EXECUTIVE SUMMARY

Introduction
The research project titled “Status, Ecology and Conservation of Striped Hyena (Hyaena hyaena) in Gir National Park and Sanctuary, Gujarat, India” funded by Ministry of Environment and Forest (Government of India) was started in joint collaboration of Wildlife Society of India, Aligarh and Gujarat Forest Department in April 2006. I was selected as research fellow in this project and worked as junior research fellow from August 2006 to July 2008 and as senior research fellow from August 2008 to September 2009. Data generated from this research project was utilized to prepare this thesis. The overall goal of the study was to generate information on population status and ecology of striped hyena in Gir National Park and Sanctuary (GNPS) for the formulation of a suitable management strategy for long term conservation of the target species.

Although striped hyena is big carnivore, but we still know very few about the animal ecology, social organization, and behavior etc. Very few studies have been done, and only few study publications from Africa (Kruuk 1976; Leakey et.al, 1999), Israel (Macdonald, 1978; Bouskil, 1984; Ilani, 1975; Kerbis-Peterhans and Horwitz, 1992; Skinner and Ilani, 1979), India (Davidar, 1990), and in captivity by Rieger, 1978, 1979a, 1979b are available. However, most of data are based on anecdotal information and were brief and relatively informal. Only systematic study was conducted by Wagner (2006), on behavioral ecology of striped hyena in Laikipia District, Kenya.

The ecology of the striped hyena (Hyaena hyaena) is little understood and has only marginally been investigated. This study was originally designed, to fill the ‘gap’ in our understanding the ecology of this species.
Objectives of this study
1. To investigate the current status, distribution and abundance of striped hyena in different management units and habitats of Gir National Park and Sanctuary.
2. To investigate feeding ecology of striped hyena in Gir National Park and Sanctuary.
3. To investigate the habitat use of striped hyena in Gir National Park and Sanctuary.
4. To investigate the social organization and behavior of striped hyena in Gir National Park and Sanctuary.
5. To evaluate the habitat suitability model for striped hyena in Gir National Park and Sanctuary.

Methodology
Several sets of methodology were used to fulfill these objectives.

Population estimation
Photographic capture-recapture sampling technique was used for estimating abundance of striped hyenas. A grid of 2.5 x 2.5 km² overlaid on the GNPS, and 15 grids in four zones, east, central, national park, and west was selected systematically to cover all the habitat types and management units for the capture-recapture sampling. The program CAPTURE was used to analyze the capture and recaptured photograph data of striped hyena.

Density estimates were generated by dividing striped hyena number by the effectively sampled area, minimum convex polygon with buffer from Half Mean Maximum Distance Moved (HMMDM).

Food habits
Scat analysis method was used to determine the food habits of striped hyena in GNPS. The scats were collected randomly from October 2006 to June 2009.
Seasonal and annual variation was also observed. To find the striped hyena food habit in different management unit of GNPS, scats collected were separated in to three zones as West Gir, Central Gir and East Gir, analyzed and represented accordingly. Also, to find any difference in striped hyena diet between different zones, chi square test was performed. Biomass of prey ingested was calculated by estimating the weight of prey eaten per scat sample for each prey type.

**Habitat use**

Habitat use of striped hyena was examined by determining proportion of location on the basis of direct and indirect evidences (foot print, resting sites, dens and scats) of striped hyena from all over the GNPS. Data on habitat use of lion (*Panthera leo persica*) and leopard (*Panthera pardus*) were also collected and recorded same as described for striped hyena, to see the variation of habitat use between these three big carnivores of GNPS.

The analysis of vegetation was done in GNPS. The study area was divided into four zones on the basis of vegetation and management unit namely west zone, east zone, Central zone and NP zone. Vegetation sampling was carried out on three transects of 3 km length in each sampled zone, with total 12 transects (36 km) in all over the Gir. Sampling of vegetation was done in 10m radius circular plots at each transect at an interval of 100m, with a total 31 plots on each transect, 93 plots at each sampling zone and 372 plots in total from all the four sampled zone.

