# A REPORT ON POPULATION AND DENSITY ESTIMATION OF LEOPARDS IN GIRNAR WILDLIFE SANCTUARY, GUJARAT, 2012





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# 1. INTRODUCTION

A major step towards conserving large carnivores should be to obtain reliable information on their basic ecology, such as population dynamics, feeding behaviour, and habitat preference. Crucial population estimates are the most fundamental parameters for ecological monitoring of a species, required as a benchmark for management decisions (Lebreton *et al.* 1992; Reid *et al.* 2002; Chauhan *et al.* 2005). Two major problems for sampling an animal population are: inability in surveying the entire of interest and inability in detection of all individuals even inside the surveyed area (Williams et al. 2002), resulting in our incapability to come up with the total count of a concerned population. Hence, we resolute to estimate population parameters by sampling a part of it.

The canonical estimator of population size is based on two functions: i) the number of unique individuals encountered over all sampling events, and ii) the probability of encountering an individual atleast once. For a single sampling event, it can be expressed as:

= C /

where, = estimate of total population size

C= number of unique individuals encountered

= probability that any individual will be encountered

Total counts or count statistics are incomplete estimates of unless is estimated. Total counts of most populations are a measure of C without estimating . In such cases two counts $C_1$ and $C_2$ are comparable only if is either constant or explicitly estimated. Therefore, most often $C_1$ and $C_2$ do not even serve as reliable indices of population abundance for estimating trends (O'Connell et al. 2011).

The basic assumptions of capture-recapture based methods are: (1) the population must be closed, i.e., the number of individuals in the population being sampled is constant over sampling interval, (2) animals should be correctly individually identifiable during the experiment, and (3) each animal should have some non zero probability of capture on each trapping occasion.

Various methods have been applied for estimating the population of large carnivores, like tigers, lions and leopards, in India. They have been: (a) the pugmark based census (Choudhary 1970, 1971, 1972; Panwar 1979; Sawarkar 1987; Sharma 2001); (b) mark-recapture using camera traps (Karanth 1995; Karanth & Nichols 1998, 2000; Jhala et al. 2010, Chauhan *et al.* 2005; Edgaonkar 2007, 2008; Sankar *et al.* 2008; Harihar *et al.* 2009;

Kalle *et al.* 2011and Mondal *et al.* 2012); (c) whisker patterns (Banerjee et al. 2011); and (d) Fecal DNA based microsatellites (Reddy et al. 2012; Borthakur et al. 2011).

Pugmarks were once the only means of population estimation in absence of other technologies. However individual identity based on pugmarks, especially when obtained from different substratum and different observers is unreliable. The subjective nature of the pugmark method and possibilities of imperfect detection have made this technique controversial (Karanth *et al.* 2003), as there is no way of estimating . Whereas, statistical methods for estimating are available e.g. Mark-recapture, Distance sampling (Williams et al. 2002).

Mark-recapture method has long been used to estimate biological populations (Otis *et al.* 1978). The use of camera traps has remarkably increased our ability to study elusive animals (Kays & Saluson 2008). They have the advantage of being non-intrusive and can be applied over considerably large areas with a relatively moderate effort (Silveira *et al.* 2003). Till date camera trapping has been used to study a wide range of aspects in wildlife ecology. It has helped us to acquire knowledge about species' presence (Linkie *et al.* 2007), behaviour (Harmsen *et al.* 2009), composition in assemblages (O'Brien *et al.* 2003) and abundance. Developments in capture-recapture theory (Otis *et al.* 1978; Pollock *et al.* 1990; Nichols 1992; White *et al.* 1996; Royle *et al.* 2009; Borchers and Efford 2008) have enabled us to use data obtained from camera trapping to estimate population status (Karanth 1995; Karanth &Nichols 1998, 2000) and dynamics (Karanth 2006; Gardner *et al.* 2010a) of species with individually identifiable coat patterns.

Because of low numbers (since they occur at the trophic apex, see Schaller 1967), poor detectability (due to their elusive nature) and movements over large areas, obtaining reliable information on population status and trends of big cats is problematic and often costly (Smallwood & Fitzhugh 1995). Amongst all large carnivores, the leopard (*Panthera pardus*) has the reputation of being the least studied despite being the most abundant (Hamilton 1976). Most studies on leopards have been done in Africa (Bailey 1993; Bertram 1982; Hamilton 1976; Jenny 1996). In India sparse information on leopards comes from studies that have actually focussed on the tiger (Karanth & Sunquist 1995, 2000; Sunquist 1981) or the lion (Chellam 1993). More recently some studies have been focussed exclusively on leopards (Chauhan *et al.* 2005; Edgaonkar 2008; Sankar *et al.* 2008; Harihar *et al.* 2009; Kalle *et al.* 2011and Mondal *et al.* 2012).

However, camera trapping of leopards holds a few constraints. Firstly, unlike the tiger or the lion, leopards are known to use all types of terrain, including steep slopes of hills.

Thus, accessibility to some locations for deploying camera traps may be problematic. Secondly, leopards are known to be camera shy. Once they experience the flash of light generated from cameras, they tend to change their routes consequently, thereby reducing the chances of their recapture (Jhala, Y. V. unpublished data).

