 4.9** Diet overlap amongst the study species during winter and summer (2007-2009) in Sariska Tiger Reserve…….....**84**

**Table 4.10** Densities of ungulate species in similar protected areas of India…….**86**

**Table 5.1** List of the variables used in Logistic Regression analysis……...**96**

**Table 5.2** Coefficient and variables used in Logistic Regression for striped hyena in Sariska Tiger Reserve……...**102**

**Table 5.3** Coefficient and variables used in Logistic Regression for jungle cat in Sariska Tiger Reserve……**102**

**Table 5.4** Coefficient and variables used in Logistic Regression for jackal in Sariska Tiger Reserve…….....**107**

**Table 5.5** Coefficient and variables used in Logistic Regression for ratel in Sariska Tiger Reserve……**107**

**Table 5.6** Coefficient and variables used in Logistic Regression for palm civet in Sariska Tiger Reserve…….….**108**

**Table 5.7** Coefficient and variables used in Logistic Regression for small Indian civet in Sariska Tiger Reserve….……**109**

**Table 5.8** Coefficient and variables used in Logistic regression for common grey mongoose in Sariska Tiger Reserve….……**110**

**Table 5.9** Coefficient and variables used in Logistic regression for ruddy mongoose in Sariska Tiger Reserve……..**111**

## LIST OF FIGURES

**Figure 2.1** Location, administrative boundary and intensive study area in Sariska Tiger Reserve, Rajasthan…….……**29**

**Figure 3.1** Two individual hyenas captured by camera trap (A) and (B) show Individual H4 with strips and spots on flanks identical in shape and pattern. While (C) shows a different individual H10 with stripes and spots on flanks being clearly different in shape and pattern……...**39**

**Figure 3.2** Camera trap locations in a sampled area in Sariska Tiger Reserve, Rajasthan during December 2008 - July 2009……**47**

**Figure 3.3** Number of striped hyena photographed and number of hyena photographs with increasing number of sampling occasions to evaluate sampling adequacy and trap shyness……...**47**

**Figure 3.4** Individual capture rates of striped hyena during winter (2007-2009) in Sariska Tiger Reserve (n=105)……...**49**

**Figure 3.5** Individual capture rates of striped hyena during summer (2008-2009) in Sariska Tiger Reserve (n=85)……**49**

**Figure 4.1** Locations of line transects (n=24) in the intensive study area of Sariska Tiger Reserve, Rajasthan……**70**

**Figure 4.2** Diagrammatic representation of rodent traps placed in a form trapping web around each trapping location in the intensive study area.....**67**

**Figure 4.3** Relationship between contributions of seven prey species in striped hyena diet with number of scats examined from Sariska Tiger Reserve during (November 2007 to June 2009)…….……**76**

**Figure 4.4** Mean frequency of occurrence of prey species in the diet of striped hyena in winter (n=170) and summer (n=107) in Sariska Tiger Reserve……**77**

**Figure 4.5** Relationship between contributions of ten prey species in golden jackal diet with number of scats examined from Sariska Tiger Reserve during (November 2007 to June 2009)…..……...**79**

**Figure 4.6** Mean frequency of occurrence of prey species in the diet of golden jackal in winter (n=107) and summer (n=172) in Sariska Tiger Reserve……**80**

**Figure 4.7** Relationship between contributions of nine prey species in jungle cat diet with number of scats examined from Sariska Tiger Reserve during (November 2007 to June 2009)……..……**81**

**Figure 4.8** Mean frequency of occurrence of prey species in the diet of jungle cat in winter (n=180) and summer (n=107) in Sariska Tiger Reserve……..……..…**82**

**Figure 4.9** Overall Niche overlap between predators in Sariska Tiger Reserve (2007-2009)…….…….……..…..**83**

**Figure 5.1** Flow chart depicting the process followed to build model and preparation of distribution map for the study species…….,….….……**97**

**Figure 5.2** Habitat suitability map of striped hyena in the intensive study area of Sariska Tiger Reserve…….…….**115**

**Figure 5.3** Concordance analysis depicting sensitivity and specificity in different cut-off values for striped hyena……..…..…..**100**

**Figure 5.4** Habitat suitability map of jungle cat in the intensive study area of Sariska Tiger Reserve……..…….**116**

**Figure 5.5** Concordance analysis depicting sensitivity and specificity in different cut-off values for jungle ca**t**……..…….**101**

**Figure 5.6** Habitat suitability map of jackal in the intensive study area of Sariska Tiger Reserve…….…….**117**

**Figure 5.7** Concordance analysis depicting sensitivity and specificity in different cut-off values for jackal……..…..**103**

**Figure 5.8** Habitat suitability map of ratel in the intensive study area of Sariska Tiger Reserve…….…**119**

**Figure 5.9** Concordance analysis depicting sensitivity and specificity in different cut-off values for ratel…….**104**

**Figure 5.10** Habitat suitability map of palm civet in the intensive study area of Sariska Tiger Reserve…….**121**

**Figure 5.11** Concordance analysis depicting sensitivity and specificity in different cut-off values for palm civet……**108**

**Figure 5.12** Habitat suitability map of small Indian civet in the intensive study area of Sariska Tiger Reserve……..……...**123**

**Figure 5.13** Concordance analysis depicting sensitivity and specificity in different cut-off values for small Indian civet……..…**109**

**Figure 5.14** Habitat suitability map of common grey mongoose in the intensive study area of Sariska Tiger Reserve…….……...**124**

**Figure 5.15** Concordance analysis depicting sensitivity and specificity in different cut-off values for common grey mongoose……...**110**

**Figure 5.16** Habitat suitability map of ruddy mongoose in the intensive study area of Sariska Tiger Reserve…….**125**

**Figure 5.17** Concordance analysis depicting sensitivity and specificity in different cut-off values for ruddy mongoose……...**111**

## LIST OF PLATES


| | | Page. No |
|---|---|---|
| **Plate 1a** | Striped hyena (*Hyena hyena*) | **20** |
| **Plate 1b** | Jungle cat (*Felis chaus*) | **20** |
| **Plate 2a** | Golden jackal (*Canis aureus*) | **21** |
| **Plate 2b** | Ratel (*Mellivora capensis*) | **21** |
| **Plate 3a** | Palm civet (*Paradoxurus hermaphroditus*) | **22** |
| **Plate 3b** | Common Indian grey mongoose (*Herpestes edwardsii*) | **22** |
| **Plate 4a** | *Anogessisus pendula* found on lower hill slopes. | **30** |
| **Plate 4b** | *Phoenix sylvestris* a typical vegetation along the forest nallahs. | **30** |
| **Plate 5a** | Open Scrubland with small patches of *Capparis sepieria* | **31** |
| **Plate 5b** | Human disturbance around open scrubland. | **31** |
| **Plate 6a** | Migratory birds during winter at Kankawas Lake | **32** |
| **Plate 6b** | Pilgrims visiting Pandupol temple. | **32** |

## LIST OF APPENDICES


| | | Page No. |
|---|---|---|
| **Appendix 1** | Script used for comparison between closeness of two methods (Camera trap and track plot) in Program R. | **151** |
| **Appendix 2** | Various rodents species captured in Sariska Tiger Reserve, Rajasthan. | **152-154** |
| **Appendix 3** | Scats of study species in Sariska Tiger Reserve. | **155** |

## SUMMARY

To assess wildlife population trends, scientifically based monitoring programs must be carried out. For species that occur in very low densities, nocturnal and shy, direct observations of animals are not possible. Moreover, monitoring cryptic wildlife species is often difficult or impossible. A new generation of camera traps and the use of well developed capture-recapture models have led to an increase in the use of remote surveying and monitoring methodologies for nocturnal species. Population estimates can be done for individually identifiable cryptic nocturnal species through camera trap. However, recent advances in 'occupancy modeling' of animal presence data derived from photographic captures might provide solutions to the problems of monitoring such species. A specific occupancy approach – the Royle and Nichols (2003) model, allows reliable estimation of abundance at best, and of an index of abundance or occupancy rate at the least, without the need for individual identification of animals. It may be used to estimate abundance of elusive and nocturnal medium and small sized species with photographic capture data derived using camera traps. In this study, both capture - recapture method and Royle -Nichols (2003) approach was applied to photographic capture trap data to estimate density and abundance of nocturnal cryptic species. Scat analysis was used to understand food habits and presence/absence data obtained from camera trapping was used to develop habitat suitability map for the study species such as striped hyena (*Hyaena hyaena*), jungle cat (*Felis chaus*), jackal (*Camis aureus*), ratel (*Mellivora capensis*), palm civet (*Paradoxurus hermaphroditus*), small Indian civet (*Viverricula indica*), common grey mongoose (*Hespestes edwardsii*) and ruddy mongoose (*Hespestes smitii*).

The study was carried out in Sariska Tiger Reserve (STR), western Rajasthan, India, (79° 17' to 76°34'N, 27° 5' to 27° 33' E) from November 2007 to June 2009. The total area of the Tiger

Reserve is 881 $km^2$, with 274 $km^2$ as notified National Park. The vegetation of Sariska correspond to (1) Northern tropical dry deciduous forests (subgroups 5B; 5/E1 and 5/E2) and Northern Tropical Thorn forest (subgroup 6B) (Champion and Seth, 1986). Wild herbivores found in Sariska are chital (*Axis axis*), sambar (*Rusa unicolor*) and nilgai (*Boselaphus tragocamelus).* Omnivores found are wild pig (*Sus scrofa)* and jackal *(Canis aureus)*. The park supports various carnivore species such as five reintroduced tiger (*Panthera tigris*), leopard (*Panthera pardus*) and striped hyena *(Hyaena hyaena).* Small carnivores found are jungle cat (*Felis chaus*), desert cat (*Felis selvestris*), common grey mongoose *(Herpestes edwardsii*), ruddy mongoose (*H.smithii*), palm civet (*Paradoxurus hermaphroditus*), small Indian civet (*Viverricula indica*) and ratel (*Mellivora capensis*). Rhesus macaque (*Macaca mulatta*) and common langur (*Semnopithecus entellus*) are the two primates found here. Porcupine (*Hystrix indica*) and rufous tailed hare (*Lepus nigricollis ruficaudatus*) also occur in Sariska. Eleven species of small rodents were identified during present study *viz* Indian gerbil (*Tatera indica*), Indian bush rat (*Golunda elliotii*), spiny tailed mouse (*Mus platythrix*), house mice (*Mus musculus*), little Indian field mice (*Mus booduga*), long tailed tree mouse (*Vandeleuria oleracea*), sand coloured Rat (*Millardia gleadowi*), soft fur field rat (*Millardia meltada*), brown rat (*Rattus norvegicus*), house rat (*Rattus rattus*) and pygmy gerbil (*Gerbillus nanus)*. There are 32 villages within Sariska TR. Due to presence of villages located inside and on the periphery of the Tiger Reserve, large number of buffaloes, goats, sheep and cattle also occur within the park.

The study was conducted in an intensive study area of 144 $km^2$ within the National Park area in two different seasons winter (November to February) and summer (March to June) for two successive years during 2007 to 2009 with the following objectives:

1 To estimate the abundance of medium and small sized carnivores such as striped hyena, jackal, jungle cat, civets and mongoose.

2 To study the prey availability and food habits of medium and small sized carnivores and

3. To assess the habitat suitability for these carnivores.

In total 100 locations were selected for placement of camera traps in six different blocks in the intensive study area. Each camera trap was placed in 1 x 1 $km^2$ grid and ran for 25 consecutive trap nights per block with total sampling period amounting to 2500 trap nights per season. The stripe patterns of hyena captured in remote camera were used for individual identification and estimation of population by capture - recapture technique. Royle and Nichols (2003) approach was used for estimation of abundance of species which could not be individually identified such as jungle cat, jackal, ratel, civets and mongoose. The track plots were laid in all locations where the camera traps were placed in 1x1 $km^2$ grid and monitored at regular intervals. Presence /absence data for each carnivore species was recorded on each track plot and abundance for each species was derived using PRESENCE program. Line transect method was adopted to estimate density of potential prey species such as ungulates and ground dwelling birds. In total, 24 transects were laid in the intensive study area. The length of each transect varied from 1.4 km to 2.0 km. All transects (72.0 km) were walked thrice in the early morning between 0630 hrs and 0930 hrs. The total effort was 145 km in each season. Density of rodents was estimated using trapping web design at twelve different sites in the intensive study area. In total, 4920 trap nights were employed at twelve different sites for 10 days. Each trap station was established every 10 m apart in the sampling area. The overall trap density was one trap/10 $m^2$. Analysis of scats (faeces) was used to study the food habits of study species. In total, 277 scats of striped hyena, 279 scats of golden jackal and 287 scats of jungle cat were collected during study period and analyzed for food remains. Frequency of occurrence (proportion of total number of scats in which prey item

was found) and percent occurrence (number of times a particular prey item occurred in the scat) in terms of percentage of prey remains were quantified in the diet of each species. Diet overlap among the three carnivores in each season was calculated using Pianka's index. Habitat suitability map of each species was prepared using presence/absence data obtained from camera trap with 11 macro habitat variables in the intensive study area. Each variable was selected to develop suitability model and further validation of logistic equation. The equation was then transferred to Geographical Information System (GIS) and probability of occurrence of each species was predicted for the intensive study area.

The total sampling effort for 25 days of trapping over 100 trapping stations amounted to 2500 trapping nights in an effective trapping area of 224.22 $km^2$ yielded 104 captures of 29 hyena individuals in winter and 83 captures of 21 hyena individuals in summer. The estimated density of striped hyena based on spatial explicit model IP dens was 18.7 ($\pm 5.8_{SE}$)/100 $km^2$ in winter and 13.5($\pm 5.2_{SE}$)/100 $km^2$ in summer. The reported hyena density in the study area was high as compared to other studies in India and Africa. This may be attributed to availability of high ungulate and domestic livestock i.e. of 105 animal/$km^2$ and 222 animals/$km^2$ respectively in study area, availability of livestock carcasses near villages and road kills of wild prey. Density of jungle cat was estimated to be 13.6 /100 $km^2$ in summer and 24 /100 $km^2$ in winter. Similarly, the estimated density of other carnivores were: jackal 4.2 /100 $km^2$ in summer and 4.1 /100 $km^2$ in winter, ratel 4.0 /100 $km^2$ in summer and 1.2 /100 $km^2$ in winter, palm civet 17.5 /100 $km^2$ in summer and 8.5 /100 $km^2$ in winter, small Indian civet 20.8 /100 $km^2$ in summer and 11.5 /100 $km^2$ in winter, ruddy mongoose 15.7 /100 $km^2$ in summer and 14.7 /100 $km^2$ in winter and common grey mongoose 11.8 /100 $km^2$ in summer and 4.7 /100 $km^2$ in winter. There was no significant difference observed in the abundance of these carnivores between seasons. Royle and

Nichols (2003) method provided a novel approach to estimate the abundance of study species whose elusive traits have so far, prevented non-invasive abundance estimation using conventional technique.

In contrast to most dietary studies of medium and small sized carnivores in India and elsewhere, results from this study showed the dominance of mammalian prey species in the diet of striped hyena, golden jackal and jungle cat. These carnivores utilized broad diet during the study period in STR. For striped hyena, chital and hare were the seasonal prey consumed while livestock (cattle and goats) are supplementary food item, while peafowl was utilized opportunistically. The *Zizyphus* fruits were consistently eaten by golden jackal in both seasons. Chital were seasonal food items for golden jackal. Small mammals like hare and rodents were eaten consistently while peafowl and cattle were opportunistic availability of these species in STR in diet of golden jackal. In the diet of jungle cat, rodents were the most consistently eaten prey species and hare were the seasonal prey item while utilization of cattle and chital by jungle cat may be attributed due to scavenging on large carnivore kills during winter and summer.

Overall niche breath for three carnivores showed that jackal (0.5) had the narrowest dietary niche followed by striped hyena (0.7) and jungle cat (1.7). Results from Pianka's Index (1981) revealed that the overall diet overlap was high between hyena and jackal (0.75) and medium between jungle cat and jackal (0.52) and hyena and jungle cat (0.49). The seasonal diet overlap amongst three carnivores was found high in summer between hyena and jackal (0.72) and medium between hyena and jungle cat (0.40) and jackal and jungle cat (0.47). Winter diet showed medium dietary overlap between hyena and jackal (0.44) and hyena and jungle cat (0.41) and low dietary overlap between jackal and jungle cat (0.28).

Availability of medium and high suitable habitat for the study species in the intensive study area of 144 $km^2$ was found to be very low for some species like striped hyena (18%), small Indian civet (24%), ratel (25%), ruddy mongoose (13%) and palm civet (6%) while high for jackal (56%), common grey mongoose (56%) and jungle cat (40%). Logistic Regression analysis revealed overall prediction accuracy which depicting the species presence in the intensive study area was 72% for striped hyena, 80.3% for jungle cat, 68.1% for jackal, 64.8% for ratel, 77.5% for palm civet, 85.9% for small Indian civet, 80.3% for common grey mongoose and 69% for ruddy mongoose. Validation based on independent variables predicted probability of occurrence and habitat suitability for each species through logistic models was best fitted for the intensive study area. The results of this study presented both numerically and also in the form of habitat suitability maps for all the study species in the study area. These finding have potential to develop basis for managing areas for these medium and small sized carnivores in Sariska and other similar habitat in semi arid zone.

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

India, in spite of fast depletion of wildlife during present century, still has a remarkable variety of large as well as small mammals. But it is all a fact that wildlife represents the country's fastest vanishing asset. However the decline of large, medium and small carnivores is a global concern. Very little is known about the biology of medium and small sized carnivores such as caracal (*Caracal caracal*), jungle cat (*Felis chaus*), striped hyena (*Hyaena hyaena*), golden jackal (*Canis aureus*), civets and mongoose in India. Most of the tropical countries are rich in the number of carnivore species they harbour (Corbett and Hill, 1992). India is especially rich in species diversity mainly, because of the location in convergence of three Bio-geographic realms-Indomalayan, Paleartic and Ethopian (Mackinnon and Mackinnon, 1974; Mani, 1974). With 55 species of carnivores distributed throughout India, several protected areas in the country have two or more sympatric carnivores (Johnsingh, 1986). Large mammals, particularly carnivores, exhibit these characteristics, but their decline in fragmented systems has received little attention (Beier, 1995; Noss *et al.,* 1996; Reed *et al.,* 1996). The disappearance of top predators from fragmented systems may have community-wide implications (Sovada *et al.,* 1995; Ralls and White, 1995; Terborgh *et al.,* 1999) and may lead to the ecological release of mesopredators (Sargeant *et al.,* 1983; Soule *et al.,* 1988; Sovada *et al.,* 1995; Crooks and Soule, 1999).

Among medium and small carnivores, jungle cat is the most common wild felid in India, inhabiting a wide variety of habitats. Its global distribution is centred in India (IUCN, 1996). Two other carnivores of African origin are hyena and jackal (Prater, 1980). Both are more of scavengers, feeding off the remains of tiger and leopard kill. Hyena occurs in open plains, deserts, rocky scrub covered hills and nullahs, grass and open jungles, and usually avoid the interior of heavy forests and live more commonly in drier parts of India (Prater, 1980). They are placed in schedule III of Indian Wildlife Protection Act (1972). The golden jackal is fairly common in India, occurs widely, inhabiting a variety of habitats, including degraded open areas around human habitation, listed in Schedule III of Indian Wildlife Protection Act (1972). Ratel (*Mellivora capensis*) in India lives in desert and in the dry and moist deciduous zones avoiding regions of heavy rainfall. They prefer hilly broken country where shelter is easier to find (Prater, 1980). They are placed in Schedule I of Indian Wildlife Protection Act (1972). Palm civet (*Paradoxurus hermaphroditus)* and small Indian civet *(Viverricula indica)* prefer well-wooded forests, plantations areas and also found close to human habitation on roofs and in homesteads (Prater, 1980). They are placed in Schedule II of Indian Wildlife Protection Act (1972). Common grey mongoose (*Herpestes edwardsii*) prefers open forest and scrubland, while ruddy mongoose (*Herpestes smithii*) prefers forested areas with rocky slopes. Both are placed in Schedule IV of Indian Wildlife Protection Act (1972).

To assess wildlife population trends, scientifically based monitoring programs must be carried out. For species that occur in very low densities, nocturnal and shy, direct observations of animals are not possible. Moreover, monitoring cryptic wildlife species such as top carnivores is often difficult or impossible. The basic ecology of lesser

carnivores makes their populations inherently difficult to monitor (Mukherjee, 1998). Moreover, the population trends of some small carnivores are even more difficult to monitor effectively.

A new generation of camera traps and the use of well-developed capture-recapture models have led to an increase in the use of remote surveying and monitoring methodologies for terrestrial species (Karanth, 1995; Jhala *et al.*, 2008). Population estimates can now be made for individually identifiable species and relative abundance indices can be calculated for other species. Camera traps have also enabled more accurate estimates of species richness, species diversity, total mammalian biomass, spatial variation and population size of some mammals. With long-term use, camera traps enable monitoring of changes in populations over time. An earlier study that was carried out in Sariska on lesser carnivores focused on the habitat use and food habits (Mukherjee, 1998). The present research conducted in Sariska Tiger Reserve (STR), Rajasthan, western India from November 2007 to June 2009, was aimed to study the population in terms of abundance using camera traps and track plots for medium and small carnivores such as striped hyena (*Hyaena hyaena*), jackal (*Canis aureus*), jungle cat (*Felis chaus*), ratel (*Mellivora capensis*), palm civet (*Paradoxurus hermaphroditus*), small Indian civet (*Viverricula indica*), common Indian grey mongoose (*Herpestes edwardsii)*, and ruddy mongoose (*Hespestes smithii*), their food habits by scat analysis and evaluation of habitat suitability for each study species in STR. Very few studies were conducted on medium and small sized carnivores in the Indian sub-continent covering aspects such as food habits, habitat use and ranging patterns (Riley, 1913; Nuryatdinov and Reimov, 1972; Acharjyo and Mohapatra, 1976; Kruuk, 1972, 1976, 1986; Mukherjee, 1989; Karanth,

1987; Chakarborty *et al.*, 1988; Bellousova, 1993; Choudhury, 1994; Ramakantha, 1994; Madusudan, 1995; Yoganand and Kumar, 1995; Gokula and Ramachandran, 1996; Christopher and Jayson, 1996; Choudhury, 1997a, b; Mukherjee, 1998; Pradhan, 1998, 1999; Datta, 1999; Mudappa, 1998, 2001; Pradhan *et al.*, 2001; Rajamani *et al.*, 2003; Mukherjee *et al.*, 2004; Gupta, 2006; Choudhury, 1999, 2008; Choudhary *et al*., 2008; Gupta *et al.*, 2009; Singh, 2008; Harihar *et al.*, 2010; Gupta *et al.*, 2010; Ogurlu *et al.*, 2010). Radio-collared brown palm civets in tropical rainforests were studied much in detail (Van Schaik and Griffiths, 1996; Mudappa, 1998, 2001, 2002; Mudappa and Chellam, 2001; Mudappa *et al*., 2007). Very few studies on medium and small sized carnivores are available from south East Asia: (Pocock, 1939, 1941; Hutton, 1949; Glanz, 1977; Finn, 1980; Jerdon, 1984; Tehsin and Tehsin, 1988; Schreiber *et al*., 1989; Duckworth *et al.*, 1994; Van Rompaey, 1995; Gannon and Foster, 1996; Tehsin, 1996; Duckworth, 1997; Loveridge and Mac Donald, 2002; Parameter *et al.*, 2003; Wagner, 2006; Grassman *et al.*, 2006; Holden, 2006; Long and Hoang, 2006; Wagner *et al.*, 2008 and Chen *et al.*, 2009).

## 1.2 LITERATURE REVIEW

### 1.2.1. Carnivore Community:

Carnivore species help control prey populations (Schaller, 1967, 1972; Smuts, 1978) and influence prey behaviour (Rice, 1986; Schaller, 1967, 1972). As parks and sanctuaries become more restricted and subject to greater human use, carnivores are often more severely affected by developmental activities than other groups of animals (Johnsingh, 1986). Therefore, an understanding of the structure and dynamics of carnivore communities is essential for tropical forest management and conservation. Despite some

excellent research conducted on large Asian carnivores and predator-prey relationships in the protected areas of India (Schaller, 1967; Johnsingh, 1983; Ramachandran *et al.,* 1986; Rice, 1986; Karanth, 1995; Jhala *et al.,* 2008), Nepal (Seidensticker, 1976; Sunquist, 1981) and Sri Lanka (Eisenberg and Lockhart, 1972; Muckenhirn and Eisenberg, 1973) there has been little investigation into south-east Asian medium and small carnivore communities. Efficient and reliable methods for rapid assessment of species richness and abundance are crucial to determine conservation priorities. Tracking animals by following footprints in dust, mud, sand or snow, is probably the oldest known method of identifying mammal's presence in an area (Bider, 1968).

In the past years, new surveying techniques, using remote triggered photographic camera units, have become popular. The method is efficient for inventories, especially for cryptic animals, as well as for population studies of species for which individuals can be recognized by individual identifying marks (Karanth, 1995; Carbone, 2001). Camera trapping has also been widely used in population studies of tigers (Karanth and Nichols, 1998; Jhala *et al.,* 2008) and bears (Kucera and Barrett, 1993; Mace *et al.,* 1994). Capture–recapture models using photo-marked individuals have also been proposed for monitoring populations of large carnivores (Mace *et al.,* 1994; Karanth and Nichols, 1998). Camera traps are ideal for identifying the species inhabitating a particular area, monitoring relative and absolute abundance of the species and studying the activity pattern (Karanth, 1995; Van Schaik and Griffiths, 1996; Miura *et al.,* 1997; Karanth and Nichols, 1998; Koreth and Kroll, 2000; Mc Coullagh *et al.,* 2000; Kawansishi, 2002; Kawansishi and Sunquist, 2004; O'Brien *et al.,* 2003). Carbone *et al.,* (2001) suggested that camera traps can be used to estimate densities of animals which cannot be individually identified.

To monitor shy or secretive species, indirect methods such as camera traps have been used. Mark - recapture models have been employed to quantitatively monitor populations of cryptic, wide ranging carnivores when individuals of the species can be identified (Karanth and Nichols, 2002; Jhala *et al.,* 2008). Mark-recapture technique was originally developed for small mammal population estimation (Otis, 1978). While it is fairly time consuming, labour intensive, and costly, it does provide a reliable estimate of population size (i.e., absolute abundance) for many carnivore species, including racoons (Kaufman, 1982), felids (Schaller, 1972; Kruuk, 1986), and striped hyena (Kruuk, 1972; Sillero *et al.,* 1996a; Singh, 2008; Harihar *et al.,* 2010; Gupta *et al.,* 2010). Capture- recapture can provide relatively accurate estimates of population size if sample sizes are adequate, data collection techniques are unbiased, and the basic assumptions for the population estimator are not violated (Caughley, 1977).

This method involves capturing and marking individuals, then re-capturing a number of marked individuals again and estimating population size based upon the ratio of marked to unmarked animals recaptured using one of several models (Seber, 1982; Pollock, 1983). Concurrently, prey populations can also be monitored using camera photographs. Thus, camera trapping furnishes an important non-invasive tool for assessing patterns of abundance throughout space and time and their link with activity patterns, habitat use and reproductive information which are key elements for wildlife conservation. Camera trapping is an efficient non-intrusive method in almost any field conditions (Yasuda, 2004). The advantages also involve the accuracy of species determinations, as well as the possibility of evaluating age, sex, population structure and density in large tracts of land (Mace *et al.,* 1994). Silveira *et al.,* (2003) studied 14 species of mammals in Emas

National Park (ENP) central-western Brazilian plateau using camera trap technique. They compared the efficiency rates between the camera trap and track plots and both the methods converge to relative similar abundance rates.

Scent stations have been widely used as a mean to monitor trends in carnivore populations. Following methods developed by Linhardt and Knowlton (1975), many studies have attempted to validate this method as an accurate means of determining abundance and trends of carnivore populations (Clark and Campbell, 1983; Conner, 1982; Smallwood and Fitzhugh, 1995; Woelfl and Woelfl, 1997; Sargeant *et al.*, 1998). Despite the numerous attempts to relate the number of carnivore visits to scent stations as a measure of carnivore abundance, many discrepancies still exist as to how these methods can be standardized. Several studies have argued the importance of transect interval, station interval within transect, type of station substrate, type of scent lure or bait and the number of sampling nights (Roughton and Sweeny, 1982). Recognizing these limitations, track surveys have been shown to be effective measures of distribution and relative abundance of mammalian species (Conner, 1982). Sargeant *et al.*, (1998) made several recommendations regarding sample unit specification and interpretation of scent station surveys. Mukherjee (1998) used scent stations for studying the relative abundance of sympatric lesser carnivores in Sariska Tiger Reserve.

**1.2.2. Prey Community (ungulates, birds and rodents):**

Wildlife managers in India have claimed significant success in increasing the ungulates densities in Protected Area, through curbing the forest fires, logging, poaching, and livestock grazing along with the development of water resources (Panwar, 1987). However due to lack of necessary professional skills they have so far not collected

quantitative data using valid methods to substantiate these claims or to formulate management strategies (Karanth, 1987). Studies by Schaller (1967), Berwick (1976), and Johnsingh (1983) in India, Eisenberg and Lockhart (1972) in Sri Lanka and Dinerstein (1980), Mishra (1982) and Tamang (1982) in Nepal have estimated populations of herbivore assemblages in the region and generated some preliminary estimates of population parameters. However, even these studies have often relied on non standard, subjected methodologies, and have not benefited from the recent advancement in line transect methods (Sen *et al.,* 1974; Burnham *et al.,* 1980; Drummer and Mac Donald, 1987). Sankar (1994), Karanth and Sunquist (1995), Khan *et al.,* (1996) estimated large herbivores population using line transect method in Sariska, Nagarhole and Gir respectively. Line transect sampling has widely been used in wildlife research for estimating the animal densities and numbers. Density estimation from line transect is practical, efficient and inexpensive for many populations (Anderson *et al.,* 1979). The estimation of size of biological populations frequently involves using strip or line transect. Often, strip transects results in incomplete counts and some ancillary information is needed to adjust for this bias. Considerable efforts have been made in developing parameters for estimating the density from line transects data (Gates *et al.,* 1968; Sen *et al.,* 1974; Caughley, 1977; Burhman *et al.,* 1980).

Small mammals are an integral component of forest animal communities, contributing to energy flow and nutrient cycling and playing extremely important roles as seed predators, dispersal agents and pollination agents in tropical forests (Fleming, 1975). They also form an important prey base for medium sized carnivores (Hayward and Phillipson, 1979; Golley *et al.,* 1975; Emmons, 1987). Anderson *et al.,* (1983) demonstrated the density

estimation of small mammal populations using a trapping web and distance sampling methods. Iriarte (1989) studied the small mammal availability and consumption by Fox (*Dusicyon culpaeus)* in Central Chilean scrublands. In recent past, many workers contributed to the distribution pattern of rodents throughout India. But these were taxonomic studies rather than assessing the ecological aspects of species assemblage, co existence and diversity in the natural habitat. Nathan (1999) studied rodent abundance using capture-recapture methods and estimated the population changes and breeding of six murid species in Lunyo forest in Uganda. Prakash (1959, 1972, 1975, 1977, 1981 and 1995) studied rodent distribution in Rajasthan region. Biswas and Tiwari (1969) studied the distribution of rodents in Rajasthan. Anjali and Sunquist (1996) studied the ecology of small mammals in tropical forest habitats of southern India where the small mammal densities ranged between 16.3 individuals/ ha and 20.7/ ha in natural forest sites and 10.4/ ha in teak plantation.

**1.2.3. Food habits:**

Diets of mammals are increasingly being inferred from identification of hard parts from prey eaten and recovered in fecal remains (scats). Historically, dietary studies of a number of species relied on identifying the stomach contents of individuals that were culled (Murie and Lavigne, 1986; Perez and Bigg, 1986; Spalding, 1964). More recently, greater emphasis has been placed on developing non-destructive methods to determine the diet (Korschegen, 1980; Putman, 1984; Pierce and Boyle, 1991; Litvaitis, 2000; Iverson *et al.*, 2004). At the forefront of these, alternative technique has been scat analysis, namely the identification and quantification of identifiable parts that have passed through the digestive systems of mammals (Storr, 1961; Dellinger and Trillmich, 1988; Harvey, 1989;

Corbett, 1989; Reynolds and Aebischer, 1991; Ciucci *et al.,* 1996; Bowen, 2000; Orr and Harvey, 2001; Katona and Altbacker, 2002; Arim and Naya, 2003; Zabala and Zuberogoitia, 2003; Tollit *et al.,* 2004). Scat analysis is increasingly being used to determine the diets of pinnipeds (seals and sea lions), canids (wolves, dogs, coyotes, jackals and foxes), ursids (bears), felids (cats), viverrids (civets and genets), and mustelids (otters and badgers) (Bartoszewicz and Zalewski, 2003; Bulle, 2000; Ferreras and MacDonald, 1999; Hewitt and Robbins, 1996; Hutchings, 2003; Krueger *et al.,* 1999; Moleo and Gil-Sanchez, 2003; Mukherjee *et al.,* 2004; Nunez *et al.,* 2000; Pardini, 1998; Patterson *et al.,* 1998; Silva and Talamoni, 2004; Virgo *et al.,* 1999).

Scats analysis has been widely used to know the food and feeding habits of cats, wild canids by several investigators. Scott (1941) described the methods of computation in feacal analysis with reference to red fox. Windberg and Mitchell (1990) worked on the winter diet of coyotes in relation to prey abundance in Southern Texas, Norton *et al.,* (1986) studied the prey utilization of leopard of South Western Cape provinces. Reynold and Aebischer (1991) provided critiques with recommendation, based on a study on Fox (*Vulpes vulpes*) for comparison and quantification of the carnivore diet by faecal analysis. Mukerjee *et al.,* (1994 a and b) further refined and standardized the method of scat analysis for Asiatic lion (*Panthera leo persica*) and leopard (*Panthera pardus*). Johnson and Hansen (1978) estimated biomass intake by coyotes (*Canis latrans*) from undigested residues in their scats.

Using the scat analysis, most of information regarding the diet of carnivores has been based on frequency of occurrence of prey found in proportion to prey consumed (Floyd *et al.,* 1978; Corbett, 1989). To address the problem of small prey being over represented in

scats, a linear regression model has been developed to convert scat data to relative biomass and relative number of prey consumed by foxes and wolves (Mech, 1970; Floyd *et al.,* 1978; Ackerman *et al.,* 1984; Weaver, 1993; Jethva and Jhala, 2004).

Bothma (1971) has worked on ecology of black backed jackals; Ferguson (1978) worked on social interaction among black backed jackals in Africa; Ferguson (1981) conducted studies on sympatric position of golden jackal and occurrence of wolf in North Africa. Mc Shane and Gretterberger (1984) studied the food habits of golden jackal in Central Niger. Poche *et al.,* (1987) have investigated golden jackal in Bangladesh. Sankar (1988) investigated food habits of jackals in Bharatpur. Fuller *et al.,* (1989) worked on ecology of sympatric jackals species in the Rift Valley of Kenya. Mukherjee (1989) studied ecological separation of three sympatric carnivores, in Keoladeo National Park, Bharatpur. Jaedger *et al.,* (1996) reported the impact of jackal population on pre-harvest rat damage in Bangladesh. Kotwal *et al.,* (1991) worked on immobilization and radio collaring of golden jackals in Gujarat. Atkinson *et al.,* (2002) identified 24 species of fruits in the diet of jackal in Zimbabwe. Mukherjee *et al.,* (2004) studied the importance of small mammals in the diet of sympatric lesser carnivores in Sariska Tiger Reserve by analyzing 140 scats and reported that more than 90% of scats contained remain of small mammals. Gupta (2006) worked food habits of golden jackals in Keoladeo National Park, Bharatpur and reported 56% of *Zizyphus* fruits contribution in their diet.

**1.2.4. Habitat suitability:**

In order to develop efficient conservation and recovery strategies, wildlife and conservation biologists need to understand and evaluate various threats confronting populations, and to predict the potential distribution and explore ways to reach it. The

Geographic Information System (GIS) combined with habitat modelling has proved to be an important tool to assess the habitat suitability for a given species. It gives among others information about the spatial extent, arrangement and fragmentation of suitable habitat. This is a necessary prelude to estimate the potential population size (Mladenoff *et al.,* 1999). Habitat models based on presence–absence data are the most standard approach to habitat modelling (Schadt *et al.,* 2002b; Woolf *et al.,* 2002; Naves *et al.,* 2003; Seoane *et al.,* 2003; Niedzialkowska *et al.,* 2006). These models are often based on coarse grained landscape and species information allowing coarse habitat inferences and predictions, but they may overlook biological details important for species conservation. Indeed, fine-scale models based on detailed species and landscape information have shown a great potential to detect crucial habitat structures not obvious at broader scales (Fernandez *et al.,* 2003). However, the expandability of fine-scale models for habitat predictions remains largely unexplored partly because the required information is difficult to gather. Therefore, current challenge in conservation is to reconcile fine-scale habitat inferences with broad scale predictions required for more comprehensive species management.

## 1.3 OBJECTIVES:

The present study on medium and small sized carnivores in Sariska Tiger Reserve, Western India, was carried out with the following objectives:

1. To estimate the abundance of medium and small sized carnivores such as striped hyena, jackal, jungle cat, civet and mongoose.
2. To study the prey availability and food habits of medium and small sized carnivores and
3. To assess the habitat suitability for these carnivores.

**1.4 STUDY PERIOD:** The study was conducted from November 2007 to June 2009 in two different seasons winter (November to February) and summer (March to June).

