

# Ecology of Leopard (*Panthera pardus fusca* Meyer) in Dry Tropical Forests of Gir National Park and Sanctuary, Gujarat, India

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## ABSTRACT

We studied ecology of leopard (*Panthera pardus fusca*) in dry tropical forests of GNPS, Gujarat, India from 2009 to 2012. We used direct counts of leopard, direct homing of collared individuals, road transect counts, detection and monitoring of kills for assessing leopard abundance, habitat use, home range size, prey availability and utilization in the intensive study area (ISA) of ca. 200 km<sup>2</sup>. The mean leopard sighting produced to be  $0.65 \pm 0.197$  (95% LL 0.249698 – UL 1.050302) per site (2x2 km). Ninety percent certainty produced upper limit of finding one leopard per site satisfactory. Among the available wild prey species, chital was abundant Nd (Ni) = 2388 (12050) followed by langur 334 (3968) and peafowl 1858 (3788). Age-wise, detection rate was high for chital of adult age, whereas chital fawn and sub-adults were detected with almost similar rates (2.11 and 2.06 km<sup>-1</sup>). Sambar of sub-adult age, yearlings and fawn were detected with slightly decreasing rates (0.13, 0.11 and 0.10 km<sup>-1</sup>). Detection rates of nilgai and wild pig were found almost similar. Large MGS found for chital adults ( $3.12 \pm 0.03$ ). A total of 328 leopard kills were searched and monitored which were comprising chital (ca. 78.53%) of adult age to maxima. However sambar (ca. 2.09%), nilgai (ca. 1.05%), wild pig ca. 0.52%), peafowl ca. 8.38%) and langur (ca. 7.85%) were also found. The sex ratio of leopard kills was 1 male:1.58 females. The overall kill rate was 3.7 days/kill. Leopards killed chital and langur in proportions to their availabilities. The lion *Panthera leo persica* overtook ca. 41% of leopard kills in the study area. The overall mean home range size of male leopard was estimated to be ca. 28.15 km<sup>2</sup> with significant random point patterns. The activity pattern of the leopard was crepuscular diurnal as well as nocturnal. Among available habitats, Teak Mixed Forest (TMF) was intensively used by leopards from direct sightings while Riverine Forest (RF) was used for kill protection purpose. Leopards also used TMF and RF extensively while resting close to water sources.

Key Words: Feeding Ecology; GNPS; Home Range; Leopard Population Size; Radio Collaring; Habitat Use.

## INTRODUCTION

The leopard (*Panthera pardus fusca* Meyer) exists as a major co-predator in Indian protected areas and due to its ability to adapt, it survives in a variety of habitats in India including sub optimal and degraded habitats outside the protected areas. Although there has been a general decline in its number in India throughout its distribution range, the increase in population size locally has led to a significant increase in cases of leopard-human conflict in some Indian states (Maharashtra, Uttarakhand, Jammu and Kashmir etc.). Despite being

more widely distributed and co-existing as major co-predator playing a key role in ecosystem functioning, the leopard has not been studied in detail in the wild, unlike Tiger (*Panthera tigris* Linnaeus) and lion (*Panthera leo persica* Linnaeus) which have been studied in detail over the past several decades (Schaller 1967, Joslin 1973, Ravi Chellam 1993 and Karanth and Sunquist 1995). The leopard co-exists with lion in dry tropical forests of Gir National Park and Sanctuary (henceforth GNPS) in fairly good numbers. However, its co-existence with the lion was poorly understood in the absence of a detailed ecological study. Around 2000, the occurrence of leopard

outside GNPS in a mosaic of human habitations and agro-ecosystems was first documented and the number of such cases rose on a yearly basis and leopard-human conflict became a widespread phenomenon especially on the southern periphery of the GNPS by 2005-06. It was hypothesized that the leopard moved out of Gir due to serious competition with lion for food and space. It was however not clear that whether lion and leopard actually competed for any ecological resource in GNPS. The present study was carried out with the overall goal to document the ecology of leopard in GNPS, understand how leopard co-existed with lion and to document its ecological role in tropical forest ecosystems of GNPS. The study was conducted from 2009 to 2012.

## STUDY AREA

The GNPS is located at 21° 55' to 21° 20' N latitude and 70° 25' to 71° 15' E longitude and it covers an area of 1412.13 km<sup>2</sup> in the Saurashtra region of Gujarat, India. Khan et al. (1996) described GNPS in detail and the prevailing ecological conditions are much similar to what was reported by Khan et al. (1996). Figure 1 provides the location of the intensive study area (ISA) of approximately 200 km<sup>2</sup>, located in the western part of the GNPS.

