ECOLOGY OF GOLDEN JACKAL (*Canis aureus*) IN SARISKA TIGER RESERVE, RAJASTHAN.

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Certificate

This is to certify that the thesis entitled **"Ecology of golden jackal (*Canis aureus*) in Sariska Tiger Reserve, Rajasthan" in Wildlife Institute of India, Dehradun** submitted for the award of the **Doctor of Philosophy** in Wildlife Science to Saurashtra University, Rajkot is a record of original and independent research work carried out by **Ms. Pooja Chourasia** under our guidance. No part of this thesis has been submitted to any other university or institution for the award of any degree and it fulfills all the requirements laid down by the Saurashtra University.

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This is to certify that **Ms. Pooja Chourasia (Regd. No. 4875, 01.01.2012)** has made Pre Ph.D. presentation as per UGC Guide Line "University Grant Commission (Minimum Standard and Procedure for award of Ph.D. Degree) Regulation–2009" and Saurashtra University Ordinance for Ph.D. Programme (O.Ph.D. 6.2), on the research work entitled **"Ecology of Golden Jackal *(Canis aureus)* in Sariska Tiger Reserve, Rajasthan."** in the **Wildlife Institute of India, Dehra Dun,** Research Centre of Saurashtra University, Rajkot, on **18th February 2015** before all faculty members and students of the Department for getting feedback and comments.

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

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Dedicated to:

Late Mr. D. Basu

My Supervisors

And

My Parents

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EXECUTIVE SUMMARY

Habitat features may determine spatial distribution of animal species in an area since they exploit a variety of habitats and resources where resource partitioning is the outcome of species coexistence especially for sympatric species. This study aimed to examine the abundance and occupancy of jackal with the application of photographic captures using camera traps and diet composition through scat analysis, investigate species-habitat relationships from habitat features (non-spatial) and remotely sensed features (spatial) to understand how these variables govern occurrence pattern and predict the distribution of jackal in Sariska Tiger Reserve, Rajasthan. In India, jackal populations achieve high densities in pastoral areas such as Kutch, Maharashtra, Rajasthan, and Haryana. Over its entire range, except in Protected Areas, the jackal population is steadily declining (MacDonald and Zubiri, 2004). Traditional land use practices are being replaced by intensive agriculture, while wilderness area and rural landscape are being rapidly urbanized. Jackal population can adapt to this change up to some extent, but eventually disappear from such area. Estimated 80,000 jackal remain on the Indian subcontinent, but there are no estimates for Africa (Jhala and Moehlman, 2004). They suffer from common issues of lack of awareness of their plight and the deficiency of reliable data on their distribution and conservation requirements. Without careful consideration of population dynamics and habitat associations across species and habitats, conservation efforts may be poorly applied, thus delaying species recovery.

This study will vitally improve our state of knowledge to protect jackal and assist the development of theory on their social structure, behavior and habitat preferences in forested ecosystem. The study will help in suggesting localized monitoring mechanisms wherever necessary as this is important in minimizing surprise cases of extinction. The objectives of this study are as follows:-

1. To determine the abundance of golden jackal.
2. To estimate the food availability, food habits and dietary niche overlap between golden jackal and other meso-carnivores.
3. To evaluate the den site selection by golden jackal and,
4. To evaluate the habitat use by golden jackal.

The study was conducted from 2010-2013 in Sariska Tiger Reserve (79° 17' to 76°34'N and Latitude: 27° 5' to 27° 33' E), Rajasthan. I selected 160 km^2 of intensive study area which was divided into four blocks. A total of 160 locations were selected for the placement of camera traps where, each block having 21 camera trap stations. Total 84 trapping locations covered minimum convex polygon area of 118.7 $km^2$and an effective trapping area (ETA) of 223.8 km^2. Total 42 units of digital cameras that worked on passive infrared motion and heat sensors were deployed in grid of 2 x 2 km^2 (20 units of Spy-point FLA1 and 22 units of Moultrie cam).The mean inter-camera trap distance was 750 m.

I calculated Relative Abundance Index (RAI) for each camera trap location by dividing the total number of independent records from the total trap nights x 100 (Carbone et al., 2001, O'Brien et al., 2003). Hence the RAI for species is presented as the number of photo captures per 100 trap nights. To compare RAI of jackal, hare and porcupine between year and seasons, I used Student's t-test in program SPSS 16 (SPSS 2007). I used Royle and Nichols (2003) heterogeneity model and repeated count method (Royle 2004). Both models were analyzed in program Presence 4.1 (http://www.mbrpwrc.usgs.gov/software/presence.html).

I assessed differences in detection probability, occupancy rates and average abundance between seasons in two years. Mean abundance estimates were compared between years and seasons using Student's t-tests in program SPSS 16 (SPSS 2007). I performed a Pearson correlation test between mean abundance (λ) as obtained from occupancy approach and relative abundance index (captures/100 trap nights).

Totally, 6720 trap-nights yielded 202 photographs of golden jackal, of which 11.88 % (n = 17) was obtained in summer 2011, 40.56 % (n = 58) in winter 2011-12, 14.69 % (n = 21) in summer 2012 and 32.87 % (n = 47) in winter 2012-13. Average capture frequencies of jackal across the years ranged from 1.26 captures/100 trap-nights to 4.31 captures/100 trap-nights. Jackal RAI differed significantly yearly (t test; t =6.23, df = 2, P = 0.00) but, did not differ seasonally (t test, t = 9.51, df = 1, P = 0.06).

Estimates of detection probability of jackal varied from 0.039 to 0.069, with standard errors from 0.012 to 0.014 (table.3.2). Detection probability varied across the years (t test, t = 7.26, df = 3, P = 0.01) and did not differ significantly in summer (t test, t = 1.48, df = 1, P = 0.07) and winter (t test, t = 10.5, df = 1, P = 0.06) across two years.

Detection probability (*r*) of jackal was estimated high in winter (0.07±0.01) as compared to summer (0.04±0.01) and the probability of site occurrence (Ψ) of jackal was found high in winter (0.31±0.06) than summer (0.23±0.19). Seasonal estimates of occupancy varied from 0.22 to 0.31, with standard errors from 0.07 to 0.12 and the average abundance ranged from 0.22 to 0.38 with standard errors from 0.09 to 0.13 in two years. Modeled site occupancies were observed greater than naïve occupancy. Abundance (*N*) and relative abundance index (captures/100 trap nights) were not significantly correlated (Pearson correlation test, p = 0.93, n = 4, P = 0.07) with each other and there was a significant positive relationship between mean abundance (λ) and RAI (Pearson correlation; R_2 =0.87, n = 8, P = 0.004).

Densities of ungulates and ground birds were estimated using line transects (Anderson *et al.,* 1979; Burnham *et al.,* 1980; Buckland *et al.,* 1993, 2001) of length varied from 2 km to 3 km. All transects (total length = 61.0 km) were walked thrice in a season amounting total effort of 183 km per season. The data was analyzed using DISTANCE 5.0 software (Laake *et al.,* 1998). Density of rodents and shrews were estimated using a trapping web design (Anderson *et.al.*, 1983) and conducted in 14 locations using 41 Sherman traps (H. B. Sherman Traps, Inc., Tallahassee, Florida). Trapping was conducted for two years amounting to a total effort of 5740 trap-nights in each season. All rodents and shrews captured were sexed, weighed, measured, marked and released at the trap site. Density was estimated using program Distance 6.0 (Thomas et al., 2009) and Mark (White and Burnham 1999). Camera trapping was used to estimate abundance of hare and porcupine in the study area using the same design as used for jackal abundance estimation. Ten *Zizyphus mauritiana* trees were permanently marked with tags at 12 different locations (n = 120 sampling trees). For fruit biomass estimation, fruit production of the tagged trees was monitored every week. Ten iron mesh frames of size 50 x 50 cm were deployed under the canopy of sample tree. I estimated the availability of fruits in g/ha and g/km^2 for various analysis.

For dietary analysis, total 18 trails, each 5 km in length were surveyed systematically once a month. Jackal scats were collected and analysed using method described by Mukherjee *et. al.* (2004). I calculated biomass of different prey types consumed per predator by multiplying the average prey biomass with number of prey items consumed by small carnivores. I estimated the diversity of each predator's diet using the Shannon diversity index (Magurran 2004), randomizing the original order of scat

samples (1000 iterations) using the software EstimateS (Colwell 2006). I expressed diet composition in three complementary ways: fresh biomass consumed (D), percentage of occurrence, and expected number of individual consumed (C). Biomass consumed was calculated as frequency of occurrence of prey remains multiplied by correction factor Y i.e. number of collectible scats produced per prey (F x Y) and number of individual consumed was calculated as relative biomass consumed divided by average body weight of a prey(D/B). Shannon's (Pielou 1966) diversity index (*H'*) and Levins' (1968) index ($B = 1/\Sigma$ pi2) was also calculated. To assess similarity of food composition between jackal, jungle cat and hyena, the Pianka's niche overlap index was calculated (Pianka 1973) for the entire study period. I used Ivlev's index (*E*) to determine food selectivity of small carnivores. Mann-Whitney *U* test was applied to evaluate for the seasonal differences between species. I used SPSS 16 (SPSS 2007) statistical package to process data.

Peafowl was observed to be the most abundant prey species throughout the study period. Amongst the wild prey species, nilgai was observed to be the most abundant wild ungulate prey species followed by, chital, wild pig and sambar in the study area. The density of common langur in the study area varied across the study years. The abundance of livestock was comparatively high in the study area. The density of young once of common langur was observed highest 9.19/ km^2 during the study period followed by wild piglets 4.70/km^2, nilgai calf 3.34/km^2, peafowl chickens 2.72/km^2, chital fawn 2.21/km^2, sambar fawn 1.67/km^2 and cow calf 0.71/km^2. In the intensive study area, the available total prey biomass was calculated to be 7506.5 kg/ km^2 in 2010-11, 13291.6 kg/ km^2 in 2011-12 and 18354.2 kg/ km^2 in 2012-13.

Rodent and shrew abundance: The recorded abundance of rodents was higher in winter (45.23 individuals/ha) than summer (1.09 individuals/ha). Species recorded with highest density in summer were *Mus budooga* (3.51 ± 1.59) followed by *Golunda ellioti* (1.77 ± 0.69) and *Tatera indica* (1.21 ± 0.49). Species recorded with highest density in winter were *Mus budooga* (9.71 ± 7.74) followed by *Mus platythrix* (8.12 ± 4.21) *Suncus montanus* (5.89 ± 4.61) and *Vandeleuria oleracea* (5.55 ± 4.62). Difference in capture rates was observed for the entire study period where, female capture rates were significantly lower than that of male capture rates (t test, t = -4.85, df = 6, $p = 0.003$). Body weight of females were higher than males but the difference was not found significant (t test, t = 0.99, df = 9, $p = 0.35$).

Porcupine and hare abundance: Estimates of detection probability of hare varied from 0.072 to 0.126, with standard errors from 0.009 to 0.014. Estimates of detection probability of porcupine varied from 0.045 to 0.088, with standard errors from 0.009 to 0.010. Seasonal estimates of hare occupancy varied from 0.39 to 0.59, with standard errors from 0.05 to 0.07 and, average abundance ranged from 0.50 to 0.90 with standard errors from 0.05 to 0.07 in two years. Seasonal estimates of porcupine occupancy varied from 0.70 to 0.80, with standard errors from 0.04 to 0.07 and, average abundance ranged from 1.21 to 1.63 with standard errors from 0.16 to 0.31 in two years. Modeled site occupancies were observed greater than naïve occupancy. Data showed that there was a positive relationship between site occupancy (Ψ) and RAI of hare (Pearson correlation; R_2 =0.94, n = 4, p = 0.06) and porcupine (Pearson correlation; R_2 =0.91, n = 4, p = 0.09).

Zizyphus Fruit biomass availability: The *Zizyphus mauritiana* species was examined for fruit availability, as they were identified as important species based on their percent occurrence (≥ 17%) in jackal scat. The species contributed to 17.61 % (246 *Zizyphus* seeds) out of total 26.76% of fruit frequency of occurrence in the diet of jackal in 2011-12 and, during the year 2012-13, the contribution was 16.91% (290 *Zizyphus* seeds) out of total 24.64% of fruit frequency of occurrence in the diet of jackal.

Prey selection and food habits: In total 104 jackal scats were collected during 2010-11, 284 scats during 2011-12 and 349 scats were collected during 2012-13. In total, 12 prey species were identified in jackal's scat in 2010-11, 13 prey species in 2011-12, and 14 prey species were identified in 2012-13. Amongst all the food items, four highest occurring food types during the year 2010-11 was vegetative material, which contributed maximum (17.57%) in jackal diet followed by rodent (15.77%), cattle (15.32%) and chital (10.81%). In 2011-12, vegetative material again contributed the most (14.18%) followed by nilgai (12.20%), fruit (11.59%) and rodents (8.08%). In 2012-13, vegetative material contributed maximum (18.23%) in jackal's diet followed by chital (13.61%), nilgai (13.48%) and fruit (10.74%).

Estimation of biomass consumption using feeding trials on Jackal: Of the scats produced, the percentage of non-collectable scats ranged from 2.6% to 18.4%, for an average of 9.9%. The consumption of carcasses by jackals in 15 feeding trials ranged from 25.7% to 100%, for an average of 79.4% and was negatively correlated with size of prey (r=0.72, P=0.001). Loss of moisture from the prey bait carcass accounted

for a 0.5% (in chicken) to 50% (in buffalo) weight loss in 72 hr. Moisture loss was recorded less for bird and fruits and high for rabbit and buffalo. Consumption of prey biomass (Y) per collectable scat increased with an increase in live body weight of prey (X). The correction factor so derived as: $Y = 0.003x + 0.228$ ($R^2 = 0.825$; $F = 37.6$; $df = 1$; $p < 0.001$). The conversion of prey body mass into a number of scats and their weights excreted by an individual carnivore is inferred using seven quantities (Wachter et. al. 2012) to establish the relationship between consumed prey mass and the number of consumed prey individuals derived from carnivore scats collected in the field. Data on utilization (from scat analysis) and availability (from distance sampling analysis) of prey species was compared and index of selection were obtained (Ivlev 1961). During 2010-11, rodent ($p<0.01$), hare ($p<0.01$), chital ($p<0.01$) and *Zizyphus* fruits ($p<0.01$) were consumed more than their availability, while wildpig ($p<0.01$) goat ($p<0.01$) and nilgai ($p<0.01$) were consumed less than their availability. Sambar, cattle and bird was preyed in proportion to its availability ($p>0.05$). In 2011-12, rodent ($p<0.01$), hare ($p<0.01$), bird ($p<0.01$), chital ($p<0.01$) and *Zizyphus* fruits ($p<0.01$) were preyed more than their availability, while wildpig ($p<0.01$), cattle ($p<0.01$), goat ($p<0.01$) and sambar ($p<0.01$) were preyed less than their availability. Nilgai was preyed in proportion to its availability ($p>0.05$). In 2012-13, *Zizyphus* fruits ($p<0.01$), rodent ($p<0.01$), hare ($p<0.01$), goat ($p<0.01$), bird ($p<0.01$) and chital ($p<0.01$) were preyed more than their availability, while wild pig ($p<0.01$), cattle ($p<0.01$) and sambar ($p<0.01$) was preyed less than their availability. Nilgai was preyed in proportion to its availability ($p>0.05$).

Trophic niche overlap and niche breadth: No significant diet difference was observed between jackal and hyena (Mann–Whitney U test: $U = 99$, $p = 0.28$), jackal and jungle cat (Mann–Whitney U test: $U = 88$, $p = 0.14$) and hyena and jungle cat (Mann–Whitney U test: $U = 124.5$, $p = 0.89$) in the study area. The estimated dietary overlap (Pianka's index, Pianka 1973) for three years between striped hyena and golden jackal was found to be (0.81) 81%. The estimated dietary overlap between jungle cat and golden jackal was found to be (0.67) 67% and between striped hyena and jungle cat it was (0.31) 31% during the entire study period. Niche breadth for golden jackal was calculated as 0.73, for striped hyena it was 0.40 and for jungle cat it was 0.36. The calculated value of niche overlap of jackal on hyena was observed to be (1.04) 100%, niche overlap of hyena on jackal was calculated as 0.62 or 62% and, value of niche overlap of jackal on jungle cat was observed to be 0.87 or 87%.

For den site surveys I systematically searched the study area on foot and spent a total of approximately 1752 man hours along with a field assistant searching for jackal dens in the ~ 160 km^2. Active dens were identified by signs of fresh digging, pup and adult scat deposition around the den site and tracks along the ramp of the den openings. All the active dens of different pairs were monitored simultaneously. The distance between the two dens was estimated using the GPS. The orientation of den openings was noted. I used circular plot of 10m radius, with the den site at the centre, to measure surrogate variables, also measured the same variables outwardly at a distance of 100 m in four cardinal directions from the den site (Lesmeister et al. 2008). I recorded the substrate and terrain type at the den site, measured tree and shrub density in the 10m radius circular plot and recorded percentage canopy cover using a spherical densiometer. I also measured visibility, ground layer height, measurements on den openings and den temperature. The distance to nearest settlement, distance to nearest water source and distance to the nearest road was measured using spatial analyst tool in ArcMap software. For this, I used a GIS land cover classification layer, land and water hole layers from WII's GIS laboratory. For micro site selection, variables in consideration were i) substrate, ii) terrain, iii) tree number, iv) shrub number, v) vegetation composition, vi) grass cover and vii) distance to road, water and settlement. I used use-availability design along with discrete choice models (Cooper and Millspaugh, 1999) for micro site selection using SPSS 16 (SPSS 2007) statistical package for data analysis. For macro site selection, variables in consideration were i) proportional value of forest type, ii) proportional value of forest cover, iii) densities of various prey items, iv) elevation, v) slope, vi) ruggedness and vii) distance to road, water and settlement. I evaluated prey density for different prey classes by exploratory analysis using DISTANCE 5.0 software in conventional distance sampling (CDS) and multiple covariate distance sampling (MCDS) framework. To examine factors that influenced den site selection at the micro scale by the jackal, I used four ecological hypotheses created by Punjabi *et al.* (2013), which might best predict den site selection. These hypotheses were: habitat and prey availability, thermoregulation (substrate and terrain), predatory avoidance (cover) and edge effects (distance to road, water and settlement) and, are represented by explanatory variables measured at each den and available sites. I used an information theoretic approach of testing *a priori* models by Akaike's information

criterion (AIC) to assess model weights (ω_i) and ranked candidate models using Δ AIC (Burnham and Anderson 2002).

Physical attributes: Thirty six jackal dens were located in the intensive study area (0.23 den / km^2) where NVD (*Zizyphus **n**ummularia*, *Adathoda **v**asica*, *Capparis **d**ecidua*) and EC (*Balanites a**e**geptiaca, **C**apparis sepiaria*) vegetation classes were observed more in denning sites but no significant difference was observed (chi-square test: $\chi^2 = 6.25$, d.f. = 3, $p = 0.10$) among four vegetative classes between natal and resting dens. Among the four substrate types, selectivity of natal dens were recorded more than expected for mud-loam and for resting dens the selectivity for rock-mud was recorded more than expected but were not found at significant level (chi-square test: $\chi^2 = 1.97$, d.f. = 3, $p = 0.58$).

Cover dependence: The average size of den opening was recorded as 47.11 cm, ranging from 18 cm to 90 cm (n=36). The percentage cover for natal and resting den were not different (One way ANOVA test: $F = 0.01$, $p = 0.92$) and, in areas with high percent cover, significantly lesser number of dens were observed ($r = -0.76$, $p = 0.02$, n=9). Natal den selection sites were indifferent to water availability (One way ANOVA test: $F = 1.02$, $p = 0.32$) and other human induced disturbance such as to road (One way ANOVA test: $F = 1.45$, $p = 0.24$) and human settlements (One way ANOVA test: $F = 2.53$, $p = 0.12$).

Thermoregulation: The mean 'minimum' ambient temperature in den site was recorded as 31.7°C and the mean 'maximum' ambient temperature was recorded as 34.7°C. Difference in temperature oscillation inside and outside dens ranged between 0.4°C and 3.6°C in 'minimum' scale and 'maximum' temperature difference ranged between 0.1°C and 5.8°C. The variation in 'minimum' ambient temperature and den temperature was not much (One way ANOVA test: $F = 1.02$, $p = 0.32$) but, the variation in 'maximum' ambient temperature and den temperature was recorded high at significant level (One way ANOVA test: $F = 4.20$, $p = 0.05$). The 'maximum' temperature were recorded less in natal dens but not at significant level (One way ANOVA test: $F = 1.53$, $p = 0.26$). Temperature variation was neither significant in the four substrate types nor for natal and resting dens (Kruskal-wallis test, $\chi^2 = 3.00$; df = 3; $p = 0.39$). The 'maximum' temperature variation was not found significant among aspects (chi-square test: $\chi^2 = 5.49$; df = 7; $p = 0.60$) although 'maximum' temperature recorded for SW was lower than N and NE.

Aspect dependence: No selectivity was observed for spatial orientation of den entrances of jackal in terms of aspect (pearson's chi-square test: $\chi^2 = 633$; df = 7; p = 0.50) however the natal den facing aspect SW (20%), NW (20%) and NE (13.3%) were observed more than expected, and for resting dens aspect N (16.7%) was observed more than expected.

Den placements: There was a negative correlation observed at significant level between average 'maximum distance' among Jackal dens and the size of regional area (Spearman's rho correlation test; r_s = 0.89, n = 5, P < 0.04). The larger areas have dens that are closely located to each other (≥ 1 km). The 'region two', having area of 28.11 km^2 was recorded to have the smallest average 'maximum distance' between dens, where the composition of forest types were significantly different (One sample t test; t = 2.63, df = 5, p = 0.03) suggesting the clumpy distribution of favorable habitat prevailing close allowance of dens with each other. No relation was observed between average 'minimum distance' among dens and region (Spearman's rho correlation test; r_s = 0.36, n = 5, P < 0.55).

Micro site selection: At the micro scale (314 m^2), the hypothesis 'ease of excavation' received much support as the underlying factor for den site selection. The substrate suitable for excavation i.e. mud-loam and rock base and vegetation classes NVD (*Zizyphus* ***n****ummularia*, *Adathoda* ***v****asica*, *Capparis* ***d****ecidua*) and LJN (***L****entana camara*, *Prosopis* ***j****uliflora, Acacia* ***n****ilotica*) were found as determining variables for the selection of denning site as represented by the top model (AIC = 69.22; ωi = 0.096). All other models representing the predatory avoidance, vertical cover (tree number, canopy cover) and disturbance received no support. Variables favoring natal den selection were no different than that of overall selected den sites (Kruskal-wallis test, $\chi^2 = 5.00$; df = 5; p = 0.42). Results suggest an idea that the choice of plain areas is frequent in jackal 'natal den' sites and no significant selection or avoidance for any forest types (*Anogeissus* dominant forest, *Boswellia* forest, *Acacia* mixed forest, *Zizyphus* mixed forest, *Butea* dominant forest and Scrub forest) was observed by jackal.

Macro site selection: At the macro scale (3.14 km^2), the hypothesis 'cover and resource' received most support to infer the underlying factor for den site selection by jackal at macro scale. The presence of small mammal density in respective forest types and favorable distance form settlements and roads, that occasionally offer food supplements in terms of garbage and road kills respectively, were evaluated as the

most influential factors at macro scale as represented by the top model (AIC = 66.50; ω_i = 0.82). Jackal showed no significant avoidance for large carnivore presence (tiger, leopard and hyena). Rodent abundance and visibility were the most important predictors for selection of den-sites at larger scale.

Habitat use by jackal was studied using an approach proposed by Hirzel *et. al.* (2002). The Species distribution data was collected from camera trapping, direct sighting records, scat locations and track locations and was pooled for the entire study period 2010-2013, collectively making 413 observed point locations in the intensive study area. These were plotted in ArcGIS 9.3 and overlaid on 2 km^2 grid cells giving distribution map of jackal. Topographical variables, biological variables and anthropogenic variables were extracted using Zonal Statistic tool in the Spatial Analyst toolbox and, an evaluated variable values were assigned in each 4 km^2 pixel (201 grids of size 2 x 2 km^2). Digital data on contour and drainage were used for Digital Elevation Model (DEM). Surface ruggedness, Slope and aspect were calculated from elevation layer using Surface analysis tool from spatial analyst toolbox. All village locations and water points were recorded using GPS. I used the Euclidean distance tool to create a raster "distance to" (km) layer. Spatial prediction of species' distribution was supplemented using occurrence-only records and environmental covariate by the combination and comparison of ENFA and regression modeling. Requiring only presence data as input, the Ecological-Niche Factor Analysis (ENFA) computes suitability functions by comparing the species distribution in the EGV space with that of the whole set of cells. Species are expected to be non-randomly distributed regarding eco-geographical variables. The final data set used were 9 variable layers which were projected to the UTM zone to match their coordinates, clipped to the boundary along with 2 km buffer, and entered with the occurrence data into *idrisi selva* version 3.2 (Eastman, 2012 Clark University). Maps usable by *Biomapper* and *idrisi* were used to derive biologically meaningful map with reference to the focal species (Eco-Geographical Variable, EGV). Species presence map was boolean map (containing 1 and 0 only). I selected the medians algorithm for Habitat Suitability (HS) computation. The predictive power of HS map was evaluated by cross validation process for which, the *Biomapper* software use method described by Boyce *et. al.*, (2002).

Application of the ENFA method to the calibration set provided an overall marginality of M = 0.64 and an overall specialization value of S = 3.01 indicating a tendency of a species to live in extreme habitats and that the jackal are rather open on the range of conditions they withstand. Tolerance (1/S) value (= 0.33, close to zero) indicates that a species is not very discriminating on its living environment. The three factors retained (out of the nine computed) accounted for 91.25 % of the total sum of Eigen values. The marginality factor alone accounted for 87 % of this total specialization, meaning that jackal showed restricted range on conditions mostly differed from background intensive study area conditions i.e. forest area, whereas the affinity was observed towards open plain areas. Marginality coefficient factor showed that jackal are essentially linked to moderate ungulate density (0.31), optimum distance to village (0.08), water (0.04) and rodent density (0.07). By contrast, jackal tend to avoid rugged terrain (-0.98), high hare density (-0.11) and ground bird density (-0.04). Distance to road and vegetation type had only marginal effects. The distribution of habitat suitability values were differed slightly from the global distribution. Predicted suitability exceeded with marginal value of 0.60 ± 0.25 whereas, the absolute validation index (AVI) value obtained was 89.9 ± 33.9 which differed notably from contrast validation index (CVI) value of 28.9 ± 3.2. Distribution models performed 'reasonably' based on the area adjusted frequency (AAF) curve inferring selection of a marginal habitat by jackal, which is in accordance with the generalist behavior of the species. Since, the Boyce index value was average, multi models were constructed and analyzed using binary logistic regression in generalized linear model in same size grids (4 km^2). The 'resource' factor received most support to infer the habitat selection by jackal. The presence of small mammal density and favorable distance form water source in open to moderately dense forest, were evaluated as the most influential factors at the scale of 4 km^2 grid (AIC = 528.7; ω_i = 0.51). The selected habitat factor variables obtained from logistic regression were compared with the ENFA factor spectrum and further used for preparing the habitat suitability map. There was no significant difference observed between the selected models of ENFA and GLM (student t test; t = 0.57, df = 14, p = 0.58). The little disparity observed was due to unreliability of absences data used in logistic regression. ENFA was found more robust since the predictive power of the maps was better.

The distribution of the jackal in the study area was consistent with information available from other areas where scrubland, *Zizyphus* woodland and human habitation was important for deciding its distribution (Moehlam, 1983, 1986 and 1989; Mukherjee, 1989). Their responses to habitat were consistent with predictions based on ecological characteristics of the species. The habitat suitability for jackal in Sariska highlighted the importance of maintaining landscape configuration, by combination of spatial elements, and landscape connectivity in agreement with other studies on meso-carnivores (Kareiva and Wennergren, 1995; Gehring, 2000). The conservation of species should begin with habitat protection and restoration (e.g. Danielson, 1994; Fahrig, 1997) and arrangement of spatial elements that can strongly affect the ability of species to move among and between elements (Gehring, 2000). The niche modeling in the present study depicts contrast spatial distribution pattern between jackal and leopard (Mondal *et. al.*, 2012), also the site has fair density of hyena population (24.5/100 km^2, Gupta *et. al.*, 2011). The future surveys in forested and non forested regions of adjoining Alwar and Jamwa Ramgarh forest division is recommended since the, insufficient occurrence data exist from bordering areas to investigate spatial or temporal changes in ecological niches of jackal, and too little is known about the other biotic factors, such as predation and disease, or the presence of key resources outside the reserve (e.g., den sites, food distribution), which also have played a role in determining jackal distribution patterns. The jackal in Sariska appeared spatially separated towards the open bordering areas, probably to avoid competition however; more detailed field studies are needed to determine each species' microhabitat usage, behavior, food habits and the adaptive threshold of jackal towards anthropogenic activities. It is suggested to promote the species as pest controlling agent to ensure its safety and acceptance in agro ecosystem surrounding the reserve boundary. Linkage of ecological and social sciences to answer complex questions about human aspects, interactions and benefits from jackal is yet to be explored. I am hopeful that herein I have encouraged the process by highlighting species-specific ecology at a regional scale.

CHAPTER 1

INTRODUCTION

1. 1. Introduction:

India is rich in species diversity because of the location in convergence of three Bio-geographic realms-Indomalayan, Paleartic and Ethopian (Mackinnon and Mackinnon, 1974; Mani, 1974). Most of the tropical countries are rich in the number of carnivore species they harbor (Corbett and Hill, 1992). With 55 species of carnivores distributed throughout India, several protected areas in the country have two or more sympatric carnivores (Johnsingh, 1986). The disappearance of top predator 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). Meso-carnivores represent an ecologically diverse and influential guild of vertebrates playing key roles as predators and seed dispersers. Carnivore species, having small body size, have varied life histories showing highly species-specific responses to habitat and human-induced habitat changes, and attain varied conservation status. They are much more diverse in their behavior and ecology.

1.2. Canids:

Canids form one of the most prominent families of carnivores, with 36 taxa in 13 genera that occur throughout most of the world (Zubiri, Hoffmann and Macdonald, 2004). Foxes, dholes, dingoes, wolves, jackals, coyotes and various dogs comprise the family. As a family, canids occupy every continent except Antarctica. The order canidae evolved in open grassland and modern members are adapted to a wide range of habitats. Canid possess morphological adaptations that help them run swiftly after their prey such as long legs, digitigrade feet, non-retractile claws, fused scaphoid and lunar bones (wrist bones) which give their wrists unidirectional strength and locked radius and ulna which prevents rotation of the upper fore legs. The family Canidae belongs to a large group of predatory mammals characterized by their common

possession of a pair of carnassial teeth (upper fourth premolar and lower first molar) that are modified to maximize efficiency for shearing skins, tendons, and muscles in their prey. Canids are characterized by an inflated entotympanic bulla (bony chamber enclosing the middle ear region) that is divided by a partial septum along the entotympanic and ectotympanic suture. Other feature characteristics of canids are the loss of a stapedial artery and the medial position of the internal carotid artery that is situated between the entotympanic and petrosal for most of its course and contained within the rostral entotympanic anteriorly (Wang and Tedford 1994). These basicranial characteristics have remained more or less stable throughout the history of canids.

The smallest canid member is the Blanford's and fennec foxes (*Vulpes cana* and *V. zerda*) with 24 cm body height and body weight of less than 1 kg where, the largest member is the Gray wolf with 200 cm of body high and exceeding 60 kg body weight. Canid distributions may be highly restricted (Yankhe *et al*. 1996) or span several continents, about 70 million km² in the case of the red fox (Lloyd 1980) where, the grey wolf was the most widely distributed terrestrial mammal. Their diets range from omnivory (with, at times, almost exclusive emphasis on frugivory or insectivory) to strict carnivory—and they glean these livings in habitats ranging from deserts to icefields, from mountain to swamp or grassland, and from rain forest to urban 'jungle' (Johnson *et al*. 1996; Macdonald 1992b). To do this they may travel home ranges as small as 0.5 km^2 (island fox—Roemer *et al*. 2001b) or as large and non-defensible, as 2000 km^2 in African wild dogs (*Lycaon pictus*) (Frame *et al*. 1979). Canid dispersal is important to several aspects of evolutionary biology, including population genetics and fitness; the theoretical importance of dispersal was as a primary factor whose costs were offset against possible benefits of group-living (Vehrencamp 1983; Macdonald and Carr 1995). The Canidae are the most widespread family of extant Carnivora, with at least one species present in all continents except Antarctica. A perusal of the ranges of all canid species (Macdonald and Sillero-Zubiri 2004b) indicated that over the last century the geographical ranges of seven species have increased, eight have decreased and nine have remained stable. The kaleidoscope of species diversity has changed and there are places where the grey wolf and the red fox have been replaced by what amounts to their 'ecological average', the coyote, once confined to mainly arid areas in western North America

and now found in every state, province and country north of Panama (Moore and Parker 1992; Reid 1997; Bekoff and Gese 2003).

Many Canidae groups have distributions that span a whole continent. Red foxes and grey wolves have the most extensive natural range of land mammal (with the exception of humans and some commensal rodents). Red foxes are the only canid species present on five continents, recorded in a total of 83 countries. Grey wolves occur naturally in North America, Europe and Asia with their range spanning 62 countries. Two species are present on three continents, namely the golden jackal (*canis aureus*) and Arctic fox (*Alopex lagopus*) and two other, the red fox and dingo were introduced in Australia and Oceania.

Although behavioral monogamy is fundamental to canid societies (Kleiman 1977; Kleiman and Malcolm 1981), Macdonald and Moehlman (1982) noted that canid social systems appeared to be size related (Creel and Macdonald 1995). Canids can be categorized according to three size classes. Small canids (<6 kg) are either largely monogamous e.g. Blanford's, swift (*V. velox*) and kit foxes (Geffen and Macdonald 1992; Cypher *et al*. 2000; List and Macdonald 2003) or form small, loose knit groups with a female-biased sex ratio, from which young males tend to emigrate, and females stay in their natal range as helpers until a breeding opportunity arises e.g. red and Arctic foxes (Macdonald 1979a; Hersteinsson and Macdonald 1982). Medium-sized canids (probably excluding the bush dog) (6–13 kg) have an equal adult sex ratio and emigration rate, and both sexes may be helpers and thus both sexes also disperse (golden, black-backed (*Canis mesomelas*) and side-striped jackals, coyotes, and crab-eating foxes (Bekoff and Wells 1982; Moehlman 1983; Macdonald and Courtenay 1996; Loveridge and Macdonald 2001). Larger canids excluding the maned wolf (Dietz 1984), and perhaps the grey wolf (Packard *et al*. 1983) (>13 kg), in contrast, exhibit an adult sex ratio skewed towards males, female emigration and male helpers e.g. Ethiopian wolves, dholes, African wild dogs (Kuhne 1965; Johnsingh 1982; Sillero-Zubiri *et al*. 1996a) and perhaps the bush dog is an atypically diminutive member of this category (Macdonald 1996b).

Geographical variability in body size can be explained by differences in availability of food, with small canids (e.g., fennec fox) usually associated with arid and poor habitats in which only a small body mass can be supported year round,

whereas large canids (e.g., Ethiopian wolf and African wild dog) are often associated with habitats in which prey is abundant (table.1). Thus, canids have borne a high proportion of the conflict between humans and carnivores. The more prolific and adaptable canids, like the jackal and coyote, have fared well despite this competition, while the more specialized members of the family, like the Ethiopian wolf, have become threatened with extinction.

At least 155 of the 192 countries across the world have canid species (81%) where, Sudan is the country with the highest number of species (10 species), followed by USA (9 species) and Ethiopia (8 species). Those countries that do not host any canid species are island states are Caribbean islands, Madagascar, Malta and most Australasian islands. Africa, Asia and South America support the greatest diversity with more than 10 canid species each. Red foxes are sympatric with 14 other canids from three geographical regions, golden jackals with 13 from two regions and grey wolves with 11 from three regions. Within any one location, canid diversity is usually limited to one to five species.

There are five canid species endemic to a single country i.e. Ehtiopia. Most are also threatened (red wolf, Ethiopian wolf, Darwin's fox, island fox and hoary fox – *Pseudalopex vetulus*), with the Sechuran fox (*P. sechurae*) a near-endemic to Peru. Of the two continents with the highest species diversity, South America harbours nine species (out of 11 species present) confined entirely to south of Panama, while Africa has eight endemics (of 13 species present). Of 12 canid species found in Asia, only two are restricted to that continent i.e Indian fox (*Vulpes bengalensis*) and dhole (*Cuon alpines*).

The protein-coding gene phylogeny, which is consistent with tree based genetic approaches, shows that the wolf genus *Canis* is a monophyletic group that also includes the dhole or Asian wild dog. The grey wolf, coyote and Ethiopian Wolf or Simien Jackal (*Canis simensis*) form a monophyletic group, with the golden jackal (*C. aureus*) as the most likely sister taxon (Figure.1.1). The black-backed (*C. mesomelas*) and side-striped jackals (*C. adustus*) are sister taxa, but they do not form a monophyletic group with the golden jackal and Ethiopian wolf. Basal to *Canis* and *Cuon* are the African wild dog and a clade consisting of two South American canids, the bush dog (*Speothos venaticus*) and the maned wolf (*Chrysocyon brachyurus*).

Consequently, although the African wild dog preys on large game as does the grey wolf and dhole, it is not closely related to either species but is sister to the clade containing these species. In sum, the living Canidae is divided into five distinct groupings. These include the wolf-like canids, which consists of the coyote, grey wolf, Ethiopian wolf, jackals, dhole and African wild dog. This clade is associated with a group containing bush dog and maned wolf in some trees and, further, this larger grouping is associated with the South American foxes (Wayne *et al*. 1997). The red fox group is a fourth independent clade containing *Alopex* and *Vulpes* (including the fennec fox). Finally, three lineages have long distinct evolutionary histories and are survived today by the raccoon dog, bat-eared fox and island and gray fox.

Table.1.1. Canid species and their distribution in the World

Species	**Common name**	**Geographic range**
Canis aureus	Golden jackal	Old World
Canis adustus	Side-striped jackal	Subsaharan Africa
Canis mesomelas	Black-backed jackal	Subsaharan Africa
Canis simensis	Simien jackal	Ethiopia
Canis lupus	Gray wolf	Holarctic
Canis latrans	Coyote	North America
Canis rufus	Red wolf	Southern US
Cuon alpinus	Dhole	Asia
Lycaon pictus	African wild dog	Subsaharan Africa
Speothos venaticus	Bushdog	Northeast S. America
Lycalopex uetulus	Hoary fox	Northeast S. America
Cerdocyon thous	Crab-eating fox	Northeast S. America
Chrysocyon brachyurus	Maned wolf	Northeast S. America
Vulpes aelox	Kit fox	Western US
Vulpes vulpes	Red fox	Old and New World
Vulpes chama	Cape fox	Southern Africa
Alopex lagopus	Arctic fox	Holarctic
Fennecus zerda	Fennec fox	Sahara
Otocyon megalotis	Bat-eared fox	Subsaharan Africa
Urocyon cinereoargenteus	Gray fox	North America
Nycteruetes procyonoides	Raccoon dog	Japan, China

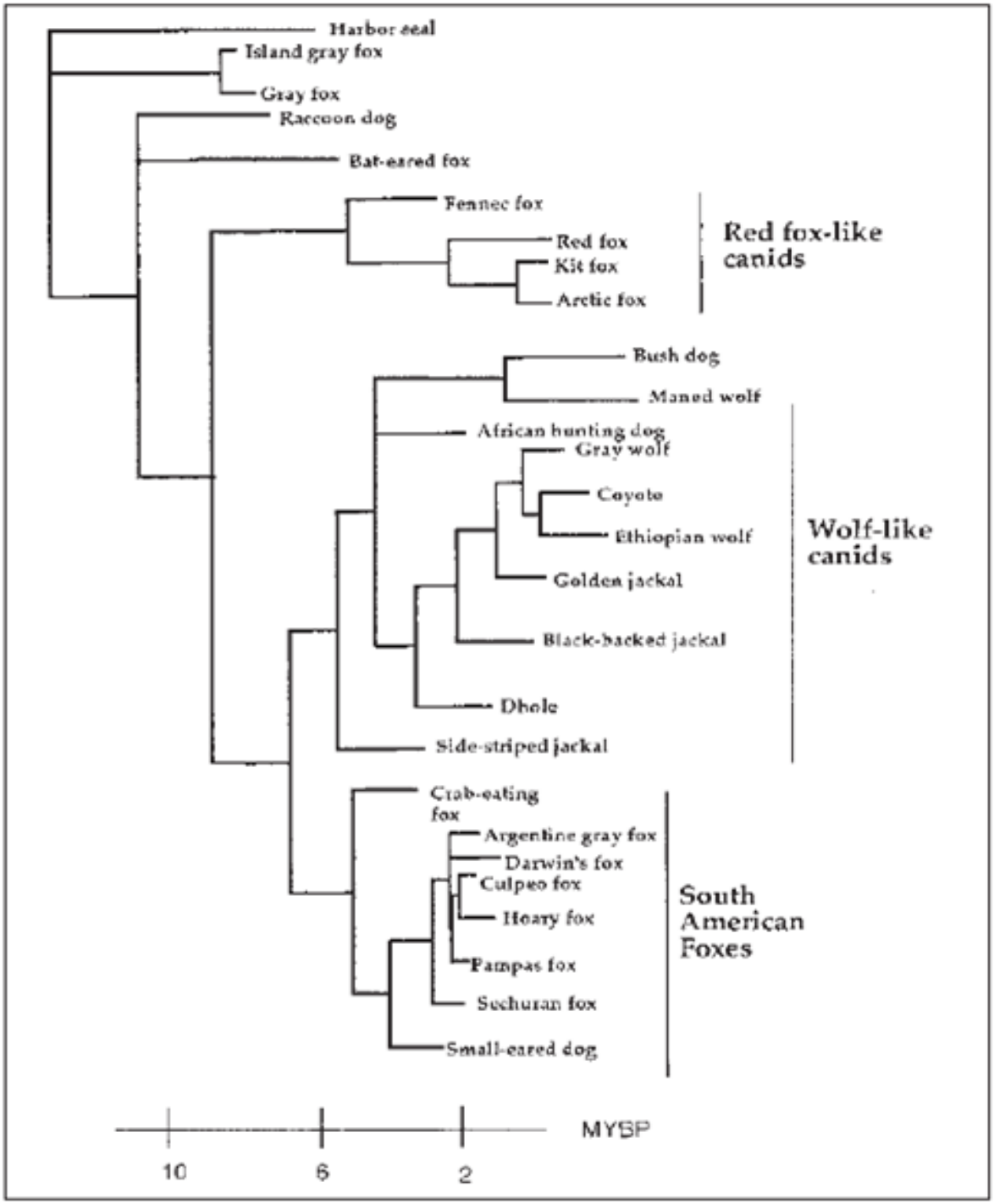


Figure.1.1. Consensus tree of 26 canid species based on analysis of 2,001 bp of DNA sequence from mitochondrial protein coding genes (Wayne *et al*. 1997). Time scale in millions of year before present (MYBP) is based on comparisons of DNA sequence divergence to first appearance times in the fossil record.

1.3. Golden Jackal:

Golden Jackal (*Canis aureus*) is a medium sized canid, considered a most typical representative of genus Canis, and is one of the 37 species of Canidae (Moehlman, 1983) occurring in the world. The golden jackal is widely distributed from East Africa through Middle East into South Asia. According to IUCN Red List and Indian Wildlife (Protection) Act, 1972 they are placed in Lower risk and Schedule III respectively. Three Indian races of jackal are recognized – *Canis aureus aureus, C. aureus indicus* and *C. aureus naria* (Prater, 1980). Jackal is a generalist predator and occurs in variety of habitats from savannah and woodland in Protected Area (Moehlman, 1983; Fuller *et. al.*, 1989) to farmland around human habitation (Pouche *et. al.*, 1987; Jeager *et. al.*, 2001). In areas, particularly where large predators have been eliminated they are most abundant carnivores (Yom-Tov *et. al.*, 1995; Krystufek *et. al.*, 1997). The golden jackal is widespread in North Africa and north-east Africa, occurring from Senegal on the west coast of Africa to Egypt in the east, in a range that includes Morocco, 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 (Genov and Wassiley 1989; Sheldon 1992), and eastwards into Turkey, Syria, Iraq, Iran, Central Asia, the entire Indian subcontinent, then east and south to Sri Lanka, Myanmar, Thailand and parts of Indo-China (figure.1.2). The golden jackal is fairly common throughout its range. High densities are observed in areas with abundant food and cover.

In India, jackal populations achieve high densities in pastoral areas such as Kutch, Maharashtra, Rajasthan, and Haryana. Based on intensive observations on breeding pack units and radio-collared individuals, jackal densities in the semi-arid Velavadar National Park were estimated between one and two jackals per km^2 (Y. Jhala *et al*. unpubl.); On the African continent, in the Serengeti National Park, densities can range as high as four adults per km^2 (Moehlman 1983, 1986, 1989). Population estimates for Africa are not available. Due to their tolerance of dry habitats and their omnivorous diet, the golden jackal can live in a wide variety of habitats. These range from the Sahel Desert to the evergreen forests of Myanmar and Thailand. They occupy semi-desert, short to medium grasslands and savannahs in Africa; and forested, mangrove, agricultural, rural and semi-urban habitats in India and Bangladesh (Clutton-Brock *et al*. 1976; Poche *et al*. 1987; Y. Jhala pers. obs.).

Golden jackals are opportunistic and will venture into human habitation at night to feed on garbage. Jackals have been recorded at elevations of 3,800m in the Bale Mountains of Ethiopia (Sillero-Zubiri 1996) and are well established around hill stations at 2,000m in India (Prater 1980).

Golden jackals are omnivorous and opportunistic foragers, and their diet varies according to season and habitat. Great quantities of vegetable matter occur in the diet of jackals and, during the fruiting season in India, they feed intensively on the fruits of *Ziziphus* sp., *Carissa carvanda*, *Syzigium cuminii, Phoenix sylvestris* and pods of *Prosopis juliflora* and *Cassia fistula* (Kotwal *et al*. 1991; Y. Jhala pers. obs.). Single jackals typically hunt smaller prey like rodents, hares and birds. They use their hearing to locate rodents in the grass and then pounce on them by leaping in the air; they also dig out gerbils (*Tatera indica*) from their burrows. They have been observed to hunt young, old, and infirm ungulates that are sometimes 4–5 times their body weight (Van Lawick and Van Lawick- Goodall 1970; Eisenberg and Lockhart 1972; Kotwal *et al*. 1991; Y. Jhala pers. obs.). Indeed, cooperative hunting permits them to harvest much larger prey in areas where it is available, and cooperative hunting of langurs (*Presbytis pileata* and *P. entellus*) has been reported (Newton 1985; Stanford 1989). Aggregations of between five and 18 jackals have been sighted scavenging on carcasses of large ungulates (Y. Jhala pers. obs.), and Macdonald (1979a) reports similar aggregations on clumped food resources in Israel. Golden jackals cause damage to melon, peanut, grape, coffee, maize and sugarcane crops; they sometimes take to killing lambs, kids, weak sheep, goats and poultry (Jerdon 1874; Kingdon 1977; Prater 1980; Poche *et al*. 1987).

The social organization of golden jackals is extremely flexible depending on the availability and distribution of food resources (Macdonald 1979a; Moehlman 1983, 1986, 1989; Fuller *et al*. 1989; Moehlman and Hofer 1997). The basic social unit is the breeding pair, which is sometimes accompanied by its current litter of pups and/or by offspring from former litters (Moehlman 1983, 1986, 1989). In Tanzania, golden jackals usually form long-term pair bonds, and both members mark and defend their territories, hunt together, share food, and cooperatively rear the young (Moehlman 1983, 1986, 1989). Moehlman and Hofer (1997) reported average group size of jackal as 2.5 in the Serengeti, Tanzania, while average pack size in Velavadar National Park, India, was 3.0 (n=7) (Y. Jhala unpubl.). Scent marking by urination

and defecation is common around denning areas and on intensively used trails. Such scent flag posts are considered to play an important role in territorial defense (Rosevear 1974). Although Moehlman (1983) reports maintenance of year-round exclusive territories in Tanzania, aggregations in Israel (Macdonald 1979a) and India (Y. Jhala pers. obs.) point towards the flexibility of social organization depending on available food resources. Data obtained by telemetry from the Bhal area of India suggest that most breeding pairs are spaced well apart and likely maintain a core territory around their dens (Y. Jhala unpubl.). Jackals were observed to range over large distances in search of food and suitable habitat, and linear forays of 12–15km in a single night were not uncommon (A. Aiyadurai and Y. Jhala unpubl.). Recorded home range sizes vary from 1.1–20km^2 (Van Lawick and Van Lawick-Goodall 1970; Kingdon 1977; Poche *et al*. 1987; Y. Jhala unpubl.), depending on the distribution and abundance of food resources. Affiliative behaviours like greeting ceremonies, grooming, and group vocalizations are common in jackal social interactions (Van Lawick and Van Lawick-Goodall 1970; Golani and Keller 1975). Vocalization consists of a complex howl repertoire beginning with 2–3 simple, lowpitch howls and culminating in a high-pitched staccato of calls. Jackals are easily induced to howl and a single howl evokes responses from several jackals in the vicinity. Golden jackals often emit a warning call that is very different from that of their normal howling repertoire in the presence of large carnivores like tigers, hyaenas and wolves (Jerdon 1874; Y. Jhala pers. obs.). In India, howling is more frequent between December and April, a time when pair bonds are being established and breeding occurs, perhaps suggesting a role in territory delineation and defence (Jaeger *et al*. 1996).

Over its entire range, except in Protected Areas, the jackal population is steadily declining (MacDonald and Zubiri, 2004). Traditional land use practices are being replaced by intensive agriculture, while wilderness area and rural landscape are being rapidly urbanized. Jackal population can adapt to this change up to some extent and may persist for a while, but eventually disappear from such area. Estimated 80,000 jackal remain on the Indian subcontinent, but there are no estimates for Africa (Jhala and Moehlman, 2004).

A few long term (Moehlman, 1993; Vanlewick Goodall and VanLawick, 1970; Sharma, 1998) and short term studies (Sankar, 1994; Mukherjee *et. al.*, 2004; Aiyadurai and Jhala, 2005; Home and Jhala, 2010) have been conducted on jackal in

Indian sub continent. Golden jackal occupies variety of habitats by adapting to the varied condition. Therefore, several aspects of jackal ecology are not fully understood (Patil and Jhala, 2008).

Deriving meaningful estimates of their abundance is a challenging task. As National Parks and Sanctuaries become subjected to greater human use, carnivores are severely affected by developmental activities, wildlife trade and hunting (Johnsingh 1986, Ashraf et al., 1993, Gupta 1997). There is a large void in the information available on the ecology of most of the small Indian carnivores (Mukherjee 1989, Mukherjee 1998). They are in urgent need of a focused conservation program which can achieve many successes with many challenges and identify a range of future work. They suffer from common issues of lack of awareness of their plight and the deficiency of reliable data on their distribution and conservation requirements.

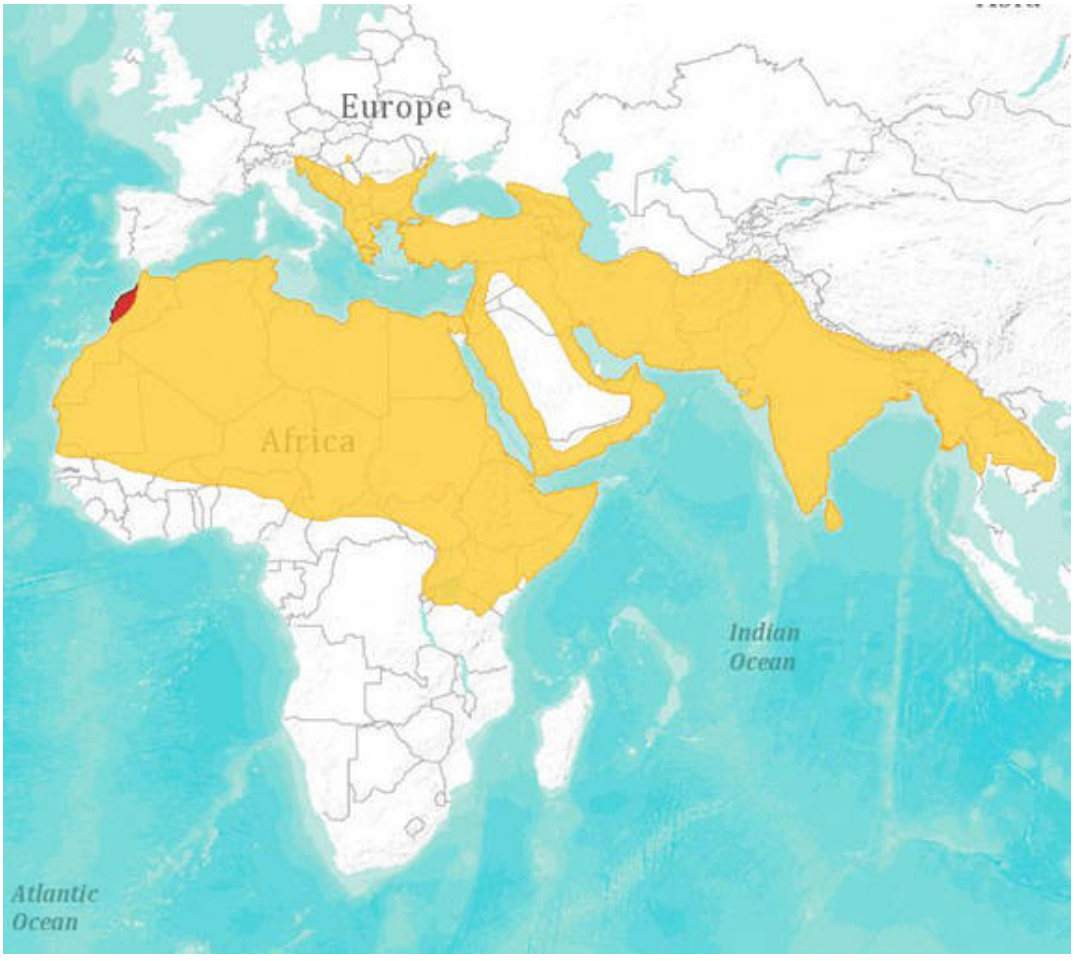


Figure.1.2. Geographical distribution of golden jackal

1.4. Literature Review:

Despite their widespread distribution, studies on jackal had been limited mostly to certain parts of African Savannahs (Wyman, 1967; Van Lawick Goodall and Van Lawick, 1970; Moehlman, 1986). Towards the end of last century, studies on jackal were conducted in Middle East (McDonald, 1979; Golani and Keller, 1975) and parts of Indian subcontinent (Sankar, 1988; Sharma, 1998; Soni *et. al.*, 1995). Sankar (1988) and Moehlman (1993) explained their usefulness in any ecosystem as a scavenger and controllers of rodent population. Fuller *et al.* (1989) worked on ecology of sympatric jackal species in the Rift Valley of Kenya. Mukherjee (1989) studied ecological separation of three sympatric carnivores including jackal, in Keoladeo National Park, Bharatpur. Jaeger *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 jackal 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 jackal scats contained remain of small mammals. Gupta (2006) worked on food habits of golden jackal in Keoladeo National Park, Bharatpur and reported contribution of 56% of *Zizyphus* fruits in their diet.