## 1.5 STUDY SPECIES

### 1.5. 1. Striped hyena (*Hyaena hyaena*):

The striped hyena (*Hyaena hyaena*) **(Plate 1a)** is an most important large scavengers, its role in clearing off carrion in tropical ecosystems and in recycling mineral compounds from dead organic matter enhances its biological importance (Kruuk, 1976). They generally prefer arid to semi arid environment and avoid open desert and dense thickets (Prater, 1980; Kruuk, 1976; Leakey *et al.*, 1999). The current distribution range of this species extends from East to North east Africa, through the Middle East, Caucasus region, Central Asia and into the Indian subcontinent (Mills and Hofer, 1998). This medium sized, dog like animal has a back sloping downwards towards the tail, and black vertical stripes on the sides (Kruuk, 1976; Wagner, 2006). Its general colour is pale grey or beige. It has a black patch on the throat, five to nine more or less distinct vertical stripes on the flanks and clearer black transverse and horizontal stripes on the fore and hind legs. The head is roundish with a pointed muzzle and pointed ears. Its black and white tail is long and bushy with hair that is generally coarse and long. The feet have four toes and short, blunt, non-retractable claws. Five subspecies are distinguished, mainly by their differences in size and pelage, although this classification is provisional. Body mass varies between 26 and 41 kg for males and 26 and 34 kg for females. Total body length excluding tail varies between 1.0 and 1.15 m and shoulder height between 0.66 and 0.75 m. In the Indian sub-continent they occur in arid and semi arid ecosystems, as well as in the extremely wet regions of south-western coast (Karanth, 1986; Prater, 1980). According to Mills and

Hofer (1998), the estimated population of striped hyena in India was *ca* 1000 which was a gross under estimate. According to IUCN Red List status and Indian Wildlife (Protection) Act, 1972 they are placed in Lower risk and Schedule III respectively.

### 1.5. 2. Jungle cat (*Felis chaus*):

The Jungle cat **(Plate 1b)** ranges from through North Africa, Southwest Asia and Tropical Asia. In the east its distribution does not goes beyond the Isthmus of Kra (Nowell and Jackson, 1996). It is most common wild cat in India, distributed throughout the country except high Himalayas up to 2400 m (Prater, 1980; Nowell and Jackson, 1996). They are found in grassland, scrub, dry deciduous, evergreen forest, semi urban and near human habitation (Prater, 1980). Whatever little information is available on this cat suggests that it prefers areas with access to water sources and good ground cover (Dayen *et al.*, 1990). Jungle cat is morphologically similar to caracal (Mukherjee, 1989; Kitchener, 1991; Nowell and Jackson, 1996). They have long legs, a short tail, and long ears with small tufts at the tip. The main distinguishing features are the bands on the tail and legs. Jungle cat has shorter gestation period, 63 to 68 days. They produce between 1 to 6 kittens in a litter (Nowell and Jackson, 1996). According to IUCN Red List status and Indian Wildlife (Protection) Act, 1972 they are placed in Lower risk and Schedule II respectively.

### 1.5.3. Jackal (*Canis aureus*):

Out of four species of golden jackal globally, *Canis aureus aureus* found in Indian sub-continent. This is northern most distribution among the jackals (Sheldon, 1992). The golden jackal **(Plate 2a)** is widespread in North Africa and Northeast Africa occurring from Senegal on the west coast of Africa to Egypt in the east, in a range that includes

Algeria and Libya in the north to Nigeria, Chad and Tanzania in the South. They have expanded their range from the Arabian Peninsula into Western Europe to Austria and Bulgaria (Sheldon, 1992) and eastwards into Turkey, Syria, Iran, Iraq, Central Asia, and the entire Indian sub-continent as well as east and south to Sri Lanka, Myanmar Thailand and parts of Indo-China. Golden jackal is fairly common throughout its range. High densities are reported in areas that have abundant food material and cover. They are more nocturnal when it occurs near human habitation. In relatively less disturbed areas it is diurnal (Fox, 1975). Golden jackals are opportunistic feeders and will venture into human habitation at night to feed on (Fox, 1975). They are monestrous having gestation period of 63 days. Litter size ranges from 1 to 4 pups. According to IUCN Red List status and Indian Wildlife (Protection) Act, 1972 they are placed in Lower risk and Schedule II respectively.

### 1.5.4. Ratel (*Mellivora capensis*):

The honey badger **(Plate 2b)** appears to be of Ethiopian origin and has invaded the Indo-Pakistan subcontinent through southern Baluchistan. Currently it occurs through most of Africa, through west Asia, Afghanistan, Iran, Pakistan, India, Nepal, eastward as far as Myanmar (Pocock, 1941; Roberts, 1977). The honey badger is a large mustelid weighing around 8 to 10 kg, with a short tail, which is not very bushy. According to Prater (1980) ratels in India live in the desert and in the dry and moist deciduous zones avoiding regions of heavy rainfall. They prefer hilly broken country where shelter is easier to find. In the plains they choose the banks of streams or rivers where burrows are easy to dig. They live in burrows of their own or of some other animal, rock crevices or by the shelter provided by tree roots or among thick bushes. They are largely nocturnal and also seen during day

hours, occasionally in pairs. The gestation period is believed to be around 180 days and the litter size is two (Pocock, 1941). According to IUCN Red List status and Indian Wildlife (Protection) Act, 1972 they are placed in Lower risk and Schedule I respectively.

### 1.5.5. Common palm civet (*Paradoxurus hermaphroditus*):

The common palm civet **(Plate 3a)** is distributed in northern Pakistan and in entire India from east of Gujarat to Jammu and Kashmir, whole of the peninsula down south up to Sri Lanka. In the north of India from Nepal, Bhutan and south China, eastward through West Bengal, Assam, Arunachal Pradesh (Pocock, 1939; ZSI, 1992; Choudhury, 1997 a and b; Datta, 1999; Jha, 1999) to Myanmar, Thailand, Malaysia, Indonesia, Philippines, New Guinea and Japan (Pocock, 1939; Medway, 1978; Corbet and Hill, 1992; Wozencraft, 1993). A black or blackish-brown civet heavily built, with long, coarse and shaggy hair and short limbs. The tail is long as compared to head and body. The ground colour of the coat varies seasonally and individually from olive-grey to almost cream with darker bases to the hair. The back is always marked with three indistinct black or dark brown longitudinal stripes in the midline. The tail is sometimes tipped white. It is distinguished from *Viverra* and *Viverricula* by uniformly grey un-patterned throat, and unringed tail. Like other civets it is mostly solitary, nocturnal and largely arboreal, although freely descending to the ground to cross open spaces. It prefers well-wooded forests, and roams around in plantations taking shelter in hollows of trees. It also lives close to human habitation on roofs and in homesteads. It is an omnivore and feeds on birds, rodents, insects and fruits such as Tendu (*Diospyros melanoxylon*), banana, pineapple, coffee and berries (Pocock, 1939; Medway, 1978; Singh, 1982). The litter size is usually 3 to 4.

They mature at the age of 11 to12 months. According to IUCN Red List status and Indian Wildlife (Protection) Act, 1972 they are placed in Lower risk and Schedule II respectively.

### 1.5. 6. Small Indian civet (*Viverricula indica*):

Small Indian civet is distributed over most of India, Pakistan, eastward to south China, Myanmar, Thailand, southward from Sri Lanka, Singapore, Malaysia and Indonesia (Pocock, 1939; Roberts, 1977; Medway, 1978; Corbet and Hill, 1992; Datta, 1999). The small Indian civet is somewhat cat like in general appearance having relatively long forelegs and conspicuous rounded ears. The general body colour varies from sandy-buff to greyish-white and is heavily spotted with blackish patches in parallel horizontal lines. The spots are smaller in the region of the spine where they tend to coalesce into continuous lines. The spots at the flanks are considerably bigger and set apart than from the dorsal spots. All four legs are blackish or very dark brown and are often marked with small white patches. The tail is almost two third the length of head and body and is conspicuously marked with 9 to 10 concentric black rings. It is normally solitary and strictly nocturnal and prefers tall grasses and scrub to live in. It is mostly omnivorous in nature. Its diet includes rodents, lizards, insects, small birds, bird eggs and nestling and often fruits. It is polyestrous, and young ones are seen throughout the year, with litter size between 3 to 5. The life span is around 22 years in captivity (Jones, 1968). According to IUCN Red List status and Indian Wildlife (Protection) Act, 1972 they are placed in Lower risk and Schedule II respectively.

### 1.5. 7. Common Indian grey mongoose (*Herpestes edwardsii*):

The Indian grey mongoose **(Plate 3b)** or common grey mongoose (*Herpestes edwardsii*) is found in southern India and Sri Lanka. The grey mongoose is commonly found in open forests, scrub lands and cultivated fields, often close to human habitation (Prater, 1980). It lives in burrows, hedgerows and thickets, among groves of trees, taking shelter under rocks or bushes and even in drains. It is very bold and inquisitive but wary, seldom venturing far from cover. It climbs well. Usually found singly or in pairs. It preys on rodents, snakes, bird eggs and hatchlings, lizards and variety of invertebrates. Along the Chambal River it occasionally feeds on gharial eggs. It breeds throughout the year. According to IUCN Red list status and Indian Wildlife (Protection) Act, 1972 they are placed in Least concern and Schedule-IV respectively.

### 1.5.8. Ruddy Mongoose (*Herpestes smithii*):

It is distributed in peninsular India, in Western and Eastern Ghats, extending northwards up to Madhya Pradesh, and atleast up to 250 N in Rajasthan as far as Delhi and eastwards 240 N in Bihar (Pocock, 1939; Prater, 1980; Corbet and Hill, 1992). The ruddy mongoose is very closely related to common Indian grey mongoose *H. edwardsii*, but distinguished by its slightly larger size and black tipped tail extending for 2 to 3 inches at the distal end. Body is generally darker in colour with black and grayish-white speckling and a reddish cast traceable in the hair of the upper side, particularly on the head, neck and between the shoulders. The ruddy mongoose is mainly a forest loving animal in contrast to the grey or small Indian mongoose and prefers more secluded areas. They have also been recorded from secluded paddy fields and in comparatively open fields.

Like other mongoose, it hunts by day as well as by night but it is in fact crepuscular in nature. Its normal food is similar to other mongoose species including carrion. According to IUCN Red list status and Indian Wildlife (Protection) Act, 1972 they are placed in Least concern and Schedule-IV respectively.

## 1.6 ORGANIZATION OF THESIS:

The thesis is organized in five chapters. Chapters 1 and 2 deals with introduction and study area respectively. Rest of the three Chapters (3, 4, 5) are based on the above three broad objectives. Each chapter includes a brief introduction followed by methodology, results and discussion. The Chapter-1 provides general introduction and explains the background of the present study followed by literature review on each species based on objectives. It further explains the objectives and duration of study. Chapter-2 deals with the study area, different vegetation types and available flora and fauna in STR. Chapter-3 deals with population estimation of each species based on camera trap and track plots followed by comparison between two different methods using different programs. Chapter-4 deals with the prey abundance, food habits of study species and comparison between their diet overlaps between seasons. Chapter-5 deals with habitat modeling based on logistic regression using different environmental variables (including different vegetation classes) and generated habitat suitability maps for each species in the intensive study area.

**Plate 1 a Striped hyena (*Hyena hyena*)**

**Plate 1 b Jungle cat (*Felis chaus*)**

**Plate 2 a Golden jackal (*Canis aureus*)**

**Plate 2 b Ratel (*Mellivora capensis*)**

**Plate 3 a Palm civet (*Paradoxurus hermaphroditus*)**

**Plate 3 b Common Indian grey mongoose (*Hespestes edwardsii*)**

# CHAPTER 2

# STUDY AREA

## 2.1 GENERAL, LOCATION AND TOPOGRAPHY

Sariska Tiger Reserve (STR) is situated in the Alwar district of Rajasthan between Longitude: 79° 17’ to 76°34’N and Latitude: 27° 5’ to 27° 33’ E **(Figure 2.1)**. The total area of Tiger reserve is 881 $km^2$, with 274 $km^2$ as a notified National Park. The major part of the area is occupied by rocks of the Delhi system and Aravalli system comprising of quartzites, conglomerates, grits, limestone, phyllite, granites and schists (Pascoe, 1950; Sankar, 1994).

STR is characterized by rugged terrain, valleys and plateau with the altitudinal variation from 540 m to 777 m. The two main plateaus are Kankawari (524 m above mean sea level) and Kiraska (592 m above the mean sea level). The most remarkable characteristics of the hills are their homogenetic regularity of height, level summits and uniform appearance, stretching out from north-east to south-west, in more or less parallel lines (Soni, 2000).

The depth of soil layer is more than 1 m in valleys, whereas it is only a few centimeters deep on the hill slopes. The soil is sandy loam and alkaline with pH varying from 7.25 to 8.00 (Yadav and S. K Gupta, 2006). The Alwar Thanaghazi- Jaipur State Highway passes through the reserve and 2000 vehicles ply on it everyday. Another state highway that passes through the reserve is Sariska- Kalighati- Pandupol road which is 20 km in length (Sankar, 1994).

## 2.2 CLIMATE:

The climate is subtropical, characterized by a distinct winter, summer, monsoon and post-monsoon. Winter commences from November. In winter, the temperature has been observed to drop to 3° C. Summer commences from mid March and continues till end of June. July and August are rainy season. Summer is followed by monsoon from south-west in July and August. The study area also receives occasional winter and summer rains. Average annual rainfall recorded is 650 mm (Sankar, 1994).

## 2.3 HISTORY AND ARCHAELOGICAL RICHNESS:

Sariska Tiger Reserve was created in 1978. In the pre-independence period, the forest within the Reserve was a part of the erstwhile Alwar State and maintained as a hunting Reserve for the royalty. After independence, these were first notified as a Reserve wherein it was unlawful to hunt, shoot, net, trap, snare, capture or kill any kind of wild animals in 1955. The Reserve status was upgraded to that of a Sanctuary in 1958. Later, in view of the preservation of wild animals in a better way, a few forest areas contiguous to the Sanctuary were also included. Within STR there are several places of historical interest. The pandupol temple which is a major attraction for tourist lies in the notified National Park of the reserve.

## 2.4 MAJOR VEGETATION TYPES:

The vegetation of Sariska correspond to (1) Northern tropical dry deciduous forests (subgroups 5B; 5/E1 and 5/E2) and Northern Tropical Thorn forest (subgroup 6B) (Champion and Seth, 1986). *Anogeissus pendula* is the dominant tree species covering over 40 percent area of the forest (Sankar, 1994). *Boswellia serreta* and *Lannea*

*coromandelica* grow on rocky patches. *Acacia catechu* and bamboo are common in the valleys. Some valleys support *Butea monosperma* and *Zizyphus mauritiana*. *Dendrocalamus strictus* is extremely limited in distribution and is found along well drained reaches of the streams and moist and cooler parts of the hills. *Albizia lebbeck, Diospyros melanoxylon, Holoptepia integrifolia* and *Ficus spp*. are found in moist localities (Sankar, 1994).

Parmar (1985) and Rodgers (1985) have classified vegetation of Sariska as follows:

1. *Anogeissus pendula* forest
2. *Boswellia serrata* forest
3. *Acacia catechu* forest and
4. *Miscellaneous forest,* which can be further sub-divided into three categories *viz*.
    a) *Butea monosperma* forest
    b) Forest along nallas and
    c) Scrub land

### 2.4.1 *Anogessius pendula* forest:

This vegetation is most dominant in the undulating areas as well as on the lower hill slopes **(Plate 4a)**. This is most gregarious and may form up to 100% of the canopy (Sankar, 1994). The others tree species associated with this vegetation are *Acacia catechu, Capparis sepieria, Cassia fistula, Diospyros melanoxlyon, Lannea coromandelica* and *Grewia flavescens*. Species like *Ficus racemosa, Mallotus philippinensis, Mitragyna parviflora* and *Syzgium cumini* are found in moist localities.

### 2.4. 2 *Boswellia* forest:

This is another very distinctive zone, typically found on the steep upper slopes on hills. This species is associated with *Anogessius* forest while *Euphorbia neriifolia* is found in understorey on steep slopes.

### 2.4. 3 *Acacia catechu* forest:

*Acacia catechu* is found on the hill slopes as well as on plains. This species is associated with *Anogessius pendula*, *Boswellia serrata and Zizyphus mauritiana* trees. The other common trees and shrubs are *Bauhinia racemosa*, *Capparis sepieria*, *Wrightia tinctoria* and *Grewia flavesense.*

### 2.4.4 Miscellaneous forests:

**a) *Butea monosperma* forest**

This species is found at the foothills and plains throughout the forest. *Butea monosperma* trees in STR commonly seen in association with *Zizyphus mauritiana*, *Capparis sepieria* and *Phoenix sylvestris.*

**b) Forest along nallas**

In sariska, forests along the nallahs is more of wet conditions and have patches of trees like *Antherocephalus kadamba*, *Ficus* spp, *Phoenix sylvestris* and *Syzygium cumini* **(Plate 4b)**.

**c) Scrubland:**

These areas **(Plate 5a)** typically have grasses and herbs as ground cover and shrubs species such as *Grewia flavesence*, *Capparis sepieria*, *Zizyphus nummularia* and *Adhathoda vasica* as the next layer. Trees are scattered and the predominant species are *Balanites aegyptiaca*, *Zizyphus mauritiana*, *Acacia leucophloea* and *Acacia senegal*.

**2.5 FAUNA:**

Wild herbivores found in Sariska are chital (*Axis axis*), sambar (*Rusa unicolor*) and nilgai (*Boselaphus tragocamelus).* Omnivores found are wild pig (*Sus scrofa)* and jackal *(Canis aureus)*. The park supports carnivore species such as five reintroduced tigers (*Panthera tigris*), leopard (*Panthera pardus*), and striped hyena *(Hyaena hyaena).* Small carnivores found are caracal (*Felis caracal*), jungle cat (*Felis chaus*), common mongoose *(Herpestes edwardsii*), small Indian mongoose (*H.auropunctatus*), ruddy mongoose (*H. smithi*), palm civet (*Paradoxurus hermaphroditus*), small Indian civet (*Viverricula indica*) and ratel (*Mellivora capensis*). In 2009, desert cat (*Felis selvestris*) was reported from Sariska (Gupta *et al.*, 2009). Earlier, the wild dog or dhole (*Cuon alpinus*) was reported in STR (Sankar, 1994) but they are not sighted in recent past. Rhesus macaque (*Macaca mulatta*) and common langur (*Semnopithecus entellus*) are the two primates found here. Porcupine (*Hystrix indica*), rufous tailed hare (*Lepus nigricollis ruficaudatus*) and eleven species of rodents *viz* Indian gerbil (*Tatera indica*), Indian bush rat (*Golunda ellioti*), spiny tailed mouse (*Mus platythrix*), house mice (*Mus musculus*), little Indian field mice (*Mus booduga*), long tailed tree mouse (*Vandeleuria oleracea*), sand coloured rat (*Millardia gleadowi*), soft fur field rat (*Millardia meltada*), brown rat (*Rattus norvegicus*), house rat (*Rattus rattus*) and pygmy gerbil (*Gerbillus nanus*) are found in Sariska. Due to presence

of villages inside and on the periphery of STR a large number of domesticated livestock are also occurs within the park **(Plate 5b**). These include buffaloes, brahminy cattle, goats, camel, dogs and domestic cats. Sankar *et al.,* (1993) listed a checklist of 211 bird species belonging to 52 families in STR. These include 73 migratory **(Plate 6a)** and 120 resident species and a number of aquatic birds also visit the park during winter.

## 2.6 HUMAN SETTLEMENT:

There are 32 villages within the Tiger Reserve boundary and out of them ten are situated in the notified National Park. Earlier there were twelve villages due for relocation since 1984 in the notified National Park. Of these, village Bhagani has been relocated during November 2007. In the revenue villages the occupation of the people is based on agriculture but in the grazing camps it is animal husbandry.

## 2.7 TOURISM:

Tourism is not so regulated and most of the tourists coming to the reserve, come to pandupol temple especially on Tuesdays and Saturdays, when entry to the reserve is free. In the peak season which is from July to August there is a fair held at the pandupol temple and Bartari temple that results in heavy traffic inside the core area even during night **(Plate 6b)**. However on other days only day time tourism is allowed and the reserve remains closed after dusk.

## 2.9 INTENSIVE STUDY AREA (ISA).

The study was conducted in an intensive study area of 144 $km^2$ which comes under the National Park **(Figure 2.1)** in two different seasons, winter (November to February) and summer (March to June).

**Figure 2.1 Location, administrative boundary and intensive study area in Sariska Tiger Reserve, Rajasthan.**

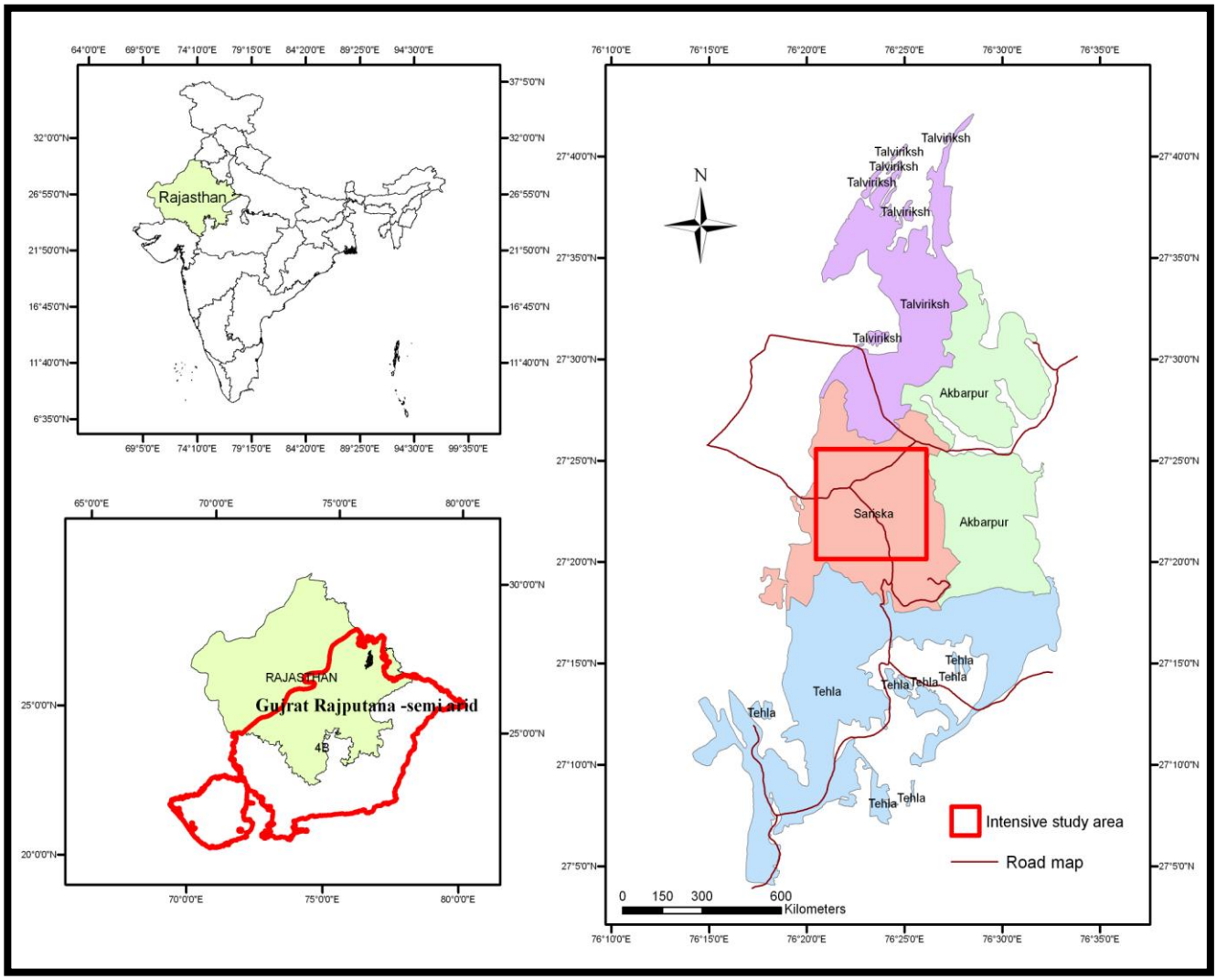


**Plate 4a.** ***Anogessisus pendula*** **found on lower hill slopes.**

**Plate 4b.** ***Phoenix sylvestris*** **typical vegetation along the forest nallahs.**

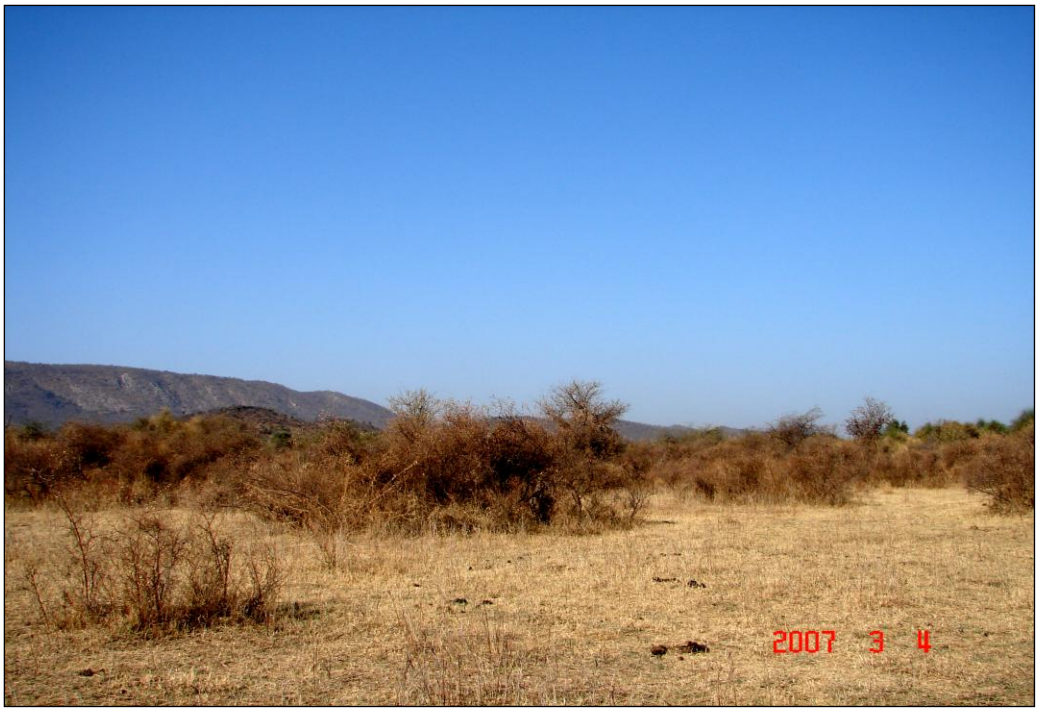



**Plate 5a. Open scrubland with small patches of *Capparis sepieria***

**Plate 5b. Human disturbance in open scrubland.**

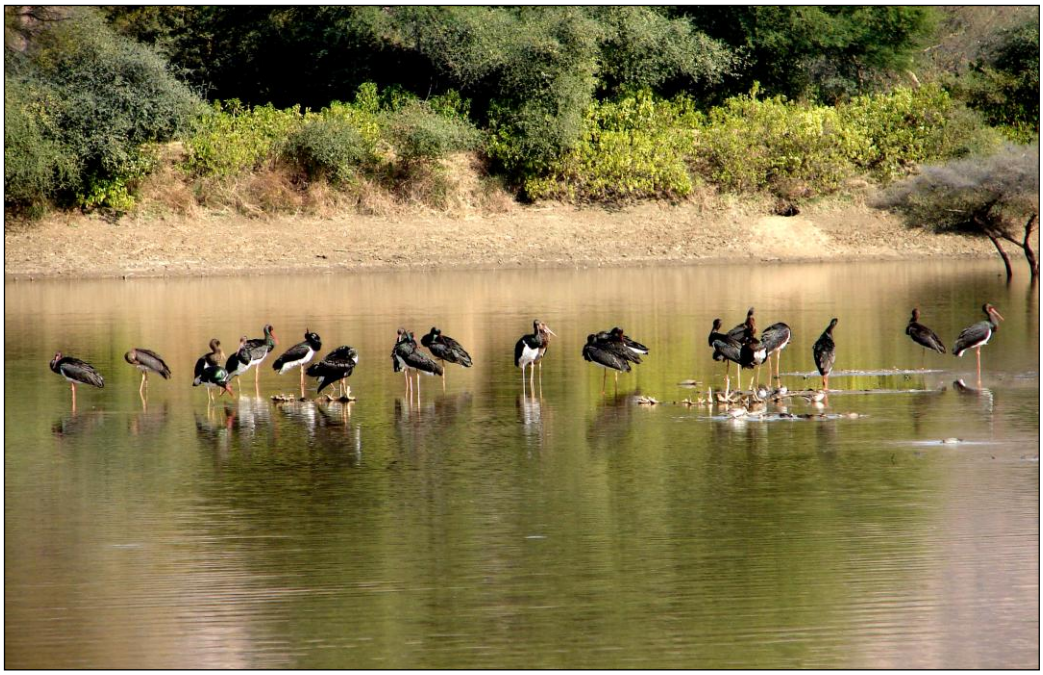


**Plate 6a. Migratory birds at Kankawas Lake.**

**Plate 6b. Pligrims visiting Pandupol temple.**

# CHAPTER 3

# POPULATION ESTIMATION

## 3.1 INTRODUCTION

Population estimation of wild animals is of prime importance to ecologists and managers. A variety of methods are available for estimating animal abundance (Lancia *et al.,* 1994), but all involve the issue of estimating detection probabilities for specific kinds of count statistics (Buckland *et al.,* 1993; Seber, 1982; Williams *et al.,* 2002). Depending on the species being studied, the techniques available for gathering appropriate data, and incorporating the limitations of time, money and effort, only one or just a few of these methods may be suitable. Capture-recapture methods require repeated efforts to capture or observe animals (Otis *et al.,* 1978; Pollock *et al.,* 1990) and even observation based methods such as distance sampling (Buckland *et al.,* 1993) or multiple observers (Cook and Jacobson, 1979; Nichols *et al.,* 2000) are viewed as being too time and effort consuming (Royle and Nichols, 2003). Despite the logistical constraints, these methods have been widely applied for estimation of large mammal abundance.

A population estimate is an approximation of population size (*N*) derived from a sample of the population (*C*), accounting for the fact that not all the animals in the study area are counted but assuming that the sample represents the entire population to draw inferences. The estimate of the population size is thus computed by estimating the proportion of animals of the entire population that have been sampled.

$$N = C / p$$

*N*- The estimate of the population size

*p*- Detection probability or capture probability

The estimation of population size is thus computed by estimating the proportion of animals of the entire population that have been sampled. While estimating the populations of tigers and other individually identifiable species camera trapping within a capture-recapture framework has been found reliable (Karanth and Nichols, 1998, 2002; O'Brien *et al.,* 2003; Trolle and Kery, 2003; Karanth *et al.,* 2004; Jhala *et al.,* 2008). The camera trap based on capture-recapture framework to estimate population of large carnivores has proven to be amongst the most successful non-invasive method based on the natural markings on their bodies, such as tiger *Panthera tigris* (Karanth and Nichols, 1998; Karanth *et al.,* 2004), leopard *Panthera pardus* (Harihar *et al.,* 2009), jaguar *P. onca* (Silver *et al.,* 2004), Geoffrey's cat *Oncefelas geoffroyi* (Cuéller *et al.,* 2006), snow leopard *Uncia uncia* (Jackson *et al.,* 2006) and striped hyena *Hyaena hyaena* (Singh, 2008; Harihar *et al.,* 2010; Gupta *et al.,* 2010). This technique takes advantage of distinctive individual markings through photographs for even heavily furred animals such as ocelot *Leopardus pardalis* (Trolle and Kery, 2003), wolf *Chrysocyon brachyurus* (Trolle *et al.,* 2007) and puma *Puma concolor* (Kelly *et al.,* 2008). The individual identification in spotted hyena has been done earlier using pellage and nicks in ears (Holekamp and Smale, 1990; Hofer and East, 1993). Thus, camera trapping furnishes an important non-invasive tool for assessing patterns of abundance throughout space and time, and their link with activity patterns, habitat use and reproductive information, which are key elements for wildlife conservation. Despite the variety of field techniques that can be used for terrestrial mammal surveys, not all can be efficiently applied in every ecosystem and for all species. Some landscapes can be so remote, steep or so densely

vegetated that only a few methods could be applicable. Sometimes the choice is limited not by technique efficiency, but by field costs. Track plot method is efficient and usually involves low costs, but depend on suitable field conditions and trained personnel (Burnham *et al.,* 1980; Smallwood and Fitzhugh, 1995). Camera trapping is more costly at the beginning, but is not so dependent on the environment to be sampled, constant assistance or even experienced field staff (Rappole *et al.,* 1985). There is an increasing need for comparing methods to be used in rapid faunal assessment, due to urgent conservation needs worldwide.

## 3.2 METHODS

### 3.2.1 Sampling design for camera traps and track plot:

**Camera traps:** A preliminary survey was carried out during November 2007 in the intensive study area of 144 $km^2$ in the National Park by surveying available trails. Indirect signs such as spoor, scats and track signs of carnivores were identified and marked using a handheld Global Positioning System (Garmine ©72). Camera traps were placed in 1x1 $km^2$ grid on the basis of any evidence (spoor, scats and track sign) on the trails where the probability of theft was low. Total 30 units of Deercam™ analog cameras that worked on passive infrared motion/ heat sensors were deployed. The camera traps were equipped with 35 mm lens which recorded the date and time of each photograph. The camera delay was kept at a minimum/ default of 15 seconds and sensor sensitivity was set at high. A total of 100 locations were selected for the placement of camera traps in the study area. Since logistically impractical to conduct sampling at all these camera trap locations simultaneously, the trap points were divided into six blocks. Block A consisted of 17 camera trap sites, blocks B had14 sites and C had 18, D block consisted of 16 while E and

F had 20 and 15 sites respectively depending upon the feasibility of camera trap locations in the study area. The mean inter trap distance was 726 m (ranging from 700 m to 1.2 km) and each camera traps ran for 25 consecutive occassions with the total sampling period amounting to 150 days (2500 trap nights per season). Capture matrix was prepared from each sampling occasion combined with captures from 1 day drawn from each block (Otis *et al.,* 1978; Harihar *et al.,* 2010; Gupta *et al.,* 2010). Rolls of film used during the trapping session were given a unique code (Block1/Trap point1/Roll1) in order to correctly note the date, time, and location of the captures. The camera trapping was done in two seasons winter (November to February) and summer (March to June) depending on the logistics.

**Track plots:** A small patch of forest floor (5 m x 2 m) was cleared off vegetation and other material such as pebbles and litter and flattened and smoothened. A thin layer of soft soil was sieved over the plots so that tracks of the target species (striped hyena, jackal, civets, ratel and mongoose) walked on the track plots were recorded. The plots were laid in locations where the camera traps were placed in 1x1 $km^2$ grid in every block and monitored at regular intervals. Presence/absence data for each carnivore species were recorded on each track plot. The track plots were monitored everyday in the morning in both the seasons (winter and summer). The abundance for medium and small sized carnivores on the track sites was estimated using PRESENCE software (Royle and Nichols, 2003).

### 3.2.1 a) Analytical methods for the species where individual recognition is possible (striped hyena):

Individual hyena obtained from camera trap photographs were identified by combination of distinguishing character such as position and shape of stripes on flanks, limbs and

forequarter and even tail, pattern and spots on flanks (Schaller, 1967; Karanth, 1995; Singh, 2008 and Harihar *et al.,* 2010; Gupta *et al.,* 2010) **(Figure 3.1)**. Any photograph with distorted perspective or which lacked clarity, were not used for identification. Every hyena captured was given a unique identification code like H1, H2, H3, etc. Capture history of each individual was generated in an X matrix format (Otis *et al.,* 1978). Estimation of population size using closed capture models requires the population under investigation to be both demographically and geographically closed. Population closure test was done by using software CAPTURE (Otis *et al.,* 1978; Rexstad and Burnham, 1991). The density (D) of hyena in the study area was estimated as the population size (N) divided by the effective sampled area A ($\hat{W}$), where A ($\hat{W}$) was estimated by creating a polygon over the trapping stations (A) and a buffer width (W) estimated as half the mean maximum distance moved (1/2 MMDM) by recaptured hyena added to the camera trap polygon (A) (Karanth and Nichols, 1998; Jhala *et al.,* 2008). The density of striped hyena was calculated using, DENSITY 4.4 software by four different methods (full MMDM, 1/2 MMDM, IP density and spatial ML) for two different seasons (summer and winter).

A

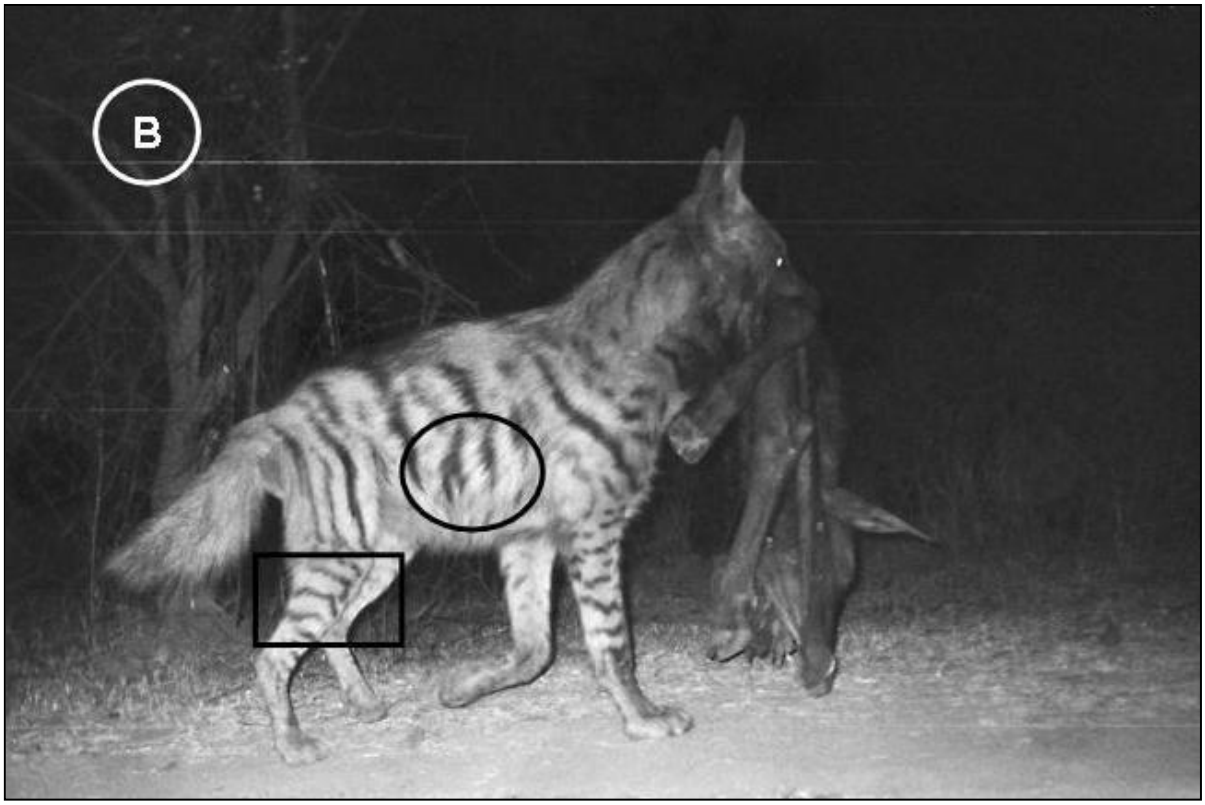

B

**Figure 3.1** Two individual hyenas captured by camera trap (A) and (B) show individual H4 with strips and spots on flanks identical in shape and pattern. While (C) shows a different individual H10 with stripes and spots on flanks being clearly different in shape and pattern.