## MATERIALS AND METHODS

### Data Collection

The ISA was searched intensively and all riverbeds, animal trails and roads were monitored at dawn and dusk to collect information on occurrence of leopard. Five months were spent in observing areas of high and low use by leopard through sampling of direct and indirect evidences (e.g. scats, kills, scraps, spoor etc.) in order to minimize time in capturing of leopard and path selection for sampling of direct evidences of leopard. Information about leopard movement was also collected from Maldharis (local livestock herders) who resides in the study area and lion trackers who search and locate lions on a daily basis. The selected paths were monitored systematically on seasonal account for direct count of leopard following Gese (2001). All sightings of leopards were described by location coordinates recorded with a hand held Magellan GPS. The assumptions of the direct count and the estimators used to determine population size were carefully followed for whole sampling period.

The monitorings were carried out in the morning and evening hours when leopards were most active.

Forty-two grids of 2×2 km were overlaid on thematic map of ISA and all leopard sightings were plotted to assess the overall distribution and population size of leopard. Data samples were employed to construct a matrix for each season separately in the form of presence-absence (sequence of 1's and 0's = presence and absence) in a particular grid where each grid was considered as an independent site as described in Zehra et al. (2016b). The overall distribution was analysed using the Poisson distribution which produces mean number of sightings and its probability. A total of 136 sightings of leopard were used out of which 70 sightings were registered in the summer and 66 sightings in the winter season. The distribution and occupancy of leopards were monitored 16 times for each site.

Road vehicle count method was used to estimate densities of major prey species such as chital *Axis axis* Erxleben, sambar *Rusa unicolor* Kerr, nilgai *Boselaphus tragocamelus* Pallas, chinkara *Gazella bennetti* Sykes, wild pig *Sus scrofa* Linnaeus, langur *Presbytes entellus* Pocock, peafowl *Pavo cristatus* Linnaeus, black naped hare *Lepus nigricollis* F. Curler considering open habitat conditions and availability of good road network inside the ISA following Khan et al. (1996). The detail of census has been provided in Zahra et al. (2016). Data on group size, species, sex-age categories and distance in metre were recorded for each sighting of the animal following Khan et al. (1996).

The home range was estimated using radio-telemetry, which involved leopards trapping, handling and collaring. Leopards were live-trapped using iron cages with manually drop-door mechanism. A domestic goat was used as bait throughout the trapping operation except one-night effort where the fresh carcass of one sub-adult female nilgai was used as a bait. The trapping operation was held out by deploying 7 cages per night for five days. Two leopards were trapped and radio-collared at Pilipat and Valadara site within ISA in GNPS. Both captured leopards were immobilized using drug dose i.e. Ketamine Hydrochloride and Xylazine in a ratio of 3 mg kg<sup>-1</sup> + 1 mg kg<sup>-1</sup> inside the cage with free hand darting by a blowpipe. Tranquillized leopards were examined for general body condition. Age of the captured leopards was assessed based on their weight, tooth wear, gum recession, wear on the pads, pelage, scarring and body size. During the examination both leopards were also marked with electronic identification chip (EIC) for records. Both leopards were fitted with a standard VHF radio collar (Telonics Inc., USA) with life