**Figure 1: Photo-capture of leopard (*Panthera pardus*) during the study**

In this study we estimate the abundance of leopards in the recently declared Wildlife Sanctuary of Girnar, Gujarat. We use camera trap based mark –recapture to cover 139.47 $km^2$ of Girnar Wildlife Sanctuary between12$^{th}$ March to 7$^{th}$ May 2012 to estimate leopard density and population size.

# 2. STUDY AREA

The Girnar Hills lie between 21.25' and 21.35' North latitude and 70.30' and 70.40' East longitude. In an overview, the forest area looks like a circular disc of about 16 km. diameter. The area is bound on the east by the agrarian-pastoral revenue areas of Bhesan taluka and on the remaining three directions by the revenue areas of Junagadh taluka.

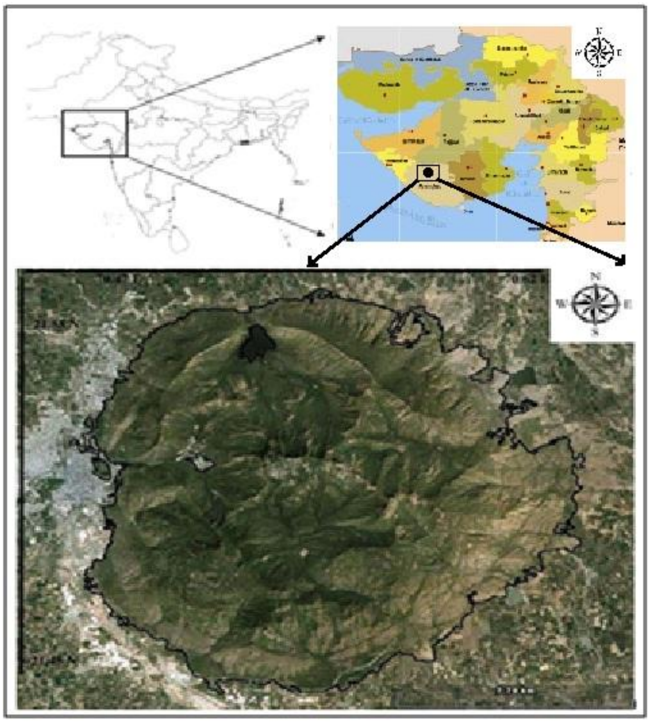

**Figure 2: Location and imagery of Girnar Wildlife Sanctuary**

Previously designated as a reserve forest, the area was declared as the Girnar Wildlife Sanctuary in May 2008, with a forested habitat of about 180 $km^2$. There is very little flat or undulating area in the Girnar forests. The Ground is extremely hilly and rugged with moderate to very steep slopes, the maximum elevation being 1,117.4 meters. The terrain could be roughly classified as: hill top, steep slope, gentle to moderate slope, flat plain, river bed and reservoir bed.

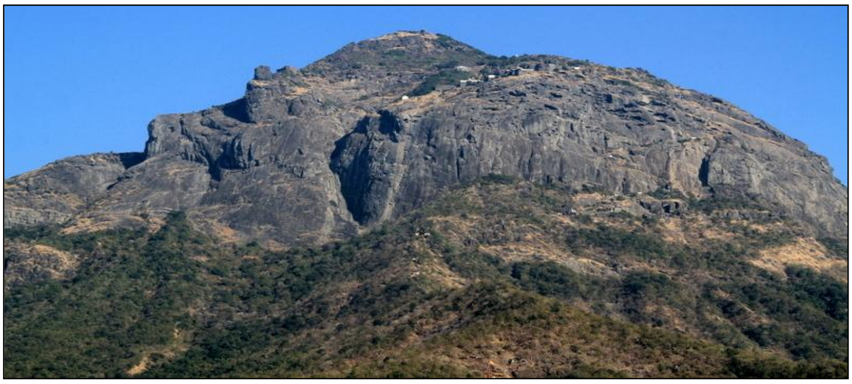

**Figure 3: Mount Girnar**

Its unique position and physiographic features has made Girnar Wildlife Sanctuary rich in biodiversity. Apart from the flagship species Asiatic lion (*Panthera leo persica*), the Girnar forest harbours 37 other mammalian species and 38 species of herpetofauna. Girnar is a bird watcher's paradise as the sanctuary has more than 300 species of birds and acts as a breeding ground for many migratory birds.

Girnar Wildlife Sanctuary belongs to the Afro-tropical (palaeotropical) zoo-geographic realm. As per Rodgers and Panwar (WII) Classification, the sanctuary is classified under 4-B Gujarat-Rajputana Biotic Province in the semi-arid bio-geographic zone of the country and designated as Type VII-A/C-I 'Southern Tropical Dry deciduous-dry Teak forests' of Champion and Seth (1968) classification. These Forests can further be classified into: teak forests (Type 1), miscellaneous forests (Type 2); and scrub forests (Type 3). The area is rich in floral diversity. As many as 537 plant species have been recorded in Girnar forests by Shri R. J. Asari, (IFS) in his floristic study of Girnar forest (1990).

Climate of the area is generally dry. The temperature range varies greatly. The mean variation in temperature is high and the maximum temperature is $41^{O}$ C and minimum $7^{O}$ C, the hottest month being May-June and coldest being Dec-Jan. Monsoon generally sets in by the end of June and continues up to middle of September, with maximum precipitation in July and August.