### 3.2.1 b) Analytical methods for species abundance where individual recognition is not possible (jackal, jungle cat, civets, ratel and mongoose):

#### 3.2.1 b) 1. Selection of site

Recent advancements in occupancy based techniques (Mac Kenzie *et al.*, 2004; Royle and Nichols, 2003; Gopalaswamy, 2006; Nag, K, 2008) allowed to estimate population status using detection-non detection data from repeated surveys at several sampling units (or sites). Surveys of this kind implicitly assume that sample units are independent, that is animals do not move between sites within the survey period. Unless the movement of animal is very small compared to the selected site size, setting up grid cells and sampling adjacent cells, will violate the above assumption. To avoid this, I considered grid-cells in the study area that are geographically separated by >1 $km^2$ home range diameter of the species, as sites for this analysis and abundance of species whose identification was not possible was assessed by Royle Nichols method (Royle and Nichols, 2003; Gopalaswamy, 2006; Nag, K, 2008) by considering the area as home range of each species as a unit for estimating abundance.

#### 3.2.1 b) 2. Selection of home range size for analysis

Information on home range sizes of all study species was obtained from available literature in India and elsewhere. Since there is no documentation on ranging pattern of jungle cat, bobcat home range size was used that varied from 2.5 $km^2$ (prey-abundant areas) to 107 $km^2$ (prey-scarce areas) (Bailey, 1974). Home range size of golden jackal was estimated as 14.3 $km^2$ in Velavedar National Park (Ambika, 2005). Ratel home range in south east Finland varied from 6.7 to 9.2 $km^2$ (Kauhala *et al.*, 2006). In Chitwan (Nepal), the common palm civet (*Paradoxurus hermaphroditus*) had mean monthly home

range size of 0.14 $km^2$ (Joshi *et al.*, 1995). Rabinowitz (1991) estimated the home range size of four sympatric civet species ranging from 0.5 to 2.4 $km^2$ in Huai Kha Khaeng Wildlife Sanctuary, Thailand. Home range size of Indian grey mongoose (*Herpestes edwardsii*) was found to be 0.04 to 0.05 $km^2$ in Nilgiri Biosphere Reserve, Tamil Nadu (Kumar and Umapathy, 1999), while *Herpestes auropunctatus* the reported home range was 0.31 $km^2$ (Gittleman and Harvey, 1982). Accordingly, grid-cell size was selected to define site for the study species as 1 x 1 $km^2$ for civets and mongoose, 2 x 2 $km^2$ for jungle cat, and 4 x 4 $km^2$ for golden jackal and ratel.

Total number of sampling units in this study varied with selected grid-cell size as follows: 67 sites for civet and mongoose, 30 sites for jungle cat and 10 sites for golden jackal and ratel.

**3.2.1 b) 3. Capture history for all species:**

Following Royle and Nichols (2003), capture history matrix for a species was constructed from its detection at all sites across repeated sampling occasions (or visits). I constructed separate capture history matrices for camera traps and track plots. I defined one sampling occasion to be comprised of 25 trap nights/ block. If the species was detected at least once at a site over the entire sampling duration, it was recorded its capture history as '1', or '0' otherwise for non detection. Total number of detection at $i^{th}$ number of sites is $w_i$ **(Table 3.1)**.

**Table 3.1 An example of capture matrix for all species detections.**

| **Camera traps in a site** | **Number of detection at each site** | | | | | | | | | | | | | | **Total number of detections** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sites** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **$_{wi}$** |
| Site 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 8 |
| Site 2 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 6 |

### 3.2.1 b) 4. Royle Nichols model of abundance:

The Royle and Nichols Induced Heterogeneity model (Royle and Nichols, 2003) assumes that heterogeneity in detection probability among sites primarily results from variation in animal abundance. This relationship can be explained using likelihood techniques to estimate abundance from repeated detection/non detection data at sites, by assuming abundance to be a random variable with Poisson or Negative Binomial probability distribution. The Royle and Nichols (2003) model relating detection probability and abundance, is using the following formula:

$$\boldsymbol{pi = 1\text{-}(1\text{-}r)^{Ni}}$$

where *pi* is the species specific detection probability at site *i*

*r* is the animal specific detection probability at site *i*

and *Ni* is the actual animal abundance at site *i*.

To characterize the underlying estimation of abundances, the Poisson model can be a good starting point as it arises under a random distribution of animals in space (Royle and Dorazio, 2006). Using this model for abundance estimation, the final likelihood equation to estimate parameters (mean abundance at site and animal specific detection probability)

is as follows:

$$L(w \mid r, \lambda) = \prod_{1}^{R} \sum_{k=0}^{\infty} {}_{T}C_{w_{i.}} [1-(1-r)^{k}]^{w_{i.}} [(1-r)^{k}]^{T-w_{i.}} \frac{\lambda^{k} e^{-\lambda}}{k!}$$

Where, *R* is the number of sites,

*T* is the number of repeated samples,

*w* is the detection vector of the total number of detections from each site *i*, i.e. a vector of all the individual site-specific detections, *wi*

and $\lambda$ is the expected abundance at each site, also the Poisson mean.

Parameters were estimated separately using camera trap and track plot capture matrices, in Program PRESENCE *version 2.0* (http://www.mbr-pwrc.usgs.gov/software/presence/). Following this, Program R (Vienna University of Economics and Business Administration, 2006) was used to compare closeness between two methods, camera trap and track plots. Script used in the program R was given in **Appendix-1**. Two sample t-test was used to compare mean and standard deviation to check any significant difference in species abundances between seasons, using Program NCSS (Hintze, 2006).

## 3.3. RESULTS

### 3.3.a) Estimation of striped hyena population using capture-recapture analysis

#### 3.3a) 1. Photographic capture of striped hyena:

The total sampling effort for 25 days of trapping over 100 trapping stations amounted to 2500 trapping nights (November 2007 to June 2009). The intensive trapping resulted in a total of 104 captures of 29 hyena individuals in winter and 83 photographs of 21 hyena individuals in summer were identified using the right flank profile. As the number of individuals identified from the right flank was higher, this data was used for further

analysis. The 100 trapping stations covered an area of 95.99 $km^2$ (MCP) **(Figure 3.2)** and the numbers of new individuals stabilized after $19^{th}$ trap night **(Figure 3.3)**. The program 'CAPTURE' requires that all individually identifiable animals have to be identified with absolute surety (Otis *et al.,* 1978). Therefore, the derived population estimates from individually identified hyena was based on their right flanks in both the seasons separately. The density of hyena was calculated by three different methods, full MMDM, 1/2 MMDM and spatial explicit models (IP dens and ML dens).

**3.3a) 2. Model selections:**

The statistical test for population estimation of hyena using program CAPTURE (Otis *et al.,* 1978; Rexstad and Burnham, 1991) was consistent with the assumption that the population was closed for the duration of study (test using CAPTURE z = -0.49, P=0.10) (Otis *et al.,* 1978). The model selection algorithm of CAPTURE identified Mh as most appropriate model which was highest in the model selection criteria for winter and Mo for summer. Although Mo scored high in summer, this model is not robust to any deviations from the model assumption of homogeneous capture probabilities among individuals (Singh, 2008; Gupta *et al.,* 2010). Mh jackknife and half normal detection function for spatially explicit density was used for both the seasons. Goodness of fit test for model Mt (as opposed to any alternative model) could not be tested for both the seasons. The overall model selection test based on discriminant functions comparatively scored over various models in two different seasons is given in **Table 3.2 and 3.3**.

**Table 3.2 Model selection criteria for individual hyena identified based on right flank**.

**A) Winter**

| Model | M(o) | M(h) | M(b) | M(bh) | M(t) | M(th) | M(tb) | M(tbh) |
|---|---|---|---|---|---|---|---|---|
| Criteria | 0.92 | **1.00** | 0.34 | 0.35 | 0.00 | 0.09 | 0.56 | 0.72 |

**B) Summer**

| Model | M(o) | M(h) | M(b) | M(bh) | M(t) | M(th) | M(tb) | M(tbh) |
|---|---|---|---|---|---|---|---|---|
| Criteria | 1.00 | **0.93** | 0.37 | 0.43 | 0.00 | 0.00 | 0.41 | 0.56 |

**3.3a) 3. Estimation of capture probabilities, density and population:**

To generate parameter estimates under the Mh model, the jackknife estimator (Otis *et al.*, 1978) implemented in CAPTURE, performed well in earlier photographic capture studies of hyena (Singh, 2008; Harihar *et al.*, 2010; Gupta *et al.*, 2010). From capture history data of winter, eight individuals were captured once, seven individuals were captured twice, five individuals were captured thrice, five were captured four times and four individuals were captured more than five times thus revealing the sample size (number of individual captured) of 29 individuals. Whereas in summer four individuals were captured once, four had double captures, six were captured thrice, three individuals were captured four times and four individuals were captured more than five times thus revealing a smaller sample size of 21 individuals.

The closed capture–recapture model Mh, with jackknife estimator which incorporates individual heterogeneity in capture probabilities, fitted the photographic capture history data with the estimated capture probability p-hat = 0.10, resulted in an estimated hyena

population size, N (SE) = 34.9 (±4.3) in winter and 24.10 (±3.6) in summer **(Table.3.3 and 3.4)**. Density D (SE) and effective trapping area ETA was calculated by different methods using program DENSITY4.4 is shown in **Table 3.3** and **3.4**. The estimated density of hyena in summer based on spatial explicit model IP dens was 13.5 (± $5.2_{SE}$)/ 100 $km^2$ in summer and 18.7(±$5.8_{SE}$)/100 $km^2$ in winter. Student t test revealed no significant difference between densities of striped hyena between seasons (t= 6.192, df=1, P=0.102).

**3.3a) 4. Required sampling efforts:**

Population estimates were calculated using model Mh by considering a very small sampling occasions and systematically increasing them. The estimate suggests that minimum 20 days/block of sampling is required to get reliable estimates of the population of hyena **(Figure 3.3)**. This method is used to optimize the trapping effort and minimum cost for camera trap studies for hyena. High individual capture rates of striped hyena did not show any behavior response and trap shyness against the camera trap in both the seasons **(Figure 3.4 and 3.5)**.

**Figure 3.2 Camera trap locations in a sampled area in Sariska Tiger Reserve, Rajasthan during (December 2008-July 2009).**

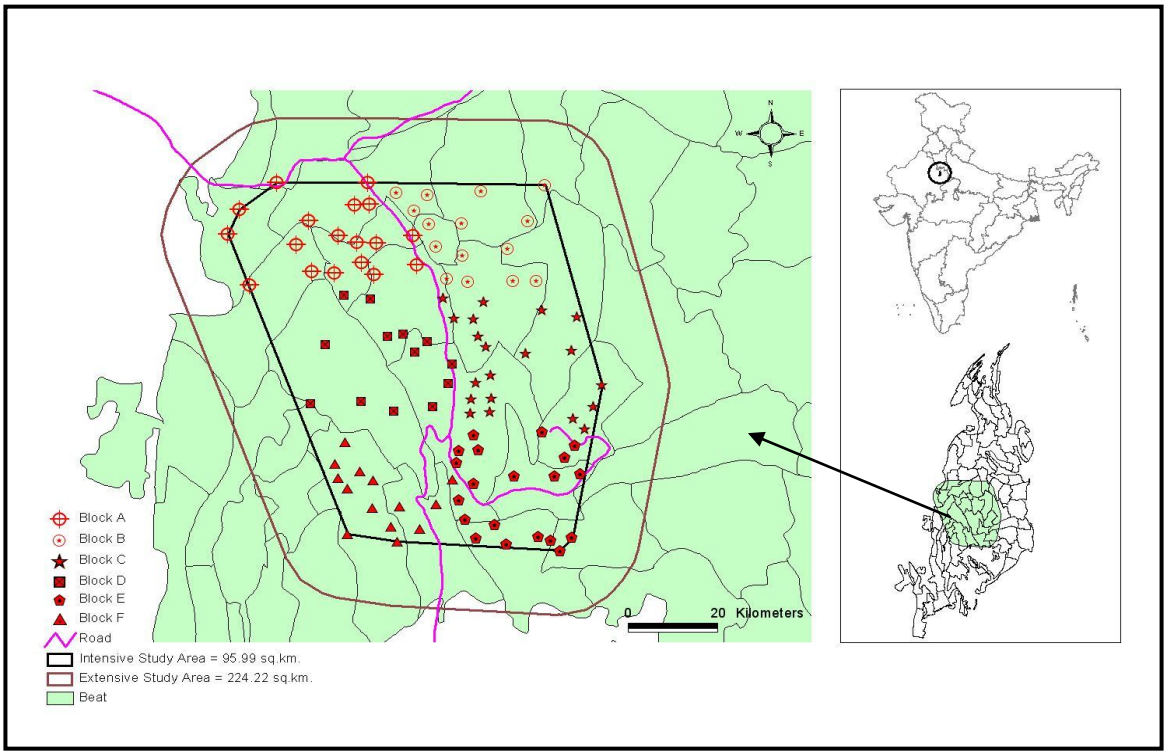



**Figure 3.3 Number of striped hyena photographed and number of hyena photographs with increasing number of sampling occasions to evaluate sampling adequacy and trap shyness.**

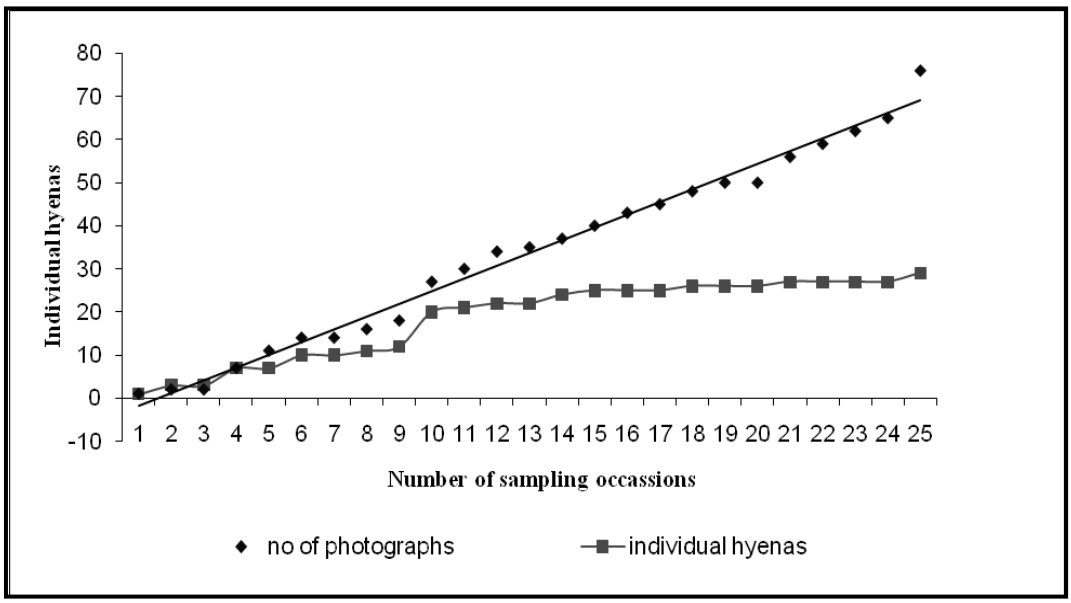


**Table 3.3 Density estimates of striped hyena from camera trap data during summer (2008-2009) in Sariska Tiger Reserve.**

| Model | N | SE(N) | P(hat) | Methods for calculating ETA | Width in km | ETA in $km^2$ | D (hyena/100 $km^2$ | SE |
|---|---|---|---|---|---|---|---|---|
| **Mh Jacknife** | 24.10 | 3.6 | 0.12 | MMDM | 6.02 | 445.65 | 4.70 | 0.81 |
| | | | | MMDM/2 | 3.01 | 224.22 | 8.60 | 1.05 |
| | | | | IP Dens | | | **13.50** | **5.20** |
| | | | | ML Dens | | | 12.34 | 2.70 |

**Table 3.4 Density estimates of striped hyena from camera trap data during winter (2007-2009) in Sariska Tiger Reserve.**

| Model | N | SE(N) | P(hat) | Methods for calculating ETA | Width in km | ETA in $km^2$ | D (hyena/100 $km^2$ | SE |
|---|---|---|---|---|---|---|---|---|
| **Mh Jacknife** | 34.90 | 4.30 | 0.10 | MMDM | 5.90 | 436.37 | 8.00 | 1.60 |
| | | | | MMDM/2 | 2.90 | 240.73 | 14.29 | 2.30 |
| | | | | IP Dens | | | **18.70** | **5.80** |
| | | | | ML Dens | | | 16.70 | 3.20 |

(N= Population estimate, P (hat) = capture probability, Width =Buffer strip width, ETA=effectively trapped area, D=Density stimate, MMDM=Mean maximum distance moved, IP Dens= Inverse prediction density, ML Dens= Maximum likelihood density, SE = Standard error)

**Figure 3.4 Individual capture rates of striped hyena during winter (2007-2009) in Sariska Tiger Reserve (n=105).**

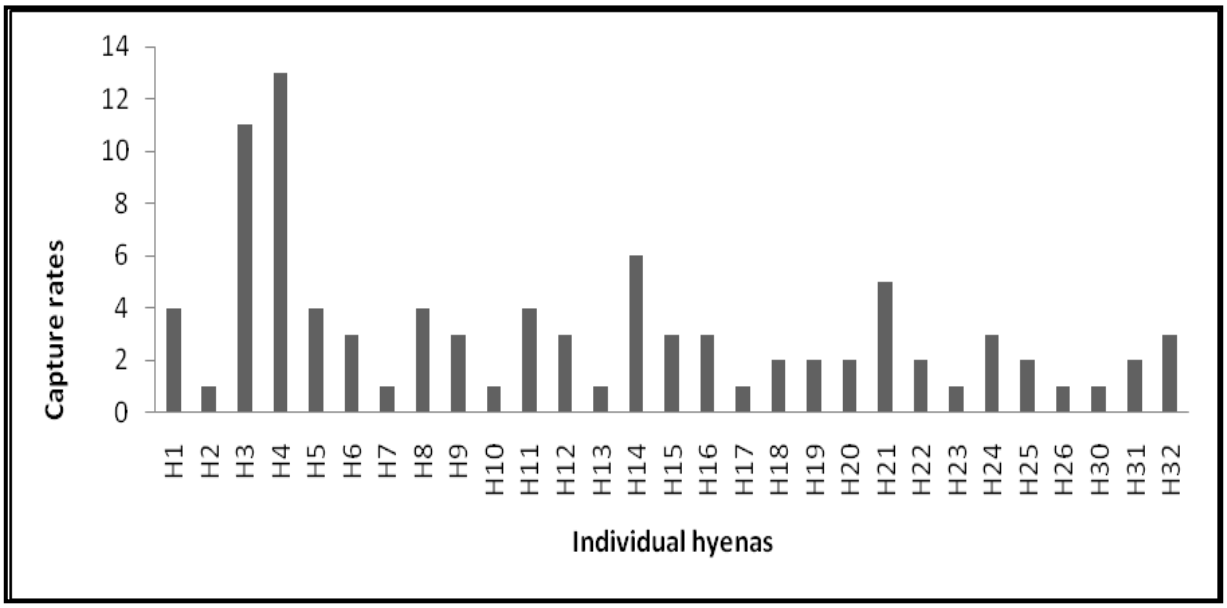
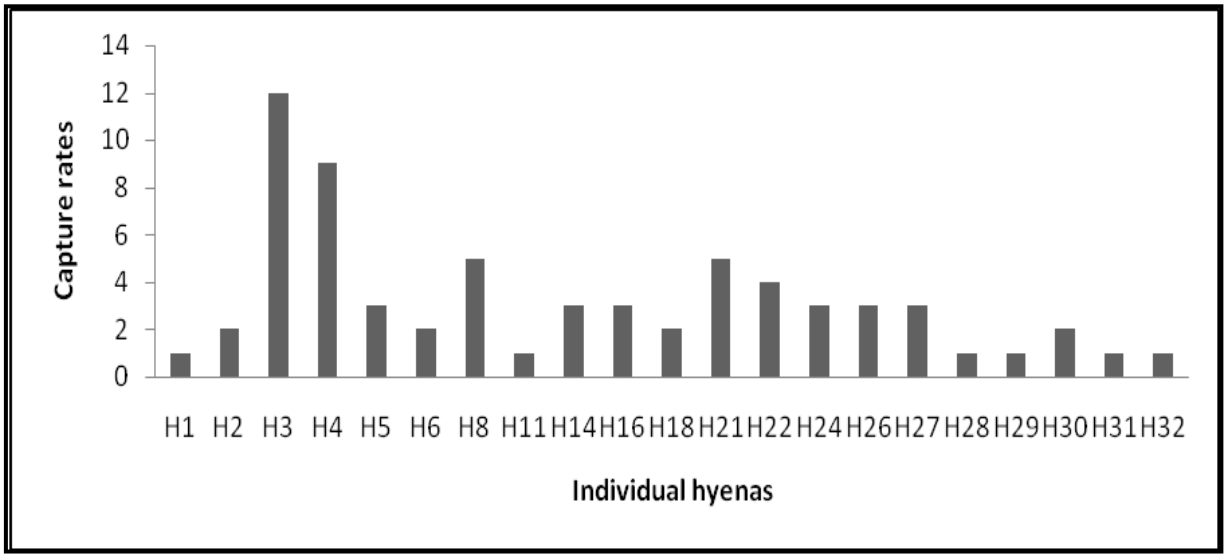



**Figure 3.5 Individual capture rates of striped hyena during summer (2008-2009) in Sariska Tiger Reserve (n=85).**



**3.3b). Estimation of occupancy and abundances of non identifiable species from camera trap:**

Occupancy results derived from the analyses are presented species-wise here below. Abundance results of all species in two seasons are presented in **Table 3.6** and **3.7**.

**3.3b) 1. Jungle cat:**

Naive occupancy of jungle cat was 63%. Detection probability (*r*) was estimated as $0.019_{Mean} \pm 0.2_{SE}$ in winter and $0.16_{Mean} \pm 0.02_{SE}$ in summer. After correcting for imperfect detection, probability of site occurrence ($\Psi$) of jungle cat was found high in winter $0.60_{Mean} \pm 0.29_{SE}$ than summer $0.48_{Mean} \pm 0.36_{SE}$. The average abundance/ unit ($\lambda$) was estimated as $1.2_{Mean} \pm 0.96_{SE}$ in winter and $0.65_{Mean} \pm 0.69_{SE}$ in summer. Two sample t-test from mean and standard deviation revealed no significant difference in its abundance between seasons (t=1.018, df=8, p=0.34).

**3.3b) 2. Golden jackal:**

Naive occupancy of golden jackal was 40%. Detection probability (*r*) was estimated as $0.63_{Mean} \pm 0.13_{SE}$ in summer and $0.60_{Mean} \pm 0.13_{SE}$ in winter. After correcting for imperfect detection, probability of site occurrence ($\Psi$) of golden jackal was found high in summer $0.40_{Mean} \pm 0.15_{SE}$ than winter $0.37_{Mean} \pm 0.14_{SE}$. The average abundance/ unit ($\lambda$) was estimated as $0.52_{Mean} \pm 0.26_{SE}$ in summer and $0.46_{Mean} \pm 0.24_{SE}$ in winter. Two sample t-test revealed no significant difference in its abundance between seasons (t= 0.116, df=8, P= 0.91).

**3.3b) 3. Ratel:**

Naive occupancy for ratel was 30%. Detection probability (*r*) was estimated as $0.16_{Mean} \pm 0.17_{SE}$ in summer and $0.34_{Mean} \pm 0.25_{SE}$ in winter. After correcting for imperfect detection, the probability of site occurrence ($\Psi$) for ratel was found high in summer

$0.30_{Mean}$ $\pm 0.27_{SE}$ than in winter $0.11_{Mean} \pm 0.10_{SE}$. The average abundance/ unit (λ) for ratel was estimated as $0.36_{Mean}$ $\pm 0.39_{SE}$ in summer and $0.12_{Mean} \pm 0.12_{SE}$ in winter. Two sample t-test revealed no significant difference in abundance of ratel between seasons (t=1.493 df=8, P=0.173).

**3.3b) 4. Palm civet:**

Naive occupancy for palm civet was 40%. Detection probability (*r*) was estimated as $0.04_{Mean} \pm 0.01_{SE}$ in summer and $0.03_{Mean} \pm 0.01_{SE}$ in winter. After correcting for imperfect detection, probability of site occurrence ($\Psi$) for palm civet was found high in summer $0.22_{Mean} \pm 0.06_{SE}$ than winter $0.16_{Mean}$ $\pm 0.08_{SE}$. The average abundance/ unit (λ) was estimated as $0.25_{Mean}$ $\pm 0.18_{SE}$ in summer and $0.18_{Mean} \pm 0.1_{SE}$ in winter. Two sample t-test revealed significant difference in abundance of palm civet between seasons (t=2.77, df=8, P=0.02).

**3.3b) 5. Small Indian civet:**

Naive occupancy for small Indian civet was 40%. Detection probability (*r*) was estimated as $0.013_{Mean} \pm 0.013_{SE}$ in summer and $0.16_{Mean} \pm 0.08_{SE}$ in winter. After correcting for imperfect detection, the probability of site occurrence ($\Psi$) for small Indian civet was found high in summer $0.34_{Mean}$ $\pm 0.26_{SE}$ than winter $0.16_{Mean} \pm 0.08_{SE}$. The average abundance/ unit (λ) was estimated as $0.43_{Mean}$ $\pm 0.4_{SE}$ in summer and $0.25_{Mean}$ $\pm 0.12_{SE}$ in winter. Two sample t-test revealed no significant difference in abundance of small Indian civet between seasons (t=1.024, df=8, P=0.335).

**3.3b) 6. Common grey mongoose:**

Naive occupancy for common grey mongoose was 40%. Detection probability (*r*) was estimated as $0.02_{Mean} \pm 0.017_{SE}$ in summer and $0.075_{Mean} \pm 0.029_{SE}$ in winter. After

correcting for imperfect detection, the probability of site occurrence ($\Psi$) for common grey mongoose was found high in summer $0.19_{Mean} \pm 0.10_{SE}$ than in winter $0.08_{Mean} \pm 0.04_{SE}$. The average abundance/ unit ($\lambda$) was estimated as $0.22_{Mean} \pm 0.13_{SE}$ in summer and $0.09_{Mean} \pm 0.04_{SE}$ in winter. Two sample t-test revealed no significant difference in the abundance of common grey mongoose between seasons (t=2.092, df=8, P=0.06).

**3.3b) 7. Ruddy mongoose:**

Naive occupancy for ruddy mongoose was 30%. Detection probability (*r*) was estimated as $0.018_{Mean} \pm 0.015_{SE}$ in summer and $0.013_{Mean} \pm 0.015_{SE}$ in winter. After correcting for imperfect detection, the probability of site occurrence ($\Psi$) for ruddy mongoose was found high in summer $0.26_{Mean} \pm 0.01_{SE}$ than in winter $0.24_{Mean} \pm 0.2_{SE}$. The average abundance/ unit ($\lambda$) was estimated as $0.31_{Mean} \pm 0.25_{SE}$ in summer and $0.28_{Mean} \pm 0.33_{SE}$ in winter. Two sample t-test revealed no significant difference in the abundance of ruddy mongoose between seasons (t=0.105, df=8, P=0.918).

**3.3c) Estimation of occupancy and abundance of small carnivores from track plot**

Occupancy results derived from Royle and Nichols (2003) model through track plots are presented species-wise here below. Abundance results of all species are presented in **Table 3.8** and **3.9.**

**3.3c) 1. Jungle cat:** Naive occupancy for jungle cat was 56%. Detection probability (*r*) was estimated as $0.70_{Mean} \pm 0.20_{SE}$ in winter and $0.51_{Mean} \pm .02_{SE}$ in summer. After correcting for imperfect detection, the probability of site occurrence ($\Psi$) for jungle cat was found high in winter $0.69_{Mean} \pm 0.11_{SE}$ than summer $0.68_{Mean} \pm 0.15_{SE}$. The average abundance/unit ($\lambda$) was estimated as $1.18_{Mean} \pm 0.37_{SE}$ in winter and $1.14_{Mean} \pm 0.48_{SE}$ in summer. Two

sample t-test from mean and standard deviation revealed no significant difference in the abundance of jungle cat based on track plots between seasons (t=0.121, df=8, P=0.90).

**3.3c) 2. Golden jackal:** Naive occupancy for golden jackal was 40%. Detection probability (*r*) was estimated as $0.60_{Mean}\pm0.13_{SE}$ in winter and $0.57_{Mean}\pm0.13_{SE}$ in summer. After correcting for imperfect detection, the probability of site occurrence ($\Psi$) for golden jackal was found high in summer $0.72_{Mean}$ $\pm0.15_{SE}$ than winter $0.37_{Mean}\pm0.14_{SE}$. The average abundance/unit ($\lambda$) was estimated as $0.46_{Mean}$ $\pm0.24_{SE}$ in winter and $0.54_{Mean}\pm0.27_{SE}$ in summer. Two sample t-test revealed no significant difference in the abundance of golden jackal based on track plots between seasons (t=0.191 df=8, P=0.85).

**3.3c) 3. Ratel:** Naive occupancy for ratel was 30%. Detection probability (*r*) was estimated as $0.58_{Mean}$ $\pm0.23_{SE}$ in winter and $0.53_{Mean}\pm0.13_{SE}$ in summer. After correcting for imperfect detection, the probability of site occurrence ($\Psi$) for ratel was found high in summer $0.38_{Mean}\pm0.15_{SE}$ than in winter $0.09_{Mean}\pm0.09_{SE}$. The average abundance/unit ($\lambda$) was estimated as $0.10_{Mean}$ $\pm0.1_{SE}$ in winter and $0.48_{Mean}\pm0.25_{SE}$ in summer. Two sample t-test revealed significant difference in the abundance of ratel based on track plots between seasons (t=3.611 df=8, P=0.006).

**3.3c) 4. Civet:** Naive occupancy for civets (palm and small Indian civet) was 40%. Detection probability (*r*) was estimated as $0.44_{Mean}$ $\pm0.014_{SE}$ and $0.47_{Mean}\pm0.018_{SE}$ in summer and in winter respectively. After correcting for imperfect detection, the probability of site occurrence ($\Psi$) for civet was found high in summer $0.36_{Mean}$ $\pm.09_{SE}$ than winter $0.18_{Mean}\pm0.06_{SE}$. The average abundance/unit ($\lambda$) was estimated as $0.21_{Mean}\pm0.09_{SE}$ in winter and $0.46_{Mean}\pm0.15_{SE}$ in summer. Two sample t-test revealed significant

difference in the abundance of civet based on track plots between seasons (t=3.34 df=8, P=0.01).

**3.3c) 5. Mongoose:** Naive occupancy for mongoose (common grey mongoose and ruddy mongoose) was 40%. Detection probability (*r*) was estimated as $0.08_{Mean} \pm 0.03_{SE}$ in winter and $0.04_{Mean} \pm 0.02_{SE}$ in summer. After correcting for imperfect detection, the probability of site occurrence ($\Psi$) for mongoose was found high in summer $0.14_{Mean} \pm 0.06_{SE}$ than winter $0.08_{Mean} \pm 0.03_{SE}$. The average abundance/unit ($\lambda$) was estimated as $0.09_{Mean} \pm 0.04_{SE}$ in winter and $0.16_{Mean} \pm 0.07_{SE}$ in summer. Two sample t-test revealed significant difference in the abundance of mongoose based on track plots between seasons (t=3.34 df=8, P=0.01).

**3.3 d) Estimation of abundance and occupancy of study animals (comparison between camera trap and track plots):**

Program R based on Monte Carlo t test statistics was used to estimate the proportion of rejection (P) in percentage between two population abundance estimates from camera trap and track plots for all small carnivores (**Table 3.10** and **3.11)**. In case of jungle cat it showed 10.99% rejection between camera trap and track plot in summer while 55.71% rejection in winter. Golden jackal's population estimates showed 20.41% rejection in summer and 19.71% in winter. In case of ratel 35.41% rejection was found between two methods in summer and 11.00% in winter. Similarly for civets, 12.78% rejection was found in summer and 26.10% in winter, while for mongoose 86.56% rejection in summer and 11.34% in winter was observed. If the proportion of rejection is less than 70% than abundance estimates from two different methods, camera trap and track plots for any study species was considered to be same while if it was more than 70% than it was considered to be different.

**Table 3.6 Abundance estimation of small carnivores from camera trap data based on Royle- Nichols Induced heterogeneity model (2003) during summer (2008-2009) in Sariska Tiger Reserve**.

| Species | Grid size $Km^2$ | Sampling size (#Grid) | Group abundance | SE | Mean group size | SE | Population Size (N)* | SE | Density/ 100 $km^2$ | SE |
|---|---|---|---|---|---|---|---|---|---|---|
| Jungle cat | 2 x 2 | 30 | 19.620 | 20.830 | 1.000 | 0.000 | 19.620 | 20.830 | 13.61 | 14.46 |
| Golden jackal | 4 x 4 | 10 | 5.200 | 2.600 | 1.189 | 0.037 | 6.184 | 3.098 | 4.29 | 2.15 |
| Ratel | 4 x 4 | 10 | 5.020 | 4.130 | 1.170 | 0.700 | 5.873 | 5.975 | 4.07 | 4.14 |
| Palm civet | 1 x 1 | 67 | 25.270 | 8.110 | 1.000 | 0.000 | 25.270 | 8.110 | 17.54 | 5.63 |
| Small Indian civet | 1 x 1 | 67 | 30.060 | 28.240 | 1.000 | 0.000 | 30.060 | 28.240 | 20.87 | 19.61 |
| Ruddy mongoose | 1 x 1 | 67 | 20.480 | 16.700 | 1.107 | 0.058 | 22.674 | 18.528 | 15.74 | 12.86 |
| Common mongoose | 1 x 1 | 67 | 14.560 | 8.810 | 1.176 | 0.125 | 17.129 | 10.522 | 11.89 | 7.30 |

*** estimated in the intensive study area of 144 $km^2$**

**Table 3.7 Abundance estimation of small carnivores from camera trap data based on Royle- Nichols Induced heterogeneity model (2003) during winter (2007-2009) in Sariska Tiger Reserve**.

| Species | Grid size $Km^2$ | Sampling size (#Grid) | Group abundance | SE | Mean group size | SE | Population Size (N)* | SE | Density /100$km^2$ | SE |
|---|---|---|---|---|---|---|---|---|---|---|
| Jungle cat | 2 x 2 | 30 | 35.850 | 28.910 | 1.000 | 0.000 | 35.850 | 28.910 | 24.89 | 20.07 |
| Golden jackal | 4 x 4 | 10 | 4.630 | 2.370 | 1.288 | 0.055 | 5.963 | 3.063 | 4.14 | 2.12 |
| Ratel | 4 x 4 | 10 | 1.700 | 1.230 | 1.070 | 0.050 | 1.819 | 1.319 | 1.26 | 0.91 |
| Palm civet | 1 x 1 | 67 | 12.240 | 6.400 | 1.000 | 0.000 | 12.240 | 6.400 | 8.5 | 4.44 |
| Small Indian civet | 1 x 1 | 67 | 16.610 | 8.090 | 1.000 | 0.000 | 16.610 | 8.090 | 11.53 | 5.61 |
| Ruddy mongoose | 1 x 1 | 67 | 19.020 | 22.150 | 1.115 | 0.063 | 21.215 | 24.735 | 14.73 | 17.17 |
| Common mongoose | 1 x 1 | 67 | 6.110 | 2.900 | 1.118 | 0.078 | 6.829 | 3.276 | 4.74 | 2.27 |

*** estimated in the intensive study area of 144 $km^2$**

**Table 3.8 Abundance estimation of small carnivores from track plot data based on Royle- Nichols Induced heterogeneity model (2003) during summer (2008-2009) in Sariska Tiger Reserve**.

| Species | Grid size $Km^2$ | Sampling size (#Grid) | Group abundance | SE | Mean group size | SE | Population Size (N)** | SE | Density /100 $km^2$ | SE |
|---|---|---|---|---|---|---|---|---|---|---|
| Jungle cat | 2 x 2 | 30 | 34.350 | 14.310 | 1.000 | 0.000 | 34.350 | 14.310 | 23.88 | 9.93 |
| Golden jackal | 4 x 4 | 10 | 5.450 | 2.720 | 1.189 | 0.037 | 5.190 | 2.580 | 3.61 | 1.80 |
| Ratel | 4 x 4 | 10 | 4.830 | 2.500 | 1.170 | 0.700 | 5.651 | 2.580 | 3.92 | 1.80 |
| Civet* | 1 x 1 | 67 | 30.890 | 10.080 | 1.000 | 0.000 | 30.890 | 10.080 | 21.45 | 7.01 |
| Mongoose* | 1 x 1 | 67 | 10.680 | 4.990 | 1.214 | 0.093 | 12.969 | 6.139 | 9.02 | 4.23 |

***combined data**
**** estimated in the intensive study area of 144 $km^2$**

**Table 3.9 Abundance estimation of small carnivores from track plot data based on Royle- Nichols Induced heterogeneity model (2003) during winter (2007-2009) in Sariska Tiger Reserve**.

| Species | Grid size $Km^2$ | Sampling size (#Grid) | Group abundance | SE | Mean group size | SE | Population Size (N)** | SE | Density /100 $km^2$ | SE |
|---|---|---|---|---|---|---|---|---|---|---|
| Jungle cat | 2 x 2 | 30 | 35.330 | 11.030 | 1.000 | 0.000 | 35.330 | 11.030 | 24.51 | 7.76 |
| Golden jackal | 4 x 4 | 10 | 4.630 | 2.720 | 1.288 | 0.055 | 4.860 | 2.863 | 3.40 | 2.01 |
| Ratel | 4 x 4 | 10 | 1.040 | 1.040 | 1.070 | 0.050 | 1.113 | 1.114 | 0.76 | 0.76 |
| Civet* | 1 x 1 | 67 | 13.630 | 5.610 | 1.000 | 0.000 | 13.630 | 5.610 | 9.44 | 3.88 |
| Mongoose* | 1 x 1 | 67 | 5.870 | 2.730 | 1.192 | 0.077 | 6.999 | 3.287 | 4.86 | 2.29 |

***combined data**
**** estimated in the intensive study area of 144 $km^2$**

**Table 3.10 Abundance estimation of small carnivores in summer (2008-2009) using camera trap and track plot method.**

| Species | Camera trap | | Track plot | | Proportion of rejection(P) | Comparison between methods |
|---|---|---|---|---|---|---|
| | Abundance | SE | Abundance | SE | | |
| Jungle cat | 19.6 | 20.8 | 34.4 | 14.3 | 55.41% | No difference |
| Golden jackal | 6.2 | 3.1 | 5.2 | 2.6 | 19.74% | No difference |
| Ratel | 5.9 | 6 | 5.7 | 2.6 | 11.00% | No difference |
| Civet | 26.7 | 7.7 | 30.9 | 10.1 | 26.10% | No difference |
| Mongoose | 12.3 | 8.8 | 13.0 | 6.1 | 11.34% | No difference |

**Table 3.11 Abundance estimation of small carnivores in winter (2007-2009) using camera trap and track plot method.**

| Species | Camera trap | | Track plot | | Proportion of rejection(P) | Comparison between methods |
|---|---|---|---|---|---|---|
| | Abundance | SE | Abundance | SE | | |
| Jungle cat | 35.9 | 28.9 | 35.3 | 11 | 10.90% | No difference |
| Golden jackal | 6 | 3.1 | 4.9 | 2.9 | 20.41% | No difference |
| Ratel | 1.8 | 1.3 | 1.1 | 1.1 | 35.41% | No difference |
| Civet | 11.8 | 12.4 | 13.6 | 5.6 | 12.78% | No difference |
| Mongoose | 15.1 | 8.3 | 7.0 | 3.3 | **86.56%** | **Difference** |

## 3.4 DISCUSSION

### 3.4.1 Density estimates of striped hyena:

The capture – recapture technique based on camera trap photographs of hyena provided a statistically robust estimate in estimating the population in STR. The reported hyena density of 18.7/100 $km^2$ in STR (**Table 3.3** and **Table 3.4**) was found to be high as compared to other studies in India and Africa (Kruuk, 1976; Wagner, 2006, 2008; Singh, 2008; Harihar *et al.,* 2010; Gupta *et al.,* 2010). This may be attributed to availability of high wild prey base and domestic livestock i.e. of 105 animal/$km^2$ and 222 animals/ $km^2$ respectively in the study area (Sankar *et al*., 2009) availability of livestock carcasses near villages and road kills of wild prey species.