Jhala and Moehlman (2004) stressed the need for more intensive studies on jackal. They also emphasized that jackal ecology needs to be studied in forested ecosystems of Southeast Asia where a different set of factors are likely to operate affecting food availability, ranging patterns and survival of the species.

1.4.1. Abundance Estimation

There is lack of reported efforts at estimating abundance of jackal using direct sightings in a given habitat. Pyrah (1984) had used den area surveys and siren station method to estimate an index of coyote (*Canis latrans*) population in North Central Montana. Since, indirect methods only give an index of abundance of an animal species and direct methods give number or densities; integration of these two methods can give reliable results.

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 of animals using detection/non-detection data from repeated surveys at several sampling units (or sites). To estimate the abundance of species whose identification was not possible, Royle and Nichols (2003) model was used by Gupta (2009) in Sariska Tiger Reserve for small and medium sized carnivore by considering home range area of species as a unit for estimating abundance. Home range size of golden jackal was estimated as 14.3 km^2 in Velavedar National Park (Ambika, 2005). Gupta (2009) reported that golden jackal are found to be abundant in number based on direct sightings in the study area 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.

Capture-recapture methods require repeated efforts to capture or observe animals (Otis *et al.*, 1978; Pollock *et al.*, 1990). The vehicle based transects (Verman and Sukumar, 1995) can be used for estimating densities of animal species where obtaining adequate sample size may be difficult, in low density areas only the indirect sings can give a better estimation of abundance of a species. Mukherjee (1998) used direct sighting methods to estimate an index of predator abundance in the Sariska using vehicle and foot transects across various habitats. A comparison of the different methods used for direct sightings in her study showed that the vehicle based transects were more reliable than foot transect.

1.4.2. Evaluation of food availability:

Carnivores occupy the top position in the terrestrial food chain and greatly influence the communities they inhabit. Selection of prey is of primary interest in the ecology and management of predators and their prey. The characteristic of habitat, availability of prey species and prey behavior have much influence on hunting technique and on selection of prey by predators.

Examination of prey selection by carnivore and the factors influencing such selection could aid in predicting the effects of these predators on prey populations. Partitioning of prey because of interference and exploitation competition between carnivores could produce additive effects on prey populations. The patterns of prey

selection exhibited by various predator species tend to be shaped by a suite of factors, including predator and prey behavior, morphology, and habitat requirements related to hunting or escape (Kruuk, 1986). In general, such factors interact to affect predator-prey encounter and capture probabilities, and thus ultimately determine prey selection patterns occurring within a particular predator-prey system. Yet, even within a given prey species the attributes of depredated individuals may vary spatially, temporally, or between predator species.

Canids are coursing predators, and thus typically exhibit prolonged pursuit of prey through relatively open terrain (Kruuk, 1972; Schaller, 1972). Because canids usually chase swift prey, capture success tends to be low and depredated individuals typically are disadvantaged in some way (Schaller, 1972; Ewer, 1973; Kunkel *et al.*, 1999).

Golden jackal is reported to prey primarily upon rodents (Sankar, 1988; Mukherjee, 1998; Lanszki and Heltai, 2002; Gupta, 2009), including bandicoot rats (Khan and Beg, 1986). Rodents are also an important prey for side-striped jackal (*C. adustus*) (Atkinson *et. al.*, 2002). They also consume a variety of fruits and vegetables, together with poultry and livestock (Sarker and Ameen, 1990). Golden jackal is 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 comprised of 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 jackal's 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 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*, pods of *Prosopis juliflora* and *Cassia fistula* (Kotwal *et al*., 1991; Gupta, 2006).

Results from the study by Gupta (2009) showed the dominance of mammalian prey species in the diet of striped hyena, golden jackal and jungle cat. These

carnivores utilized broad diet in Sariska. For striped hyena, chital and hare were the seasonal prey consumed while livestock (cattle and goats) are supplementary food item, and peafowl was utilized opportunistically. The *Zizyphus* fruits were consistently eaten by golden jackal in its fruiting season. Chital were seasonal food items for golden jackal. Small mammals like hare and rodents were eaten consistently while peafowl and cattle were eaten opportunistically in Sariska by 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 was attributed due to scavenging on large carnivore kills during winter and summer (Gupta, 2009).

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. Line transects have been found to be very effective and reliable in estimating densities of ungulates in the Indian Subcontinent (Karanth *et. al.*, 2004). Small mammals are an integral component of forest animal communities and they form an important prey base for medium sized carnivores (Emmons, 1987; Golley *et al.*, 1975; Hayward and Phillipson, 1979). Anderson *et al.* (1983) estimated 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. Prakash (1959, 1972, 1975, 1977, 1981 and 1995) extensively studied the rodent distribution in Rajasthan.

The study by Gupta (2009) reported that, hare remains were found in 25.9 % of jungle cat's dite, 14.6 % in the diet of striped hyena and 4.4 % in the diet of golden jackal in Sariska where, the density of hare was probably underestimated since they were counted on line transects during morning hours. Rabbits and hare are crepuscular/nocturnal, and their activity follows circadian rhythms; thus, the timing of the census can significantly affect the results (Ballinger and Morgan, 2002).

To quantify rabbit abundance and population trends, crude population indices such as the kilometric abundance index (KAI), i.e. the number of individuals observed per kilometer, have been widely used in Spain (Beltrán, 1991; Moreno, *et al.*, 2007) and France (Marchandeau and Gaudin, 1994). Night counts have been widely used to monitor rabbit populations (Marchandeau and Gaudin, 1994; Martins *et al.*, 2003; Marchandeau *et al.*, 2006) and to estimate population trends (Caley and Morley, 2002; Williams *et al.*, 2007). Caley and Morley (2002) selected the population growth model to estimate the observed rate of increase of rabbits and the precision of spotlight-counts as an index of rabbit abundance, and to evaluate the utility of spotlight-count data for detecting significant changes and trends in rabbit abundance.

1.4.3. Feeding habit and dietary niche overlap

The extent of niche differentiation and resource partitioning determines the degree to which different species can either coexist or competitively exclude each other (Pianka, 1973; Carvalho and Gomes, 2004). An important mode of resource partitioning is the degree of dietary overlap between sympatric species (Hayward and Kerley, 2008). This overlap is influenced not only by each species' physical ability to obtain food (Radloff and du Toit, 2004; Owen-Smith and Mills, 2008), but also by variation in the spatial and temporal availability of food (Azevedo *et. al.*, 2006). Complex and dynamic patterns of spatial and temporal coexistence within carnivore guilds therefore often require long-term studies to disentangle the interactions between predators and prey species (Carvalho and Gomes, 2004; Azevedo *et. al.*, 2006).

One of the basic tenets of community ecology is that sympatric species occupying a common tropic level tend to exhibit niche differentiation and resource partitioning (Pianka, 1969; Schoener, 1974, 1986). Among the most important modes of resource partitioning in ecological communities is the differentiation of food resources, such that cases of extensive dietary overlap between similar species are limited. Patterns of resource partitioning and characterizing resident carnivore populations within particular ecological communities may be complex and dynamic. For distinct carnivore guilds different mechanisms seem to be involved, such as

different body sizes of predators (Carvalho and Gomes, 2004), different prey species (Karanth and Sunquist, 2000), different prey sizes (Juarez and Marinho-Filho, 2002), different activity patterns (Loveridge and Macdonald, 2003) and differential microhabitat use (Johnson and Franklin, 1994a). Gupta (2009) studied medium and small sized carnivore in Sariska and reported that, the overall niche breath for three carnivores (hyena, jackal and jungle cat) was narrowest for the jackal (0.5) followed by striped hyena (0.7) and jungle cat (1.7). 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) (Gupta, 2009).

Dietary studies based on prey remains in feces are generally accepted to represent accurately the components of an animal's diet (Putman, 1984), and in carnivores it is possible to identify remains to the level of family. Habitat conditions are usually well indicated by the diet composition and feeding habits of predators. The jackal is a typical food generalist carnivore. Depending on food availability, jackal may be solitary hunters, co-operate in pairs or hunt as groups (mainly while the parents teach the offspring to hunt). Jackal cannot run persistent like the wolf; it is derived from its anatomy (relatively short legs). That is why jackal attacks from ambush mainly (Szabó *et. al.*, 2010). Jackal feeding habits were studied in Hungary (temperate climate agricultural area, Lanszki *et. al*., 2006), Greece (Mediterranean marshland, Giannatos *et. al.*, 2005), and Israel (Mediterranean agricultural area, Yom-Tov *et. al.*, 1995). Large differences were detected in the consumption of domestic animals between the above mentioned study areas. According to biomass consumption the highest rates were recorded in Israel (74.0%), medium in Greece (62.6%) and substantially lower levels in Hungary (1.4%). In Israel, domestic animal food type consumption by jackal was dominated by poultry followed by eggs, cow and cat. In Greece jackal consumed mostly goats, sheep, poultry, dogs (2.9%) and cats. Cat and poultry consumption was also recorded in the Hungarian study. According to Yom-Tov *et. al.* (1995), domestic animals along with small wild mammals were the most important dietary components of jackal in Israel. Small mammals also were found to be a main food source also in Kazakhstan, Azerbaijan and Uzbekistan, India, Bangladesh as well as in Tanzania close to the equator (Macdonald and Zubiri, 2004).

In Greece, having extensive grazing and Israel where high density of poultry farming reported, the primary foods of jackal were mainly goat and poultry respectively. While jackal are able to hunt the young of domestic ungulates especially during their birth season (Yom-Tov *et. al.*, 1995) or poultry, direct predation by jackal on goat and poultry was minimal in the study areas in Greece and Israel. The consumption of domestic animals (excluding domestic dog and domestic cat) cannot be attributed to seasonal predation, but rather to carcasses left in the field (Greece) and around poultry farms (Israel) which are consequently cleared up by the scavenging jackal (Mac-donald, 1979). Gupta (2009) reported the presence of *Zizyphus* fruits in golden jackal's diet in Sariska and chital were utilized as seasonal food item. Small mammals like hare and rodents were eaten consistently while peafowl and cattle were opportunistically consumed.

1.4.4. Den Site Selection

The availability and use of denning sites are important aspect of the ecology of most of canids and are indicative of breeding units within the habitat (Tannerfeldt *et. al.*, 2003) as well, the reproductive success of a den dependent species would directly depend on the availability of good denning habitats (Alt, 1984; Ruggiero *et. al.*, 1998). The selection of denning and resting sites can be considered as a form of resource selection therefore; the availability of suitable denning and resting sites may be limiting factors for carnivore distribution and abundance (Lesmeister *et. al.*, 2008; Zielinsnki *et. al.*, 2004). The availability of such crucial resource could potentially limit where a den dependent species may be present. The response of a species to changes induced in the habitat by human presence may be positive or negative depending on the generalist or specialist nature of the species (Kamler *et. al.*, 2003). If the species is a specialist dependent on the native habitat, then loss of the native habitat may affect the species negatively. An example in this case would be the Swift fox (*Vulpes velox*), which has been shown to decline in number due to the loss of native prairie habitat. Whereas, red foxes (*Vulpes vulpes*) are known to thrive even in urban areas (Kamler *et. al.*, 2003). Finding a suitable den site might be a stronger limiting factor for specialist carnivores living in human dominated areas, whereas generalist species may find greater denning opportunities due to habitat alteration in

such landscapes. Therefore, understanding factors that influence resource selection for such carnivore species becomes important.

Dens offer a number of benefits, such as thermoregulation (Magoun and Copeland, 1998), protection for altricial offspring (Linnell *et. al.*, 2000) and security from predators (Frafjord, 2003), and therefore finding a suitable den may influence the territory size as well as ranging behavior of a carnivore (Doncaster and Woodroffe, 1993; Fernandez and Palomares, 2000). Habitat for denning could be largely determined by factors such as patchiness (Dell'Arte and Leonari, 2007), food availability (Eberhardt *et. al.*, 1983), presence of conspecific predators (Tannerfeldt e*t. al.*, 2003; Arjo *et. al.*, 2003; Szor *et. al.*, 2008) and human disturbance (Rova, 2003). Earlier, researchers thought jackal breed throughout year (Prater, 1980) but detailed study revealed that jackal have distinct breeding season, which generally coincides with the abundant availability of food (Van Lawick Goodall and Van Lawick, 1971). Jackal form permanent pair bonds and they show elaborate precopulatory sequences (Golani and Keller, 1975). Golden jackal makes or occupy den at the onset of breeding season and maybe used for many years (Sharma, 1998). Preferred den sites are natural or manmade embankments viz., rivulets, gullies, road and check dam embankments (Soni *et. al.*, 1995; Jhala and Moehlman, 2004). Dens may be 2 to 3 m long tunnels leading into a large chamber 0.5 to 1 m below the ground surface (Jhala and Moehlman, 2004).

1.4.5. Habitat use.

Resource selection by animals is a scale-dependent hierarchical process of behavioral responses to environmental factors. Lack of information on such habitat selection dynamics can hamper the conservation management of species and habitats. The inconsistency in the distribution and abundance of carnivore is associated with many of their prey species, temporal or demographic variability in prey vulnerability to predation, the influence of intra- as well as interspecific competition on carnivore food habits and even the potentially strong individual-based variability in carnivore food preference (Maddock and Perrin, 1993; Wu, 1999). Evidence suggests that breeding pairs of jackal were annual residents that defended cover sites but not foraging areas beyond (Jaeger *et. al.*, 2007). The golden jackal is a habitat generalist,

similar to the coyote (*Canis latrans*) in North America (Bekoff and Gese, 2003). Both species are generalist predators with adaptable social systems (Macdonald, 1979) that are able to exist in close proximity to humans and exploit agro-ecosystems. However, in some parts of their range, golden jackals have either disappeared or their numbers are shrinking due to anthropogenic causes (Jhala and Moehlman, 2004). Surveys in Greece indicate that jackals have a fragmented distribution associated with coastal wetlands and that local populations are disappearing coincident with the destruction of the remaining patches of this habitat (Giannatos *et. al.*, 2005). In contrast, golden jackal are reported to be expanding their range in Bulgaria (Krystufek *et. al.*, 1997). Breeding adults may not occur where they cannot be territorial throughout the year, as seems to be the case for the coyote (Shivik *et. al.*, 1996; Gantz and Knowlton, 2005). High overlap in resource utilization could increase the potential for resource competition between species and, theoretically, result in decreased inferior species abundance (Case and Gilpin, 1974). Shifts in habitat use by less competitive species can occur as large carnivores recolonize or are reintroduced into areas where other carnivore species are established. Differential use of habitat types or topographic characteristics is one method of spatial partitioning that allows for coexistence of congeneric species. Therefore, a better understanding of the extent of resource overlap between species could contribute in understanding its role in ecosystem. The behaviour and ecology of golden jackal has been studied in detail in East Africa. On the short-grass plains of the Serengeti National Park, monogamous pairs of jackal defend territories of 1 to 3 km^2 within which subadult helpers contribute to pup-rearing (Moehlman, 1979, 1983, 1986, 1989). The range size over three months of an adult pair of radio-tagged golden jackal in Acacia woodland in Kenya was 2.4 km^2 (Fuller *et. al.*, 1989). Flexibility in golden jackal social organization is illustrated by a study in Israel where, over two months, jackal feed primarily on a rubbish tip occurred in stable groups of ten and twenty individuals and defended territories of <0.1 km^2 (Macdonald, 1979). The literature on spatial memory (Macdonald, 1976; Roberts, 1979, 1981; Vander Wall, 1982, Kamil and Balda, 1985) and navigation in animals (Tolman, 1948; Menzel, 1973; Peters, 1978; Gould, 1986; Chapuis *et. al.*, 1987; Gallistel, 1993) suggests following orderly paths is within the capabilities of a wide variety of species. Canids are well-equipped to detect and follow specific scent trails (Neuhaus, 1953; Kaimus, 1955; Becker *et. al.*, 1957; Moulton *et. al.*, 1960; Albone, 1984; Hepper, 1988; Thorne, 1995), to re-trace paths (Peters and Mech,

1975; Macdonald, 1979 a, b; Bowen and McTaggart Cowan, 1980), to orient an individual (Eisenberg and Kleiman, 1972; Walther, 1978; Wells and Bekoff, 1981), and to otherwise increase foraging success (Henry, 1977; Harrington, 1981, 1982). It is therefore highly feasible that a foraging jackal can track the resources within its home range, perhaps using prior knowledge of locations and a navigational strategy based on the ‘‘principle of least effort’’ (Zipf, 1949). Indeed, there is evidence that canids can and do follow predictable routes (red foxes, *Vulpes vulpes*, Doncaster and Macdonald 1997; Blandford's foxes, *Vulpes cana*, Geffen and Macdonald, 1993).

1.5. Justification of the Study:

Golden jackal can be regarded as either meso-carnivores or apex predators, depending on the presence or absence of larger carnivores. Despite of its wide range of distribution, little is known about the ecology of the species in general, and in forested ecosystem, in particular, where a different set of factors operate, affecting food availability, ranging patterns and survival of the species. Little quantitative information is available on jackal densities, habitat use, and ranging patterns in relation to food availability. Some important aspects of jackal ecology such as den site selection and dietary niche overlap with other carnivore in the study area were addressed in the present study. The jackal fills an ecological niche as predators and scavengers in their ecosystem. Thus the present study is on the role and importance of the jackal as a small mammal predator in the semi-arid landscape thus become useful to plan an efficient conservation and management strategy of the species.

1.6. Objectives:

1. To determine the abundance of golden jackal.
2. To estimate the food availability, food habits and dietary niche overlap between golden jackal and other meso-carnivores.
3. To evaluate the den site selection by golden jackal and,
4. To evaluate the habitat use by golden jackal.

The study was conducted from November 2010 to June 2013 in two different seasons winter (November to February) and summer (March to June) in Sariska Tiger Reserve Rajasthan.

1.7. Organization of the thesis:

The thesis is organized in five chapters. Chapters 1 and 2 deal with the introduction and study area respectively. Chapters 3, 4 and 5 are based on the three broad objectives of the present study. Each chapter includes a brief introduction followed by methodology, results arrived at and discussion of the results. The Chapter-1 provides general introduction and details of canid group and study species followed by literature review based on objectives. It further describes the objectives and duration of study. Chapter-2 deals with the study area, different vegetation types and available flora and fauna in Sariska Tiger Reserve. Chapter-3 deals with abundance estimation of the study species based on camera traps. Chapter-4 deals with the food availability, food habits of study species and comparison between dietary niche overlap with other meso-carnivores. Chapter-5 deals with the evaluation of the den site selection and Chapter-6 deals with evaluation of habitat use and habitat suitability modeling based on Ecological Niche Factor Analysis 'ENFA' and logistic regression using different environmental variables (including different vegetation classes) and generated habitat suitability maps for the species in Sariska Tiger Reserve.

CHAPTER 2

STUDY AREA

2.1. General, Location and Topography:

Sariska Tiger Reserve (Sariska TR) is situated in Aravalli hills in Alwar district of Indian state 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 and Sankar 1994). Sariska TR 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 northeast 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 Gupta 2006). The Alwar Thanaghazi- Jaipur State Highway passes through the reserve, and 2000 vehicles ply on it every day (Johnsingh *et al.* 1997). Another main road passes through the reserve is Sariska-Kalighati- Pandupol road which is 20 km and along the wildlife rich valley of the reserve.

2.2. Climate

The climate is subtropical, characterized by a distinct winter, summer and 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 archaeological richness

Sariska Tiger Reserve was created in 1978. In the pre-independence period, the forests within the Reserve were a part of the erstwhile Alwar State and maintained as a hunting preserve for the royalty. After independence, Sariska was declared as a Wild Life Reserve on 7th November, 1955, under the Rajasthan Wild animals and Birds Protection Act, 1951. The Reserve status was upgraded to that of a Sanctuary in 1958. Sariska was included in the list of Tiger Reserves by Government of India in 1978 as the 11th Tiger Reserve. In 1982, an area of 274 km^2 was declared as Sariska National Park vide Preliminary Notification *NO. F11 (22) Raj-8/78 Jaipur Dated 27 August 1982 under Wild Life Protection Act 1972 (Central Act No. 53) section 35 (1)*. Within Sariska TR, there are several places of historical interest. The Pandupole temple which is a major attraction for tourists and pilgrims lies in the National Park area of the Reserve. The Kankawari fort, originally built by *Maharaja* Jai Singh II of Jaipur, located in the National Park area of the Reserve, where in the *Mughal* Emperor Aurangzeb had briefly imprisoned his elder brother Darashikoh during the struggle for succession of the throne.

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 per cent 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. *Acaccia catechu* forest and

a) *Miscellaneous forest,* which can be further sub-divided into three categories viz.

b) *Butea monosperma* forest

c) Forest along nallas and…….

d) Scrub land

Nine different vegetation and land cover categories have been delineated in Sariska TR (Sankar *et al.* 2009). They are *Anogeissus* dominated forest, *Boswellia* dominated forest, *Butea* dominated forest, *Acacia* mixed forest, *Zizyphus* mixed forest, Scrubland, Agricultural land, Water body and Barren land.

***Anogeissus* dominated forest:** The *Anogeissus pendula* that occupies 35.4% of the overall vegetation types is the dominant vegetation type in the entire STR distributed largely in gentle slopes. This species is found in association with *Acacia catechu* and *Lanea coromandelica,*. The under storey is formed by *Adathoda vasica, Grewia flavescens, Capparis sepiaria* and *Nycatanthus sp*. Ground cover mainly comprises of *Aristida sp*., *Setaria sp.,* and *Chloris sp*.

***Boswellia* dominated forest:** *Boswellia serrata* that occupies 15.4% of the overall vegetation types is found largely in steep slopes and plateaus. This species is found in association with *Anogeissus pendula*, *Doispyros melanoxylon*, *Acacia catechu*, *Wrigtia tinctoria, Bauhinia racemosa, and Ehretia laevis*. The under storey comprises of *Eurphobia nerifolia*, *Grewia flavescens, G. tenax* and *Capparis sepiaria.* Grass cover is sparse and is formed by *Aphluda sp* and *Chloris sp.*

***Butea* dominated forest:** *Butea* dominat forest occupies 7.9% of the Tiger Reserve. This species is found in association with *Zizyphus mauritiana, Cordia mixa, Phoenix Slyvesteris* (along the streams), *Holoptelea integrifolia* and *Cassia fistula*. The *Capparis sepiaria, Grewia flavescence, and Rhus mysorenses* are the common under storey. Ground layer comprises of *Heteropogon sp* and *Chloris dolichostachya*.

Scrubland: This vegetation type occupies 19.1% of the forest cover in which the tree species such as *Prosopis juliflora, Acacia leucophloea, Acacia nilotica, Acacia senegal, Maytenus senegalensis and Balanites aegeptiaca* are sparsely

distributed. The under story is formed by *Capparis decidua, C. sepiaria, Rus mysorensis, Grewia favescens, G. tenax, , Adathoda vasica and Dicrostachys cinerea.* Grass cover is sparse and is mainly formed by *Cynaodon sp, Chloris sp, Sporobolus sp,* and *Synchrus sp.*

***Acacia* mixed forest:** The *Acacia* mixed forest occupies 4.1% of the total vegetation types in Sariska TR. The *Acacia leucophloea* is the dominant vegetation type is found in association with *Prosopis juliflora, Acacia senegal, Dicrostachys cineria* and *Maytenus emarginata.* The understorey is formed by *Capparis sepiaria, D. cinera and M. emarginata,* Grasses found are *Apluda mutica, Cynodon dactylon* and *Desmostachya bipinnata*.

***Zizyphus* mixed forest:** This vegetation community that occupies 5.9% of the total vegetation type in STR is dominated by *Zizyphus mauritiana* in combination with *Acacia catechu, A. leucophloea* and *B. monosperma.* The understorey is formed by *Adathoda vasica, Cassia tora, Capparis sepiaria and Zizyphus nummularia. Cynodon sp, Eragrostis sp, and Chloris sp* are typical grasses found along with this type of vegetation type.

Riverine forest: In sariska, forests along the nallahs is more of wet conditions and have patches of trees like *Antherocephalus kadamba*, ficus species, *Phoenix sylvestris* and *Syzygium cumini* trees which are the typical trees species in those areas.

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 scorfa)* and jackal *(Canis aureus)*. Large carnivores found are eight reintroduced tigers (*Panthera tigris*), leopard (*Panthera pardus*), striped hyaena *(Hyaena hyaena)*. Small carnivores are caracal (*Caracal caracal*), jungle cat (*Felis chaus*), common mongoose *(Herpestes edwardse*), small Indian mongoose (*H. auropunctatus*), ruddy mongoose (*H. smithi*), palm civet (*Paradoxurus hermaphroditus*), small Indian civet (*Viverricula indica*) and ratel (*Mellivora camensis*). In 2009, recently desert cat (*Felis selvestris*) was reported from Sariska (Gupta *et al.* 2009). Earlier, the wild dog or

dhole (*Cuon alpinus*) was used to occur in STR (Sankar 1994) but there have been no sighting in the recent past. Rhesus macaque (*Macaca mulatta*) and common langur (*Seminopithecus entellus*) are the two primates found here. Procupine (*Hystrix indica*), rufous tailed hare (*Lepus nigricollis ruficaudatus*) are also found in Sariska TR.

Eleven species of small rodents captured during present study *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 norwegicus*), house rat (*Rattus rattus*) and pygmy gerbil (*Gerbillus nanus*).

Due to presence of villages inside and on the periphery a large variety of domesticated animals are also occurs within the park. These include buffaloes, cows, goats, camel, dogs and domestic cats.

Sariska also holds a variety of bird species including some winter migrants. Sankar *et al.* (1993) recorded 211 species of birds, of which 120 resident, 73 were migrant visitors and 18 considered as vagrants. It has very high density of peafowl as well as grey francolin (Kidwai 2009).

Though there is no perennial river or water stream (Ajith kumar and Sankar 1993), there are a number of ephemeral streams and pools found in Sariska TR. Except for a few natural springs, water in these locations dries up in summer (Sankar 1994). The common fish species found in water bodies in this park are *Noemachilus botia, Labio boggut, Puntius sarana, Garra gotyla* and *Rasbora daniconius.*

2.6. Human settlements

There are 31 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 Umri and Rotkala were relocated during 2013. In the revenue villages the occupation of the people is based on agriculture but in the grazing camps it is animal husbandry. A large number of buffaloes and goats, cattle, sheep and a few camels are kept in the villages. The human population is over 8500 in the villages of Sariska TR along with

a population 30000 livestock including buffalo, cow, goat and sheep (Sankar *et al.* 2009). These villagers depend totally on forests for their livelihood. The people inhabiting these villages are traditionally pastoralist and their main source of income is selling milk and its products like “Mawa and Ghee”.

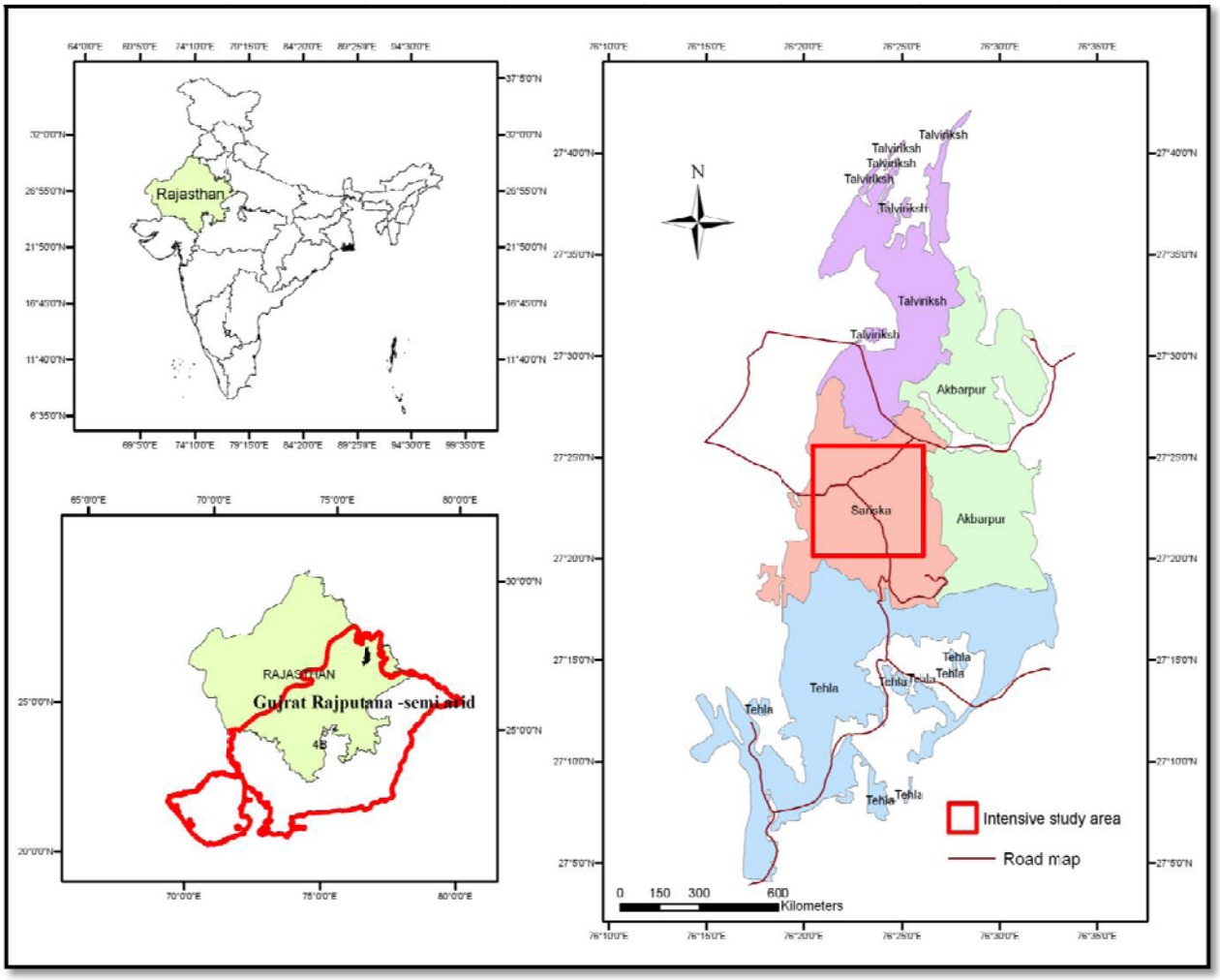
2.7. Tourism

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 hours. However on other days only day time tourism is allowed and the reserve remains closed after dusk.

2.8. Administrative units

Sariska Tiger Reserve comes under Sariska Circle and Sariska Division (Figure 2.1). Sariska TR has four ranges: Sariska, Akbarpur, Tehla and Talvriksh. Sariska range constituted of 20 beats, Akbarpur 17 beats, Tehla 25 beats and Talvriksh 13 beats.

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



CHAPTER 3

ABUNDANCE AND OCCUPANCY ESTIMATION OF JACKAL

3.1. Introduction:

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 i.e. $\boldsymbol{N = C / p}$ (*N*- The estimate of the population size; *p*- Detection probability or capture probability) (Royle and Nichols 2003). Abundance (the number of individuals in a population) is one measure that can be used to characterize the state of a population for a single species, with changes in abundance reflecting changes in the population's status. However, in order to make an accurate conclusion about changes in abundance, it is important that the probability of observing an individual is incorporated into the inferential process. The estimation of animal abundance is an important measure in both the theoretical and applied biological sciences.

Ecological research depends on the knowledge of animal abundance and how abundance is changing over space and time (Krebs, 2001). For many species, however, an accurate measure of abundance is difficult to obtain because some animals present in the study area may go undetected (Thompson, 1992). Instead of accounting for this, some monitoring programs use the observed counts as a proxy for true population size. This comes with the implicit assumption that either detection probability is perfect (if interest is in abundance), or the detection probability is constant on average across time (if interest is in trend in abundance). It has been shown for many species that analyzing raw counts without accounting for detection probability leads to bias in abundance and trend estimates (Wenger and Freeman, 2008).

In many monitoring programs one of the most difficult steps to overcome is obtaining data on elusive species. It is more challenging to estimate abundance of

some species that are nocturnal, cryptic and not individually identifiable from natural markings, by using conventional non-invasive techniques, such as distance sampling or photographic capture-recapture methods.

The reason behind using occupancy rather than abundance is that at an appropriate scale the two state variables should be positively correlated (i.e., occupancy may increase with increasing abundance), although the two state variables address distinctly different aspects of the population dynamics. However, for certain species the discrepancies between the two state variables may be minimal if the size of sampling unit is chosen appropriately. Few species are likely to be so conspicuous that they will always be detected at a sampling unit (site) when present. Dependent upon the survey methods being used, there may be a reasonable chance that the species goes undetected and is declared to be "falsely absent". By not correcting for the fact that the species may go undetected, a naïve count of the number of sites where the species is detected will underestimate the true level of occupancy. Inferences about changes in occupancy based upon an observed difference between two (or more) naïve counts to be made carefully, as the difference may be the result of a change in ability to detect the species rather than a change in occupancy. The arguments against using a naïve count for occupancy are very similar to those given for not using a simple count as an index of abundance (e.g., Yoccoz et al., 2001, MacKenzie & Kendall, 2002; Williams et al., 2002; Schmidt et al, 2003).

In biodiversity monitoring, it has become increasingly important to use presence-only data due to the high cost of collecting count data with a strict protocol. However, recent advances in 'occupancy modeling' of animal presence data derived from photographic captures might provide solutions to the problems of monitoring non-identifiable species. Site occupancy (presence/absence) modeling is recognized as an effective technique for monitoring populations of secretive species on a landscape scale, historically considered a daunting or even impossible task. Site occupancy modeling may be the only feasible metric for monitoring population status of some species, such as those with recapture probabilities too low to use mark-recapture models effectively (Dorcas and Willson 2009). For categorical, presence–absence data to be useful, however, estimates of species-specific detection probabilities must be incorporated into surveys. A specific occupancy approach – the

Royle and Nichols (2003), allows for 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. 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.

The density of lesser carnivores is perceived to be relatively low, thus making mark-recapture studies highly impractical for conspecifics. It is not always possible to obtain photographs of individuals within the species from camera traps. Mark-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., 2001) or multiple observers (Cook and Jacobson 1979, Nichols et al., 2000) are viewed as being time and effort consuming.

Despite the logistic constraints, these methods have been widely applied. A potential approach to estimating abundance involves shifting the focus from numbers of animals to numbers of sample units occupied by animals (Royle and Nichols 2003). Methods employing this general approach are based on presence-absence data from the sampling units. Royle and Nichols (2003) have developed a model based on this focus to estimate abundance from repeated presence-absence data or point counts. They link the probability of detecting presence and the abundance at a sampling unit by using repeated detection-non-detection data gathered from occupancy surveys, suggesting a maximum likelihood approach at estimating the parameters (that includes abundance). In spite of the relative ease with which presence-absence data may be gathered, achieving large samples for analysis as suggested by Royle and Nichols (2003) for even practical estimates of the parameters might be difficult. Therefore this study has relevance to advancing both the scientific understanding and conservation of non identifiable species in the study area and elsewhere in the world.

Management and conservation of species relies heavily on understanding the variation in population abundance or density of a target species. Small carnivore species tend to be difficult to study due to their elusive habits, and crepuscular or

nocturnal activities. The population density of carnivores is governed by several factors, including prey availability (Carbone and Gittleman 2002, Ramesh 2010), habitat structure (Pereira 2009) and hunting by humans (Duckworth et al., 2005). Camera trapping is becoming increasingly common in documenting small carnivores (Gardner et al., 2010, Gerber et al., 2010, Pereira et al., 2011). Field studies have recently provided empirical support for the use of a maximum likelihood spatially-explicit capture-recapture model (Kalle et al., 2011). Despite the availability of newer models, it is still common for studies to use traditional *ad hoc* density estimation techniques (Negroes et al., 2010). Small carnivores often have low detection rates, even with intense sampling efforts, which can either inhibit the application of closed capture-recapture analyses or simply provide imprecise estimates (White et al., 1982, Maffei et al., 2004).

However, modern analytical approaches that shift focus from counting animals to counting patches or sites potentially occupied by them can permit estimating populations of non-uniquely identifiable species. They must also deal with the fact that not all animals present even within a sampled unit are detected during the survey, and therefore that the probability of detecting an animal in the sampled area is often less than one (Williams et al., 2002, Karanth et al., 2004). Camera traps can indicate relative abundance of a species with the assumption that photo detection rates are related to animal abundance (Morruzzi et al., 2002). Although trapping rate surveys (e.g. Carbone et al., 2001) have been used as indicators of animal abundance, detection probability is generally not estimated while doing so. As a result, its use is controversial both on theoretical and practical grounds (Jennelle et al., 2002). If species presence data from camera trap photos could be used to model and derive animal abundances or at least to derive reliable indices of abundance, (which can effectively deal with imperfect detections) it will be a major advance in animal monitoring science.

In this chapter, I estimated the abundance of jackal using presence/absence data from repeated samples using camera traps. The present study also attempted to compare jackal occupancy and detection probability between seasons in Sariska.

3.2 Materials and methods

3.2.1 Sampling design for camera traps

Camera traps: A preliminary survey was carried out in the intensive study area of 160 km^2 in the National Park by surveying available trails. Indirect signs such as spoor, scats and track signs of jackal were identified and marked using a handheld Global Positioning System (Garmine ©72). Camera traps were placed in 2 x 2 km^2 grid on the basis of any evidence (spoor, scats and track sign) on the trails where the probability of theft of cameras was low (figure.3.1). Total 42 units of digital cameras that worked on passive infrared motion and heat sensors were deployed, out of which 20 units of cameras were of Spy-point FLA1 and 22 units were of Moultrie cam. The camera traps were having resolution of 4 megapixel, detection angle of 95° where, one sensor covering five zone detection and having date, time and identity (as specified by the user) printed in the picture obtained. The camera delay was kept at a minimum by default of 15 seconds and multi shot options at level three (three consecutive picture in every detection). A total of 160 locations were selected for the placement of camera traps in the study area. At each location, pair of passive infrared digital camera traps was placed opposite each other along the roads and trails. Since it was logistically difficult to conduct sampling at all these camera trap locations simultaneously, the trap points were divided into four blocks, having 21 camera trap stations at each block depending upon the feasibility of camera trap locations in the study area. Total 84 trapping locations covered minimum convex polygon area of 118.7 $km^2$and an effective trapping area (ETA) of 223.8 km^2. The mean inter trap distance was 750 m (ranging from 700 m to 1.2 km) and each camera traps ran for 32 consecutive occasions with the total sampling period amounting to 128 days (1344 trap nights per season). Capture matrix was prepared from each sampling occasion combined with captures from one day drawn from each block (Otis *et al.,* 1978; Harihar *et al.,* 2010; Gupta *et al.,* 2010). The camera trapping was done in two seasons, winter (mid of October to February) and summer (March to July mid) depending on the logistics.

Cameras were kept approximately 25 cm above the ground and set to be active for 24 h/day. Bob cat lure was used at each location to attract animals. I

checked sampling stations on an average of every 5 days to ensure continued operation of cameras and replaced batteries and SD memory cards when required.

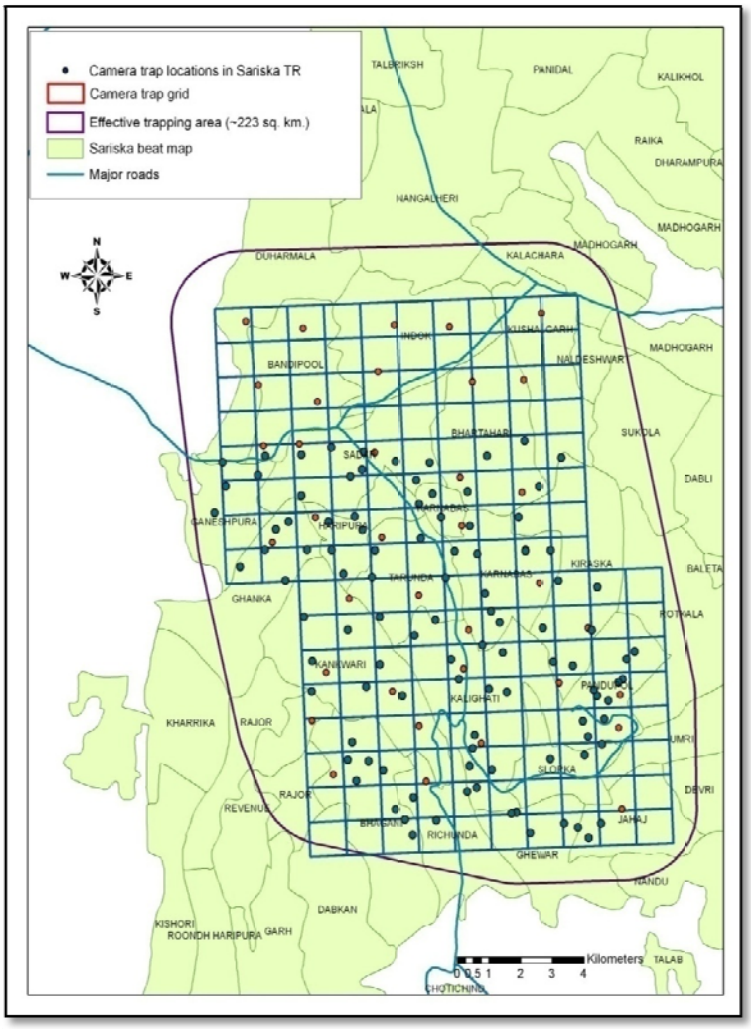


Figure.3.1. locations of camera traps and effective trapping area in the study area.

3.2.2. Relative abundance index

Photographic rate is the relative index of the animal's spatial use and a crude abundance estimate (Carbone et al., 2001). Photographs provided information on date and time of the picture taken. Sometimes, individuals were photographed from only one of the two cameras operating at a single camera station. The event of capturing an individual, whether it was photographed by two camera traps or one, was considered to be an independent record of that individual. On some occasions, individuals were captured more than once at a camera station during a period (<1 min); thus, to avoid

pseudo-replications, I considered the first capture of the jackal as an independent record. Photos with more than one individual in the frame were counted as single detection for the species. I calculated relative abundance index (RAI) for each camera trap location by dividing the total number of independent records from the total trap nights x 100 (Carbone et al., 2001, O'Brien et al., 2003). Hence the RAI for each species is presented as the number of photo captures per 100 trap nights (Kalle, 2013). To compare RAI of a species between seasons, I used Student's t-test in program SPSS 16 (SPSS 2007).

3.2.3. *Occupancy analysis*

Since the identification of individual jackal is difficult, the estimation of abundance using capture-recapture models used in camera-trap surveys of large cats was not possible. One possible solution is to use occupancy as a surrogate for abundance (MacKenzie and Nichols 2004). MacKenzie et al., (2002) developed a model to estimate site occupancy and detection probability based on repeated presence–absence data from multiple sites. Royle and Nichols (2003) extended this model to allow for abundance-induced heterogeneity. The Royle and Nichols (2003) model assumes that populations are closed and individuals are distributed in space according to a Poisson process. If these assumptions are violated, the estimated parameters should not be interpreted as abundance but rather as a random effect (MacKenzie et al., 2006). However, occupancy estimates will still be less biased than models that do not include heterogeneity. For analysis, I defined the minimum time between two independent events as 5 min. This means that if the individual was photographed more than once by the same camera in the course of 5 min, this was only counted as one event. Capture histories were developed for each location by treating one day as 1 trapping occasion (eg., days 1 = first trapping occasion, days 2 = second trapping occasion, etc.). For each occasion the target species could get a 1 or a 0, where 1 indicates that the animal was captured at the sampling station during that trapping occasion and 0 if it was not captured.

I used Royle and Nichols (2003) heterogeneity model and repeated count method (Royle 2004). The Royle and Nichols (2003) model assumes that variation in animal abundance from one site to the next is probably the most important source of heterogeneity in detection probability among sites. They suggest that by basing heterogeneity in detection probability on varying site-specific animal abundance, it is

possible to exploit this very relationship to estimate the abundance parameter, and consequently derive the probability of occupancy. They use the occupancy based approach and assume that the detection probability of a given species at a particular site is directly dependent on the abundance of that species in that site for a given animal's specific detection probability. Consequently, the heterogeneity in detection probabilities across sites is caused by the heterogeneity in abundance across those sites. And, by modeling the variation in abundances according to some probability distribution model (e.g., Poisson, when the number of animals inhabiting one site is random and independent of the number of animals at other sites), they build a model based on maximum likelihood to arrive at estimates of abundance in these sites. Modeling was conducted based on *a priori* ecological information and home range estimates of these species from available literature. There could be a possibility that these species would even travel beyond 1 km^2 thus modeling based on the aforementioned assumption would give unbiased abundance estimates.

The Royle and Nichols (2003) model assumes that populations are closed and that individuals are distributed in spaces according to a Poisson process , and the probability of detecting an animal at a site is a function of how many animals are actually at that site. The spatial distribution of animals is simply how many animals occur at each camera site within the study area. Each of the camera sites will contain some number of animals (some sites may contain 0 animals). That number, the site abundance, is a function of the mechanism governing the distribution. The spatial distribution of animals can meet Poisson assumptions when the number of animals inhabiting one camera site is random and independent of the number of animals at other sites. Eventually there are chances of multiple individuals occupying a camera trap site. Both models were analyzed in program Presence 4.1 (http://www.mbrpwrc.usgs.gov/software/presence.html).

To investigate the relative abundance for golden jackal I looked at differences in detection probability, occupancy rates and average abundance between seasons in each year. Hence estimated average abundance (λ) is interpreted as individuals per km^2. Mean abundance estimates were compared between two years and seasons using Student's t-test in program SPSS 16 (SPSS 2007). I performed a Pearson correlation

test between mean abundance (λ) as obtained from occupancy approach and relative abundance index (captures/100 trap nights).

3.3 Results

3.3.1 *Capture success and sample adequacy*

Totally, 6720 trap-nights yielded 202 photographs of jackal, of which 11.88 % (n = 17) was obtained in summer 2011, 40.56 % (n = 58) in winter 2011-12, 14.69 % (n = 21) in summer 2012 and 32.87 % (n = 47) in winter 2012-13 (table.3.1). Jackal photo captures rate stabilized at minimum of 29 occasions (29 days) in 223 km^2 effective trapping area in the study area (figure.3.2).

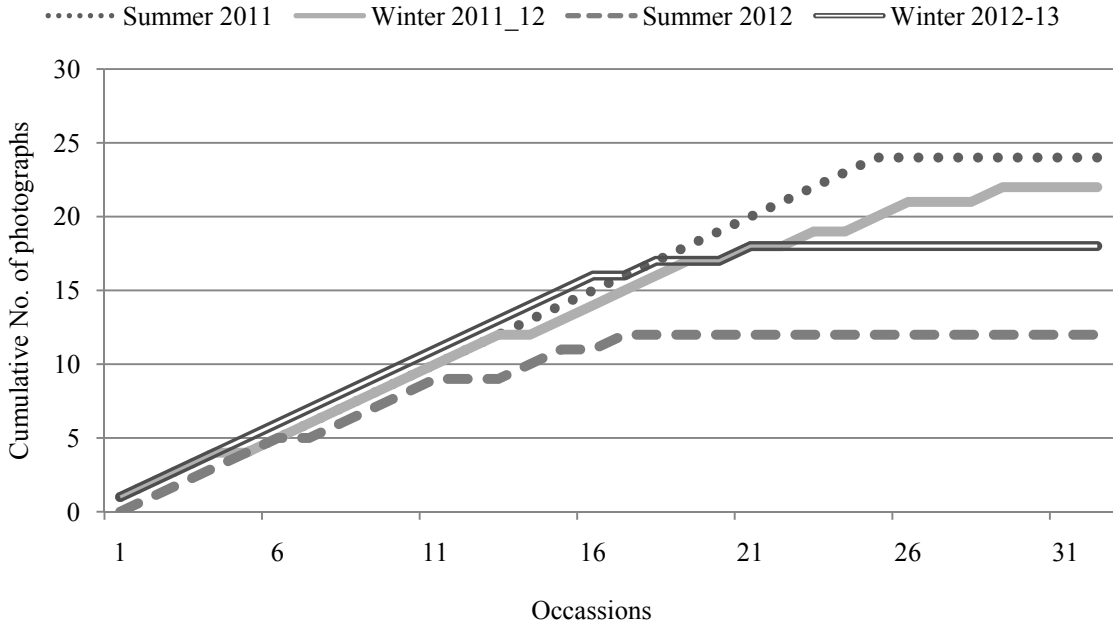


Figure.3.2. Number of total photographs with increasing number of sampling occasions to evaluate sampling adequacy during the study period in Sariska Tiger Reserve, Rajasthan.

3.3.2. *Relative abundance index*

Average capture frequencies of jackal across the years ranged from 1.26 captures/100 trap-nights to 4.31 captures/100 trap-nights. Jackal RAI differed significantly across two years (t test; t =6.23, df = 2, P = 0.00) but, did not differ seasonally (t test, t = 9.51, df = 1, P = 0.06).

Table.3.1. Overall photo captures and relative abundance index (captures/100 trap nights) of golden jackal in Sariska Tiger Reserve (2011 to 2013).

Table.3.1. Overall photo captures and relative abundance index (captures/100 trap nights) of golden jackal in Sariska Tiger Reserve (2011 to 2013)

Year	**Season**	**Photo captures**	**RAI**
2011	Summer	17	1.26
2011-12	Winter	58	4.31
2012	Summer	21	1.56
2012-13	Winter	47	3.49
Average		35.75	2.65

Table.3.2.Detection probability (*r)*, average abundance/km^2 (λ), site occupancy (Ψ) and total abundance (N) with associated standard errors (± SE) for golden jackal based on camera trap data using the Royle-Nichols Heterogeneity model.

Year	Season	r_{mean} ± SE	λ_{mean} ± SE	Naïve occupancy	Ψ_{mean} ± SE	N_{mean} ±SE	95% CI_{mean}
2011	Summer	0.04±0.01	0.22±0.13	0.17	0.22±0.12	14 ± 6	7.5-34.2
2011-12	Winter	0.06±0.01	0.37±0.09	0.25	0.31±0.06	29 ±7	18.2-47.2
2012	Summer	0.04±0.01	0.28±0.10	0.19	0.24±0.07	16 ± 5	7.9-33.4
2012-13	Winter	0.07±0.01	0.38±0.10	0.26	0.31±0.06	27 ± 6	16.9-49.3

3.3.3. *Detection probability*

Estimates of detection probability of jackal varied from 0.039 to 0.069, with standard errors from 0.012 to 0.014 (table.3.2). Detection probability varied across the years (t test, t = 7.26, df = 3, P = 0.01) and did not differ significantly in summer (t test, t = 1.48, df = 1, P = 0.07) and winter (t test, t = 10.5, df = 1, P = 0.06) across two years.

3.3.4. *Occupancy and average abundance*

Detection probability (r) of jackal was estimated high in winter (0.07 ± 0.01) as compared to summer (0.04 ± 0.01) and the probability of site occurrence (Ψ) of

jackal was found high in winter (0.31 ± 0.06) than summer (0.23 ± 0.19). Seasonal estimates of occupancy varied from 0.22 to 0.31, with standard errors from 0.07 to 0.12 (table.3.2) and the average abundance ranged from 0.22 to 0.38 with standard errors from 0.09 to 0.13 in two years (tables.3.2). Modeled site occupancies were observed greater than naïve occupancy. Jackal site occupancy differed significantly across years (t test, t = 11.51, df = 3, P = 0.001) and in summer (t test, t = 23.00, df = 1, P = 0.03) although no significant difference was observed in winter across two years (t test could not be done for the same values of the occupancy estimates). Abundance (*N*) obtained from occupancy approach and relative abundance index (captures/100 trap nights) were not significantly correlated (Pearson correlation test, p = 0.93, n = 4, P = 0.07) with each other. And there was a significant positive relationship between mean abundance (λ) and RAI (Pearson correlation; R_2 =0.87, n = 8, P = 0.004, figure.3.3).

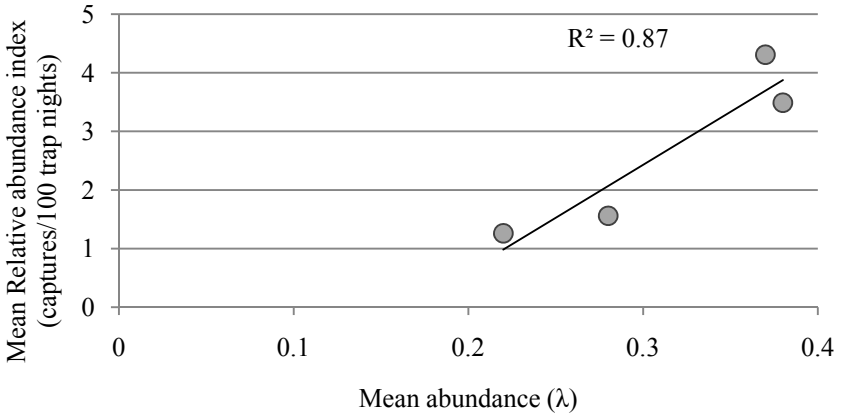


Figure.3.3. Relationship between mean abundance (λ) and relative abundance index (captures/100 trap nights) for jackal in Sariska Tiger Reserve, Rajasthan.

3.4 Discussion

I provided estimates of detection probability, site occupancy and relative abundance for jackal in Sariska using occupancy based Royle and Nichols (2003) model which provides 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. There was considerable inter season variability in species detectability. However, occupancy estimates for frequently occurring species such as jackal, were statistically robust and useful as a population index over time, although results should be interpreted cautiously. Confidence intervals were high indicating

small sample size of captures in terms of total effort. Home range of jackal is unknown for the area and hence it could exceed the subunit area sampled such that occupancy estimates represent an area that is used by the species (MacKenzie et al., 2006). Occupancy and abundance estimates are comparable to the other studies (Gupta 2011). 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). Although heterogeneity could be accounted for indirectly, in traditional methods, by inclusion of covariates in a model for *p* (capture probability), it is not always possible to observe covariates that are correlated with abundance. The benefit of occupancy approach (Royle and Nichols 2003) is that it is based on the direct linkage between *p* and local abundance *N*, which is a consequence of binomial sampling. The approach uses the data from occupancy surveys to draw inferences not only about proportional occupancy of sample units, but also about abundance in some situations.