Girnar Wildlife Sanctuary is a pilgrimage hub for many religions (Hinduism, Jainism, Buddhism and Islam). This leads to an influx of devotees throughout the year. During two major events, "Parikrama" and "Mahashivratri" fairs, >10 hundred thousand pilgrims visit this area along a 36 km long route through the wildlife sanctuary.

**Figure 4: The flagship species of Girnar, Asiatic Lion (*Panthera leo persica*)**

# 3. METHODOLOGY

## 3.1 Field methods

Photographic capture-recapture analysis (Karanth 1995; Karanth and Nichols 1998) was used to estimate the abundance of leopards in Girnar Wildlife Sanctuary. Sampling grids of 2.235×2.235 km$^2$ dimensions were overlaid on the study area using ArcMAP v9.3, and were realized on ground using a handheld GPS unit (GARMIN GPS 72). To intensify sampling, the study area was divided into the northern (21°33'51.8'' to 21°31'25.6'') and southern (21°31'25.6'' to 21°26'34.1'') blocks. Camera trapping was carried out for 26 days in each block, with a total effort of 884 trap nights (442 trap nights in each block). Each day was considered as one occasion.

To increase the photographic rate (i.e., capture probability) of leopards, camera trap locations were chosen based on reconnaissance of the area (Karanth 1995) and a minimum of one camera pair was installed at the best potential site within each grid to have a systematic camera coverage over the entire study area.

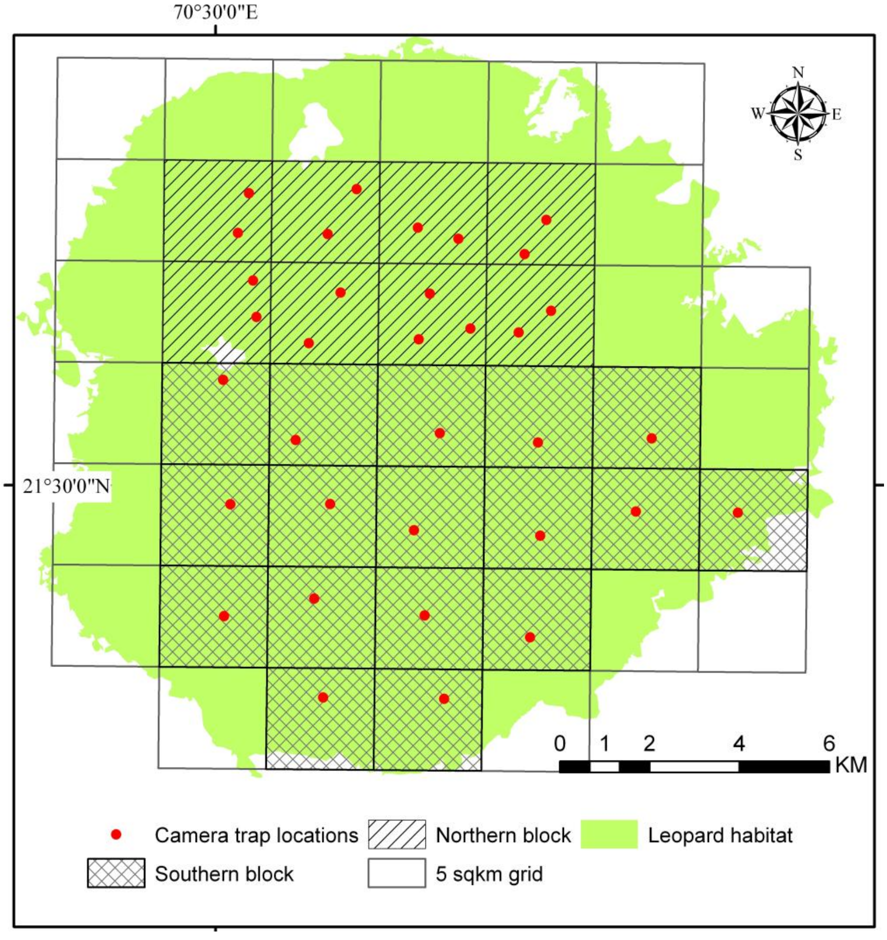


**Figure 5: Sampling design: grids, blocks and camera trap locations in the study area**

The camera locations covered the entire area without leaving any sampling holes to minimize the chance of missing out individual leopards, thereby giving every individual leopard some probability of being capture.

We used MOULTRIE D40 Game Cameras that have passive motion detectors. The cameras were attached to trees or supported by rocks at knee height at an average distance of 6 m from the centre of the trail, perpendicular to the expected direction of animal movement. Cameras were also camouflaged to prevent their detection and avoidance/damage by animals and humans.