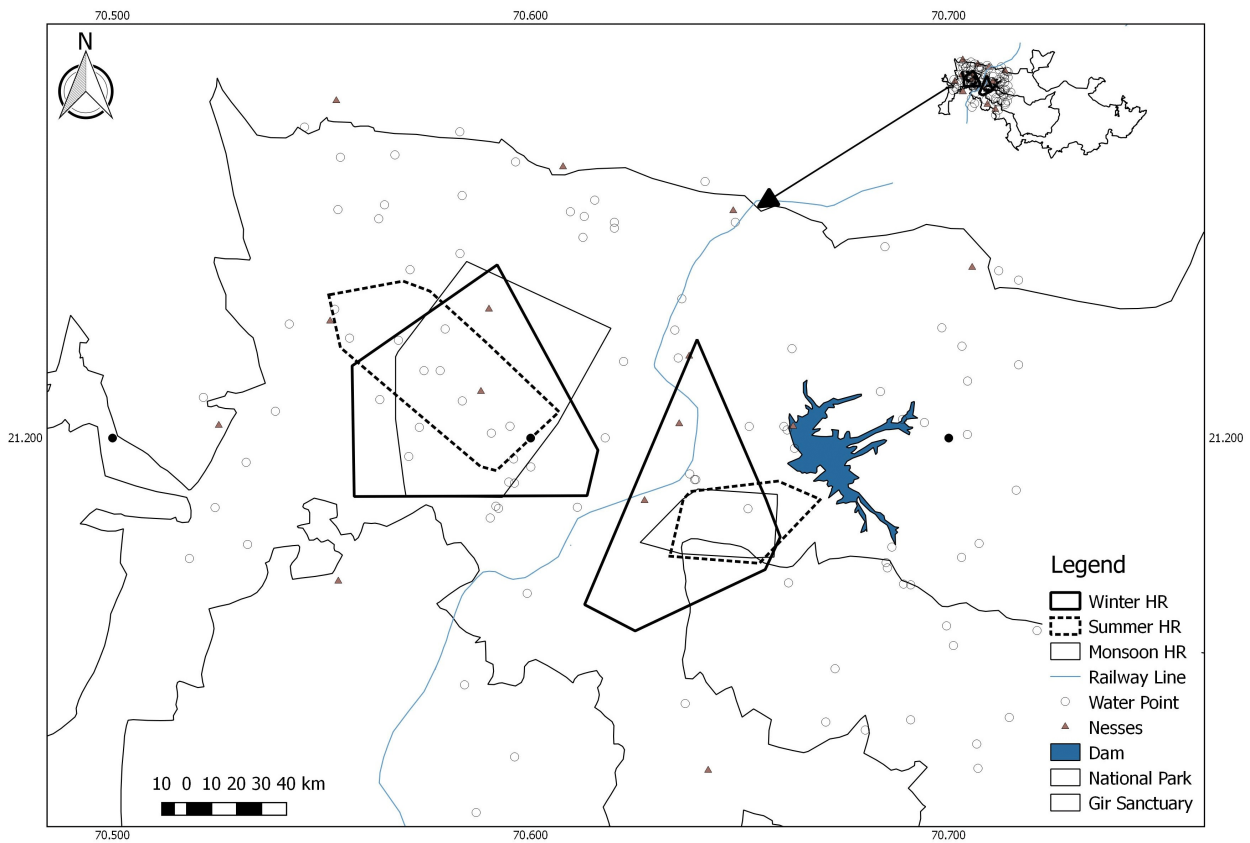


Figure 1. Location of intensive study area (ISA) in Gir National Park and Sanctuary and home ranges of M1 and M2 RC leopards.

expectancy of 36 months. The collar weight was <1% of the body weight of the leopards (Marker and Dickman 2005). Yohimbine was given ( $1 \text{ mL kg}^{-1}$ ) for revival of each leopard, which revived them within 8-10 minutes. Collared leopards were kept under observations till they became normal and were released later. Radio-collared leopards (henceforth M1 and M2 leopards) were monitored on daily basis and their precise locations were pinpointed through crosscheck using Telonics TR-4 receiver and a hand held rubber ducky "H" directional antenna from two or more situations. The smooth signal frequencies were followed consistently to reach the exact location of the radio-collared (RC) leopard. RC leopards were within <50 m distance when signal beeps were very strong or cable cached signals without an antenna. In such situations, the area was searched carefully and silently for locating the RC leopard. All locations were obtained primarily by homing in and actually locating the RC leopards. Once the location of the RC leopard was confirmed a hand held GPS unit was used to record location coordinates. For assessing activity pattern, both RC leopards were monitored for 12 hours duration for 10-12 days in each season. The activity was recorded as

either non-active or active along with each GPS coordinates. When RC leopards were observed directly for long durations, it was found that the actual activity corresponded well with data on the activity generated through telemetry.

Monitoring of RC leopards was relatively helpful in searching of kills to track predation pattern. Sites with location of RC leopards were searched thoroughly with field assistants to locate prey kills. Smell of decaying meat, insect activity, tracks of leopard, signs of struggle, blood on the ground, drag marks and prey alarm calls significantly increased probability of locating kills of Non-collared (NC) leopards. Data on sex and age class (adult, sub-adult, yearling and fawn), body weight, physical condition of killed animals were recorded for each detected kill. Tracks, scrap marks, teeth marks, nature of killing and prey size were considered to identify the predator in case the kill was located without predator. In case of RC leopards, consecutive diurnal presence of a cluster was considered to represent the best predictor for a possible kill site. The area was searched on foot in a diameter of 100 m following the search procedure described by Anderson and Lindzey (2003).

For each kill, first location was consistently considered within the cluster to be the date and approximate time when the predation event took place. Fresh kills were monitored till the time of their complete consumption. The data on all kills were used to calculate kill rate following Laundre (2008).

Data on habitat types were collected at the time of direct sighting of leopard and from kill location. Following habitat types: Teak Mixed Forest (TMF), Teak-*Acacia-Zizyphus* Woodland (TAZ), Thorn Woodland (TW), and Riverine Forest (RF) were taken into sampling following Khan et al. (1996).