In capture-recapture studies, especially for large mammals, the trapping was done in a small area and a buffer strip is added to it to account for the space use by animals trapped at the periphery. The strip width is calculated, most often through the MMDM (mean maximum distance moved) between recaptures and a strip of half the size of MMDM is added to the intensively sampled area. In this study, I considered hyena density arrived from 1/2 MMDM and spatial explicit IP dens model which gave more reliable estimates than full MMDM and ML dens. The estimates obtained through spatial IP Dens seems to be more ecologically realistic than the ones obtained through 1/2 MMDM while full MMDM method is a theoretical construction (Royle and Dorazio, 2006; Contractor, 2007; Jhala *et al*., 2008; Efford, 2008; Singh, 2008; Sharma *et al*., 2009; Harihar *et al.,* 2010; Gupta *et al.,* 2010). Comparing the standard errors reported from earlier studies (Singh, 2008, and Harihar *et al.,* 2010; Gupta *et al.,* 2010) for both population and density of striped hyena indicates that the results are precise in the present study. Individual heterogeneity is an important aspect in this study. Every individual has different capture probability depending upon their movement pattern, access to trap sites and response to

photographic flash. From the capture history data it is evident that some individuals became trap shy after being captured once. Poor recaptures rates of some individuals in both the seasons can affect population estimation and it is understandable that larger number of recaptures will result in more accurate and precise population estimates (**Figure 3.4 and 3.5**). In case where hyena sex determination from camera traps was not possible, separate male and female capture matrix was not generated during the analysis. The present study also suggests that cameras should not be kept at a fixed location for longer duration. During my study period I kept changing the location of camera trap at radial distance of upto 1 km to maximize the capture probabilities and to reduce trap shyness. Individual hyena showed considerable variability in their captures owing to the difference in individual behaviour. Since, no hyena cubs were recorded in camera traps but pugmarks of hyena were recorded several times near the trap stations, it is assumed that the population is closed demographically i.e. no birth and death took place during the study period. When closure is affected by trap response (trap shyness) it becomes difficult to differentiate it from death or emigration of the animal. Therefore it becomes very important to camouflage cameras properly to avoid trap shyness. Effort required in terms of sampling occasions suggested that a minimum of 20 days are required to get reliable density estimates for hyena in the study area, while for large carnivores like tigers it varies from 30 to 40 days to get reliable density estimates (Contractor, 2007). Camera traps deployed near villages Haripura and Kiraska showed high individual capture rates such as 11% (n=7) and 14% (n=9) respectively. This may be attributed to availability of dumped carcasses (livestock) around these villages on which hyenas might be scavenging. Livestock depredation (n=63) and road accidents (n= 28) resulting in hyena deaths during summer were identified as major threat to its population.

### 3.4.2 Abundance of non- identifiable species from camera traps and track plot:

The simulation results from present study showed that the occupancy based Royle and Nichols (2003) model can provide a useful tool for the estimation of abundance of non-uniquely identifiable and cryptic species, since it is relatively inexpensive to obtain presence-absence data from sites. The use of this model for a suite of species that may not be uniquely identifiable provides a solution to monitoring populations of cryptic and nocturnal species in a systematic and statistically sound manner. The results showed that increase in number of sites had a little effect on variability of parameter estimates. This is because increase in home range sizes of species have added more spatial replicates to each site/location for analysis, thus there was reduction in number of available sites for analysis which caused little variability in my estimates. Assumption of Royle and Nichols model (2003) showed that animal detected on one site will not be detected in another site, and instead making the assumption that the abundance at each site at any given point remains constant, irrespective of immigration or emigration to or from the site, the estimate of the animal specific detection probability is still very low (Gopalaswamy, 2006). Hence, it is suggested that placing more camera trap per grid may improve detection probability and provide better estimates for $\lambda$.

The data gathered from this study showed reliable estimates of abundances of seven medium and small carnivores in STR. Since the abundance estimates showed high standard error in both the seasons for some species like jungle cat, civet and mongoose there would be possibility of their high estimates of abundance. These abundance estimates in the present study are likely to improve (lower standard errors) when animal specific detection probabilities are improved, and also when the numbers of repeated visits are increased and more sites (grids) will be surveyed. In Sariska, the jungle cat was found to be the most abundant species based on camera trap and track

plot data in both the seasons followed by small Indian civet, palm civet, ruddy mongoose, common grey mongoose, golden jackal and ratel. The camera trap sites which were in open scrubland (Sadar beat) and *Zizyphus* mixed forest near Kalighati showed high capture rates for all species. High abundance of jungle cat in the study area was also documented by Mukherjee (1998) which may be due to the presence of suitable habitat and availability of rodent biomass i.e. 223.79 gm/ha (as discussed in Chapter 4). It is estimated that in central Asia, in natural Tugai habitat (floodplain forest vegetation) the density of jungle cat population per 10 $km^2$ area was 4 to 15 individuals (Belousova, 1993) and in habitats with sparse vegetation, the density was 2 per 10 $km^2$ (Nuratdinov and Reimov, 1972). Civets (n=12) and mongoose (n=7) in sariska showed high capture rates in hilly trap sites (Malajorka and Pandupol area). The significant difference in abundance of civets as observed between seasons may be due to less captures in winter (n=15).

Density of ratel 4.07/100$km^2$ in STR was found to occurred high compared with Serengeti National Park, Tanzania 0.1 individuals/$km^2$ (Waser, 1980), Niokolo-Koba National Park, Senegal 0.07 individuals/100$km^2$ (Sillero-Zubiri and Marino, 1997) and in Kgalagadi Transfrontier Park, South Africa was found to be 0.03 adults / $km^2$ (Begg, 2001a). In sariska, low density of ratel in winter may be due to winter hibernation of this animal as reported by Kauhala *et al.*, (2006). In case of golden jackals they are found to be abundant in number based on direct sightings but showed low capture rates in camera traps. This may be attributed to not using of trails/roads frequently by this species in the study area. Animal specific detection probability(r) for all study species showed great variability (0.2 to 0.6) and abundance from 1 to 35. When the value of abundance was very high (>30), the site specific detection probability was less sensitive to change the abundance (Gopalaswamy, 2006). Hence it is suggested to use Royle and Nichols (2003) model with respect to occupancy of small carnivores as compared to the Mac Kenzie *et al.*,

(2002) model which implicitly assumes that sites have a constant or nearly constant abundance. Camera trap and track plot method proved to be efficient in many earlier studies for estimation of small carnivore abundance (Seydack, 1984; Kelly *et al.*, 1998; Mace *et al.*, 1994; Nag, K, 2008). Results obtained from camera traps and track plots during the present study further compared for closeness which showed no difference between two different methods for all species except for mongoose. This may be due to the presence of fallen leaves/ flowers and fruits on track plots encountered during winter that resulted in missing out some tracks of small carnivores in the study area.

### 3.4.3 Comparison between track plots and camera traps for estimating abundance of study species:

The present study showed no difference between the abundance of the study species in STR from camera trap and track plot but some consideration taken into account like climate and ground conditions can be relevant limitations, and too wet or too dry ground can determine the detection ability and identification of tracks, and thus validate or invalidate a survey and finally, the costs of a sampling method are commonly a limiting factor for surveying large areas. Despite the high initial costs of camera-trapping, this method, compared with track census, can be handled more easily and with relatively low costs in a long term run. The advantages of camera trap includes accuracy of species identification and their track sign, low environmental disturbance, similar efficiency in the detection of nocturnal and diurnal species (at least when compared with direct counts) and additional possibility of studying activity patterns, ease in handling by non-trained personnel, extent of area that can be simultaneously sampled and possibility of being used in further population studies.

# CHAPTER 4

# PREY ABUNDANCE AND FOOD HABITS

## 4.1 INTRODUCTION

Prey abundance has been studied using several techniques depending upon the group of animals they belong to. The ungulates, rodents (Murids and Sciurids), birds and hare, which constitute major portion of predator's diets (Schaller, 1967, 1972; Johnsingh, 1986; Mukherjee, 1998) can be quantified using direct and indirect methods. The line transect method (Burnham *et al.*, 1980; Buckland *et al.*, 1993) is considered to be the most appropriate method for estimation of herbivore abundance and has been used extensively to determine animal abundance (Sunquist, 1981; Mathur, 1991; Karanth and Sunquist, 1995; Varman and Sukumar, 1995; Biswas and Sankar, 2002; Sankar and Johnsingh, 2002; Bagchi *et al.*, 2003). Since estimating animal densities using Distance Sampling method corrects the bias of non-detection, this method is preferred over others (Karanth and Nichols, 1998). Line transects have been found to be very effective and reliable in estimating densities of ungulates in the Indian Subcontinent (Karanth *et al.*, 2004a). Small mammals are an integral component of forest animal communities, they form an important prey base for medium sized carnivores (Emmons, 1987; Golley *et al.*, 1975; Hayward and Phillipson, 1979). Anderson *et al.*, (1983) demonstrated the density estimation of rodents using a trapping web and distance sampling method. In recent past, many workers contributed to the distribution pattern of rodents throughout India. But these were taxonomic studies rather than assessing the ecological aspects of species assemblage, co existence and diversity in the natural habitat. Prakash (1959, 1972, 1975, 1977, 1981 and 1995) extensively studied the rodent distribution in Rajasthan.

Striped hyena has been reported to consume a wide variety of vertebrates, invertebrates, vegetables, fruit, and human originated organic wastes (Kruuk, 1976; Leakey, 1999; Wagner, 2006). It is known to scavenge on lion and spotted hyena kills (Kruuk, 1976; Wagner, 2006) as well as discarded livestock carcasses (Leakey, 1999; Wagner, 2006; Singh, 2008). The overall reputation, therefore, of the species is that of an omnivorous scavenger. However, in central Kenya analysis of bone fragments and hairs from faecal samples indicate that hyenas regularly consume smaller mammals and birds that are unlikely to be scavenged (Wagner, 2006). In sariska, over 35% of striped hyena's diet comprised of chital, while unidentified birds, rodents and *Zizyphus* fruits constituted 13% (Sankar, 2002).

Golden jackals are omnivorous and opportunistic foragers, and their diet varies according to season and habitat. In East Africa, although they consume invertebrates and fruit, over 60% of their diet comprises rodents, lizards, snakes, birds (from quail to flamingos), hares, and Thomson's gazelle (*Gazella thomsoni*) (Wyman, 1967; Moehlman, 1983, 1986, 1989). In Bharatpur, over 60% of jackals diet comprised of rodents, birds and fruit (Sankar, 1988) and while in Kanha, Schaller (1967) found that over 80% of the diet consisted of rodents, reptiles and fruit. In Sariska Tiger Reserve, scat analysis (n=60) revealed that their diet comprised mainly mammals (45% occurrence, of which 36% was rodents), vegetable matter (20%), birds (19%), and reptiles and invertebrates (8% each) (Mukherjee, 1998). Great quantities of vegetable matter occur in the diet of jackal and during the fruiting season, they feed intensively on the fallen fruits of *Ziziphus* spp, *Syzigium cuminii* and pods of *Prosopis juliflora* and *Cassia fistula* (Kotwal *et al*., 1991; Gupta, 2006).

Throughout the world, the diet of jungle cat (*Felis chaus*) was dominated by mammalian prey. They feed primarily on rodents (Allayarov, 1964; Schaller, 1967; Heptner and Sludskii, 1972,

Roberts, 1977; Khan and Beg, 1986; Mukherjee, 1998), including large rodents such as the introduced Coypu (weight 6-7 kg) in Eurasia (Heptner and Sludskii, 1972) to Spiny tailed mouse *Mus platythrix* (16 gm) in semi arid area in India (Mukherjee, 1998). Birds are of secondary importance in their diet since they are versatile predators and consume a broad range of prey species like hares, reptiles, amphibians and insects (Rathore and Thapar, 1984). They are strong swimmers, and will dive to catch fish (Mendelssohn, 1989), or to escape when chased by man or dog (Heptner and Sludskii, 1972).

## 4.2 METHODS

### 4.2 a) Estimation of prey populations:

#### 4.2a).1 Ungulates and ground birds:

Densities of the wild prey species including ungulates and ground birds in the study area were estimated using line transects (Anderson *et al.,* 1979; Burnham *et al.,* 1980; Buckland *et al.,* 1993, 2001). Twenty four transect were laid in the intensive study area (National Park) **(Figure 4.1)**. The length of transects varied from 1.4 km to 2.0 km. All transects (72.0 km) were walked thrice in the early morning between 0630 hrs and 0930 hrs during November 2007 to June 2009 in two seasons, winter (November to February) and summer (March to June). The total effort was 145 km in each season. The data was analyzed by using DISTANCE 5.0 software (Laake *et al.,* 1998). Minimum Akaike Information Criterion (AIC) was used to select the best fitted models (Buckland *et al.,* 1993).

#### 4.2a).2 Rodents:

Density of rodents was estimated using trapping web design at twelve different sites in the intensive study area during the study period. The study area was divided into six blocks of 20 $km^2$. Two trap points were randomly selected per block for rodent sampling. The standard

Sherman live traps (n=41) (5 x 6.5 x 16.5 cm) were used for trapping at twelve different site. Each trap was ran for 10 consecutive trap nights with total sampling period amounted to 4920 trap nights/ season. A trap night is defined as the use of one trap per night. The traps were operated in one hector area (100 m x 100 m) concentric rings of 50 m radius **(Figure 4.2)**. Each trap station was established every 10 m apart in the sampling area, and the overall trap density was one trap/10 $m^2$. Traps were placed on forest floor and concealed with bushes and bamboo leaves. All traps were painted with brown colour before deployed to the trapping site just to avoid trap shyness if any. The traps were kept near bushes, trees, rocks, fallen logs or any other possible run way of rats in sampling area. All the traps were baited with peanut butter between 17.30 hrs to 18.30 hrs and checked for animals between 5.30 hrs to 7.30 hrs. Equal efforts were made in all the blocks in both seasons in the study area. Trapped rodents were identified, weighed and measured for the tail length and body to head length (HBL). Rodents were identified up to species level using field guides (Prater, 1980; Corbett and Hill, 1992). The captured animals were photographed for identification **(Appendix-II)**. Animal sex was identified based on their genitalia. Adult and sub adults or pregnant females were not identified separately. The animals were released at the spot where they were trapped. Software DISTANCE 5.0 (Laake *et al.,* 1993) was used for the data analysis in two different seasons (summer and winter). Minimum Akaike Information Criterion (AIC) was used to select the best fitted models (Buckland *et al.,* 1993).

**4.2. b) Food habits:** Analysis of scats (faeces) was used to study the food habits of medium and small sized carnivores such as striped hyena, golden jackal and jungle cat in the study area, since, this method is meaningful and non – destructive and cost effective (Schaller, 1967; Johnsingh, 1983; Karanth and Sunquist, 1995; Biswas and Sankar, 2002; Bacchi and Sankar, 2003).

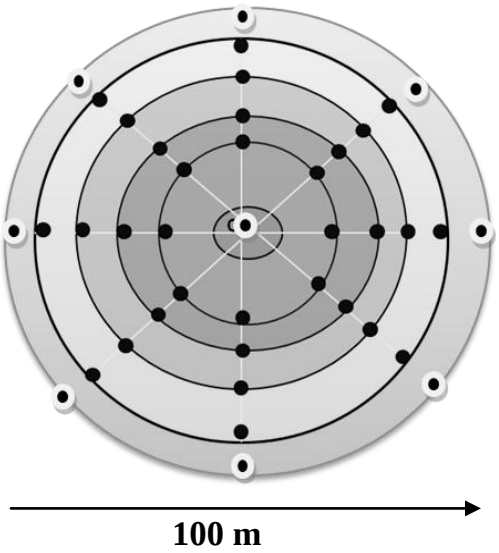



**Figure 4.2 Diagrammatic representation of rodent traps placed in a form trapping web around each trapping location in the intensive study area.**

Scats of study species were collected whenever encountered on the trails, tracks or during transect walk and were identified in field primarily using visual characteristics like shape, color, size, location of scat and associated foot prints of the predators **(Appendix III)**. All unidentified scats were excluded from analysis. Each scat was retained in plastic bags, marked with proper label with information like date, location, season, old and fresh etc. All the scats were washed and the remains such as hair, bones and tooth of the prey consumed were separated for species identification (Sunquist, 1981; Mukherjee *et al.*, 1994a, b; Karanth and Sunquist, 1995; Biswas and Sankar, 2002; Bacchi and Sankar, 2003). Identification was based on the general appearance of the hair, colour, length, width, medullary structure and cuticle pattern as suggested by Mukherjee *et al.*, (1994). Frequency of occurrence (proportion of total number of scats in which prey item was found) and percent occurrence (number of times a particular prey item occurred in the scat in terms of percentage of prey remains) were quantified in the diet as suggested by Ackerman *et al.*, (1984). A total 20 hairs were selected randomly from each scat (Mukherjee *et*

*al.*, 1994 a and b) to circumvent the possible biases (Karanth and Sunquist, 1995). While 10 scats were chosen randomly to assess the influence of sample size and it was continued until all scats had been included. The cumulative frequency of occurrence of different prey species was used to infer the effect of sample size on the results (Biswas and Sankar, 2002; Bacchi and Sankar, 2003). Program Simstat (Peladeau, 2002) was used for re-sampling the scat analysis using 1000 bootstrap stimulation. The original samples were iterated 1000 times to generate the mean and bias corrected for 95% CI. For estimating overall biomass of prey species the body weights of the potential prey species were taken from literature (Prater, 1980; Eisenberg and Seidensticker, 1976; Karanth and Sunquist, 1995; Ali and Ripley, 1987; Prakash, 1981). Analysis of variance, one way Anova (Zar, 2004) was carried out to check the significance level in percent occurrence of food item between seasons for each species.

**4.2 c) Niche breath and seasonal diet overlap between three carnivores:** Individual species Niche breadth was assessed using Levins measure (Levins, 1968) and standardized to a scale of 0-1 following Hurlbert (1978). Overlap in diet of different pairs of species was assessed using Pianka's (1981) index. Levin's Niche breadth was calculated using the formula $B= 1/\sum p^2_i$ where $p_i$ = Proportion of diet contributed by prey species *i*, and the Standardized Niche breadth was calculated using the formula $B_s= (B-1)/ (n-1)$, where n= Total number of prey species. Diet overlap among the three carnivores in each season was calculated using Pianka's index of diet overlap *i.e.* $O_{jk}= \sum (P_{ij}. P_{ik})/\sqrt{\sum P_{ij}^2. \sum P_{ik}^2}$ where, $O_{jk}$= Pianka's measure of diet overlap between species j and k, $P_{ij}$= Proportion of resource i of the total resources used by species j, $P_{ik}$= Proportion of resource i of the total resources used by species k. A diet overlap of 0 indicates no overlap whereas 1 indicates the two diets are exactly same.

## 4.3. RESULTS

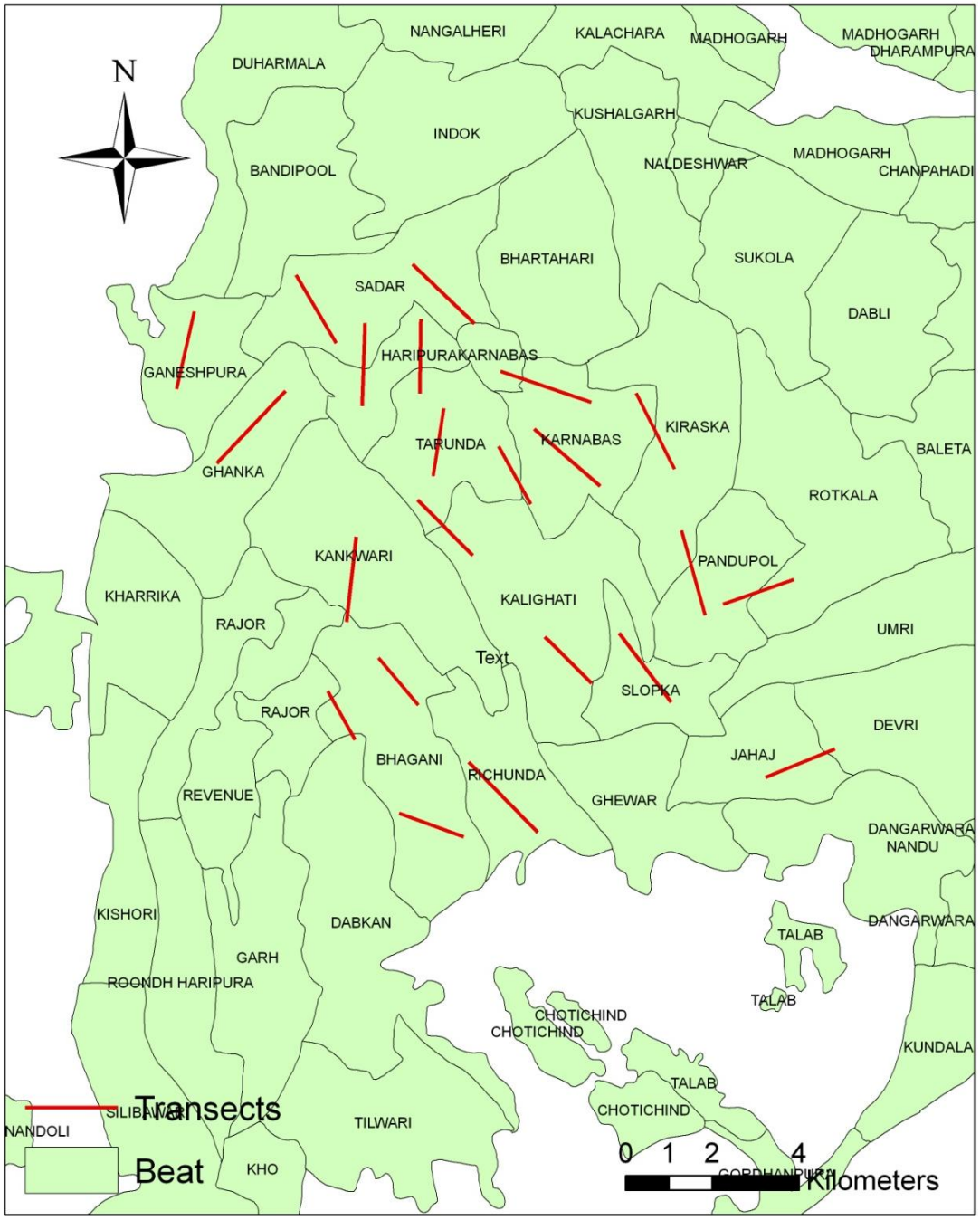
### 4.3a. Estimation of prey availability:

#### 4.3a.1. Density estimates of ungulates and ground birds:

**a) Overall density:** In total 15 potential prey species were detected on line transects. These were five ungulate species (sambar, chital, nilgai and wild pig), one primate (common langur), one small mammal (hare), three livestock (cattle, goat and sheep) and five bird species as peafowl (*Pavo cristatus*), jungle bush quail (*Perdicula asiatica*), grey partridge (*Francolinus pondicerianus*), painted spur fowl (*Galloperdix lunulata*) and red spur fowl (*Galloperdix spadicea*). Density estimates for 11 prey species was computed. There were only few sightings of sheep (n=14), painted spur fowl (n=11) and red spur fowl (n=9), hence their densities could not be computed seperately. All the species detection was best explained by half normal detection function with cosine adjustment of order one. Among the prey species, peafowl (174/km$^2$) had the highest prey density in the study area followed by grey partridge (40.8/km$^2$), chital (40.2/km$^2$), cattle (68.7/km$^2$), wild pig (33.9/ km$^2$), goat (29.3/km$^2$), sambar (25.1/km$^2$), nilgai (23.9/km$^2$), common langur (23.4/km$^2$) and jungle bush quail (20/km$^2$). The overall ungulate density of 190 animals/km$^2$ was estimated in the study area. The density of wild ungulates when multiplied with the average body weight of the respective species gave a biomass density of 15308.83 kg/ sq. km for the study area.

**b) Seasonal density:** Density of different prey species estimated through line transects in winter and summer is given in **Table 4.1**. Peafowl was found to be the most abundant prey species and chital was found to be the most common ungulate species in both the seasons in the study area

**Figure 4.1 Locations of line transects (n=24) in the intensive study area of Sariska Tiger Reserve, Rajasthan.**



followed by cattle, sambar, jungle bush quail, langur, nilgai, grey partridges, wild pig, goat and hare in summer and cattle, goat, nilgai, sambar, wild pig, langur, jungle bush quail, grey partridges and hare in winter. The estimated total individual prey density was 363.7 ± 34.3SE animals/km$^2$ in summer and 313.4 ± 33.8 SE animals/ km$^2$ in winter. Effective strip width (ESW) was 32.3 m in summer and 34.8 m in winter. One tailed t-test revealed significant difference in densities of prey species between the two seasons (t=13.38, df=1, P=0.047).

**Table 4.1 Density of potential prey species during winter and summer (2007-2009) in the intensive study area of Sariska Tiger Reserve.**

| | Winter (Nov- Feb) | | Summer (Mar- June) | | Overall (winter-summer) | |
|---|---|---|---|---|---|---|
| **Species** | **Density/km$^2$** | **SE** | **Density/km$^2$** | **SE** | **Density/km$^2$** | **SE** |
| Sambar | 12.7 | 2.4 | 23.9 | 5.3 | 25.1 | 2.6 |
| Chital | 35.2 | 8.0 | 47.01 | 8.3 | 40.2 | 5.0 |
| Nilgai | 14.9 | 2.8 | 19.4 | 3.5 | 23.9 | 2.8 |
| Wild pig | 9.2 | 3.3 | 11.9 | 4.1 | 33.9 | 10.3 |
| Hare | 1.8 | 0.8 | 2.7 | 0.8 | 12.6 | 1.7 |
| Langur | 7.8 | 3.0 | 21.0 | 5.7 | 23.4 | 5.5 |
| Goat | 48.4 | 22.3 | 37.7 | 25.0 | 29.3 | 6.8 |
| Cattle | 57.4 | 21.0 | 52.2 | 21.2 | 68.7 | 14.0 |
| Peafowl | 98.2 | 14.2 | 96.5 | 12.5 | 174.9 | 17.7 |
| Grey Partridge | 10.8 | 3.1 | 16.8 | 4.3 | 40.8 | 7.6 |
| Jungle bush quail | 14.7 | 5.3 | 21.4 | 6.8 | 20.0 | 4.7 |

### 4.3a.2. Density of murid rodents

**a) Overall density:** In total 336 individuals of eleven species of rodents were captured in the study area. All the species detection was best explained by half normal detection function with cosine adjustment of order two. Among the rodents, *Mus platythrix* (1.6 / ha) was found to be the most abundant species in the study area followed by *Golunda ellioti* (1.1 /ha), *Millardia gleadowi* (0.9 /ha), *Mus booduga*, *Mus musculas* and *Gerbillus nanus* (0.5 /ha). The other rodent species

was occured in very low densities **(Table 4.2)**. Total rodent density was 5.16 animals/ ha in the study area. The estimated total biomass density of rodents was 223.8 gm/ha for the study area.

**b) Seasonal density:** Density and effective distance radius (EDR) and model selection of different rodent species captured during winter and summer is given in **Table 4.3** and **Table 4.4**. Least trap success was recorded in summer (0.89%) and maximum trap success was found in winter (2.6%). All the species detection was best explained by half normal detection function with cosine adjustment of order two best fitted in model in summer and uniform with cosine and uniform with simple polynomial of order two was best fitted in winter. Out of 336 captures, *Mus platythrix* (n=127) found to be the most abundant rodent species in both the seasons followed by *Golunda ellioti* (n=11), *Mus musculas* (n=5), *Mus booduga* (n=4), *Indian gerbil* (n=4), *Gerbillus nanus* (n=5), *Vandeleuria oleracea* (n=1), *Mellardia gleadowi* (n=6), *Rattus rattus* (n=7). The *Rattus norvegicus* (n=10) was captured only in summer while *Golunda ellioti* (n=62), *Mus booduga* (n=20), *Rattus rattus* (n=8), *Mellardia gleadowi* (n=5), *Mus musculas* (n=13), *Vandeleuria oleracea* (n=11), *Rattus norvegicus* (n=20), *Indian gerbil* (n=12) and *Mellardia meltada* (n=5) were captured in winter. The overall rodent density in winter was observed to be 6.33 ± 1.13 (SE) animals/ha, while in summer it was 2.32 ± 0.51(SE) animals /ha. Student one tailed t- test revealed no significant difference in the densities of rodents between seasons (t=1.16, df =1, P =0.45). The *Vandeleuria oleracea* was only captured in *Anogessius* dominant forest, three species of *Mus* were captured in open scrub land and *Zizyphus* woodland and hill forest, while two species of gerbils were captured *in Zizyphus* woodland and scrubland, *Rattus rattus*, *R. norvegicus* and *Mellardia meltada* were found in *Butea* mixed forest. *Mellardia gleadowi* was captured only in *Zizyphus-Butea* mixed forest, while *Golunda ellioti* was maximum captured in open scrubland in the study area. The sex ratio (male: female) of some rodent species was highly

skewed towards males such as *Mus booduga* 13:11, *Mellardia gleadowi* 7:4, *Rattus norvegicus* 7:2, *Rattus rattus* 5:1, *Indian gerbil* 6:2, *Golunda ellioti* 2:1, *Vandeleuria oleracea* 2:1 and *Mus platythrix* 1:2 while sex ratio (female: male) was found skewed towards females in *Mus musculas* 9:8, *Mellardia meltada* 4:1 and *Gerbillus nanus* 3:2. The overall weight of male and female, average HBL and average tail length of all the rodent species is given in **Table 4.5**.

**4.3 b) Estimation of food habits:** In total, 277 scats of striped hyena, 279 scats of golden jackal, 287scats of jungle cat and five scats of small Indian civet were collected during the study period. The small Indian civet scats were not analyzed because of small sample size.

**4.3b).1 Food habits of striped hyena**

**a) Overall diet:** Seven prey items were identified from 277 scats of hyena and of which 201 scats contained single prey species, 68 scats contained double prey species, six scats contained three prey species and two scats had four prey species. Both in terms of frequency of occurrence and percentage occurrence, chital (27.8%) constituted the major prey in the diet of striped hyena followed by cattle (19.1%), peafowl (16.3%), goat (15.7%), hare (15.2%), sambar (4.2%) and nilgai (1.7%). I estimated minimum number of scats required to adequately represent the diet of striped hyena in the study area. The relative contribution of each species in striped hyena's diet stabilized after 103 scats were examined and hence the sample size of 277 is deemed sufficient **(Figure 4.3)**. Hence from this study, I suggest that minimum of 103 scats are required to be analyzed to understand the food habits of striped hyena in the intensive study area of STR.

**Table 4.2 Overall density estimates of rodent species during November 2007- June 2009 in Sariska Tiger Reserve.**

| S. No | Species | Overall | | | |
|---|---|---|---|---|---|
| | | Density/ha | SE | EDR (m) | SE |
| 1 | *Golunda ellioti* | 1.1 | 0.5 | 28.4 | 3.9 |
| 2 | *Vandeleuria oleracea* | 0.2 | 0.1 | 29.5 | 5.6 |
| 3 | *Mus booduga* | 0.5 | 0.3 | 24.1 | 4.9 |
| 4 | *Mus musculus* | 0.5 | 0.6 | 16.6 | 8.3 |
| 5 | *Mus platythrix* | 1.6 | 0.7 | 31.8 | 5.2 |
| 6 | Millardia gleadowi | 0.9 | 0.6 | 44.3 | 10.4 |
| 7 | *Millardia meltada* | 0.2 | 0.1 | 23.4 | 4.8 |
| 8 | *Rattus norvegicus* | 0.1 | 0.5 | 50.0 | 6.3 |
| 9 | *Rattus rattus* | 0.3 | 0.1 | 25.2 | 2.5 |
| 10 | *Indian Gerbil* | 0.1 | 0.7 | 41.9 | 6.6 |
| 11 | *Gerbillus nanus* | 0.5 | 0.6 | 16.7 | 7.1 |

**Table 4.3 Density estimates of rodent species during winter (2007-2009) in Sariska Tiger Reserve.**

| S. No | Species | Model selection | Winter ( Nov- Feb) | | | |
|---|---|---|---|---|---|---|
| | | | Density /ha | SE | EDR (m) | SE |
| 1 | *Golunda ellioti* | 1 | 1.18 | 0.48 | 35.74 | 3.75 |
| 2 | *Vandeleuria oleracea* | 1 | 0.26 | 0.20 | 33.05 | 4.50 |
| 3 | *Mus booduga* | 2 | 0.67 | 0.36 | 25.82 | 4.10 |
| 4 | *Mus musculus* | 1 | 0.47 | 0.58 | 50.00 | 0.00 |
| 5 | *Mus platythrix* | 1 | 2.03 | 0.60 | 34.63 | 2.57 |
| 6 | Millardia gleadowi | 2 | 0.63 | 0.51 | 50.00 | 0.00 |
| 7 | *Millardia meltada* | 1 | 0.10 | 0.67 | 23.37 | 4.81 |
| 8 | *Rattus norvegicus* | 1 | 0.15 | 0.58 | 44.09 | 7.36 |
| 9 | *Rattus rattus* | 2 | 0.65 | 0.63 | 14.74 | 3.63 |
| 10 | *Indian Gerbil* | 2 | 0.15 | 0.13 | 43.72 | 8.43 |
| 11 | *Gerbillus nanus* | - | * | * | * | * |

**1= Uniform+ simple polynomial, 2= uniform+ cosine,* Not captured, EDR= Effective distance radius**

**Table 4.4 Density estimates of rodent species during summer (2008-2009) in Sariska Tiger Reserve.**

| S. No | Species | Summer (Mar- June) | | | |
|---|---|---|---|---|---|
| | | Density /ha | SE | EDR (m) | SE |
| 1 | *Golunda ellioti* | 0.71 | 0.58 | 20.15 | 5.21 |
| 2 | *Vandeleuria oleracea* | 0.26 | 0.26 | 10.30 | 1.50 |
| 3 | *Mus booduga* | 0.42 | 0.23 | 50.00 | 0.00 |
| 4 | *Mus musculus* | 0.47 | 0.58 | 10.00 | 0.00 |
| 5 | *Mus platythrix* | 1.32 | 0.76 | 25.26 | 5.04 |
| 6 | Millardia gleadowi | 0.23 | 0.19 | 25.78 | 6.34 |
| 7 | *Millardia meltada* | * | * | * | * |
| 8 | *Rattus norvegicus* | 0.10 | 0.51 | 50.00 | 0.00 |
| 9 | *Rattus rattus* | 0.22 | 0.14 | 30.45 | 3.44 |
| 10 | *Indian Gerbil* | 0.42 | 0.42 | 50.00 | 0.00 |
| 11 | *Gerbillus nanus* | 0.40 | 0.47 | 18.20 | 5.94 |

***Not captured, EDR= Effective distance radius**

**Table 4.5 Weight and body measurements of rodent species in Sariska Tiger Reserve.**

| Species | Average weight (gm) | | Average HBL* (cm) | | Average tail length (cm) | |
|---|---|---|---|---|---|---|
| | Female | Male | Min | Max | Min | Max |
| *Golunda ellioti* | 41.7 | 53.7 | 6.5 | 12.1 | 7.3 | 12.1 |
| *Vandeleuria oleracea* | 16.0 | 18.9 | 4.5 | 7.0 | 9.0 | 11.5 |
| *Mus booduga* | 8.3 | 7.3 | 4.3 | 6.8 | 5.0 | 8.5 |
| *Mus musculus* | 7.8 | 8.8 | 4.0 | 7.2 | 4.7 | 11.3 |
| *Mus platythrix* | 15.3 | 13.7 | 4.3 | 7.8 | 5.1 | 9.1 |
| Millardia gleadowi | 54.5 | 52.0 | 8.2 | 11.5 | 8.0 | 15.5 |
| *Millardia meltada* | 66.8 | 68.0 | 7.1 | 11.5 | 9.0 | 17.0 |
| *Rattus norvegicus* | 108.8 | 124.9 | 9.2 | 20.0 | 16.0 | 21.0 |
| *Rattus rattus* | 135.1 | 134.9 | 12.5 | 17.3 | 18.6 | 23.5 |
| *Indian Gerbil* | 54.3 | 50.2 | 8.2 | 13.5 | 10.2 | 20.5 |
| *Gerbillus nanus* | 41.3 | 45.0 | 7.0 | 8.7 | 9.5 | 12.5 |

***HBL= Head to body length**

**b) Seasonal food habits:** Seasonal diet pattern of striped hyena both in terms of frequency of occurrence and percent occurrence were summarized in **Table 4.6**. Mean frequency of occurrence with confidence interval using 1000 bootstrap for both seasons are shown in **Figure 4.4**. In winter, 140 scats contained single prey, 24 had double prey, four had three prey items and two had four prey species while in summer 70 scats contained single prey items, 35 had double prey and two scats had three prey species. Among the prey species, wild prey contributed maximum in the diet of striped hyena in winter (67.61%) than summer (61.7%) while domestic livestock (cattle and goat) contributed highest in summer (38.3%) than in winter (32.39%). Chital, peafowl and hare together made highest contribution of wild prey both in winter (62.38%) and summer (54.8%), while other prey species made less contribution in winter (5.24%) and summer (6.8%). One way Anova showed no significant difference in prey species utilization between summer and winter (F=0.968, df=1, P=0.345).