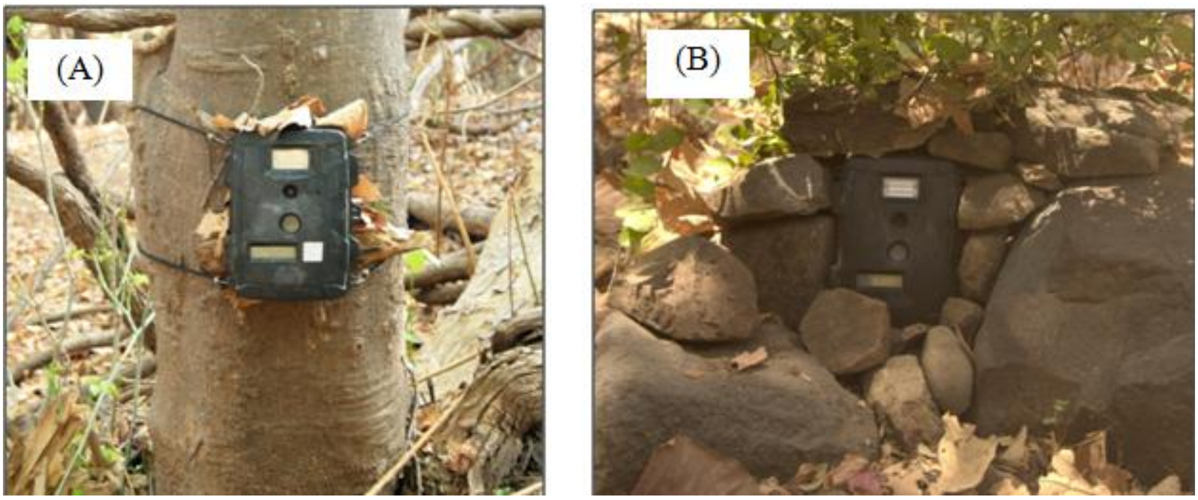


**Figure 6: Cameras attached on (A) tree trunk and (B) supported by rocks and stones**.

Each location had a setup of two cameras, placed opposite to each other, with an objective to obtain captures of both the flanks of an individual leopard. Each camera unit was given a unique identification number and the date and time of every photograph were programmed to be recorded. Cameras were checked at an interval of about three days to ensure their proper functioning. Leopards are considered to be camera shy and are known to change their routes after experiencing camera flash (Jhala, Y. V. unpublished data.). To circumvent this problem, camera trap locations were kept dynamic by regularly shifting them within a radius of 50-80 m from the original locations.

### 3.2 Analytical methods

On some occasions we failed to get pictures of both flanks of an animal. This resulted in many single flank captures. First leopards with both flank pictures were identified. Then from the remaining single flank captures, the flank that yielded more numbers of unique individuals was used for further estimation. The flank of each leopard photographed was compared to every other leopard photograph obtained (of the same flank). Each leopard was identified with the rosette patterns on its flanks, limbs and forequarters. When match in a pattern was found between two photographs, the identity was confirmed after verifying the rosette patterns of different parts. Pattern recognition software Wild-ID ver 1.0 (Bolger et al. 2011) was also used to confirm identification. Each individual leopard identified was assigned with a unique identification code (e.g., L1, L2, L3, L4…).