### Data Analysis

Statistical analysis was executed using computer program SPSS (version 11.0). Spearman's Rho test was employed to measure the association at ordinal level. Poisson distribution was performed to assess probability of occurrence mean number of individuals per site. The Mann Whitney U test was applied to test for differences in annual and seasonal home ranges of M1 and M2 leopard. Prey availability was estimated using DISTANCE software program (version 7.2). A detection was defined as an individual or cluster of individuals of a species seen during a census survey. Prey utilization was calculated in terms of percentage of a particular prey species killed by leopards. The mean prey weight consumed by leopard was calculated using single sample t-test(2-tailed) to test significant difference between observed and expected mean values. The Jacobs' index (Jacobs 1974) was employed to estimate prey selection. The index was computed using the following equation:

$$D = \frac{r-p}{r+p-2rp}$$

where,  $r$  is the proportion of total kills of a prey species, and  $p$  is the proportion of the total abundance of that species. The value of the index ranges from +1 to -1 indicating maximum preference and maximum avoidance respectively.

Physical parameters of RC leopards are presented in Table 1. M1 leopard was tracked for the longer period from June 2009 to March 2012 but M2 leopard was tracked for one year from June 2009 to June 2010 after which the radio collar malfunctioned and stopped giving signals. A total of 552 radio-locations were recorded for M1 leopard and 150 locations were recorded for M2 leopard. 453 GPS coordinates of M1 leopard and 99 GPS coordinates of M2 leopard were plotted on an ISA map

for home range estimation and remaining locations were discarded from the matrix due to overlapped locations. Home range sizes were estimated using the Minimum Convex Polygon (MCP) method following Jennrich and Turner (1969) and Schoener (1981). Movement and ranging pattern were drawn and measured by circular and linear statistics on angular and directional changes using Rayleigh's and Run test. Activity rate was calculated by dividing the number of active times by the total number of times for each leopard of interest. The GIS software program GEO MEDIA PROFESSIONAL (Version 5.0) was used to plot the distribution of leopard sightings and kills. Computer program LOAS and BIOTAS (Ecological Software Solutions, 2000) were used to analyse the radio tracking data for estimation of home ranges and movement pattern. Habitat use of leopard was assessed in terms of percentage of sightings of leopard and their kills viz-a-viz habitat types. For accuracy, it was also assessed using data of RC leopards using One-way ANOVA in combination of posthoc Bonferroni Function. The data on different ecological aspects of lion included for comparison have also been analysed using a similar strategy used for leopard (Zehra et. al. 2013).

Table 1. Physical parameters and capture information of male leopards radio collared in June 2009 in Gir National Park and Sanctuary, Gujarat.

Physical Measurements	M1 leopard	M2 leopard
Capture location	Kundiwadla	Mindholiwala
Age and sex	Adult male	Adult male
Weight (kg)	54	52
Total length (m)	2.5	2.5
Tail length (cm)	91	85
Height at shoulder (cm)	76	75
Neck circumference (cm)	46	46
Canine right upper (cm)	3.50	3.54
Canine right lower (cm)	2.75	2.93
Canine left upper (cm)	3.34	3.4
Canine left lower (cm)	2.73	2.96
Foot pad front right (cm)	4.28	4.21
Foot pad hind right (cm)	4.43	4.40
Foot pad front left (cm)	4.32	4.53
Foot pad hind left (cm)	4.41	4.46
<b>Biological Details:</b>		
Respiration rate min <sup>-1</sup> .	17	18
Heart beat min <sup>-1</sup> .	78	76
<b>Drug composition:</b> Ketamine HCl (2.5 mL) + Xylazine (1.5 mL) [100mg mL <sup>-1</sup> ]		

RESULTS

**Distribution and Abundance of Leopard**

The mean leopard sightings produced to be  $0.65 \pm 0.197$  (95% LL 0.249698 – UL 1.050302) per site. The probability of finding 1, 2, or >2 leopards per site were produced to be 33%, 11% and 48% respectively. As these probabilities were not found satisfying, we estimated the upper limit of leopard sightings per site with at least 90% certainty which was produced to be one and found more satisfactory (Figure 2).

**Home Range and Movement Pattern**

Table 2 and Figure 1 provide home range data for M1 and M2 RC leopards. The overall home range of M1 leopard was estimated to be 33.3 km<sup>2</sup> using 100% MCP and 509 directional angles. The home range of M1 leopard for winter, summer and monsoon season was 27.2 km<sup>2</sup>, 15 km<sup>2</sup> and 32.7 km<sup>2</sup> based on 100, 145 and 261 directional angles respectively. The overall home range for M2 leopard was 23 km<sup>2</sup> and it varied seasonally. The home range estimates for winter, summer and monsoon were