**Figure 4.3 Relationship between contributions of seven prey species in striped hyena diet with number of scats examined from Sariska Tiger Reserve (November 2007 to June 2009).**

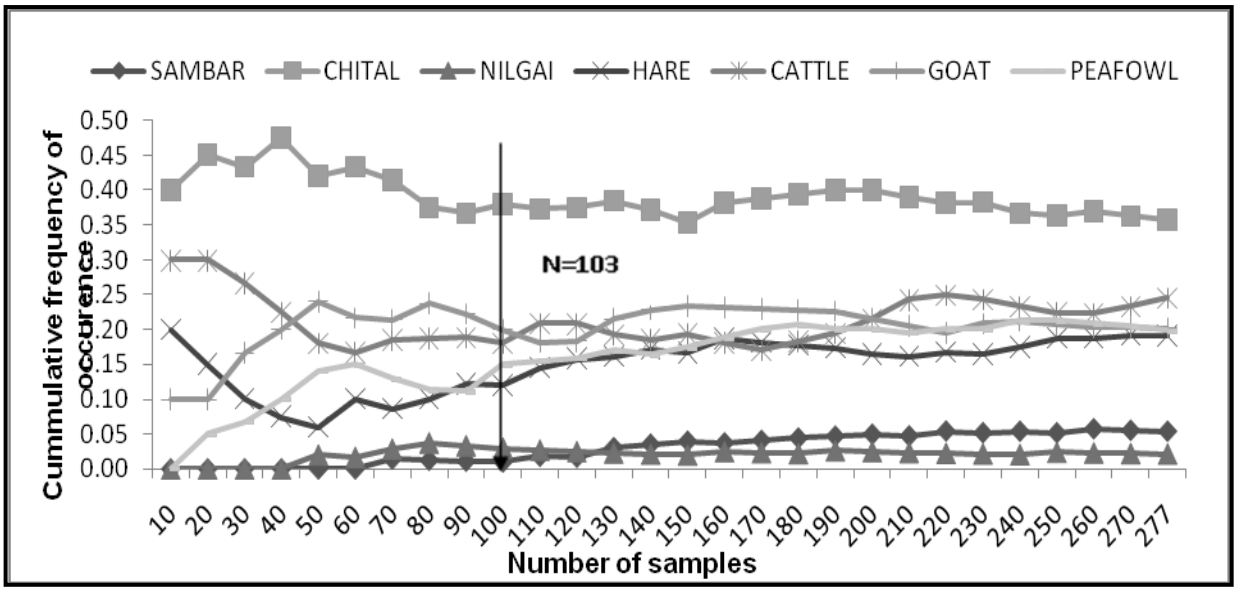
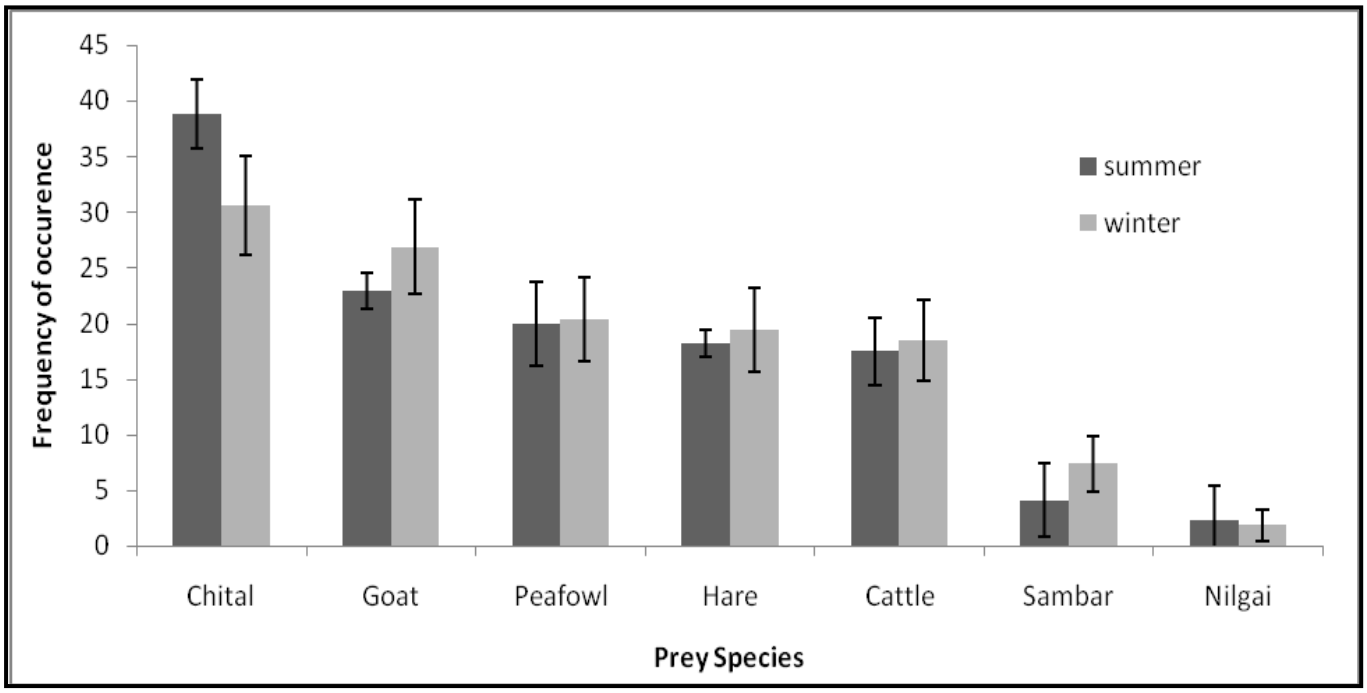


**Table 4.6 Diet composition of striped hyena in winter and summer (2007-2009) in Sariska Tiger Reserve.**

| Species | Summer (N=107) (Mar- June) | | | Winter (N=170) (Nov- Feb) | | | Overall (winter and summer) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Count of occurrence | Percent occurrence | Frequency of occurrence | Count of occurrence | Percent occurrence | Frequency of occurrence | Count of occurrence | Percent occurrence | Frequency of occurrence |
| Nilgai | 2 | 1.4 | 1.9 | 4 | 1.9 | 2.4 | 6 | 1.7 | 2.2 |
| Sambar | 8 | 5.5 | 7.5 | 7 | 3.3 | 4.1 | 15 | 4.2 | 5.4 |
| Chital | 33 | 22.6 | 30.8 | 66 | 31.4 | 38.9 | 99 | 27.8 | 35.7 |
| Hare | 23 | 15.8 | 21.5 | 31 | 14.8 | 18.2 | 54 | 15.2 | 19.5 |
| Cattle | 39 | 26.7 | 36.4 | 29 | 13.9 | 17.1 | 68 | 19.1 | 24.5 |
| Goat | 17 | 11.6 | 15.9 | 39 | 18.6 | 23.0 | 56 | 15.7 | 20.2 |
| Peafowl | 24 | 16.4 | 22.4 | 34 | 16.2 | 20.0 | 58 | 16.3 | 20.9 |

**Figure 4.4 Mean frequency of occurrence of prey species in the diet of striped hyena in winter (n=170) and summer (n=107) in Sariska Tiger Reserve.**



### 4.3b).2 Food habits of golden jackal

**a) Overall diet:** Ten food items were identified from 279 jackal scats, of which, 192 scats contained single food item, 69 contained double and 18 had three prey species. Both in terms of frequency of occurrence and percentage occurrence *Zizyphus* fruits (28.6%) constituted as major food in the diet of golden jackal, followed by chital (20.8%), cattle (12.2%), sambar (9.1%), nilgai (8.1%), unidentified birds (8.1%), hare (4.4%), rodents (4.4%), common langur (2.6%) and wild pig (1.6%). I estimated minimum number of scats required to adequately represent the diet of golden jackal. The relative contribution of each species in jackal's diet stabilized after 80 scats were examined and hence the sample size of 279 is deemed sufficient **(Figure 4.5)**. Hence from this study, I suggest that minimum of 80 scats are required to be analyzed to understand the food habits of golden jackal in the intensive study area of STR.

**b) Seasonal diet:** Seasonal diet pattern of golden jackal both in terms of frequency of occurrence and percent occurrence were summarized in **Table 4.7**. Mean frequency of occurrence with confidence interval for both seasons are shown in **Figure 4.6**.

In summer, 148 scats were constituted with single prey, 23 had double prey, single scat had three prey items, while in winter 44 scats contained single prey items, 46 scats had double prey and 17 scats had three prey species. Among all prey species, wild prey contributed highest in summer (65.5%) than winter (52.4%), while domestic livestock (cattle) contribution was the highest in summer (15.7%) than in winter (8.6%). Occurrence of *Zizyphus* fruits in jackal scat was found to be highest in winter (39%) than in summer (18.8%). One way Anova showed no significant difference in prey utilization between summer and winter ($F=0.014$, $df=1$, $P=0.907$).

**Figure 4.5 Relationship between contributions of ten prey species in golden jackal diet with number of scats examined from Sariska Tiger Reserve (November 2007 to June 2009).**

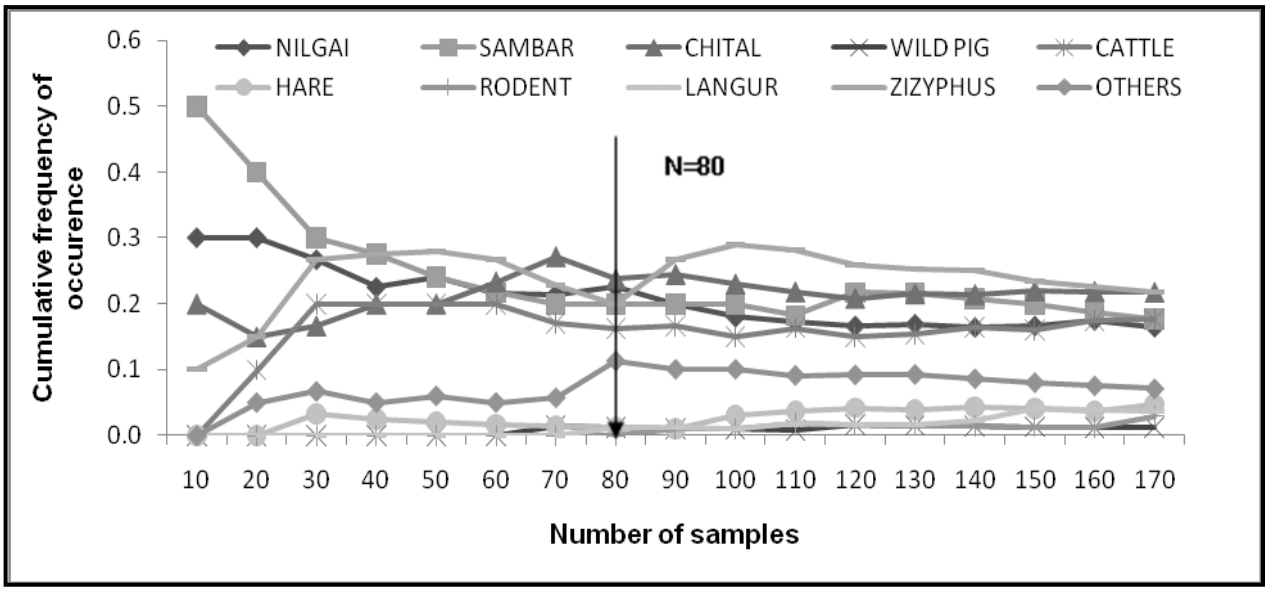
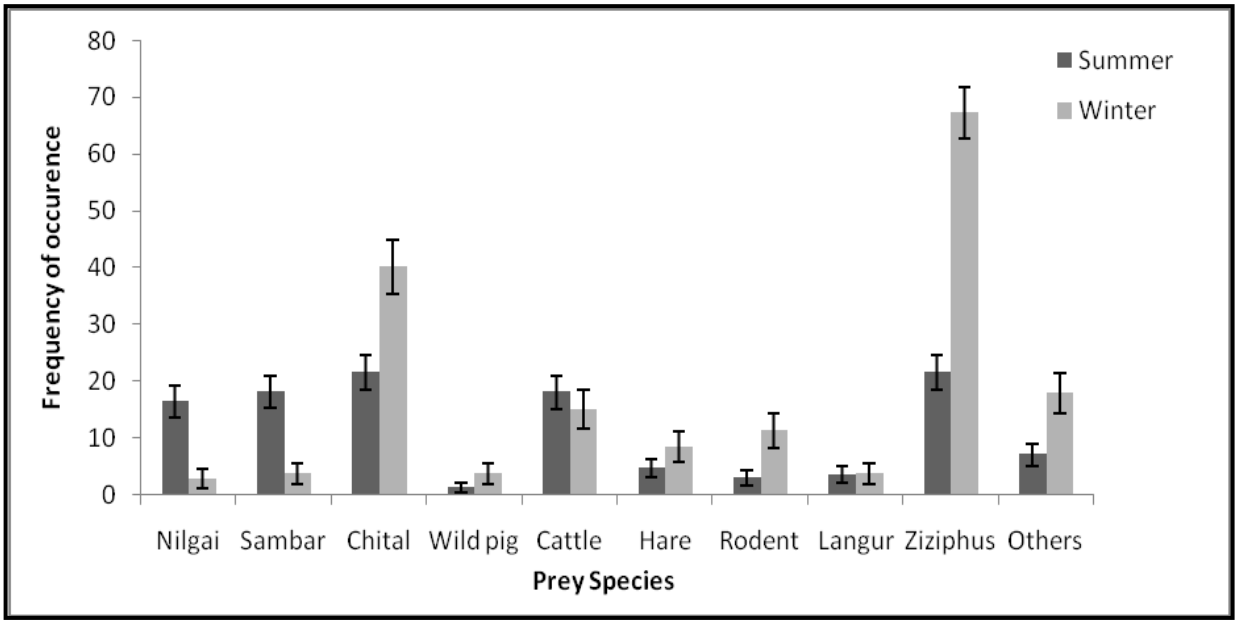



**Table 4.7 Diet composition of golden jackal in summer and winter (2007-2009) in Sariska Tiger Reserve.**

| Species | Winter (n=107) (Nov- Feb) | | | Summer (n=172) (Mar- June) | | | Overall (winter and summer) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Counts of occurrence | Percent occurrence | Frequency of occurrence | Counts of occurrence | Percent occurrence | Frequency of occurrence | Counts of occurrence | Percent occurrence | Frequency of occurrence |
| Nilgai | 3 | 1.6 | 2.8 | 28 | 14.2 | 16.3 | 31 | 8.1 | 11.1 |
| Sambar | 4 | 2.1 | 3.7 | 31 | 15.7 | 18.0 | 35 | 9.1 | 12.5 |
| Chital | 43 | 23.0 | 40.2 | 37 | 18.8 | 21.5 | 80 | 20.8 | 28.7 |
| Wild pig | 4 | 2.1 | 3.7 | 2 | 1.0 | 1.2 | 6 | 1.6 | 2.2 |
| Cattle | 16 | 8.6 | 15.0 | 31 | 15.7 | 18.0 | 47 | 12.2 | 16.8 |
| Hare | 9 | 4.8 | 8.4 | 8 | 4.1 | 4.7 | 17 | 4.4 | 6.1 |
| Rodent | 12 | 6.4 | 11.2 | 5 | 2.5 | 2.9 | 17 | 4.4 | 6.1 |
| Langur | 4 | 2.1 | 3.7 | 6 | 3.0 | 3.5 | 10 | 2.6 | 3.6 |
| *Zizyphus* | 73 | 39.0 | 68.2 | 37 | 18.8 | 21.5 | 110 | 28.6 | 39.1 |
| Others* | 19 | 10.2 | 17.8 | 12 | 6.1 | 7.0 | 31 | 8.1 | 11.1 |

***Unidentified birds**

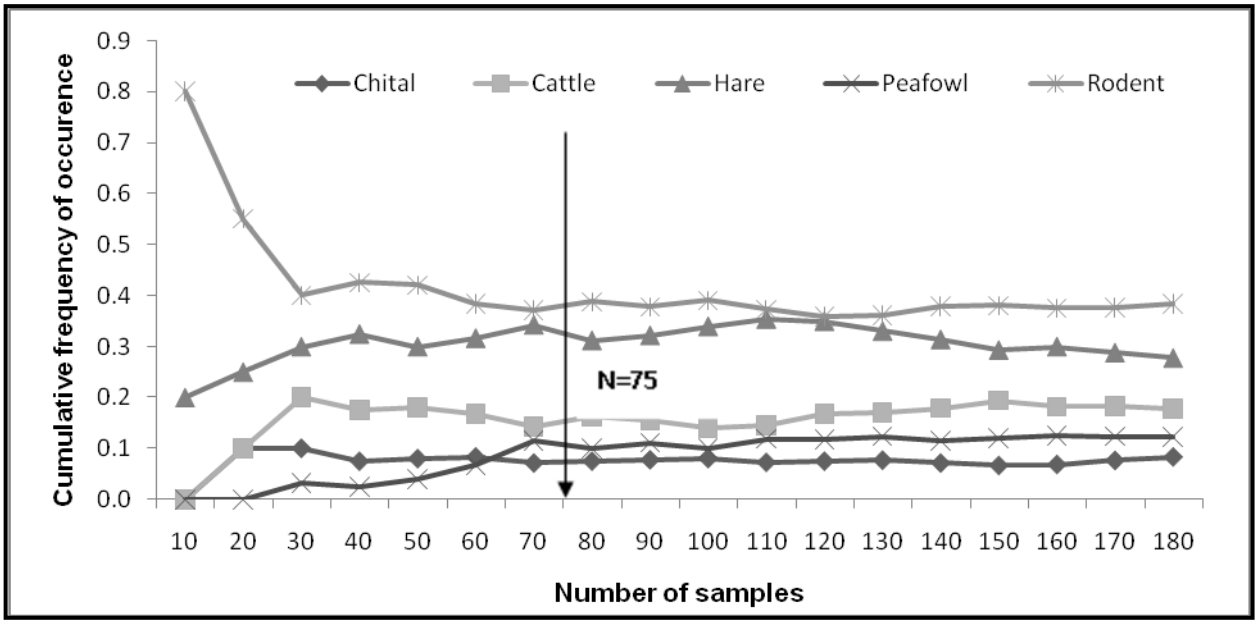
**Figure 4.6 Mean frequency of occurrence of prey species in the diet of golden jackal in winter (n=107) and summer (n=172) in Sariska Tiger Reserve.**




**4.3b).3 Food habits of jungle cat:**

**a) Overall diet:** Nine prey items were identified from 287 jungle cat scats, of which, 253 scats constituted with single prey species, 31 scats had double prey species and three scats had three prey species. Both in terms of percent occurrence and frequency of occurrence rodents (34.3%) were found to be the most common prey species in the diet of jungle cat followed by hare (25.9%), peafowl (15.1%), cattle (13.9%), chital (6.5%), common langur (0.9%), sambar (0.6%), nilgai (0.3%) and some unidentified birds (2.5%). I estimated minimum number of scats required to adequately represent the diet of jungle cat. The relative contribution of each species in jungle cat stabilized after 75 scats were examined and hence sample size of 287 is deemed sufficient **(Figure 4.7)**. Hence from this study, I suggest that minimum of 75 scats are required to be analyzed to understand the food habits of jungle cat in the intensive study area of STR.

**Figure 4.7 Relationship between contributions of nine prey species in jungle cat diet with number of scats examined from Sariska Tiger Reserve (November 2007 to June 2009).**




**b) Seasonal diet:** Seasonal diet pattern of jungle cat both in terms of frequency of occurrence and percent occurrence were summarized in **Table 4.8**. Mean frequency of occurrence with confidence interval for both seasons are shown in **Figure 4.8**.

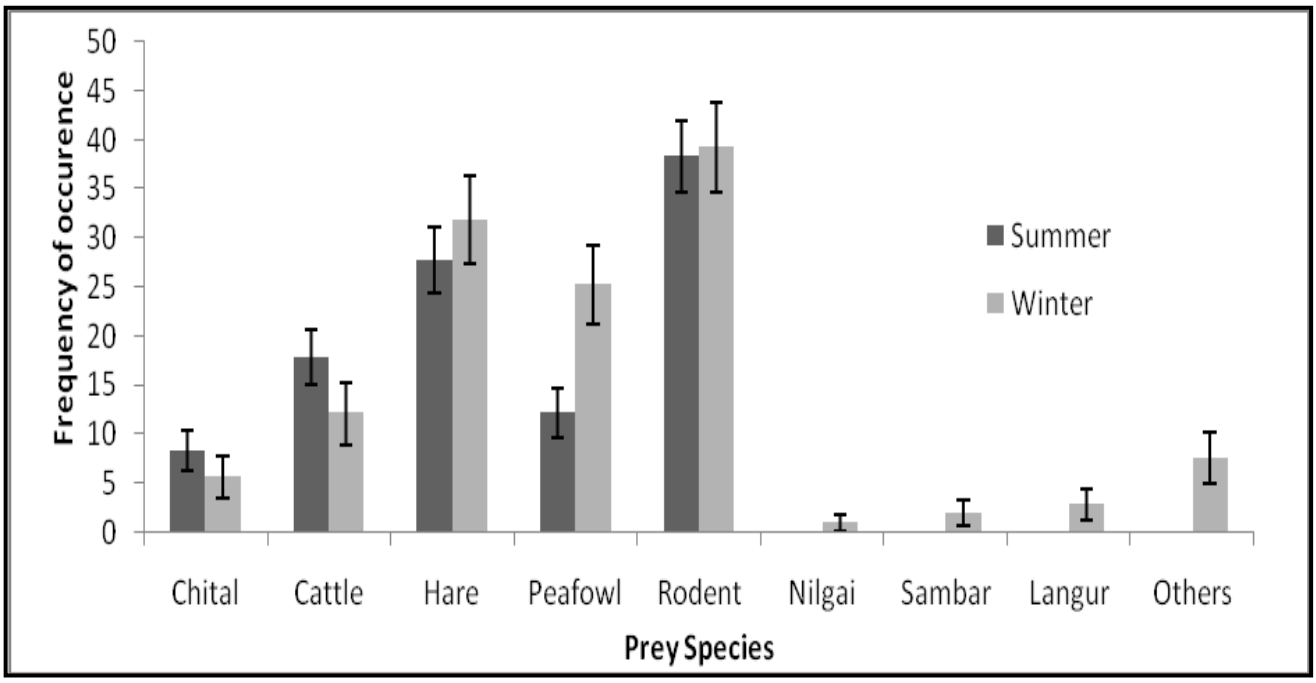
Nine prey species were identified in jungle cat scat during summer and five during winter. In winter (n=180), 172 scats were constituted with single prey, eight had double prey while in summer (n=107) 81 scats had single prey species, 23 scats had double prey species and three had three prey species. Among the prey species, small mammals (rodents and hare) contributed highest in winter (63.3%) than in summer (55.9%) while other prey contributed highest in summer (44.1%) than in winter (36.7%). One way Anova showed no significant difference in prey utilization between the summer and winter (F=0.346, df=1, P=0.565).

**Table 4.8 Diet composition of jungle cat in summer and winter (2007-2009) in Sariska Tiger Reserve.**

| Species | Summer (n=107) (Mar- June) | | | Winter (n=180) (Nov- Feb) | | | Overall (winter and summer) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Counts of occurrence | Percent occurrence | Frequency of occurrence | Counts of occurrence | Percent occurrence | Frequency of occurrence | Counts of occurrence | Percent occurrence | Frequency of occurrence |
| Cattle | 13 | 9.6 | 12.1 | 32 | 17.0 | 17.8 | 45 | 13.9 | 15.7 |
| Nilgai | 1 | 0.7 | 0.9 | 0 | 0.0 | 0.0 | 1 | 0.3 | 0.3 |
| Chital | 6 | 4.4 | 5.6 | 15 | 8.0 | 8.3 | 21 | 6.5 | 7.3 |
| Sambar | 2 | 1.5 | 1.9 | 0 | 0.0 | 0.0 | 2 | 0.6 | 0.7 |
| Langur | 3 | 2.2 | 2.8 | 0 | 0.0 | 0.0 | 3 | 0.9 | 1.0 |
| Hare | 34 | 25.0 | 31.8 | 50 | 26.6 | 27.8 | 84 | 25.9 | 29.3 |
| Rodent | 42 | 30.9 | 39.3 | 69 | 36.7 | 38.3 | 111 | 34.3 | 38.7 |
| Peafowl | 27 | 19.9 | 25.2 | 22 | 11.7 | 12.2 | 49 | 15.1 | 17.1 |
| Others* | 8 | 5.9 | 7.5 | 0 | 0.0 | 0.0 | 8 | 2.5 | 2.8 |

***unidentified birds**

**Figure 4.8 Mean frequency of occurrence of prey species in the diet of jungle cat in winter (n=180) and summer (n=107) in Sariska Tiger Reserve.**



### 4.3 c) Niche and dietary overlap between species:

Overall niche breath for three carnivores showed that jackal (0.5) had the narrowest dietary niche followed by striped hyena (0.7) and jungle cat (1.7) **(Figure 4.9)**. Results from Pianka's Index (1981) revealed that the overall diet overlap was high between hyena and jackal (0.75) and medium between jungle cat and jackal (0.52) and hyena and jungle cat (0.49). The seasonal diet overlap amongst three carnivores showed high in summer between hyena and jackal (0.72), and medium between hyena and jungle cat (0.40) and jackal and jungle cat (0.47). Winter diet's showed medium dietary overlap between hyena and jackal (0.44) and hyena and jungle cat (0.41) and low dietary overlap between jackal and jungle cat (0.28) **(Table 4.9)**.

## 4.4 DISCUSSION:

In contrast to most dietary studies of medium and small sized carnivores in India and elsewhere, results from this study showed the dominance of mammalian prey species in the diet of striped hyena, golden jackal and jungle cat. Reptiles and invertebrates which were earlier being reported from many studies (see literature review Chapter-1) were not found in the diet of three carnivores in STR. These carnivores utilized broad diet during the study period. For striped hyena, chital and hare were the seasonal prey consumed while livestock (cattle and goats) were supplementary food item, while peafowl were eaten opportunistically by this species. The *Zizyphus* fruits were consistently consumed by golden jackal in both seasons during this study. Chital were the seasonal food item for golden jackal. Small mammals like hare and rodents were eaten consistently while peafowl and cattle were opportunistic prey items in the diet of golden jackal. In the diet of jungle cat, rodents were the most consistently eaten prey species and hare were the seasonal prey item, while utilization of cattle and chital by jungle cat may be due to scavenging on large carnivores kills during winter and summer.

**Figure 4.9 Overall Niche breath of study species in Sariska Tiger Reserve (2007-2009).**

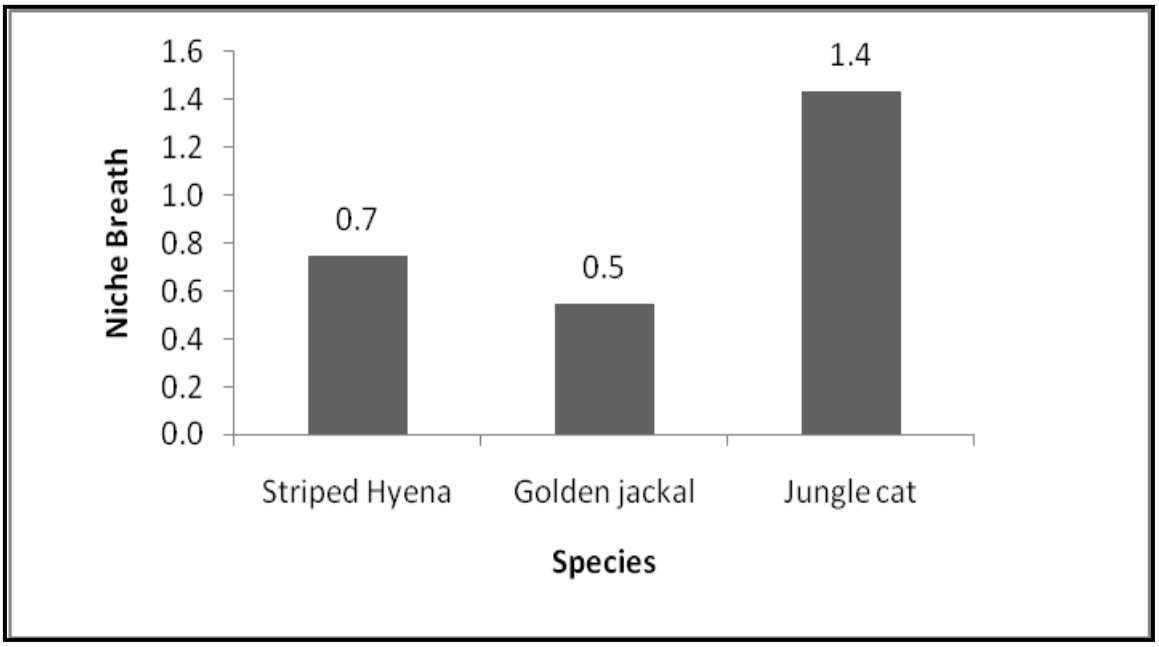



**Table 4.9 Diet overlap amongst the study species during winter and summer (2007-2009) in Sariska Tiger Reserve.**

| | | Striped hyena | Golden jackal | Jungle cat |
|---|---|---|---|---|
| Winter (Nov-Feb) | Striped hyena | | 0.44 | 0.41 |
| | Golden jackal | 0.44 | | 0.28 |
| | Jungle cat | 0.41 | 0.28 | |
| Summer (Mar- June) | Striped hyena | | 0.72 | 0.41 |
| | Golden jackal | 0.72 | | 0.47 |
| | Jungle cat | 0.41 | 0.47 | |
| Overall (winter & summer) | Striped hyena | | 0.75 | 0.49 |
| | Golden jackal | 0.75 | | 0.52 |
| | Jungle cat | 0.49 | 0.52 | |

### 4.4.1 Importance of wild ungulates and livestock:

When prey biomass was taken into account chital and sambar was the most important prey species found in the diet of large carnivores in India (Sankar, 1994; Bagchi *et al.*, 2003, Biswas and Sankar, 2002; Johnsingh, 1983). The estimated density of wild ungulates from this study, when compared with other parts of the country (Haque, 1990; Chundawat, 1999; Khan *et al.*, 1996; Biswas and Sankar, 2002; Bagchi *et al.*, 2003; Banerjee, 2005) revealed that the study area harbors high densities of chital, sambar, and nilgai **(Table 4.10)**. The high densities of different prey species in the present study may be attributed to the availability of variety of vegetation types ranging from dry thorn forests to riparian forests, availability of food, water and forest protection. During the study period, high availability of the grass species like *Chloris dolychostachya*, *Heteropogon contortus*, *Cynodon dactylon*, etc, and fallen fruits *Zizyphus* fruits might have influenced high congregation of chital, sambar and nilgai in the study area. The percent occurrence of these three ungulates was relatively higher in the diet of striped hyena, golden jackal and jungle cat in both the seasons. The wild ungulates remains were found higher in the diet of golden jackal (38%), striped hyena (33%) and jungle cat (7.39%). The livestock remains were found higher in striped hyena (37.2), jungle cat (13.8) and golden jackal (12.2%). Presence of wild ungulates and livestock in the diet of three carnivores may be largely due to scavenging on large carnivores kills in the study area. Jackals were seen scavenging on several occasions on abandoned tiger kills and also on carcasses of dead livestock around villages or on dumping sites. Mc Shane and Grettenberger (1984) found that 23% scats of golden jackals from Niger, Africa had the remains of domestic livestock. Mukherjee (1998) found 10% scats from STR had the remains of wild ungulates and livestock. Gupta (2006) reported 24% and 55% of jackal's diet comprised of chital and cattle respectively from Bharatpur. On several occasions

(n=39) in STR, near Kankawas Lake, I observed jackals watching vultures and running towards the kill sites from distance of over 500 m to 1 km. Apart from tracking vultures their keen sense of smell might help them in locating carcasses. Jackals in STR were usually seen in pairs (>95%, n=264) near Kalighati and Kankawas area. Sometimes they formed group upto five individuals during summer. These groups were mostly seen around kill sites. Co-operative hunting of large mammals (fawn of deer or nilgai calf) by jackal was not observed during the study period and was not reported in earlier study (Mukherjee, 1998). Sankar (2002) reported that nearly 80% of diet of striped hyena from STR was that of wild ungulates and livestock. The presence of ungulates and livestock carcasses was frequently found near the dens of striped hyena in STR but predation on these wild animals was not observed during the study period. Incidence of livestock lifting (n=67) especially goats by striped hyena occured frequently in villages like Indok, Bhartari and Duharmala. Occurrence of ungulate and livestock remians in of jungle cat scats is attributed to scavenging on carcasses.

**Table 4.10 Densities of ungulate species in similar protected areas of India.**

| **Locations** | **Chital** | **Sambar** | **Nilgai** | **Wild pig** | **Sources** |
|---|---|---|---|---|---|
| Present study* | **50.00** | **46.00** | **25.00** | **69.00** | **Present study** |
| Ranthambore NP | 31.00 | 17.15 | 11.36 | 9.77 | Bagchi *et al.*, 2003 |
| Panna TR | 10.80 | 9.16 | 6.02 | - | Chundawat, 1999 |
| Gir WLS | 57.30 | 3.50 | 0.58 | - | Khan *et al.*, 1996 |
| Kuno WLS | 4.63 | 0.31 | 3.93 | - | Banerjee, 2005 |
| Pench TR | 80.70 | 6.09 | 0.43 | 2.59 | Biswas and Sankar, 2002 |
| Keoladeo NP | 9.79 | 0.75 | 7.00 | 2.24 | Haque, 1990 |

### 4.4.2 Importance of small mammals (rodents and hare) in the diet of study species:

The importance of rodents in the diet of many small cats (e.g. bobcats, ocelot, African wild cat, feral cats and jungle cat) has been documented by various studies (Pearson, 1964; Comman and Brunner, 1972; Jones and Smith, 1979; Ludlow and Sunquist, 1987; Palmer and Fairall, 1988; Mukherjee, 1998). The study area harbored low rodent densities as compared to tropical areas (Jayahari, 2008). Trapping success of murid rodent in the present study was high (2.6%) as compared to earlier study (0.9%) (Mukherjee, 1998). The estimated sex ratio of the rodent species in the study area was skewed, both towards male and female. Since the reliable information about the behavior of these species is lacking, it is difficult to propose a sex specific difference in trap response, which might cause decrease in number of males trapped in some sessions. Majority of protected areas reported female biased sex ratio especially in *Rattus Rattus* (Jayahari, 2008). It is difficult to conclude from the present study whether the skewed sex ratios was due to the larger home range of rodent species than the sampled area (sex specific home ranges), population structure or varying trap response of different species across the landscape. It is evident from the results that for better interpretation of the densities of these species, use of Capture Mark Recapture (CMR) would be more appropriate method and detailed behavioral studies are necessary in Protected Areas. The results revealed high abundance of rodents in the study area during winter (6.33 animals/ha) than summer (2.32 animals/ha) and this might be due to availability of the seasonal fruits like *Zizyphus spp* and *Balanites aegyptiaca* that were consumed by rodents during winter in STR. Prakash (1995) reported low abundances of rodents in summer and rodents like gerbils switch over their diets to insects when vegetation is without water content in semi arid area. Some rodents showed spectacular fluctuation in feeding on various plant parts over the year depending on their availability in the desert ecosystem (Prakash, 1995). Low

densities of different rodent species in STR may be attributed to low captures rates at some trap sites or due to predation by jungle cats, jackals or birds (common crows and tree pies) which were recorded many times (n=48) at the trapping points. It was also observed that sometimes traps were found >500 m away from trapping area which were dragged either by jungle cat, jackal or wild pig.