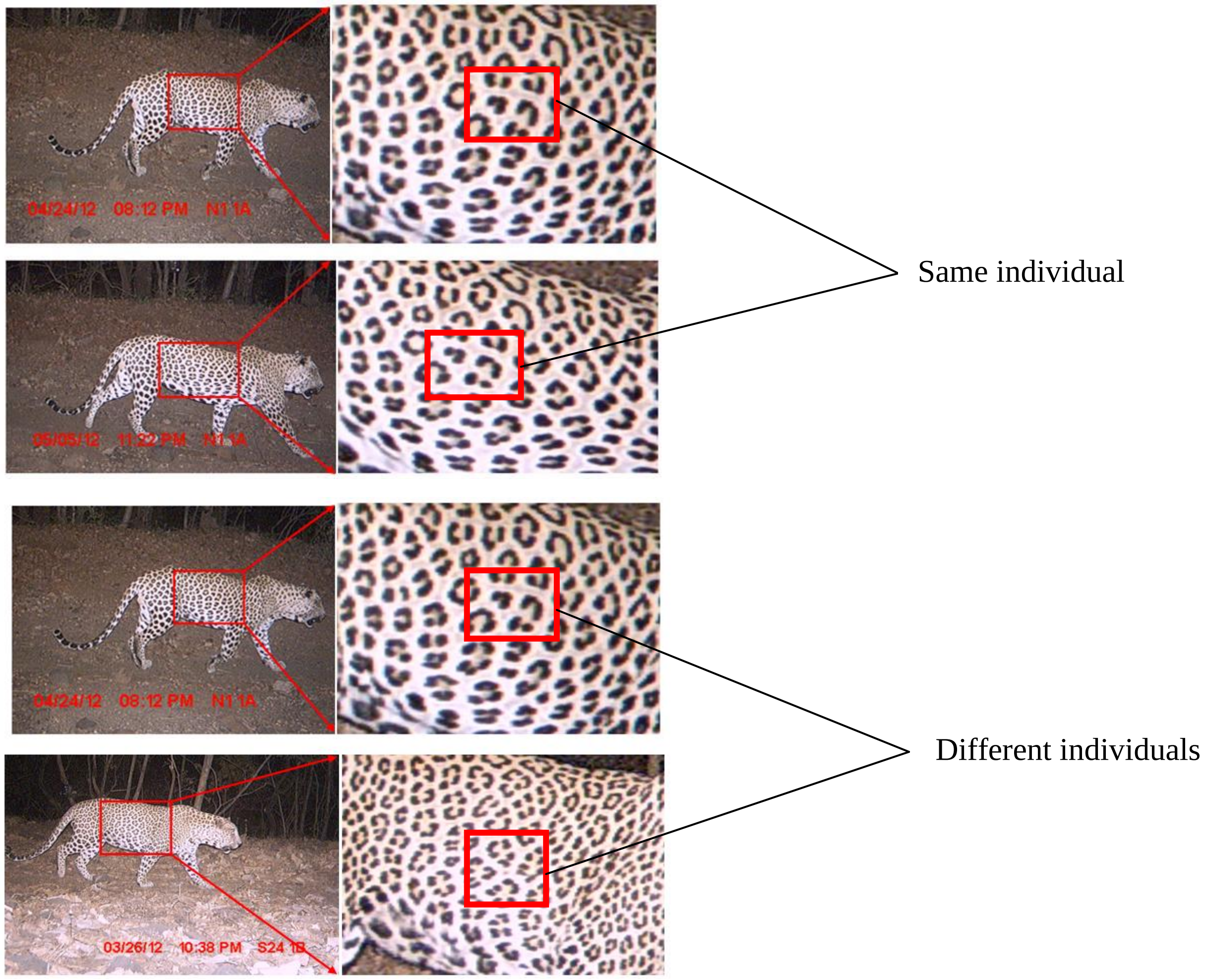


**Figure 7: Leopard identification by comparing rosette coat patterns**

### 3.2.1 Estimation of Population Size

Once all the leopard pictures were identified to unique individuals, capture histories were developed for each individual leopard using each day as a sampling occasion. For an animal, L1, the capture history was formed of a row vector of 26 entries, representing the number of sampling occasions (here 26 days). Each entry, denoted by $X_{ij}$ , for an individual $i$ on occasion $j$ , acquired a value of "1" if the animal got photographed on that occasion, or "0" if the animal was not photographed on that occasion. This matrix, composed of several 1s and 0s, is referred to as $X$ matrix (Otis et al. 1978) was used to estimate population size.

Closed population capture-recapture framework has been used to estimate the population parameters of leopards in this study (Pollock et al. 1990).

Recent probabilistic capture-recapture estimators can model biologically important factors like capture probabilities ( ) being heterogeneous among individual animals in a single population. Current capture-recapture models also permit incorporation of other biologically relevant factors, such as behavioural response to trapping or temporal variation in trapping probabilities. These models for closed population can be summarized as: null ($M_o$), individual heterogeneity ($M_h$), behavioural heterogeneity ($M_b$) and time ($M_t$) (Otis et al. 1978).

The null model, $M_0$ is the simplest of all models with the assumption that all members of the population have an equal chance of capture on every trapping occasion. The occasions themselves do not affect capture probabilities. The individual heterogeneity model, $M_h$ works under the assumption that that there is no difference between trapping occasions and no behavioural response to capture, but there remains a heterogeneity among the capture probabilities of individuals. The behavioural heterogeneity model, $M_b$ takes into account the assumption that capture probability varies after the initial capture. Thus, the model takes into account the consideration of an animal to exhibit a behavioural response to capture and become either “trap happy” or “trap shy”. The time model, $M_t$ assumes that all individuals of a population have an equal chance of capture on any single trapping occasion, but the probability can change from one occasion to the next. Other models, namely $M_{tb}$, $M_{bh}$, $M_{th}$, $M_{tbh}$, work under the assumption that variation in capture probability is explained by a combination of the above sources of variation. To test the suitability of models for analysis (from the above described models), goodness-of-fit test was done using program CAPTURE available in the MARK 6.1 package. Program CAPTURE uses a series of discriminant function analysis to select between sets of models. It then returns different models on a scale of 0 to 1 where models rated near 1 fit the data better. The resultant best fit model was then used to estimate the population parameters in this study. The selected model when used with the above mentioned *X* matrix, in program CAPTURE estimated the abundance of leopards in the study area.

### 3.2.2 Estimation of population density of leopards

The density of leopard population was estimated by two methods: by Effective Trapping Area (ETA) estimated by adding a buffer strip of half mean maximum distance moved by recaptured leopards and the Spatially Explicit Maximum Likelihood (ML SECR) method.

Population density may be defined as / , where denotes the number of individuals in the area and the effective area (ETA) where the sampling was carried out (Karanth & Nichols 1998,2002). This area is actually the summation of the area encompassed by the trapping grid and a strip of buffer around it (Dice 1938). Program DENSITY 4.4 was used to generate a convex buffer around the actual trapping area, also known as Minimum Convex Polygon or MCP. This Boundary Width or the buffer width is estimated using half of the mean maximum distance moved (half- MMDM) by recaptured leopards (Parmenter et al. 2003). The MMDM is estimated by the mean of the maximum distance between two capture locations of each individual leopard for all leopards that got photographed in more than one camera trap location. Thus the buffer generated added to MCP gives the ETA or the effective trapping area. Non leopard habitat like water bodies, human habitation etc. were removed from the ETA using ArcGIS package (ESRI ArcMap 9.3). This operation to estimate the density only in suitable habitat patches is known as habitat masking.