19 km<sup>2</sup>, 10 km<sup>2</sup> and 11 km<sup>2</sup> respectively. There was significant difference between seasonal home ranges of M1 leopard between monsoon-summer and winter-summer seasons ( $Z = 1.06, p < 0.01$  for each one) and non-significant between winter-monsoon seasons. The seasonal home ranges of M1 leopard differed significantly from seasonal home ranges of M2 leopard (Mann-Whitney  $Z_{3&3} = -2.52, p < 0.01$ ) for 2009-10 data respectively. There was significant difference between calculated and expected mean distances in points of M1 leopard which were distributed completely in cluster patterns on seasonal basis and completely in random pattern on overall account. However, there was no significant difference between calculated and expected mean distances ( $CMD \geq EMD$ ) in points of M2 leopard, which were distributed in a completely random pattern (Table 2). During tracking it was possible to monitor and recognize major topographical features within the home ranges of M1 and M2 leopards. Home ranges comprised of a wide network of roads, hills, riverbeds, and flat areas with dissected and undulating terrain in the hills. The higher elevations of hill ranges such as Panchali hill, Sagbagdi hill and Hanuman hill were within the home ranges but were seldom used. M1 leopard used the

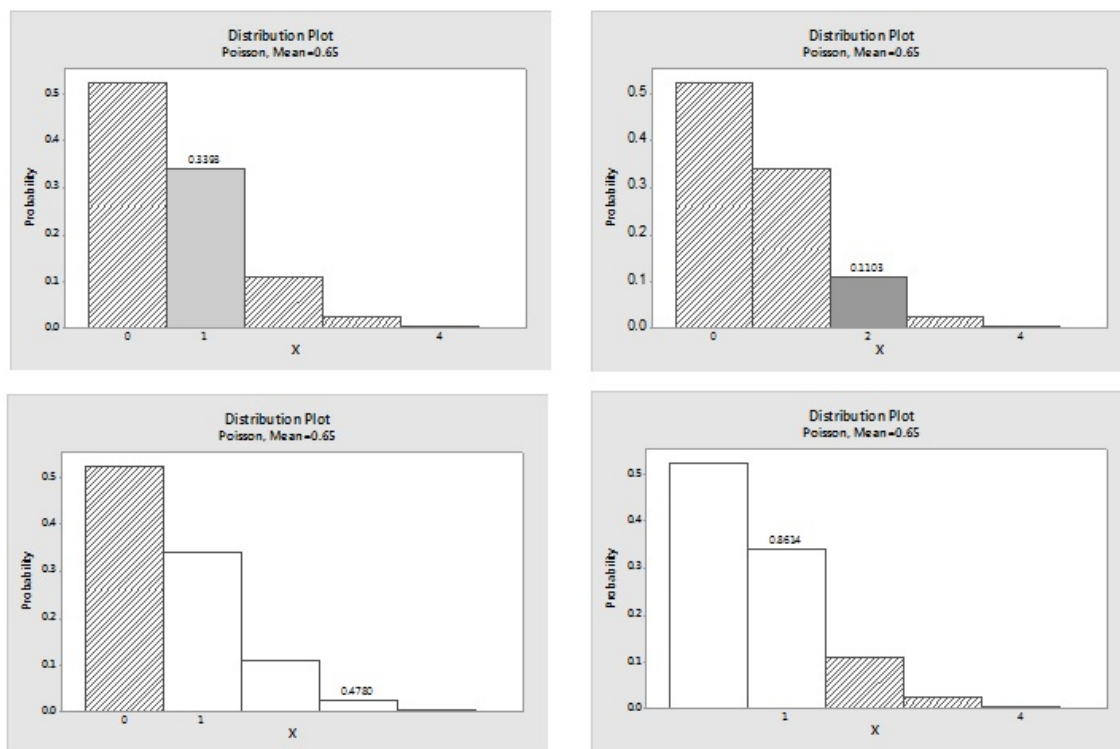


Figure 2. It shows the Poisson distribution with probability of finding: a) One leopard per gird, b) Two leopards per gird, c) Two or more leopards per gird, d) Upper limit of finding leopards per gird in ISA using leopard direct sightings. (left to right).

Table 2. Estimated home range sizes (km<sup>2</sup>) of RC leopard M1 and M2 in Gir National Park and Sanctuary, Gujarat. Range sizes were computed using Minimum convex polygon (MCP) method.

Predator/ Duration	Monitoring period	Home Range (km <sup>2</sup> )	Circular statistics			Movement pattern	Linear statistics K	Z score
			Angle count	R	p			
RC leopard M1 2009-2012	Overall	33.2	509	0.037	0.506	Random	3.06*	1.96
	Summer	15	145	0.1	0.235	Random	2.93*	
	Monsoon	32.7	261	0.024	0.863	Random	-0.31	
	Winter	27.2	100	0.066	0.646	Random	3.01*	
RC leopard M2 2009-2010	Overall	23	40	0.065	0.845	Random	-1.16	
	Summer	10	-	-	-	-	-	
	Monsoon	11	-	-	-	-	-	
	Winter	19	-	-	-	-	-	

Note: "R" = Rayleigh's Test Results, "K" = Runs Test Result, circular test compared with 0.05 for significance, linear statistics compared with 1.96 score for significance. (-) = data were not calculated.