It is believed that occupancy surveys also will be useful in meta-population studies involving multiple visits to many different sites among which animal movement is hypothesized (Royle and Nichols 2003). The method provides a means of properly estimating occupancy probabilities and associated functional relationships when there is heterogeneity of detection probabilities associated with variation in abundance over patches or sampling units. In addition to reasonable estimation of occupancy rates, the information on the distribution of abundance over sampling units may be very useful in meta-population studies as well (Royle and Nichols 2003). Meta population models range from very simple to fairly complex. Under the simplest models (e.g., Levins 1969, 1970), all patches are assumed to be equal with respect to the parameters governing patch occupancy dynamics, local colonization, and extinction probabilities. Perhaps the most detailed meta-population models involve the use of structured multisite matrix models that model the abundance of each age or stage class at each location as functions of class and location specific vital rates and rates of movement (Rogers 1966, Le Bras 1971, Schoen 1988, Lebreton 1996, Lebreton et al. 2000). Models of intermediate complexity and detail include those of Gyllenberg and Hanski (1992) and Gyllenberg et al. (1997), in which the abundance or population size of each patch is a state variable of interest. The method

provides means of estimating distribution and yield opportunities to test model predictions.

The results from the study by Gupta (2011) in the same study area 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. Jackal seemed to be a generalist with high occupancy in Sariska where, variation in detection rate was observed across the four blocks. High abundance of jackal in open scrub habitat was documented by Mukherjee (1998) and Gupta (2011). Jackal spatial distribution in the dry season could have been clumped towards water sources resulting in its low site occupancy in summer. Estimates of carnivores from available studies were mostly photographic indices that are only an index of abundance. Much work on lesser carnivores have used night walks along established trails to estimate encounter rates or densities, however in many areas, these may be time consuming and labour-intensive and preclude wider spatial coverage (Kalle, 2013). In this study, occupancy rate under both the models and abundances were expected to be close to those estimated. However, fair estimates with relatively high standard errors can be expected when the numbers of detection sites are clumped or close to each other as revealed in the present study. Jackals were 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 the season showed variability (0.03 to 0.06) and abundance range from 14.46 to 29.31. 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 as compared to the Mac Kenzie *et al.,* (2002) model which implicitly assumes that sites have a constant or nearly constant abundance.

Nevertheless this study will serve as scale database against which future estimates from the same area/habitats/landscape can be compared and refined. This study showed that the models can indeed be used to estimate abundance for jackal for

which conventional methods cannot be used. To understand jackal ecology and status, future monitoring should consider comparative methods to assess abundance with field methodological modifications such as howling (Jaeger et. al., 1996).

The use of a simple Relative Abundance Index (RAI) based on camera-trap encounter rates for ecological studies is controversial particularly when a large number of variables (e.g. body size, average group-size, behavior) are likely to affect trapping rates and detection probability and thus confound the relationship with actual abundance (Carbone et al., 2001, Jennelle et al., 2002, Treves et al., 2010). However, there was an increasing evidence for a linear relationship between RAI and abundance estimated through more rigorous methodologies (Rovero and Marshall 2009). I used scent stations using bobcat lures to address the issues with the variable body size and behavior in photo trapping success. Camera trapping rate proved to be a useful index of abundance for jackal in this study. However further comparative studies over different habitats, forest types at the landscape scale may aid in standardizing this technique. It is intuitive that camera trapping rate should be related to abundance. As density increases, the chance of encounters between individuals and cameras would be expected to increase. The likelihood of the observed relationship between camera trapping rates and density (from line transect) was applicable in forest ungulates (Rovero and Marshall 2009). This method has the potential for temporal comparison of populations and may facilitate to standardize and reduce costs of monitoring programmes. However different camera trap models would have different detection probabilities that could affect trapping rates which should be considered. However, the performance of the camera traps used in present study were satisfactory having average of 1032.2 ± 473.6 pictures/camera trap/day obtained in each block seasonally. High standard error was accounted for variability in detection rate at different location and climatic conditions such as rain and wind resulting in waste captures.

Jackals are observed to be more patchily distributed than large species in the study area. Sariska is a relatively large contiguous semi-arid forest system now having eight villages inside the Intensive Study Area (ISA), inducing high human and livestock disturbance. The border of Sariska is surrounded by crop fields and small towns which are strongholds of crop land, open scrub and human generated waste that

have great potential in having high rodent densities and other food source in terms of garbage. Although the study area is under tremendous pressure from anthropogenic activities, jackal seem to be tolerant to some degree of habitat alteration however, through long-term monitoring it is necessary to understand their spatial responses towards the degree of human disturbance and weather Protected Area (PA) provides them cover. The results of this study showed that the occupancy-based Royle and Nichols (2003) can provide useful tool for the estimation of abundance of non-uniquely identifiable and cryptic species. Parameter estimates with high standard errors have high uncertain estimates, and therefore reliable estimates of absolute abundance may not be obtained. However, it is still possible to arrive at an index of abundance that takes detection probability into account. Such an index is comparable across temporal scales for instance, and can provide important insights into population trends.

Jackals were not widely dispersed across sampling locations, but clustered in a few locations in the ISA. Sites may not be independent, especially if sites are adjacent (such as in a grid) because animals leaving one site will enter another site by necessity **(**Dail and Madsen 2010). One way to model this dependence may be to include the abundance at surrounding sites, weighted by distance. An alternative is to use Bayesian hierarchical modeling and the spatial dependence models developed by Royle et al. (2007). However, incorporating these models has proved difficult, so this remains an area of active research. Second, the number of animals surviving and staying at a site will not be a binomial random variable if clusters of animals survive or emigrate together. Although, Royle (2008) gives a framework for modeling the effect of cluster size in wildlife surveys, patch occupancy provide extremely useful tools for the detection of trends in wildlife population abundance and species presence/absence (Mackenzie et al., 2006). The main advantages they offer are explicit treatment of detection probabilities, error assessments, and estimation of confidence intervals (Mackenzie et al., 2006). The inter-annual variation as well as seasonal variation in abundance of jackal could be related to changes in resource abundance, shifts in habitat use or other non measured biotic/abiotic factors such as competition with dominant predators, suggesting that future studies on population monitoring must be continued over time taking these unmeasured variables into account. I recommend that in order to efficiently document abundance camera-

trapping will need to be augmented by other methods such as spotlight surveys and howling stations to detect jackal presence and territorial behavior. This study confirms that Sariska Tiger Reserve harbors fair abundance of jackal population, an opportunistic predator surviving in presence of large carnivore like tiger, leopard and hyena.

CHAPTER 4

FOOD HABITS OF JACKAL

4.1. Introduction:

Ecologists have often acknowledged differences in body-size, feeding behavior and morphology among sympatric carnivores enabling differential food exploitation to potentially reduce competition (Rosenzweig 1966). Diet of small carnivores includes a wide range of animals, plants, insects, crustaceans, vertebrates from birds to large mammal carrion and fruits. Although they must respond at some level to site productivity, the tremendous range of food items they eat is produced in such a wide range of environment, and so difficult to measure, that the apparent food abundance is not highly predictive of the distribution or abundance of most species. A central theme in ecology is how animals respond to variation in food abundance and distribution. For some species, resource fluctuation may drive seasonal movements or regulate populations (Wiens 1976) where, other species may simply switch their diet in response to scarcity of a given prey type (Martin et al., 1951, Whelan et al., 2000). Some predators switch between primary and alternative prey items as the availability of food resources change. Although temporal switching of prey is well documented, spatial switching (e.g. foraging in different habitats) remains controversial (Prugh 2005). Generally, prey switching may be a consequence of the choice of prey items within a habitat or of the choice of habitat with different types of prey. This diet switching has been documented for the red fox *Vulpes vulpes* (Ferrari and Weber 1995, Kjellander and Nordstro¨m 2003), martens *Martes Americana* (Thompson and Colgan 1990) and masked palm civet *Paguma larvata* (Zhou et al., 2008).

One way of understanding community organizations, could be to measure overlap in resource use among the different species in a community guild (Krebs 1989). The extent of niche differentiation and resource partitioning determines the degree to which different species can either coexist or competitively exclude each other (Pianka 1973; Carvalho & Gomes 2004). An important mode of resource partitioning is the degree of dietary overlap between sympatric species (Hayward &

Kerley 2008). This overlap is influenced by each species' physical ability to obtain food (Radloff & du Toit 2004; Owen-Smith & Mills 2008), and also by variation in the spatial and temporal availability of food (Azevedo *et al.* 2006). For distinct carnivore guilds different mechanisms may be involved, such as different body sizes of predators (Carvalho & Gomes, 2004), different prey species (Karanth & Sunquist, 2000), different prey sizes (Juarez & Marinho-Filho, 2002), different activity patterns (Loveridge & Macdonald, 2003) and differential microhabitat use (Johnson & Franklin, 1994). Higher food overlap, however, does not necessarily mean competition. Species can still coexist if: 1) food is abundant, 2) prey is partitioned by size (Rosenzweig 1966) or differential use (Mills 1984), and/or diversity is greater in the diet of one species' than it is in the other (White et al., 1995). However, where resources are limited, the strength of competition between sympatric species generally decreases with increased resource partitioning (Pacala & Roughgarden 1985).

Factors affecting food choice by predators generally differ across landscapes, and this knowledge is essential to determine the ability of predators to deal with different prey compositions and habitat characteristics. Diet studies have shown that seasonal variation in fruit consumption is quite common in frugivorous carnivores (Ferrari and Weber 1995, Martinoli et al., 2001). Study by Dickman (1988) showed that the smaller predators in an insectivorous mammal guild took the smaller prey but then switched to larger prey when the larger predators were removed. Consequently prey selection could depend more on competition among predator guild members than on any inherent relationship between predator and prey sizes. Most of the earlier studies recorded the overall frequency of occurrence of various food items in the scats or stomach content. Rarely can one find enough information to compare the diet of the species and seasonal variation, especially where they are sympatric (Rabinowitz 1991). However, explicit and quantitative covariation with fruit supply (i.e. spatio-temporal variation in fruit abundance is linked to changes in the diet of carnivores) is yet to be addressed in most carnivores and other fruit eating mammals (Moegenburg and Levey 2003).

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 transects 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.

In studies including wide size range of mammalian predators there is high variability in the diets of the smaller species, which can switch between insectivory, omnivory and canivory. Canid and felid species above certain threshold weight class prey purely on vertebrates, while those below may feed omnivorously or prey on both invertebrates and vertebrates. This implies that large carnivores (>21.5 kg) constitute a distinct functional group from which predator-prey size relationships should emerge more clearly than from carnivore assemblages that are distributed across both sides of the body mass threshold (Ray & Sunquist 2001). The diet of golden jackal comprises high proportion of small and large mammals, corroborating that they do both scavenge and hunt competently. 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).

A few studies in India documented the feeding ecology of sympatric small carnivores (Joshi et al., 1995, Mukherjee et al., 2004, Mudappa et al., 2010, Gupta 2011). For the present study I evaluated the food habits of jackal (*Canis aureus*), striped hyena (*Hyaena hyaena*) and jungle cat (*Felis chaus*) and compared dietary overlap amongst them in Sariska Tiger Reserve. These three species are abundant in the semiarid part of the country and their diet ranges from wild undulates to domestic livestock and rodents. Although few studies investigated the diet of above mentioned species separately (Sankar 1988; Mukherjee *et. al.* 2004; Aiyadirai & Jhala 2006; Singh 2008) in India and in other countries (Reynolds & Aebischer 1991; Lanszki *et. al*. 2006; Giannatos *et. al.* 2005 Yom-Tov *et. al.*, 1995), only Merve *et. al.* (2009) investigated the overlap and resource partitioning, which may vary with the presence or absence of apex predators. The potential food availability increases for meso-predaror as dietary items previously unattainable, are killed by apex predators, and inter-specific competition declines concomitantly. The objectives of my research were: 1) to study the interspecific differences in feeding habits of golden jackal, striped hyena and jungle cat 2) to examine the preferences for major food items preyed upon in relation to their biomass; 3) to analyze the tropic niche separation and overlap between these sympatric carnivores based on diet composition.

4.2 Materials and methods

The study was conducted from April 2011 to March 2013.

Estimation of prey populations:

4.2.1 Ungulates and ground birds:

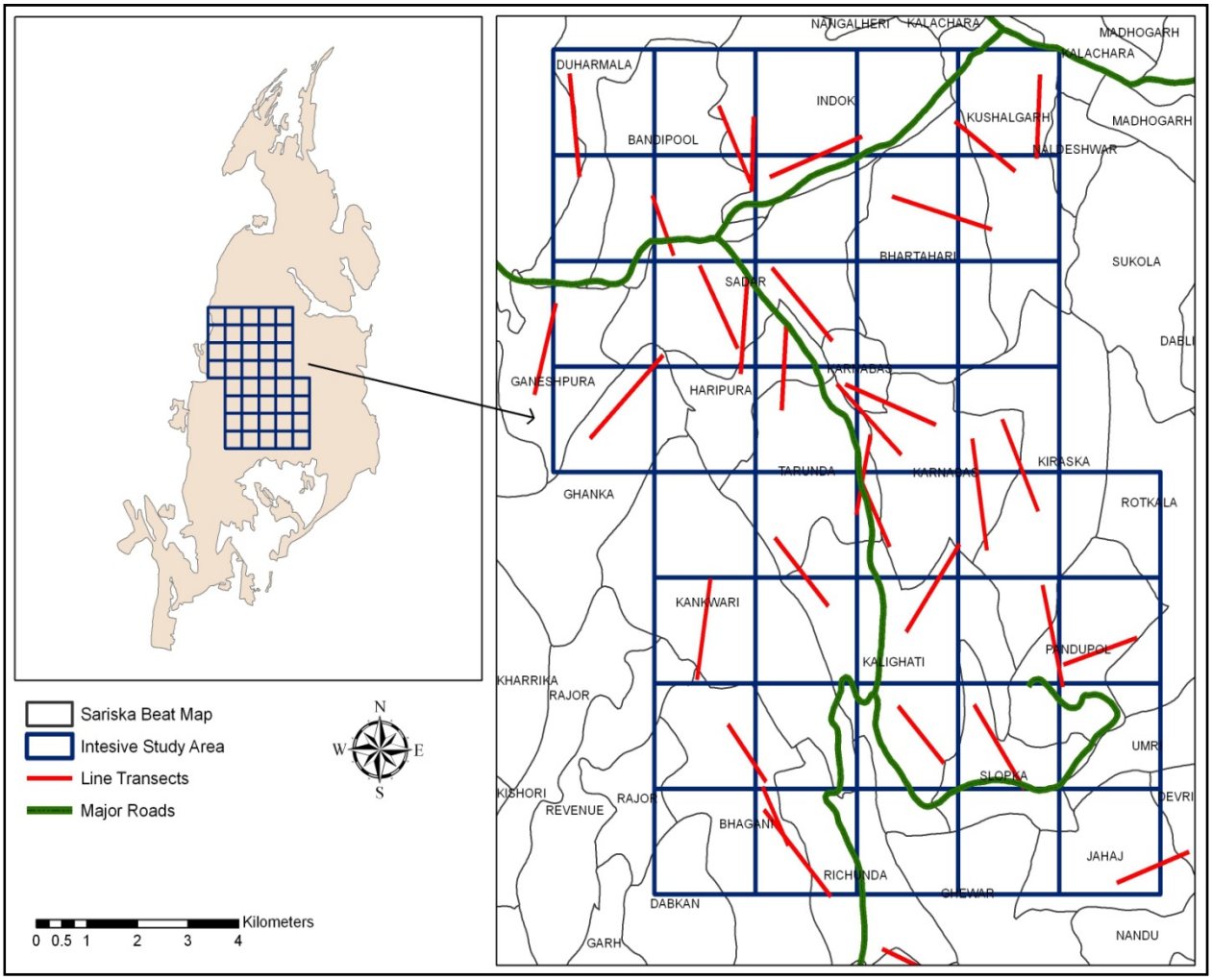
Densities of the wild prey species including ungulates and ground birds in the study area were estimated using line transects (Anderson *et al.,* 1979; Burnham *et al.,* 1980; Buckland *et al.,* 1993, 2001). Thirty transects were laid in the intensive study area **(**Figure 4.1**)**. The length of transects varied from 2 km to 3 km. All transects (total length = 61.0 km) were walked thrice in the early morning between 0700 hrs and 0930 hrs during winter (November to February) and between 0630 hrs and 0930 hrs during summer (March to June) during the study period. The total effort was 183 km in each season. The data was analyzed 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).

4.2.2 ***Rodent and shrew abundance estimation***

Web trapping is preferable to other techniques in estimating population density of small mammals (Otis et al., 1978, Wilson and Anderson 1985). Few studies on rodent abundance are available in India (Chandrasekar-Rao and Sunquist 1996, Shanker and Sukumar 1998, Gupta *et. al.* 2013). Density of rodents and shrews were estimated using a trapping web design by Anderson *et.al.* (1983). Rodent trapping was conducted in 14 locations to assess seasonal changes in relative abundance. Each location was operated by a single trapping web using 41 Sherman traps (H. B. Sherman Traps, Inc., Tallahassee, Florida). Trapping was conducted for two years at each location once in summer and winter amounting to a total effort of 5740 trap-nights in each season. Each trapping web consisted of eight radial lines 50 m each at cardinal directions. Each trapping line had 5 traps; placed at 10-m intervals from the center (10, 20, 30, 40 and 50 m). The traps were baited with peanut butter. The circular area of each web was 0.25 ha. Traps were set in the evening and checked the next day morning. All rodents and shrews captured were sexed, weighed, measured, marked and released at the trap site. Oil paint was used for marking an individual and different body location of an animal was chosen for marking corresponding to their number of captures. Animal captured for first time was marked in right fore limb, second time in left fore limb, third time in right hind limb, firth time in left hind limb, fifth time in right ear, sixth time in left ear, seventh time in

forehead, eighth time in nape, ninth time in back and tenth time in tail. The paint used was not long lasting but it sustained till completion of the trapping session of a site. Small mammals were identified using appropriate field guides (Prater 1971, Menon 2003). Data for each trapping period were pooled for two years for statistical analyses. Rodent and shrew density was estimated using program Distance 6.0 (Thomas et al., 2009) and Mark (White and Burnham 1999). Analysis was done with fitting different detection functions to the observed data.

Figure 4.1. The locations of line Transects in the intensive study area (Sariska National Park)



The best model was selected on the basis of the lowest Akaike Information Criteria (AIC) values (Burnham et al., 1980, Buckland et al., 2001). Each dataset was analyzed by four models (uniform, half-normal, and hazard and negative exponential) with three possible model adjustments (cosine, polynomial, and hermite). Suitable

modifications in right truncation were made so as to ensure a reliable fit of key functions and adjustment terms to the data so as to arrive at density estimate.

4.2.3 *Porcupine and hare abundance estimation*

Camera trapping was used to estimate abundance of hare and porcupine in the study area using the same design as mentioned in chapter 3. Camera traps were placed in 2x2 km^2 grid. Total 42 units of digital cameras that worked on passive infrared motion and heat sensors were deployed, total of 160 locations were selected for the placement of camera traps in the study area. At each location, pair of passive infrared digital camera traps was placed opposite each other along the roads and trails. The trap points were divided into four blocks, having 21 camera trap stations at each block depending upon the feasibility of camera trap locations in the study area. Total 84 trapping locations covered minimum convex polygon area of 118.7 $km^2$and an effective trapping area (ETA) of 223.8 km^2. Each camera traps ran for 32 consecutive occasions with the total sampling period amounting to 128 days (1344 trap nights per season). Capture matrix was prepared from each sampling occasion combined with captures from one day drawn from each block (Otis *et al.,* 1978; Harihar *et al.,* 2010; Gupta *et al.,* 2010). The camera trapping was done in two seasons, winter (mid of October to February) and summer (March to July mid) depending on the logistics. Cameras were kept approximately 25 cm above the ground and set to be active for 24 h/day. Bob cat lure was used at each location to attract animals. Abundance of the study species was compared between seasons using Student's t-test (Zar 1999).

4.2.4. *Zizyphus Fruiting seasonality and biomass estimation*

Ten *Zizyphus mauritiana* trees were permanently marked with tags and monitored every week in one hectare area at 12 different locations (n = 120 sampling trees). The tagged trees were monitored every week for presence/absence of fruits and fruit production during the fruiting season from December to March. For fruit biomass estimation, fruit production of the tagged trees was monitored every week. Ten iron mesh frames of size 50 x 50 cm were deployed under the canopy of tagged sample tree and grounded with the help of iron nails to avoid its replacement by wild animals. Total fruit biomass was estimated by weighing the total number of fruits deposited in a mesh net for a week and multiplying it by an average weight of fruit.

The average frit deposition of an area (10 plants) was then used to calculate expected availability by multiplying it with the area of forest falling under *Zizyphus* forest type category. I estimated the availability in g/ha and g/km^2 for various analysis.

4.2.5. Diet composition

4.2.5. a. Scat sample collection and identification of scats

Diet of jackal was studied through scat analyses, a widely used method as described by Mukherjee *et. al.* (2004). In total 18 trails, each 5 km in length were surveyed systematically once a month. During the first visit to each trail all detected scats were removed to ensure that only fresh scat were collected during later visits. In addition, scats were also collected along roads and trails opportunistically. Jackal scats were identified from their characteristic shape, size and nearby tracks.

4.2.5. b. Identification of food remains in jackal scats

After collection, scats were kept in a paper bags, and subsequently air-dried. Scats were washed in water through a nylon mesh sieve to separate food remains and later sun-dried. Dietary components were identified to species/taxa level based on pertinent anatomical elements such as hair, mandibles, scales, feathers, wings, fruit cuticles, and seeds. Hair remains were identified with the help of reference slides available at the Research Laboratory of Wildlife Institute of India.

4.2.5.c .Prey species biomass consumption using feeding trials on jackal

I conducted feeding trials on jackal at Jaipur Zoo, Rajasthan during January to March 2013 to evaluate biomass consumption of food items using the procedure followed by Floyd *et. al.* (1978), Weaver (1993) and Jethva and Jhala (2004) for wolves. They conducted feeding trials of Indian wolf, where biomass consumption was computed from prey occurrences. The whole carcass of prey species such as rabbit (*Oryctolagus spp*) which is similar to wild hare in size, goats (*Capra hircus*), sheep (*Ovis aries*), chicken (*Gallus gallus domesticus*) buffalo (*Bubalus bubalus*) and fruits were weighed and fed to the group of six jackals in captivity. In most of their range in India, jackal thrives on domestic livestock, and hence the feeding trials covered the entire range of weights for prey normally consumed by jackal except for small rodent like rats and shrews. Rats and shrews could not be included in the trials because of the quarantine issues in the Zoo envirnment. The jackals were fasted for

36–48 hr before each trial to clear their digestive systems, and all scats were removed from the enclosure. All of the jackals included in the feeding trials were fed with a single type of prey in each trial. The carcasses were kept in the enclosure until the jackal ceased feeding on them. Uneaten carcasses were removed and weighed to determine the weight (kg) of the carcass consumed by the jackals. Scats were divided into two categories according to their structure: collectable (firm feces) and non-collectable (dark, watery, loose feces) (Floyd et al., 1978; Weaver, 1993). Collectable scats were collected in the enclosure once a day for 72 hr after the jackals' last feeding attempt. The scats were collected in paper bags, sun-dried, and then oven-dried in the laboratory at 60°C. The wet weight and dried weight of scats were recorded. The correction factor was determined by calculating consumed prey mass per excreted collectable scat for each feeding experiment. The apparent digestibility was determined for different prey sizes as (mean fresh prey mass consumed per jackal – mean fresh collectable scat mass per jackal) *100/mean fresh prey mass consumed per jackal. This digestibility is termed 'apparent' because the scats also contain metabolic components from the animal (Jethva and Jhala, 2004). The moisture loss was estimated from a dressed fresh carcasses of bait provided for 72 hr. The carcasses were accurately weighed every 12 hr and left exposed to the environment. Percent weight loss from the entire carcass and from a separated portion of bones and hide was regressed against time to estimate moisture loss.

I estimated the diversity of jackal's diet using Shannon diversity index (Magurran 2004), randomizing the original order of scat samples (1000 iterations) using the software EstimateS (Colwell 2006). Following this I assessed dietary diversity against sample size to determine whether the sample size was adequate to describe the diet of each predator.

I expressed diet composition in three complementary ways: fresh biomass consumed (D), percentage of occurrence, and expected number of individual consumed (C). Biomass consumed was calculated as frequency of occurrence of prey remains multiplied by correction factor Y i.e. number of collectible scats produced per prey (F x Y) and number of individual consumed was calculated as relative biomass consumed divided by average body weight of a prey(D/B).

The percent occurrence of prey items in the diet (Genovesi et al., 1995) was calculated as: number of occurrences of species / taxonomic group or fruit remain x 100/total number of fecal samples. The relative frequency of occurrence (Loveridge and Macdonald 2003) was defined as: number of occurrences of species / taxonomic group or fruit remains x 100/total occurrences of all food types in all samples. All three measures were treated cautiously because scats collected in series can contain common contents from a single large meal, or similar locally common small items, but small items can be overestimated (Atkinson et al., 2002). Mann- Whitney *U* test was applied to evaluate for the seasonal differences between species.

To assess similarity of food composition between golden jackal, striped hyena and jungle cat, the Pianka's niche overlap index was calculated (Pianka 1973) during the study period by using the following formula:

$$O_{AB} = \frac{\sum_{i=1}^{n} P_{iA} \times P_{iB}}{\sqrt{\sum_{i=1}^{n} {P_{iA}}^2 \times \sum_{i=1}^{n} {P_{iB}}^2}}$$

Where, p_i is the relative frequency of prey items i in the diet of species A and B (jackal, hyena or jungle cat in following case). The index of overlap (O) ranges in value from 0 (indicating no overlap) and 1 (complete overlap). To estimate niche breadth, Levin's measure (1968) was used, which is represented as in following equation:

$$B = \frac{1}{\sum {p_i}^2}$$

Where B is the Levin's measure of niche breadth and p_i is the proportion of individuals found using resource I. p_i provides percent biomass of a given item and it is a useful indicator of food diversity and niche breadth hence, it was used to examine diet variation and overlap between the study species. To derive measures of niche breadth for my study species, I typically counted the number of resource items used by a set of individuals of that species.

These measures are standardized on a scale of 0 to 1 by using the formula (Hurlbert 1978).

$$B_A = \frac{\mathrm{B} - 1}{\mathrm{n} - 1}$$

Where, *n* is the total number of food species recorded.

Data on utilization was derived from scat analysis and the data on availability was derived from distance sampling analysis of prey species. An index of selection of each species was obtained using Ivlev's index (Ivlev 1961). The electivity was calculated by dividing subtracted value of utilization and availability by sum value of utilization and availability ie. E=U-A/U=A. I used SPSS 16 (SPSS 2007) statistical package to process the data.

4.3. Results

4.3.1. Estimation of prey abundance

Total ten potential prey species were recorded on line transects. These were four ungulate species (chital, sambar, nilgai and wild pig), one primate (common langur), one small mammal (hare), two livestock (cow and goat) and three birds (peafowl, francolin and quail). Although domestic buffaloes were encountered on line transects, but these were excluded from the analysis.

In the intensive study area, the estimated cluster size, group encounter rate and density of different prey species are given in the table 4.1 to table 4.3 for consecutive years between 2010 and 2013. The selected model was half normal with cosine adjustment 2, 3, 4 (p = 0.45662, Chi-square = 0.5542 and degree of freedom = 1), during 2010-11 the selected model was half normal with cosine adjustment 2 (p = 0.45501, Chi-square = 1.5749 and degree of freedom = 2), during 2011-12 the selected model was half normal with cosine adjustment 2 (p = 0.39456, Chi-square = 1.8600 and degree of freedom = 2) and during 2012-13 the selected model was half normal with cosine adjustment 2 (p = 0.2737, Chi-square = 0.87210 and degree of freedom = 2). The selected model for sub-adult prey species for three years was half normal with cosine adjustment 2 (p = 0.17284, Chi-square = 0.23547 and degree of freedom = 2).

The total number of walk was calculated to be 96 with total effort of 192 km in 2010 and 2011. During 2012 the total number of walk was 90 with total effort of 183 km. The effective strip width for all species in the intensive study area was calculated to be 34.09 m, 32.37 m and 20.01 m during year 2010-11, 2011-12 and 2012-13 respectively (figure 4.2 to 4.4).

Peafowl was observed to be the most abundant prey species throughout the study period. The density of peafowl varied from 113.77/ km^2 in 2010-11, 103.53/ km^2 in 2011-12 and 169.08 / km^2 in 2012-13. Amongst the wild prey species, in 2010-11, nilgai (13.53 / km^2) was observed as most abundant wild ungulate prey species followed by chital (12.55 / km^2), sambar (8.27 / km^2) and wild pig (4.06 / km^2) (table 4.1). In 2011-12, nilgai (19.98 / km^2) was observed to be the most abundant wild ungulate prey species followed by chital (18.10 / km^2), sambar (16.01 / km^2) and wild pig (6.99/ km^2) (table 4.2). In 2012-13 again, nilgai (36.62 / km^2) was observed to be the most abundant wild ungulate prey species followed by, chital (37.12 / km^2), wild pig (20.51 / km^2) and sambar (15.82 / km^2) in the study area (table 4.3).

The density of common langur in the study area varied from 4.28/ km^2 in 2010-11, 23.40/ km^2 in 2011-12 and 40.27 / km^2 in 2012-13. Since there are ten villages inside the Sariska National Park area, the abundance of livestock was comparatively high in the study area. The density of goat in the study area was recorded as 58.9/ km^2 in 2010-11, 45.69/ km^2 in 2011-12 and 8.65 / km^2 in 2012-13. Since the observation of sub adults of different prey species were low for yearly estimation i.e. less than 30 observation, density, cluster size and group encounter rate of sub adults of seven prey species was collectively calculated for the entire study period (2010- 2013) in the intensive study area (National Park) (table 4.4). The density of young once of common langur was observed highest 9.19/ km^2 during the study period followed by wild piglets 4.70/km^2, nilgai calf 3.34/km^2, peafowl chickens 2.72/km^2, chital fawn 2.21/km^2, sambar fawn 1.67/km^2 and cow calf 0.71/km^2. In the intensive study area, the available total prey biomass was calculated to be 7506.5 kg/ km^2 in 2010-11, 13291.6 kg/ km^2 in 2011-12 and 18354.2 kg/ km^2 in 2012-13 (table.4.4).

Table 4.1. Density, cluster size and group encounter rate of different prey species in the intensive study area (National Park) in 2010.

Species	**No. of sightings**	**Cluster Size**		**Group Encounter Rate**		**Density/km2**		**Biomass/km^2**
		Mean	**SE**	**ER**	**SE**	**D**	**SE**	
Chital	50	3.34	0.25	0.25	0.03	12.55	2.14	564.75
Sambar	54	2.03	0.15	0.27	0.04	8.27	1.44	1033.75
Nilgai	72	2.50	0.17	0.36	0.04	13.53	2.06	2435.40
Wild pig	17	3.17	0.39	0.08	0.01	4.06	1.03	154.28
Peafowl	299	5.06	0.67	1.53	0.13	113.77	18.72	386.82
Cow	24	6.00	0.99	0.12	0.03	10.82	3.87	1947.60
Goat	30	26.13	2.49	0.15	0.03	58.95	14.33	943.20
Hare	21	1.14	0.07	0.10	0.02	1.80	0.40	6.48
Com. langur	10	5.70	1.04	0.05	0.01	4.28	1.51	34.24

SE = Standard error Group ER = Group encounter rate D = Density

Continued….

Figure 4.2. Detection probability of all prey species in the intensive study area in 2010.

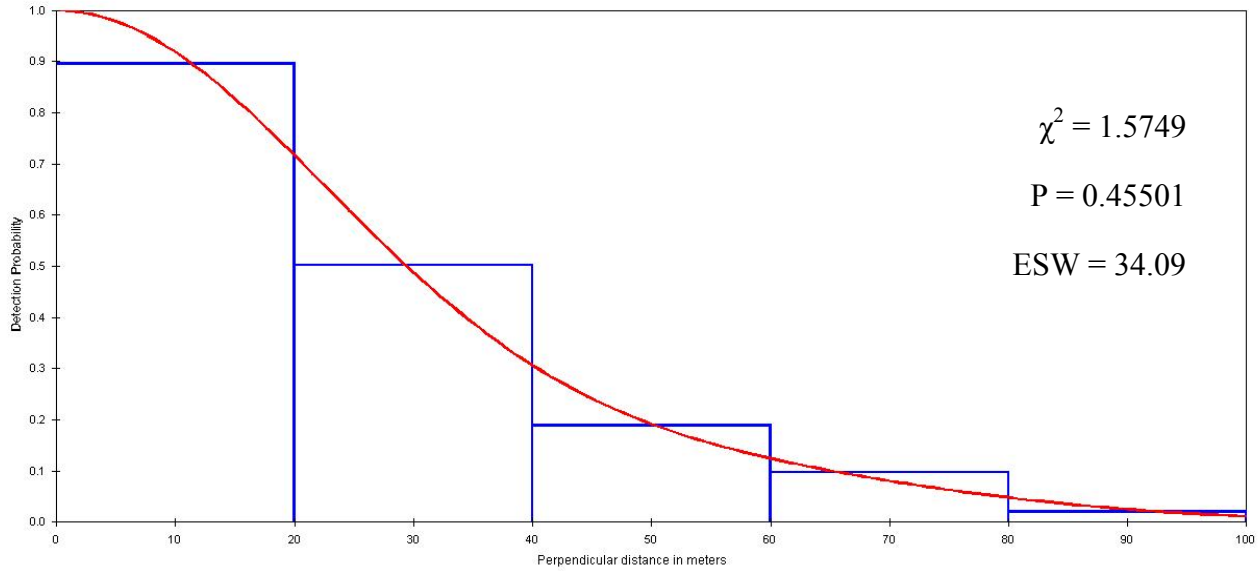


Table 4.2. Density, cluster size and group encounter rate of different prey species in the intensive study area (National Park) in 2011.

Species	No. of sightings	Cluster Size		Group Encounter Rate		Density/km^2		Biomass/ km^2
		Mean	SE	ER	SE	D	SE	
Chital	39	5.76	0.75	0.20	0.03	18.10	4.03	814.5
Sambar	69	2.88	0.27	0.36	0.04	16.01	2.52	2001.25
Nilgai	91	2.73	0.22	0.47	0.05	19.98	2.79	3596.4
Wild pig	24	3.62	0.63	0.13	0.02	6.99	1.94	265.62
Peafowl	380	3.38	0.23	1.97	0.12	103.53	10.31	352.002
Cow	49	7.51	0.85	0.25	0.05	29.60	7.03	5328
Goat	15	37.88	5.52	0.07	0.03	45.69	19.29	731.04
Hare	42	1.28	0.07	0.21	0.03	4.34	0.81	15.624
Com. langur	29	10.03	1.21	0.15	0.03	23.40	5.59	187.2

SE = Standard error; Group ER = Group encounter rate; D = Density

Figure 4.3. Detection probability of all prey species in the intensive study area in 2011.

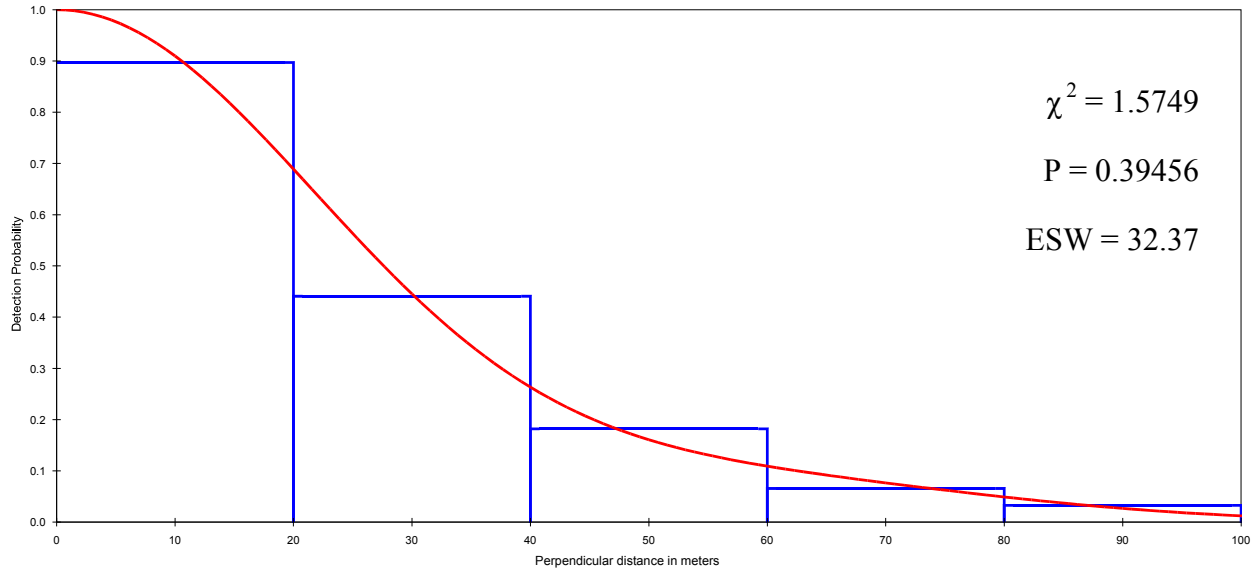


Table 4.3. Density, cluster size and group encounter rate of different prey species in the intensive study area (National Park) in 2012.

Species	No. of sightings	Cluster Size		Group Encounter Rate		Density/km^2		Biomass/km^2 Kg
		Mean	SE	ER	SE	D	SE	
Chital	120	6.37	0.34	0.32	0.02	37.12	8.31	1670.4
Sambar	90	3.04	0.22	0.24	0.01	15.82	3.43	1279.8
Nilgai	215	2.54	0.08	0.58	0.08	39.62	4.45	3205.3
Wild pig	87	3.63	0.30	0.23	0.01	20.51	3.51	779.3
Peafowl	645	4.24	0.10	1.70	0.41	169.08	12.62	5748.72
Cow	61	7.57	0.80	0.16	0.02	28.80	7.82	5184
Goat	8	22.62	5.82	0.02	0.05	8.65	5.65	138.4
Hare	42	1.11	0.05	0.11	0.08	7.68	1.45	26.1
Com. langur	74	10.10	0.63	0.20	0.14	40.27	7.55	322.2

SE = Standard error; Group ER = Group encounter rate; D = Density

Figure 4.4. Detection probability of all prey species in the study area in 2012.

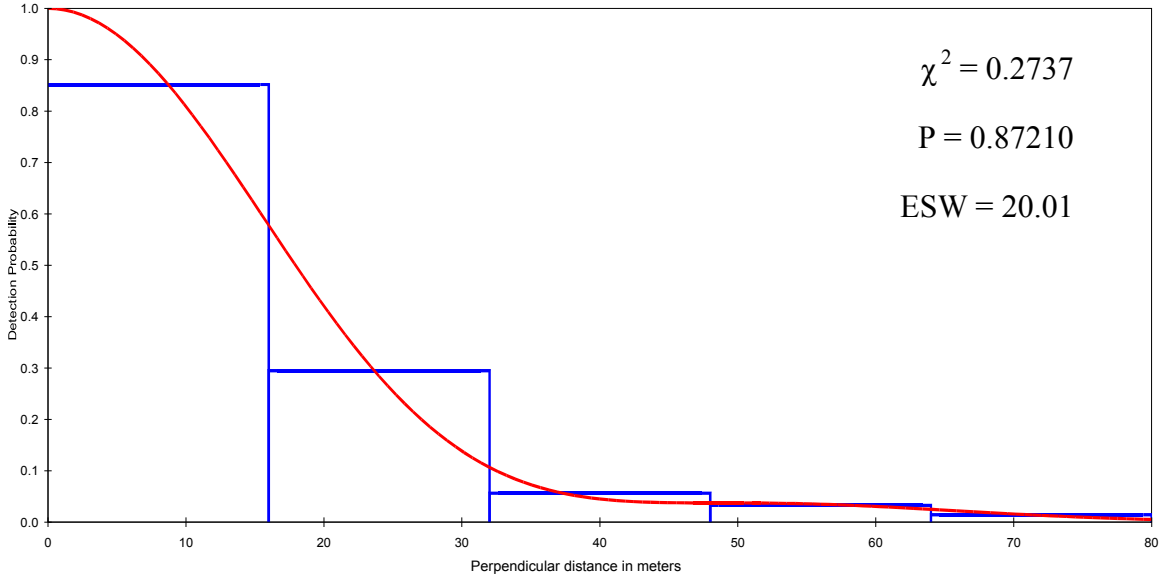


Table 4.4. Density, cluster size and group encounter rate of sub adults of different prey species for three years (2010- 2013) in the intensive study area (National Park).

Species	No. of sightings	Cluster Size		Group Encounter Rate		Density/km^2	
		Mean	SE	ER	SE	D	SE
Chital fawn	17	1.91	0.20	1.16	0.24	2.21	0.50
Sambar fawn	41	1.19	0.06	1.41	0.23	1.67	0.69
Nilgai fawn	48	2.04	0.13	1.63	0.28	3.34	0.69
Wild piglets	30	4.60	0.06	1.02	0.17	4.70	0.95
Peafowl chicks	24	3.33	0.39	0.82	0.18	2.72	0.71
Cow calf	7	3.00	0.48	0.24	0.11	0.71	0.35
Com. langur baby	66	4.09	0.29	2.25	0.31	9.19	1.42

SE = Standard error; Group ER = Group encounter rate; Density

4.3.2. *Rodent and shrew abundance*

4.3.2. *a. Distance Sampling*

In total 41 Sherman traps were placed under trapping web designed in six locations for ten consecutive days in summer 2011, amounting for total effort of 2460 trap night, in winter 2011-12, trapping web was deployed in 13 locations amounting for total effort of 5330 trap nights, in summer 2012 trapping web was deployed in 18 locations amounting for total effort of 7380 trap nights and in winter 2012-13, the trapping web was deployed in 14 locations amounting for total effort of 5740 trap nights. The two year trapping sessions revealed the presence of eight species of rodents and one species of shrew. There was no significant difference observed in rodent abundance between two summer seasons (t test, t = 0.84, df = 12, p = 0.41) and two winter season (t test, t = -0.15, df = 12, p = 0.88). Overall, there was a significant difference observed in rodent abundance between summer and winter seasons (t test, t = -4.54, df = 12, p = 0.00) (Table 4.5). Collectively, the recorded abundance of rodents was higher in the winter (45.23 individuals/ha) than summer (1.09 individuals/ha) (table 4.5).

Analysis under distance sampling using point count method revealed that, *Mus budooga* had the highest density (3.91 ± 1.59) in summer 2011 followed by *Golunda ellioti* (1.02 ± 0.50). In winter 2011-12 as well, *Mus budooga* had the highest density (9.71 ± 7.74) followed by *Mus platythrix* (7.19 ± 2.47) and *Suncus montanus* (6.74 ± 2.51). In summer 2012 *Golunda ellioti* had the highest density (1.77 ± 0.69) followed by *Mus platythrix* (2.00 ± 0.42) and, in winter 2012-13 *Mus platythrix* had the highest density (8.12 ± 4.21) followed by *Vandeleuria oleracea* (5.55 ± 4.62) and *Golunda ellioti* (3.37 ± 1.81) (table 4.5).

Some rodent species were observed more frequently in summer and some species were observed more frequently in winter. Species recorded with highest density in summer were *Mus budooga* (3.51 ± 1.59) followed by *Golunda ellioti* (1.77 ± 0.69) and *Tatera indica* (1.21 ± 0.49). Species recorded with highest density in winter were *Mus budooga* (9.71 ± 7.74) followed by *Mus platythrix* (8.12 ± 4.21) *Suncus montanus* (5.89 ± 4.61) and *Vandeleuria oleracea* (5.55 ± 4.62) (table 4.5).

Table 4.5. Density of rodents and shrew estimated (per hectare) during the summer and winter in Sariska Tiger Reserve (2011-2013).

Year	Species	Density ± SE	# of Captures	% CV	95% CI	ERD ± SE	Model	p value	AIC
Summer 2011	BR	1.02 ± 0.5	12	49.39	0.39 ± 2.64	24.97 ± 4.15	HNC	0.32	36.81
	GRBL	0.10 ± 0.0	5	43.18	0.04 ± 0.24	50.00 ± 0.00	UP	0.28	15.61
	LTTM	0.62 ± 0.40	5	64.73	0.17 ± 2.26	20.58 ± 4.96	HNC	0.55	17.34
	MB	3.91 ± 1.59	16	40.79	1.77 ± 8.58	14.73 ± 1.97	HNC	0.06	50.02
	RR	0.14 ± 0.06	7	41.21	0.06 ± 0.32	50.00 ± 0.00	UP	0.9	25.27
	MM	0.29 ± 0.14	5	48.27	0.11 ± 0.73	30.22 ± 3.26	UP	0.09	18.71
	SCR	1.01 ± 1.01	1	100	0.002 ± 442	7.21 ± 7.21	UP	1	2
	MP	0.50 ± 0.36	4	72.67	0.11 ± 2.15	20.58 ± 5.55	HNC	0.52	13.42
	SQRL	2.14 ± 1.11	10	51.86	0.78 ± 5.85	15.73 ± 2.97	HNC	0.19	32.5
Winter2011 - 12	BR	3.66 ± 0.87	71	23.91	2.30 ± 5.83	23.25 ± 1.65	UC	0.82	224.31
	GRBL	1.59 ± 0.91	18	62.9	1.23 ± 7.54	8.71 ± 1.79	HRP	0.02	47.33
	LTTM	3.02 ± 1.17	28	38.87	1.43 ± 6.35	16.08 ± 1.96	HNC	0.1	84.29
	MB	9.7 ± 7.74	90	79.84	2.40 ± 39.12	16.09 ± 6.31	HRP	0.1	290.42
	MM	6.03 ± 4.93	51	81.79	1.43 ± 25.37	15.35 ± 6.17	HRP	0.09	163.33
	MP	7.19 ± 2.47	88	34.4	3.71 ± 13.91	18.49 ± 2.47	UC	0.13	284.12
	PGRBL	0.02 ± 0.01	2	70.04	0.01 ± 0.07	50.00 ± 0.00	UC	1	6.78
	RR	0.41 ± 0.26	5	64.73	0.11 ± 1.47	18.42 ± 4.37	HNP	0.13	16.34
	SCR	0.62 ± 0.30	12	48.52	0.24 ± 1.56	23.2 ± 3.74	HNP	0.21	37.86
	SHRW	6.74 ± 2.51	50	38.88	3.07 ± 13.63	14.68 ± 2.37	HRP	0.08	138
	SQRL	7.83 ± 3.98	110	50.88	3.03 ± 20.22	19.80 ± 4.70	HRP	0.15	354.59
Summer 2012	BR	1.77 ± 0.69	35	38.9	0.84 ± 3.74	18.75 ± 2.46	HNC	0.14	114.31
	GRBL	1.21 ± 0.49	15	40.97	0.54 ± 2.66	14.88 ± 2.10	HNC	0.08	48.03
	LTTM	0.26 ± 0.13	9	50.23	0.09 ± 0.70	24.68 ± 4.71	HNC	0.24	30.33
	MB	0.24 ± 0.05	34	24.23	0.15 ± 0.38	50.00 ± 0.00	UP	1	106.09
	MM	1.48 ± 0.98	4	75.23	0.00 ± 23.28	6.93 ± 5.84	UP	0.01	2
	MP	1.00 ± 0.42	25	42.04	0.44 ± 2.26	31.11 ± 3.84	HNC	0.17	83.84
	PGRBL	0.07 ± 0.02	11	36.83	0.03 ± 0.15	50.00 ± 0.00	UP	1	34.77
	RR	0.06 ± 0.03	3	63.19	0.01 ± 0.19	29.29 ± 3.86	UP	0.34	9.84

	SCR	0.05 ± 0.02	8	38.92	0.02 ± 0.12	50.00 ± 0.00	UP	1	21.73
	SHRW	0.01 ± 0.01	1	100	0.00 ± 0.00	50.00 ± 0.01	UP	1	2.04
	SQRL	1.65 ± 0.66	33	40.03	0.77 ± 3.55	18.88 ± 2.79	HNC	0.14	107.81
Winter2012 - 13	BR	3.37 ± 1.81	129	24.61	4.57 ± 11.81	19.94 ± 1.98	HNC	0.15	415.05
	GRBL	1.92 ± 1.34	24	46.21	1.38 ± 8.90	2.23 ± 1.05	HRC	0	69.92
	LTTM	5.55 ± 4.62	34	84.1	0.64 ± 34.21	3.73 ± 2.02	HRC	0.01	110.14
	MB	10.8 ± 7.51	117	68.8	2.18 ± 21.32	4.59 ± 1.7	HRC	0.01	378.54
	MM	6.49 ± 2.12	47	32.82	3.44 ± 12.20	12.83 ± 1.44	HNC	0.06	137
	MP	8.12 ± 4.21	125	52.76	2.17 ± 20.30	5.91 ± 1.54	HRC	0.01	404.04
	PGRBL	0.01 ± 0.01	2	100	0.00 ± 0.09	50.00 ± 0.00	UC	1	8.89
	RR	2.04 ± 0.91	10	44.55	0.85 ± 4.92	10.54 ± 1.70	UC	0.04	24.08
	SCR	0.09 ± 0.07	2	76.48	0.02 ± 0.36	22.09 ± 3.28	UP	0.19	7.42
	SHRW	5.89 ± 4.61	42	59.29	0.75 ± 5.46	4.02 ± 2.05	HRC	0.01	133.55
	SQRL	4.91 ± 4.55	64	48.63	0.80 ± 9.59	17.20 ± 9.59	HRC	0.11	209.26

BR = bush rat (*Golunda ellioti*); GRBL = Indian gerbil (*Tatera indica*); LTTM = long tailed tree mouse (*Vandeleuria oleracea*); MB = little Indian field mouse (*Mus budooga*); MM = house muse (*Mus musculus*); MP = spiny tailed field mouse (*Mus platythrix*); PGRBL = pigmy gerbil (*Gerbillus nanus*); RR = rat (*Rattus rattus*); SCR = sand colored rat (*Millardia gleadouwi*); SHRW = shrew (*Suncus montanus*); SQRL = squirrel (*Funambulus pennantii*).

4.3.2. b. Mark Recapture

For mark recapture based rodent trapping Huggins closed capture model was used (Huggins, 1989). In this model, the likelihood is conditioned on the number of animals detected and abundance *N* therefore drops out of the likelihood. These models contain only captures *pi* and recaptures *ci*; the abundance *N* is estimated as a derived parameter. The primary advantage of the Huggins data type is that individual covariates can be used to model *p* and *c*. Individual covariates cannot be used with the full likelihood approach because no covariate value is available for animals that were never captured. In contrast, the Huggins parameterization has conditioned this multinomial term out of the likelihood, and so an individual covariate can be measured for each of the animals included in the likelihood (Cooch & White, 2009).

For mark-recapture analysis, behavior model was selected in comparison to null model and time model based on lowest AIC values (table 4.6) for the four sampling seasons. Rat (*Ruttus ruttus*) was found to be the most abundant rodent species (18.86 ± 6.58) followed by house mouse (*Mus musculus*) (7.86 ± 2.75) and little Indian field mouse (*Mus budooga*) (4.71 ± 1.60) in summer 2011. In winter 2011-12, little Indian field mouse (*Mus budooga*) was found to be the most abundant rodent species (15.15 ± 1.01) followed by spiny tailed field mouse (*Mus platythryx*) (14.27 ± 0.97) and house mouse (*Mus musculus*) (10.19 ± 0.77). In summer 2012, sand color rat (*Millardia gleadowi*) was found to the most abundant rodent species (17.11 ± 11.02) followed by spiny tailed field mouse (*Mus platythryx*) (11.64 ± 7.60) and little Indian field mouse (*Mus budooga*) (10.95 ± 7.17). In winter 2012-13, little Indian field mouse (*Mus budooga*) was found to be the most abundant rodent species (19.52 ± 1.80) followed by followed by spiny tailed field mouse (*Mus platythryx*) (19.21 ± 1.78) and shrew (*Suncus montanus*) (17.57 ± 1.66). No capture of shrew was obtained in summer of the two consecutive study years while the species was fairy captured in winter. The abundance estimates of rodents and shrew form mark-recapture sampling in hectare is given table 4.7.a.

Average of rodent and shrew species abundance for four seasons was calculated under the mark-recapture framework and distance sampling for comparison between the two methods (table 4.7.b and figure 4.5). No significant difference was observed between the two methods (t test, $t = 0.56$, $df = 18$, $p = 0.62$).

In summer 2011, 44.83% female and 55.17% male rodent were captured. In winter 2011-12, female captures were 37.22% and male captures were 62.08%. In summer 2012, 30% female and 69.13% male were captured and in winter 2012-13, female captures were 23% and male captures were 76.76%. Difference in capture rates was observed for entire study period where, female capture rates were significantly lower than that of male capture rates (t test, $t = -4.85$, $df = 6$, $p = 0.003$). Weight of female bush rat (*Golunda ellioti*) ranged between 19.35g and 56.28g and male bush rat raged between 23.5g and 57.73g. Weight of female Indian gerbil (*Tatera indica*) ranged between 33.34g to 89g and male Indian gerbil ranged between 37g and 97.54g. Weight of female long tailed tree mouse (*Vandeleuria oleracea*) ranged between 14g and 38g and male long tiled tree mouse ranged between 14g and 38g in the entire study period. The weight of female little Indian field mouse (*Mus*

budooga) ranged between 13g and 20.63g and male ranged between 9.5g and 28.93g during the study period.

Weight of female house mouse (*Mus musculus*) ranged between 12g and 59g and male house mouse ranged between 20g and 89g. Weight of female spiny tailed field mouse (*Mus platythryx*) ranged between 20.23g and 22.36g and male ranged between 12g and 28g. Weight of female pigmy gerbil (*Gerbillus nanus*) ranged between 34g and 50.5g and male ranged between 16 and 61.63g. Weight of female rat (*Ruttus ruttus*) ranged between 36.25g and 100.5g and male ranged between 19g and 82.33g. Weight of female sand color rat (*Millardia gleadowi*) ranged between 60g and 84g and male ranged between 29.14g and 45.8g. Weight of female shrew (*Suncus montanus*) ranged between 10g and 25.85g and no male shrew was captured during the entire study period. Weight of females were higher than males but the difference was not found significant (t test, t = 0.99, df = 9, p = 0.35).

Table.4.6. Rodent and shrew abundance estimates and statistical parameters using mark-recapture analysis in SariskaTiger Reserve (2011-2013).

Year	**Model**	**Effective Sample size**	**AIC**	**AIC weight**	**c-hat**	**Parameter estimates**			
						p	**SE**	**c**	**SE**
2011	{behavp(.),c(.)}	280	254.2	0.000	9.624	0.017	0.065	0.177	0.033
2011-12	{behvp(.),c(.)}	2330	2077.1	0.177	8.975	0.178	0.021	0.127	0.009
2012	{behavp(.),c(.)}	950	752.6	0.001	8.049	0.044	0.034	0.106	0.014
2012 - 13	{behavp(.),c(.)}	2630	2608.1	0.002	9.977	0.136	0.020	0.187	0.010

Continued….

Table.4.7.a. Species wise abundance estimates (per hectare) of nine rodent species and a shrew using mark-recapture analysis in Sariska Tiger Reserve (2011-2013).