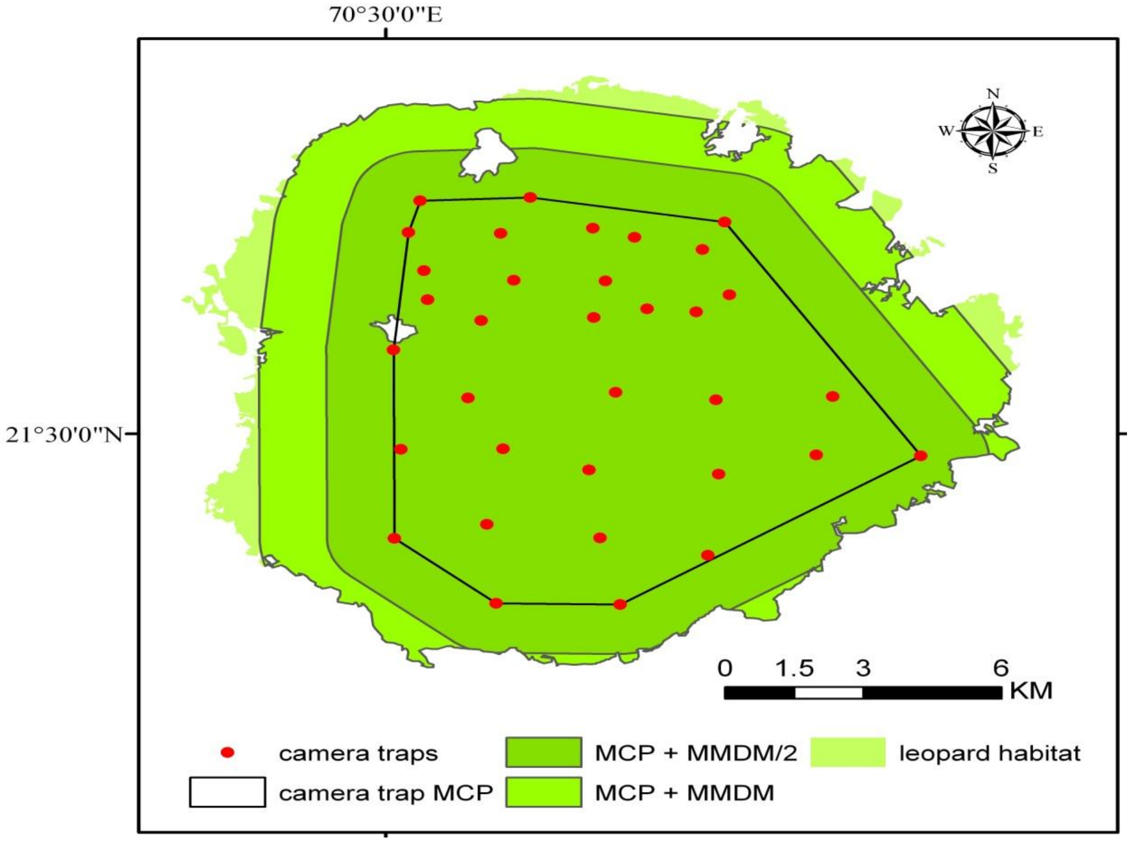


**Figure 8: Camera trap locations and the effective trapping area for estimating leopard density.**

### 3.2.3 Spatially explicit capture-recapture method

In this method density can be directly estimated from trapping data resulting from a simulation of the trapping process. The need for a buffer around the trapping area is not required in this method as the density is estimated in a spatially explicit framework. The distribution of individuals is modelled by a homogeneous Poisson process. It provides room for using three different detection functions, namely: half normal, hazard rate and negative exponential (Borchers and Efford 2008). As in conventional capture-recapture, incorporation of sources of heterogeneity ($M_h$, $M_t$, and $M_b$) is also possible in this method. In analysis of this study Poisson distribution was assumed, and proximity trap option was chosen which allowed for multiple captures on the same occasion. The behavioural heterogeneity model ($M_b$) that proved to be best fit in the goodness-of-fit test in program CAPTURE, was used in the run. The detection function (half normal, hazard rate or negative exponential) was selected based on the lowest Akaike Information Criterion ($AIC_c$) value, and fitted to the distance between the home range centre and the trap. Hence, the density of leopard population was estimated using Program DENSITY 4.4 (Efford et al. 2009).

# 4. RESULTS

A total number of 222 pictures of leopards were obtained during the study period. A total of 26 individual leopards were identified.

### 4.1 Adequacy of sampling

Camera trapping was carried out in an area of 87.6 $km^2$ (MCP). The cumulative number of individual leopards photographed plotted against sampling occasions to check the adequacy of sampling showed that capture of new individual plateaued after 18 days of sampling, while rate of obtaining leopard photographs remained constant across the study period ($R^2$=0.96, P<0.01) (fig 9).