Among the scats that had remains of mammalian prey, 34.5% of jungle cat and 4.4 % of golden jackal scats had rodent prey remains. High occurrence of rodent remains in winter in both jungle cat (36.7%) and jackal (6.4%) was attributed due to high availability of rodents in winter. Felids being highly specialized carnivores combine knowledge of their habitat along with prey activity and habits while hunting (Griffiths, 1975; Thapar, 1986 and Bothma and Le Riche, 1989), while feral cats identify rodents runway and burrows and concentrate their activities in these zones (Pearson, 1964). Earlier study in Sariska showed that felids depend largely on rodents in terms of energetic predictions (60-93%) while jackal gets between 44-70% of energy from rodents (Mukherjee, 1998). Although small cats are considered opportunistic predators which predate on the most abundant prey, they seem to specialize on small mammals and consume the most abundant species within the groups (Kruuk, 1986). High occurrence of rodents in the diet of jungle cat indicates that they are dietary specialist (Mukherjee, 1998). Next to rodents, hare was found to be the second highest occurrenced prey species in the diet of jungle cat (25.9%) than striped hyena (14.6%) and golden jackals (4.42%). The density of hare in the study area was probably underestimated since they were counted on line transects only during morning hours (hare is largely nocturnal otherwise).

### 4.4.3 Importance of birds in the diet of study species:

Birds were found to be an important prey species in the diet of all three carnivores in winter and summer. According to Kitchener (1991) cats were not good in catching birds and most of the birds were killed opportunistically. The occurrence of birds in the diet of jungle cat during the present study was lower than that of studies from Bharatpur (55%), and Sariska (30.4%), (Mukherjee, 1989, 1998). The present study showed similar occurrence of birds in the diet of jungle cat (15.1%) and striped hyena (15.2%) while low occurrence in case of golden jackal (6.07%). High occurrence of birds in the diet of all three carnivores was attributed to available high density of peafowl (174.9/km$^2$), grey partridge (40.8/km$^2$) and jungle bush quail (20.0/km$^2$) in the study area. In sariska, 23 peafowl kills were found near Kalighati and Tarunda areas during winter. No caracal sighting or photographs were captured during the study period. On 56 camera trap pictured hyena was found carrying peafowl or some unidentified bird. Six percent scats of jackal had bird remains. This is lower than other studies on golden jackals as reported from Bangladesh and Niger, Africa which had 31% and 23.7% scats respectively containing birds (Mc Shane and Grettenberger, 1984) and from Bharatpur, which had 20% (Mukherjee, 1998) and 12% bird remains (Gupta, 2006).

### 4.4.4 Importance of *Zizyphus* fruits in the diet of jackal:

Jackal diet throughout its geographical range is very flexible depending on the availability of different food items. Being omnivores, fruit and other vegetable matter are also included in its diet (Kingdom, 1989). Fruits included in the diet of jackal in natural habitat are usually fallen fruits (Mc Shane and Grettenberger, 1984). In the present study, *Zizyphus* fruits constituted 39% in the jackal scats in winter. On several occasions jackals were found feeding on fallen *Zizyphus* fruits. Mc Shane and Grettenberger (1984) also found *Zizyphus* seeds in 83.2% of jackal scats in

Africa. In Bharatpur 53% of jackal scats contained *Zizyphus* fruits (Gupta, 2006). In Sariska 20% of jackals scats had *Zizyphus* fruits which were absent from felids scats (Mukherjee, 1998). Silver backed jackals in Serengeti plains of Africa consumed large number of *Balanites aegyptica* fruits during whelping season (Mohelam, 1986). Though *Balanites aegyptica* occurs commonly in STR in scrubland, the fallen fruits were not eaten by jackal.

**4.4.5 Diet overlap between study species:**

Studies have shown that species that are more similar taxonomically or morphologically are more likely to compete (Rosenzweig, 1966; MacArthur, 1972). Consequently, focusing on similar or related species provides a fruitful means to investigate the role of competitive forces in structuring communities (Hutchison, 1959; Rosenzweig, 1966; MacArthur 1972). Species that are similar in size are more likely to utilize similar prey items (Rosenzweig, 1966). Habitat separation is likely to be the major factor for aiding coexistence (Dayan *et al.*, 1990). Habitat separation is usually higher in more closely related species than the ones that are relatively distant as seen in many studies on coyotes and foxes and coyotes and bobcats; this was despite bobcats and coyotes having greater overall niche overlap (Major and Sherburne, 1987). In Sariska, it seemed that both striped hyena and jackal prefer *Zizyphus* woodland, scrubland and areas near to villages (Chapter 4). The present study showed considerable dietary overlap between striped hyena and jackal and this may be due to the utilization of chital, hare and livestock in their diet. These two species obtained lot of energy from scavenging also (Mukherjee, 1998). High dietary overlap and choice of same prey groups cannot indicate high level of competition between hyena and jackal in the study area. Dietary overlap is only the first level prerequisite for competition among two species; spatial overlap, preference for food items and availability of preferred food items in the area also influence the level of competition between two species. Since prey availability as perceived by

carnivores is ample, it cannot be concluded if prey is limiting factor for competition to take place (Dayen *et al.*, 1990). As the study area harbored high density of ungulates and adequate presence of *Zizyphus* fruits as an alternative food resource available for jackal, only dietary overlap cannot be very conclusive to predict competition between hyena and jackal in the study area. As a larger body size enables exploitation of larger prey, in STR striped hyena was largely utilizing chital, livestock and peafowl while jackal was utilizing more hare, rodents and other unidentified birds. As in felids mode of hunting in canids is more flexible and depend upon prey size, body size and group size. Large prey is hunted in pairs and groups whereas as group size decreases, the amount of small prey increases in diet (Moehlam, 1986, 1989). In Sariska both jungle cat and jackal prefer same habitat *Zizyphus* woodland and scrubland (Chapter 4) but their resource utilization pattern varied as they utilized similar food items in different proportions. Hence, in the present study striped hyena, jackal and jungle cat would rely on similar mode of resource use such as hunting and scavenging, but differ in prey size selection and proportion of food item consumption to avoid any inter-specific competition, if exist.

# CHAPTER 5

# HABITAT SUITABILITY MODEL

## 5.1 INTRODUCTION:

Loss of habitat is widely recognized as the greatest threat to wildlife (as one of the main elements of the natural environments) today. But even on land that has been permanently protected within our reserves, habitat does not remain constant over time. It is normal for changes in vegetation to occur as a result of long periods of wet or dry weather, fire, and other natural causes. Species have adapted to these natural processes, sometimes known as succession. Evaluating the degree of association between wildlife and their habitat, and to determine the relative importance of specific habitat characteristics for conservation purposes, requires procedures that are relatively inexpensive and that yield fast accurate results.

Since fragmentation is among the important known threats to natural wildlife habitats, it must be detected at the early stages for better decision making. The detection method should be reliable, applicable and cost effective. A variety of analytical methods have been used to investigate the relationship of species distribution and environment. These include logistic regression (Pereira and Itami, 1991; Buckland and Elston, 1993; Osborne and Tigar, 1992; Walker, 1990; Ramesh, 2003), discriminant analysis (Haworth and Thompson, 1990) classification and regression trees (Walker and Moore, 1988; Skidmore *et al.*, 1996), canonical correlation analysis (Andries *et al.*, 1994), supervised non-parametric classifiers (Skidmore, 1998; Skidmore *et al.*, 1996) and neural networks (Skidmore *et al.*, 1997).

During recent years there has been growing attention to the need to consider models as an integral part of Geographical Information System (GIS) and to improve understanding and application of models. When models are applied to the environment, it is expected that insights about the physical, biological, or socioeconomic system may be derived. They may also allow prediction and simulation of future conditions. The reasons for building models are to understand, and ultimately manage, a sustainable system.

Habitat suitability modeling can be used as a tool to help explain or predict important ecological parameters for different species, including species distribution and habitat quality (Heglund, 2002). With the advent of GIS, species environment models can now be expanded into a spatial dimension (Heglund, 2002). These models utilize a variety of statistical techniques to analyze the relationship between species distribution and habitat quality.

The use of statistical models to predict the likely occurrence or distribution of species is becoming an increasingly important tool in conservation planning and wildlife management. Such models were based on presence or absence of a species at a set of survey sites in relation to environmental or habitat variables, thereby enabling the probability of occurrence of the species to be predicted at unsurveyed sites. The use of statistical modeling techniques such as logistic regression is increasing, relatively little attention has been devoted to the development and application of appropriate evaluation techniques for assessing the predictive performance of habitat models.

Logistic regression models can be very effective tools for managers in regional planning and conservation when more exact information on species habitat use is available. The models are constructed from site-specific binary data (presence/absence) of a species and mapped with environmental variables (Pearce *et al.*, 2002; Ramesh, 2003). A logistic regression equation is applied to the variables to determine which are most important in determining species use.

Models are then developed in a GIS format where input data are selected based on the criteria defined by the regression to predict the likelihood of species occurrence across the area of interest (Pearce *et al.,* 2002; Ramesh, 2003).

## 5.2 METHODS

### 5.2.1 Species studied:

The eight species of medium and small sized carnivores of STR *viz* striped hyena, jungle cat, jackal, ratel, palm civet, small Indian civet, common grey mongoose and ruddy mongoose were studied for evaluating the habitat suitability in the intensive study area of STR.

### 5.2.2 Presence and absence data:

Camera trapping method was adopted to collect presence/absence information on each species in the intensive study area from November 2007 to June 2009. A total of 100 locations were selected for the placement of camera traps in the study area. Each camera trap location was considered as the representative of the animal presence/absence data.

### 5.2.3 Spatial data and digitization:

Records on presence /absence of the each species were converted into digital data in GIS using Arc/info software, and were stored on the base map previously prepared for the intensive study area in STR. The entire map was divided into 144 grids of 1 x 1 $km^2$ grids and the records were plotted as presence/absence information on each grid. If the species was detected at least once at a site over the entire sampling duration then it was recorded as present ‘1’ or ‘0’ otherwise. Spatial data which was currently generated for STR (Sankar *et al.,* 2009) was used for preparing spatial layers on habitat features relevant for each species. Total of 11 macro habitat characteristics and

variables considered for the preliminary analysis which were characterized under four environmental descriptor classes is given in **Table 5.1**. Topographical variables include elevation (DEM), anthropogenic variables (includes Euclidean distance from villages and roads), habitat variable (includes vegetation types) and Normalized Differential Vegetation Index (NDVI) and hydrological variables (include Euclidean distance to water). These variables were chosen on the basis of field knowledge and information on species biology (Prater, 1980; Schaller, 1967).

Mapping of vegetation types was done earlier in Sariska based on remotely sensed data of Landsat -7 – ETM+ imagery for the month of September 2007 Geocoded False Color Composite (FCC) on 1:50,000 scale for entire study area was procured and different colour tones for 30 classes was prepared (Sankar *et al.,* 2009). The colour classes were merged depending on the similarity in vegetation types. The map was further improved using supervised maximum likelihood classifier to incorporate unclassified and misclassified data. Nine vegetation and land cover classes were delineated and mapped with 80% accuracy (Sankar *et al.,* 2009). Area occupied by each vegetation type was extracted grid wise (1 x 1 $km^2$) from vegetation map. A separate layer was prepared for each vegetation type thereby computing the area for each habitat variables. Digital data on contour and drainage were used to create Digital Elevation Model (DEM) on the basis of interpolation. All village locations and water points were recorded using GPS. The locations were further downloaded and Euclidean distance was calculated for each grid from the nearest water sources and villages. Information on presence of prey species from camera trapping like chital, hare, cattle, goat, peafowl and rodents (trapping web) were used for some species like striped hyena, jungle cat and jackal while for other carnivores (ratel, civets and mongoose) only habitat variables were used in analysis.

### 5.2.4. Probabilistic model:

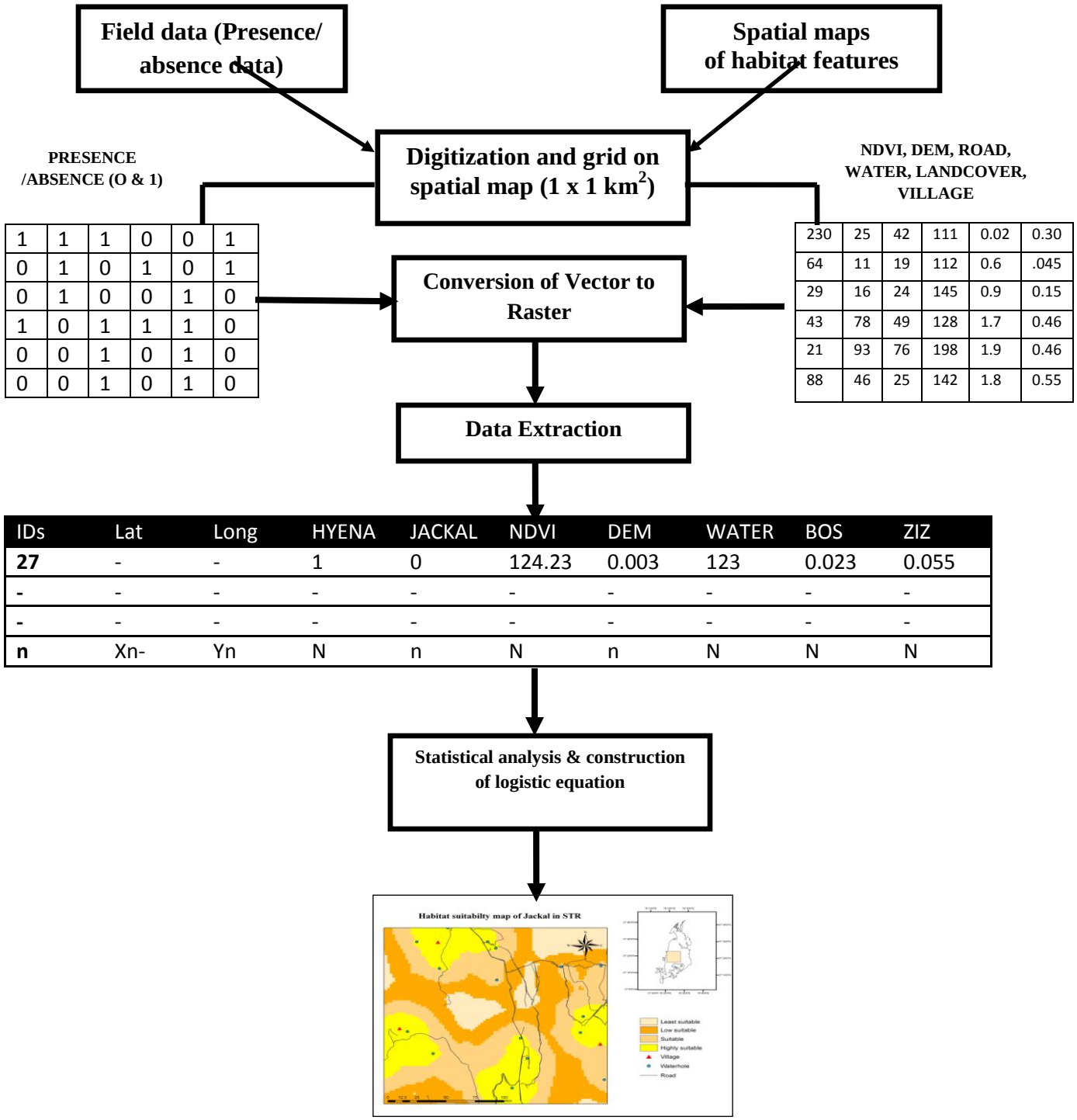
This model was used to prepare a probability of surface distribution for the study species in the study area. As the model was attempted on grid based raster information, all the maps in vector format such as land cover, distance to water source, distance to village source and species presence/absence data were rasterized using Arc View 3.2 (ESRI, 1996) and Arc Map (ESRI, 2004). The fishnet of 1x1 $km^2$ was laid over all the raster layers and the information on these variables corresponding to each grid was extracted in GIS. The data were taken to SPSS/PC software for further analysis and construction of equation to generate probability distribution maps for each species **(Figure 5.1)**.

**Table 5.1 List of the variables used in Logistic Regression analysis.**

| Variables | Variables type | Source |
|---|---|---|
| 1. Habitat | *Anogessius* dominated forest | Land use and land cover map from Landsat -7 – ETM+ data (source: Sankar *et al.*, 2009) |
| | *Boswellia* dominated forest | |
| | *Butea* dominated forest | |
| | *Zizyphus* mixed forest | |
| | *Acacia* mixed forest | |
| | Scrubland | |
| | NDVI | |
| | Prey information* | Field data (camera trapping) |
| 2. Anthropogenic | Distance from village (mean) | Village and road map, WII |
| | Distance from roads (mean) | |
| 3. Topographical | DEM | Contour map, WII |
| 4. Hydrological | Distance from water (mean) | Water source map, WII |

* Only for hyena, jackal and jungle cat.

**5.1 Flow chart depicting the process followed to build model and preparation of distribution map for the study species**




| | | | | | |
|---|---|---|---|---|---|
| 1 | 1 | 1 | 0 | 0 | 1 |
| 0 | 1 | 0 | 1 | 0 | 1 |
| 0 | 1 | 0 | 0 | 1 | 0 |
| 1 | 0 | 1 | 1 | 1 | 0 |
| 0 | 0 | 1 | 0 | 1 | 0 |
| 0 | 0 | 1 | 0 | 1 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| 230 | 25 | 42 | 111 | 0.02 | 0.30 |
| 64 | 11 | 19 | 112 | 0.6 | .045 |
| 29 | 16 | 24 | 145 | 0.9 | 0.15 |
| 43 | 78 | 49 | 128 | 1.7 | 0.46 |
| 21 | 93 | 76 | 198 | 1.9 | 0.46 |
| 88 | 46 | 25 | 142 | 1.8 | 0.55 |

| IDs | Lat | Long | HYENA | JACKAL | NDVI | DEM | WATER | BOS | ZIZ |
|---|---|---|---|---|---|---|---|---|---|
| **27** | - | - | 1 | 0 | 124.23 | 0.003 | 123 | 0.023 | 0.055 |
| **-** | - | - | - | - | - | - | - | - | - |
| **-** | - | - | - | - | - | - | - | - | - |
| **n** | Xn- | Yn | N | n | N | n | N | N | N |

#### 5.2.4.1 Logistic Regression:

Habitat selection of medium and small carnivores operates through a series of behavioural decisions at several spatial scales, that's why studying their distributional pattern is difficult. Based on available natural history and ecological information of the study species, some of the most relevant biophysical and anthropogenic factors that may largely affect their habitat suitability were studied in order to develop a distribution model.

For binary logistic regression all grid data including eleven explanatory variables (DEM, NDVI, vegetation classes etc) and six categorical variables (prey) were used for all species. Since prey information (presence/absence data) was available only for hyena, jungle cat and jackal, the model prediction was done only for these species while for rest four species, only eleven explanatory variables were used for their model prediction. These variables were selected for model building and further validation of model. A cross-correlation matrix was prepared initially to see if the variables were highly correlated to one another. Removal of highly correlated variables can lead to over fitting of the model and lead to overestimating the performance of the model. Variables with correlation coefficients > 0.60 were removed from the analysis. Enter elimination processes were applied to identify and remove redundant variables and those variables that did not contribute significantly in detecting presence of any species in the study area. Enter method was more useful as it enables better control over variables and consequently, allows inclusion of desired variables that have biological significance, but could have been compromised over better model fit by different elimination processes (Ramesh, 2003). Overall prediction efficiency of the variables was assessed based on Nagelkerke-$R^2$ and – Log Likelihood values. Influence of individual variables including categorical variables was assessed using Wald statistics. Hosmer and Lemeshow goodness-of-fit test (chi square test) and concordance analysis

(classification tables) were done to understand the fit of the model (Hosmer and Lemeshow, 1989). Sensitivity (percentage true positive or presence correctly predicted) and specificity (percentage true negative or absence correctly predicted) were calculated for each cut-off point (0.1 to 0.9) and best cut-off point was chosen on the basis of optimum sensitivity and specificity. The cut-off level would allow categorization of the probability values to represent either 0 if it is below the cut-off point or 1 if it is above the cut-off point. Logistic regression was done using the selected variables and at an appropriate cut-off level and the probability of occurrence was estimated for each of the species using the following formula.

Probability of event (or presence) = 1 / (1 – EXP–z)

**where, Z = a + (b1 ´ X1) + (b2 ´ X2) + (b3 ´ X3) + …….. (bk ´ Xk),**

**a =constant, b = coefficients and X = predictor variable.**

Further the equation was then taken to GIS and probability of occurrence of each species was predicted for the intensive study area and habitat suitability map was generated using Arc info and Arc view software for each species. The transformed output was then at equal interval sliced into very low, low, medium and high suitable areas for each species in the intensive study area. No attempt was made to extrapolate data for the entire Tiger Reserve.

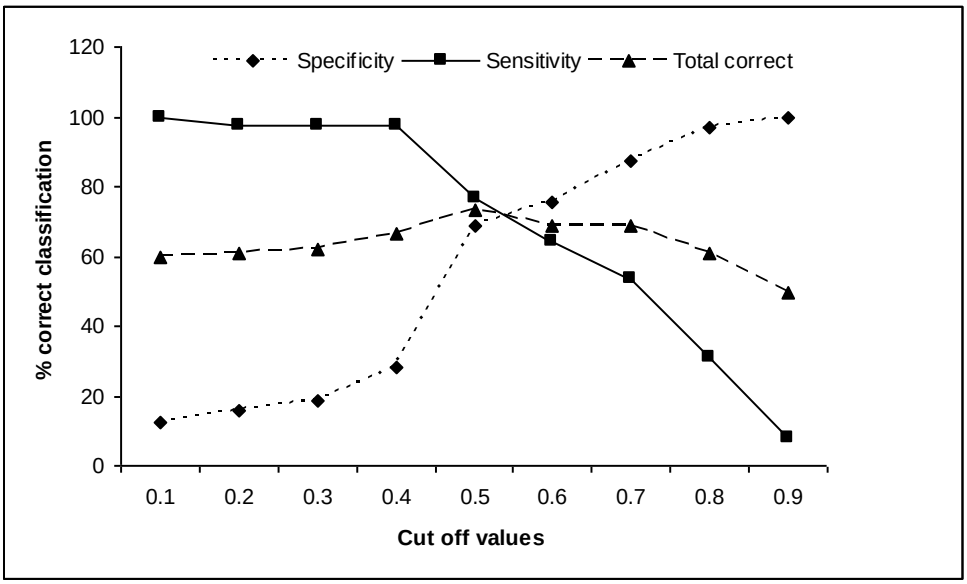
## 5.3 RESULTS:

### 5.3.1 Habitat suitability model for striped hyena:

Logistic regression analysis revealed clear pattern of presence grids for each explantory variable involved in model building for striped hyena. It was found that striped hyena largely used *Boswellia* forest, scrubland and areas near villages **(Figure 5.2)**. Enter method was initially applied for all eleven variables and six categorical variables, the variables which were strongly correlated (P>0.6), were then discarded to avoid redundancy in the predictors. Based on quality of

information, final eight variables were retained to develop a better model fit and also for development of final equation for striped hyena **(Table 5.2)**. The -2 Log Likelihood value and Nagelkerke $R^2$ were 78.399 and 0.319 respectively, indicating improvement of model fit with inclusion of the above variables and a combined effect of the variables in predicting probability of occurrence. Hosmer and Lemeshow goodness-of-fit test indicated that the obtained model did not differ significantly from null model or expected fit ($\chi^2$ = 9.511, p = 0.30). Overall correct prediction rate of the model was 71.8%. Prediction rate for true positives (presence - 1) was 79.5 and it was 62.5% for true negatives (not present -0). The best cut-off level that optimized sensitivity and specificity was at 0.5 **(Figure 5.3)**. Final analysis at this cut-off point had six explanatory variables (with three land cover variables) and two categorical variables (prey) were used to develop final equation **(Table 5.2)**.

**Figure 5.3 Concordance analysis depicting sensitivity and specificity in different cut-off values for striped hyena.**



### 5.3.2 Habitat suitability model for jungle cat:

It was found that jungle cat largely used *Zizyphus* woodland, scrubland, high canopy cover (indicated by high NDVI values) and areas close to road **(Figure 5.4)**. A total of six variables were retained in the analysis to develop a better model fit and also for development of final equation for jungle cat. Estimated -2 Log Likelihood and $R^2$ in the model obtained for jungle cat was 67.21 and 0.249 respectively was found significant with the model prediction values. Hosmer and Lemeshow goodness-of-fit test revealed better model fit ($\chi^2$ =11.87, p=0.157). Overall correct classification rate of the model was 80.3%, while predicted positives and negatives were 96.2% and 33.3 % respectively. The best cut-off point optimizing sensitivity and specificity was found to be at 0.5 for the species **(Figure 5.5)**. The coefficient values incorporated in the final logistic regression equation for this species are shown in **Table 5.3**.

**Figure 5.5 Concordance analysis depicting sensitivity and specificity in different cut-off values for jungle cat.**

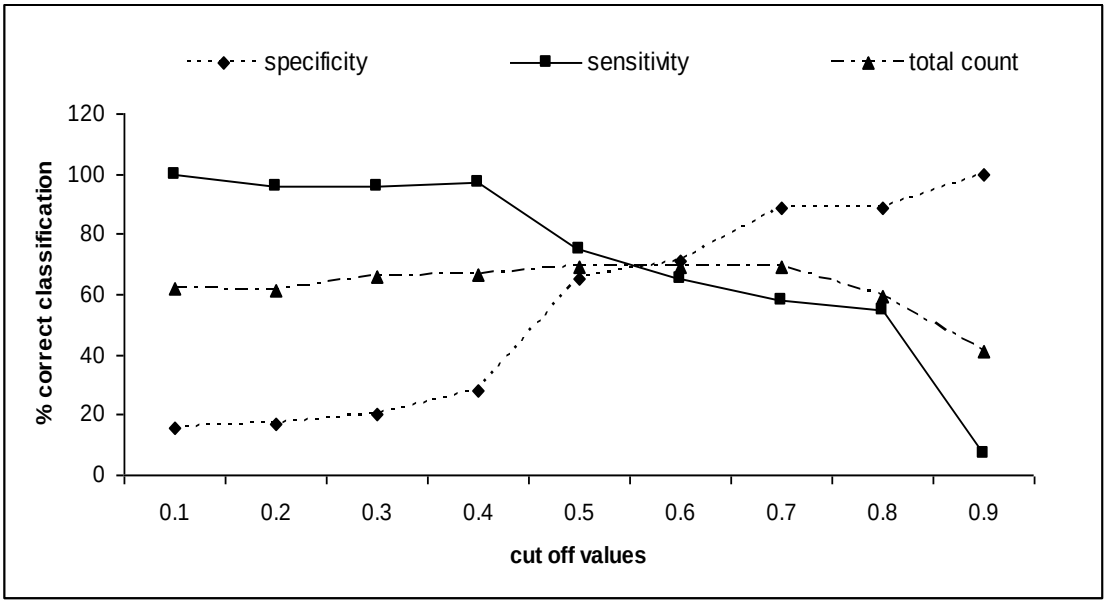


**Table 5.2 Coefficient and variables used in Logistic Regression for striped hyena in Sariska Tiger Reserve.**

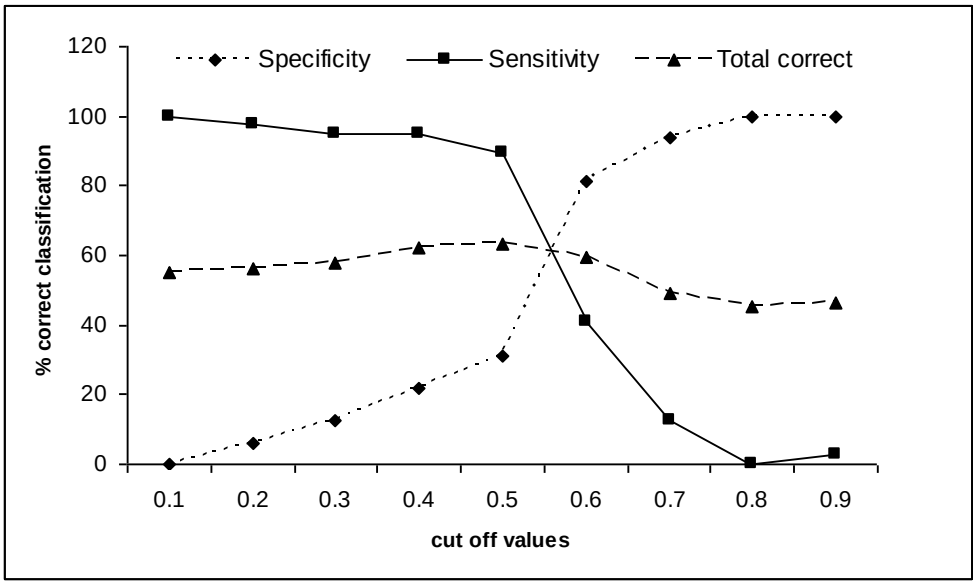
| Variables | Coefficient | S.E. | Wald | df | Sig. | Exp(B) |
|---|---|---|---|---|---|---|
| **NDVI** | -7.141 | 10.089 | .501 | 1 | .479 | .001 |
| **ROAD** | .006 | .006 | .954 | 1 | .329 | 1.006 |
| **VILLAGE** | .004 | .003 | 1.276 | 1 | .259 | .996 |
| **BOSWELLIA** | 38.200 | 19.960 | 3.663 | 1 | .056 | .000 |
| **ZIZYPHUS** | 10.133 | 9.200 | 1.213 | 1 | .271 | 2.515 |
| **SCRUBLAND** | -45.959 | 30.185 | 2.318 | 1 | .128 | .000 |
| **CHITAL** | -2.504 | .969 | 6.680 | 1 | .010 | .082 |
| **HARE** | 1.535 | .883 | 3.024 | 1 | .082 | 4.642 |
| **Constant** | 3.589 | 4.244 | .715 | 1 | .398 | 36.187 |

**Table 5.3 Coefficient and variables used in Logistic Regression for jungle cat in Sariska Tiger Reserve.**

| Variables | Coefficient | S.E. | Wald | df | Sig. | Exp(B) |
|---|---|---|---|---|---|---|
| **NDVI** | -12.337 | 9.432 | 1.711 | 1 | .191 | .000 |
| **ROAD** | -.004 | .005 | .575 | 1 | .448 | .996 |
| **ZIZYPHUS** | 10.733 | 8.630 | 1.547 | 1 | .214 | 4.586 |
| **SCRUBLAND** | -5.512 | 4.567 | 1.456 | 1 | .228 | .004 |
| **RODENT** | .352 | .804 | .192 | 1 | .412 | .704 |
| **DEM** | .019 | .018 | 1.172 | 1 | .279 | 1.019 |
| **Constant** | 5.699 | 4.021 | 2.009 | 1 | .156 | 298.643 |

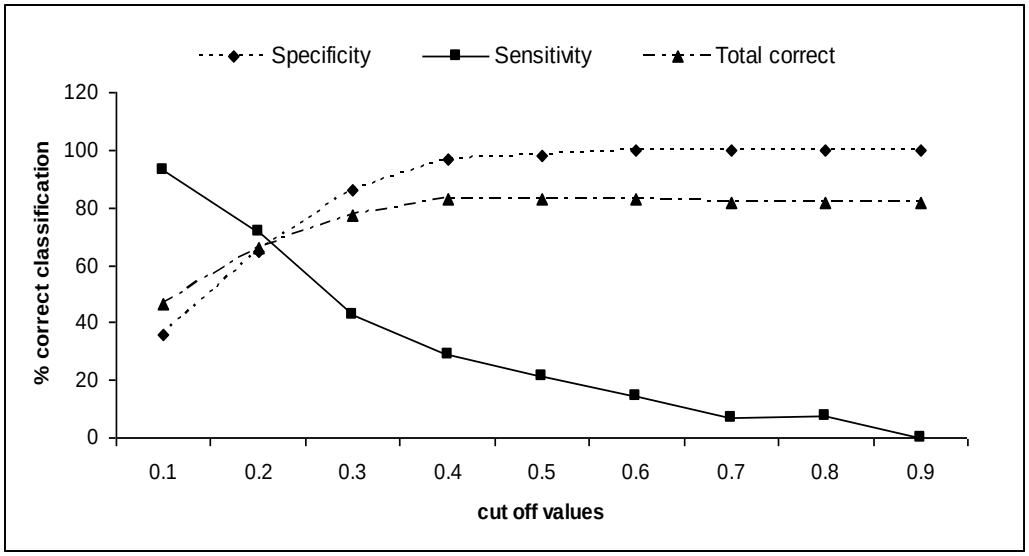
**5.3.3 Habitat suitable model for jackal:** Jackal largely used *Zizyphus* woodland and areas close to road and water **(Figure 5.6)**. A total of seven variables were retained for the analysis to develop a better model fit and also for development of final equation. Estimated -2 Log Likelihood and $R^2$ in the model obtained for jackal was 85.88 and 0.227 respectively was found significant with the model prediction values. Hosmer and Lemeshow goodness-of-fit test revealed better model fit ($\chi^2$ =12.06, p=0.148). Overall correct classification rate of the model was 68.1%, while predicted positives and negatives were 79.5% and 54.5 % respectively. The best cut-off point optimizing sensitivity and specificity was found to be at 0.5 for the species **(Figure 5.7)**. The coefficient values incorporated in the final logistic regression equations for this species at this cut off point is shown in **Table 5.4**.

**Figure 5.7 Concordance analysis depicting sensitivity and specificity in different cut-off values for jackal.**



**5.3.4 Habitat suitability model for ratel:** Ratel largely used *Anogessius* forest, *Zizyphus* woodland, scrubland and areas close to road and water **(Figure 5.8)**. Estimated -2 Log Likelihood and $R^2$ in the model obtained for ratel was 63.11 and 0.157 respectively was found significant with the model prediction values. Hosmer and Lemeshow goodness-of-fit test revealed better model fit ($\chi^2$ =6.685, p=0.5711). Overall correct classification rate of the model was 64.8%, while predicted positives and negatives were 57.1% and 66.7 % respectively. The best cut-off point optimizing sensitivity and specificity was found to be at 0.2 for the species **(Figure 5.9)**. In total eight explanatory variables including land cover were selected to develop better model fit and also for development of final equation at this cut off point is shown in **Table 5.5**.

**Figure 5.9 Concordance analysis depicting sensitivity and specificity in different cut-off values for ratel.**




**5.3.5 Palm civet:** Palm civet was largely used *Acacia* mixed forest, *Zizyphus* woodland and areas close to village **(Figure 5.10)**. Estimated -2 Log Likelihood and $R^2$ in the model obtained for palm civet was 71.73 and 0.13 respectively was found significant with the model prediction values. Hosmer and Lemeshow goodness-of-fit test revealed better model fit ($\chi^2$ =5.192,

p=0.737). Overall correct classification rate of the model was 77.5%, while predicted positives and negatives were 23.5% and 94.4 % respectively. The best cut-off point optimizing sensitivity and specificity was found to be at 0.2 for this species **(Figure 5.11)**. Final analysis at this cut off point retained five variables (all land cover variables) for better prediction of best fitted model and development of logistic equation is shown in **Table 5.6**.

**5.3.6 Habitat suitability model for small Indian civet:** Logistic regression analysis revealed that small Indian civet largely used *Anogessius* and *Acacia* forests, dense canopy forest and areas close to road and water **(Figure 5.12)**. Estimated -2 Log Likelihood and $R^2$ in the model obtained for small Indian civet was 46.02 and 0.56 respectively was found significant with the model prediction values. Hosmer and Lemeshow goodness-of-fit test revealed better model fit ($\chi^2$ =2.77, p = 0.94). Overall correct classification rate of the model was 85.9%, while predicted positives and negatives were 61.1% and 94.3 % respectively. The best cut-off point optimizing sensitivity and specificity was found to be at 0.2 for this species **(Figure 5.13)**. Final analysis at this cut off point retained nine variables (with land cover variables) for better prediction of best fitted model and development of logistic equation is shown in **Table 5.7**.

**5.3.7 Habitat suitability model for common grey mongoose:** Logistic regression analysis revealed that common grey mongoose largely used *Anogessius* forest and areas close to water, road and villages **(Figure 5.14)**. Estimated -2 Log Likelihood and $R^2$ in the model obtained for common grey mongoose was 48.98 and 0.329 respectively was found significant with the model prediction values. Hosmer and Lemeshow goodness-of-fit test revealed better model fit ($\chi^2$ =7.602, p = 0.473). Overall correct classification rate of the model was 80.3%, while predicted positives and negatives were 16.7% and 93.2 % respectively. The best cut-off point optimizing sensitivity and specificity was found to be at 0.2 for this species **(Figure 5.15).** Final analysis at

this cut off point retained five variables (with one land cover variable) for better prediction of best fitted model and development of logistic equation is shown in **Table 5.8**.

**5.3.8 Habitat suitability model for ruddy mongoose:** Logistic analysis revealed that ruddy mongoose largely used *Boswellia* forest and *Zizyphus* woodland and areas near to villages **(Figure 5.16)**. Log Likelihood and $R^2$ in the model obtained for ruddy mongoose was 73.90 and 0.27. Hosmer and Lemeshow goodness-of-fit test revealed better model fit ($\chi^2$ =6.96, p = 0.54). Overall correct classification rate of the model was 69.0%, while predicted positives and negatives were 34.8% and 85.4 % respectively was found significant with the model prediction values. The best cut-off point optimizing sensitivity and specificity was found to be at 0.4 for this species **(Figure 5.17)**. Final analysis at this cut off point retained eight variables (with four land cover variables) for better prediction of best fitted model and development of logistic equation is shown in **Table 5.9**.

All equations developed for all the eight study species responded well with collected data set. These equations once applied to spatial maps of variables produced probability of occurrence map or habitat suitability map for the intensive study area for striped hyena **(Figure 5.2)**, jungle cat **(Figure 5.4)**, jackal **(Figure 5.6)**, ratel **(Figure 5.8)**, palm civet **(Figure 5.10)**, small Indian civet **(Figure 5.12)**, common grey mongoose **(Figure 5.14)** and ruddy mongoose **(Figure 5.16)**. The habitat suitability map was categorized into four classes based on probability values since the classification accuracies was calculated at cut off value 0.5 and 0.2. The final output map was prepared showing the habitat suitability map for study species as very low (0 - 0.25), low (0.25 - 0.50), medium (0.50 – 0.75) and high suitable (0.75 - 1.00).