Seasonal habitat use was calculated and chi square test was computed to test seasonal variation in habitat use of striped hyena and variation in habitat use between lion, leopard, and hyena in GNPS. Habitat availability and utilization by striped hyena in GNPS was assessed following Neu et al., 1974. Data was also subjected to PCA using SPSS to observe the relation between striped hyena and habitat.
Denning and behavior

Dens and resting sites were selected for the sampling and data pertaining to vegetation characteristics and den parameters were collected. Standard vegetation sampling protocol was used to analyze the vegetation. Den opening parameter and slope of terrain and direction of opening or hill slope were also recorded. GPS location and elevation was recorded using GPS receiver. All the possible measurements of den and resting sites were taken for the analysis.

Active dens were monitored regularly at dawn and dusk from a hide from an appropriate distance, which varied from place to place depending on terrain (moderate hilly to steep slope) and vegetation, using binocular and spot scope avoiding disturbance to animals. Wherever possible, behavioral activities were documented using a camera (Canon EOS 350D).

Habitat suitability modelling using remote sensing and GIS

Application of remote sensing and Geographic Information System (GIS) as a tool has assumed immense significance in habitat suitability modelling for various wildlife species. Models are now widely used in conservation ecology and wildlife management. This study evaluated habitat suitability for striped hyena (*Hyaena hyaena*) in GNPS, India. The satellite imagery and topographic maps were used to generate spatial data of different variables *viz.*, forest type, forest density, measures of proximity to disturbances (road, railways and settlements) and water. Satellite data of Landsat-TM dated 15th May 2009, path-row: 149-45 and the digital elevation model (DEM) data of shuttle radar topographic machine (SRTM) was used for the modelling. Application of binomial multiple logistic regression (BMLR) is a statistical technique for predictive modelling. Binomial logistic regression is a form of regression which is used when the dependent variable is dichotomous and independent variables are continuous. For BMLR statistical analysis, statistical package for the Social Sciences (SPSS) has been widely used. The BMLR applies maximum likelihood estimation after transforming the dependent variable into a logit variable. A digital terrain model
was used to create slope, aspect, elevation and GPS location of animal’s presence were used in a “binomial multiple logistic regression” model in striped hyena habitat suitability analysis in GNPS. The overall classification accuracy was done to know the validity of the model. We also used receiver operating characteristic (ROC) for assessing the accuracy of the model.

Results

Population estimation
A total of 150 trap-nights of sampling effort was expended at each zone and with total of 600 trap-nights from all four zones over six months from December 2007 to May 2008, and as a result 34 usable striped hyena photographs were obtained with an average trapping effort of 17.6 trap-nights per hyena photograph.

The effectively sampled area of capture-recapture sampling was calculated for central as 132.37 km², for east 145.44 km², for NP 159.03 km², and for west 132.29 km². The estimated adult striped hyena density for central was 3.78 striped hyena/100 km², for east 11.69 /100 km², for NP 7.55/100 km², and for west was 2.27/100 km². The mean density of striped hyena for the GNPS was calculated as 6.50 striped hyena/100 km².

Food and feeding habits
Analysis of 699 striped hyena scats from GNPS showed that 12.92% scats were found to have single mammalian prey item, while only 0.43% scats were found with five prey items. The minimum number of mammalian hair to be examined per scat to detect all mammalian prey species in a particular striped hyena scat in GNPS with 95% certainty was found at 21 hairs. The ‘Observation area-curve’ shows that the all striped hyena prey species could be detected by analyzing 40 scats.

A variety of food items were identified in the diet of striped hyena in GNPS, including large mammals to small rodents, birds, insects and even fruits. Total 12
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mammalian prey species were detected. Chital was found to be the most common prey item in the diet of striped hyena. Seasonal variation in the diet was observed in the mammalian as well as non mammalian prey items. Significant differences were observed in diet composition in different zones of GNPS. On average 50.91% of total relative consumed biomass was contributed by the wild prey while livestock contribution was found as 49.08%.