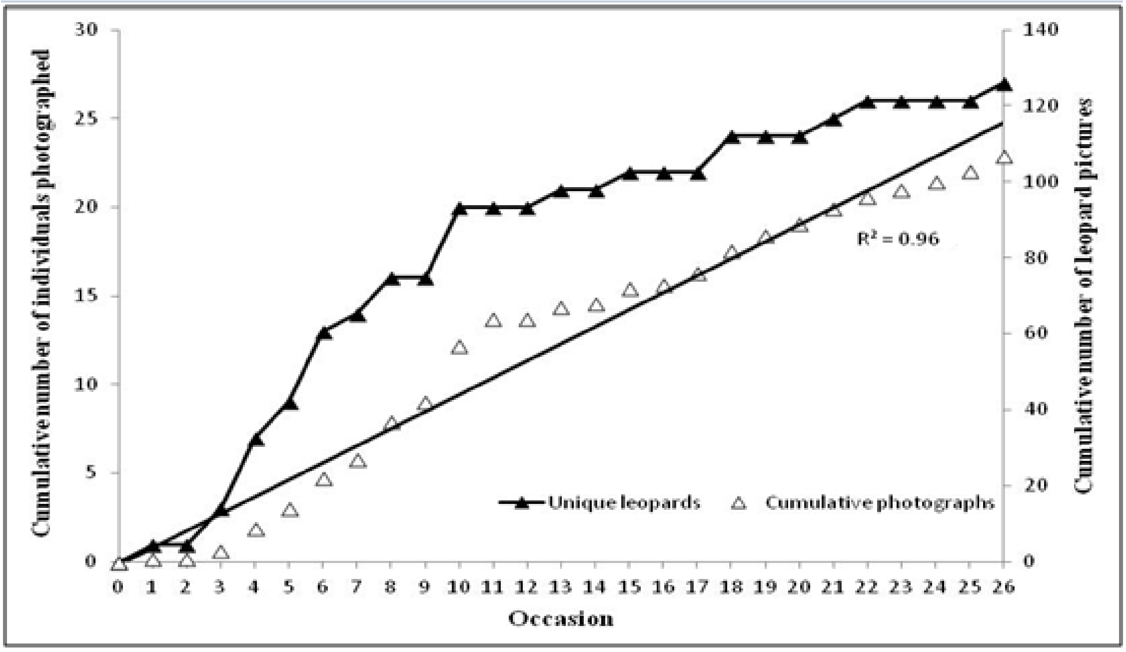


**Figure 9: Rate of accumulation of new individuals and rate of photographic captures of leopards in camera-trap photographs with increase in the sampling occasion.**

### 4.2 POPULATION ESTIMATION

#### 4.2.1 Population estimation from Effective Trapping Area method

Model selection criterion was highest for the behavioural heterogeneity model ($M_b$, table 1). This model estimated leopard capture probability ( ) at $0.086_{Mean}\pm0.03_{SE}$, recapture probability ( ) at $0.14_{Mean}\pm0.02_{SE}$, and abundance at ( ) at $28_{Mean}\pm2.89_{SE}$ adult individuals. The mean maximum distance moved by leopards between successive recaptures (MMDM) was estimated at $2867.5_{Mean}\pm397_{SE}$ metres. Removing unsuitable habitat areas within and outside the Sanctuary, the effective trapping area was estimated at $139.47_{Mean}\pm19.31_{SE}$ $km^2$ using MMDM/2 buffer width. The population abundance ( ) obtained from program

CAPTURE was used to estimate density of leopards using the afore-computed effective trapping area (table 2).

**Table 1: Results of model selection test in Program CAPTURE**

| Model | $M_0$ | $M_h$ | $M_b$ | $M_{bh}$ | $M_t$ | $M_{th}$ | $M_{tb}$ | $M_{tbh}$ |
|---|---|---|---|---|---|---|---|---|
| **Selection value** | 0.87 | 0.87 | **1.00** | 0.49 | 0.00 | 0.33 | 0.85 | 0.86 |

**Table 2: Population and density estimates of leopards in Girnar Wildlife Sanctuary, Gujarat in 2012**

| Parameters | Values |
|---|---|
| **Trapnights** | 26 |
| **$M_{t+1}$** | 26 |
| | $28_{Mean} \pm 2.89_{SE}$ |
| **Effective Trapping area (km²)** | $139.47_{Mean} \pm 19.31_{SE}$ |
| | $0.086_{Mean} \pm 0.03_{SE}$ |
| **Density (# 100 km$^{-2}$)** | $20.08_{Mean} \pm 3.46_{SE}$ |
| **MMDM/2 (**meters) | $1433.75_{Mean} \pm 198.5_{SE}$ |
| **Density MLSECR** | $17.17_{Mean} \pm 3.48_{SE}$ |

**$M_{t+1}$:** Total number of leopards photo captured

Population abundance

**MMDM:** Mean Maximum Distance Moved by recaptured leopards

**MLSECR:** Maximum Likelihood based Spatially Explicit Capture Recapture

### 4.2.2 Population estimation from spatially explicit capture recapture technique

The maximum likelihood spatially explicit capture recapture density was estimated using $M_b$ Zippin estimator (see table 1) and Hazard rate detection function (see table 3). Density was estimated at $17.17_{Mean} \pm 3.48_{SE}$ leopards / 100 km$^2$.

**Table 3: Detection functions of leopard ranked by Information Theoretic approach**

| Function | Log likelihood | AIC | $AIC_c$ | $\Delta AIC_c$ |
|---|---|---|---|---|
| Hazard rate | -540.17 | 1088.33 | 1090.24 | 0 |
| Negative exponential | -545.17 | 1096.35 | 1097.44 | 7.20 |
| Half Normal | -551.96 | 1109.9 | 1111 | 20.76 |

The MLSECR density ($17.17_{Mean} \pm 3.48_{SE}$) when extrapolated to suitable leopard habitat in and around the Sanctuary area of 189.62 $km^2$, yielded a total population of $33_{Mean} \pm 7_{SE}$ individual leopards.