Year	**BR**	**GRBL**	**LTTM**	**MB**	**MM**	**MP**	**SHRW**	**RR**	**PGRBL**	**SCR**
2011	3.14 ± 1.3	1.57 ±0. 56	1.57 ± 0.66	4.71 ± 1.60	7.86 ± 2.75	3.14 ± 1.11	-	18.86 ± 6.58	3.14 ± 1.11	-
2011-12	8.16 ± 0.67	2.62 ± 0.35	0.58 ± 0.16	15.15 ± 1.01	10.19 ± 0.77	14.27 ± 0.97	4.95 ± 0.50	2.04 ± .30	9.32 ± 0.54	-
2012	4.11 ± 2.89	1.37 ± 1.10	4.79 ± 3.32	10.95 ± 7.17	1.37 ± 1.15	11.64 ± 7.60	-	7.53 ± 5.03	6.16 ± 4.18	17.11 ± 11.02
2012-13	8.13 ± 0.96	0.65 ± 0.23	1.95 ± 0.41	19.52 ± 1.80	8.78 ± 1.01	19.21 ± 1.78	17.57 ± 1.66	6.51 ± 0.83	-	3.25 ± 0.54

**

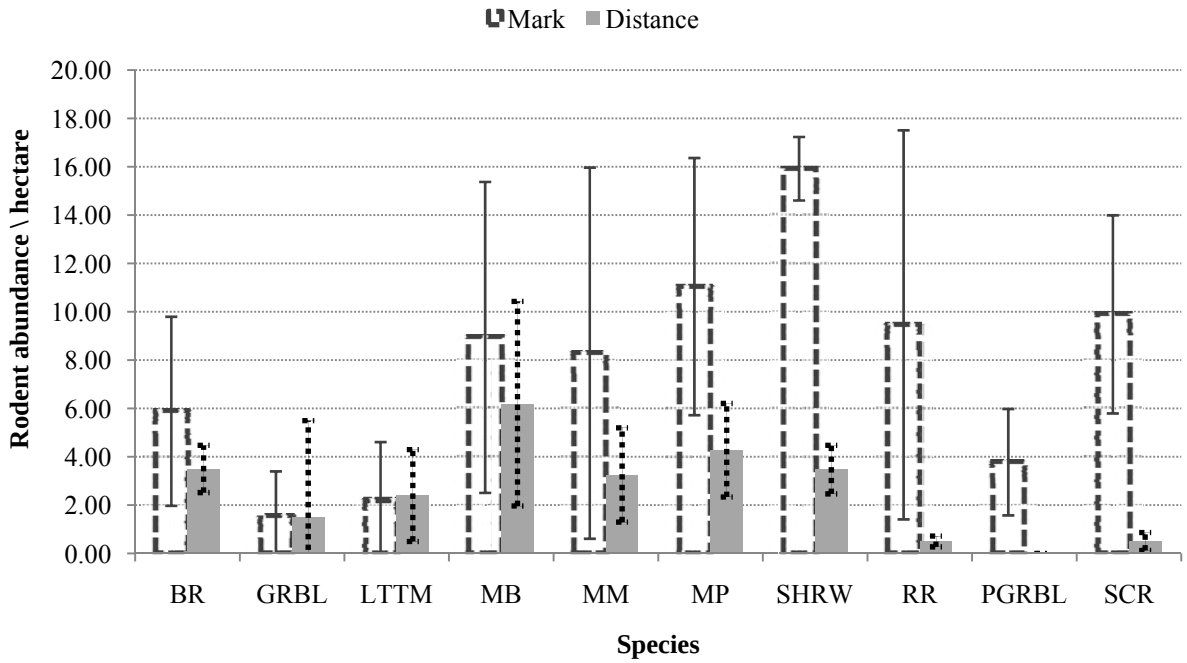
Table.4.7.b. Species wise abundance estimates (per hectare) of nine rodent species and a shrew using distance sampling analysis in Sariska Tiger Reserve (2011-13).

Year	BR	GRBL	LTTM	MB	MM	MP	SHRW	RR	PGRBL	SCR
2011	1 ± 0.49	-	1 ± 0.64	4 ± 163	-	1 ± 0.72	2 ± 1	-	-	1 ± 1
2011-12	4 ± 0.95	1.6 ± 1.3	3 ± 1.2	10 ± 7.9	6 ± 4.9	7 ± 2.4	6 ± 2.3	-	-	1 ± 1.48
2012	2 ± 0.77	1 ± 0.4	-	-	1 ± 1	1 ± 4.2	-	-	-	-
2012-13	7 ± 1.7	1.9 ± 1.3	5.6 ± 1.6	10.8 ± 7.4	6 ± 1.9	8.1 ± 4.2	5.9 ± 0.7	2 ± 0.89	-	-

**

** BR = bush rat (*Golunda ellioti*); GRBL = Indian gerbil (*Tatera indica*); LTTM = long tailed tree mouse (*Vandeleuria oleracea*); MB = little Indian field mouse (*Mus budooga*); MM = house muse (*Mus musculus*); MP = spiny tailed field mouse (*Mus platythrix*); PGRBL = pigmy gerbil (*Gerbillus nanus*); RR = rat (*Rattus rattus*); SCR = sand colored rat (*Millardia gleadouwi*); SHRW = shrew (*Suncus montanus*); SQRL = squirrel (*Funambulus pennantii*).

Figure 4.5. Species wise comparison of average abundance estimates (per hectare) of nine rodent species and a shrew for the entire study period using distance sampling analysis and mark-recapture analysis in SariskaTiger Reserve (2011-2013).



BR = bush rat (*Golunda ellioti*); GRBL = Indian gerbil (*Tatera indica*); LTTM = long tailed tree mouse (*Vandeleuria oleracea*); MB = little Indian field mouse (*Mus budooga*); MM = house muse (*Mus musculus*); MP = spiny tailed field mouse (*Mus platythrix*); PGRBL = pigmy gerbil (*Gerbillus nanus*); RR = rat (*Rattus rattus*); SCR = sand colored rat (*Millardia gleadouwi*); SHRW = shrew (*Suncus montanus*); SQRL = squirrel (*Funambulus pennantii*).

4.3.3. Porcupine and hare abundance estimation

4.3.3.a. Relative abundance index:

Average capture frequencies of hare across the years ranged from 4.83 captures/100 trap-nights to 15.77 captures/100 trap-nights and for porcupine it ranged from 10.39 captures/100 trap-nights to 23.73 captures/100 trap-nights (table 4.8). Hare Relative Abundance Index (RAI) differed significantly between summer and winter (t test; t =3.69, df = 3, p = 0.03). Across two years the hare RAI differed (t test, t = -0.32, df =2, p = 0.78) but, the difference was not found significant. The porcupine RAI differed between summer and winter but not significantly (t test; t =5.95, df = 3, p = 0.01). The porcupine RAI did not differ across two years (t test, t = -0.61, df =2, p = 0.60).

Table.4.8. Overall photo captures and Relative Abundance Index (captures/100 trap nights) of hare and porcupine in Sariska Tiger Reserve (2011 to 2013)

Year	Season	Hare		Porcupine	
		Photo captures	RAI	Photo captures	RAI
2011	Summer	78	5.80	147	10.39
2011-12	Winter	147	10.93	276	20.53
2012	Summer	65	4.83	205	15.25
2012-13	Winter	212	15.77	319	23.73
Average		125.5	9.33	236.75	17.47

Table.4.9. Detection probability (*r)*, average abundance/km^2 (λ), site occupancy (Ψ) and total abundance (N) with associated standard errors (± SE) for hare based on camera trap data using the Royle-Nichols Heterogeneity model.

Year	Season	*r*mean ± SE	λmean ± SE	Naïve occupancy	Ψmean ± SE	*N*mean ±SE	95% CImean
2011	Summer	0.072±0.012	0.50±0.11	0.37	0.39±0.06	38.02±8.02	25.15-57.48
2011-12	Winter	0.075±0.009	0.81±0.13	0.49	0.55±0.05	64.55±10.47	46.98-88.70
2012	Summer	0.060±0.011	0.57±0.13	0.38	0.43±0.07	34.77±7.81	22.59-54.01
2012-13	Winter	0.126±0.014	0.90±0.14	0.53	0.59±0.05	66.54±10.14	49.36-89.70

4.3.3. b. Detection probability

Estimates of detection probability of hare varied from 0.072 to 0.126, with standard errors from 0.009 to 0.014 (table 4.9). Estimates of detection probability of porcupine varied from 0.045 to 0.088, with standard errors from 0.009 to 0.010 (table 4.10). Detection probability of hare varied across the years (t test, t = 5.69, df = 3, p = 0.01) and did not differ significantly in summer (t test, t = 11.00, df = 1, p = 0.06) and winter (t test, t = 3.94, df = 1, p = 0.16) across two years.

Table.4.10. Detection probability (*r)*, average abundance/km^2 (λ), site occupancy (Ψ) and total abundance (N) with associated standard errors (± SE) for porcupine based on camera trap data using Royle-Nichols Heterogeneity model.

Year	Season	*r*mean ± SE	λmean ± SE	Naïve occupancy	Ψmean ± SE	*N*mean ±SE	95% CImean
2011	Summer	0.045±0.009	1.43±0.31	0.64	0.76±0.07	108.42±23.64	70.71±166.23
2011-12	Winter	0.096±0.010	1.21±0.16	0.64	0.70±0.04	96.52±12.56	74.48±125.09
2012	Summer	0.074±0.010	1.56±0.24	0.73	0.79±0.05	93.68±14.51	69.15±126.92
2012-13	Winter	0.088±0.010	1.63±0.22	0.76	0.80±0.04	120.63±16.09	92.88±156.67

Detection probability of porcupine varied across the years (t test, t = 6.76, df = 3, p = 0.01) and did not differ significantly in summer (t test, t = 4.10, df = 1, p = 0.15) but significant difference was observed between two winter (t test, t = 23.00, df = 1, p = 0.03).

4.3.3. c. Occupancy and average abundance

Seasonal estimates of hare occupancy varied from 0.39 to 0.59, with standard errors from 0.05 to 0.07 and, average abundance ranged from 0.50 to 0.90 with standard errors from 0.05 to 0.07 in two years (Tables 4.9). Seasonal estimates of porcupine occupancy varied from 0.70 to 0.80, with standard errors from 0.04 to 0.07 and, average abundance ranged from 1.21 to 1.63 with standard errors from 0.16 to 0.31 in two years (Tables 4.10). Modeled site occupancies were observed greater than naïve occupancy. Hare site occupancy differed significantly across two years (t test, t = 10.29, df = 3, p = 0.002) and significant difference was observed in summer and winter in two years (t test, t = -4.16, df = 3, p = 0.03). Porcupine site occupancy differed significantly across years (t test, t = 33.88, df = 3, p = 0.00) and no significant difference was observed in summer and winter across two years (t test, t = -2.46, df = 3, p = 0.09).

Hare and porcupine abundance (N) obtained from occupancy approach and relative abundance index (captures/100 trap nights) were not significantly correlated with each other (Pearson correlation test, p = 0.94, n = 4, p = 0.06 and Pearson

correlation test, $p = 0.34$, n = 4, $p = 0.66$ respectively). Data showed that there was a positive relationship between site occupancy (Ψ) and RAI of hare (Pearson correlation; $R^2 = 0.94$, n = 4, $p = 0.06$) and porcupine (Pearson correlation; $R^2 = 0.91$, n = 4, $p = 0.09$).

4.3.4. Zizyphus Fruit biomass availability

The *Zizyphus mauritiana* species was examined for fruit availability, as they were identified as important species based on their percent occurrence (≥ 17%) in jackal scat. The species contributed to 17.61 % (246 *Zizyphus* seeds) out of total 26.76% of fruit frequency of occurrence in the diet of jackal in 2011-12 and, during the year 2012-13, the contribution was 16.91% (290 *Zizyphus* seeds) out of total 24.64% of fruit frequency of occurrence in the diet of jackal. *Zizyphus mauritiana* showed variation in fruiting pattern, producing fruits from January to March. The variation in fruiting was dependent on environmental factors such as rain and strong winds at the time of flowering, affecting the fruiting in following season. *Zizyphus* fruit production was different from patch to patch, tree to tree in a same patch and even branch to branch in a same tree. Weekly deposition of number of fruits in fixed mesh nets during the fruiting season is given in figure 4.6, 4.8 and 4.10. Pattern of number of frit deposited and average weight of fruit is given in figure 4.7, 4.9 and 4.11, showing its relation with average biomass of deposited fruit.

4.3.5. Identification of prey remains in the jackal's scat

4.3.5 .a. Prey selection and food habits

In total 104 jackal scats were collected during 2010-11. 284 scats during 2011-12 and 349 scats were collected during 2012-13. It was observed that the proportion of different prey species in jackal scats got stabilized after analyzing 78 scats samples for the year 2010-11, 71 scat samples for the year 2011-12 and analyzing 165 scats samples for the year 2012-13 (figure 4.12, 4.14 and 4.16 respectively). In addition, no new prey species was found after analyzing 165 jackal's scats, as shown by diet stabilization curve (figure 4.12, 4.14 and 4.16 respectively). In total, 12 prey species were identified in jackal's scat in 2010-11, 13 prey species in 2011-12, and 14 prey species were identified in 2012-13. No attempt was made to

identify rodents at species level from the remains of jackal scats. Wild pig remains were found only once during the year 2012-13 in jackal scat.

Figure.4.6. Total number of *Zizyphus* fruits deposited at each site in fixed mesh net locations in every week during fruiting season from January to February 2011.

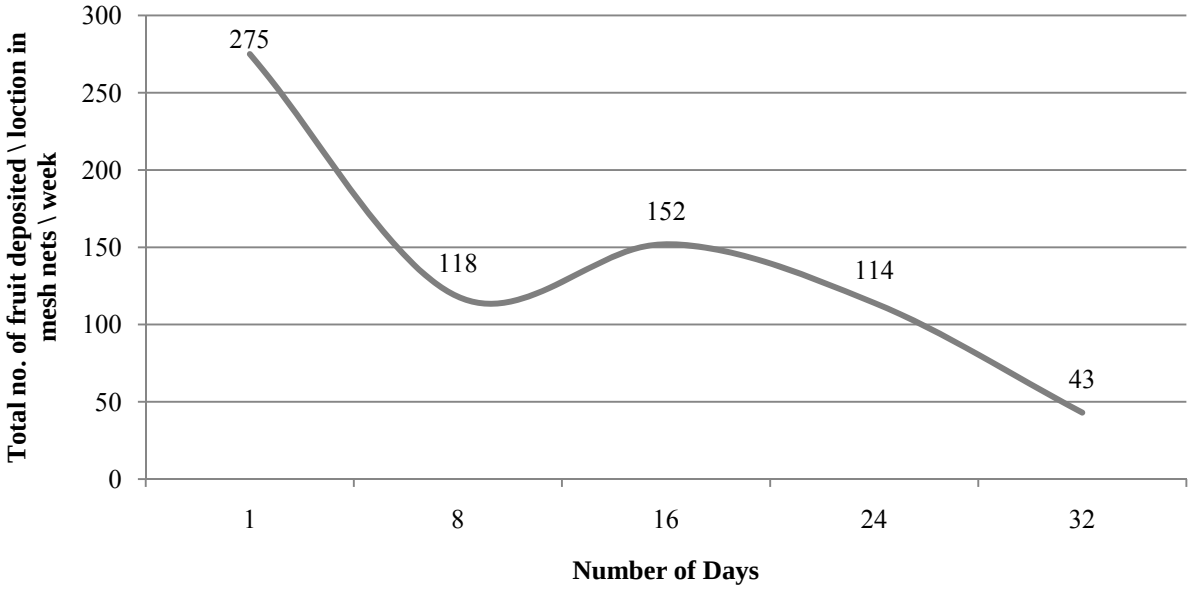


Figure 4.7. Average *Zizyphus* fruits deposition and total biomass of deposited fruits in grams in comparison with average fruit weight from January to February 2011.

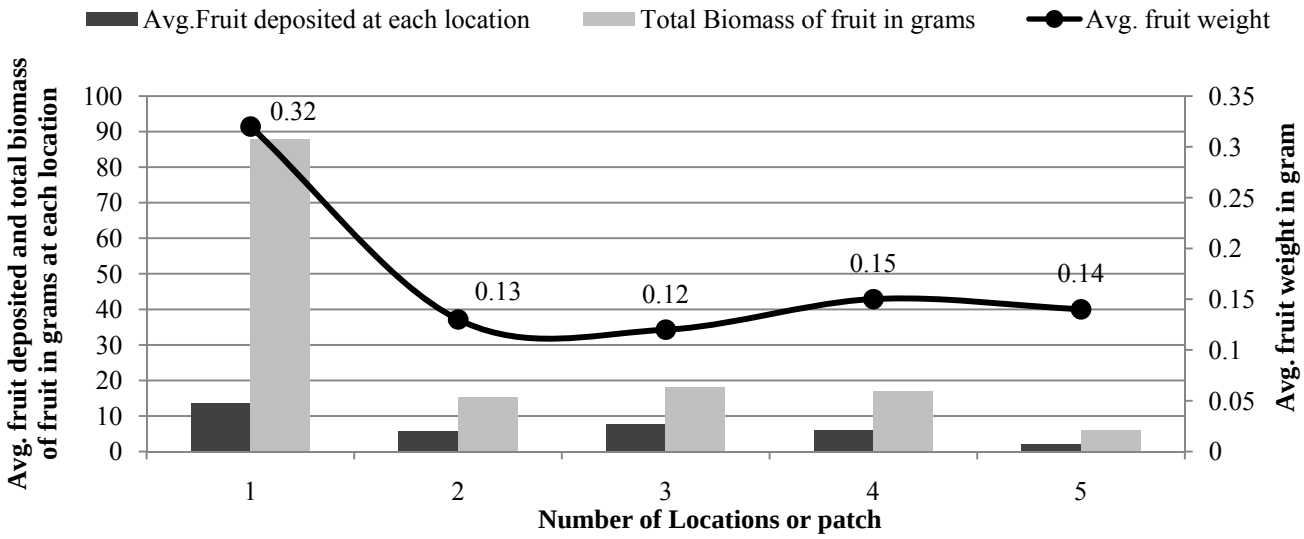


Figure 4.8. Total number of *Zizyphus* fruit deposited at each site in fixed mesh net locations every week during the fruiting season from mid of December 2011 to February 2012.

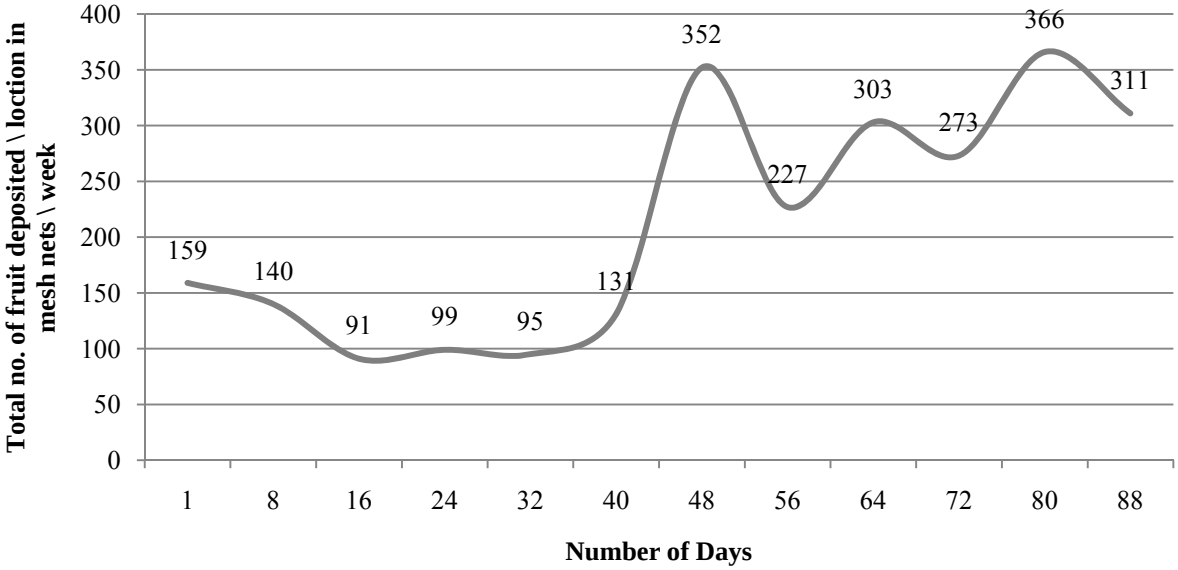


Figure 4.9 Average *Zizyphus* fruits deposition and total biomass of deposited fruits in grams in comparison with average fruit weight from December 2011 to February 2012.

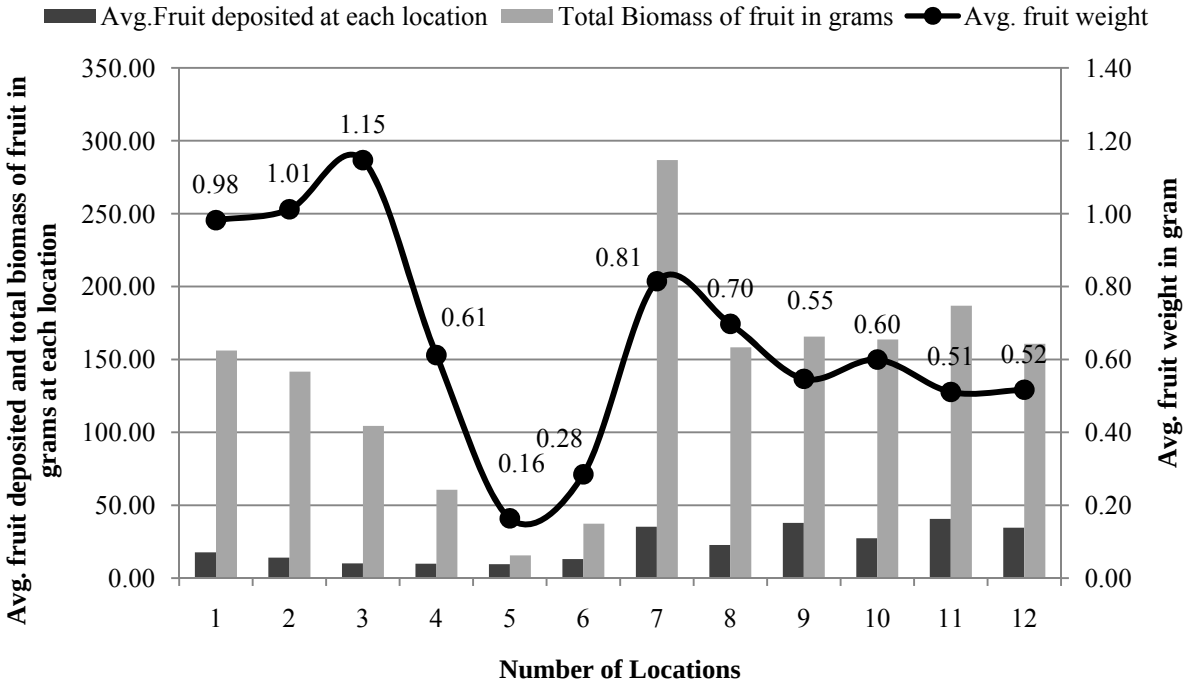


Figure 4.10 Total numbers of *Zizyphus* fruits deposited at each site in fixed mesh net locations every week during the fruiting season from January 2013 to March 2013.

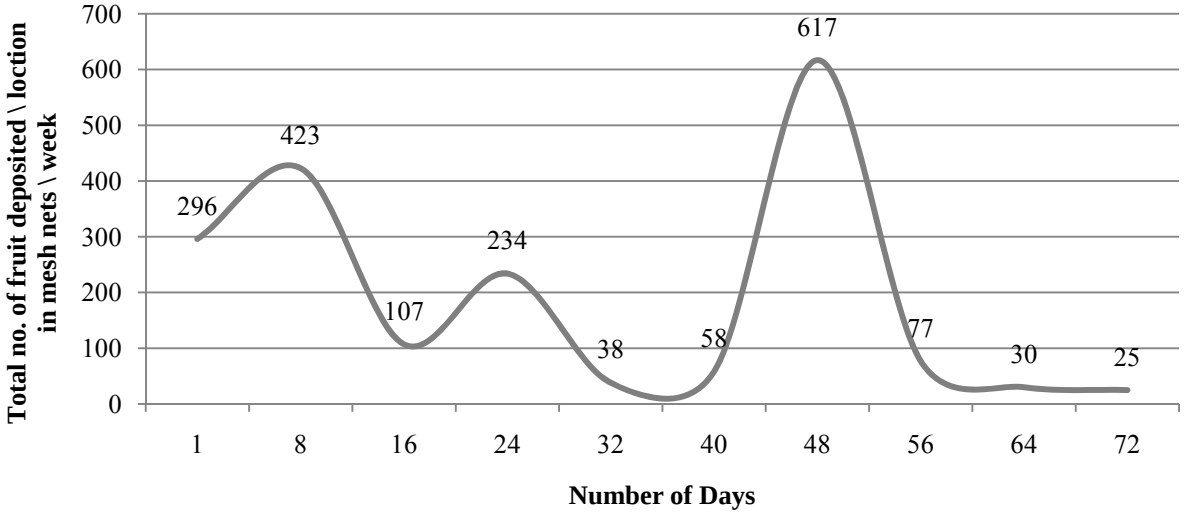
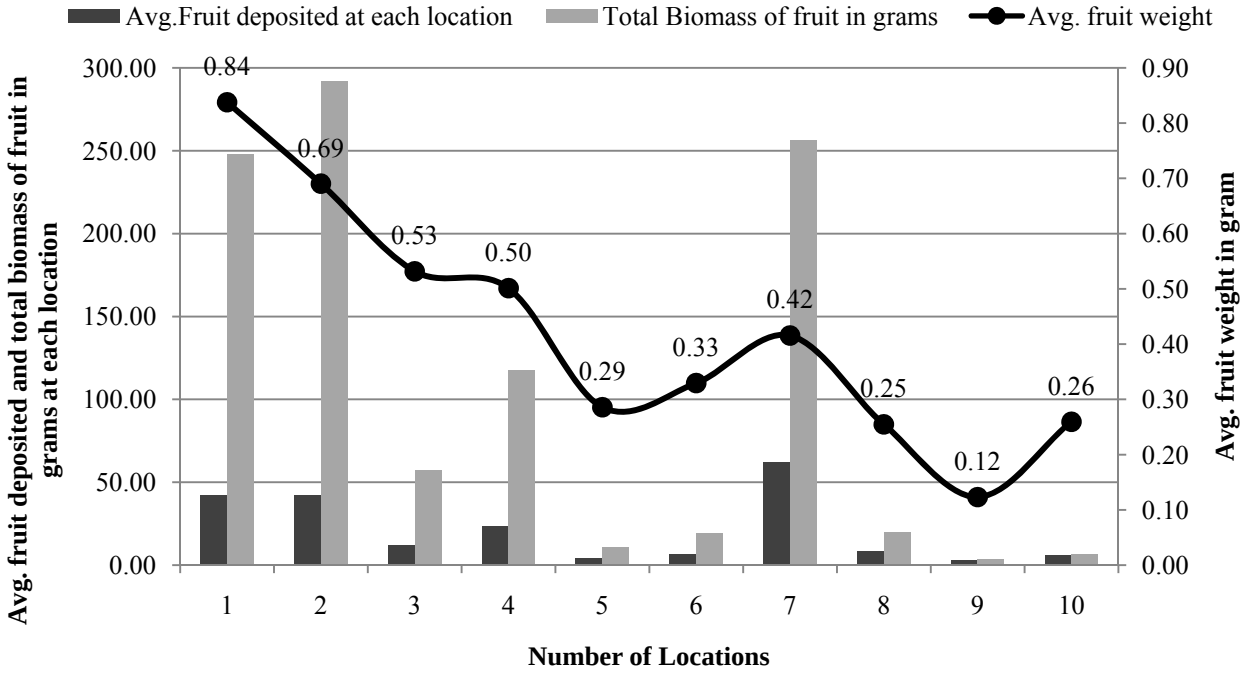


Figure 4.11. Average *Zizyphus* fruits deposition and total biomass of deposited fruits in grams in comparison with average fruit weight from January 2013 and lasted till March 2013.



Frequency of occurrence and percentage frequency of occurrence of prey remains in jackal scats are given in table 4.12 and in figure 4.13, 4.15 and 4.17 from 2010 to 2013 respectively in the study area. Amongst all the food items, four highest occurring food types during the year 2010-11 was vegetative material, which contributed maximum (17.57%) in jackal diet followed by rodent (15.77%), cattle (15.32%) and chital (10.81%). In 2011-12, vegetative material again contributed the most (14.18%) followed by nilgai (12.20%), fruit (11.59%) and rodents (8.08%). In 2012-13, vegetative material contributed maximum (18.23%) in jackal diet followed by chital (13.61%), nilgai (13.48%) and fruit (10.74%).

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Figure 4.12. Sample adequacy for analysis of jackal scats during 2010-11 in Sariska Tiger Reserve.

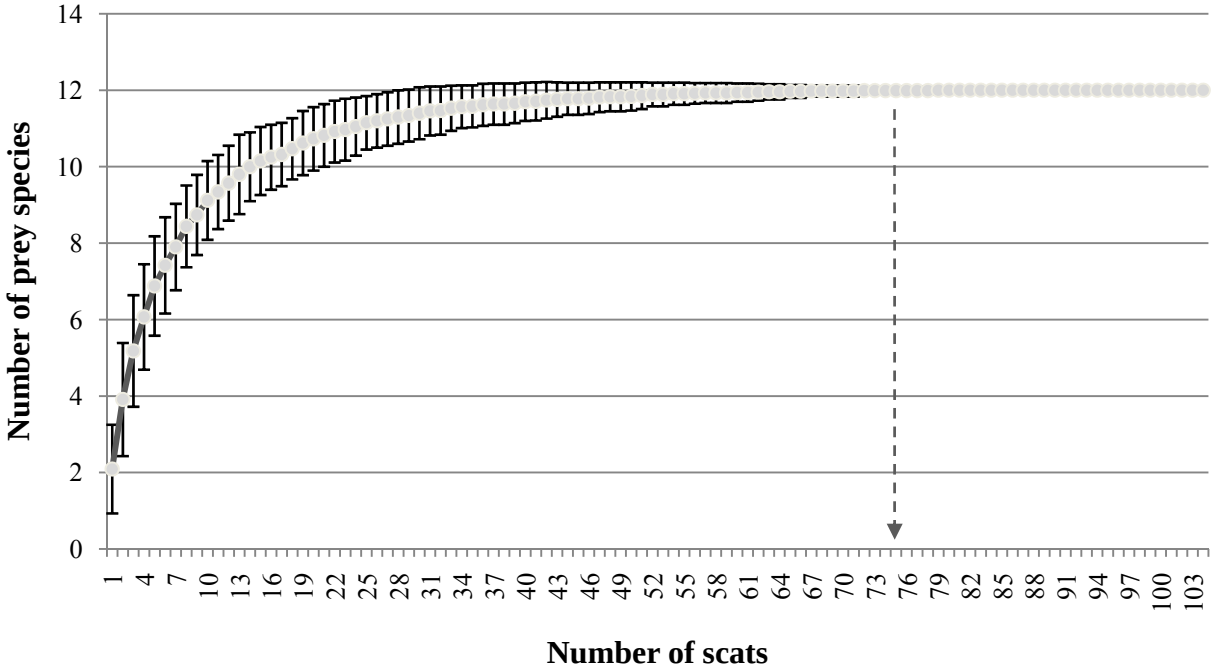


Figure 4.13. Frequency of occurrence of different food items in Jackal scat during year 2010 – 2011 in Sariska Tiger Reserve.

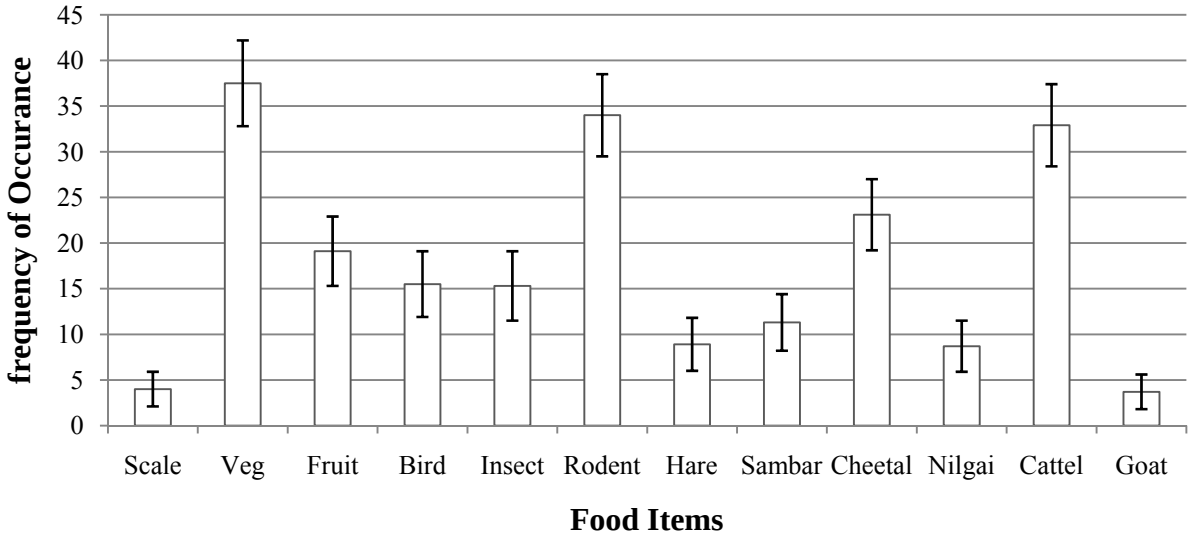


Figure 4.14. Sample adequacy for analysis of jackal scats during 2011-12 in Sariska Tiger Reserve.

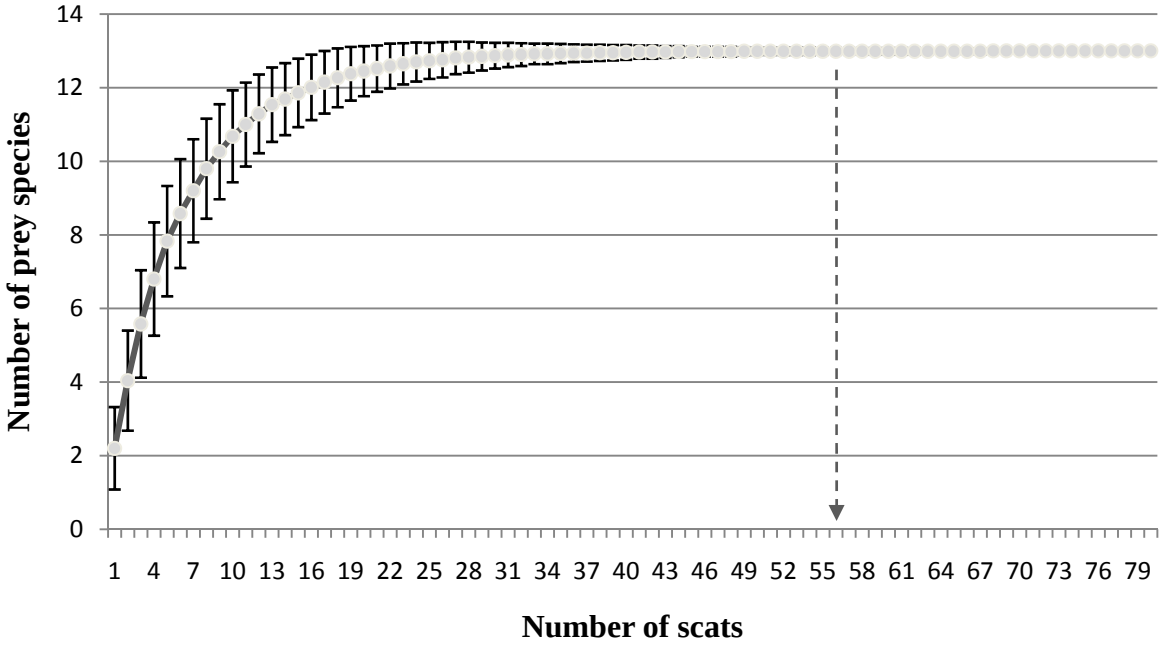


Figure 4.15. Frequency of occurrence of different food items in Jackal scat during year 2011 - 2012 in Sariska Tiger Reserve.

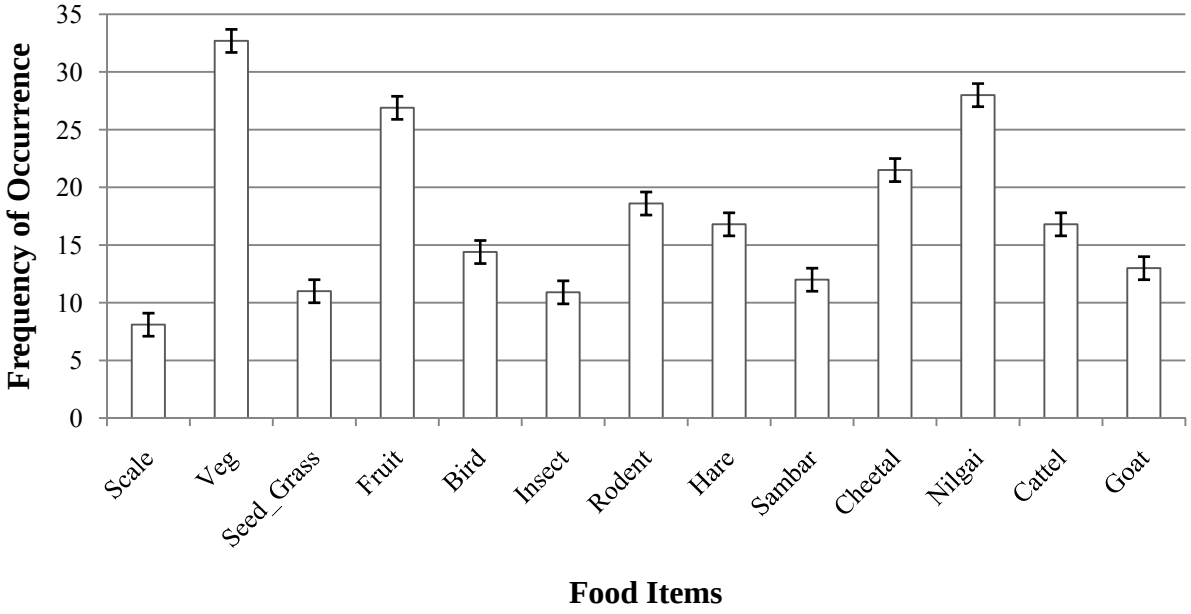


Figure 4.16. Sample adequacy for analysis of jackal scats during 2012-13 in Sariska Tiger Reserve.

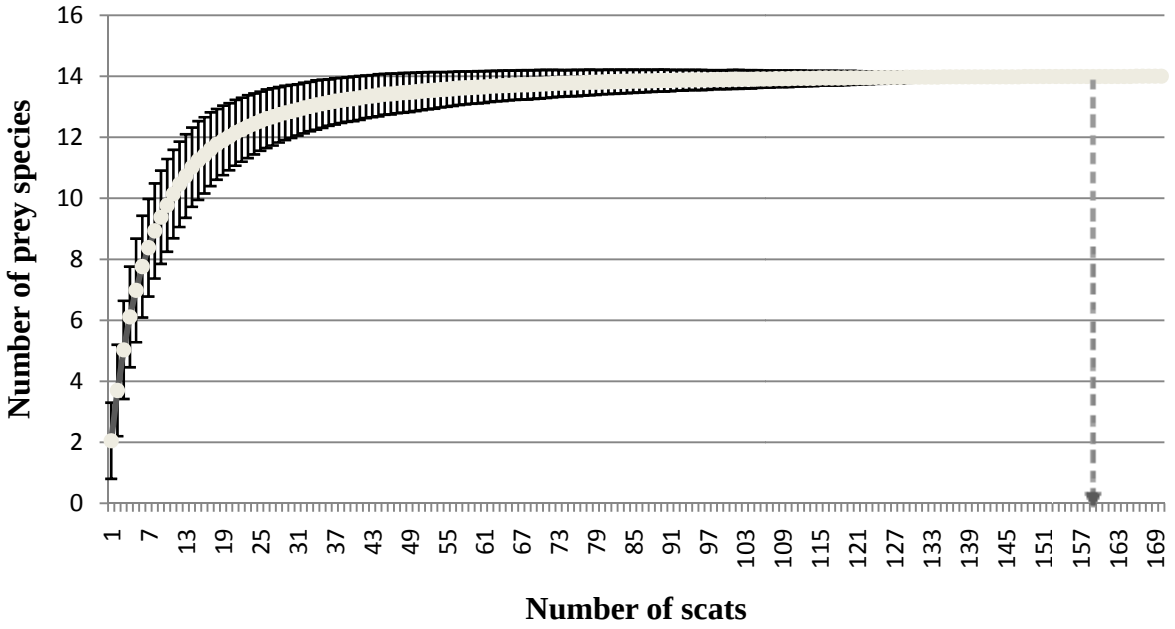
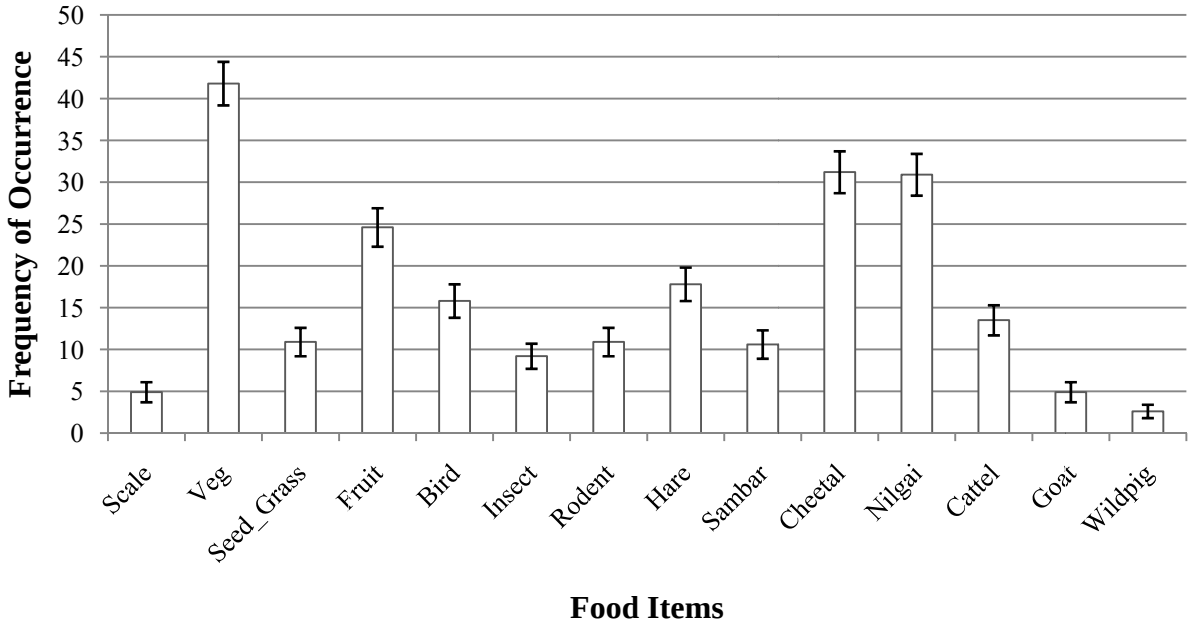


Figure 4.17. Frequency of occurrence of different food items in Jackal scat during year 2012 - 2013 in Sariska Tiger Reserve.



4.3.5.b. Estimation biomass consumption using feeding trials on golden jackal

Of the scats produced, the percentage of non-collectable scats ranged from 2.6% to 18.4%, for an average of 9.9%. The consumption of carcasses by jackals in 15 feeding trials ranged from 25.7% to 100%, for an average of 79.4% and was negatively correlated with size of prey (r=0.72, P=0.001). Loss of moisture from the prey bait carcass accounted for a 0.5% (in chicken) to 50% (in buffalo) weight loss in 72 hr. Moisture loss was recorded less for bird and fruits and high for rabbit and buffalo (table 4.11). The maximum consumption by jackals over a 24-hr period was 132 g/jackal and maximum consumption in 72-hr for a trial was 3.17 kg/jackal.

Consumption of prey biomass (Y) per collectable scat increased with an increase in live body weight of prey (X) (Figure 4.18).

$$Y = 0.003x + 0.228$$

($R^2 = 0.825$; F = 37.6; df = 1; $p < 0.001$)

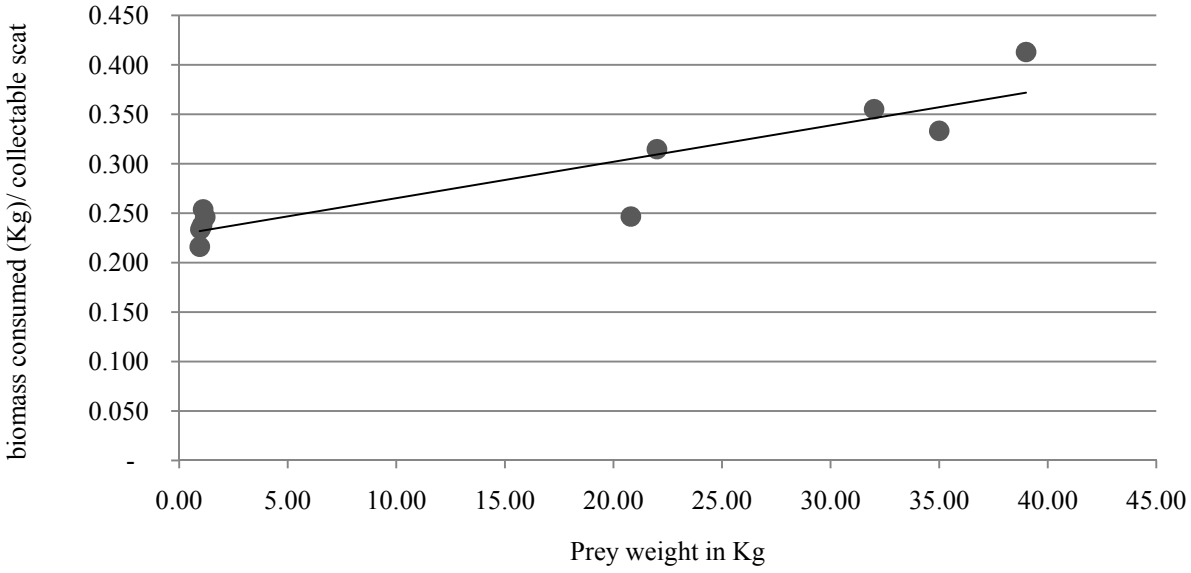


Figure 4.18. Relationship between prey weight (kg) consumed per collectable scat with prey weight, derived from data obtained in the present study.

The above equation provides a better prediction in cases in which detailed scat analysis permits prey to be assigned to groups of different weight classes. Therefore, I pooled data obtained by the prey species of same weight class which, belongs to the same species class (Figure 4.19).

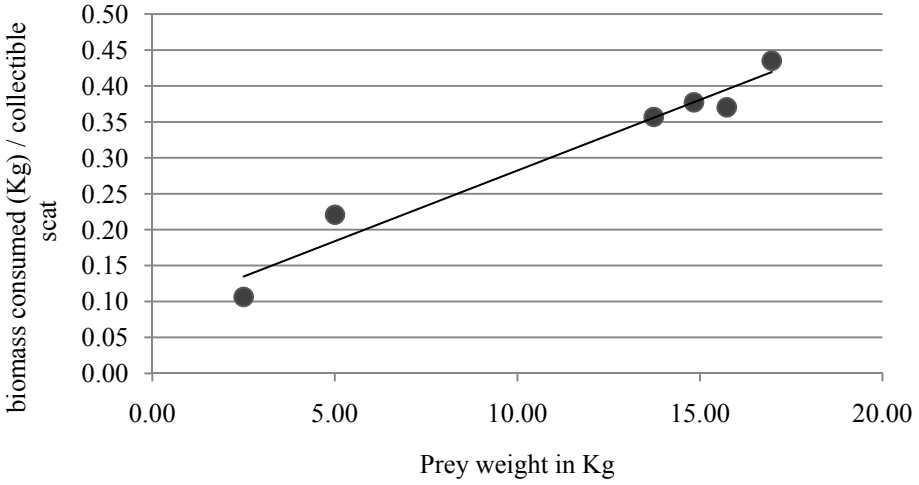


Figure 4.19. Linear regression between average prey biomass consumed per collectable scat (Y) and average weight of prey consumed.

$$Y = 0.019x + 0.085$$
$$(R^2=0.96;\ F = 95.8;\ df = 1;\ p = 0.001$$

Table.4.11. Moisture loss in different prey/food items of jackal during the feeding trail experiment.

Prey	Weight of portion of carcass for moisture loss in Kg	Weight after 72 hr	Weight loss in terms of moisture	% moisture loss
Zizyphus	0.011	0.011	0	0
Zizyphus	0.01	0.01	0	0
Dates	0.005	0.005	0	0
Dates	0.005	0.005	0	0
Chicken	1.175	1.169	0.006	0.5
Zizyphus	0.015	0.014	0.001	0.6
Chicken	1	0.89	0.11	11.0
Goat	2	1.5	0.5	25.0
Chicken	1.426	1.048	0.378	26.5
Buffalo	2.6	1.8	0.8	30.8
Sheep	2.2	1.5	0.7	31.8
Goat	1.7	1.1	0.6	35.3
Rabbit	1.1	0.64	0.46	41.8
Rabbit	1.4	0.76	0.64	45.7
Buffalo	1	0.5	0.5	50.0

The number of scat produced for each animal for each prey species was calculated dividing the average body weight (B) of each prey species by the weight of prey consumed per field collectible scat (Y) (table 4.14). Biomass contribution of

each prey species in different years in the diet of jackal is given in table 4.15 Proportions of number of individual consumption by jackal for each species in different years is given in table 4.12.

Table.4.12. Number and frequency of occurrence of each prey species in jackal scats in Sariska National Park (2010-2013).

Food Item	2010-2011		2011-2012		2012-2013	
	N=104	% of occurrence	N=284	% of occurrence	N=349	% of occurrence
Scale	4	1.80	23	3.51	17	2.12
Veg	39	17.57	93	14.18	146	18.23
Grass	-	-	31	4.73	38	4.74
Fruit	20	9.01	76	11.59	86	10.74
Bird	16	7.21	41	6.25	55	6.87
Insect	16	7.21	31	4.73	32	4.00
Rodent	35	15.77	53	8.08	38	4.74
Hare	9	4.05	48	7.32	62	7.74
Sambar	12	5.41	34	5.18	37	4.62
Cheetal	24	10.81	61	9.30	109	13.61
Nilgai	9	4.05	80	12.20	108	13.48
Cattel	34	15.32	48	7.32	47	5.87
Goat	4	1.80	37	5.64	17	2.12
Wildpig	-	-	-	-	9	1.12

The conversion of prey body mass into a number of scats and their weights excreted by an individual carnivore after prey consumption is a crucial step. To infer it accurately seven quantities (Wachter et. al. 2012) were used to evaluate the steps required to establish the consumed prey mass and the number of consumed prey individuals derived from carnivore scats collected in the field (table.4.13). Average body weight of a prey and proportion of prey consumed by jackal for each prey species is given in table 4.14. Proportion of biomass consumed and number of different prey species consumed by jackal during year 2010 to 2013 is given in table.4.15.

Continued….

Prey/ food items	Prey provided		Group size of jackal (Q2)	Prey consumed		Scat		collectable scat/animal (Q4)	mean wt of collectable scat/animal (Q6)	Prey consumed/collectable scat in kg (Q5=Q3/Q4)	Digestibility % (Q7)	
	No.	Mean kg (Q1)		Total	mean/animal (Q3)	Collectible	Non collectable				(Q3-Q6)	(Q3-Q6)/Q3*100
Chicken	20	0.950	6	14.7	0.123	68	6	0.567	0.073	0.216	0.050	40.8
Chicken	20	0.980	6	18	0.150	77	2	0.642	0.085	0.234	0.065	43.3
Chicken	19	1.053	6	19	0.167	80	1	0.702	0.056	0.238	0.111	66.6
Rabbit	19	1.105	6	16	0.140	63	2	0.553	0.085	0.254	0.056	39.7
Rabbit	15	1.200	6	16	0.178	65	7	0.722	0.041	0.246	0.137	77.0
Sheep	1	20.800	6	14.8	2.467	60	5	10.000	0.044	0.247	2.422	98.2
Goat	1	22.000	6	17	2.833	54	3	9.000	0.045	0.315	2.788	98.4
Goat	1	32.000	6	13.5	2.250	38	5	6.333	0.357	0.355	1.893	84.1
Buffalo	1	35.000	6	9	1.500	27	3	4.500	0.222	0.333	1.278	85.2
Buffalo	1	39.000	6	19	3.167	46	4	7.667	0.124	0.413	3.043	96.1
Zizyphus	-	0.002	6	6	0.000	67	-	0.004	0.036	0.090	-	-
Zizyphus	-	0.002	6	5.8	0.000	69	-	0.004	0.028	0.084	-	-
Zizyphus	-	0.002	6	4	0.000	47	-	0.004	0.013	0.085	-	-
Dates	-	0.002	6	2	0.000	30	-	0.004	0.012	0.067	-	-
Dates	-	0.002	6	3	0.000	41	-	0.004	0.014	0.073	-	-

Table.4.13. Correction factor as determined by fitting logistic regression to consumed prey mass per collectable scat (Q5) as a function of mean prey body mass provided per feeding experiment (Q1) and number of excreted collectable scats (Q4) as a function of mean prey body mass provided per feeding experiment (Q1). Calculations were based on the consumed rabbits and chicken. Mean weight (kg) of collectable scats per jackal are based on mean weights of collectable scats, multiplied by the number of collectable scats per jackal.

Table. 4.14. Average body weight and proportion of prey consumed for each prey species of jackal in the study area.

Species	**Average body weight (Kg)(B)**	**Prey consumed per field collectible scat (kg) (Y)**	**Number of scats produced/animal (B/Y)**
Chital	45	0.36	124.0
Sambar	125	0.60	207.3
Nilgai	184	0.78	235.9
Wild pig	38	0.34	111.1
Cattle	180	0.77	234.4
Hare	3.6	0.24	15.1
Bird	3.4	0.24	14.3
Rodent	0.033	0.23	0.1
Goat	26	0.31	85.0

Table.4.15. Proportion of biomass consumed and number of individual consumed by jackal for different prey species in the study area (2008-2012).