**Table 5.4 Coefficient and variables used in Logistic Regression for jackal in Sariska Tiger Reserve**

| Variable | Coefficient | S.E. | Wald | df | Sig. | Exp(B) |
|---|---|---|---|---|---|---|
| **DEM** | .006 | .006 | .829 | 1 | .363 | 1.006 |
| **VILLAGE** | .003 | .003 | .777 | 1 | .378 | 1.003 |
| **WATER** | .003 | .004 | .494 | 1 | .482 | 1.003 |
| **ZIZYPHUS** | .000 | .000 | .795 | 1 | .372 | 1.000 |
| **CHITAL** | 1.429 | .771 | 3.431 | 1 | .064 | 4.175 |
| **RODENT** | -1.531 | .860 | 3.170 | 1 | .075 | .216 |
| **PEAFOWL** | -1.479 | .741 | 3.985 | 1 | .046 | .228 |
| **Constant** | .103 | 1.540 | .004 | 1 | .947 | 1.109 |

**Table 5.5 Coefficient and variables used in Logistic Regression for ratel in Sariska Tiger Reserve.**

| Variable | Coefficient | S.E. | Wald | df | Sig. | Exp(B) |
|---|---|---|---|---|---|---|
| **SCRUBLAND** | -26.668 | 34.077 | .612 | 1 | .434 | .000 |
| **ROAD** | -.005 | .006 | .667 | 1 | .414 | .995 |
| **DEM** | .011 | .008 | 1.910 | 1 | .167 | 1.011 |
| **ZIZYPHUS** | 10.078 | 9.747 | 1.069 | 1 | .301 | 2.381 |
| **VILLAGE** | -.003 | .003 | .816 | 1 | .366 | .997 |
| **ANOGESSUS** | -3.223 | 2.925 | 1.214 | 1 | .270 | .040 |
| **ACACIA** | -4.895 | 4.874 | 1.008 | 1 | .315 | .007 |
| **WATER** | .004 | .006 | .398 | 1 | .528 | 1.004 |
| **Constant** | -.086 | 2.341 | .001 | 1 | .971 | .918 |

**Table 5.6 Coefficient and variables used in Logistic Regression for palm civet in Sariska Tiger Reserve.**

| Variables | Coefficient | S.E. | Wald | df | Sig. | Exp(B) |
|---|---|---|---|---|---|---|
| **SCRUBLAND** | -16.722 | 24.495 | .466 | 1 | .495 | .000 |
| **ZIZYPHUS** | 7.544 | 8.048 | .879 | 1 | .349 | 1.889E3 |
| **VILLAGE** | -.006 | .003 | 3.786 | 1 | .052 | .994 |
| **ANOGESSIUS** | -1.982 | 2.400 | .682 | 1 | .409 | .138 |
| **ACACIA** | -4.544 | 4.495 | 1.022 | 1 | .312 | .011 |
| **Constant** | .943 | 1.088 | .751 | 1 | .386 | 2.567 |

**Figure 5.11 Concordance analysis depicting sensitivity and specificity in different cut-off values for palm civet**

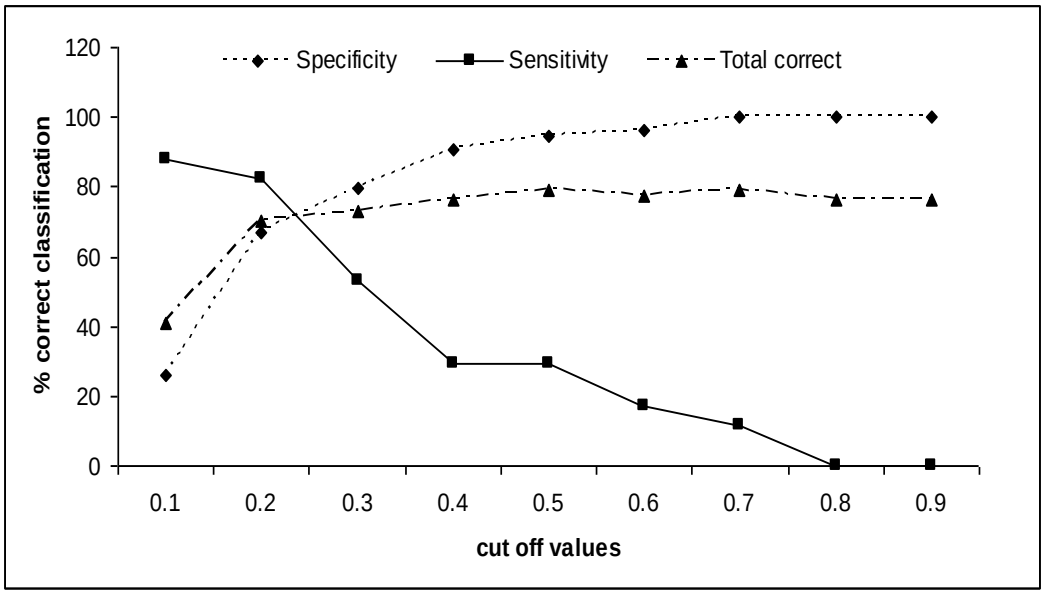


**Table 5.7 Coefficient and variables used in Logistic Regression for small Indian civet in Sariska Tiger Reserve.**

| Variables | Coefficient | S.E. | Wald | Df | Sig. | Exp(B) |
|---|---|---|---|---|---|---|
| **SCRUBLAND** | 9.992 | 5.749 | 3.021 | 1 | .082 | 2.185 |
| **ZIZYPHUS** | 19.912 | 11.639 | 2.927 | 1 | .087 | 4.442 |
| **ANOGESSIUS** | -12.843 | 4.918 | 6.818 | 1 | .009 | .000 |
| **ACACIA** | -24.402 | 11.071 | 4.858 | 1 | .028 | .000 |
| **NDVI** | 32.674 | 18.148 | 3.242 | 1 | .072 | 1.550 |
| **DEM** | .065 | .033 | 3.979 | 1 | .046 | 1.068 |
| **ROAD** | .017 | .009 | 3.471 | 1 | .062 | 1.017 |
| **WATER** | -.010 | .007 | 2.147 | 1 | .143 | .990 |
| **BOSWELLIA** | 20.143 | 15.541 | 1.680 | 1 | .195 | 5.600 |
| **Constant** | -14.965 | 7.478 | 4.005 | 1 | .045 | .000 |

**Figure 5.13 Concordance analysis depicting sensitivity and specificity in different cut-off values for small Indian civet.**

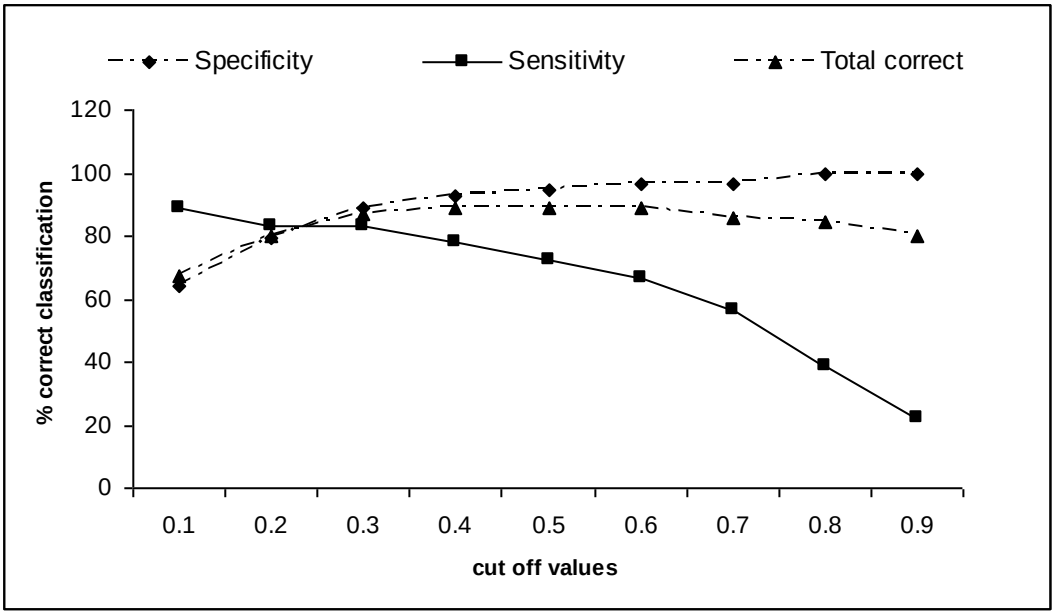


**Table 5.8 Coefficient and variables used in Logistic Regression for common grey mongoose in Sariska Tiger Reserve**

| Variables | Coefficient | S.E. | Wald | df | Sig. | Exp(B) |
|---|---|---|---|---|---|---|
| ANOGESSUS | -3.542 | 2.883 | 1.510 | 1 | .219 | .029 |
| DEM | -.017 | .019 | .804 | 1 | .370 | .983 |
| ROAD | -.009 | .006 | 2.139 | 1 | .144 | .991 |
| WATER | .036 | .015 | 5.966 | 1 | .015 | 1.036 |
| VILLAGE | .006 | .005 | 1.237 | 1 | .266 | 1.006 |
| Constant | -8.672 | 4.000 | 4.700 | 1 | .030 | .000 |

**Figure 5.15 Concordance analysis depicting sensitivity and specificity in different cut-off values for common grey mongoose.**

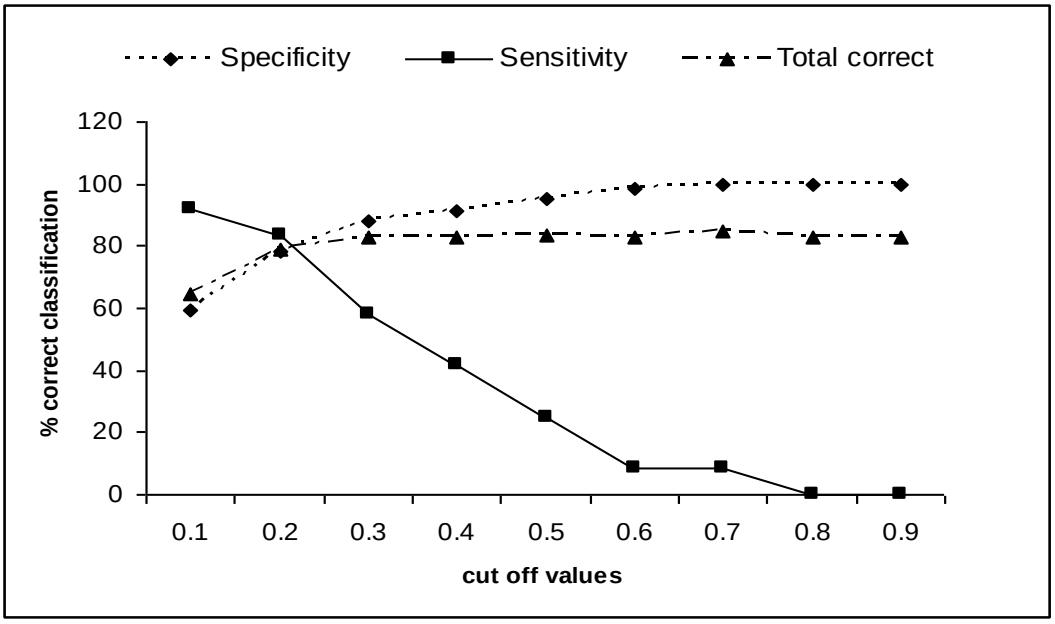
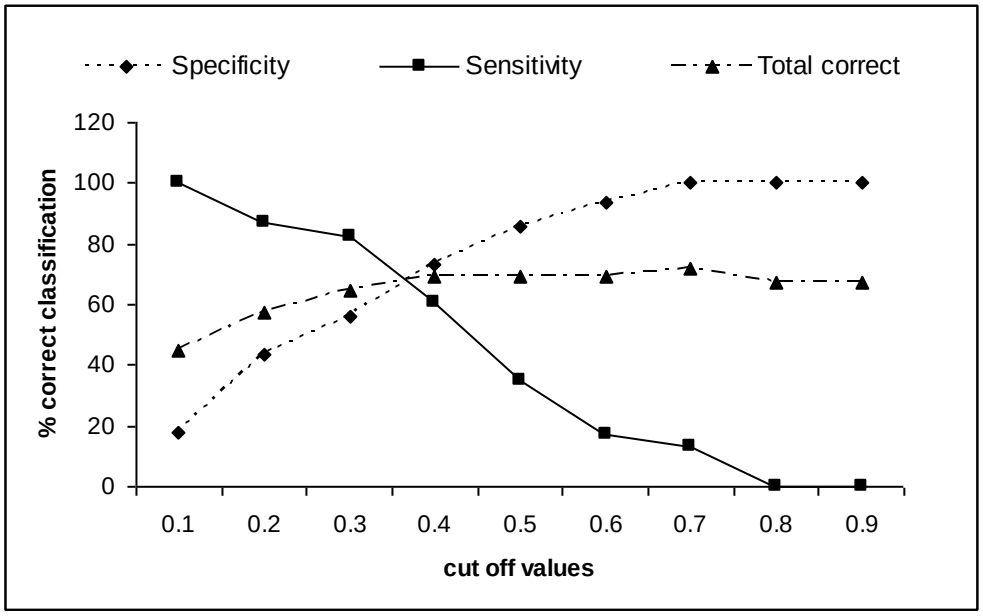


**Table 5.9 Coefficient and variables used in Logistic Regression for ruddy mongoose in Sariska Tiger Reserve.**

| Variable | Coefficient | S.E. | Wald | df | Sig. | Exp(B) |
|---|---|---|---|---|---|---|
| **DEM** | .006 | .007 | .827 | 1 | .363 | 1.006 |
| **ROAD** | .006 | .006 | 1.063 | 1 | .303 | 1.006 |
| **WATER** | .005 | .005 | .973 | 1 | .324 | 1.005 |
| **VILLAGE** | -.004 | .003 | 1.823 | 1 | .177 | .996 |
| **BOSWELLIA** | -154.449 | 96.092 | 2.583 | 1 | .108 | .000 |
| **ACACIA** | -3.752 | 3.983 | .887 | 1 | .346 | .023 |
| **ZIZYPHUS** | 10.538 | 7.879 | 1.789 | 1 | .181 | 3.7734 |
| **SCRUBLAND** | -4.575 | 7.224 | .401 | 1 | .526 | .010 |
| **Constant** | -1.913 | 2.030 | .888 | 1 | .346 | .148 |

**Figure 5.17 Concordance analysis depicting sensitivity and specificity in different cut-off values for ruddy mongoose.**



## 5.4 DISCUSSION

Distribution maps obtained for study species in this study represents probability values (0-1) in 144 $km^2$ (1 x 1 $km^2$ grid cells) indicating chance of encountering the species in the intensive study area in STR. The entire approach was based on the premise that species distribution is related to vegetation and topographic features. Spatial mapping of probability of occurrence using logistic regression method has been found to be effective in predicting occurrence of several species of mammals (Buckland and Elston, 1993; Augustin *et al.,* 1996; Carroll *et al.,* 1999; Odom *et al.,* 2001), birds (Beard *et al.,* 1999; Manel *et al.,* 1999; Franco *et al.,* 2000; Osborne *et al.,* 2001; Ramesh, 2003) and also for predicting natural events such as fire ignition probability and weed growth (Collingham *et al.,* 2000; Gunter *et al.,* 2000; De Vasconcelos *et al.,* 2001).

### 5.4.1 Striped hyena:

In the present study, logistic regression technique provided a basis for constructing probabilistic model and enabled to remove redundant variables from the equation. Besides DEM and water, seven variables (including vegetation classes) were found insignificant with the model building for this species. The explanatory variables used in the final equation collectively accounted for 72% for the explained variables for striped hyena ($R^2$=0.319). Scrub and canopy cover as indicated by NDVI, land cover class (scrubland) and prey variable (chital) were found to be negatively correlated with the striped hyena occurrence and other variables like distance to road and village, land class (*Boswellia* and *Zizyphus*) and prey variable (hare) were found to be positively correlated with species occurrence.

Although above explanation indicate the role of individual variables in the equation, it could not be substantiated due to observed multicollinearity in the explanatory variables, as indicated by large p-values. Multicollinearity is known to exist when explanatory variables are highly correlated with each other and is an intractable problem in all regression analysis as it undermines

statistical significance of individual variables (Allen, 1997; Ramesh, 2003). However, since the objective was to come up with an overall prediction of species distribution regardless of which variable is contributing in relative magnitude, multicollinearity was not a problem. Moreover, it was found that these variables together predicted the distribution well and removal of any of the covariates from the model resulted in reduction of prediction rates.

Out of total intensive area 144 $km^2$, 36 $km^2$ and 82 $km^2$ were found very low and low suitable areas respectively for striped hyena which represented 82% of total study area while 25 $km^2$ and 1 $km^2$ was considered as medium and high suitable areas respectively and these areas represented for 18% of study area **(Figure 5.2)**. The present result on distribution of striped hyena was consistent with the information available on this species from other areas where it typically inhabits the scrubland, woodland and rocky terrain (Kruuk, 1976; Wagner, 2006). They are commonly found near human habitation in India (Prater, 1980). In East Africa they are mostly observed in *Acacia* savannah with little shrub and trees (Kruuk, 1976). Suitable sites for striped hyena in STR were largely dependent upon areas near to road and village and some vegetation classes like *Boswellia* and *Zizyphus* **(Figure 5.2)**. Among the prey species, distribution of chital and hare highly affected the distribution and suitable sites for striped hyena in the intensive study area.

### 5.4.2 Jungle cat:

For jungle cat, logistic regression technique provided a basis for constructing probabilistic model and enabled to remove redundant variables from the equation. Besides distance to village and water, eight variables (including vegetation classes) were found insignificant with the model building for this species. The explanatory variables used in final equation collectively accounted for 80.3% for the explained variables for jungle cat ($R^2$=0.249). Scrub and canopy cover as

indicated by NDVI, distance to road, one land cover class (scrubland) were found to be negatively correlated with the jungle cat occurrence and other variables like DEM, land cover class (*Zizyphus*) and prey variable (rodent) were found to be positively correlated with species occurrence. The higher use by jungle cat of scrubland when compared to other habitat in STR is consistent with the information available on jungle cat from other areas where scrubland and presence of rodents are important for deciding its distribution (Nowell and Jackson, 1996; Mukherjee, 1998). Studies on bobcats (*Lynx rufus*) and ocelots (*Leopardus pardalis*) have shown dense cover to be important factor in determing choice of habitat in felids (Mc Cord, 1974; Zerulak and Schwab, 1979; Lawhead, 1984; Rolley, 1983, 1985). Out of total intensive study area of 144 $km^2$, 15 $km^2$ and 71 $km^2$ were found to be very low and low areas respectively for jungle cat which represented 60% of total study area while 52 $km^2$ and 6 $km^2$ were considered to be medium and high suitable areas respectively and these were accounted for 40% of the total study area **(Figure 5.4)**. The present study showed suitable sites for jungle cat were largely dependent upon NDVI, DEM, and area close to road and two vegetation classes (*Zizyphus* woodland and scrubland) **(Figure 5.4)**. Among the prey species distribution of rodents highly affected the distribution and suitable sites for jungle cat in the intensive study area.

**5.4.3 Jackal:** Besides NDVI, area close to road and nine variables (including vegetation classes) were found insignificant for this species. These variables collectively accounted for 68.1% for the explained variables for jackal ($R^2$=0.227). DEM, distance to village and water, one land cover class (*Zizyphus*) and prey variables (chital) were found to be positively correlated with the jackal occurrence and other prey variable (rodent and peafowl) were found to be negatively correlated for jackal distribution. Most of the canids inhabit relatively open areas which can be attributed to their life history traits like social organization (Jaedger, 1996; Ambika, 2005). Out of total

intensive study area of 144 $km^2$, 22 $km^2$ and 41 $km^2$ were found to be very low and low suitable areas respectively which represented 44% of total study area while 49 $km^2$ and 32 $km^2$ were found to be medium and high suitable areas respectively for jackal which represented nearly 56% of total study area **(Figure 5.6)**. The high distribution of the jackals in the study area is consistent with information available on jackal from other areas where scrubland, *Zizyphus* woodland and human habitation was important for deciding its distribution (Moehlam, 1983, 1986 and 1989; Mukherjee, 1989). Suitable sites for jackal were largely dependent upon DEM, areas close to road and two vegetation classes (*Zizyphus* and scrubland) **(Figure 5.6)**. Among the prey species distribution chital and rodent highly affected the distribution and suitable areas for jackal in the intensive study area.

**5.4.4 Ratel:**

Besides NDVI, three variables (including vegetation classes) were found insignificant with the model building for this species. These variables collectively accounted for 64.8% for the explained variables for ratel ($R^2$=0.5711). DEM, distance to water and one land cover class (*Zizyphus*) were found to be positively correlated with the ratel occurrence and distance to road and village and vegetation types such as *Anogessius*, *Acacia* and scrubland were found to be negatively correlated with the occurrence of ratel. Results obtained from present study were consistent with available studies where riverine habitats for foraging and undulating dry deciduous patches were important for its distribution (Pati *et al.*, 2000). Out of total intensive study area of 144 $km^2$, 103 $km^2$ and 4 $km^2$ were found to be very low and low suitable areas respectively which represented 75% of the total study area, while 6 $km^2$ and 31 $km^2$ were found to be medium and high suitable areas respectively for ratel which represented for 25% of the total study area **(Figure 5.8)**. Suitable sites for ratel were largely dependent upon DEM, area close to

water and one vegetation class (*Zizyphus*) highly affected the distribution and suitable areas for ratel in the intensive study area **(Figure 5.8)**.

### 5.4.5 Palm civet:

Besides NDVI, DEM and four variables (including vegetation classes) were found insignificant with the model building for this species. These variables collectively accounted for 77.5% for explained the variables for palm civet ($R^2$=0.737). *Zizyphus* woodland was found to be positively correlated with the palm civet occurrence and distance to villages, *Anogessius* forest, *Acacia* forest and scrubland were found to be negatively correlated with the occurrence of species.

Out of total intensive study area of 144 $km^2$, 119 $km^2$ and 16 $km^2$ were found to be very low and low suitable areas respectively which represented 94% of total study area while 6 $km^2$ and 3 $km^2$ were found to be medium and high suitable areas respectively for palm civet which represented for 6% of the total study area **(Figure 5.10)**. Based on available information palm civets live in tropical forested habitats, parks and suburban gardens where mature fruit trees and fig trees grow and areas with undisturbed vegetation (Prater, 1980). Results obtained from present study showed *Zizyphus* woodland highly affected the distribution and suitable areas for the palm civet in the intensive study area **(Figure 5.10)**.

**Figure 5.2 Habitat suitability map for striped hyena in the intensive study area of Sariska Tiger Reserve.**

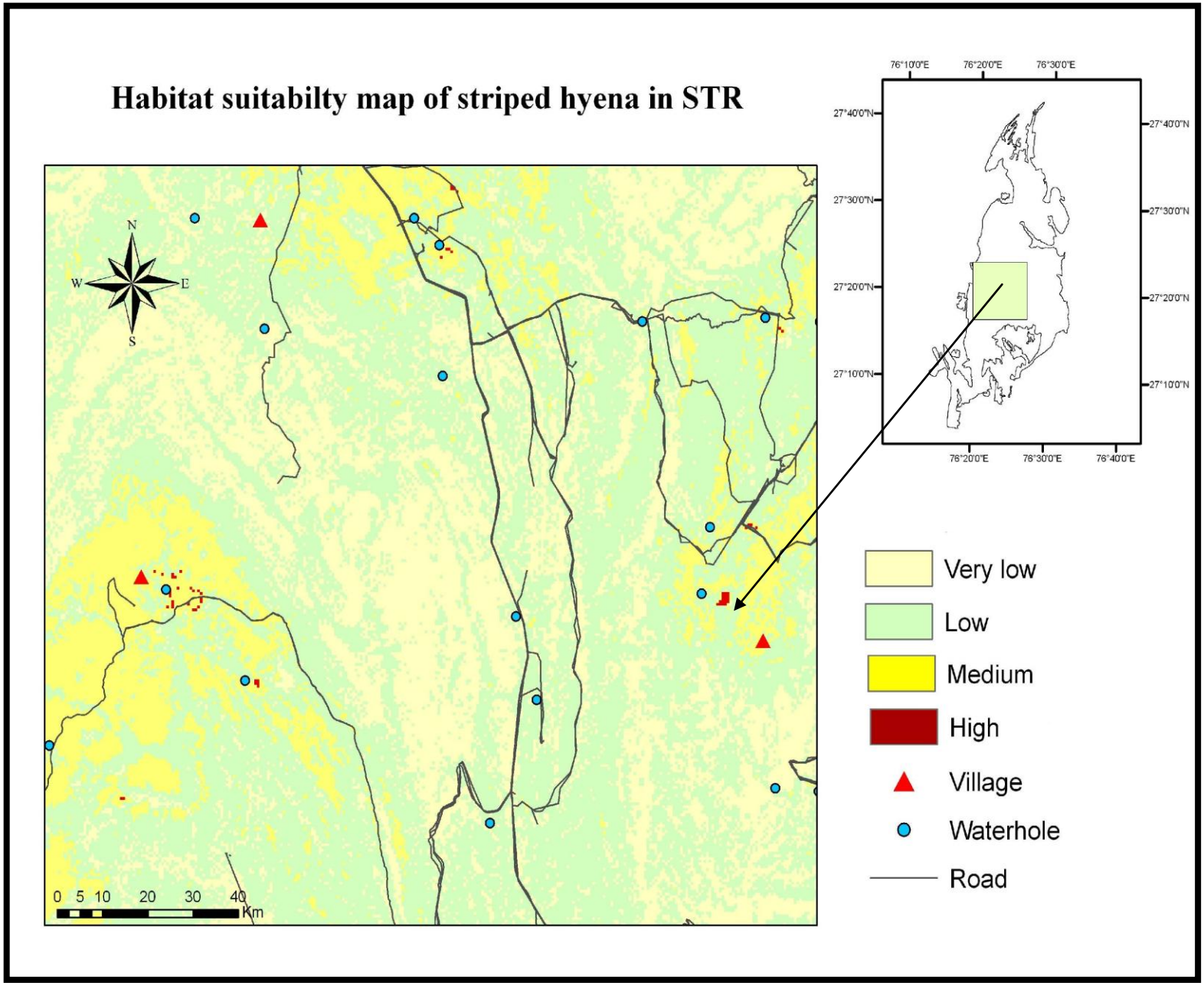


**Figure 5.4 Habitat suitability map for jungle cat in the intensive study area of Sariska Tiger Reserve.**

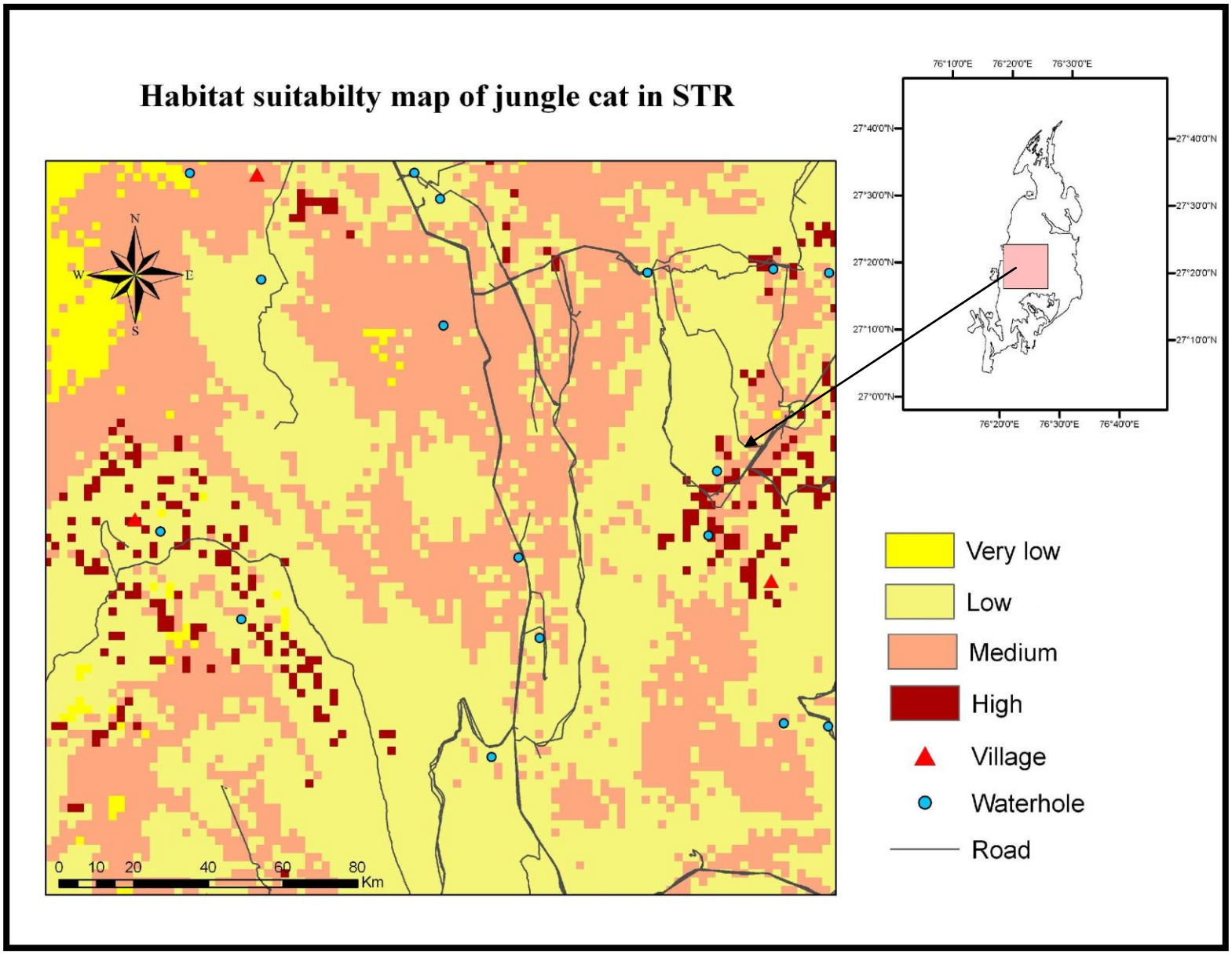


**Figure 5.6 Habitat suitability map of jackal in the intensive study area of Sariska Tiger Reserve.**

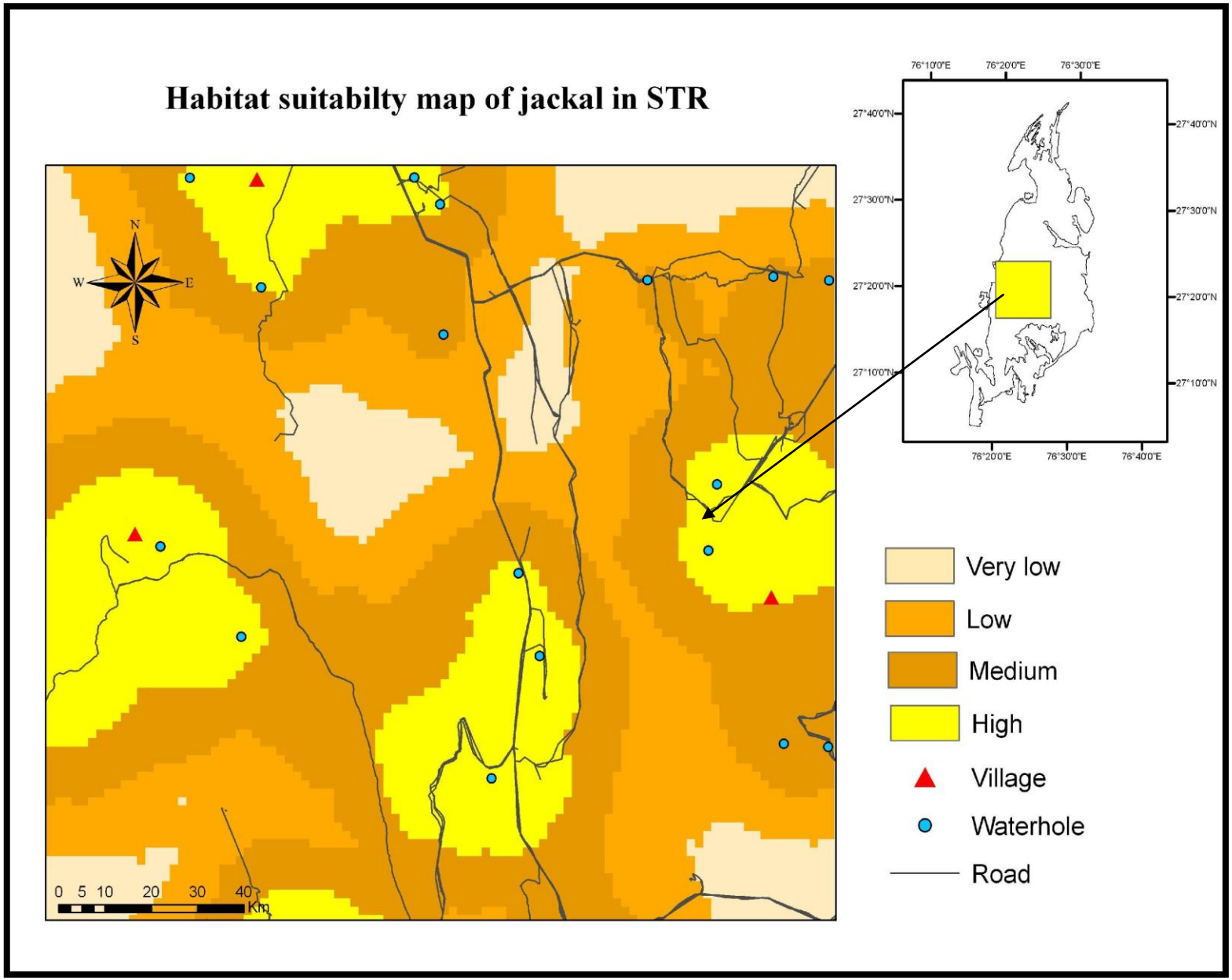


**Figure 5.8 Habitat suitability map of ratel in the intensive study area of Sariska Tiger Reserve.**

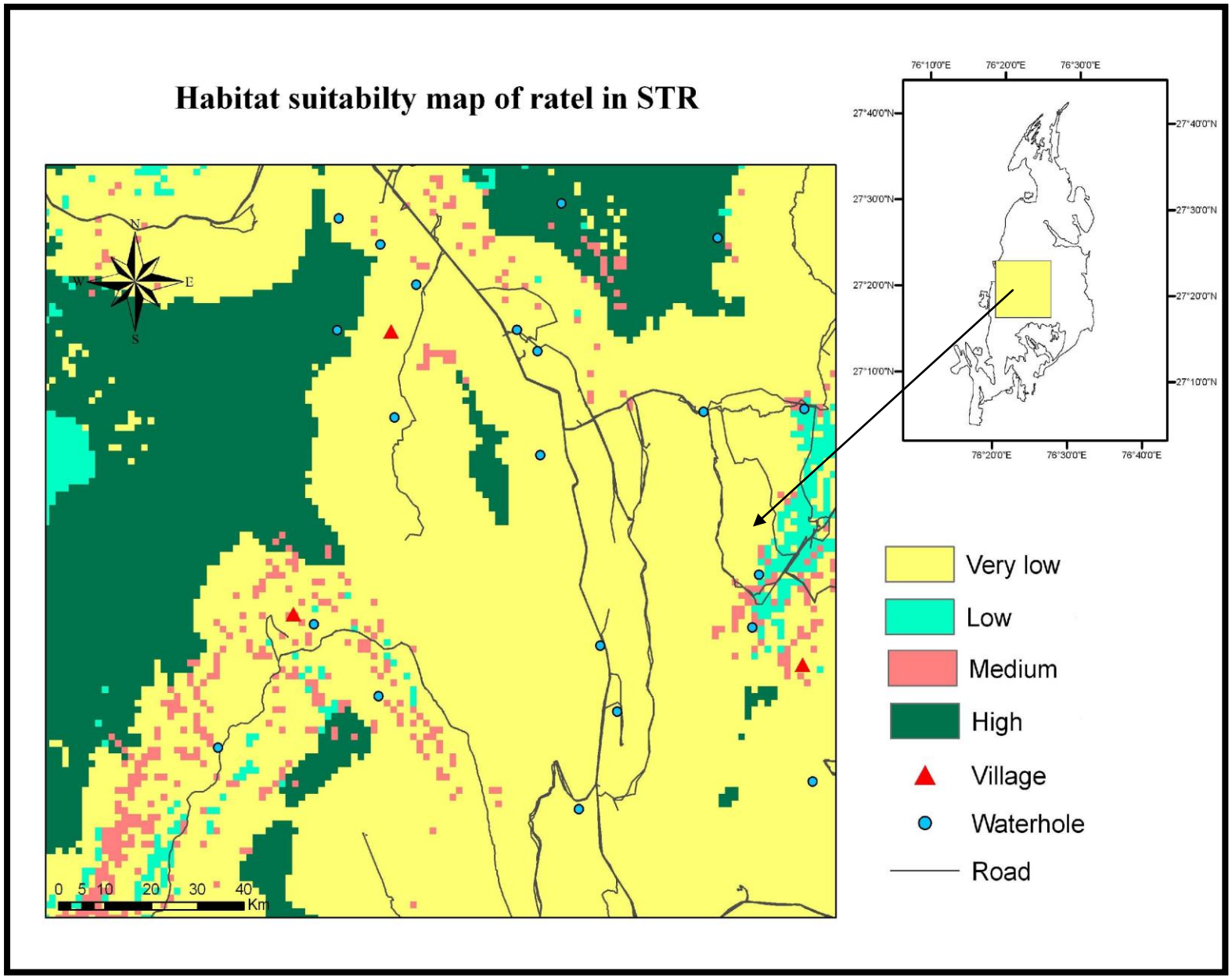
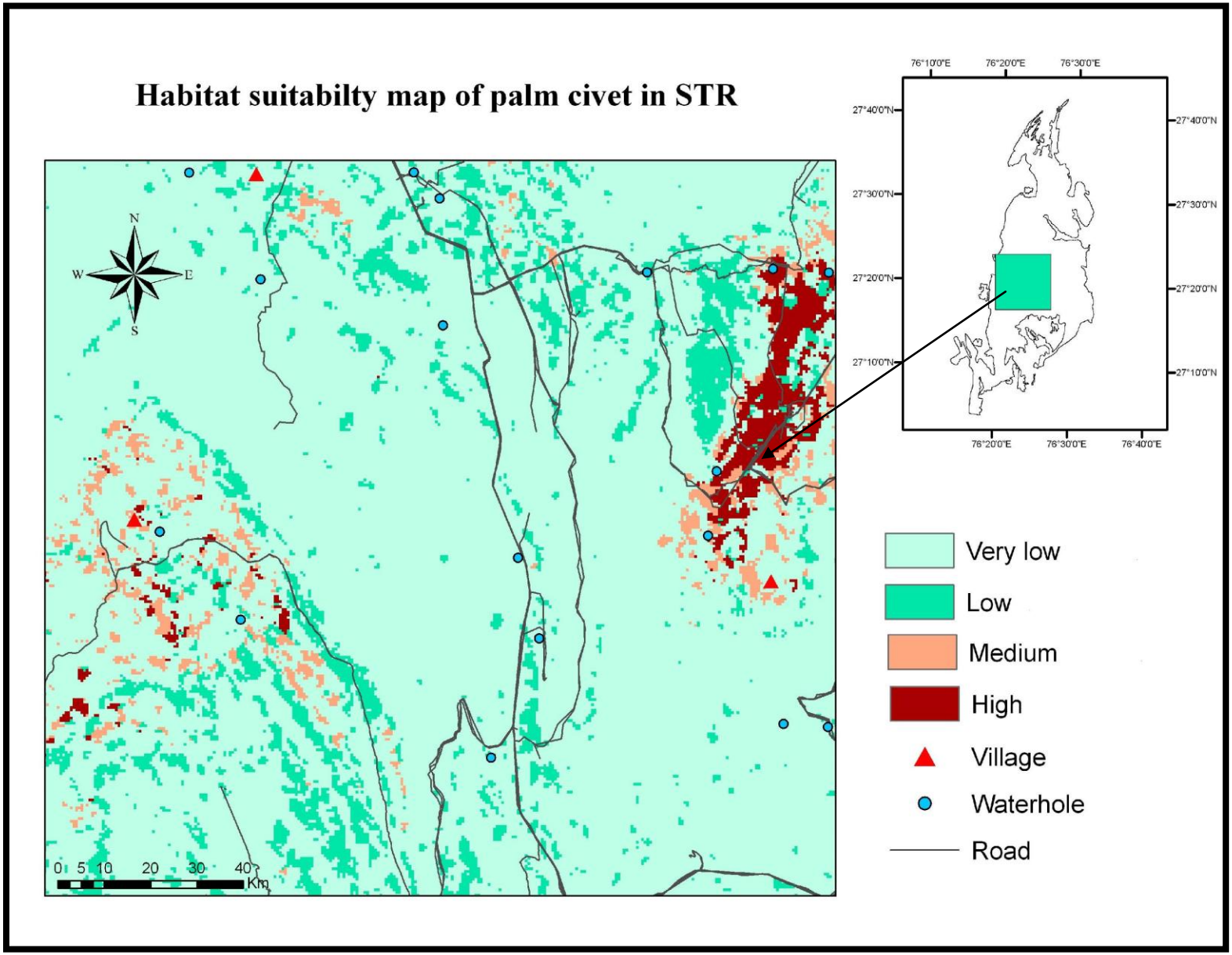


**Figure 5.10 Habitat suitability map of palm civet in the intensive study area of Sariska Tiger Reserve.**



### 5.4.6 Small Indian civet:

Besides area close to village, one habitat variable (*Butea* mixed forest) was found insignificant with the model building for this species. These variables collectively accounted for 85.9% for the explained variables for small Indian civet ($R^2$=0.56). NDVI, DEM, area close to road, *Boswellia* forest, scrubland and *Zizyphus* woodland were found to be positively correlated with the small Indian civet occurrence and distance to water, *Anogessius* forest and *Acacia* forest were found to be negatively correlated with the occurrence of this species. Out of total intensive study area of 144 $km^2$, 54 $km^2$ and 56 $km^2$ were found to be very low and low suitable areas respectively which represented 76% of total study area while 18 $km^2$ and 16 $km^2$ were found to be medium and highly suitable areas respectively for small Indian civet which represented nearly 24% of the total study area **(Figure 5.12)**. Suitable sites for small Indian civet were largely dependent upon DEM, NDVI and presence of *Boswellia f*orest, scrubland and *Zizyphus* woodland in the intensive study area **(Figure 5.12)**.