**Table 4: Photo captures of some other animals**

| Animal | Number of photo captures |
|---|---|
| Lion (*Panthera leo persica*) | 79 |
| Ratel (*Mellivora capensis*) | 22 |
| Small Indian civet (*Viverricula indica*) | 23 |
| Jungle cat (*Felis chaus*) | 1 |
| Rusty spotted cat (*Prionailurus rubiginosus*) | 2 |
| Sambar (*Rusa unicolor*) | 475 |
| Cheetal (*Axis axis*) | 101 |
| Nilgai (*Boselaphus tragocamelus*) | 27 |
| Wild pig (*Sus scrofa*) | 52 |

# 5. DISCUSSION

To check the adequacy of this study the graph plotted for the cumulative number of individual leopards photo-captured against the occasions (see section 4.1), depicted an asymptote after 18 days of sampling. Hence, trapping effort >18 occasions is recommended for subsequent studies. The present study revealed an abundance of $28_{Mean} \pm 2.89_{SE}$ individual adult leopards in $139.47_{Mean} \pm 19.31_{SE}$ $km^2$ (ETA) of the Girnar Wildlife Sanctuary. While the total population in the Wildlife Sanctuary was estimated at $33_{Mean} \pm 7_{SE}$ individual leopards, we therefore photo-captured almost 80% of the entire population during the study.

Since spatially explicit models are computationally and biologically more robust than the traditionally used MMDM/2 approach, we use MLSECR density for further analysis and as a baseline. The traditioan computation is provided as a comparison to earlier studies done before the advent of spatially explicit methods. Comparison with other studies reveals a very high density of leopard population in Girnar Wildlife Sanctuary, Gujarat.

**Table 8: Densities of leopards in different landscapes of India.**

| Study site | MMDM/2 Density (#/100 $km^2$) | Author |
|---|---|---|
| Girnar | $20.08_{Mean} \pm 3.46_{SE}$ | This study. 2012 |
| Sariska TR, Rajasthan | 10.7 ± 1.8 | Mondal et al. 2007 |
| Satpura TR, Madhya Pradesh | 7 ± 2.1 – 10 ± 5.1 | Edgaonkar 2007 |
| Sariska TR, Rajasthan | 7 ± 0.2 | Sankar et al. 2008 |
| Rajaji NP, Uttarakhand | 14.99 ± 6.9 | Harihar et al. 2009 |
| Sariska TR, Rajasthan | 3.1 ± 0.4 | Mondal et al. 2010 |
| Mudumalai TR, Tamil Nadu | 28.91 ± 7.22 | Kalle et al. 2011 |

As far as the spatial use of leopards with the other apex predator of the region is concerned, both leopard and lion captures were found in 44% of the grids sampled, only leopard captures were found in 40% of the grids sampled and only lion captures were found in 4% of the grids sampled.

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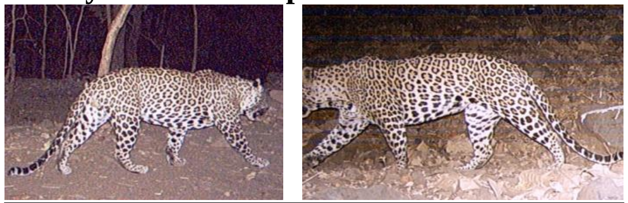
# APPENDIX 1

**Photographs of 26 individually identified leopards in Girnar Wildlife Sanctuary during 2012**

L1



L2

L4

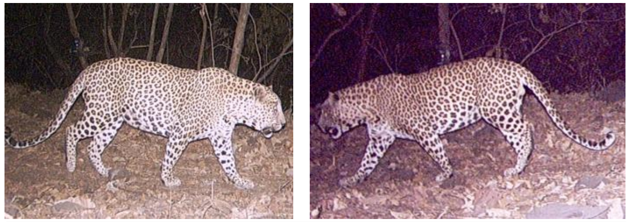
L3

L5

L6

L10

L7



L8

L9

L11

L12

L13

L14

**Contd…**

L15

L16

L17

L18

L19

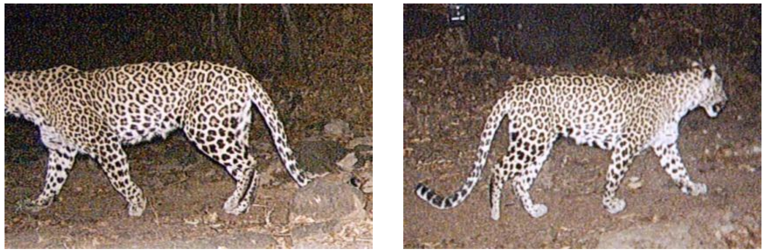
L20

L21


L22

L23

L24



L25

L26

## APPENDIX 2

**Some other species captured in camera traps**

Asiatic lion (*Panthera leo persica*)

Ratel (*Mellivora capensis*)

Small Indian civet (*Viverricula indica*)

Jungle cat (*Felis chaus*)

Rusty spotted cat (*Prionailurus rubiginosus*)

Wild pig (*Sus scrofa*)

Cheetal (*Axis axis*)

Nilgai (*Boselaphus tragocamelus*)

Sambar (*Rusa unicolor*)