Species	2010 ± 11		2011 ± 12		2012 ± 13	
	D	C	D	C	D	C
Chital	8.712	0.003	22.143	0.003	39.567	0.004
Sambar	7.236	0.001	20.502	0.001	22.311	0.001
Nilgai	7.020	0.001	62.400	0.002	84.240	0.002
Wild pig	0.000	0.000	0.000	0.000	3.078	0.000
Cattle	26.112	0.002	36.864	0.001	36.096	0.001
Hare	2.149	0.009	11.462	0.017	14.806	0.018
Bird	3.811	0.017	9.766	0.015	13.101	0.017
Rodent	7.983	3.765	12.089	1.964	8.668	1.157
Goat	1.224	0.001	11.322	0.002	5.202	0.001

D = Biomass consumed (F x Y) in %; C = Number of individual consumed (D/B) in %

Data on utilization (from scat analysis) and availability (from distance sampling analysis) of prey species was compared, an index of selection for each prey species were obtained (Ivlev's index) (Ivlev 1961). It was found that, during 2010-11, rodent (p<0.01), hare (p<0.01), chital (p<0.01) and *Zizyphus* fruits (p<0.01) were consumed more than their availability, while wildpig (p<0.01) goat (p<0.01) and nilgai (p<0.01) were consumed less than their availability. Sambar, cattle and bird was preyed in proportion to its availability (p>0.05) (figure 4.20). In 2011-12, rodent (p<0.01), hare (p<0.01), bird (p<0.01), chital (p<0.01) and *Zizyphus* fruits (p<0.01) were preyed more than their availability, while wildpig (p<0.01), cattle (p<0.01), goat (p<0.01) and sambar (p<0.01) were preyed less than their availability. Nilgai was preyed in proportion to its availability (p>0.05) (figure 4.21). In 2012-13, *Zizyphus* fruits (p<0.01), rodent (p<0.01), hare (p<0.01), goat (p<0.01), bird (p<0.01) and chital (p<0.01) were preyed more than their availability, while wild pig (p<0.01), cattle (p<0.01) and sambar (p<0.01) was preyed less than their availability. Nilgai was preyed in proportion to its availability (p>0.05) (figure 4.22).

Figure 4.20. Prey selection by jackal in the study area based on availability of food items and utilization through scat data in 2010-11.

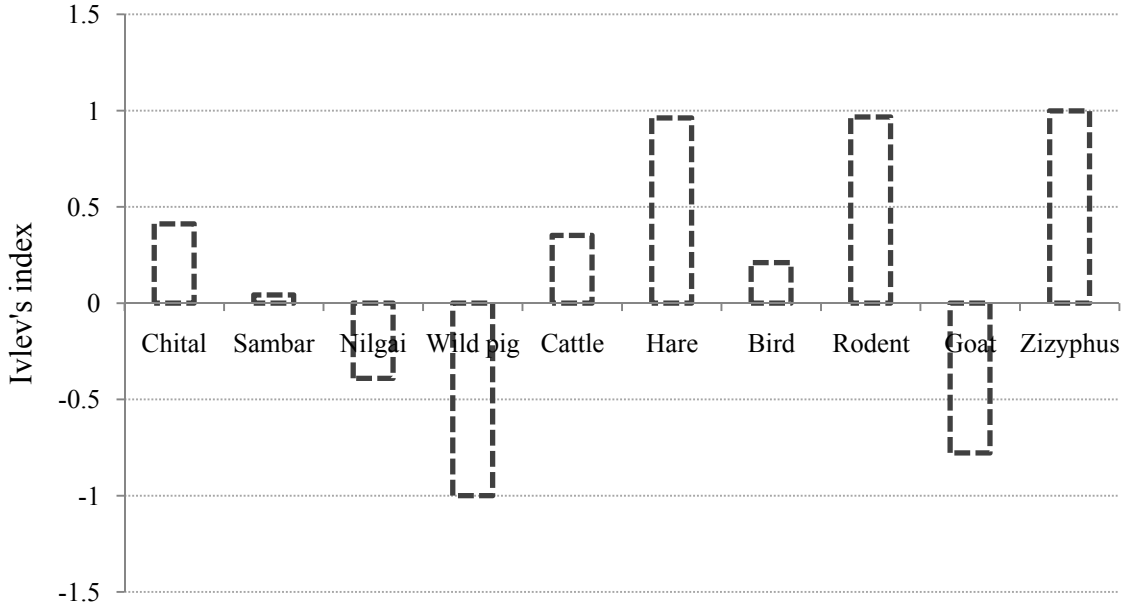


Figure 4.21. Prey selection by jackal in the study area based on availability of food items and utilization through scat data in 2011-12.

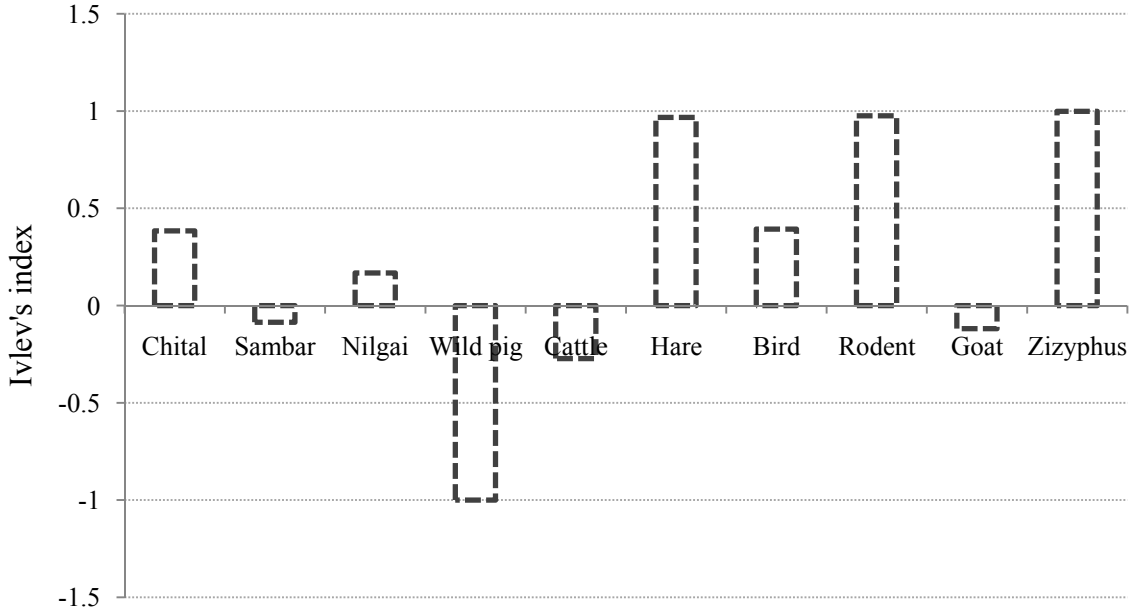
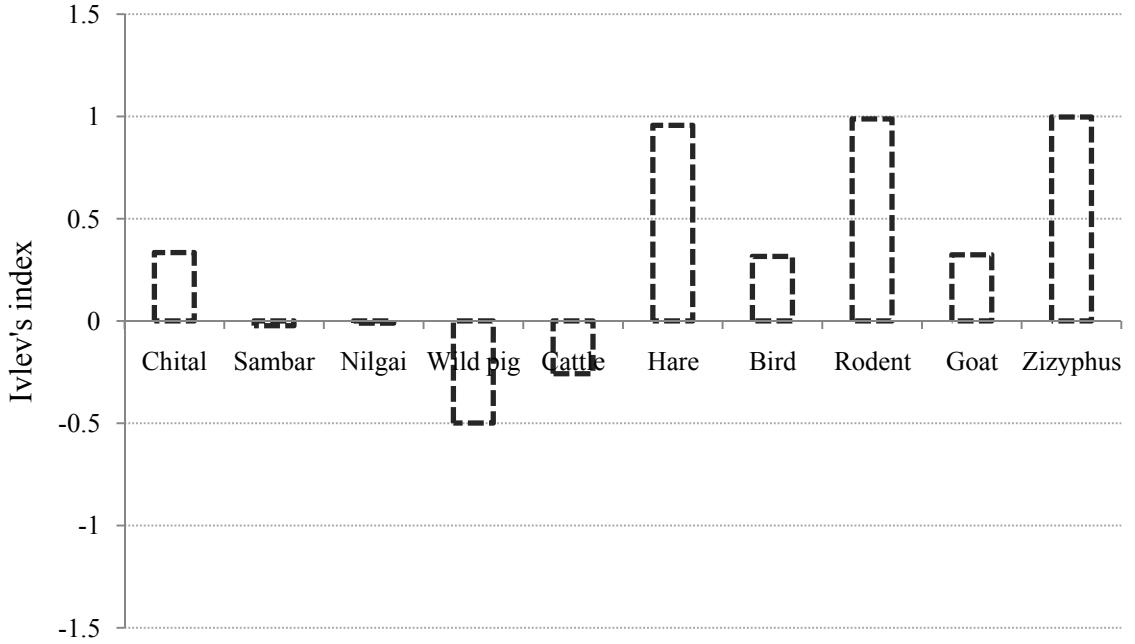


Figure 4.22. Prey selection by jackal in the study area based on availability of food items and utilization through scat data in 2012-13.



4.3.5.c. *Trophic niche overlap and niche breadth*

Frequency of occurrence and percentage frequency of occurrence of prey remains in hyena and jungle cat scats are given in table 4.16 and table 4.17 respectively during 2010 to 2013 in the study area. The occurrence of 14 food items did not vary between the three species. No significant diet difference was observed between jackal and hyena (Mann–Whitney U test: $U = 99$, $p = 0.28$), jackal and jungle cat (Mann–Whitney U test: $U = 88$, $p = 0.14$) and hyena and jungle cat (Mann–Whitney U test: $U = 124.5$, $p = 0.89$) in the study area.

Pianka's index (Pianka 1973) was used for measuring diet overlap between jackal and hyena (table 4.18), jungle cat and jackal (table 4.19) and hyena and jungle cat (table 4.20). The index of overlap (O) ranges in value from 0 (indicating no overlap) and 1 (complete overlap). The estimated dietary overlap for three years between striped hyena and golden jackal was found to be (0.81, table 4.18) 81%. The estimated dietary overlap between jungle cat and golden jackal was found to be 67% (table 4.19) and between striped hyena and jungle cat was found to be 31% (table 4.20) during the entire study period.

Niche breadth for golden jackal was calculated as 0.73, for striped hyena it was 0.40 and for jungle cat it was 0.36 (table 4.21, 4.22 and 4.23 respectively). Also, MacArthur and Levin's (1967) niche overlap was calculated as an overlap measure *of species A on species B* and vice-versa. The calculated value of niche overlap of jackal on hyena was observed to be (1.04) 100% i.e. out of total diet range of hyena, 100% of food items are common with jackal. The niche overlap of hyena on jackal was calculated as 0.62 or 62% i.e. out of total diet range of Jackal, 62% of food items are common with hyena (table 4.21). The calculated value of niche overlap of jackal on jungle cat was observed to be 0.87 or 87% i.e. out of total diet range of jungle cat, 87% of food items are common with jackal. The niche overlap of jungle cat on jackal was calculated as 0.44 or 44% i.e. out of total diet range of Jackal, 44% of food items are common with jungle cat (table 4.22).

Table.4.16. Number and frequency of occurrence of each prey species in hayena scats in Sariska National Park (2010-2013).

Food Item	2010-2011		2011-2012		2012-2013	
	N=86	% of occurrence	N=214	% of occurrence	N=191	% of occurrence
Buffalo	-	-	7	3.27	-	-
Bird	2	2.33	11	5.14	8	4.19
Cattle	26	30.23	28	13.08	52	27.23
Chital	17	19.77	63	29.44	55	28.80
Goat	3	3.49	-	-	2	1.05
Hare	1	1.16	2	0.93	-	-
Nilgai	26	30.23	43	20.09	61	31.94
Rodent	1	1.16	4	1.87	3	1.57
Sambar	18	20.93	57	26.64	59	30.89
Vegetation	11	12.79	79	36.92	42	21.99
Wildpig	-	-	7	3.27	-	-
Fruits			5	2.34	2	1.05
Insects			4	1.87	17	8.90
Langur			2	0.93		

Table.4.17. Number and frequency of occurrence of each prey species in jungle cat scats in Sariska National Park (2010-2013).

Food Item	2010-2011		2011-2012		2012-2013	
	N=0	% of occurrence	N=183	% of occurrence	N=184	% of occurrence
Bird	-	-	47	25.68	88	47.83
Cattle	-	-	5	2.73	2	1.09
Chital	-	-	15	8.20	19	10.33
Fruits	-	-	4	2.19	1	0.54
Goat	-	-	3	1.64	1	0.54
Grass seeds	-	-	-	-	6	3.26
Hare	-	-	22	12.02	64	34.78
Insects	-	-	5	2.73	10	5.43
Nilgai	-	-	16	8.74	2	1.09
Rodent	-	-	111	60.66	79	42.93
Sambar	-	-	2	1.09	3	1.63
Scale	-	-	19	10.38	15	8.15
Vegetation	-	-	41	22.40	36	19.57

Table.4.18: Dietary overlap between Jackal and striped hyena as shown by scat analysis in Sariska Tiger Reserve (2010 – 2013).

Food Item	Hyena relative occurrence (p_{iA})	Jackal relative occurrence (p_{iB})	P_{iA}*P_{iB} (C)	P_{iA}^2 (D)	P_{iB}^2 (E)
Buffalo	1.67	0	0.00	2.79	0.00
Birds	5.01	15.20	76.17	25.12	230.94
Cattle	25.30	17.50	442.81	640.01	306.37
Chital	32.22	26.32	848.11	1038.10	692.90
Fruits	1.67	24.69	41.26	2.79	609.83
Goat	1.19	7.87	9.39	1.42	61.93
Hare	0.72	16.15	11.56	0.51	260.71
Insects	5.01	10.72	53.72	25.12	114.90
Langur	0.48	0.00	0.00	0.23	0.00
Nilgai	31.03	26.73	829.33	962.63	714.49
Rodent	1.91	17.10	32.64	3.65	292.28
Sambar	31.98	11.26	360.16	1022.78	126.83
Reptile/ bird scale	0.00	5.97	0.00	0.00	35.64
Vegetation	31.50	47.08	1483.19	992.48	2216.53
Wild pig	1.67	1.22	2.04	2.79	1.49
			4190.38 (F)	4720.41 (G)	5664.85 (H)
				68.71 (I)	75.27 (J)
				Diet Overlap	0.8103 (O)

piA - percentage of food item *i* in the diet of golden jackal; *piB* - percentage of food item *i* in the diet of striped hyena; **C** = *piA***piB*; **D** = *pA*^2; **E** = *pB*^2; **F**= ΣC; **G** = ΣD and **H** = ΣE; **I** = G^0.5; **J** = H^0.5, **O** = F/ (I*J); L = Dietary overlap.

Table.4.19. Dietary overlap between Jackal and jungle cat as shown by scat analysis in Sariska Tiger Reserve (2010 – 2013).

Food Item	Jungle cat relative occurrence (p_{iA})	Jackal relative occurrence (p_{iB})	P_{iA}*P_{iB} (C)	P_{iA}^2 (D)	P_{iB}^2 (E)
Birds	36.78	15.20	559.01	1353.12	230.94
Cattle	1.91	17.50	33.39	3.64	306.37
Chital	9.26	26.32	243.86	85.83	692.90
Fruits	1.36	24.69	33.64	1.86	609.83
Goat	1.09	7.87	8.58	1.19	61.93
Hare	23.43	16.15	378.37	549.12	260.71
Insects	4.09	10.72	43.81	16.71	114.90
Nilgai	4.90	26.73	131.10	24.06	714.49
Rodent	51.77	17.10	885.10	2680.25	292.28
Sambar	1.36	11.26	15.34	1.86	126.83
Reptile/ bird scale	9.26	5.97	55.31	85.83	35.64
Vegetation	22.61	47.08	1064.48	511.21	2216.53
Wild pig	0.00	1.22	0.00	0.00	1.49
			3451.98 (F)	5314.65 (G)	5664.85 (H)
				72.43 (I)	75.27 (J)
				Diet Overlap	0.6291 (O)

piA - percentage of food item *i* in the diet of golden jackal; *piB* - percentage of food item *i* in the diet of jungle cat; **C** = *piA***piB*; **D** = *pA*^2; **E** = *pB*^2; **F**= ΣC; **G** = ΣD and **H** = ΣE; **I** = G^0.5; **J** = H^0.5, **O** = F/ (I*J); L = Dietary overlap.

Table.4.20. Dietary overlap between striped hyena and jungle cat as shown by scat analysis in Sariska Tiger Reserve (2010 – 2013).

Food Item	Hyena relative occurrence (p_{iA})	Jungle cat relative occurrence (p_{iB})	P_{iA}*P_{iB} (C)	P_{iA}^2 (D)	P_{iB}^2 (E)
Buffalo	1.67	0	0	2.79	0.00
Birds	5.01	36.78	184.3627	25.12	1353.12
Cattle	25.30	1.91	48.25294	640.01	3.64
Chital	32.22	9.26	298.4919	1038.10	85.83
Fruits	1.67	1.36	2.276082	2.79	1.86
Goat	1.19	1.09	1.300618	1.42	1.19
Hare	0.72	23.43	16.77798	0.51	549.12
Insects	5.01	4.09	20.48474	25.12	16.71
Langur	0.48	0.00	0.00	0.23	0.00
Nilgai	31.03	4.90	152.1724	962.63	24.06
Rodent	1.91	51.77	98.847	3.65	2680.25
Sambar	31.98	1.36	43.57072	1022.78	1.86
Reptile/ bird scale	0.00	9.26	0.00	0.00	85.83
Vegetation	31.50	22.61	712.30	992.48	511.21
Wild pig	1.67	0.00	0.00	2.79	0.00
			1578.83 (F)	4720.41 (G)	5314.65 (H)
				68.71 (I)	72.92 (J)
				Diet Overlap	0.3152 (O)

piA - percentage of food item *i* in the diet of striped hyena; *piB* - percentage of food item *i* in the diet of jungle cat; **C** = *piA***piB*; **D** = *pA*^2; **E** = *pB*^2; **F**= ΣC; **G** = ΣD and **H** = ΣE; **I** = G^0.5; **J** = H^0.5, **O** = F/ (I*J); L = Dietary overlap.

Similarly, the calculated value of niche overlap of hyena on jungle cat was observed to be 0.33 or 33% i.e. out of total diet range of jungle cat, 33% of food items are common with hyena. The niche overlap of jungle cat on hyena was calculated 0.28 or 28% i.e. out of total diet range of hyena, 28% of food items were common with jungle cat (table 4.23)

Table.4.21**.** Dietary niche breadth between jackal and hyena as shown by scat analysis in Sariska Tiger Reserve (2010 - 2013).

Variable	$Jackal_1$	$Hyena_2$
n	14	14
B	10.46621	6.220726
B_A	0.72817	0.401594
M MacArthur and Levins measure	1.04	0.62

Table.4.22. Dietary niche breadth between jackal and jungle cat as shown by scat analysis in Sariska Tiger Reserve (2010 - 2013).

Variable	$Jackal_1$	Jungle cat_2
n	14	13
B	10.46621	5.370015
B_A	0.72817	0.364168
M MacArthur and Levins measure	0.87	0.44

Table.4.23. Dietary niche breadth between hyena and jungle cat as shown by scat analysis in Sariska Tiger Reserve (2010 - 2013).

Variable	$Hyena_1$	Jungle cat_2
n	14	13
B	6.220726	5.370015
B_A	0.401594	0.364168
M MacArthur and Levins measure	0.33	0.28

4.4. Discussion

Finding food is one of the most challenging tasks for survival of the species in any environment. This requires well-adapted strategies of food acquisition. One strategy is to specialize on one exploitable source, whilst the alternative is to generalize. Research shows that the flexibility of jackal in their food choice and their ability to adopt suitable foraging behaviors enables them to survive in different habitats (Rowe-Rowe 1976, Stuart 1976, Lamprecht 1978, Nel & Loutit 1986, Avery et al. 1987). This indicates that jackal are opportunistic feeders. But, there is evidence that indicates that jackal are opportunistic in general but, as predicted by the optimal foraging theory, prefer highly nourishing, protein rich food sources even in periods of low food abundance (MacArthur & Pianka 1966). Similar results were obtained from coyotes in the Chihuahuan Desert (Hernández et al. 2002). For jackal, as mesopredators, the potential food availability increases as dietary items previously unattainable (large herbivore species) are killed by apex predators, and interspecific competition can be expected to decline. However, when acting as apex predators in the ecosystem, available food may be limited and differences in body size can lead to niche differentiation in terms of food size, and could also establish an inter-specific dominance hierarchy in which size reflects strength and superiority (Caro & Stoner 2003).

Sariska Tiger Reserve has matrix of open scrubs, barren lands, and moderate to dense forest, human settlements and agricultural land in and around. The jackal responses to fragmented habitat were consistent with a predictions based on a consideration of ecological characteristics of the species. For a given amount of available habitat, species with generalized diets potentially can avail themselves of a broader array of resources. In a heterogeneous landscape, energy can be extracted from a greater fraction of non matrix habitat by species with broader diets. Generalist species often are regarded as benefiting from agriculturally induced habitat fragmentation (e.g. Matthiae and Stearns, 1981) because they often are highly mobile, able to use diverse habitats or food items, or exploit edge habitats (Saunders et al., 1991; Noss and Csuti, 1997). In accordance with predictions, species with broad niches exhibited relatively little differentiation in resource selection as a function of multiple spatial scales, whereas species with narrower niches apparently were more constrained spatially in their resource selection.

The present study showed the dominance of mammalian prey species in the diet of striped hyena, golden jackal and jungle cat. Reptiles and invertebrates were also found in the diet of jackal and jungle cat but their identification and quantification was not possible. The most important food for jackal was small mammals, while they consumed invertebrates frequently, their remains were difficult to identify at species level. In the diet of black-backed jackal (*Canis mesomelas*) as well, insects in particular beetles form a major part. Since large beetles and locusts are protein rich and easy to catch, a rather large proportion was expected in the jackal scats in present study. In fact, they were found in many of the samples (n = 16 in 2010 – 11, n = 31 in 2011 – 12 and n = 32 in 2012 – 13) but in a lower proportion than other prey items. However, the insect proportion of consumed biomass is comparable to the study by Lanszki et al. (2009) for golden jackals in Hungary, Greece and Israel. Mammals, like rodents and ungulates, are apparently major food source with high nutritive value.

The study area harbored low rodent densities as compared to tropical areas (Jayahari, 2008). Trapping success of rodent in the entire study period was 5.27%. The earlier studied recorded trapping success of 2.6% (Gupta, 2010) and 0.9% (Mukherjee, 1998). Trapping success in winter was high 8.43% as compared to summer 2.11%. The estimated sex ratio of the rodent species in the study area was skewed, towards male. Since the reliable information about the behavior of these species is lacking, it is difficult to propose a sex specific difference in trap response (Gupta, 2010). 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 observed 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. For better interpretation of the densities of these species I used mark recapture analysis. More reliable density estimates were obtained for species with low capture rates. Frequently occurring species like little Indian field mouse (*Mus budooga*), spiny tailed field mouse (*Mus platythryx*), bush rat (*Golunda ellioti*) etc, different individual were 'getting trapped' in different occasions 'may be' with variable number of captures per location leads to underestimation of density in distance sampling where, it was

fairy accounted in mark-recapture frame work. 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.

Among the scats that had remains of mammalian prey, an earlier study in Sariska showed that felids depend largely on rodents in terms of energetic predictions (60 to 93%) while jackal gets between 44 to 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).

The diet of jackal also consisted of fruits in Sariska. The choice of fruit species in the diet of jackal was comparatively less and because it may not have fulfilled optimum nutritional requirements that could have prompted foraging even on invertebrates. Fruits generally have relatively low protein content but the ease with which they can be procured, relative to time and effort invested, allow meeting at least minimal protein requirements (Rode and Robbins, 2000). Besides the consumption of principal food items obtained by predators for scavenging, they also supplemented their diet with other food items. The general feeding habits of jackal in Sariska appear to confirm the results from available studies (Schaller 1967; Sankar 1988; Mukherjee 1998; Lanszki and Heltai 2002; Gupta 2009; Khan and Beg 1986; Wyman 1967 and Moehlman 1983, 1986, 1989). Small mammals contribute to the major biomass of numerous small carnivores which was also evident from this study. Rodents can appear in cyclical outbursts and are usually taken in higher proportion during peak season by small carnivore (Krebs & Myers 1974). Seasonal dominance of small mammals is known in jackal (Taryannikov 1974; Ishunin 1980; Mukherjee *et. al.* 2004). I measured seasonal changes in rodent abundance in this study. The recorded rodent abundance was higher in the winter (45.23 individuals/ha) as compared to summer (1.09 individuals/ha) (table 4.5), but the scat analysis indicated that rodents were consumed by the jackals throughout the year.

Relationships between frequency of occurrence of insect and mammal remains in individual scat samples in the present study suggest that when jackal were able to feed on rodents or scavenge on larger mammal carcasses they rarely search for insects. In grassland habitats, groups of jackals are known to kill antelopes (Lamprecht 1978). Considering the biomass proportions, mammals are assumed to be

the preferred prey of the jackal. On the other hand, plant parts in scats demonstrate the opportunistic aspect of their foraging behavior. The presence of grass/ grass seeds in the scat is consistent with other studies, mostly concluding a possible role in scouring the intestine during digestion (Kalle 2013).

The abundance of primary prey items in jackal's diet could possibly allow them to coexist with other competitive species without competing for food, although periods of food shortage might increase the food-niche overlap but this may not necessarily indicate competition among the three species. The food items selected by lesser carnivores are generally abundant in the environment yet not all food items can be quantified easily due to high diversity. The notable diet breadth variability and large interspecific differences as observed in the present study coincided with presumed levels of niche similarity.

In Sariska Tiger Reserve, hyena and jackal are the two mesocarnivore that were distributed in the entire study area. The hyena generally occupied all the major habitat types, compared to jackal that was mainly present in open scrub land and valley areas. There are predictions that body size and behavioral flexibility would influence the response of predators and this response would be evidenced in individual use of habitat elements and in the spatial distribution of predators (Lidicker and Koenig 1996). Specifically, larger species (i.e. striped hyena) would be more equitably distributed among all spatial habitat elements compared to smaller species (i.e. golden jackal), because large size would confer an increased ability to traverse the habitat matrix with minimal risk of predation. Similarly, species with a broader niche would be more equitably distributed among spatial habitat elements because broader diet breadth would allow a species to use the majority of spatial elements and exploit a wider range of resources. Additionally presence of larger species and species with broader niches would be more closely linked to characteristics of favorable elements (cover or food) and the landscapes surrounding an element, because the combined effects of large size and a broad niche on the species would impose fewer constraints on its element and landscape use compared to smaller, more specialized species (Gehring & Swihart 2002). Lidicker and Koenig (1996) suggested that landscape perception by mammals is dependent on body size, with large-bodied mammals perceiving landscapes as more homogenous than smaller species. Relative to smaller, less vagile mammals, larger mammals appear to view the habitat matrix

less as a barrier to movement, and patches within landscapes as less isolated and largely undivided (Addicott *et. al.* 1987). In Sariska although the range wise distribution of striped hyena was more than golden jackal, jackal were more confined to the areas where range of smaller prey species as well fruiting trees (*Zizyphus* sp.) are available. Hence, broader dietary niche was observed for jackal as compared to hyena in Sariska.

Many of the studies have explained dietary differences within the context of alternative feeding strategies (i.e. generalist vs. specialist foraging) or intrinsic niche differentiation (i.e. disparity in habitat requirements or body size) (Rosenzweig 1966; Schoener 1974; Brown 1975; Tokeshi 1999). However, not all species fall into such discrete categories (Fox & Morrow 1981). Indeed, within a given community, the relative breadth of a particular carnivore's diet (and by extension levels of interspecific dietary overlap) is best defined in relation to the feeding habits manifested by its tropic counterparts (Azevedo *et. al.* 2006). Feeding specialization has been described as 'use of a relatively narrow portion of the resource spectrum' (Cody 1974) or 'the stable use of a particular food type irrespective of fluctuations in the availability of that food type' (Kruuk & Parish 1981). With these traditional definitions providing a conceptual framework, several carnivore species have been shown to exhibit rather pronounced feeding specialization (Martı´n, Rodrı´ guez & Delibes 1995; Fedriani, Ferras & Delibes 1998). However, when prey abundance fluctuates dramatically over a period of time, even alleged specialist species may exhibit more generalist feeding patterns (O'Donoghue *et. al.* 1998). Moreover, a review of dietary breadth among herbivorous insects revealed that while generalization characterized the diet of many insect species, the dietary choices of individuals within particular populations were often specialized (according to the traditional framework described above), suggesting that in many cases dietary breadth may be a local (i.e. system-specific) phenomenon rather than an immutable species characteristic (Fox & Morrow 1981).

The considerable overlap (81%) characterizing the diets of hyena and jackal, in Sariska was due to mutual reliance on ungulates that indicates resource competition between these two species is high. However, hyena relied more on large ungulates, whereas jackal preyed largely on small ungulates and rodents and hence these dietary specializations may have alleviated overall levels of competition between two

species. On an average, the wild ungulates remains were found higher in the diet of striped hyena (24.22%), golden jackal (16.38%), and jungle cat (5.18%) during the study period in Sariska. The average livestock remains were found higher in jackal (12.69) and hyena (9.39) scat in present study. Sankar (2002) reported that nearly 80% of diet of striped hyena from STR was that of wild ungulates and livestock. Hyena predation on chital fawn (n = 9) and baby langur (n = 1) was captured in camera trap during the study period. The pattern of exclusive use of particular prey items, despite overall dietary similarity, also characterizes the relationships between sympatric coyotes *Canis latrans* and gray foxes *Vulpes velox* (Kitchen *et. al.* 1999) and coyotes and red foxes *Vulpes vulpes* (Azevedo *et. al.* 2006).

Depending on food availability, jackal may be solitary hunters, co-operate in pairs or hunt as groups (mainly while the parents teach the offspring to hunt). Co-operative hunting of large mammals (fawn of deer or nilgai calf) by jackal was observed twice during the study period and this was not otherwise reported in Sariska by the earlier study (Mukherjee, 1998). The differences in large mammal and small mammal proportions between the diets resulted in a significant difference between jackal and hyena diets. However, at 81%, the niche overlap between jackal and hyena was still high. Jackal diet comprised high proportions of small and large mammals infer that they both scavenge and hunt competently. Results from the present study are comparable to the studies of Nowell & Jackson (1996) and Walton & Joly (2003) on black-backed jackcal (*Canis mesomelas*) in Africa. Study by Owens & Owens (1978) on Brown hyenas showed that they are predominantly scavengers and black-backed jackals are generally excluded from carcass sites by the much larger brown hyenas, forcing them to hunt more frequently. The similar case may be likely to happen in Sariska Tiger Reserve where striped hyena occurs in high density (Gupta *et. al.* 2009). Study by Merwe *et. al.* (2009) on assessment of diet overlap between brown hyena and black-backed jackal suggested that in jackal's diet, more large mammals were consumed outside of protected areas whereas more small mammals were consumed inside protected areas in South Africa's North West Province. This observation supports the idea that jackal may be excluded from scavenging sites and forced to actively hunt when competing with striped hyena as may be the case in the present study or, brown hyena in case of Africa as mesopredators in protected areas. The low frequency of smaller species in the diet of the striped hyena may reflect

sufficient carrion resources, as most samples originated in the part of study area where the hyenas are relegated to mesocarnivore status by the presence of apex predators like tiger and leopard. This suggests that niche partitioning in protected areas in the presence of an apex predator results in a form of competitive exclusion of jackal at carcasses by hyena, resulting in a greater level of hunting by the jackals, connatural to the study in Africa (Merwe *et. al.* 2009).

Review of the various studies shows marked interspecific difference in plant-matter consumption by golden jackal. Plant matter did not play an important role in the feeding of jackal in Hungary (Lanszki *et. al.* 2006), Balasubramanian & Bole (1993) reported seasonal dependence on plants in jackal's diet where *Zizyphus* fruits (24.69%) were the most important food source between May and November. 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). Mukherjee (1998) reported that 20% of jackal's scats contained *Zizyphus* fruits from Sariska whereas, they were encountered in less proportion in jungle cat (1.36%) and hyena (1.67) scats. 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 Sariska Tiger Reserve in scrubland, the fallen fruits were not eaten by jackal. No garbage consumption was observed (Macdonald 1979) by jackal during the present study, as scats were collected only from the forested area where there was an abundance of other food items available.

Study by Lanszki *et. al.* (2006) on feeding habits and tropical niche overlap between golden jackal (*Canis aureus*) and red fox (*Vulpes vulpes*) in the Pannonian ecoregion Hungary revealed that functional response of the jackal to a limited but favored food item was more rapid than that of the fox. The jackal shifted from small prey to other food items when the availability of small mammals declined, and also returned to rodent hunting when they are abundent (Lanszki *et. al.* 2006).

The considerable overlap characterizing the diets of jackal and jungle cat (63%) in Sariska was primarily due to heavy mutual reliance on small mammals which indicates that resource competition between these two species may be severe. However, jackal relied more largely on ungulates and lagomorphs, whereas jungle cat preyed largely on small rodents and hence these dietary specializations may have

alleviated overall levels of competition between 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 (*p*earson, 1964; Comman and Brunner, 1972; Jones and Smith, 1979; Ludlow and Sunquist, 1987; Palmer and Fairall, 1988; Mukherjee, 1998).

Birds were found to be an important prey species in the diet of all three carnivores. The occurrence of birds in the diet of jungle cat was 36.78% which is lower than that reported from Bharatpur (55%), and comparable with previous studies in Sariska (30.4%) (Mukherjee, 1989, 1998). The bird remains were found in 15.2% scats of jackal in Sariska as observed in the present study. This is lower than other studies on golden jackals as reported from Bangladesh and Africa which had 31% and 23.7% scats respectively (Mc Shane and Grettenberger, 1984) and from Bharatpur 20% (Mukherjee 1998) and 12% (Gupta 2006). This pattern of exclusive use of particular prey items, despite overall dietary similarity, also characterizes the relationships between sympatric coyotes and gray foxes (*Vulpes velox*) (Kitchen et al., 1999) or bobcats (*Lynx rufus*) (Neale & Sacks, 2001b).The dietary breadth among hyena and jungle cat revealed an overlap of 31% in Sariska. As compared to jackal and hyena, jungle cat is more specialized in hunting rodents. Mukherjee et al., (2004) estimated that up to 70% of the daily metabolizable energy in the jungle cat and caracal is obtained from small rodents. The minimal occurrence of fruits and seeds in small cat diet was observed during the present study and the same was reported in the diet of other cat species as well. 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. Mukherjee (1998) found 10% scats from Sariska Tiger Reserve had the remains of wild ungulates and livestock. Gupta (2006) reported that 24% and 55% of jackals diet comprised of chital and cattle respectively from Bharatpur.

While jackals are able to hunt the young of domestic ungulates (Stenin *et al*. 1983, Yom-Tov *et al*. 1995), direct predation by jackals on live stock was observed minimal in the study area. The results are comparable with the study in Greece and Israel (Giannatos 2010, A. Dolev and G. Bino, pers. comm.). In more human-influenced landscapes comprising of partly natural and partly cultivated areas, jackal's dietary composition may represents remains of live stock, accounted by

domestic ungulate carcasses originating from open dumps. Jackals residing in the human-dominated landscapes of Israel were found to take full advantage of available resources, specifically the dominant presence of poultry carcasses and plants from agricultural plots, and were able to thrive and maintain an extremely dense population (Bino 2008). This is in accordance with other studies that demonstrate that the species could flourish where human waste is abundant and food is no longer a limiting resource (Macdonald 1979, Yom-Tov *et al.* 1995).

I attempted to derive an equation of correction factor to compute biomass consumption using feeding trials on jackal known to be an omnivorous species. In the study by Akerman (1984) on cougar food habits, proportionately more collectible scats were produced when cougars consumed smaller prey. Jethva and Jhala (2004) reported that the consumption of carcasses by wolf was negatively correlated with size of prey and consumption of prey biomass per collectable scat increased with an increase in body weight of prey. The relationship obtained using average prey weight consumed per collectable scat with average weight of prey as per weight classes fed to jackal suggested that prey consumption per collectable scat increased with an increase in prey weight. In the study by Floyed *et. al.* (1978) on relating wolf scat content to prey consumed, the total number of collectible plus non collectible scats was relatively constant per kg of prey for all carcasses. However, the number of collectible scats per kg of prey eaten decreased as the size or weight of the prey increased. The strong inverse relationship indicated that smaller or lighter weight prey was composed of relatively more indigestible matter. The relationship obtained (figure.4.18), supports Mech's (1970) hypothesis and is in agreement with Floyd *et. al.* (1978) and Weaver (1993), that the percentage frequency of occurrence of prey species tends to over represent smaller prey in terms of biomass, and to under represent them in terms of numbers when compared to larger prey species. This was attributed to the fact that there is a larger surface area to volume ratio for smaller prey.

Results from the present study further suggest that the percent utilization of carcass was higher in smaller prey compared to larger prey by jackal which is in agreement with findings of Jethva and Jhala (2004). When jackal feed on larger prey, they tend to feed more selectively on the choicest body parts. This resulted in higher

digestibility for larger prey. A major limitation of present study was inability to conduct feeding trials using rats and insects, the natural prey of jackals. Because of quarantine issues for rodents in Jaipur Zoo, difficulties were encountered in obtaining permits. Also the insects that were eaten by jackal in natural conditions were not available in the open market and hence they were not used in feeding trial experiments on jackal. The present study on jackal feeding trial was based on scats containing remains of one prey species only. However, scats sometimes contain more than one prey species. For scats with more than one prey item per scat, the proportion of each prey item comprising the scat must be estimated visually. These proportions are then summed for each prey item for the entire sample of scats, and multiplied by the respective Y value of the regression to obtain the total biomass of the prey item consumed (Floyd et. al. 1978). If no information on dry mass or volume is available, equal Q5 contributions of the different prey species to the scats can be allocated, as this is likely to represent a mean Q5 contribution to the scats in a reasonably large sample size. Similarly, to calculate the consumed number of individuals per prey species, equal Q4 contributions of different prey species can be allocated to the scats. Ciucci *et. al.* (1996) and Spaulding *et. al.* (1997) found that using the frequency of occurrence directly for biomass estimation without correcting for the proportional contribution of a prey item to a scat for scats with more than one prey item gave results similar to those obtained with the use of proportional contribution data. They recommend using the percent frequency of occurrence of prey data directly to estimate consumption of biomass (Spaulding et al., 1997).

The results on jackal feeding trial confirmed that the accuracy of correction factor depends on the number of feeding experiments and the range of prey sizes included. Present study, like previous studies determined correction factor fitted a linear regression through the data. However, an exponential function is likely to be biologically more meaningful and physiologically more realistic than a linear function, because it predicts that the amount of prey consumed by a carnivore to excrete one scat reaches an asymptote at large prey sizes (Wachter et. al. 2012). Because of logistic limitations the weight of prey provided to jackals during the experiment was restrained to 50 kg. Hence, the asymptote could not be reached. Such a maximum is reasonable because the total amount of food a carnivore can consume of a large prey is limited and the ratio of indigestible to digestible matter that is

consumed does not change after reaching this limit. Also, the apparent digestibility increased with increasing prey body mass and reached an upper limit. The conversion of prey body mass into a number of scats and their weights excreted by an individual carnivore after prey consumption is a crucial step that diet studies based on scats ought to infer accurately (Wachter et. al. 2012). The seven quantities were used to evaluate the steps required to establish the consumed prey mass and the number of consumed prey individuals derived from carnivore scats collected in the field.

No single method of predator scat analysis is ideal; each provides unique information and allows interpretations not possible with others (Latham 1951). Assuming random sampling, percent occurrence in scats indicates how pervasive the food item is in the diet of the predator population and is not unduly biased by food preferences of individual predators (Weaver and Hoffman 1979). Percentage of identified items partially corrects for this but assumes that all individuals are equally detectable. Biomass adjustments for weight differences among prey species are achieved by multiplying average weight for a species by its percentage of items identified (Weaver 1977). However, heavier individuals may be detected more often than lighter ones, and conversions to biomass could be misleading if data are not corrected for differential detectability. Prey as large as lagomorphs and ungulates may provide enough undigested material for many scats (Floyd *et. al.* 1978), thereby further distorting the relative importance of larger prey. Inferences about the relative importance of different prey in predator diets may not be valid unless differences in detectability (related to biomass of the prey) are considered and data appropriately adjusted. More feeding trials on jackal will be required to establish detectability relationships over a range of prey sizes. The effects of the size of the prey, presence of non vertebrate constituents (i.e. insects and reptiles), and metabolic state of the Jackal on prey detectability need quantitative evaluation (Weaver and Hoffman 1979).

Correction factor determined in this study are only applicable to carnivore feeding chiefly on mammalian prey species and on species that are not completely consumed. Whereas, Jackal is a generalist predator and occurs in variety of habitats from savannah and woodland in Protected Area (Moehlman, 1983; Fuller *et. al.*, 1989) to farmland around human habitation (Pouche *et. al.*, 1987; Jeager *et. al.*, 2001). Their foraging strategies are highly variable in different habitats. Adaptations in foraging behavior in relation to abundance and quality of food sources are expected

to be highly pronounced in an extreme habitat and in presence of larger predators. Jackals are not exclusively opportunistic but, as predicted by the optimal foraging theory, prefer highly nourishing, protein-rich food sources even in periods of low abundance (MacArthur & Pianka 1966). For carnivore such as golden jackal, black-backed jackal, side-striped jackal and red fox that mainly feeding on fruits, invertebrates, birds and small mammals, the diet can be better determined using the specific conversion factors for these food items (Goszczynski, 1974; Atkinson et.al. 2002; Reynolds and Aebischer, 1991; Loveridge and Macdonald, 2003). For small canids, new feeding experiments should be conducted to account for the differential detectability and to derive an exponential function equation that is biologically more accurate to get correction factor.

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). The results from the present study in Sariska showed considerable dietary overlap between striped hyena and jackal. These two species obtained lot of energy from scavenging as well (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 a limiting factor for competition to take place (Dayen *et al.,* 1990). Since Sariska 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, striped hyena was largely utilizing ungulates while jackal was utilizing more hare, rodents and birds. As compared to felids, mode of hunting in canids is more flexible and depends 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).

CHAPTER 5

DEN SITE SELECTION BY JACKAL

5.1. Introduction

The availability of denning habitat is essential for successful recruitment and for the persistence of populations. Dens are used by jackal for both shelter and rearing of young. Jackal dig dens, adapt existing burrows from other species (i.e., porcupine)**,** and opportunistically select dens. Underground dens provide shelter especially during breeding. The young are born blind and are dependent on their parents for approximately 2 months. The den dependence has become a useful tool, as den surveys can give good estimates of reproductive success in a population. Den surveys lead to assessments of breeding frequency and litter sizes, which serve as indicators of reproductive success between years and regions (Egoscue 1975, Covell 1992, White and Ralls 1993, White and Garrott 1997). Jackals are regularly associated with dens unless if they are hunting, which typically occurs during the late nocturnal hours and early dawn. Jackal are reliant on dens both for moderation of microclimate in the arid regions that they inhabit and for security from predation by large-bodied carnivores, similar to the trait observed in Kit fox (*V. macrotis*) and for colder regimes in Arctic foxes (*Alopex 1agopus*) (Egoscue 1962 and 1975; Golightly and Ohman 1984). Dens are therefore an important habitat requirement for jackal and may also be a confining factor for their distribution (Morrell 1972). Clearly, the structural characteristics of dens and denning sites determine their ability to satisfy these functions. On the other hand, in carnivores the need for breeding dens may affect the ecological behavior of individuals in several ways. First, dens can influence the spatial configuration of territory borders (Doncaster and Woodroffe, 1993). Second, by regulating the abundance and distribution of individuals, they act as a limiting resource (Neal, 1986; Weber, 1989; Halliwell and Mac- Donald, 1996; Ruggiero et al., 1998). Third, they lead breeding pairs into changing their spatial behavior during the denning period by enlarging or displacing their home ranges in order to access suitable structures for denning (Bailey, 1981). Therefore, the presence of suitable dens is one of the key factors that make a habitat suitable for den dependent carnivore species. Finding a suitable den site might be a stronger limiting

factor for specialist carnivores living in human dominated areas, whereas generalist species may find greater denning opportunities due to habitat alteration in such landscapes. Therefore, understanding factors that influence resource selection for such carnivore species becomes important.

Den entrance characteristics such as the number of entrances, diameter of entrance, and orientation are frequently referenced as important selection factors for many den using species. Rodrick and Mathews (1999) documented natal kit fox dens in the northern Chihuahuan Desert with tall den entrances, although the number of entrances did not influence whether the den site was used as a natal den. The "keyhole"- shaped entrance was thought to provide kit foxes easier access to the den and discourage other predators such as coyotes. In addition, den entrance orientation provides microclimate advantages for Arctic foxes (*Alopex 1agopus*) in the winter (Chesemore 1969; Smits et al. 1988; Prestrud 1992). Harsh climates in western India might influence the selection of jackal dens with entrances oriented to decrease den temperature, especially in the summer during the pup-rearing season. In addition to terrain, the height of vegetation surrounding the den is also a factor that may play a larger role in den selection during pup-rearing season than at other times. Dens with little vegetation that provide maximum visibility of surroundings and potential predators may be preferred (Arjo et al. 2003). Jackal generally uses the same den throughout a breeding season, unless disturbed. Similar observation is recorded for Arctic fox (*Alopex lagopus*) (Angerbjörn, Ströman and Becker 1997). Jackal use two types of dens, viz. dens excavated in soil and dens situated in rocky areas, the latter mostly along river side. Understanding den characteristics may help to develop effective management and conservation strategies for the jackal.

In the study on Iberian lynx (*Lynx pardinus*) by FernaÂndez and Palomares (2000), they identified two types of dens: (a) Natal dens used by the female for giving birth; (b) Auxiliary dens (Bailey, 1981) to which cubs are moved afterwards. However for my study the term resting dens were used for all the dens other then natal dens. I considered several factors being the determinants of den selection: protective advantages against predators, microclimatic stability, proximity to food resources, closeness to the core zone of the territory and distance to the neighboring territory. With this, I approached the analysis of den selection in two ways. First, I analyzed the physical structure of the den and its protective capabilities (i.e.

preventing detection and access by predators, and maintaining stable internal thermal conditions) i.e. microsite selection; and second, I investigated den site selection in relationship to environmental factors (structure of the vegetation, disturbance and prey availability) i.e. macrosite selection. Herein, I described den structures (the actual features jackal denned within) and analyzed den site selection based on 15 natal and 21 resting den sites used by jackal in Sariska Tiger Reserve. Out of 21 resting dens, those observed having less frequent usage (< twice; n = 6) were excluded from analysis for adjoining habitat features. My objectives were (1) to describe structures used for natal and resting dens, and (2) to test the hypothesis that jackal select den sites based on structural and habitat attributes.

Although several studies focused on the distribution and use of dens in different habitat types, only few have data on the den settlement and habitat composition in semi-arid regions (Aiyadurai and Jhala, 2006; Patil and Jhala, 2008; Soni *et. al*, 1995; Ginsberg and Macdonald, 1990; Wilson and Reeder, 1993; Macdonald et al., 1999). Studies demonstrated that generalist predators such as the red fox (Johnson et al., 2002) and golden jackal modify their territories in relation to patch dispersion. Thus, different patterns of the use of space and differences in territorial defense by jackal inhabiting large and small ranges can promote overlapping between jackal groups or selective exploitation of patches (Goszczynski, 2002; Dell'Arte and Leonardi, 2005). Although Moehlman (1983) reports maintenance of year-round exclusive territories in Tanzania, aggregations in Israel (Macdonald 1979a) and India (Y. Jhala pers. obs.) point towards the flexibility of social organization depending on available food resources. However, suitable areas for dens can also influence the territory size and social organization of a terrestrial predator (Lovari et al., 1996). Data obtained by telemetry from the Bhal area of India suggest that most breeding pairs are spaced well apart and are likely to maintain a core territory around their dens (Y. Jhala unpubl.). Feeding ranges of several jackals in the Bhal overlapped, and the same was also reported by Van Lawick and Van Lawick-Goodall (1970), in fact, landscape modifications such as habitat patchiness made by human activities (agricultural practices, urbanization) create ample unfavorable zones for den settlement (Baker *et. al.* 2000).

The western part of India, which is largely arid and semi-arid, has a large, fast growing human and livestock population. To meet their needs, this region has been

subjected to large-scale land use change, and consequent opening and conversion of habitats into scrub and agriculture in several areas over the decades (http://goidirectory.nic.in/fstateut.htm). Despite their relative simplicity, grasslands, deserts and semi-arid environments have been less studied as far as the process of habitat fragmentation is concerned (Whitford and Fenton, 1999 and McGarigal and Cushman, 2002). In the semi-arid and arid tracts of western India, there has been a vast expansion of land under irrigated agriculture over the decades and this has benefited some rodent species while exterminating others (Sharma and Sankhala, 1984; Prakash, 1995; Prakash *et al*., 1995). In this region, not only have numbers of some generalist rodent species increased to pest proportions, but their distribution ranges have also expanded due to expansion of irrigated farming (Sharma and Sankhala, 1984; Prakash, 1995; Prakash, Singh and Saravanan, 1995).

Rodents are generally viewed as pests due to the economic losses caused to agriculture and the prospects of spread of disease from them. However, they play an important ecological role as prey of numerous small carnivores (Pearson, 1964; Moehlman, 1986; Kitchener, 1991; Sillero-ZubiriandGottelli, 1995). Thus, cultivation could create variable conditions for the establishment of dens by terrestrial mammals and limit their distribution, especially in highly fragmented landscapes (Nakazono and Ono, 1987; Jia et al., 1991; Meia and Weber, 1992). This is apparent mainly when suitable areas for a particular species are separated by large areas of unsuitable matrix habitat such as arid rocky terrain or urban areas (Kruuk and Macdonald, 1985; Taylor et al., 1993; Macdonald et al., 1999). However, jackal is a generalist predator with adaptable social systems (Macdonald 1979) that are able to exist in close proximity to humans and exploit agro-ecosystems. Jackal are reported to prey primarily upon rodents (Lanszki and Heltai 2002), including bandicoot rats (Khan and Beg 1986). Rodents are also an important prey for side-striped jackal (*C. adustus*) (Atkinson et al. 2002). While an increase in rodent abundance would seemingly benefit rodent-eating carnivores (here jackal), it must be noted that conversion to agriculture in many cases destroy cover, which is essential for hunting and denning. If conservation of this predator can be facilitated, it could have economic benefits especially in areas where rodents have reached pest proportions and jackal could use agricultural lands may be on a limited basis, and also inhabit urban environments.

In India, jackal den excavations begin in late April to May, with dens primarily located in natural and man-made embankments, usually in scrub habitat. Rivulets, gullies, road, and check-dam embankments are prime denning habitats (Soni *et al*. 1995; Y. Jhala pers. obs.), although drainage pipes and culverts have served as dens on several occasions in the Bhal. Dens may have 1 to 3 openings and typically are about 2 to 3m long and 0.5 to 1.0m deep. Loose textured soils may be preferred for denning. Scent marking by urination and defecation is common around denning areas and on intensively used trails. Such scent flag posts are considered to play an important role in territorial defense (Rosevear 1974). Affinitive behavior like greeting ceremonies, grooming, and group vocalizations are common in jackal social interactions (Van Lawick and Van Lawick-Goodall 1970; Golani and Keller 1975). Vocalization consists of a complex howl repertoire beginning with 2 to 3 simple, low pitch howls and culminating in a high-pitched staccato of calls. Jackal are easily induced to howl and a single howl evokes responses from several jackals in the vicinity. Jackals often emit a warning call that is very different from that of their normal howling repertoire in the presence of large carnivores like tiger, hyens and wolf (Jerdon 1874; Y. Jhala pers. obs.). In India, howling is more frequent between December and April, a time when pair bonds are being established and breeding occurs, perhaps suggesting a role in territory delineation and defense (Jaeger *et al*. 1996).

Reproductive activity of jackal commences from February to March in India and Turkmenistan, and from October to March in Israel (Golani and Keller 1975; Ginsberg and Macdonald 1990). Females are typically monoestrus, but there is evidence in Tanzania of multiple litters (P. Moehlman pers. obs.). Mating results in a copulatory tie that lasts for several minutes (Golani and Mendelssohn 1971; Golani and Keller 1975). Gestation lasts about 63 days (Sheldon 1992). Timing of birth coincides with abundance of food supply; for example, the beginning of the monsoon season in northern and central India, and the calving of Thomson's gazelle in the Serengeti (Moehlman 1983; Ginsberg and Macdonald 1990). Moehlman and Hofer (1997) reported mean litter size of jackal as 5.7 (range=1–8) in Tanzania, while in the Bhal area in India, average litter size was 3.6 (range=2–5; n=11) (Y. Jhala unpubl.). In Tanzania, Wyman (1967) reported an average of two pups emerging from the den at three weeks of age. Pups are born blind and their eyes open at approximately nine

days and their teeth erupt at 11 days after birth (Moehlman and Hofer 1997). Lactation usually lasts for 8–10 weeks. Young pups could be moved between 2–4 dens prior to joining their parents. In Tanzania both parents and 'helpers' (offspring from previous litters) guard the new pups. The male also feeds his mate during her pregnancy, and both the male and the 'helpers' provision the female during the period of lactation (Moehlman 1983, 1986, 1989; Moehlman and Hofer 1997). The 'helpers' are full siblings to the young pups that they are provisioning and guarding, and the presence of 'helpers' results in a higher pup survival (Moehlman 1986).

5.2 Materials and methods

The study was conducted from April 2011 to March 2013.

5.2.1. Den surveys

I systematically searched the study area on foot for jackal active den sites. I spent a total of approximately 1752 man hours along with a field assistant searching for jackal dens in the ~ 160 km^2 study area using information obtained from sings as well secondary information from shepherds. Systematic efforts were invested to search the entire area however; some bias is expected since I surveyed more intensively the areas around camera trap locations where even a single jackal picture was captured and where prior known existing dens were reported in the study area. Active dens were identified by signs of fresh digging, pup and adult scat deposition around the den site and tracks along the ramp of the den openings. The presence of pup scat deposition and pup tracks around the den site was used as a sign to differentiate between active natal and resting dens. At many occasions, this was reconfirmed by the presence of pups outside the dens during dawn and dusk. I recorded the number of active and inactive holes at the den-site and whether the site was a natural dig-out or was located in a man-made structure such as an earthen bund, canal or well tailings. All the active dens of different pairs were monitored simultaneously. The distance between the two occupied dens was estimated using the GPS. The orientation of den openings was noted. The magnitude of disturbance as a result of livestock movement with increasing age of pups was measured during active denning stages. Pup activities around dens in the presence and absence of adults were

also recorded. In the absence of adults, pups of increasing age usually emerge from their dens to explore the surroundings.