Habitat use
Striped hyena was found around all the habitat type with preference of Mixed forest (40.46 ± 5.97 SE) and others as Moist mixed forest (8.09 ± 1.13 SE), Teak-Acacia-Zizyphus (30.64 ± 4.5 SE), Acacia-Tectona/Anogeissus (1.16 ± 0.06 SE), Acacia-Lannea-Boswellia (8.67 ± 1.22 SE), Acacia-Zizyphus ((8.67 ± 1.22 SE), Scrubland (1.73 ± 0.17 SE), and Open area (0.58 ± 00 SE) and no difference was observed in the seasonal habitat use pattern. Significant difference between two habitats that is Mixed forest and Acacia-Lannea-Boswellia in lion, leopard and striped hyena habitat utilization was observed in GNPS.

Mixed forest is most preferred habitat type by striped hyena in GNPS. Habitat types like Moist mixed forest, Tectona-Acacia-Zizyphus, Acacia-Lannea-Boswellia, Thorn forst, Scrub lands and open area were utilized in proportion to its availability, while Acacia-Tectona/Anogeissus, savanna and wetlands were avoided. Tree density was found as negative and grass was found as positive correlated with the striped hyena density in GNPS.

Denning and behavior
A total 28 dens and 30 resting sites at six locations were searched from different parts of GNPS. All were found in hilly terrain and most of them in middle of the hill slope and some of them on top of the hill. Out of 28 dens 23 dens were sandy and only 5 were rocky, while out of 30 resting sites 24 were sandy and only 6 dens were rocky.
The striped hyena uses three types of structures for the resting and pup rearing, resting sites, resting den and rendezvous site in GNPS. The mean litter size was found $3 \pm 0.24$ SE, ranges from 2-4 pups. The newly born pups were observed in winter from January – March (n=9) and age was estimated from body size. Striped hyena was found solitary at all the active times but clans (a group of hyena) was observed at den site. Mean number of individuals in clan was estimates with confidence interval as $3.74 \pm 0.05$. The largest clan was of 8 individual and smallest of 3 individuals in GNPS. Mother usually stayed with pups in the same den, seldom moves out of den but remains in close proximity when pups are very young (1-3 month), and mothers were observed resting at far place around 50m to 150m (n=5), in day time when pups became little old. The mean duration of lactation with 95% confidence interval was $12.94 \pm 1.09$ minutes that vary from 5-25. The striped hyena was found very calm animal that rarely uttered any sound.

Habitat suitability modelling using remote sensing and GIS
The geo-coded FCC of Landsat-TM was digitally analyzed. The forest cover and land use map (habitat map) of the study area was prepared through digital analysis of satellite data using supervised maximum likelihood classification technique. Normalized difference vegetation index (NDVI) was used for preparation of forest density map. The NDVI values were grouped into four canopy density classes viz., <10% (non-forest), 10–40% (open), 40–70% (medium) and >70% (dense). Image elements like tone, texture, shape, size, shadow, location and association were evaluated for this purpose. The coefficients derived from BMLR were used to integrate all layers to arrive at the probability/suitability maps. Suitability map was further categorized into four classes i.e., highly suitable, suitable, moderately suitable and least suitable.

For modelling environmental factors were used as independent variables and striped hyena evidence (direct/indirect) were considered as Boolean (dependent
and intersected). Results indicated that 1108.65 km$^2$ (78.51%) of GNPS area is highly suitable to suitable for striped hyena. The overall classification accuracy of 86.5 percent was observed which depict, that model is only 13.5 present away from the ideal. The model performance assessed by the area under the ROC curve was found 0.902 implying that the present model is an effective model. Habitat suitability modelling accurately predicted striped hyena habitat with respect to density in GNPS. The model output can easily be interpreted by experts and managers, having thereby a great practical importance and would serve as baseline for future management planning for the conservation of the species. We concluded that GNPS is appropriate to serve as important conservation area for striped hyena in India.