Panchali hill for resting purposes in the evenings, especially during summer season. Favourite resting sites were rivulets of Kadeli area, Vadliwala Point and flat areas from Dudhala to Billi Wali Kundi. Artificial and natural water sources facilitated range use extensively (Figure 1). The presence of huge boulders in riverbeds provided the resting and bedding sites particularly during hot seasons. M2 leopard used road sides very frequently for resting purposes. There were 5 groups of lions which had their home ranges within the ISA.

### Activity Pattern and Habitat Use

A total of 234 radio locations was used to assess the activity pattern (Figure 3). Of that ca. 65% activities were recorded for continuous movement or walking, ca. 14% for mate pairing, ca. 14% on kills and only ca. 7% on hunting. Activities of RC leopard M1 started in the early morning before sunrise at 05:30 hr and remained active up to 10:00 hr after which the leopard rested up to 16:00 hr. It became active again in the evening and activity levels were high at around 17:00 hr where the leopard was found searching and hunting for prey. The overall diurnal activity rate was calculated as ca. 0.66 day<sup>-1</sup> and it varied seasonally with ca. 0.55 day<sup>-1</sup> during summer season, ca. 0.7 day<sup>-1</sup> during monsoon season ca. 0.87 day<sup>-1</sup> during winter season respectively.

Within its overall home range, RC leopard M1 was tracked maximum time to use Karamdi (*Carrisa conjesta*) and lantana (*Lantana camara*) thickets as bedding site where ca. 34 direct sightings, 42 kills of RC leopards and 32 kills of NC leopards were found.

Dens beneath big boulders in river beds were second favourite sites where 32 kills of RC leopards, and 54 kills of NC leopards were located. Trees such as Banyan (*Ficus benghalensis*) and Amli (*Tamarindus indica*) were used more intensively for sleeping purposes where ca. 20 direct sightings and large number of kills (n = 21 for RC leopards, n = 10 for NC leopards) were found. However, 23 kills of RC and 4 kills of NC leopards were also located in open areas. Leopards also dragged ca. 45% kill over a mean distance of 400 m to protect the kills on upper slopes. However, higher elevations were seldom used as bedding sites (n=4; Table 5). The use of these bedding sites correlated significantly with the size of the overall home range of the M1 leopard ( $R_{tho} = 1.000$ ,  $p < 0.01$ ).

In case of habitat use by leopard, TMF was intensively used with ca. 41% direct sightings while RF was intensively used for prey hunting (ca. 53%) as well as second preferred habitat with ca. 39% direct sightings respectively. The habitat use also varied seasonally. RF was used more intensively (ca. 52.5%) during summer season as compared to other habitat types, while TMF was used more intensively (ca. 53.5%) during winter and the monsoon season (ca. 41.67%; Figure 4). The differential habitat use pattern was also confirmed based on habitat selection indices calculated for RC leopards for the data set of entire study period within the ISA. One-way ANOVA with posthoc comparison using Bonferroni Function showed significant difference ( $F_{3,16} = 3.3$ ,  $p = 0.04$ ) between RF and TW habitat at 95% confidence interval (0.3495 LL - 70.2595 UL).

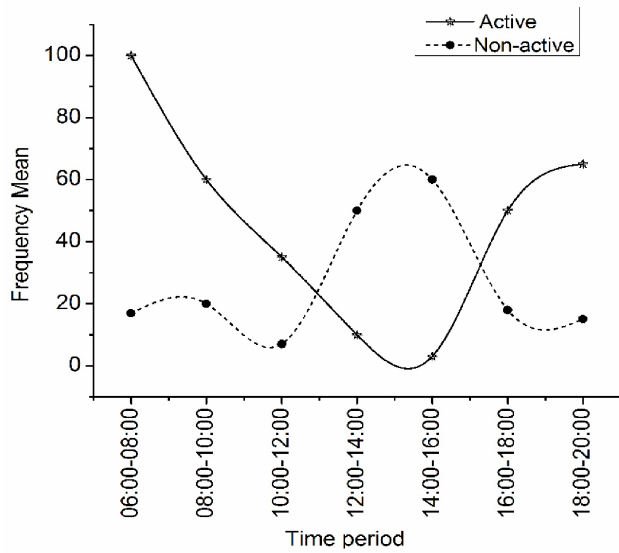


Figure 3. Activity pattern of leopard in Gir National Park and Sanctuary, Gujarat.