5.2.2. Den characteristics

On finding a den site, I recorded the geographical location using a hand-held GPS. I used circular plot of 10m radius, with the den site at the centre, to measure surrogate variables representing the *a priori* hypotheses at the den area scale. I also measured the same variables outwardly at a distance of 100 m in four cardinal directions from the den site (Lesmeister et al. 2008). I recorded the substrate and terrain type at the den site, measured tree and shrub density in the 10m radius circular plot and recorded percentage canopy cover using a spherical densiometer. I also measured visibility using percent shrub cover in terms of shrub volume around the den site by recording length and width of every shrub species and adding the results to amount for the percent of area covered by shrubs in 10m radius circular plot. I measured ground layer height using a steel ruler and measuring tape. All these den characteristics were measured during late mornings and afternoons to avoid disturbance to jackal inside the den. On occasions when jackal were not present in and around dens, measurements on den openings and den temperature was recorded using Taylor 1441E Digital Waterproof Minimum Maximum Thermometer. I also measured from each den site, the distance to nearest settlement, distance to nearest water source and distance to the nearest road using spatial analyst tool in ArcMap software. For this, I used a GIS land cover classification layer, land and water hole layers from WII's GIS laboratory.

5.2.3. Statistical analyses and Model Selection-

In this study, I studied factors affecting den site selection in jackal at two levels; the selection scale at micro site and the selection scale at macro site. For micro site selection, variables in consideration were i) substrate, ii) terrain, iii) tree number, iv) shrub number, v) vegetation composition, vi) grass cover and vii) distance to road, water and settlement. For defining the vegetation composition for a plot I did 'indicator species analysis' using program "PC.ord" (McCune and Mefford 2011) where the species with lowest AIC values were chosen as a dominant species for the

plot. Different plant groups were provided with an identity in a way it describes vegetation composition of the plot. To examine the effect of various habitat variables at 100m distances on jackal den site selection, I paired each den site with four points at a distance of 100 meters in the four cardinal directions. I used use-availability design along with discrete choice models (Cooper and Millspaugh, 1999) for micro site selection to test for the models that best explained den site selection using SPSS 16 (SPSS 2007) statistical package for data analysis. Variables with lowest AICs were tested in various model combinations. The model combination with lowest AIC was selected as a best model.

For macro site selection, variables in consideration were i) proportional value of forest type, ii) proportional value of forest cover, iii) densities of various prey items, iv) elevation, v) slope, vi) ruggedness and vii) distance to road, water and settlement. For 31 den locations 60 random points were generated in the intensive study area, where efforts for searching dens were invested, using Arc GIS tool. The buffer of 1 km radius was layered around each den locations and random locations. I selected the buffer distance as 1km radius considering 3.14 km^2 as a minimum distance movement per day for jackal during denning. I extracted the values of the target variables form the 1 km radius buffer layer for both random and den locations. The proportional value of forest type, forest cover, elevation, slope, ruggedness and distance to road, water and settlements was extracted from the GIS land cover classification layer from WII's GIS laboratory.

I evaluated prey density for different prey classes by exploratory analysis using DISTANCE 5.0 software in conventional distance sampling (CDS) and multiple covariate distance sampling (MCDS) framework. For modeling detection function forest type was used as a factor covariate. The model with the lowest AIC value was selected for density estimation of the prey classes. Among the different proportion of forest types in the study plots (random as well den plots), the three dominant forest types were selected. I assigned prey density to each plot by multiplying the proportional value of the three dominant forest types in a plot area with the prey density values for the respective forest types. The resultant values form dominant forest types were then added to get prey density values of different prey species in various plots. I used Pearson's correlation to evaluate correlation between

different variable groups and among different parameters within the group. The related variables were checked for AIC values and one with the lowest AIC was used for model construction. Multi models were constructed and analyzed using binary logistic regression in generalized linear model using selected parameters of different variables with significant values.

To examine factors that influenced den site selection at the micro scale by the jackal, I used four ecological hypotheses created by Punjabi *et al.* (2013), which might best predict den site selection. These hypotheses were: habitat and prey availability, thermoregulation (substrate and terrain), predatory avoidance (cover) and edge effects (distance to road, water and settlement) and, are represented by explanatory variables measured at each den and available sites. I used an information theoretic approach of testing *a priori* models by Akaike's information criterion (AIC) to assess model weights (ω_i) and ranked candidate models using Δ AIC (Burnham and Anderson 2002).

5.3. Results

5.3.1. Physical attributes:

Thirty six jackal dens were located in the intensive study area in Sariska Tiger Reserve (0.23 den / km^2) out of which information from 30 dens were used for data analysis (excluding less used dens, n = 6). Pairs of jackal observed started visiting dens in March, the beginning of the breeding season (March-April). Natal dens generally had young once present during the rearing season (May-August). Jackal was known to use more than one den but no attempt was made to search for shifted auxiliary dens. In the study area, NVD (*Zizyphus **n**ummularia*, *Adathoda **v**asica*, *Capparis **d**ecidua*) and EC (*Balanites a**e**geptiaca, **C**apparis sepiaria*) vegetation classes were observed more in denning sites (figure 5.2) but no significant difference was observed (chi-square test: $\chi^2 = 6.25$, d.f. = 3, $p = 0.10$) among four vegetative classes between natal and resting dens. Substrate mud-loam was associated with plain terrain type and substrate rock-mud was associated with undulating terrain type at significant level (chi-square test: $\chi^2 = 25.86$, d.f. = 9, $p = 0.00$). The distribution of dens across four terrain types and six substrate types is presented in figure 5.3. Among the four substrate types, selectivity of natal dens were recorded more than

expected for mud-loam and for resting dens the selectivity for rock-mud was recorded more than expected but were not found at significant level (chi-square test: $\chi^2 = 1.97$, d.f. = 3, $p = 0.58$). Number of natal dens were observed more in plain terrain where, resting dens under human construction was observed more than expected however, the values were not found significant ($\chi^2 = 2.03$, d.f. = 3, $p = 0.57$) (figure 5.4).

5.3.2. Cover dependence:

The average size of den opening was recorded as 47.11 cm, ranging from 18 cm to 90 cm (n=36). One-way analysis of variance showed that the percentage cover for natal and resting den were not different (One way ANOVA test: $F = 0.01$, $p = 0.92$)(table 5.1) however, in areas with high percent cover, significantly lesser number of dens were observed ($r = -0.76$, $p = 0.02$, n=9) (figure 5.7). Natal den selection sites were indifferent to water availability (One way ANOVA test: $F = 1.02$, $p = 0.32$) and other human induced disturbance such as distance to road (One way ANOVA test: $F = 1.45$, $p = 0.24$) and human settlements (One way ANOVA test: $F = 2.53$, $p = 0.12$) (table 5.1).

5.3.3. Thermoregulation:

The mean 'minimum' ambient temperature in den site was recorded as 31.7°C and the mean 'maximum' ambient temperature was recorded as 34.7°C. This was higher than the minimum temperature recorded inside den (up to the depth where probe can reach with minimum disturbance) i.e. 30.8°C and maximum of 33.1°C. Difference in temperature oscillation inside and outside dens ranged between 0.4°C and 3.6°C in 'minimum' scale and 'maximum' temperature difference ranged between 0.1°C and 5.8°C. The minimum ambient temperature was 2.8% higher and, maximum ambient temperature was 4.7% higher than the temperature inside dens. The variation in 'minimum' ambient temperature and den temperature was not much (One way ANOVA test: $F = 1.02$, $p = 0.32$) but, the variation in 'maximum' ambient temperature and den temperature was recorded high at significant level (One way ANOVA test: $F = 4.20$, $p = 0.05$). Not much variation was recorded for 'minimum' temperature range for all the dens (One way ANOVA test: $F = 1.27$, $p = 0.30$) however 'maximum' temperature were recorded less in natal dens but not at significant level (One way ANOVA test: $F = 1.53$, $p = 0.26$). Temperature variation

was neither significant in the four substrate types nor for natal and resting dens (Kruskal-wallis test, $\chi^2 = 3.00$; df = 3; $p = 0.39$) (figure 5.6). To get an idea if den aspect is causing any variation in temperature inside dens, the temperature data was analyzed on the basis of various aspects. I observed that 'minimum' temperature recorded for aspect N and SW was lower than that of aspect SE and NE but not at significant level (chi-square test: $\chi^2 = 8.84$; df = 7; $p = 0.27$). The 'maximum' temperature variation was not found significant among aspects (chi-square test: $\chi^2 = 5.49$; df = 7; $p = 0.60$) although 'maximum' temperature recorded for SW was lower than N and NE (figure 5.5).

5.3.4. Aspect dependence:

No selectivity was observed for spatial orientation of den entrances of jackal in terms of aspect (pearson's chi-square test: $\chi^2 = 633$; df = 7; $p = 0.50$) however the natal den facing aspect SW (20%), NW (20%) and NE (13.3%) were observed more than expected, and for resting dens aspect N (16.7%) was observed more than expected (figure 5.6). Air current pattern in western part of the country is expected to favor these specific orientations (figure 5.9).

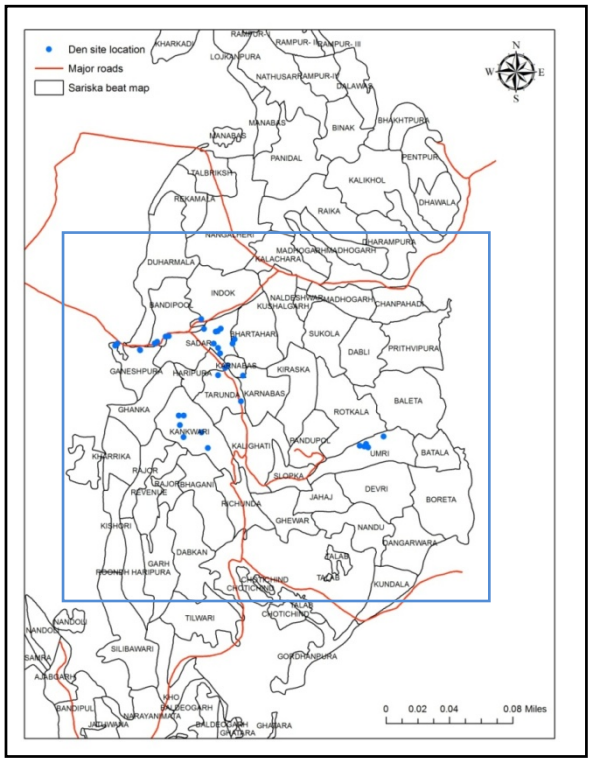


Figure.5.1. The locations of dens (resting and natal) in the intensive study area (Sariska National Park)

5.3.5. Den placements:

There was a negative correlation observed at significant level between average 'maximum distance' among dens and the size of regional area (Spearman's rho correlation test; r_s = 0.89, n = 5, P < 0.04) (figure 5.8). The region was defined as contiguous areas navigable by jackal in terms of average jackal movement and habitat topography. The larger areas have dens that are closely located to each other (≥ 1 km). Forest composition of five regions and variation among different forest types are given in table 5.2. The 'region two', having area of 28.11 km^2 was recorded to have the smallest average 'maximum distance' between dens, where the composition of forest types were significantly different (One sample *t* test; $t = 2.63$, df = 5, $p = 0.03$). The 'region two' composed a high proportion of fellow land (10.62 km^2) followed by *Acacia* dominant forest (7 km^2) and barren land (5.64 km^2) (top three) suggesting the clumpy distribution of favorable habitat prevailing close allowance of dens with each other. However, no significant variation in forest types was observed for the region where maximum distance between the den was recorded high (One sample *t* test; $t = 1.89$, df = 5, $p = 0.10$) (table 5.2). No relation was observed between average 'minimum distance' among dens and region (Spearman's rho correlation test; r_s = 0.36, n = 5, P < 0.55).

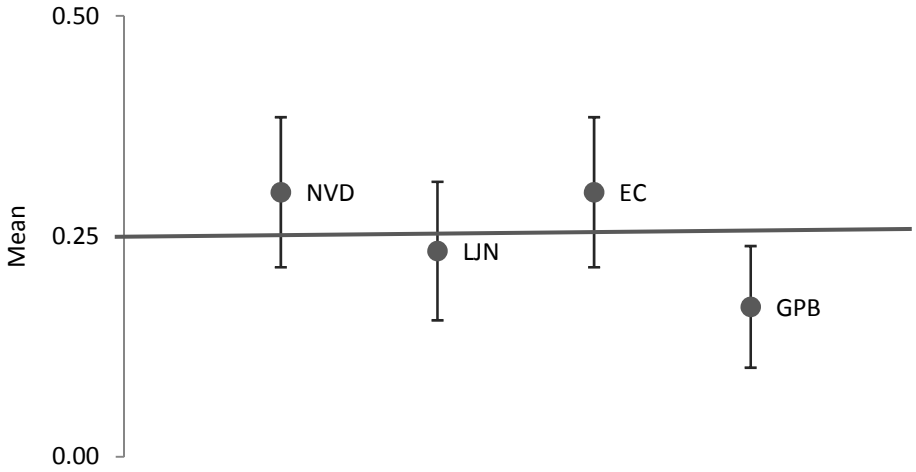


Figure.5.2. Distribution of vegetation classes in comparison to collective mean of all vegetation classes with standard error as compared to mean (0.25). Values below 0.25 indicate less preference, while values above 0.25 indicate preference of vegetation classes in den sites. Abbreviations: NVD (*Zizyphus **n**ummularia*, *Adathoda **v**asica*, *Capparis **d**ecidua*); LJN (***L**entana camara*, *Prosopis **j**uliflora, Acacia **n**ilotica*); GPB (***G**rewia flavescens, Anogeissus **p**endula, **B**utea monosperma*); EC (*Balanites a**e**geptiaca, **C**apparis sepiaria*).

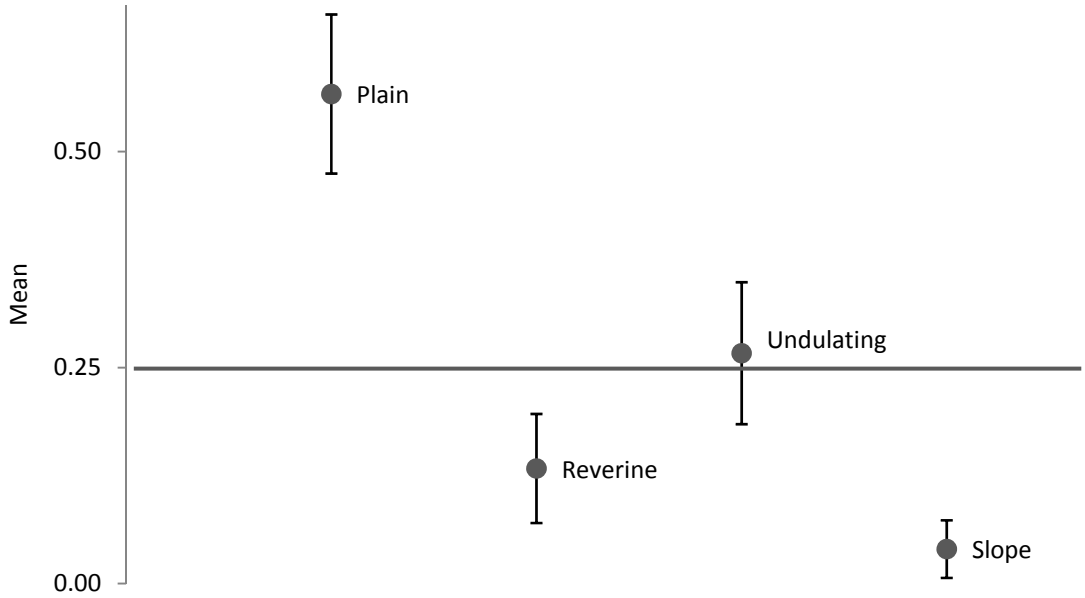


Figure.5.3. Distribution of various terrain types in comparison to collective mean of all terrain types with standard error as compared to mean (0.25). Values below 0.25 indicate less preference, while values above 0.25 indicate preference of terrain types in den sites.

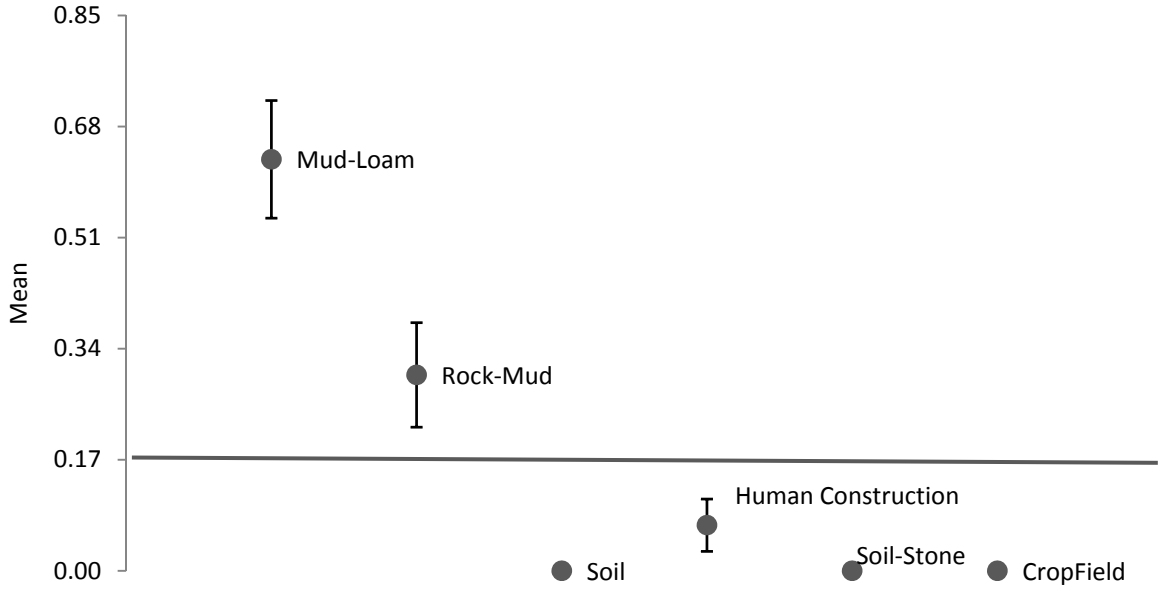


Figure.5.4. Distribution of various substrate types in comparison to collective mean of all substrate types with standard error as compared to mean (0.17). Values below 0.17 indicate less preference, while values above 0.25 indicate preference of substrate types in den sites.

Tabe.5.1. Environment characteristics of natal and resting dens sites of jackal, and comparison with each other using ANOVA test between two den types

Den characteristics	Resting (n=15)	Natal (n=15)	*F* value	*p* value
Den entrance diameter (cm) (Minimum maximum range)	49.7 ± 4.7	50.7 ± 4.5	0.02	0.82
	32 - 90	33 - 70		
Cover percentage (Minimum maximum range)	13.53 ± 3.00	13.07 ± 3.05	0.01	0.92
	2.8 - 44	0.9 - 41		
Distance from water (M) Minimum maximum range	527.3 ± 116.4	391.00 ± 68.18	1.02	0.321
	72 - 1600	25 - 900		
Distance from road (M) Minimum maximum range	1266.3 ± 395.9	2139.1 ± 607	1.45	0.239
	55 - 44.8	30 - 6150		
Distance from settlement (M) Minimum maximum range	890.27 ± 204.45	528.33 ± 100.08	2.59	0.12
	120 - 3000	80 - 1234		
Tree number Minimum maximum range	5.73 ± 1.45	3.73 ± 0.96	1.33	0.26
	0 - 20	0 - 12		
Shrub number Minimum maximum range	31.47 ± 6.57	27.33 ± 6.57	0.19	0.66
	0 - 93	0 - 95		

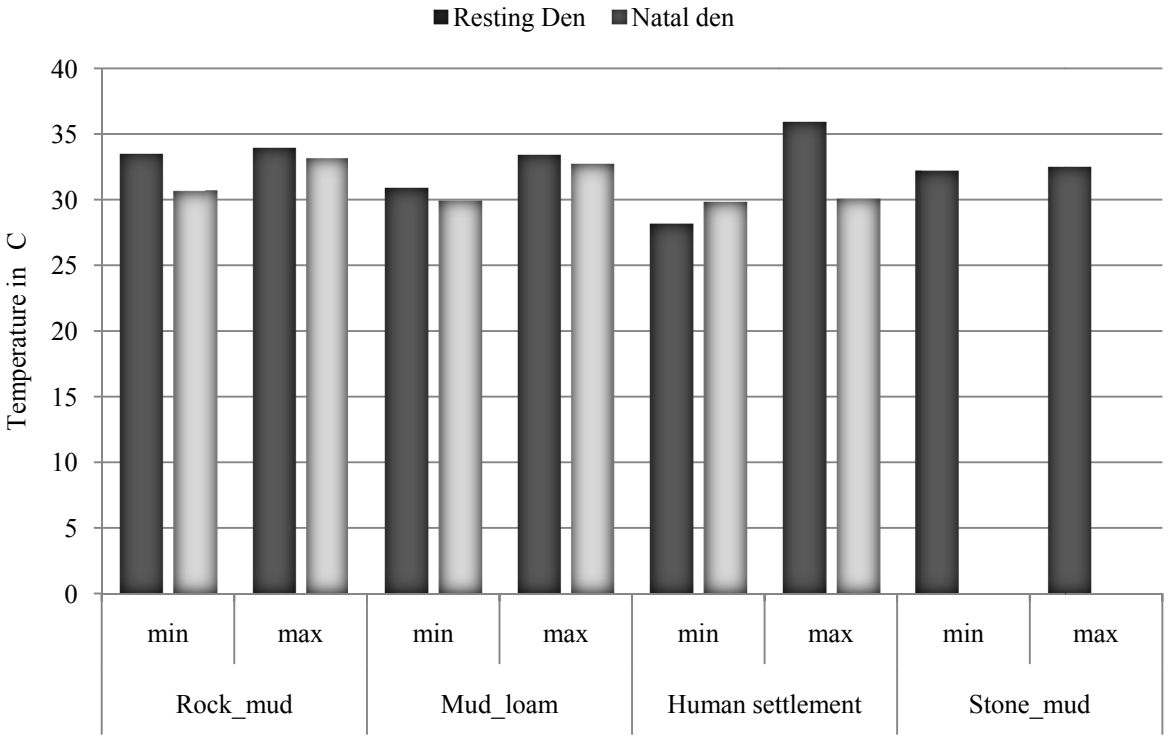


Figure.5.5. Temperature variation in natal and resting dens of jackal in minimum and maximum scale across different substrate types in Sariska Tiger Reserve.

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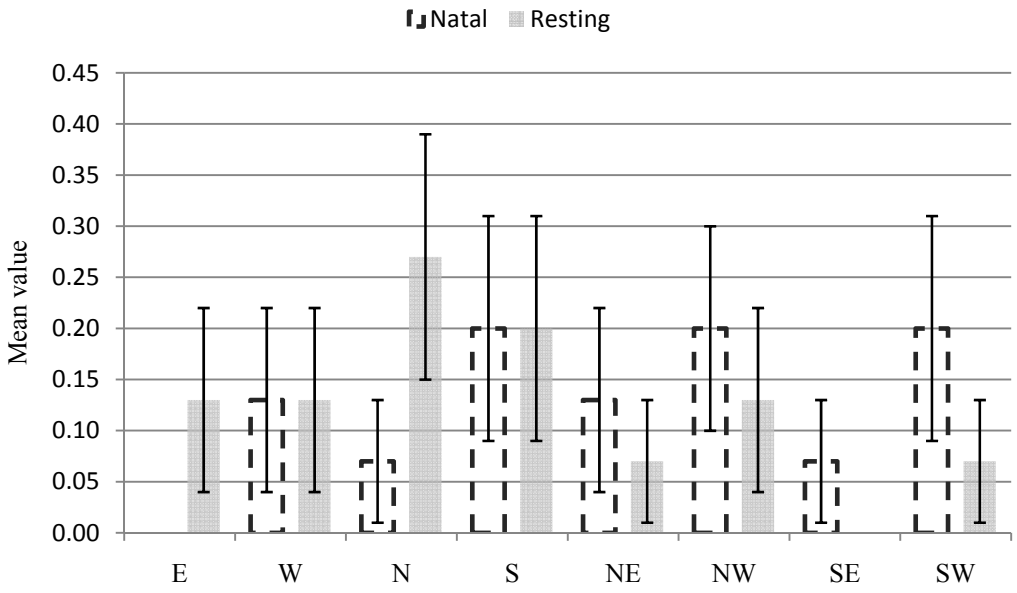

Figure.5.6. Mean values of den orientation aspects observed for natal and resting dens of jackal in Sariska Tiger Reserve.

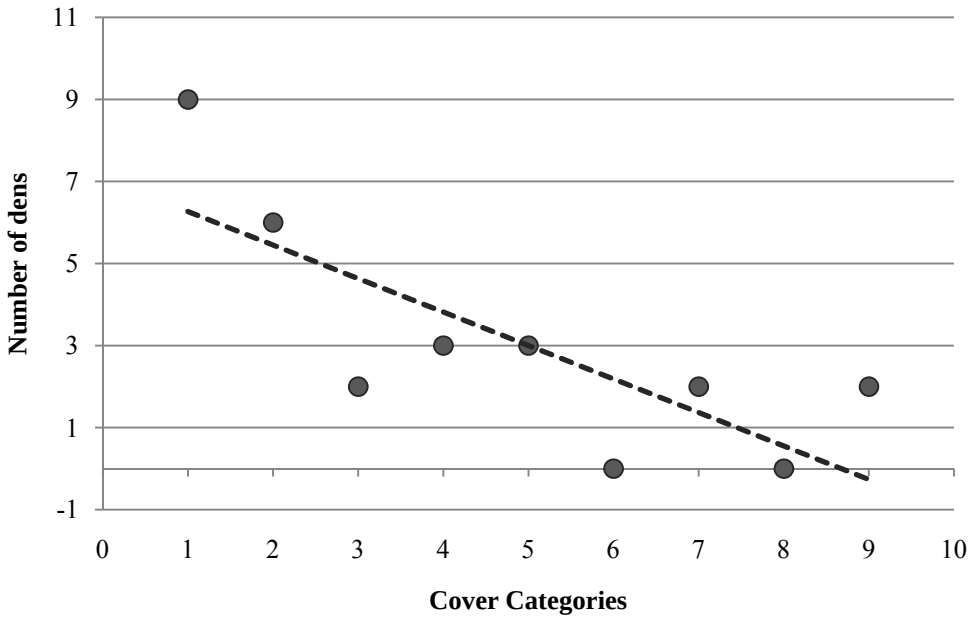

Figure.5.7. Spearman's rho correlation between cover categories (measured as, 0 = 0; 1 = 0-5 %; 2 = 5-10% …..10 = 45-50%) and number of jackal dens (r_s = -0.76, n = 9, P < 0.02). Number of dens decreased in regions having high cover (> 20-25%).

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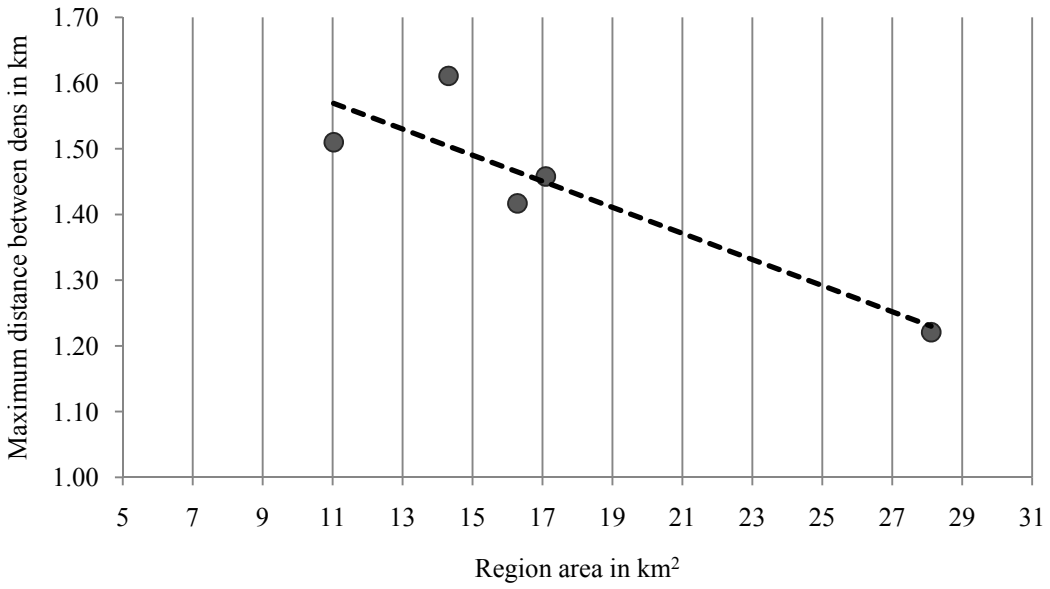

Figure.5.8. Spearman's rho correlation between region areas (measured as contiguous areas navigable by jackals in terms of average jackal moment and habitat topography) and the average maximum distances among jackal dens in five region (r_s = 0.89, n = 5, P < 0.04). Distances decreased in regions having high area (> 18 km^2).

Tabe.5.2. Five regional areas surveyed for dens, their area and three dominant forest type composing the area in relation to distance between dens and comparison using independent sample *t* test between regions.

Region	Forest type	Area (Km^2)	Region area (Km^2)	Den distance (Km)	*t*	*p*
Region One	*Acacia* dominant	4.93	17.09	1.46	3.19	0.02
	Barren land	4.79				
	Fallow land	3.29				
Region Two	Fallow land	10.62	28.11	1.22	2.63	0.03
	Acacia dominant	7.00				
	Barren land	5.64				
Region Three	*Acacia* dominant	6.02	16.28	1.42	3.29	0.01
	Barren land	2.70				
	Anogeissus dominant	2.47				
Region Four	*Acacia* dominant	8.42	14.31	1.61	1.89	0.10
	Anogeissus dominant	1.88				
	Fallow land	1.65				
Region Five	Fallow land	4.30	11.03	1.51	2.83	0.03
	Scrub land	2.31				
	Anogeissus dominant	1.88				

5.3.6. Micro site selection

At the micro scale (314 m^2), the hypothesis 'ease of excavation' received much support as the underlying factor for den site selection. The presence of suitable substrate in corresponding terrain along with characteristic vegetation composition providing 'horizontal cover' were evaluated as the most influential factors governing selection of den sites at micro scale as represented by the top model (AIC = 69.22; ωi = 0.096) (Table 5.3). The substrate suitable for excavation i.e. mud-loam and rock base and vegetation classes NVD (*Zizyphus **n**ummularia*, *Adathoda **v**asica*, *Capparis **d**ecidua*) and LJN (***L**entana camara*, *Prosopis **j**uliflora, Acacia **n**ilotica*) were found as determining variables for the selection of denning site (Table 5.4). Although high ωi value was observed for substrate only model (ωi = 0.215; AIC = 67.61), model selection was done based on field observations and hypothesis that satisfactorily explains ecological basis for den selection.

There was no significant variation observed among cover percent for four vegetation classes i.e. NVD, LJN, GPB (***G**rewia flavescens, Anogeissus **p**endula, **B**utea monosperma*) and EC (Kruskal-wallis test, χ^2 = 4.25; df = 3; p = 0.24) however, LJN class has the highest rank in terms of cover followed by GPB and NVD. Since GPB vegetation class was mostly associated with hilly areas its contribution in models was poor. Other variables in the different models seemed to have a low effect due to weak level of significance and more the number of variable contributing in mode (2K) that compromised AIC values. All other models representing the predatory avoidance, vertical cover (tree number, canopy cover) and disturbance received no support since there was a large difference in the Delta ***i*** values from the top model (=25.41, Table 5.3). Variables favoring natal den selection were no different than that of overall selected den sites (Kruskal-wallis test, χ^2 = 5.00; df = 5; p = 0.42) (Table 5.6). The substrate variable mud-loam and rock-mud scored high rank followed by reverine terrain for all denning sites whereas, for natal dens, high rank score for substrate variables mud-loam and rock-mud was observed followed by plain terrain type (Table 5.6). This suggests an idea that the choice of plain areas is frequent in jackal 'natal den' sites. To examine the variables which influenced selection at significant level, multimodal information was derived to obtain the collective effects of variables in all the models (table 5.5 and 5.6). Jackal

showed no significant selection or avoidance for any forest types (*Anogeissus* dominant forest, *Boswellia* forest, *Acacia* mixed forest, *Zizyphus* mixed forest, *Butea* dominant forest and Scrub forest).

Table.5.3. The top model from the list of models ranked by AICc explaining den site selection in the jackal at the micro site selection scale at Sariska Tiger Reserve (2011-13).

Model	-2 Log Likelihood	Chi-square	Variables in the Equation	B	SE	Wald	df	Sig.	Exp(B)	2K	AIC values	Delta *i*	exp. Values	ω_i
1	63.61	37.37	Mud-loam	3.10	1.06	8.58	2	0.003	22.19	4	67.61	0.00	1.00	0.215
			Rock-mud	4.98	1.26	15.58		0.000	146.02					
2	91.02	11.2	Riverine	2.77	1.12	6.15	1	0.013	16.00	2	93.02	25.41	0.00	0.000
3	63.33	39.04	Riverine	0.74	1.44	0.27	3	0.606	2.10	6	69.33	1.72	0.42	0.091
			Mud-loam	2.92	1.09	7.15		0.007	18.46					
			Rock-mud	4.73	1.31	13.01		0.000	113.38					
4	59.22	42.15	Riverine	0.41	1.62	0.06	5	0.801	1.50	10	69.22	1.61	0.45	0.096
			Mud-loam	2.95	1.09	7.28		0.007	19.11					
			Rock-mud	4.81	1.36	12.45		0.000	123.04					
			NVD	1.67	0.86	3.75		0.053	5.31					
			LJN	0.22	0.99	0.05		0.821	1.25					
5	61.18	40.25	Riverine	0.09	1.52	0.00	4	0.951	1.10	8	69.18	1.57	0.46	0.098
			Mud-loam	3.08	1.11	7.63		0.006	21.67					
			Rock-mud	4.81	1.33	13.15		0.000	122.69					
			Tree-num	0.13	0.09	2.05		0.152	1.14					
6	55.97	43.88	Riverine	-0.33	1.70	0.04	6	0.848	0.72	12	67.97	0.36	0.84	0.180

			Mud-loam	3.23	1.13	8.16		0.004	25.16					
			Rock-mud	4.76	1.36	12.31		0.000	117.01					
			Tree-num	0.16	0.09	3.05		0.081	1.17					
			NVD	2.06	1.00	4.27		0.039	7.84					
			LJN	0.19	1.04	0.03		0.852	1.21					
7	53.93	45.6	Riverine	2.15	2.57	0.70	7	0.403	8.59	14	67.93	0.32	0.85	0.183
			Mud-loam	3.44	1.21	8.04		0.005	31.03					
			Rock-mud	4.73	1.40	11.43		0.001	113.44					
			Tree-num	0.16	0.09	2.84		0.092	1.17					
			NVD	2.07	1.01	4.19		0.041	7.95					
			LJN	0.02	1.07	0.00		0.987	1.02					
			Shrub-num	-0.03	0.02	1.79		0.181	0.97					
8	55.92	44.02	Riverine	-0.26	1.71	0.02	7	0.879	0.77	14	69.92	2.31	0.32	0.068
			Mud-loam	3.22	1.13	8.20		0.004	25.09					
			Rock-mud	4.65	1.45	10.32		0.001	104.60					
			Tree-num	0.15	0.09	2.80		0.094	1.17					
			NVD	2.06	1.00	4.29		0.038	7.88					
			LJN	0.19	1.04	0.03		0.852	1.21					
			Settlement-Km	0.20	1.00	0.04		0.838	1.23					
			Predator-pres	0.16	0.07	2.90		0.086	1.14					

9	53.86	46.17	Riverine	2.30	2.64	0.76	8	0.384	9.95	16	69.86	2.25	0.32	0.070
			Mud-loam	3.43	1.21	8.06		0.005	30.82					
			Rock-mud	4.59	1.48	9.59		0.002	98.76					
			Tree-num	0.15	0.10	2.39		0.122	1.16					
			NVD	2.07	1.01	4.22		0.040	7.96					
			LJN	0.00	1.06	0.00		0.998	1.00					
			Settlement-Km	0.26	1.03	0.07		0.798	1.30					
			Shrub-num	-0.03	0.02	1.81		0.179	0.97					

AIC values AIC weights (ω_i) Selected model

NVD = *Zizyphus **n**ummularia*, *Adathoda **v**asica*, *Capparis **d**ecidua*; LJN = ***L**entana camara*, *Prosopis **j**uliflora, Acacia **n**ilotica*; Tree-num = Tree number; Shrub-num = Shrub number; Settlement-Km = Distance to settlement in km.

Continued….

Table.5.4. The top model from the list of models ranked by AICc explaining natal den selection in the jackal at the macro site selection scale at Sariska Tiger Reserve (2011-13).

Model	-2 Log Likelihood	chi-square	Variables in Equation	B	SE	Wald	df	Sig.	Exp(B)	2K	AIC values	Delta i	exp. Values	ωi
1	37.44	11.45	Mud-loam	2.17	1.13	3.70	2	0.05	8.73	4	41.44	0.00	1.00	0.68
			Rock-mud	3.65	1.46	6.28		0.01	38.46					
2	43.93	5.44	Plain	0.83	0.76	1.20	2	0.27	2.30	4	47.93	6.49	0.04	0.03
			Riverine	2.91	1.44	4.08		0.04	18.39					
3	36.74	11.83	Plain	0.60	0.90	0.44	4	0.51	1.83	8	44.74	3.30	0.19	0.13
			Riverine	-0.27	1.98	0.02		0.89	0.76					
			Mud-loam	2.30	1.45	2.51		0.11	9.96					
			Rock-mud	4.36	2.14	4.17		0.04	78.47					
4	35.91	12.2	Plain	0.64	0.95	0.46	6	0.50	1.90	12	47.91	6.47	0.04	0.03
			Riverine	-0.33	2.06	0.03		0.87	0.72					
			Mud-loam	2.67	1.59	2.83		0.09	14.42					
			Rock-mud	4.70	2.40	3.82		0.05	109.83					
			LJN	-0.93	1.58	0.35		0.56	0.39					
			EC	-1.15	1.46	0.61		0.43	0.32					
5	36.43	12.34	Plain	0.55	0.92	0.37	5	0.54	1.74	10	46.43	4.99	0.08	0.06
			Riverine	-0.55	2.06	0.07		0.79	0.58					

			Mud-loam	2.34	1.47	2.54		0.11	10.42					
			Rock-mud	4.31	2.12	4.14		0.04	74.37					
			Tree-num	0.06	0.11	0.31		0.58	1.07					
6	35.62	12.69	Plain	0.61	0.96	0.40	7	0.53	1.84	14	49.62	8.18	0.02	0.01
			Riverine	-0.59	2.13	0.08		0.78	0.55					
			Mud-loam	2.73	1.60	2.92		0.09	15.27					
			Rock-mud	4.69	2.39	3.87		0.05	109.09					
			Tree-num	0.06	0.12	0.30		0.58	1.07					
			LJN	-1.03	1.59	0.42		0.52	0.36					
			EC	-1.05	1.43	0.54		0.46	0.35					
			Predator-pres	0.06	0.12	0.33		0.49	1.05					
7	34.63	13.88	Plain	0.53	0.96	0.30	6	0.58	1.70	12	46.63	5.19	0.07	0.05
			Riverine	0.96	2.53	0.15		0.70	2.62					
			Mud-loam	2.33	1.47	2.51		0.11	10.27					
			Rock-mud	4.50	2.18	4.24		0.04	89.95					
			Tree-num	0.09	0.12	0.60		0.44	1.09					
			Shrub-num	-0.02	0.02	1.93		0.17	0.98					
8	36.14	12.65	Plain	0.53	0.96	0.30	7	0.58	1.70	14	50.14	8.70	0.01	0.01
			Riverine	-0.51	2.18	0.05		0.82	0.60					
			Mud-loam	2.27	1.53	2.20		0.14	9.68					

			Rock-mud	4.38	2.19	3.99		0.05	79.44					
			Tree-num	0.04	0.12	0.12		0.73	1.04					
			Dist-road	0.00	0.00	0.26		0.61	1.00					
			Dist-settlement	0.00	0.00	0.05		0.82	1.00					
9	34.46	14.13	Plain	0.62	1.02	0.37	8	0.54	1.86	16	50.46	9.02	0.01	0.01
			Riverine	1.16	2.83	0.17		0.68	3.20					
			Mud-loam	2.30	1.56	2.19		0.14	9.98					
			Rock-mud	4.56	2.30	3.94		0.05	95.31					
			Tree-num	0.07	0.13	0.28		0.60	1.07					
			Dist-road	0.00	0.00	0.17		0.68	1.00					
			Dist-settlement	0.00	0.00	0.01		0.91	1.00					
			Shrub-num	-0.02	0.02	1.66		0.20	0.98					
			Predator-pres	0.10	0.20	0.30		0.49	1.05					

AIC values AIC weights (ω_i) Selected model

NVD = *Zizyphus **n**ummularia*, *Adathoda **v**asica*, *Capparis **d**ecidua*; LJN = ***L**entana camara*, *Prosopis **j**uliflora, Acacia **n**ilotica*; EC = *Balanites **a**egeptiaca, **C**apparis sepiaria*; Tree-num = Tree number; Shrub-num = Shrub number; Settlement-Km = Distance to settlement in km; Dist-road = Distance to road.

Table.5.5. Most influential model-averaged parameter estimates of top models explaining den selection by jackal at the micro site scale at Sariska Tiger Reserve (2011-13).

Factor	Covariate	Mean B	SE±unc	Sum ω_i
Substrate	**Rock-mud**	**4.82**	**1.29**	**1.00**
	Mud-loam	**3.16**	**1.04**	**1.00**
Terrain	Riverine	0.52	1.44	0.75
Vegetation composition	LJN	0.07	0.50	0.53
	NVD	1.05	1.03	0.53
Vegetation structure	Shrub-num	-0.01	0.00	0.21
	Tree-num	0.08	0.08	0.53

NVD = *Zizyphus **n**ummularia*, *Adathoda **v**asica*, *Capparis **d**ecidua*; LJN = ***L**entana camara*, *Prosopis **j**uliflora, Acacia **n**ilotica*;

Table.5.6. Most influential model-averaged parameter estimates of top models explaining natal den selection by jackal at the macro site scale at Sariska Tiger Reserve (2011-13).

Factor	Covariate	Mean B	SE-unc	Sum ω_i
Substrate	**Rock-mud**	**3.52**	**1.54**	**0.92**
	Mud-loam	**2.02**	**1.13**	**0.92**
Terrain	Riverine	-0.02	0.53	0.24
	Plain	0.14	0.33	0.24
Vegetation structure	Shrub-num	0.00	0.00	0.05
	Tree-num	0.01	0.02	0.11

5.3.7. Macro site selection

At the macro scale (3.14 km^2), I performed a correlation analysis to test for variables influencing each other or inversely related to other variables. *Zizyphus* mixed; scrub forest and rodent densities were found to be negatively correlated with road (table 5.7). I avoided choosing variables that are correlated at significant level in model construction, and found that the hypothesis 'cover and resource' received most support to infer the underlying factor for den site selection by jackal at macro scale (table 5.9). The presence of small mammal density in respective forest types and favorable distance form settlements and roads, that occasionally offer food supplements in terms of garbage and road kills respectively, were evaluated as the most influential factors at macro scale as represented by the top model (AIC = 66.50;

ω_i = 0.82) (Table 5.9). I examined the variables those contributed in model, which influenced selection at significant level. For the same, multimodal information was derived to get the collective effect of variable in all the models (table 5.10). The results infer strong inverse relation with settlements and dense forest types (having high ungulate density attracting larger predators) and roads. Jackal showed no significant avoidance for large carnivore presence (tiger, leopard and hyena). Rodent abundance and visibility were the most important predictors for selection of den-sites at the larger scale.

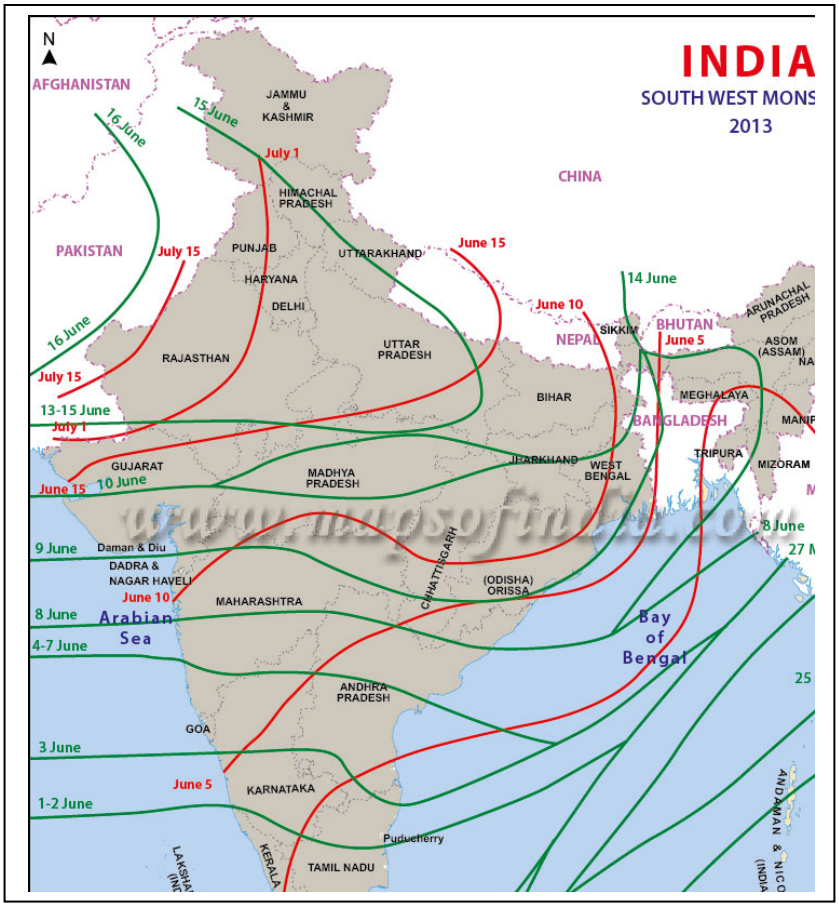

Figure.5.9. Main wind current pattern in Indian Sub-continent including the study area Sariska Tiger Reserve. (http://www.mapsofindia.com/maps/india/southwestmonsoon.htm) and http://www.vagaries.in/2012_08_01_archive.html

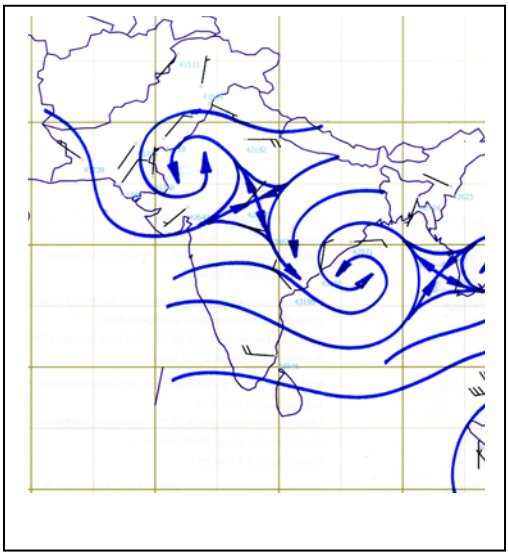

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Table.5.7. Results of amongst variables found correlated at significant level for macro site scale (3.14 km^2) for jackal dens at Sariska Tiger Reserve in 2011-13 as shown by Pearson's correlation analysis (2011-2013).

Variable and stats		ZIZYm	SCRB	REV	ACAm	OF	MDF	Dist RD	Dist Stlmnt	Dist Watr	Elev	Slope	Rugg	Ung Dnst	GrdBrd Dnst	HR Dnst
[1] ACAm	r	0.47	0.33			0.45	0.60	-0.32	0.41						0.54	0.61
	p	0.00	0.00			0.00	0.00	0.00	0.00						0.00	0.00
[2] Dist RD	r	-0.36	-0.25		-0.32				0.28	0.35	0.35	0.41	0.25			
	p	0.00	0.02		0.00				0.01	0.00	0.00	0.00	0.02			
[3] Dist Stlmnt	r					0.22	0.21	0.28		0.47	0.24	0.39	0.35	0.27	0.22	0.22
	p					0.04	0.05	0.01		0.00	0.02	0.00	0.00	0.01	0.04	0.04
[4] Dist Watr	r							0.35	0.47		0.29	0.24		0.26	0.22	
	p							0.00	0.00		0.01	0.02		0.01	0.04	
[5] Elev	r	-0.31	-0.33			0.20	0.26	0.35	0.24	0.29		0.41	0.21	0.65	0.54	0.44
	p	0.00	0.00			0.05	0.01	0.00	0.02	0.01		0.00	0.04	0.00	0.00	0.00
[6] GrdBrd Dnst	r				0.54	0.57	0.67		0.22	0.22	0.54	0.23		0.94		0.97
	p				0.00	0.00	0.00		0.04	0.04	0.00	0.03		0.00		0.00
[7] HR Dnst	r	0.32	0.21		0.61	0.59	0.73		0.22		0.44			0.89	0.97	
	p	0.00	0.05		0.00	0.00	0.00		0.04		0.00			0.00	0.00	
[8] MDF	r	0.42			0.60	0.40			0.21		0.26			0.64	0.67	0.73
	p	0.00			0.00	0.00			0.05		0.01			0.00	0.00	0.00
[9] OF	r	0.41	0.39		0.45		0.40		0.22		0.20		0.26	0.39	0.57	0.59
	p	0.00	0.00		0.00		0.00		0.04		0.05		0.01	0.00	0.00	0.00
[10] Rdnt Dnst	r	0.52	0.74	0.21	0.62	0.72	0.48	-0.22						0.33	0.63	0.67
	p	0.00	0.00	0.04	0.00	0.00	0.00	0.04						0.00	0.00	0.00
[11] SCRB	r			0.21	0.33		0.02	-0.25			-0.33					
	p			0.05	0.00		0.89	0.02			0.00					
[12] Slope	r					0.21		0.41	0.39	0.24	0.41		0.79	0.26	0.23	
	p					0.05		0.00	0.00	0.02	0.00		0.00	0.01	0.03	
[13] Ung Dnst	r				0.41	0.39	0.64		0.27	0.26	0.65	0.26			0.94	0.89
	p				0.00	0.00	0.00		0.01	0.01	0.00	0.01			0.00	0.00
[14] ZIZYm	r		0.34		0.47	0.41	0.42	-0.36			-0.31					0.32
	p		0.00		0.00	0.00	0.00	0.00			0.00					0.00

ACAm = *Acacia* mixed forest; Dist RD = Distance to road; Dist STLMNT = Distance to settlement; Dist-WTR = Distance to water; Elev = Elevation; GrdBrd = Ground bird density; HR-Dnst = Hare density; MDF = Moderately dense forest; OF = Open forest; Rdn-Dnst = Rodent density; Ung-Dnst = Ungulate density; ZIZYm = Zizyphus mixed forest.

Table.5.8. Density estimation for different prey classes using conventional distance sampling (CDS) and multiple covariate distance sampling (MCDS) framework and forest type as a factor covariate for modeling detection function in Sariska Tiger Reserve (2011-2013). Selection of framework for modeling detection function was based on low AIC value.

Detection Group	Detection function	GOF χ^2-*p*	Detection probability (*p*)	SE (*p*)	ESW	SE (ESW)	Cluster size (ES)	SE (ES)	Forest type	Number of observation (n)	effort (L)	ER (n/L)	SE (ER)	Density (D)	SE (D)
Hare	CDS-HNC	0.51	0.28	0.02	7.03	0.7	1.12	0.05	ACAm	2	684	0.0029	0.002	0.23	0.23
									ANOG	12	684	0.02	0.006	1.39	0.49
									BUTm	3	684	0.0044	0.003	0.34	0.26
									REV	6	684	0.0087	0.006	0.69	0.49
									SCRB	9	684	0.01	0.004	1.04	0.5
									ZIZYm	10	684	0.014	0.001	1.16	0.61
Peafowl	CDS-HNC	0	0.25	0.01	12.51	0.59	4.29	0.11	ACAm	29	684	0.04	0.04	7.3	7.3
									ANOG	216	684	0.32	0.08	54.12	15.08
									BOSW	23	684	0.03	0.02	5.76	4.09
									BUTm	48	684	0.07	0.04	12.03	8.54
									REV	42	684	0.06	0.04	10.53	7.68
									SCRB	178	684	0.26	0.09	44.62	16.41
									ZIZYm	65	684	0.095	0.04	16.29	7.74
Ungulates	MCDS-HNC	0.09	0.33	0.02	25.45	1.63	5.31	0.51	ACAm	7	684	0.01	0.007	1.07	0.83
									ANOG	83	684	0.12	0.032	12.68	3.7
									BOSW	7	684	0.01	0.005	1.07	0.55
									BUTm	5	684	0.007	0.007	0.76	0.78
									REV	18	684	0.02	0.009	2.75	1.36
									SCRB	25	684	0.03	0.02	3.82	1.36
									ZIZYm	21	684	0.03	0.01	3.21	1.48
Ground Birds	CDS-HNC	0.69	0.21	0.04	6.01	0.97	4.09	0.54	ACAm	2	684	0.002	0.00	1.98	198
									ANOG	30	684	0.03	0.01	5.56	2.41
									BOSW	6	684	0.009	0.01	12.13	10.17
									BUTm	6	684	0.009	0.01	1.66	1.26
									REV	7	684	0.008	0.01	1.46	1.37
									SCRB	29	684	0.03	0.01	4.41	2.02
									ZIZYm	9	684	0.01	0.01	6.52	4.52

ACAm = *Acacia* mixed forest; ANOG = *Anogeissus* dominated forest; BUTm = *Butea* mixed forest; REV = Riverine forest; SCRB = Scrubland; ZIZYm = *Zizyphus* mixed forest; BOSW = *Boswellia* dominated forest.

Table.5.9. The top model selected from the list of models ranked by AICc explaining den selection in the jackal at the macro site selection scale at Sariska Tiger Reserve (2011-13).

Model	Parameter	B	SE	Wald Chi-Square	df	p	Exp(B)	AICC	Delta i	exp. Values	ω_i
Cover	NF	0.873	0.474	3.392	2	0.066	2.394	116.13	49.63	0.000	0.000
	ANOG	-2.885	0.758	14.5		0	0.056				
Location	Dist STLMNT	-1.396	0.48	8.471	4	0.004	0.248	69.7	3.2	0.202	0.166
	Dist RD	-0.267	0.173	2.365		0.124	0.766				
	ANOG	-2.367	0.755	9.826		0.002	0.094				
	NF	0.448	0.533	0.708		0.4	1.566				
Resource	Dist STLMNT	-1.551	0.452	11.761	3	0.001	0.212	77.63	11.13	0.004	0.003
	Dist RD	-0.462	0.166	7.717		0.005	0.63				
	PreyD-comp	-0.937	0.341	7.569		0.006	0.392				
Prey-Density	PreyD-comp	-0.868	0.257	11.413	1	0.001	0.42	104.23	37.73	0.000	0.000
Cover-Resource	DSET-KM	-1.639	0.548	8.952	7	0.003	0.194	66.5	0	1.000	0.822
	DRD-KM	-0.321	0.216	2.222		0.136	0.725				
	ANOG	-12.164	5.109	5.668		0.017	0				
	NF	1.491	0.931	2.566		0.109	4.441				
	GrdBrdDnst	0.138	0.093	2.2		0.138	1.147				
	HRDnst	3.824	2.153	3.153		0.076	45.767				
	RdntDnst	0.061	0.028	4.702		0.03	0.94				
Resource-supplements	Dist STLMNT	-1.563	0.491	10.132	5	0.001	0.21	75.7	9.2	0.010	0.008
	Dist RD	-0.244	0.187	1.697		0.193	0.783				
	GrdBrdDnst	-0.061	0.03	4.016		0.045	0.941				
	HRDnst	0.975	1.272	0.588		0.443	2.651				
	RdntDnst	0.007	0.004	2.891		0.089	1.007				

AIC values AIC weights (ω_i) Selected model

Dist RD = Distance to road; Dist STLMNT = Distance to settlement; GrdBrdDnst = Ground bird density; HRDnst = Hare density; NF = Non forest; RdntDnst = Rodent density; PreyD-comp = Prey density composition; ZIZYm = Zizyphus mixed forest; ANOG = *Anogeissus* dominated forest.