### 5.4.7 Common grey mongoose:

Besides NDVI, five habitat variables (including vegetation classes) were found insignificant with the model building for this species. These variables collectively accounted for 80.3% for the explained variables for common grey mongoose ($R^2$=0.329). The area close to village and water were found to be positively correlated with the common grey mongoose distribution while DEM and area close road, *Anogessius* forest were found to be negatively correlated with the occurrence of this species. Out of total intensive study area of 144 $km^2$, 20 $km^2$ and 44 $km^2$ were found to be very low and low suitable areas respectively which represented 44% of the total study area while 29 $km^2$ and 52 $km^2$ were found to be medium and high suitable areas respectively for common grey mongoose which represented nearly 56% of the total study area **(Figure 5.14)**. Results

obtained from this study was consistent with the information available on the distribution of this species in the other areas where scrubland, water, human habitation were important for its distribution (Choudhury *et al.*, 2008). Suitable sites for common grey mongoose were largely dependent upon areas close to village and water in the intensive study area **(Figure 5.14)**.

### 5.4.8 Ruddy mongoose:

Besides NDVI, two habitat variables (vegetation classes) were found insignificant with the model building for this species. These variables collectively accounted for 69.0% for the explained variables for common grey mongoose ($R^2$=0.27). DEM and the areas close to road, water and *Zizyphus* woodland were found to be positively correlated with the ruddy mongoose distribution while areas close village, *Boswellia*, *Acacia* and scrubland were found to be negatively correlated with the occurrence of this species. Out of total intensive study area of 144 $km^2$, 53 $km^2$ and 73 $km^2$ were found to be very low and low suitable areas respectively which represented 87% of the total study area while 1 $km^2$ and 17 $km^2$ were found to be medium and high suitable areas respectively for ruddy mongoose which represented nearly 13% of total study area **(Figure 5.16)**. Suitable sites for ruddy mongoose were dependent upon DEM, areas close to road, water and villages and *Zizyphus* woodland highly affected the distribution and suitable habitat for ruddy mongoose in the intensive study area **(Figure 5.16)**.

The present study showed that specific vegetation patterns played an important role in the distribution of each species. The habitat suitability map prepared in this study successfully predicted the probability of presence of each species and developed basis for management of areas for future conservation of medium and small carnivores in the study area.

**Figure 5.12 Habitat suitability map for small Indian civet in the intensive area of Sariska Tiger Reserve.**

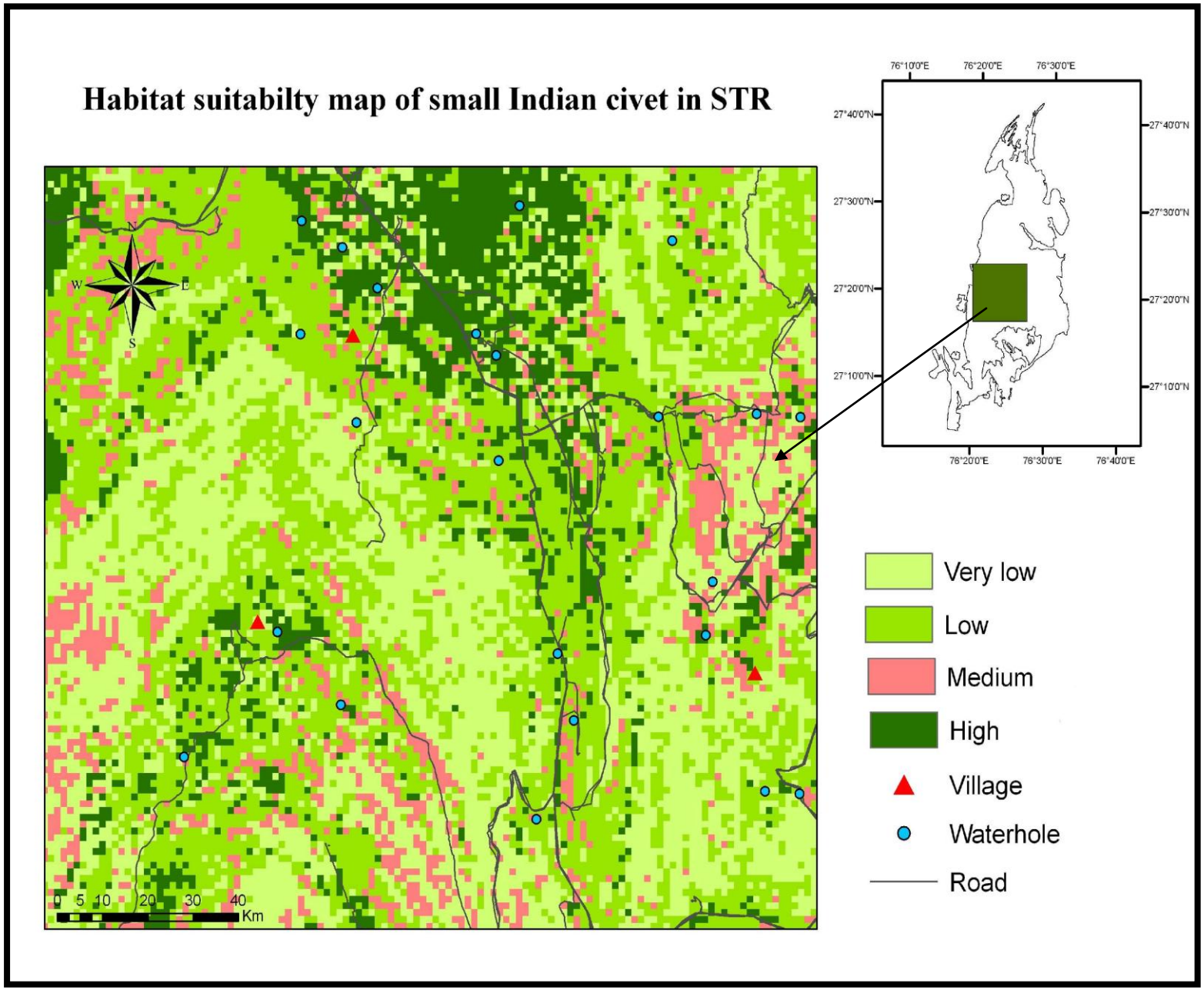


**Figure 5.14 Habitat suitability map for common grey mongoose in the intensive area of Sariska Tiger Reserve.**

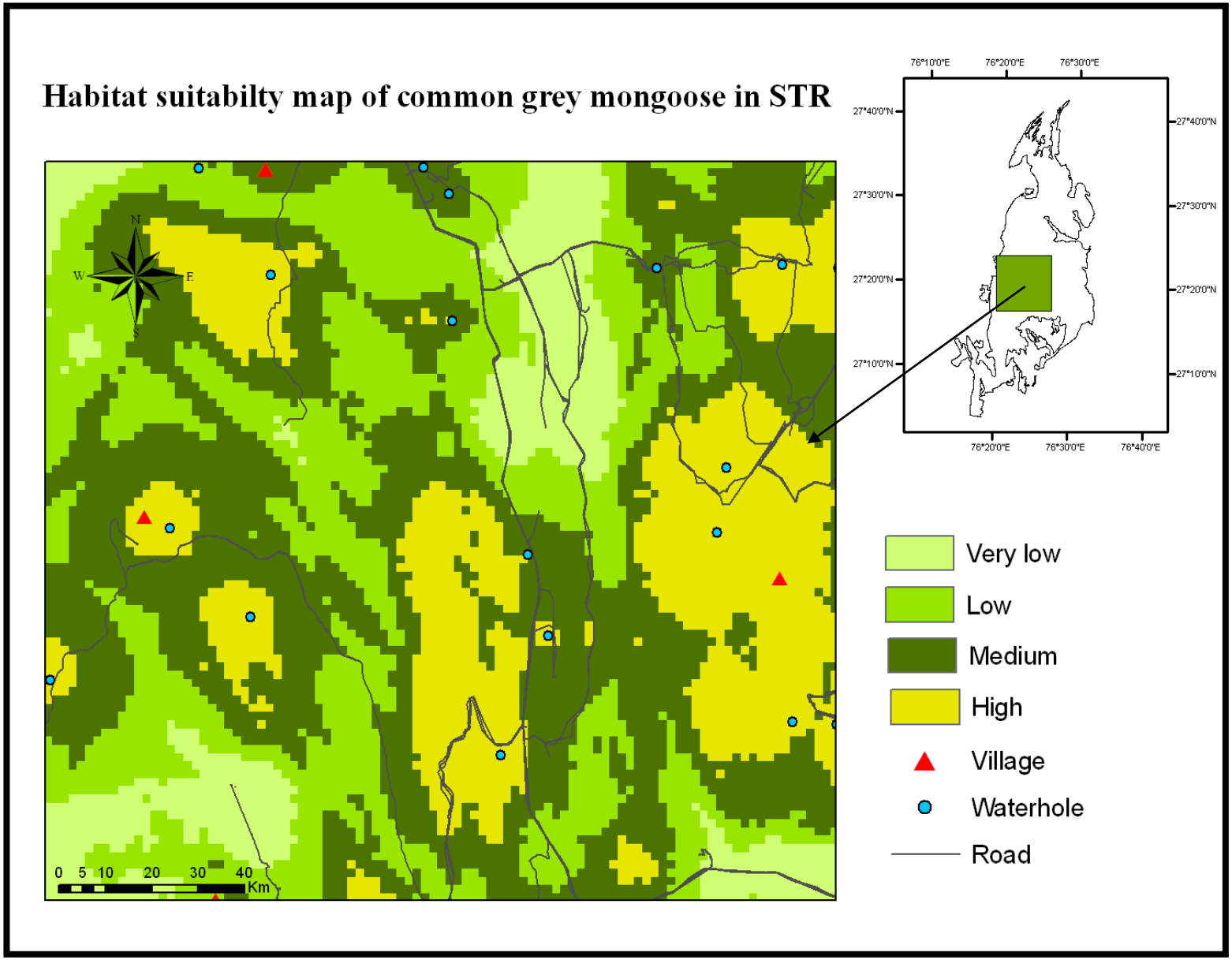
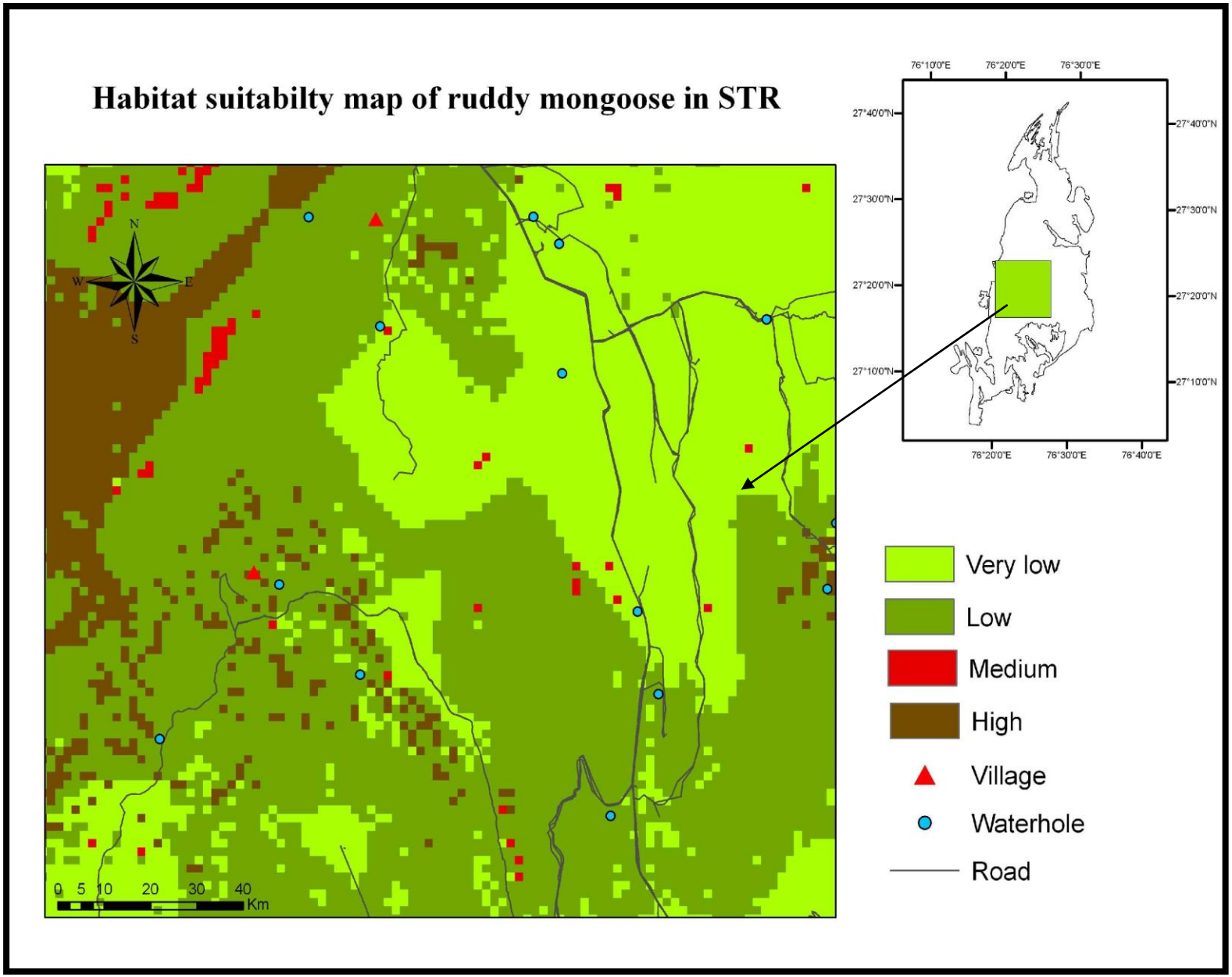


**Figure 5.16 Habitat suitability map for ruddy mongoose in the intensive area of Sariska Tiger Reserve.**



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## Appendix -1

**Script used for comparison of closeness between two camera trap and track plot in Program R**

```
<tstatistic=function(x,y)
{
m=length(x)
n=length(y)
sp=sqrt(((m-1)*sd(x)^2+(n-1)*sd(y)^2)/(m+n-2))
t.stat=(mean(x)-mean(y))/(sp*sqrt(1/m+1/n))
return(t.stat)
}
alpha=.1; m=12; n=12 # sets alpha, m, n
N=10000 # sets the number of simulations
n.reject=0 # counter of num. of rejections
for (i in 1:N)
{
x=rnorm(m,mean=2.32,sd=0.511) # simulates xs from population 1
y=rnorm(n,mean=6.33,sd=1.13) # simulates ys from population 2
t.stat=tstatistic(x,y) # computes the t statistic
if (abs(t.stat)>qt(1-alpha/2,n+m-2))
n.reject=n.reject+1 # reject if |T| exceeds critical pt
}
true.sig.level=n.reject/N # est. is proportion of rejections
true.sig.level=n.reject/N # est. is proportion of rejections
```

## Appendix-II

**Various rodents species captured in Sariska Tiger Reserve, Rajasthan**

**Indian Bush Rat (*Golunda ellioti*)**

**Long tailed tree mouse (*Vandeleuria oleracea*)**

**Little Indian field mice (*Mus booduga*)**

**Spiny field mice (*Mus platythrix*)**

**Brown Rat (*Rattus norvegicus*)**

**House Rat (*Rattus rattus*)**

**Sand coloured Rat (*Millardia gleadowi*)**

**Pgymy Gerbil (*Gerbillus nanus*)**

**Indian Gerbil (*Tatera indica*)**

## Appendix- III

## Scats of study species in Sariska Tiger Reserve, Rajasthan

**Jungle cat**

**Jackal scat with *Zizyphus* seeds**

**Striped hyena**

# ESTIMATION OF STRIPED HYENA *HYAENA HYAENA* POPULATION USING CAMERA TRAPS IN SARISKA TIGER RESERVE, RAJASTHAN, INDIA

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We used camera trap based capture-recapture method to estimate the population size of Striped Hyena *Hyaena hyaena* in Sariska Tiger Reserve. Twenty-five days of camera trapping was done with a sampling effort of 1,675 trap nights from January to April 2008. Camera traps yielded a total of 85 Hyena photographs of 26 individuals within an effective trapping area of 229.7 sq. km. Heterogeneous Jacknife model was best fit in estimating population with a capture probability of 0.31 P(hat). Population size was 34 ±(SE 5.4) and density was estimated as 15.1 ±6.2 hyena/100 sq. km (spatially explicit model). The study revealed that camera based capture-recapture method is an effective tool for assessing the population size of Striped Hyena in Sariska.

**Key words**: Camera trapping, *Hyaena hyaena*, individual identification, Sariska Tiger Reserve

## INTRODUCTION

The Striped Hyena *Hyaena hyaena* is one of the most important large scavengers; its role in clearing off carrion in tropical ecosystems and in recycling mineral compounds from dead organic matter enhances its biological importance (Kruuk 1976). They generally prefer arid to semi-arid environment and avoid open desert and dense thickets (Prater 1971; Kruuk 1976; Leakey *et al.* 1999). The current distribution range of this species extends from East to North-east Africa, through the Middle East, Caucasus region, Central Asia and into the Indian subcontinent (Mills and Hofer 1998). In the Indian subcontinent, they occur in arid and semi-arid ecosystems, as well as in the extremely wet regions of south-western coast (Prater 1971; Karanth 1986). According to Mills and Hofer (1998), the estimated population of Striped Hyena in India was *c.* 1,000, which was a gross under-estimate. The camera trap based capture-recapture framework to estimate population of large carnivores, based on natural markings on their bodies, has proven to be amongst the most successful non-invasive method for species such as Tiger *Panthera tigris* (Karanth and Nichols 1998; Karanth *et. al.* 2004; Contractor 2008; Sharma *et al*. 2009), Leopard *Panthera pardus* (Chauhan *et al.* 2005; Edgoankar *et al.* 2007; Harihar *et al.* 2009), Jaguar *P. onca* (Silver *et al.* 2004), Geoffrey's Cat *Oncifelas geoffroyi* (Cuéller *et al.* 2006), Snow Leopard *Uncia uncia* (Jackson *et al.* 2006) and Striped Hyena (Singh 2008). This technique takes advantage of distinctive individual markings through photographs for even heavily furred animals such as Ocelot *Leopardus pardalis* (Trolle and Kery 2003), Wolf *Chrysocyon brachyurus* (Trolle *et al.* 2007), and Puma *Puma concolor* (Kelly *et al*. 2008). The individual identification in Spotted Hyena has been done earlier using pelage and nicks in ears (Holekamp and Smale 1990; Hofer and East 1993). The present study was aimed to estimate the population of Striped Hyena on the basis of spatially explicit closed capture models in a semi-arid landscape and to standardize the camera trapping method.

## MATERIAL AND METHODS

### Study area

The study was conducted in Sariska Tiger Reserve (Sariska TR), (25°5'-27°33' N; 74°17'-76°34' E), which is situated in the Aravalli Hill Range and lies in the semi-arid part of Rajasthan (Rodgers and Panwar 1988). The total area of the Tiger Reserve is 881 sq. km, with 273.8 sq. km as a notified National Park. The vegetation of Sariska corresponds to Tropical dry deciduous and Northern Tropical thorn forests (Champion and Seth 1968). The Park supports various carnivore species such as Tiger, Leopard, Striped Hyena, Caracal *Caracal caracal*, Jackal *Canis aureus*, Jungle Cat *Felis chaus* and prey species like Chital *Axis axis*, Sambar *Rusa unicolor*, Nilgai *Boselaphus tragocamelus*, Common Langur *Semnopithecus entellus*, Wild Pig *Sus scrofa*, Porcupine *Hystrix indica*, Rufous-tailed Hare *Lepus nigricollis ruficaudatus* and Indian Peafowl *Pavo cristatus* (Sankar 1994). There are 32 villages within Sariska TR. A large number of buffaloes, goats, sheep and cattle are kept by people living in villages.

## METHODS

A preliminary survey was carried out from November to December 2007 in the intensive study area of 80 sq. km in

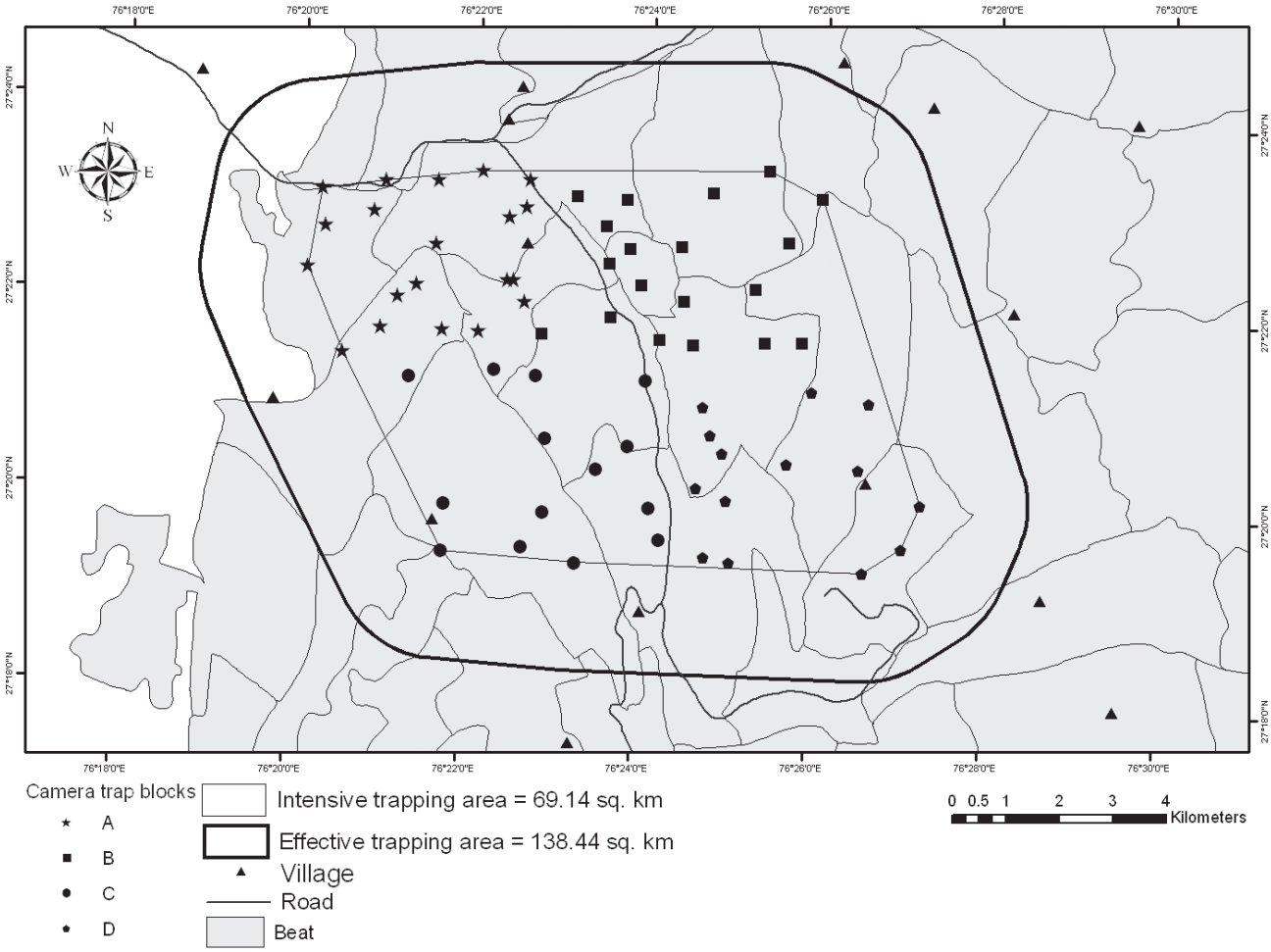


Fig. 1: Camera trap locations in intensive study area of Sariska Tiger Reserve (January to April 2008)

the National Park. Indirect signs such as spoor and scats of Hyena were identified and marked using a handheld Global Positioning System. Striped Hyena camera trapping data was collected from January to April 2008 in the intensive study area. We placed the camera in 1x1 sq. km grid. Camera traps were placed on the basis of hyena evidence (tracks, scats) on the trails. We used 20 units of analog cameras that worked on passive infrared motion/heat sensors. The camera traps were equipped with 35 mm lens which recorded the date and time of each photograph. The camera delay was kept at minimum (15 seconds) and sensor sensitivity was set at high. A total of 67 locations were selected for the placement of camera traps in the study area (Fig. 1). The study area was divided into four blocks of 20 sq. km each. Block A consisted of 20 camera trap sites, block B had 19, C and D blocks had 14 camera trap sites each. The mean inter trap distance was 726 m (ranging from 700 to 1,200 m). Camera traps were operated for 25 consecutive occasions with the total sampling period of 100 days (1,675 trap nights). Individual Hyena obtained from camera trap photographs were identified by a combination of distinguishing characters such as position and shape of stripes on flanks, limbs and forequarter, pattern and spots on flanks (Schaller 1967; Karanth 1995; Singh 2008) (Fig. 2). Any photograph with distorted perspective, or which lacked clarity, was discarded (n=8). Every Hyena captured was given a unique identification code like H1, H2, H3, etc. Capture history of each individual was generated in an X matrix format (Otis *et al.* 1978). Each day-wise sampling occasion was constructed for example by taking 1st day from block A, B, C and D as day one for entire study area and all subsequent days were combined in this manner to construct a matrix of capture for study area (Karanth 1995). Estimation of population size using closed capture models requires the population under investigation to be both demographically and geographically closed. We tested for population closure using software CAPTURE (Otis *et al.* 1978; Rexstad and Burnham 1991). The density (D) of Hyena in the study area was estimated by spatially explicit model (Efford 2004; Sharma *et al.* 2009) using Density 4.1 software (Efford 2004). The density of Striped Hyena was calculated by four different

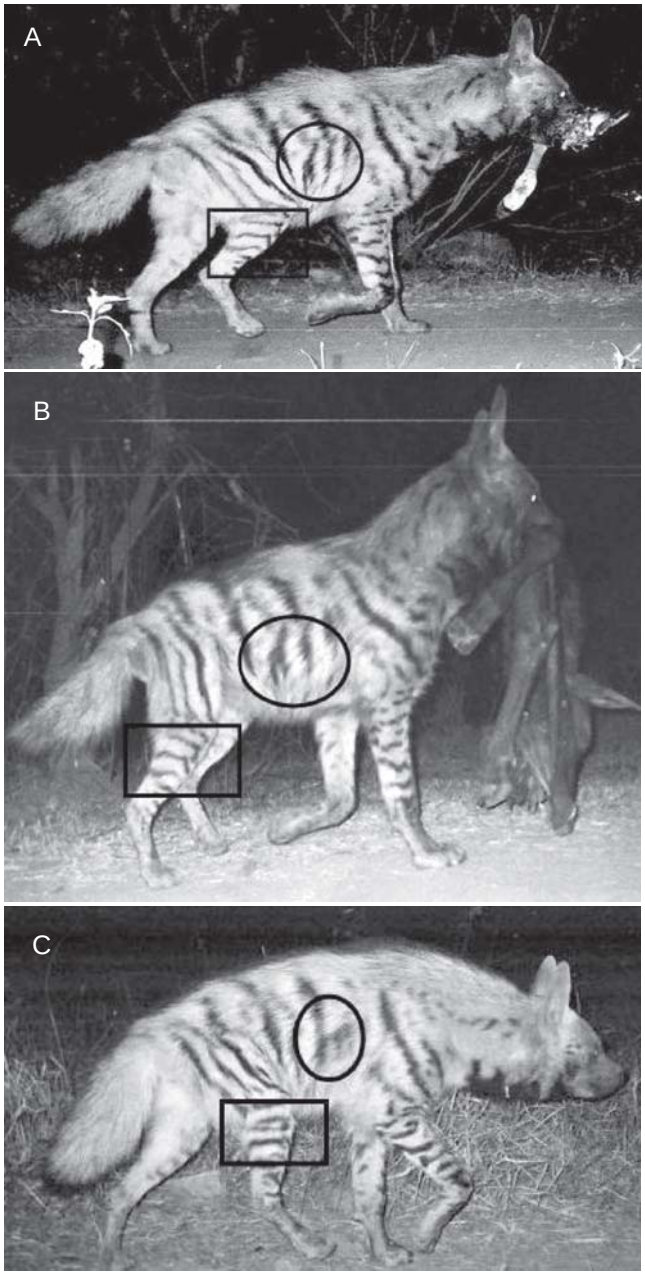


Fig. 2: Two individual hyenas captured by camera trap (A) and (B) show individual H4 with stripes and spots on flanks identical in shape and pattern. While (C) shows a different individual H10 with stripes and spots on flanks being clearly different in shape and pattern

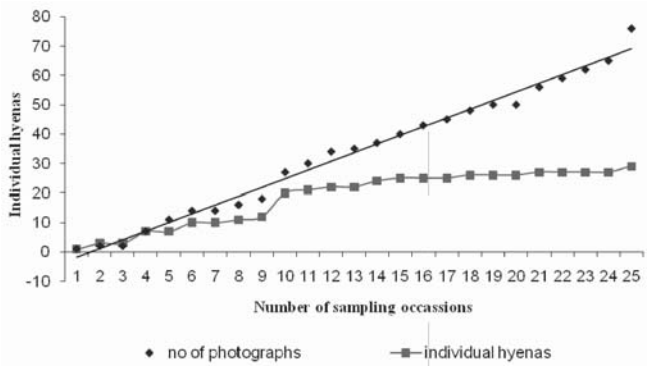


Fig. 3: Number of Striped Hyena photographed and number of hyena photographs with increasing number of sampling occasions to evaluate trap shyness and sampling adequacy in intensive study area

methods such as full mean maximum density moved (MMDM), half MMDM, spatially explicit Inverse Prediction density (IP dens) and spatial Maximum Likehood density (ML dens) (Sharma *et al.* 2009).

## RESULTS

The intensive trapping resulted in a total of 85 photographs of 26 individual hyenas, based on right flank profile, as the number of individuals identified from the right flank was maximum. The 67 trapping stations covered an effective trapping area (ETA) of 229.7 sq. km (Full MMDM) and the number of new individuals was found to stabilize after the 19$^{th}$ trap night (Fig. 3). Population was closed for the sample period (z = -0.49, P=0.31) (Otis *et al.* 1978). The overall model selection test based on discriminant functions using the model selection algorithm of CAPTURE identified Mh as the most appropriate model in our study. The model selection scores are as follows: M (h) = 1.00, M (tb) = 0.99, M (o) = 0.96, M (b) = 0.82, M (tbh) = 0.78, M (bh) = 0.68, M (th) = 0.42, and M (t) = 0.00. The estimated Hyena population size (N) was = 34± SE (5.4) (Table 1). Density (D) and flank data using spatial explicit model was 15.1 individual/100 sq. km. MMDM and effective trapping area (ETA) was calculated by different methods using the program DENSITY 4.4 (Table 1). Half normal detection function fitted the best and

**Table 1**: Density estimates of Sriped Hyena in Sariska Tiger Reserve (January to April 2008)

| Model | N | SE(N) | P (hat) | Methods for Calculating ETA | Width (km) | ETA (sq. km) | D (hyenas/ 100 sq. km) | SE |
|---|---|---|---|---|---|---|---|---|
| Mh | 34 | 5.4 | 0.31 | MMDM/2 | 1.832 | 138.9 | 24.5 | 4.3 |
| (Jackknife) | | | | MMDM | 3.663 | 229.7 | 14.9 | 3.0 |
| | | | | IP DENS | - | - | 15.1 | 6.2 |
| | | | | ML DENS | - | - | 12.7 | 2.8 |

(N= Population estimate, P (hat)=capture probability, Width=Buffer strip width, ETA=effectively trapped area, D=Density estimate, MMDM=mean maximum distance moved, IP Dens=Inverse Prediction density, ML Dens= Maximum Likelihood density, SE = Standard error)

the density arrived from right half MMDM densities were 24.5 individual/ 100 sq. km and 14.9 individual/ 100 sq. km respectively. Spatial density and full MMDM yielded almost similar results.

## DISCUSSION

The capture-recapture technique based on camera trap photographs of Hyena provided a statistically robust estimate in estimating the population. We had also corroborated hyena tracks and photographs at camera location for trap shyness response and did not observe any behavioural response during the study period. Effort required in terms of sampling occasions suggested that a minimum of 20 days are required to get reliable density estimates for hyena in the study area. Out of 85 captures, 12 individual Hyena were recaptured more than three times, 4 individuals were captured twice and 10 individuals had single captures. Some traps showed very high capture rates (2 to 20 captures/trap location), while individual captures/trap ranged from 1 to 8 individuals/trap location. Camera traps deployed near villages Haripura and Kiraska showed high individual capture rates such as 11% (n=7) and 14% (n=9) respectively. This may be attributed to availability of carcasses (livestock) in and around these villages on which hyenas might be scavenging. The estimated Hyena density in Sariska TR is the highest as compared to available studies in India and Africa (Kruuk 1976; Wagner 2006; Singh 2008; Wagner *et al.* 2008) and this might be attributed to the availability of high wild prey base and domestic livestock, i.e., of 105 animal/sq. km and 222 animals/ sq. km respectively (Avinandan *et al.* 2008; Sankar *et al.* 2009). Spatially explicit models and full MMDM give reliable estimates of density (Sharma *et al*. 2009) and we chose these estimates for density estimation. The camera trap based capture-recapture method is proven to be good to estimate Hyena abundance and can be reliably used in various habitat types.

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