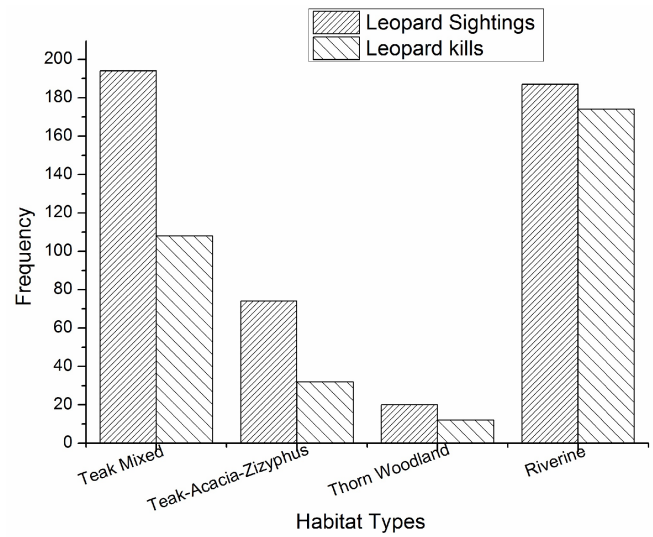


Figure 4. Habitat use of leopard using direct sightings and located kills in the ISA of Gir National Park and Sanctuary, Gujarat.

Table 3. Number of kills made by leopards of different ages of available prey species searched and recorded in ISA of Gir National Park and Sanctuary, Gujarat.

Predator	Prey species	Weight (kg)	Total kills N (%)	Adult N (%)	Sub-adult N (%)	Yearling N (%)	Fawn N(%)
NC leopards	Chital	45	150 (78.53)	97 (64.67)	26 (17.33)	8 (5.33)	19 (12.67)
	Sambar	166	4 (2.09)	2 (50)	2 (50)	-	-
	Nilgai	184	2 (1.05)	-	1 (50)	1 (50)	-
	Wild pig	32	1 (0.52)	-	-	1 (100)	-
	Livestock	226.5	3 (1.57)	1 (33.33)	-	-	2 (66.67)
	Peafowl	41	6 (8.38)	16 (100)	-	-	-
	Langur	8	15 (7.85)	10 (66.67)	5 (33.33)	-	-
	RC leopards (M1 and M2)	Chital	„	108 (78.83)	85 (78.70)	22 (20.37)	1 (0.93)
	Sambar	„	7 (5.11)	2 (28.57)	2 (28.57)	3 (42.86)	-
	Nilgai	„	1 (0.73)	1 (100)	-	-	-
	Livestock	„	5 (3.65)	-	1 (20)	4 (80)	-
	Peafowl	„	8 (5.84)	8 (100)	-	-	-
	Langur	„	8 (5.84)	8 (100)	-	-	-
Leopard kills	Chital	„	126 (95)	97 (79.51)	25 (20.49)	-	-
Overtaken by lions	Sambar	„	4 (3.10)	2 (50)	2 (50)	-	-
	Nilgai	„	1 (0.78)	-	1 (100)	-	-

**Prey Availability and Utilization**

Estimates of prey availability are provided in Table 4. Chital of adult age were detected at high rate (4.24 km<sup>-1</sup>) whereas chital fawn and sub-adults were detected with almost similar rates (2.11 and 2.06 km<sup>-1</sup>). Sambar of

sub-adult age, yearlings and fawn were detected with decreasing rates (0.13, 0.11 and 0.10 km<sup>-1</sup>) as compared to adult sambar (0.31 km<sup>-1</sup>). Detection rate of adult nilgai was 0.14 km<sup>-1</sup> which followed by nilgai of sub-adult age and fawn (0.09 and 0.07 km<sup>-1</sup>) respectively. Adult wild pig was detected with rate of 0.13 km<sup>-1</sup> which followed

by detection rate of piglets and sub-adult individuals. The mean group size of chital of adult age and piglets were found large ( $3.12 \pm 0.03$  and  $3.45 \pm 0.29$ ) as compared to other prey species of different ages.

Table 4. Overall detections (per km) of available ungulate species of different age during study period (2009-2012) in Gir National Park and Sanctuary, Gujarat.