Table.5.10. Most influential model-averaged parameter estimates of top GLM models explaining den selection by jackal at the macro site scale at Sariska Tiger Reserve (2011-13).

Variables		Mean B	SE-unc	Sum ω_i
	DSET-KM	**-1.597**	**0.544**	**1.000**
	ANOG	**-10.396**	**5.904**	**0.988**
Cover±Resource	**RdntDnst**	**0.050**	**0.034**	**0.822**
	GrdBrdDnst	-0.001	0.001	0.008
Prey±Densty	PreyD-comp	-0.003	0.006	0.003
Resource±suppliments	DRD-KM	-0.001	0.003	0.003

Dist STLMNT = Distance to settlement; Dist RD = Distance to road; ANOG = *Anogeissus* dominated forest; RdntDnst = Rodent density; GrdBrdDnst = Ground bird density; PreyD-comp = Prey density composition.

5.4. Discussion:

The variables on den characteristics and localization were used to study the factors that influenced the den site selection of jackal in the present study. For jackal dens, no previous information was available from the study site. Most of the information on jackal den sites are available only from Bhal (Aiyadurai and Jhala, 2006) and Surashtra (Soni *et. al*, 1995) region in India, other regions of India are less well documented in terms of jackal dens. The results of the present study on jackal den site characteristics are in accordance with features observed in Bhal and Saurashtra region. The apparent new breeding pairs of jackal in Sariska may have resulted in few new excavated dens by the study species, with no previous experience of breeding by the first time breeding individuals and hence, often tend to leave the den half dug perhaps due to unsuitable substrate type. All such dens (n = 6) were not included in data analysis. I studied the selection of dens analyzing their availability data using two different approaches: the immediate surroundings of dens at micro scale and the entire potential denning area at macro scale. The first scale allowed isolating the den structures from potential environment characteristics if a site selection had occurred. The second scale allowed investigating the environment characteristics of den sites as well as structuring selection in a wider context, and hence it was also used to compare the explanatory capability of each group of variables regarding den selection. I was aware of the limitations imposed by the

sample size on determining the den site selection pattern. However, I stress the limitations of having enough sample size for the study species which is widely distributed in Sariska and also the obscurity associated with identification of jackal dens.

As suggested by the results, the most important variables for jackal den use are found to be substrate, cover and resource. The selection of particular dens by jackal is, in theory, influenced by their ability to satisfy the demands for raising pups successfully during their early growth stage. Thus, the placement of litters in canids and other denning carnivore per say, has been related to a combination of factors, including security for young once and energy economy for the females (Laurenson, 1995a). In this regard, a widely accepted hypothesis deals with the demands of feeding optimization. The `central place foraging' (Orians and Pearson, 1979) pattern of the search for food during denning, together with strong energetic stress and higher requirements due to breeding (Aldman, 1993), would constrain breeding pair to den in sites with optimal access to food. Feeding optimization has been proposed as an influential factor in the location of dens in several studies on carnivores (Hewson, 1986; Ciucci and Mech, 1992; Aldama, 1993; Laurenson, 1995a), although such a relationship has not been objectively demonstrated. The results from the present study reflected preference for den site of jackals, in area having relatively high small mammal prey-density. However, the possible explanation may also be due to the territorial behavior by breeding pairs, by inheriting dens from their parents living in the same area. Re-using the den saves a lot of energy, and it would be difficult to start digging during late winter and spring when the den is needed. The study on Indian wolves (*Canis lupus pallipes*) by Habib and Kumar (2007) has showed that they overtake Indian fox dens while shifting dens. Similarly the jackal in Sariska during the present study was observed to overtake porcupine's dens (6) as well the burrows of monitor lizard (2), Indian mongoose (1) and abandoned dens of rattles (2) with little modifications as per the requirement of the species. Thus, there seems to be a dependence of larger species over smaller den providers so as to reduce the energetic costs involved in making a den (Frafjord 2003).

5.4.1. Physical attributes:

I observed that jackal frequently modifying abandoned dens, termite mounds, man-made structures and rock crevices depending upon the ease of excavation during the present study. Jackal was not appeared to be influenced by the number of available entrances when selecting den sites, especially the resting dens. However, selectivity for natal den sites appeared to be with small den entrance diameters (~23 cm; n = 15). This supports the hypothesis that jackal preferentially selected dens with small entrance diameters and avoid those with larger entrances to reduce the potential for predation by larger-bodied carnivores such as striped hyena. The result from the present study is in accordance with the similar observation recorded for Arctic foxes (Frafjord, 2003). The habit of the jackal to dig dens into fine coarser substrate in plain and undulating terrain suggests its role to maintain porosity and perforation while terrain type favoring proper drainage at time of occasional late winter showers (March-April) and early monsoon showers (May-June). Few dens were observed having rock roof and mud base (n = 8), while few are made in a base of shrubs (most likely to be modified porcupine den; n = 3) by neatly excavating mud around the roots without causing any damage to the plant, which infers that it may prevent the den from collapsing and further get supported by the vegetation that binds the substrate. This is expected to potentially help in thermoregulation and forbiddance in easy access by contenders. Vegetation classes NVD and EC were observed more in denning sights of jackal as observed during the present study. The corresponding plant species in these indicator classes are *Zizyphus nummularia, Adathoda vasica, Capparis deciduas, Balanites aegeptiaca* and *Capparis sepiaria*. The predilection for the habitat amid the above mentioned shrub species is acceptable since these arid plants bears the characteristic feature of thick bush volume, protective thorns, summer fruit production and low water dependence, which may apparently favoring the jackal breeding pair at time of pup rearing.

5.4.2. Cover dependence:

The percentage cover for natal and resting dens for jackal were not found different (One way ANOVA test: $F = 0.01$, $p = 0.92$) and lesser number of dens were observed in areas with high percent cover ($r = -0.76$, $p = 0.02$, n=9) (figure 5.7). Jackal resting dens in Sariska had comparatively high percentage of shrub cover,

whereas the natal dens had low percent shrub cover surrounding 10 m radius of the den where the den itself was well camouflaged with bushes like *Capparis sepiaria*, *Capparis deciduas*, *Zizyphus nummularia* and *Adathoda vasica*. Similar observation was reported by Zoellick et al. (1989) for natal kit fox dens, those had low surrounding vegetation heights to maximize the probability of detecting approaching predators. Shrubs have the potential to decrease visibility from the dens and hence, typical selection for areas with low shrub cover surrounding the den by jackal, which could minimize any effects on visibility and the potential to observe approaching hazards was observed in present study. However, buffer of cover at immediate 'den point location' offering camouflage was the important predictor for selection at the smaller scale by the jackal during the present study.

5.4.3. Thermoregulation:

I observed the preference by jackal for cooler and well-ventilated landscape positions for denning and the use of the streamside cut banks and mound characteristic of the landforms in Sariska. This observation was in accordance with the Arctic fox study where warmer and well-drained positions were selected by the species that is suitable for Arctic region (Dementyeff, 1955; Danilov, 1961; Macpherson, 1969). The disparity in ambient temperature and den temperature was observed where, minimum temperature was 2.8% higher outside den and maximum temperature was 4.7% higher outside the dens in Sariska. Lower den temperature may be related to the coarser texture of den substrate or den orientation towards favorable aspect. Although temperature variation was not found significant in the four substrate types for natal or resting dens of jackal (Kruskal-wallis test, $\chi^2 = 3.00$; df = 3; $p = 0.39$) (figure 5.5).The significant variation in 'maximum' ambient temperature and den temperature (One way ANOVA test: $F = 4.20$, $p = 0.05$) infers the priority to synchronize temperature at times of high heat hours. I observed that 'minimum' temperature recorded for aspect N and SW was lower than that of aspect SE and NE and 'maximum' temperature recorded for SW was lower than N and NE (figure 5.6).

5.4.4. Aspect dependence:

It is not clear whether dens at certain aspect are inherently cooler than other aspects or it is governed by den construction style, or if the favorable soil thermal regime resulting from the presence of burrows, which act as ventilation ducts. Several

studies on Arctic fox dens have discovered a significantly larger number of den entrances oriented in a southerly aspect (Chesemore 1969; Smits et al. 1988: Prestrud 1992; Nielsen et al. 1994), which is hypothesized to provide thermal and microclimatic advantages. Pruss (1999) and Jackson and Choate (2000) examined swift fox den orientation and found no significant deviation from a random distribution. In Sariska, I found that overall jackal den entrance orientation were random; however natal den entrance aspects exhibited a more westward trend. Hence, I would like to stress at the wind patterns in the western geological region of the country (Figure 5.9). Which represents northern and eastern moment of current rising from western cost, directing it from Southwest to East, West to North and occasionally Northwest to West. Neilsen et al. (1994) found that Arctic fox dens in the breeding season were constructed to minimize exposure to winds however; in semi arid region den orientation is likely to maximize wind flow inside the dens. I expect that the western wind pattern may be responsible for den orientation and temperature regulation based on ventilation, although no attempts were made to test this hypothesis in field using proper gadgets. Further research is needed to address this topic as suitable conditions probably result from a combination of inherent and altered factors.

5.4.5. Den placements:

The jackal dens were observed in clusters in Sariska during the study period. Similar observation was recorded for Swift fox (Cutter 1958, Hines and Case 1991) and kit fox (O'Neal et al., 1987). Two successively used jackal dens in Sariska were only 43.84 m apart and average distance between the dens was 857.6 m. The den clusters were found two have 2 to 4 dens which were no more than an average of 424.3 m apart from each other and formed clusters in the contagious regional area ranging from 11.03 km^2 to 28.11 km^2. Den clustering may perhaps be defensible as a fact that the smaller canids and the pups of the even larger species often run the risk of being killed by raptors and larger mammalian predators, especially when living in open habitats (e.g., Carbyn 1986, Thurber et al. 1992, Lindström et al. 1995, Ralls and White 1995, Palomares and Caro 1999) and hence, clusters of den provide an alternate refuge and protection from possible predators such as striped hyena and leopard. An influence of difference in habitat composition was empirical in the present study, as I found that the dispersion of regional area influences distances

among dens (Fig. 2). Probably, the high frequency of unsuitable areas among favorable patches becomes the main factor that limits den establishment (Andre´n, 1994; Macdonald et al., 1999; Baker et al., 2000).

In Sariska, this is obvious in uniform areas that are mainly open and arid plains with 'islands' of shrub groves where jackal dens are at the highest distances in areas such as Kankwari and Indok (Fig. 2). Some studies at Djerba Island located in the Gulf of Gabes, North Africa on fox families (Baker et al., 2000) demonstrated that when foxes occupy only suitable areas, the result is a wide separation of dens. Thus, connections among different patches are important for maintaining good populations (Taylor et al., 1993). In a semi-arid landscape, the importance of contiguous profitable areas is increased by the pressure of low productive environment and more patches reached by species near their dens favor the optimal exploitation of resources (Dell'Arte and Leonardi, 2005). In this manner, the spatial arrangements of dens in favorable zone maximize available space surrounding dens against limiting factors (roads and unsuitable areas). Some studies found that road casualties depend on the availability of different road types with an increasing mortality on major category roads (Baker et al., 2004) however, in Sariska, den site selection was indifferent towards human induced disturbance such as distance to road (One way ANOVA test: $F = 1.45$, $p = 0.24$) and human settlements (One way ANOVA test: $F = 2.53$, $p = 0.12$) (table 5.1). The edge locale delimiting cultivated patches adjoining Sariska did not have any influence on the choice of denning places by jackal. Inversely, tarmac roads seem to persuade den settlements at levelheaded distance in the study area (Fig. 3). Although the findings are contrary to expectation, it may deduce that proximity to roads offering potential hunting or scavenging opportunities as road-killed reptiles, invertebrates, and rodents offer suppliant food for jackal. Jackal denning closer to roads may also avoid potential sympatric carnivores that may not be as tolerant to human-associated disturbance. Similar avoidance was observed in denning red foxes towards coyotes in north Dakota and east-central Illinois, USA (Sargeant *et.al.* 1987; Gosselink *et.al.* 2003). Nevertheless, the role of roads as potential threat to jackal was certain in Sariska as there were 5 jackal killed by road accidents during the study period of three years.

5.4.5. Micro and Macro site selection

At the smaller scale, microhabitat characteristics such as substrate type, terrain, and shrub number determines selection of den sites of jackal in Sariska. Chosen substrates are likely to offer suitable soil depth, but I did not attempt to measure den depth during my study to avoid causing any disturbance in denning site. High visibility at den-sites should functionally reduce predation risk for vulnerable pups (Tannerfeldt *et.al.* 2003). When selecting den sites, jackal seem to avoid areas where predator detection is poor (shrub number B value = -0.006), although for natal sites substantial cover at den point location was observed in Sariska. The hyena and dogs (at the border of the reserve) are major interference competitors for jackal in this landscape (Vanak and Gompper 2010).

At the larger scale, the data suggest that any dens with suitable distance from human settlements and dense *Anogessious* forest, fair rodent and ground bird abundance, low wild ungulate moment discouraging the presence of other large predators and appropriate distance from road providing occasional food supplement should be considered as potentially important site for jackal to maintain dens at Sariska. Small rodents formed a considerable part (17.10 % occurrence in three years) of jackal's diet in Sariska during the study period. Therefore, distribution and abundance of rodents should influence selection of breeding den sites, when reproductive costs are high. Though invertebrates as well are dominant component in the diet of the species (16.69 % occurrence), I acquainted with limitation in ability to quantify them in different period of time in the study including denning period. Rodent species like rufus tailed hare and porcupine were found abundant in open areas (0.69 ± 0.13 and 1.46 ± 0.23 respectively). The characteristic vegetation composition provided good food source for these species and hence they may also act as den providers for jackal, which may expand an existing network of hare and porcupine burrows and thereby reduce energetic costs of digging dens. Other species such as the swift fox and kit fox (*V. macrotis*) have similarly been associated with den providers, such as badgers (*Taxidea taxus*) and prairie dogs (*Cynomys* spp.) (Tannerfeldt *et.al.* 2003). In Sariska, six of the dens in which pups were reported earlier, were altered by humans by means of dumping large stone over the den, closing its opening. Weather the activity caused any mortality of pups was not

known. Such dens are closely located to human habitation (~ 600 m) and expected to be of new jackal pairs, which establish their dens in inferior quality location. These activities attributed to the magnitude of disturbance on reproductive success of jackal in study area. Despite the fact, jackals were observed to re-excavate the closed dens instead of excavating in other nearby locations in the surrounding area. This infers that although a large number of denning sites are available to the jackal population, some dens are more preferred than others. Non-availability of helpers has also been reported to affect reproductive success or pup survival by influencing the amount of food delivered to pups in wolf population (Harrington, Mech and Fritts, 1983) however, in the present study helpers don't seem to strongly influence pup-rearing.

CHAPTER 6

HABITAT USE OF JACKAL

6.1. Introduction:

Resource selection by animals is a hierarchical process of behavioral responses to particular environmental characteristics (Horne, Garton & Rachlow, 2008). Establishment of a home range within a landscape and the movement of individuals within a home range may be influenced by different environmental factors and scales, and therefore animal - landscape relationships should be examined across a range of scales (Johnson, 1980; Anderson *et. al.*, 2005; Boyce, 2006). A fundamental problem in ecology is the issue of scale, and in particular, the appropriate scale at which research needs to be focused to ascertain the dynamics that function to drive and organize a community (Levin, 1992). Questions related to patterns of species distribution and occupancy need to focus on processes that may operate at multiple spatial scales. A fundamental concept in animal ecology is that each species occurs within a limited range of environmental conditions, defining its habitat niche (Hutchinson 1957). Some species have peculiar habitat preferences. The presence of a species and its association with habitat characteristics at different spatial scales is a function of vegetation structure and food availability (Lantschner *et. al.*, 2012) that may change over space and time.

Lidicker and Koenig (1996) suggested that landscape perception by mammals is dependent on body size, with large-bodied mammals perceiving landscapes as more homogenous than smaller species. Relative to smaller, less vagile mammals, larger mammals appear to view the matrix less as a barrier to movement, and patches within landscapes as less isolated and largely undivided (Addicott *et. al.*, 1987). For instance, costs of movement (i.e. travel time and predation risk) can vary among individuals and species, depending on the ease with which the potentially hostile matrix surrounding patches can be traversed and the availability of corridors that facilitate movement between foraging patches (Laurance, 1995; Nupp and Swihart, 2000). A species which, over its geographic range, is adapted to a diverse array of

environments (i.e. a species with a broad geographic niche) may be able to respond better to changes in a landscape resulting from human disturbance. Thus, characterization of a species' niche breadth over its geographic range should provide a measure of a species' behavioral plasticity to human-induced fragmentation of habitat.

The jackal primarily inhabits the drier biomes of India, characterized by low rainfall, flat or undulating terrain, and scrub, thorn forests or short grasslands (Johnsingh & Jhala, 2004). Studies indicate that wild canids exhibit a generous intraspecific variation in behavior and ecology (Moehlman, 1989). However, the behavioral ecology of all jackals, and indeed most medium-sized canids, is broadly similar. They are territorial, communicate occupancy with olfactory and vocal signals, and live in social units developed around a breeding pair (Macdonald 1979c; Skinner and Smithers 1990). Individuals might be able to expand their home range to include several fragments that together provide adequate resources (Redpath, 1995; Collins and Barrett, 1997; Little and Crowe, 1998). However, traversing such a home range requires movement through the urban matrix, which has been little studied for jackal in India (Sankar, 1994; Mukherjee *et. al.*, 2004; Aiyadurai and Jhala, 2005; Home and Jhala, 2010). The territory of an animal has been defined as the area it will defend against individuals of the same species (Burt 1943; Mech 1970). Territoriality allows animals to exclude potential competitors from access to mates, food, space, and cover. Brown and Orians (1970) proposed that territoriality is implied if there is little overlap between home ranges, scent-marking behavior is performed, and agonistic interactions occur. Several studies have demonstrated direct and indirect mechanisms that many carnivore species use to maintain their territory boundaries, including scent-marking (Peters and Mech 1975; Camenzind 1978; Rothman and Mech 1979; Barrette and Messier 1980; Bowen and Cowan 1980; Wells and Bekoff 1981; Bailey 1993; Caro 1994; Gese and Ruff 1997), howling (Harrington and Mech 1978*a*, 1978*b*, 1979; Gese and Ruff 1998), and confronting intruders (Camenzind 1978; Bekoff and Wells 1986; Mech 1993, 1994).

The resource dispersion hypothesis predicts that in environments where food is patchily distributed, canid group size is determined by patch richness, whereas territory size is determined by patch dispersion (Macdonald, 1983). This hypothesis

has been supported by research on the Red fox (*Vulpes vulpes*) (Macdonald, 1981), Arctic fox (*Alopex lagopus*) (Hersteinsson, 1984), Coyote (*Canis latrans*) (Bekoff & Wells, 1986) and Ethiopian wolf (*Canis simensis*) (Sillero-Zubiri & Gottelli, 1995). Jackal, like Coyotes and Foxes, because of their greater mobility, are characterized by larger ecological neighborhoods (sensu Addicott *et. al.*, 1987). Recorded home range sizes of jackal vary from 1.1–20km^2 (Van Lawick and Van Lawick-Goodall 1970; Kingdon 1977; Poche *et. al.* 1987; Aiyadurai and Jhala, 2005), depending on the distribution and abundance of food resources. Jackal were observed to range over large distances in search of food and suitable habitat (A. Aiyadurai and Y. Jhala, 2005). Non-breeding members of a pack may stay near a distant food source like a carcass for several days prior to returning to their original range. Similarly, coyotes and foxes as well appear capable of assessing all components of the landscape and moving relatively freely among elements (Gehring, 2000). Thus, landscape connectivity, the degree to which the landscape facilitates movements among resource patches (Taylor *et. al.*, 1993), appears to be of importance for jackal.

Species characterized by high local densities by definition are more abundant within a given area, which may be reflected in greater overall use of available habitat. For small sized carnivores, presence may not be directly related to habitat type, but to the complexity or heterogeneity of vegetation structure and landscape attributes. The "continuum model" (Fischer and Lindenmayer 2006) assumes each species response to their environment and suggests gradual change in habitat quality through space. The model conceptualizes landscape as varying across gradients of food, shelter, space, and climate, which may be defined with respect to habitat variables important for individual species. From a conservation standpoint, this model focuses on habitat heterogeneity to enhance the number of niches available for different species. Moreover, interspecific competition among carnivores (jackal and striped hyena), results in killing and/or predation of small sized species which may have marked effect on the distribution, habitat use and/or abundance of non-dominant species (Ramesh 2010). The dynamics of interference competition are particularly well documented among species in the Carnivora order (Cypher & Spencer 1998; Creel, Spong & Creel 2001; Nelson *et. al.* 2007; Ritchie & Johnson 2009). In the absence of a competitor or predator species, small carnivores should be distributed based on habitat quality and preferred food availability (van derMeer & Ens 1997; Roemer,

Gompper & Van Valkenburgh 2009). However, small carnivores are often the subordinate intraguild competitor in most communities with intact carnivore guilds (Prugh *et. al.* 2009; Roemer, Gompper & Van Valkenburgh 2009) and thus, are potentially subject to top-down effects that mediate their ability to use preferred habitat (Ritchie & Johnson 2009).

The apparent suitability of the environment for different carnivores can be explained with reference to the characteristics of microclimate and level of resources usually present. These characteristics satisfy the need for shelter (shrub cover), food (diverse communities of small mammals, birds, fruits), and anti-predator cover, which are important aspects for the survival. It is suggested that the high habitat heterogeneity in sites may contribute to a higher degree of close co-existence between sympatric species (Morris *et. al.*, 2000). Even if the same habitat space is used by similar species, there might be some segregation due to preferences of particular sites. One of the main objectives in community ecology is to understand the conditions allowing species to co-exist, which requires identifying how co-occurring species use and share space and resources. In the space composed of '*n*' dimensions accounting for the many environmental variables (ecological space), the niche is conveniently (Hutchinson 1957) defines the conditions and resources necessary for the species to persist.

Spatial ecology of meso carnivores like jackal has been studied in detail in Sariska Tiger Reserve (Mukherjee *et. al.*, 2010, Gupta, 2011). Jackal is a generalist predator with adaptable social systems (e.g., Macdonald 1979) that are able to exist in close proximity to humans and exploit agro-ecosystems. However, in some parts of their range, jackal has either disappeared or their numbers are shrinking due to anthropogenic causes (Jhala and Moehlman 2004). Surveys in Greece indicate that jackal have a fragmented distribution associated with coastal wetlands and that local populations are disappearing coincident with the destruction of the remaining patches of the habitat (Giannatos *et. al.* 2005). Vegetation cover usually associated with protected area of landscape may provide cover for avoiding humans during the daytime and be an important limiting factor for the existence of jackal in close proximity to humans. In contrast, jackal are reported to be expanding their range in Bulgaria (Krystufek *et. al.* 1997).

Understanding ecology of this species depends on developing a better appreciative of the resources that are necessary to sustain populations in agro-ecosystems. Linking models to field data like vegetation complexity, food diversity, resting and denning characteristics would be useful at the site level. I estimated the probability that a site is usable (i.e. that a species may use the site), which I defined here as habitat suitability index. I aimed to use camera trap data, scat location data and direct sighting data to determine jackal occupancy as a function of various site variables hypothesized to influence the probability of jackal habitation in Sariska during three years. Suitability index can be used to draw inferences about habitat use, selection and predict occurrence at multiple scales. 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 un-surveyed sites. The models are constructed from site-specific binary data (presence/absence) of a species and mapped with environmental variables (Pearce *et. al.,* 2002). A logistic regression equation is applied to the variables to determine which are most important in determining species habitat use. Models are then developed in a GIS format where input data was 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).

Multiple models were explored and by ranking these models using an information-theoretic approach, I examined the relative support and strength of evidence for each model based on the data. The information criterion used fir GLM was Akaike's Information Criterion (AIC) which uses the maximized log-likelihood to estimate the information distance between the best approximating model and the true generating mechanism (Anderson 2008). The criterion also allowed using the multiple models in working hypothesis through model-averaging parameter estimates (Burnham and Anderson 1998). The objectives of this study were: (1) to identify the variable combination spectrum that most strongly influence habitat selection by jackal and (2) to compare the resultant species habitat by niche factor analysis and generalized linear model in the study area. Finally I concluded my results by compiling remotely sensed and macro-scale variables thought to drive carnivore distribution. This chapter focused on habitat spectrums of jackal in Sariska Tiger Reserve. It allowed me to test hypotheses about plausible determinants of species

distribution patterns wherein I expect effects of different combinations of covariates to vary as per the biological needs of the species.

6.2 Materials and methods

The fundamental limitation of presence-only data is that sample selection bias (whereby some areas in the landscape are sampled more intensively than others) has a much stronger effect on presence-only models than on presence-absence models (Phillips *et. al.*, 2009). The sample must be unbiased to be representative of the whole population. Absence data in particular are often difficult to obtain accurately. A given location may be classified in the ‘‘absence’’ set because (1) the species could not be detected even though it was present (McArdle 1990, Solow 1993, Ke´ry, 2000) (2) for historical reasons the species is absent even though the habitat is suitable, or (3) the habitat is truly unsuitable for the species. Only the last cause is relevant for predictions, but ‘‘false absences’’ may considerably bias analyses (Hirzel *et. al.*, 2002). For any modelling method – few samples provide limited information for determining relationships between the species and its environment (Pearson *et. al.*, 2007). Here I used an approach propose by Hirzel *et. al.* (2002), specifically designed to circumvent this difficulty. Requiring only presence data as input, the Ecological-Niche Factor Analysis (ENFA) computes suitability functions by comparing the species distribution in the ‘Independent Eco-geographical Variables’ (EGV) space with that of the whole set of cells.

6.2.1. Jackal distribution data

The Species distribution data was collected from camera trapping (methodology has been explained in chapter 3), direct sighting records, scat locations (only those locations included where scats were identified with certainty) and track locations. All the records were pooled for entire study period 2010-2013. Collectively, 413 observed point locations over three years were used for habitat use analysis of jackal in the intensive study area. I created comma-separated value (.csv) file containing longitude and latitude coordinates of each occurrence location using an Excel spreadsheet. These were plotted in ArcGIS 9.3 and overlaid on 2 km^2 grid cells. Based on which the distribution map of jackal was generated (figure.6.1).

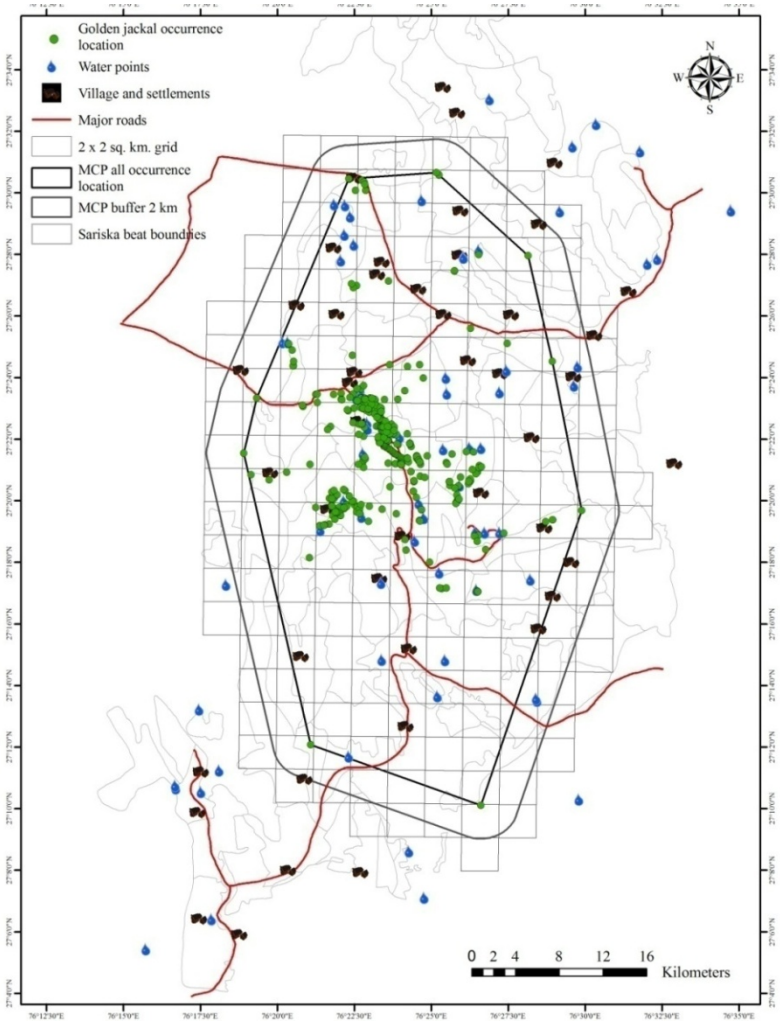

Figure.6.1. Spatial locations of jackal, water points, villages and major roads in Sariska Tiger Reserve (2010 to 2013).

6.2.2 Extraction of explanatory environmental predictors

I used the Geographic Information System (GIS) in ArcGIS 9.3 (Environmental Systems Research Institute [ESRI], Inc., Redlands, CA, USA) for data extraction. For species habitat suitability modeling the resolution or pixel size of the raster data should relate to the home range of the species under investigation, yet this assumption could be violated for the individuals that exceed more than the grid size, however a fishnet of 2 km^2 was overlayed on the MCP boundary of all the occurrence location with buffer layer of 2 km^2 around it. Topographical variables, biological variables and anthropogenic variables were extracted using Zonal Statistic tool in the Spatial Analyst toolbox and, an evaluated variable values were assigned in each 4 km^2 pixel. The entire map had 201 grids each of size 2 x 2 km^2 and the records

were plotted as presence/absence information on each grid (figure.6.1). 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 Geo-coded False Color Composite (FCC) on 1:50,000 scale for entire study area was procured and different color tones for 30 classes was prepared (Sankar *et. al.,* 2009). The color classes in the map 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 six forest cover classes were delineated and mapped with 80% accuracy (Sankar *et. al.,* 2009). A classified forest cover map of categories; 1 = water bodies, 2 = non-forest, 3 = scrub, 4 = open forest, 5 = moderately dense forest and 6 = very dense forest were obtained. The classified categorical variables of vegetation were: 1 = Barren land, 2 = *Zizyphus* mixed forest, 3 = water, 4 = Agricultural land, 5 = scrub land, 6 = *Butea* dominant forest, 7 = *Acacia* dominant forest, 8 = *Anogessious* dominant forest and 9 = *Boswellia* dominant forest (figure.6.3.i). Area occupied by each vegetation category type was extracted grid wise (2 x 2 km^2) from vegetation map. Digital data on contour and drainage were used to create Digital Elevation Model (DEM) on the basis of interpolation. In addition to mean elevation, the standard deviation was included as an indicator of surface ruggedness. Slope and aspect was calculated from elevation layer using Surface analysis tool from spatial analyst toolbox in Arcmap. All village locations and water points were recorded using GPS. I used the Euclidean distance tool to create a raster "distance to" (km) layer for the closest water source, village and road (figure6.3.a to 6.3.c). This tool calculated a straight line distance to the nearest source variable of interest within the raster layer such that each pixel is assigned a value of distance to water, village and road.

Spatial prediction of species' distribution was supplemented using occurrence-only records and environmental covariate by the combination and comparison of ENFA and regression modeling. Multi models were constructed and analyzed using binary logistic regression in generalized linear model using selected parameter of different variables with significant values. Since most variables were highly correlated (R2 = >0.5), the related variables were checked for AIC values and one with the lowest AIC was used for model construction. Multicollinearity was checked for all combinations of environmental variables. Information on prey density

estimation for different prey classes was obtained by exploratory analysis using DISTANCE 5.0 software in conventional distance sampling (CDS) and multiple covariate distance sampling (MCDS) framework as explained in chapter 5. For modeling detection function forest type was used as a factor covariate. The model with the lowest AIC value was selected for density estimation of the prey classes. Among the different proportion of forest types in each grid, the three dominant forest types were selected. I assigned prey density to the each grid by multiplying the proportional value of the three dominant forest types in a grid area (2 x 2 km^2) with the prey density values for the respective forest types. The resultant values form dominant forest types were then added to get prey density values of different prey species in each grid.

6.2.3. Modeling approach ENFA

A statistical and/or analytical algorithm that predicts (either actual or potential) distribution of a species, given field observations and auxiliary maps, as well as expert knowledge is defined as Species Distribution Model (SDM). A special group of Species Distribution Models (SDMs) focuses on the '*occurrence-only records*'—pure records of locations where a species occurred (Elith *et. al.*, 2006). The sample must be unbiased to be representative of the whole population. The most frequently used techniques to generate species' distribution from occurrence-only records are various kernel smoothing techniques, the Ecological-Niche Factor Analysis (ENFA) approach of Hirzel and Guisan (2002), the Genetic Algorithm for Rule-Set Prediction (GARP) approach of Stockwell and Peters (1999), and the maximum entropy method (Maxent) introduced by Phillips *et. al.* (2006). It has never been proven that any of these techniques outperforms its competitors. Zaniewski *et. al.* (2002) evaluated performance of General Additive Models versus ENFA models and concluded that ENFA will likely be better in detecting the potential distribution hot-spots, especially if occurrence-only data is used. Most of the methods share largely similar principles: 1) the study area is modeled as a raster map composed of *N* adjacent isometric cells. 2) the dependent variable is in the form of presence/ absence data of the focal species in a set of sampled locations. 3) independent eco-geographical variables (EGV) describe quantitatively some characteristics for each cell. These expressing topographical features (e.g., altitude, slope), ecological data

(e.g., frequency of forests, prey concentration), or human structures (e.g., distance to the nearest settlement, road density). 4) A function of the EGV is then calibrated so as to classify the cells as correctly as possible as suitable or unsuitable for the species.

Requiring only presence data as input, the Ecological-Niche Factor Analysis (ENFA) computes suitability functions by comparing the species distribution in the EGV space with that of the whole set of cells. Species are expected to be non-randomly distributed regarding eco-geographical variables. For instance, a species with a requirement of specific habitat variable is expected to occur preferentially in cells lying within that variables' optimal range. This will be quantified by comparing the distribution of that specific variable in cells in which the species was observed with that of the whole set of cells. These distributions differ with respect to their mean and their variances. The focal species may show some marginality (expressed by the fact that the species mean differs from the global mean) and some specialization (expressed by the fact that the species variance is lower than the global variance). The marginality (*M*) was defined as the absolute difference between global mean (m_G) and species mean (m_S), divided by 1.96 standard deviations (σ_G) of the global distribution. Division by σ_G removes any bias introduced by the variance of the global distribution and ensures marginality will be most often between zero and one (Hirzel *et. al.*, 2002). An overall marginality *M* can be computed over all EGV as:

$$M = \frac{\sqrt{\sum_{i=1}^{V} m_i^2}}{1.96} \qquad \textit{Equation 1}$$

The specialization (*S*) was defined as the ratio of the standard deviation of the global distribution (σ_G) to that of the focal species (σ_S), a randomly chosen set of cells is expected to have a specialization of one, and any value exceeding unity indicates some form of specialization. A global specialization index can be computed as:

$$S = \frac{\sqrt{\sum_{i=1}^{V} \lambda_i}}{V} \qquad \textit{Equation 2}$$

These statistics when extends to a larger set of variables directly leads to Hutchinson's (1957) concept of the ecological niche, defined as a hyper-volume in the multidimensional space of ecological variables within which a species can maintain a viable population (Hutchinson 1957, Begon *et. al.* 1996). The concept used in the same sense: the referred ecological niche is the subset of cells in the eco-geographical space where the focal species has a reasonable probability to occur. This multivariate niche was quantified on any of its axes by an index of marginality and specialization.

Ecological variables are not independent and some of the axes are more interesting than other. Factor analysis is performed to check multicollinearity and redundancy and to restrict the analyses to the few important factors (e.g., those explaining the largest part of the variance) without losing too much information. Also, specialization is expected to depend on interactions among variables. Species may thus specialize on a combination of variables, rather than on every variable independently. A factor analysis allows extraction of the linear combinations of original variables on which the focal species shows most of its marginality and specialization.

6.2.4. Data analyses and validation

A set of ascii environmental layers and a .csv file of known locations of a species were used to produce probability maps that predict the potential distribution of a species. The coefficients m_i (equation 1) of the marginality factor expresses the marginality of the focal species on each EGV, in units of standards deviations of the global distribution. The higher the absolute value of a coefficient, the further the species departs from the mean available habitat regarding the corresponding variable. Negative coefficients indicate that the focal species prefers values that are lower than the mean with respect to the study area, while positive coefficients indicate preference for higher-than-mean values (table.6.4). The coefficients of the next factors receive a different interpretation: the higher the absolute value, the more restricted is the range of the focal species on the corresponding variable. Only absolute values matters since signs are arbitrary. The eigen value λ_i (equation 2) associated to any factor expresses the amount of specialization it accounts for, i.e., the

ratio of the variance of the global distribution to that of the species distribution on this axis.

The Eigen value also indicates how much variance is explained by the factors. The larger they are, the more information each factor is conveying (if species was distributed randomly throughout the study area, the Eigen values would be all close to 1, marginality would be close to 0 and tolerance would be close to 1). These procedures are implemented in the software Biomapper (A. H. Hirzel, J. Hausser, and N. Perrin, University of Lausanne, Lausanne, Switzerland). The count is normalized in such a way that the suitability index ranges from zero to one. It is performed by dividing the species range on each selected factor in a series of classes, in such a way that the median would exactly separate two classes. For every cell from the global distribution, it count the number of cells from the species distribution that lay either in the same class or in any class farther apart from the median on the same side. It builds on a count of all cells from the species distribution that lay as far or farther apart from the median than the focal cell on a factor axis. Normalization is achieved by dividing twice this number by the total number of cells in the species distribution. Thus, a cell laying in one of the two classes directly adjacent to the median would score one, and a cell lying outside the species distribution would score zero (Hirzel *et.al.*, 2002). An overall suitability index of the focal cell can then be computed from a combination of its scores on each factor. The measure of fit implemented by ENFA is the area adjusted frequency curve (AAF) to find out the best threshold value (ranging from 0.5 = random to 1 = perfect discrimination) (*Biomapper*, user manual. Hirzel, 2004).

The final data set used in this study were total of 9 variable layers which were projected to the UTM zone to match their coordinates, clipped to the extent of the boundary along with 2 km buffer, and entered with the occurrence data into *idrisi selva* version 3.2 (Eastman, 2012 Clark University). Maps usable by *Biomapper* and *idrisi* were used to derive biologically meaningful map with reference to the focal species which were the Eco-Geographical Variable (EGV) (figure.6.3.a to 6.3.i). Species presence map was boolean map (containing 1 and 0 only), 1 indication the cell where the species is present. I selected the medians algorithm for Habitat Suitability (HS) computation in the program which assumes that the best habitat is at the median of the species distribution on each factor and that these distributions are

symmetric. The predictive power of HS map was evaluated by cross validation process for which, the *Biomapper* software use method described by Boyce *et. al.*, (2002). The species locations were randomly partitioned into *k* mutually exclusive but identically sized set. *k*-1 partitions were used to compute HS model and the left-out partitions were used to validate it on independent data following Hirzel (2004) (*Biomapper* user manual). Each map was reclassified in *b* bins. Each bin *i* covers some proportion of map's total area (A_i) and contains some proportion of validation points (N_i) (validation points are those observations left out during cross validation process). The area adjusted frequency for each bin was then computed as $F_i = N_i / A_i$. If the HS map is completely random, the $F_i = 1$ for all the bins. For a good model, a low HS have low *F* (below 1) and high HS have high *F* (above 1) with a monotonic increase in between (*Biomapper*, user manual. Hirzel, 2004). I selected equal counts for each bin where *Biomapper* tries to set bin limit so as they all have same number of cross validation points.

6.3. Results

6.3.1 Jackal habitat modeling

Application of the ENFA method to the calibration set provided an overall marginality of $M = 0.64$ and an overall specialization value of $S = 3.01$, showing that jackal's habitat did not differ radically from the mean conditions in a landscape. Marginality value (close to 1) indicates a tendency of a species to live in extreme habitats and that the jackal are rather open on the range of conditions they withstand. Tolerance ($1/S$) value (= 0.33, close to 0) indicates that a species is not very discriminating on its living environment (table.6.2). The three factors retained (out of the nine computed) accounted for 91.25 % of the total sum of Eigen values (that is, 100% of the marginality and 91.25 % of the specialization) (table.6.1). The marginality factor alone accounted for 87 % of this total specialization, meaning that jackal displayed a very restricted range on those conditions for which they mostly differed from background intensive study area conditions i.e. forest area, whereas the affinity was observed towards open plain areas. Global correlation matrix and species covariance matrix are given in table.6.5 and table.6.6 respectively.

Marginality coefficient factor (table.6.4) showed that jackal are essentially linked to moderate ungulate density (0.31), optimum distance to village (0.08), water (0.04) and rodent density (0.07). By contrast, jackal tend to avoid rugged terrain (-0.98) high hare density (-0.11) and ground bird density (-0.04). Distance to road and vegetation type had only marginal effects. The very large Eigen value (50.48) attributed to the second factor means that randomly chosen cells in Sariska are ~ 50 times more dispersed on this axis than the cells were jackal was recorded, or in other words, jackal were more reliant on the optimal conditions on this axis. The next factor accounted for some more specialization, where the higher frequency value of distance to water (-0.46), road (-0.40) and village (-0.37) was outwitted and the hare (0.44) and ground bird (0.35) density were favored, thus showing some sensitivity toward selection of variable frequencies, those contributing to make optimal values on these variables. Vegetation type had marginal effect in this factor as well along with ungulate density. A suitability map for jackal was prepared from the three factors (including the two mentioned above) for the entire Sariska Tiger Reserve, which is given in figure.6.3.j.

The distribution of habitat suitability values were evaluated from the validation set. As shown in figure.6.2, these cells differed slightly from the global distribution. Predicted suitability exceeded value of 0.5 with marginal value of 0.60 ± 0.25 however the absolute validation index (AVI) value obtained was 89.9 ± 33.9 which differed notably from contrast validation index (CVI) value of 28.9 ± 3.2, which is expected only if cells were randomly chosen from the global distribution. Distribution models performed ‘reasonably’ based on the area adjusted frequency (AAF) curve value (figure.6.2) where the curve values are around ‘1’ inferring selection of a marginal habitat by jackal, which is in accordance with the generalist behavior of the species.

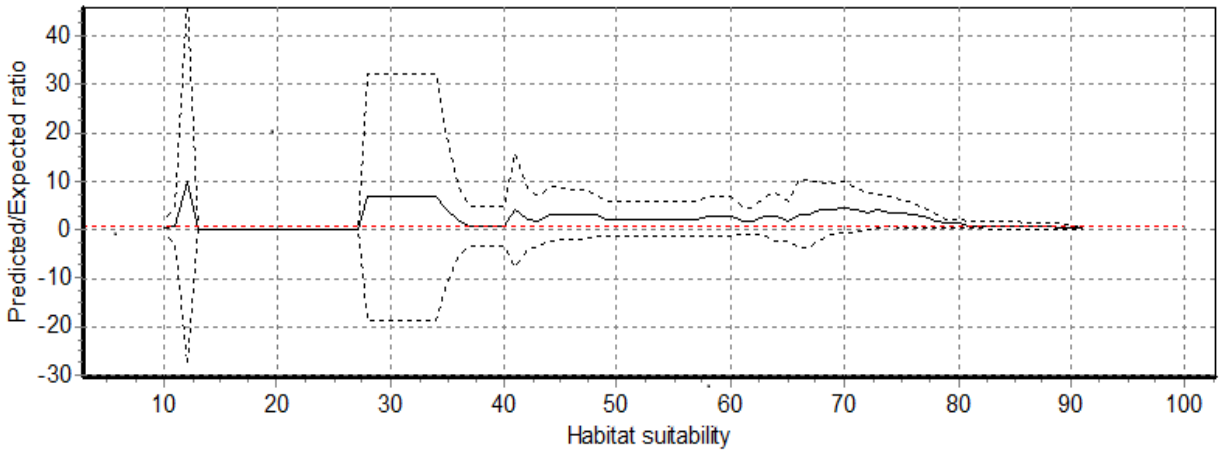

Figure.6.2. AAF curve of Sensitivity versus Specificity for the habitat model of jackal.

Since, the Boyce index value was average, to understand the habitat dependence of jackal with more certainty, multi models were constructed and analyzed using binary logistic regression in generalized linear model using selected parameter with significant values in same size grids (4 km^2). The selection and contribution of each variable was dependent on the other variables in the model, and hence the highly correlated variables may greatly influence the final model selection therefore only one of correlated variables was used in the model evaluation. The variable with the least biological importance was eliminated following the similar procedure as used in chapter 5. Graphical representation of the relationship between different ecological variables and jackal frequency of occurrence in each grid is given in figure.6.4.a to figure.6.4.l.

Continued….

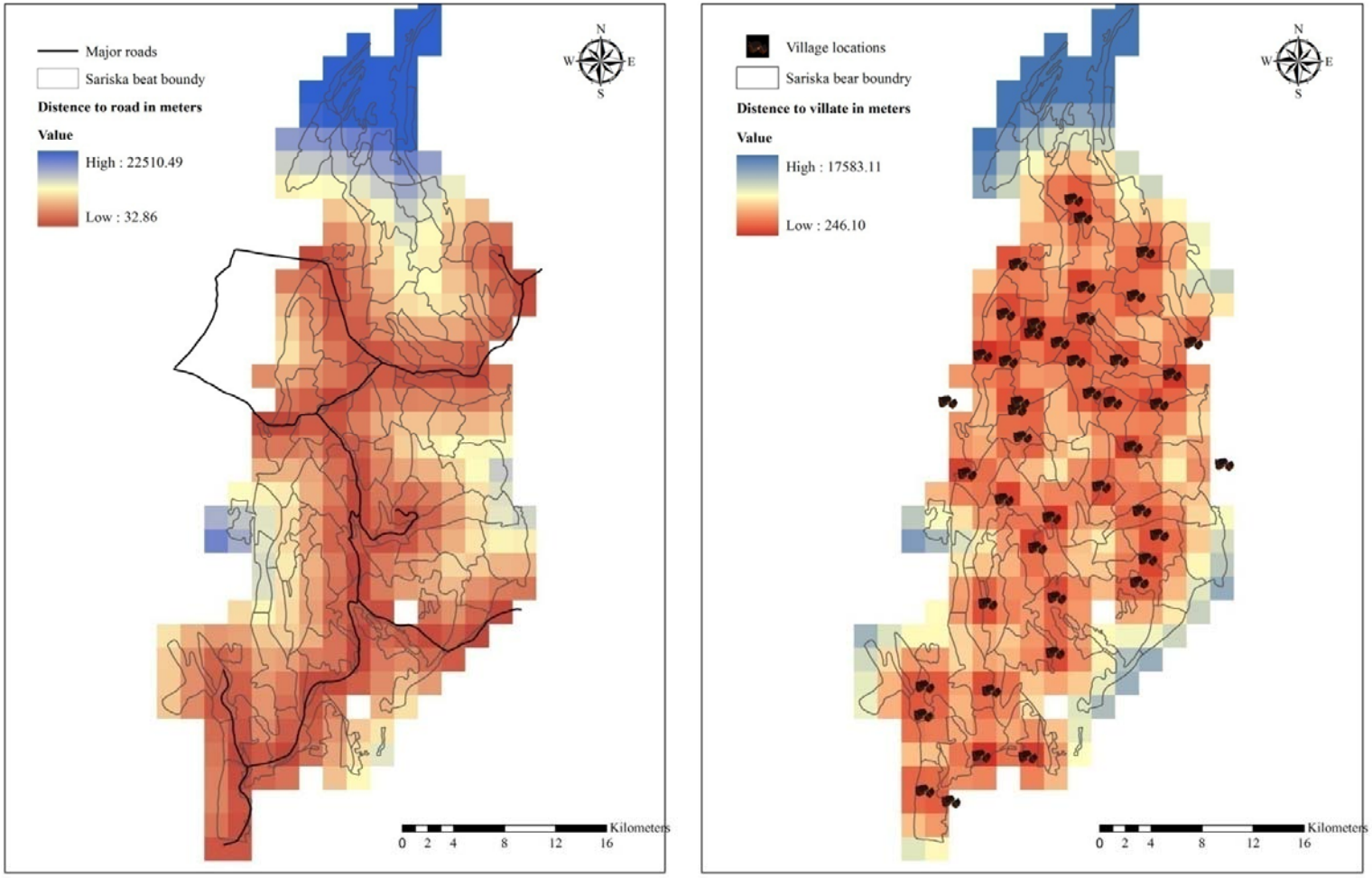

Figure. 6.3. a) Grid values assigned with respect to distance to road in meters in Sariska Tiger Reserve.
b) Grid values assigned with respect to distance to human settlements in meters in Sariska Tiger Reserve.

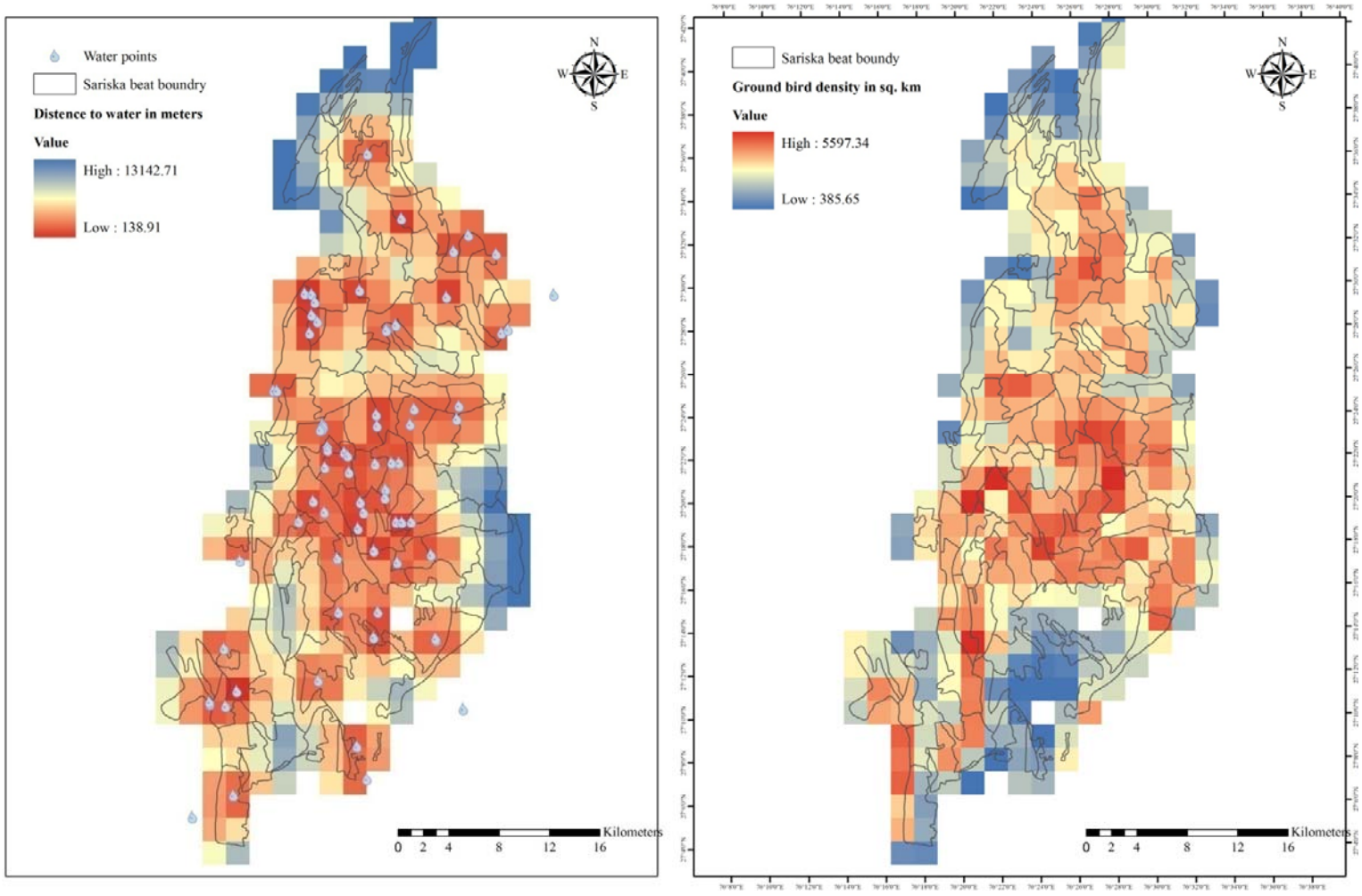

Figure. 6.3. c) Grid values assigned with respect to distance to water in meters in Sariska Tiger Reserve.
d) Grid values assigned with respect to ground bird densities (kilometer square) in Sariska Tiger Reserve.

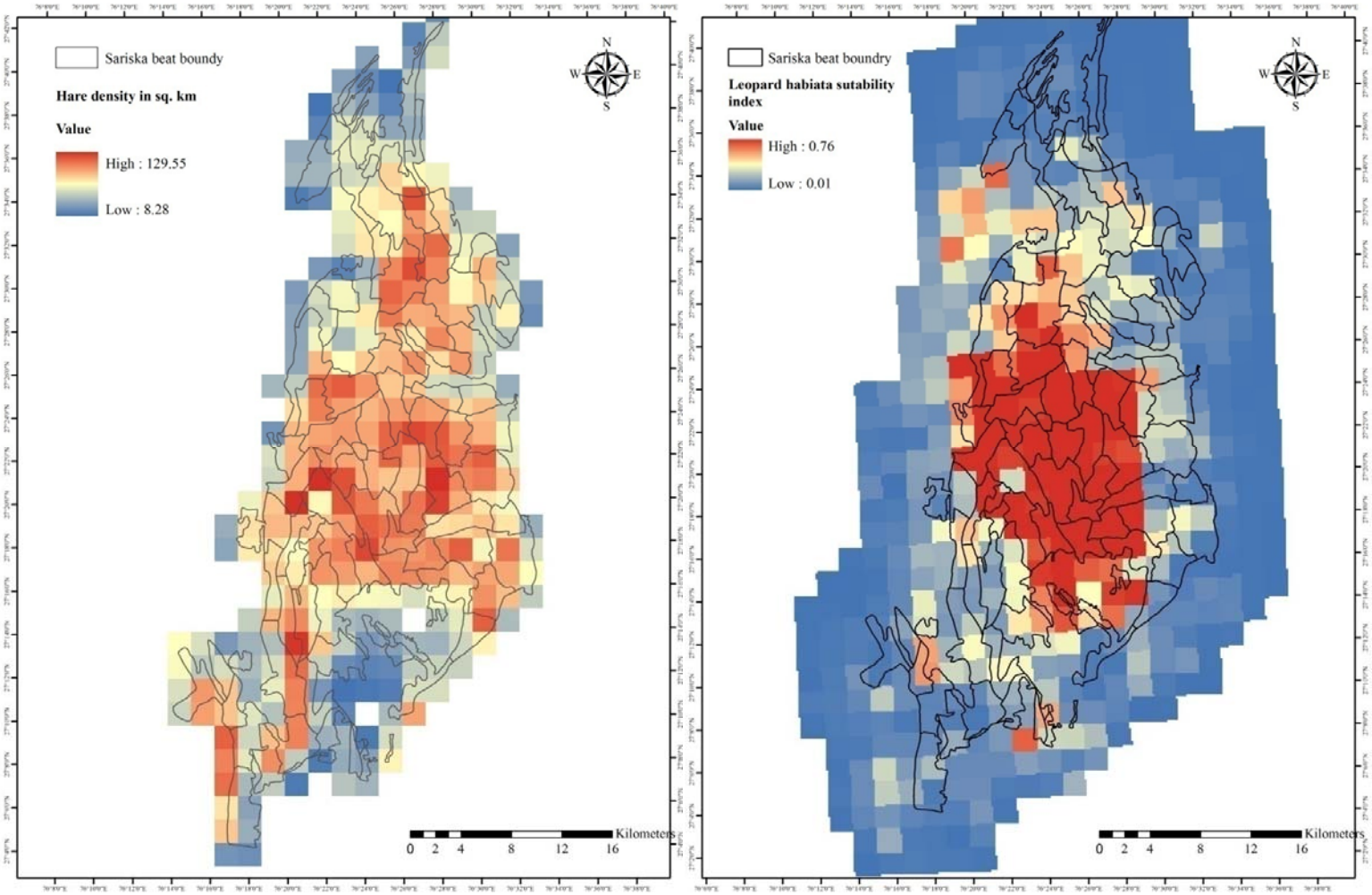

Figure. 6.3. e) Grid values assigned with respect to hare densities (kilometer square) in Sariska Tiger Reserve.
f) Grid values assigned with respect to leopard occurrence probability in Sariska Tiger Reserve (Mondal *et. al.*, 2012).

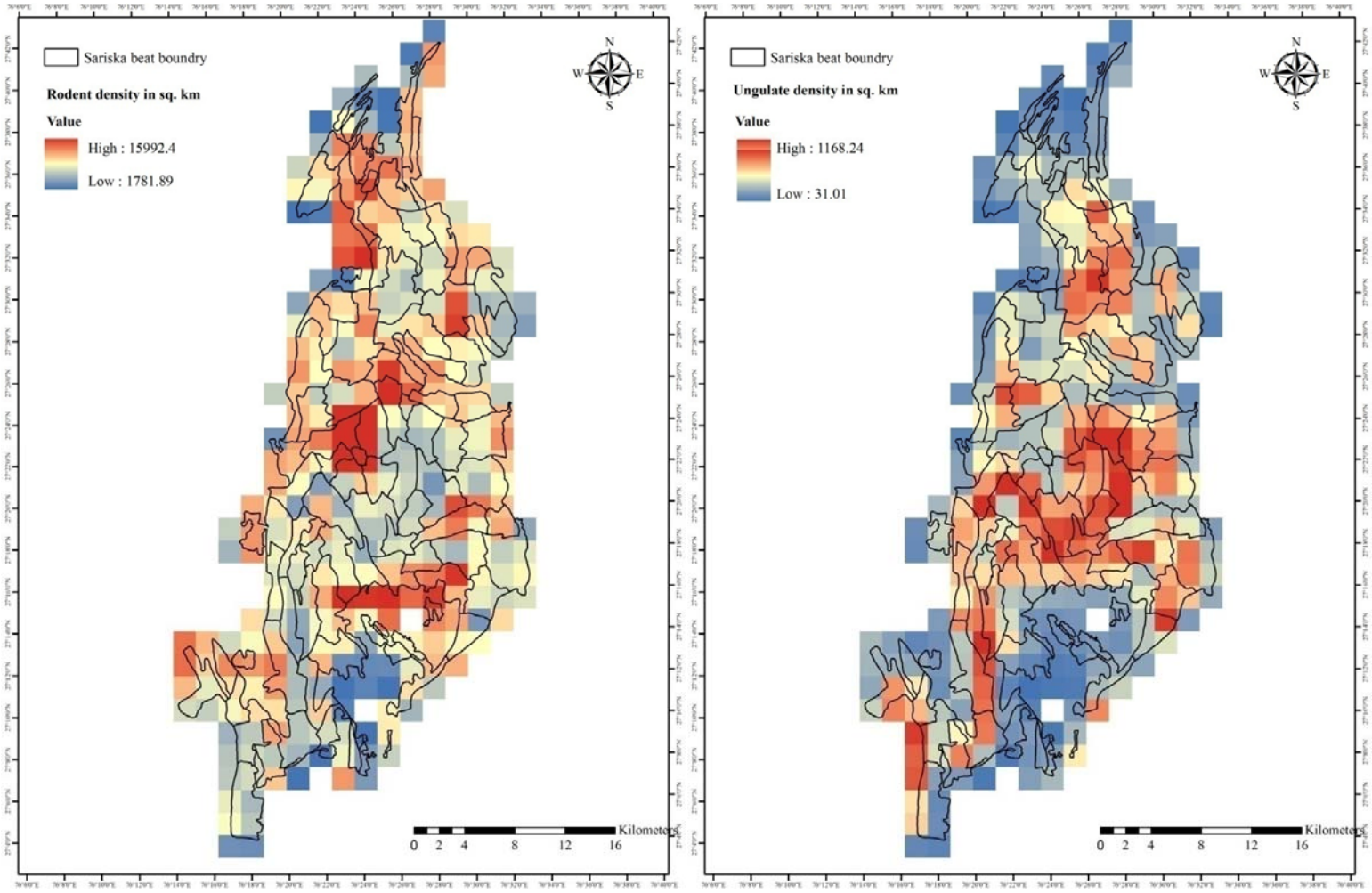

Figure. 6.3. g) Grid values assigned with respect to rodent densities (kilometer square) in Sariska Tiger Reserve.
h) Grid values assigned with respect to ungulate density (kilometer square) in Sariska Tiger Reserve.

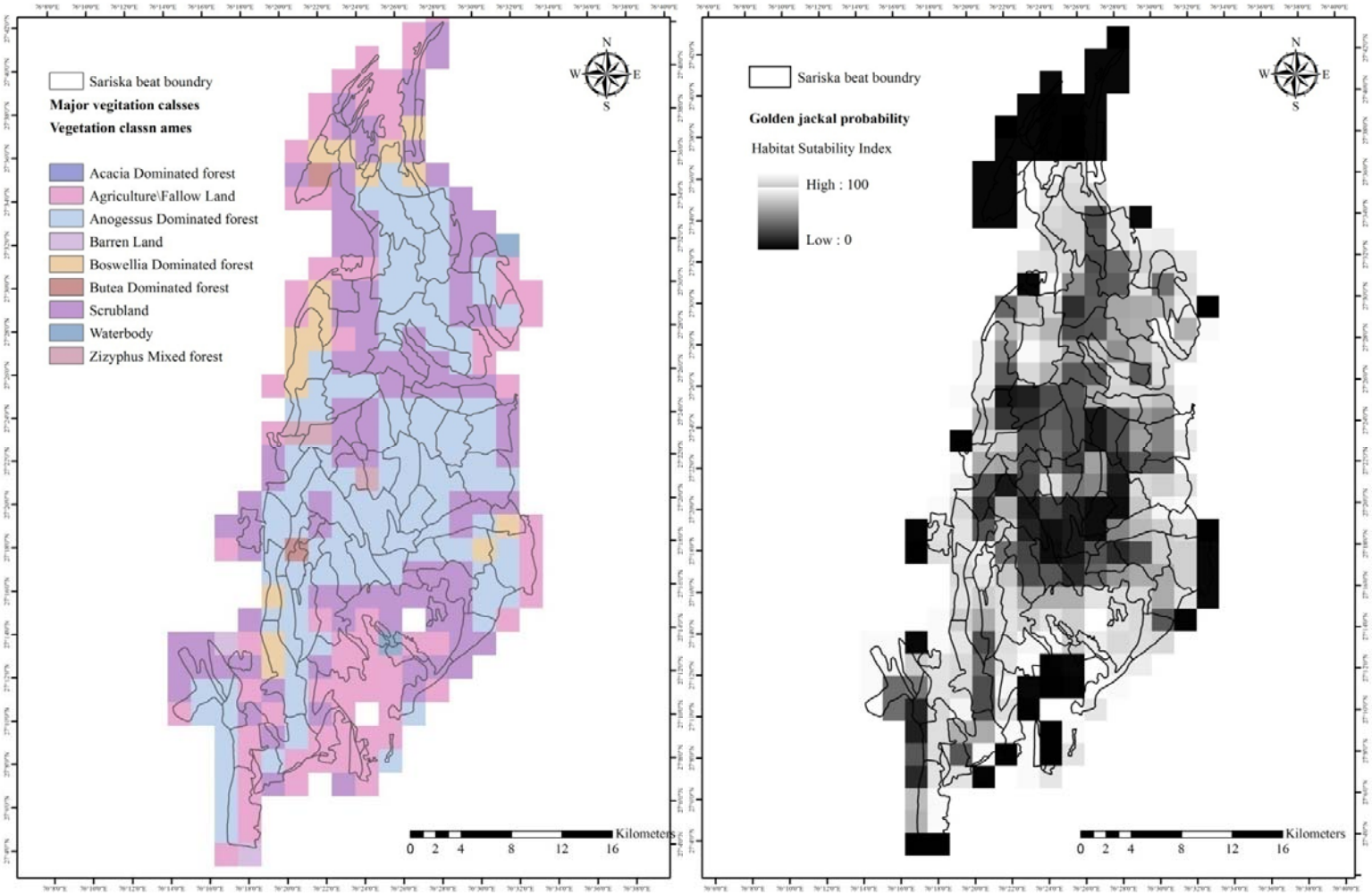

Figure. 6.3. i) Grid values assigned with respect to dominant vegetation class (kilometer square) in Sariska Tiger Reserve.
j) Predicted distribution for jackal in Sariska Tiger Reserve estimated by ENFA modeling (2010-2013). Potential areas are shown in grey shading with the white color indicating higher probabilities of occurrence.

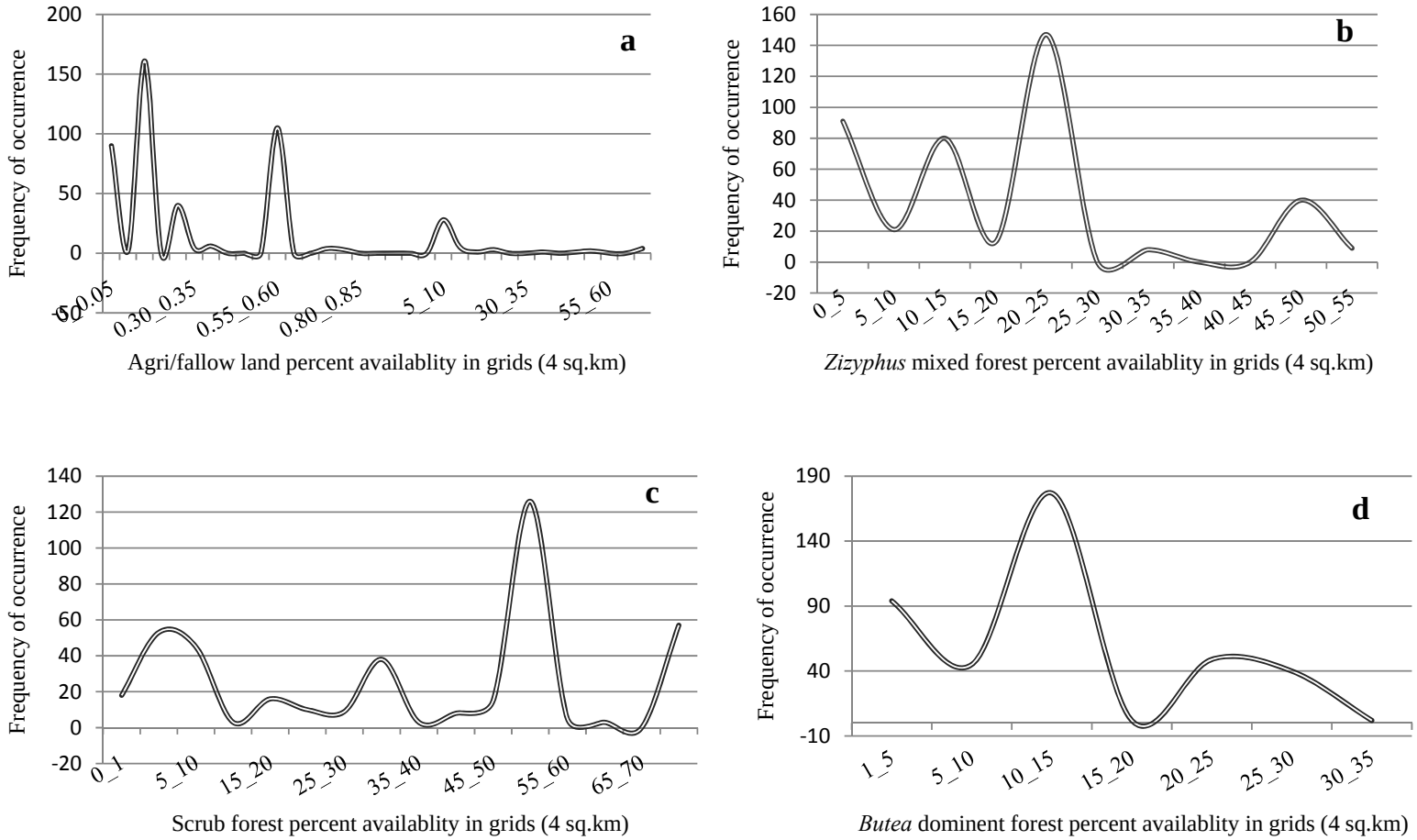

Figure.6.4. Graphical representation of the relationship between (a) agricultural land (b) *Zizyphus* mixed c) scrub d) *Butea* dominant forest, and jackal frequency of occurrence in Sariska Tiger Reserve (2010-2013).

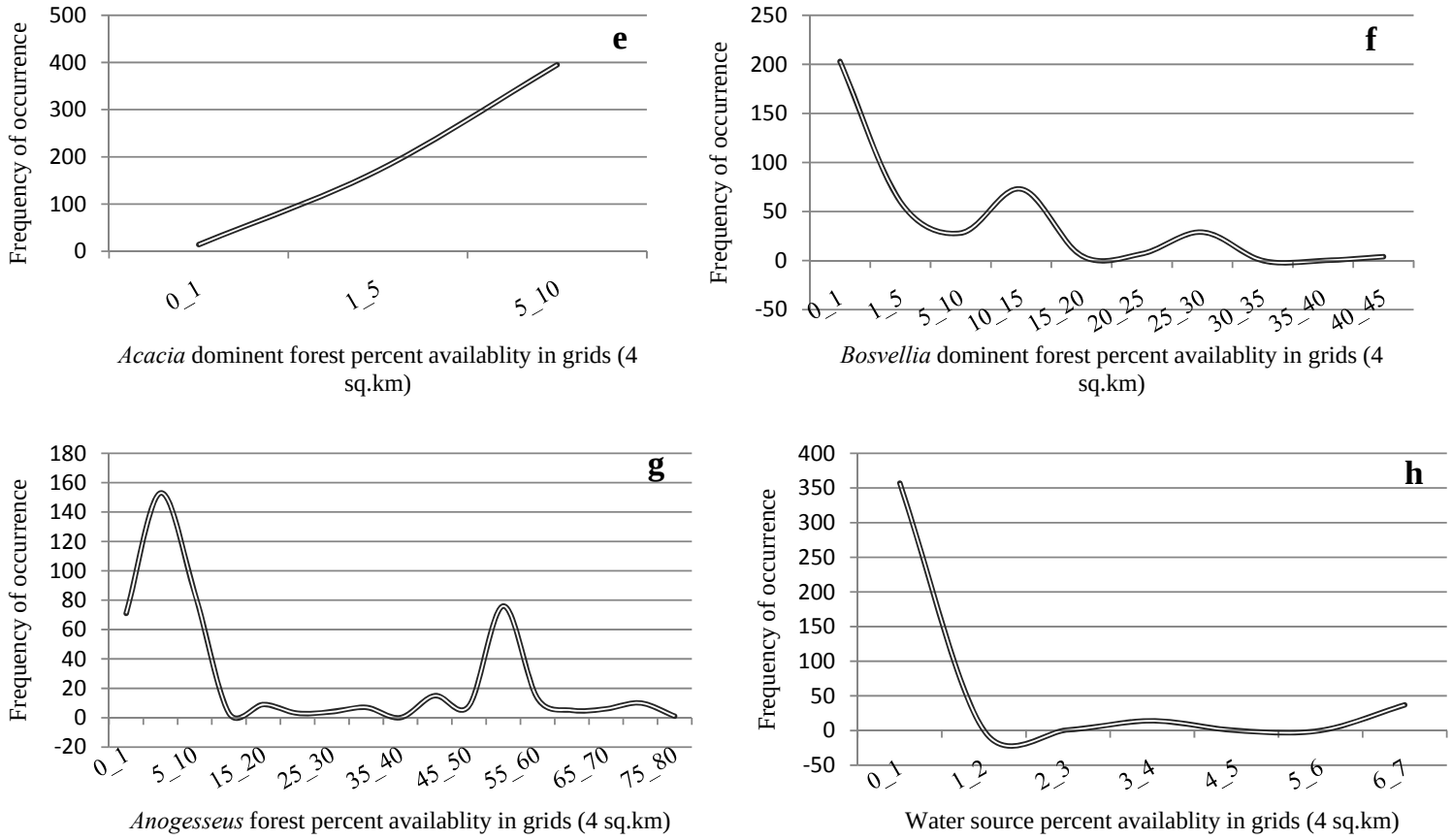

Figure.6.4. Graphical representation of the relationship between (e) *Acacia* dominent (f) *Bosvellia dominent* (g) *Anogesseus* dominent (h) water source availability, and jackal frequency of occurrence in Sariska Tiger Reserve (2010-2013).

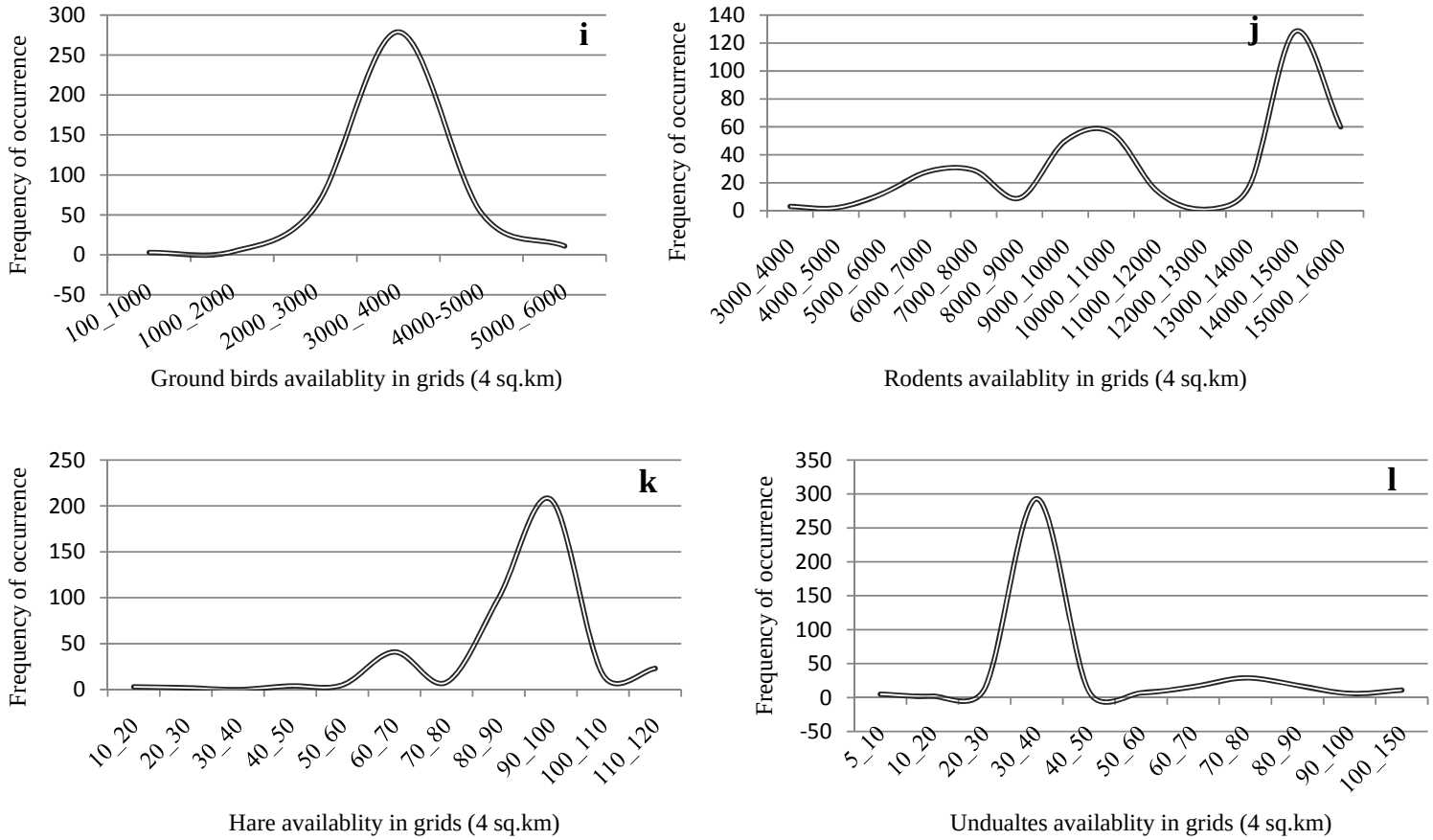

Figure.6.4. Graphical representation of the relationship between (i) ground birds (j) rodent (k) hare (l) ungulate availability, and jackal frequency of occurrence in Sariska Tiger Reserve (2010-2013).

Table.6.1. Eigen values and their explained variance obtained by ENFA

Eigen values	Value	Explained variance	Cumulative expl. Var.
1	20.332	0.249	0.249
2	50.476	0.618	0.867
3	3.696	0.045	0.913
4	2.301	0.028	0.941
5	1.738	0.021	0.962
6	1.178	0.014	0.976
7	0.879	0.011	0.987
8	0.562	0.007	0.994
9	0.482	0.006	1

Table.6.2. Marginality factor describing deviance of species optimum form the mean habitat and the tolerance factor sorted by decreasing amount of explained variance, describing how specialized the species is with reference to available range of habitats in Sariska Tiger Reserve.

Marginality:	0.642	Value (close to 1) indicates a tendency to live in extreme habitats
Specialization:	3.012	
Tolerance (1/S):	0.332	Value (close to 0) indicates species is not too picky on its living environment

Table.6.3. Factors and algorithm used for computing habitat suitability map of jackal listing explained information and specialization.

Habitat suitability map:	
- Number of factors:	3
- Explained information:	0.969
- Explained specialization:	0.939
- Number of categories:	20
- Algorithm:	Medians
Cross-validation partitions:	10

Continued….

Table.6.4. Variance explained by the nine ecological factors and coefficient values for the participating variables.

Factor 1 (25%)	Factor 2 (62%)	Factor 3 (5%)	Factor 4 (3%)	Factor 5 (2%)	Factor 6 (1%)	Factor 7 (1%)	Factor 8 (1%)	Factor 9 (1%)
dist_wtr (-0.46)	rug (-0.98)	ung_dens (0.61)	gb_dens (0.59)	ung_dens (0.78)	ung_dens (-0.68)	ung_dens (0.58)	gb_dens (0.72)	gb_dens (0.79)
hr_dens (0.44)	ung_dens (0.13)	dist_rd (-0.51)	ung_dens (-0.42)	gb_dens (-0.39)	rdnt_dens (-0.43)	veg_typ (-0.49)	ung_dens (-0.66)	hr_dens (-0.48)
dist_rd (-0.40)	hr_dens (-0.11)	hr_dens (-0.43)	dist_wtr (-0.35)	hr_dens (-0.33)	gb_dens (0.43)	hr_dens (-0.46)	rdnt_dens (-0.18)	ung_dens (-0.31)
dist_vill (-0.37)	dist_vill (0.08)	dist_wtr (0.36)	hr_dens (-0.35)	rdnt_dens (0.27)	dist_vill (-0.29)	gb_dens (0.43)	hr_dens (-0.07)	rdnt_dens (-0.15)
gb_dens (0.35)	rdnt_dens (0.07)	rdnt_dens (0.18)	dist_vill (0.33)	veg_typ (-0.15)	hr_dens (0.24)	dist_vill (0.13)	dist_vill (-0.05)	veg_typ (0.11)
ung_dens (0.28)	dist_wtr (0.04)	gb_dens (-0.09)	dist_rd (-0.24)	dist_vill (-0.14)	dist_rd (0.16)	dist_wtr (-0.07)	dist_rd (0.02)	dist_wtr (-0.08)
rdnt_dens (0.25)	gb_dens (-0.04)	veg_typ (-0.08)	rdnt_dens (-0.21)	dist_rd (0.09)	veg_typ (-0.04)	dist_rd (0.05)	veg_typ (0.00)	dist_vill (0.07)
veg_typ (0.17)	dist_rd (-0.01)	dist_vill (0.05)	veg_typ (-0.13)	Rug (-0.01)	rug (-0.04)	rdnt_dens (0.04)	dist_wtr (0.00)	dist_rd (-0.07)
rug (-0.06)	veg_typ (0.00)	rug (0.02)	rug (-0.03)	dist_wtr (-0.01)	dist_wtr (0.00)	rug (0.01)	rug (0.00)	rug (-0.01)

rugg = ruggedness; ung_dens = ungulate density; hr_dens = hare density; dist_vill = Distance to village; rdnt_dens = rodent density; dist_wtr = Distance to water; gb_dens = Ground bird density; dist_rd = Distance to road; veg_typ = vegetation type.

Table.6.5. Global correlation matrix obtained by ENFA

	dist_rd	dist_vill	dist_wtr	gb_dens	hr_dens	rdnt_dens	rugg	ung_dens	veg_typ
dist_rd	1	0.774	0.586	-0.181	-0.223	-0.095	-0.011	-0.163	0.003
dist_vill	0.774	1	0.669	-0.397	-0.416	-0.179	-0.03	-0.359	-0.283
dist_wtr	0.586	0.669	1	-0.264	-0.277	-0.177	-0.068	-0.237	-0.195
gb_dens	-0.181	-0.397	-0.264	1	0.975	0.214	-0.056	0.936	0.755
hr_dens	-0.223	-0.416	-0.277	0.975	1	0.19	-0.053	0.921	0.684
rdnt_dens	-0.095	-0.179	-0.177	0.214	0.19	1	-0.056	-0.123	-0.006
rugg	-0.011	-0.03	-0.068	-0.056	-0.053	-0.056	1	-0.036	-0.04
ung_dens	-0.163	-0.359	-0.237	0.936	0.921	-0.123	-0.036	1	0.796
veg_typ	0.003	-0.283	-0.195	0.755	0.684	-0.006	-0.04	0.796	1

rugg = ruggedness; ung_dens = ungulate density; hr_dens = hare density; dist_vill = Distance to village; rdnt_dens = rodent density; dist_wtr = Distance to water; gb_dens = Ground bird density; dist_rd = Distance to road; veg_typ = vegetation type.

Table.6.6. Species covariance matrix obtained by ENFA

	dist_rd	dist_vill	dist_wtr	gb_dens	hr_dens	rdnt_dens	rugg	ung_dens	veg_typ
dist_rd	0.149	0.033	0.097	0.092	0.041	-0.070	-0.007	0.104	0.129
dist_vill	0.033	0.171	0.046	0.082	0.094	-0.036	-0.001	0.095	0.017
dist_wtr	0.097	0.046	0.375	-0.110	-0.119	-0.044	0.000	-0.130	-0.149
gb_dens	0.092	0.082	-0.110	0.636	0.576	0.025	0.007	0.630	0.492
hr_dens	0.041	0.094	-0.119	0.576	0.632	0.099	0.003	0.558	0.296
rdnt_dens	-0.070	-0.036	-0.044	0.025	0.099	1.196	0.020	-0.420	-0.414
rugg	-0.007	-0.001	0.000	0.007	0.003	0.020	0.019	0.000	0.007
ung_dens	0.104	0.095	-0.130	0.630	0.558	-0.420	0.000	0.810	0.684
veg_typ	0.129	0.017	-0.149	0.492	0.296	-0.414	0.007	0.684	1.040

rugg = ruggedness; ung_dens = ungulate density; hr_dens = hare density; dist_vill = Distance to village; rdnt_dens = rodent density; dist_wtr = Distance to water; gb_dens = Ground bird density; dist_rd = Distance to road; veg_typ = vegetation type.

6.3.2. Probabilistic model using logistic regression analysis:

The parameters received most support to infer the habitat selection by jackal was the 'resource' factor (table.6.7). The presence of small mammal density and favorable distance form water source in open to moderately dense forest, were evaluated as the most influential factors at the scale of 4 km^2 grid as represented by the top model (AIC = 528.7; ω_i = 0.51) (table.6.7). I examined the variables those contributed in model, which influenced selection at significant level. For the same, multimodal information was derived to get the collective effect of variables in all the models (table.6.8). The results infer strong inverse relation with distance to scrub and moderate forest types, in other words more the distance less the probability of jackal's presence. Hence, jackal was found to be more perceptive towards scrub and moderate forests having respective forest types such as *Zizyphus* mixed and *Acacia* dominant forest. Also, no significant avoidance by jackal for disturbance factors like road and human settlements was obtained by the model.

Therefore, the selected habitat factor variables obtained from logistic regression were compared with the ENFA factor spectrum and further used for preparing the habitat suitability map (table.6.9). There was no significant difference observed between the selected models of ENFA and GLM (student *t* test; t = 0.57, df = 14, p = 0.58). The selected GLM models were again used to compute habitat suitability model with ENFA. A suitability map so built had index of suitability (Boyce index) below the limit of 0.5 with high error i.e. 0.37 ± 0.44 as well the AVI and CVI values as 0.67 ± 0.41 and 0.22 ± 0.39 respectively. The disparity observed could be because of unreliability of absences data used in logistic regression model. The ENFA is based on presence only data and hence was found more efficient to model the areas with average to high suitability and its predictions for low suitability regions are more sensitive in contrast to presence/absence (expected) methods such as logistic regression and GLM, which tend to model good versus bad areas causing a kind of stepped response which is different from the linear response in ENFA. ENFA was found more robust for the analysis since the predictive power of the maps was better. In contrast, the GLM is quite sensitive to data quality.

Table.6.7. The top model from the list of models ranked by AICc explaining habitat selection by the jackal at Sariska Tiger Reserve (2010-13).

Model	AIC	Parameter	B	S.E.	Wald	df	Sig.	Exp(B)	Delta *i*	exp. Values	ω_i
1	818.2	Scrub	-0.215	0.081	6.970	2	0.008	0.807	289.5	0.000	0.000
		Modforest	-0.025	0.004	34.553		0.000	0.975			
2	790.2	Scrub	-0.172	0.076	5.171	3	0.023	0.842	261.5	0.000	0.000
		ZizMixforest	0.019	0.009	4.745		0.029	1.019			
		AcaDomforest	-0.249	0.039	41.581		0.000	0.78			
3	528.7	Scrub	-0.167	0.076	4.846	5	0.028	0.846	0	1.000	0.505
		DIST_WTR	-0.938	0.104	80.674		0.000	0.392			
		GrdBrdDnst	-0.001	0.000	17.924		0.000	0.999			
		HRDnst	0.031	0.013	5.983		0.014	1.031			
		RdntDnst	0.000	0.000	10.918		0.001	1			
4	533.1	DIST_WTR	-0.949	0.104	83.181	5	0.000	0.387	4.4	0.111	0.056
		GrdBrdDnst	-0.002	0.000	25.641		0.000	0.998			
		HRDnst	0.052	0.014	13.802		0.000	1.054			
		RdntDnst	0.000	0.000	17.394		0.000	1			
		Modforest	-0.016	0.006	6.323		0.012	0.984			

5	534.6	DIST_WTR	-0.933	0.107	76.475	6	0.000	0.393	5.9	0.052	0.026
		GrdBrdDnst	-0.001	0.000	22.309		0.000	0.999			
		RdntDnst	0.000	0.000	17.847		0.000	1			
		Modforest	-0.016	0.006	6.476		0.011	0.984			
		HRDnst	0.051	0.014	12.558		0.000	1.052			
		DIST_RD	-0.047	0.070	0.440		0.507	0.955			
6	529.1	DIST_WTR	-0.891	0.107	68.753	7	0.000	0.41	0.4	0.819	0.413
		GrdBrdDnst	-0.001	0.000	20.969		0.000	0.999			
		RdntDnst	0.000	0.000	16.181		0.000	1			
		Modforest	-0.015	0.006	5.568		0.018	0.985			
		HRDnst	0.048	0.014	11.029		0.001	1.049			
		DIST_RD	-0.057	0.073	0.613		0.434	0.944			
		DIST_VILL	-0.262	0.097	7.200		0.007	0.77		1.982	

Modforest = moderately dense forest; ZizMixforest = *Zizyphus* mixed forest; AcaDomforest = *Acasia* dominant forest; DIST_WTR = Distance to water in km; GrdBrdDnst = Ground bird density in km^2; HRDnst = hare density in km^2; RdntDnst = rodent density in km^2; DIST_RD = Distance to road in km; DIST_VILL = Distance to village in km.

Table.6.8. Most influential model-averaged parameter estimates of top models explaining habitat selection by jackal at Sariska Tiger Reserve (2010-13).

Factor	Model	Mean B	SE_unc	Sum Wi
Resource	DIST_WTR	-0.919	0.016	1.000
	GrdBrdDnst	-0.001	0.000	1.000
	HRDnst	0.040	0.007	1.000
	RdntDnst	0.000	0.000	1.000
Cover	Scrub	-0.084	0.002	0.505
	Modforest	-0.008	0.000	0.495
Disturbance	DIST_RD	-0.025	0.000	0.439
	DIST_VILL	-0.108	0.004	0.413
Forest type	ZizMixforest	0.000	0.000	0.019
	AcaDomforest	0.000	0.000	0.000

Modforest = moderately dense forest; ZizMixforest = *Zizyphus* mixed forest; AcaDomforest = *Acasia* dominant forest; DIST_WTR = Distance to water in km; GrdBrdDnst = Ground bird density in km^2; HRDnst = hare density in km^2; RdntDnst = rodent density in km^2; DIST_RD = Distance to road in km; DIST_VILL = Distance to village in km.

Table.6.9. Major factors used for evaluation of Habitat Suitability and selected GLM values to ascertain the most influential factor combination used by jackal at Sariska Tiger Reserve (2010-13).

Variables	Factor 2 (62%)	Factor 1 (25%)	Factor 3 (5%)	GLM
rugg	-0.98	-0.06	0.02	-
ung_dens	-0.13	0.28	0.61	0.00
hr_dens	-0.11	0.44	-0.43	0.04
dist_vill	-0.08	-0.37	0.05	-0.11
rdnt_dens	-0.07	0.25	0.18	0.00
dist_wtr	-0.04	-0.46	0.36	-0.92
gb_dens	-0.04	0.35	-0.09	0.00
dist_rd	-0.01	-0.40	-0.51	-0.02
veg_typ	0.00	0.17	-0.08	0.00
GLM comparison	t = 0.573; p = 0.576	t = 0.91; p = 0.38	t = 0.45; p = 0.45	

rugg = ruggedness; ung_dens = ungulate density; hr_dens = hare density; dist_vill = Distance to village; rdnt_dens = rodent density; dist_wtr = Distance to water; gb_dens = Ground bird density; dist_rd = Distance to road; veg_typ = vegetation type.

6.4. Discussion:

Distribution maps of jackal as evaluated in the present study represent probability values (0-1) in 880 km^2 indicating chance of encountering the species in the entire Tiger Reserve. The entire approach was based on the premise that species distribution is related to biological, anthropogenic and topographic features. The jackal Habitat Suitability Map thus provided baseline information on the spatial arrangement of potentially suitable habitats for a study species. In the spatial model, areas predicted as highly suitable (i.e. probability of occurrence) are clearly delineated, surrounded by areas of lower habitat quality depending upon the species ecological requirements. The modeling results were congruent with our understanding and knowledge of jackal natural history and specifically their habitat preferences. While model developed from coarse-grained landscape variables can predict species distribution effectively, but unfortunately, finer scaled habitat variables, such as prey distribution and refuge habitat etc., are unlikely to be captured at a landscape level which are essential for wide ranging meso carnivore like jackal that could turn out to be a limitation in this study.

Jiménez- Valverde *et. al.* (2008b) argued that whether it is sensible to compare Species Distribution Models (SDM) that conceptually aim at different aspects of spatial distribution —especially when predicting big difference between models predicting potential and realized distributions, although both are put under SDM. Engler *et. al.* (2004) suggested a hybrid approach to spatial modeling of occurrence-only records which is a combination of Generalized Linear Model (GLM) and ENFA. In their approach, ENFA was used to generate the so-called '*pseudo-absence*' data, which were then added to the original presence-only data. No such attempt was made in this study although the regression model was used to analyze to the level where variable contribution in predicting species distribution can be certain at finer resolution. However no major difference was observed between the two methods in the present study (table.6.9). Interestingly jackal showed a sole distribution pattern; restricted or random thus indicating the importance of the landscape heterogeneity along with intermediate factors that shaped up the distribution of the study species. Identifying areas of high habitat suitability for jackal

in forested ecosystem lays the foundation for planning future research and conservation initiatives.

It's the jackal's high probability of presence at best possible resources such as moderate ungulate density, vicinity to village, water and rodent availability supported the fact that the species preferred open habitats like scrub, moderate forests (having *Zizyphus* mixed and *Acacia* dominant forest as a prime vegetation) and agro-ecosystems. It also supported negative relationship with rugged terrain, high hare and ground bird densities associated with very dense forest explaining the species preference towards low canopy areas. Distance to road and vegetation type had only marginal effects. The results from the present study are in contrary to the previous study in Sariska Tiger Reserve (Gupta 2011) where elevation was found to be positively correlated with the jackal occurrence and rodents were found to be negatively correlated for jackal distribution. A high probability at sites close to and even away from roads suggested that this species does not have any specificity towards disturbance from road. Sariska has a high density of large predators (Mondal *et. al.*, 2012; Gupta, 2011) and hence it is possible that there could be other variables like occurrence probability of competing carnivore such as leopard (figure.6.3.f) that could play a major role in its distribution and this must be investigated in detail by future research. Most of the canids inhabit relatively open areas which can be attributed to their life history traits like social organization (Jaedger, 1996; Aiyadurai, 2005). The distribution of the jackal in the study area was 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). Their responses to habitat were consistent with a priori predictions based on a consideration of ecological characteristics of the species. For a given amount of available habitat, species like jackal, with generalized diets potentially can avail themselves of a broader array of resources. In a heterogeneous landscape, then, energy can be extracted from a greater fraction of non matrix habitat by species with broader diets. Likewise, species characterized by high local densities by definition are more abundant within a given area, which may be reflected in greater overall use of available habitat (Gehring, 2000).

Three resources seem necessary for jackal to establish themselves in Sariska under the conditions: (1) cover, (2) a diet that is predominantly of small mammals and does not seriously compete with other carnivore and humans for food (e.g., poultry and livestock), and (3) access to areas with prey distribution for establishing territories and breeding. These resources are not mutually exclusive. Agro ecosystems are found to be important for jackal distribution. For example, in cultivated areas of Pakistan, sugarcane has been suggested as an important source of both cover and food for jackal (Khan and Beg 1986). In Bangladesh, jackal are relatively common in sugarcane-growing areas (Poche´ *et. al.*, 1987). Crop fields attract rodents, suggesting that effect of cultivation on the distribution of food resource, may be the more important determinant of jackal distribution.

The habitat suitability for jackal in Sariska highlighted the importance of maintaining landscape configuration, such as the combination of spatial elements, and landscape connectivity similar to the findings of other studies on meso-carnivores (Kareiva and Wennergren, 1995; Gehring, 2000). Although conservation of species should begin with habitat protection and restoration (e.g. Danielson, 1994; Fahrig, 1997) the arrangement of spatial elements can strongly affect the ability of species to move among and between elements (Gehring, 2000). The study area Sariska, is a high-production agricultural region that has been dominated by humans. Restoration of most habitats that have been destroyed via conversion to row crops will not occur in the foreseeable future, making considerations of landscape configuration critical to management efforts (Gehring & Swihart, 2003). Natural selection on jackal to alter their diet towards greater or lesser carnivory might have been constrained by the presence of the two resident competitive species i.e. hyena and leopard on either side of the tropic axis. The successful insinuation of the jackal, as an intermediate form, may be due to their independent history of evolution in more varied environments across their distribution range. The jackals tolerate a much wider array of habitats and this flexibility could have favored their success as competitors. For example, jackals are found in humid forest (e.g., Bandipur, annual rainfall of 800-2000 mm; Johnsingh 1981) as well as in dry plains and desert (Prater 1980).

The model used in present study can be tested by future research in Sariska Tiger Reserve for jackal's presence in (1) areas predicted to have a high probability

and (2) areas predicted to have no probability where the model may be wrong. The future surveys in forested and non forested regions of adjoining Alwar and Jamwa Ramgarh forest division is recommended to validate the habitat suitability model for entire geographic region. The niche modeling as observed in the present study depicts contrast spatial distribution pattern between jackal (figure.6.3.j) and leopard (figure.6.3.f). Also the site has fair density of hyena population (24.5/100 km^2, Gupta *et. al.*, 2011). Despite of large difference in body size, differences in activity pattern might reduce inter-specific competition between these groups in the intensive study area (mostly forested). The jackal in Sariska appears to be spatially separated towards the open bordering areas, which is probably to avoid competition, however the co-occurrence analyses may explain this phenomenon in greater detail. To confirm any inter-specific competition among leopard, hyena and jackal, more detailed field studies are needed to determine each species' microhabitat usage, behavior and food habits. Further research is needed to determine the adaptive threshold of jackal towards anthropogenic activities.

For some predators such as red foxes (Harris, 1981), Raccoons (Riley *et. al.*, 1998), and Cooper's Hawks (*Accipiter cooperii*; Mannan & Boal 2000), density increases and home range size decreases in human dominant areas, which is presumably because of high-density food supplies and sufficient habitat requirements. The high productivity of environments may allow jackal to meet metabolic requirements, but the constraints of habitat alteration may also restrict home range size. Although developed and altered open areas may offer increased food resources, I expect an optimistic relationship between home range size and human association. This suggests that non-natural areas are less suitable than natural areas in some important aspect. Secure resting and denning locations may be more dispersed in populated areas, and although jackal may forage in the neighborhoods, they may be less willing to rest there (Riley *et. al.*, 2008). Woodroffe and Ginsburg (1998) suggest that minimizing carnivore mortality at the boundaries of nature reserves may be more important for conserving carnivores than the size of the reserve.

The ecological niche modeling highlighted areas with the highest probabilities of occurrence of jackal thereby, indicating key localities where further research activities should be prioritized. It is suggested to promote the species as pest

controlling agent to ensure its safety and acceptance in agro ecosystem surrounding the reserve boundary. Carnivore conservation efforts in the landscapes must account for the pervasive effects of humans and development, even within reserves. Even the highly adaptable jackal was observed to utilize natural areas more than populated areas, shifts its use of human areas to periods of decreased human presence, and is vulnerable to vehicle collisions and poison.

To confirm my results and to further explore the mechanisms responsible for the distribution and niche partitioning, more detailed field studies are needed to collect data on the distribution, abundance, and ecology of jackal in the entire semi arid tract of India. For instance, insufficient occurrence data exist from bordering areas to investigate spatial or temporal changes in ecological niches, and too little is known about the other biotic factors, such as predation and disease, or the presence of key resources outside the reserve (e.g., den sites, food distribution), also have played a role in determining jackal distribution patterns. It is well documented that in the areas that border nature reserves, free-ranging dogs interact with wildlife at multiple levels, including as predators, prey, and pathogen reservoirs (Butler, du Toit & Bingham, 2004; Fiorello *et. al.*, 2004; Whiteman *et. al.*, 2007; Srbek-Araujo & Chiarello, 2008; Lacerda, Tomas & Marinho – Filho, 2009; Vanak & Gompper, 2009b). It would also be important to study the amount of competitive pressure induced by feral and domestic dogs on the jackal (in terms of foraging and breeding success) in and around Sariska Tiger Reserve boundary.

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Appendix .1. Different forest types in Sariska Tiger Reserve.

a. *Anogeissus pendula* and *Boswellia serrata* forest

b. Acaccia catechu forest

c. Butea monosperma forest

d. Scrub land

e. Zizyphus mauritiana forest

f. Phoenix Slyvesteris (along the streams)

Appendix. 2. Field activities in Sariska Tiger Reserve.

a. Jackal den site

b. Recording observations at jackal den site den

c. Zizyphus fruits on trees

d. Zizyphus fruit deposition in mesh net frame

e. Quantifying *Zizyphus* fruit abundance

f. Deployment of camera traps

g. Jackal scat collection

h. Deployment of rodent traps

i. Deployment of camera trap near jackal den site

Appendix. 3. Jackal feeding trial experiment in Jaipur Zoo.

a. Front portion of jackal enclosure in Jaipur zoo

b. Jackals in Jaipur Zoo on which feeding trials conducted on

c. Area available at the entrance inside the jackal enclosure in Jaipur zoo

d. Concrete chamber for jackals inside the enclosure in Jaipur

Appendix. 4. Food remains in jackal scat as revealed by scat analys.

a. Dates seeds observed in jackal scat

b. Human generated material observed in jackal scat

c. Bird feather observed in jackal scat

d. Grass seeds observed in jackal scat

e. Bird claws observed in jackal

f. Bird beak observed in jackal scat

g. Dates and insect remains observed in jackal scat

h. Snake scale observed in

i. Rodent remains and feather tubes observed in jackal scat

j. Rodents and vegetation observed in jackal scat

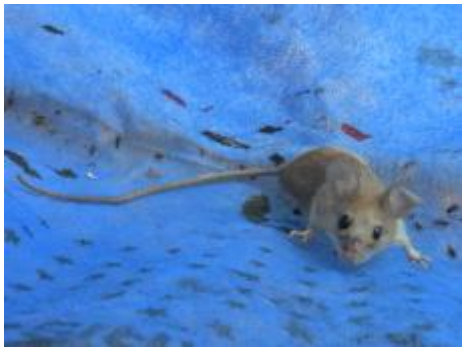
k. Jackal scat

Appendix. 5. Rodent Species recorded in Sariska Tiger Reserve.

a. *Mus platythrix*

b. *Mus budooga*

c. *Golunda ellioti*



d. *Vandeleuria oleracea*

e. *Tatera indica*

f. *Suncus montanus*

g. *Millardia gleadouwi*

h. *Gerbillus nanus*

i. *Mus musculus*

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Food Habits of Golden Jackal (*Canis aureus*) and Striped Hyena (*Hyaena hyaena*) in Sariska Tiger Reserve, Western India

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Abstract: Food habits of golden jackal (*Canis aureus*) and striped hyena (*Hyaena hyaena*) were investigated using scat analysis between November 2010 and June 2011 in Sariska Tiger Reserve, Western India. Total 104 scats of golden jackal and 86 scats of striped hyena were collected and analyzed. The frequency of occurrence of each prey species was estimated through bootstrapping using program SIMSTAT. Niche breadth of these two species was quantified using Levin's measure. The diet overlap in the two species was assessed using Pianka's index. Twelve food items were identified in golden jackal scats and nine in striped hyena scats. Vegetative matter contributed maximum (17.57%) in jackal's diet followed by rodents (15.77%), chital (10.81%), sambar (5.41%) and nilgai (4.05%). Nilgai and domestic cattle contributed maximum (24.76% each) in the diet of striped hyena, followed by sambar (17.14%), chital (16.19%) and vegetative matter (10.48%). The estimated dietary overlap between striped hyena and golden jackal was 67%. Niche breadth for golden jackal was estimated as 0.69 and for striped hyena it was 0.57. The considerable overlap was attributed to mutual dependence on ungulates, which indicated high resource competition between the two species.

Key words: *Canis aureus* % Dietary Niche Overlap % Food Habits % *Hyaena hyaena* % Prey Size % Scat

INTRODUCTION

The extent of niche differentiation and resource partitioning determines the degree to which different species can either coexist or competitively exclude each other [1, 2]. An important mode of resource partitioning is the degree of dietary overlap between sympatric species [3]. This overlap is influenced by each species' physical ability to obtain food [4, 5] and also by variation in the spatial and temporal availability of food [6]. For distinct carnivore guilds different mechanisms may be involved, such as different body sizes of predators [7] and prey species [8, 9], activity pattern [10] and microhabitat use [11]. However, whereas resources are limited, the strength of competition between sympatric species generally decreases with increased resource partitioning [12].

Study by Dickman [13] showed that the smaller predators in an insectivorous mammal guild consumed smaller prey, but switched over to larger prey when the larger predators were removed. Consequently prey selection could depend more on competition among predator guild members than on any inherent relationship between predator and prey sizes. A confounding factor in predator-prey studies that include a wide size-range of mammalian predators is the high variability in diet of smaller species, which can switch between insectivore, omnivore and carnivore. Canid and felid species above certain threshold weight class predate purely on vertebrates, while those below may be omnivorous or predate on invertebrates and vertebrates. This implies that large carnivores (>21.5 kg) constitute a distinct functional group from which predator-prey size relationships should emerge more clearly than from carnivore assemblages that are distributed across both sides of the body mass threshold [14]. The diet of the golden jackal and the striped hyena was studied through scat analysis in India [15-18] and other countries [19-22]. Merve *et al.* [23] studied diet overlap between brown hyena (*Parahyaena brunnea*) and black-backed jackal (*Canis mesomelas*) in Atherstone Nature Reserve, Pilanesberg National Park and private farm (Mankwe Wildlife Reserve) in South Africa. They inferred that, despite the marked body size differences, brown hyena and black-backed jackal can be considered as either meso-carnivores or apex predators,

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depending on the presence or absence of larger carnivores [24]. As meso-predators, the potential food availability increases as dietary items previously unattainable, are killed by apex predators and interspecific competition could decline concomitantly. The diet of black backed jackal comprises high proportion of small and large mammals, corroborating that both scavenge and hunt competently [25]. Brown hyenas, on the other hand, are predominant scavengers [26]. Thus, jackals may be excluded from carcass sites by brown hyenas, eventually forcing them to hunt more frequently [27].

Both striped hyena (*Hyaena hyaena*) and golden jackal (*Canis aureus*) are found in semi-arid zone and tropical dry and moist deciduous forests of the country and their diet ranges from wild ungulates to domestic livestock and rodents. Although numerous studies have investigated their diet separately, only a few studies [23] have investigated the overlap and resource partitioning, which may vary with the presence or absence of apex predators like tiger (*Panthera tigris*) and leopard (*Panthera pardus*). In the present study, we assessed 1) the relative contribution of different prey species to the diet of golden jackal and striped hyena and 2) the dietary overlap between these two sympatric species. In the present study we estimated the food habits of striped hyena (*Hyaena hyaena*) and golden jackal (*Canis aureus*) and compared the dietary overlap between them in Sariska Tiger Reserve, Western India from November 2010 to June 2011.

MATERIALS AND METHODS

Study Area: The study was conducted in Sariska Tiger Reserve (Sariska TR) (27°05'-27°33' N; 76°15'-76°35' E) between November 2010 and June 2011. Sariska TR is situated in the Aravalli Hill Range in the semi-arid part of Western India [28]. The total area of the Tiger Reserve is 881 km^2, of which 273.8 km^2 is notified National Park. The vegetation of Sariska corresponds to Northern tropical dry deciduous and Northern tropical thorn forests [29]. Open areas are covered with scrub forests dominated by shrubs such as *Zizyphus nummularia, Capparis sepiaria*, *Capparis decidua*, *Adathoda vasica*, *Prosopis juliflora* and *Acacia sp.* The valleys are dominated by *Zizyphus mauritiana* mixed forest, gentle slopes are dominated by *Anogeissus pendula* forest and the steep slopes are occupied by *Boswellia serrata* forest. Other than golden jackal and striped hyena, the Park supports various carnivores and omnivores such as tiger, leopard, jungle cat (*Felis chaus*), common mongoose *(Herpestes edwardsii*), small Indian mongoose (*H. auropunctatus*), ruddy mongoose (*H. smithi*), common palm civet (*Paradoxurus hermaphroditus*), small Indian civet (*Viverricula indica*), ratel (*Mellivora capensis*) 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*)[30]. There are 32 villages within Sariska TR of which six are located in the intensive study area of 160 km^2. A large number of brahmini cattle (*Bos indicus*), buffaloes (*Bubalus bubalis*), goats (*Capra hircus*) and sheep (Ovis aries) are kept by people living in villages.

Scat Analysis: Estimation of food habits of golden jackal and striped hyena was done using scat analysis. Scats were collected on transects, trails and roads whenever encountered within the intensive study area. Each collected scat sample was labeled with the name of the species, date and location. The collected scats were sun dried and later broken down and washed under running water through a sieve. The scat contents were teased apart and remain of different food items such as hair, feather, scales of reptiles, invertebrate remains and vegetable matter (grass and fruit seeds) were separated. The frequency of occurrence of each food item was estimated through bootstrapping using program SIMSTAT [31]. This technique measures 95% confidence limits of the proportion of each food item in the diet, the limits of which range measure the random sampling errors [19]. Niche breadth of the two species was quantified using Levin's measure [26] to measure the uniformity of resources being utilized by each species. The overlap in diet of the two species was assessed using Pianka's [32] index.

RESULTS

Altogether 104 scats of golden jackal and 86 scats of striped hyena were collected and analyzed. Hair samples from scats were identified from their histological structure using microscope. In total 12 food items were identified in golden Jackal scats and nine in striped hyena scats. The frequency of occurrence and percentage frequency of occurrence of each food item found in golden jackal and striped hyena scats are given in table 1.