Prey species	Nd (Ni)	%CV	MGS $\pm$ SE
Chital Adult	4.24 (13.28)	5.18	$3.12 \pm 0.03$
Chital Sub-adult	2.06 (3.38)	5.28	$1.6 \pm 0.02$
Chital Yearling	1.22 (1.81)	5.99	$1.4 \pm 0.02$
Chital Fawn	2.11 (3.45)	6.2	$1.63 \pm 0.02$
Sambar Adult	0.31 (0.76)	-	$1.43 \pm 6.82$
Sambar Sub-adult	0.13 (0.50)	0.01	$1.15 \pm 0.04$
Sambar Yearling	0.11 (2.12)	14.95	$1.2 \pm 0.07$
Sambar Fawn	0.10 (0.42)	10.32	$1.02 \pm 0.01$
Nilgai Adult	0.14 (0.41)	9.11	$1.43 \pm 6.82$
Nilgai Sub-adult	0.09 (0.54)	0.012	$1.25 \pm 0.75$
Nilgai Fawn	0.07 (1.42)	0.01	-
Wild Pig Adult	0.13 (0.73)	10.16	$2.24 \pm 0.19$
Wild Pig Sub-adult	0.09 (7.63)	0.01	$3 \pm 0.92$
Piglets	0.10 (2.03)	0.009	$3.45 \pm 0.29$

Note: Nd = Number of detections, Ni = Number of individuals, CI = Coefficient of variation, MCS = Mean Group Size, SE = Standard error; (-) = data not found, livestock weight consists weights of buffalo and cow, N =kills number (percentage) .

Table 5. Status of kills were protected by leopards at different secretive sites during study period (2009-2012) in Gir National Park and Sanctuary, Gujarat

RC leopard		NC leopard	Total kills	Sites
M1	M2			
20	1	10	31	On tree
22	10	54	86	Den in river beds
39	3	32	74	Under dense thickets
8	15	4	27	In open area

Note: RC = radio-collared, NC = Non-radio collared

A total of 328 prey kills (body weight range= 4-45 kg) were located and monitored (Table 3). The kills

comprised of five wild mammalian prey species (viz. chital, sambar, nilgai, wild pig and langur), peafowl and two species of livestock (buffalo and cow). The diet of leopard in the ISA comprised of chital (ca. 78.53%), peafowl (8.38%), langur (ca. 7.85%), sambar (ca. 2.09%), nilgai (ca. 1.05%), and wild pig (ca. 0.52%) respectively. The proportion of livestock was ca. 1.57%. Leopards mostly selected adult chital (ca. 64.67%), sub-adult and yearling of sambar and nilgai. In case of livestock, leopards mostly killed calves (ca. 66.67%) in respect to other age classes. The sex ratio of leopard kills was calculated to be 1 male to 1.58 females, which did not differ significantly from what was expected by chance ( $X^2 = 0.04$ ,  $P_{Yates} = 0.94 > 0.05$ ). 108 clusters for M1 leopard and 29 clusters for M2 leopard were investigated with the help of radio-telemetry. These clusters resulted in the detection of 137 kills which constituted ca. 41.7% of total searched kills. These kills comprised of chital (ca. 77.3%), sambar (ca. 5.1%), nilgai (ca. 0.73%), langur (ca. 7.3%), peafowl (ca. 5.8%) and livestock species (ca. 3.6%) respectively (Table 3). RC leopards also selected adult chital (ca. 78.83%), yearling sambar (ca. 42.86%) and cattle calves (ca. 80%) respectively (Table 3). On seasonal basis, maximum kills (ca. 70.7%) of leopards were recorded during summer season followed by winter (ca. 19.08%) and monsoon (ca. 10.15%) season. But the proportion of kills found during summer season differed significantly than the winter season (Fisher exact  $p$ , two-tailed = 0.0028). A total of 52 fresh kills were monitored and it was found that mean medium sized (45 kg) prey species such as chital was consumed within three days by a leopard. Using sequential telemetry data on predation, the overall kill rate was calculated to be 3.7 days/kill whereas on seasonal account it was 3.3 days/kill during summer season and 5.2 days/kill during winter season respectively. The lion took over ca. 41% of leopard kills in the ISA, consisting of maximum chital (ca. 94.57%) of adult age (ca. 79.51%) and sambar and nilgai of sub-adult age respectively.

Figure 5 provides data for prey selection and avoidance by leopards. Leopards killed chital and langur in proportions to their availabilities (JI = 0.0039 and 0.064). The peafowl and nilgai were preferred proportionally more than their availabilities (JI = 0.745668 and 0.090473) whereas wild pig and sambar were proportionally avoided (JI= -2.2624 and -0.21476) compared to their availabilities. There were significant differences between observed and expected number of prey killed ( $t_5 = 1.72$ ,  $p < 0.05$ ). The technique employed to kill the prey

by leopard could be determined as throat, biting by a leopard, removing rumen sac first to start feeding from the back portion. Kill sites were occupied by leopards for 2-3 days during which they moved and rested around the kills. Leopards shared kills more often only when they were in mating pairs (n=15).

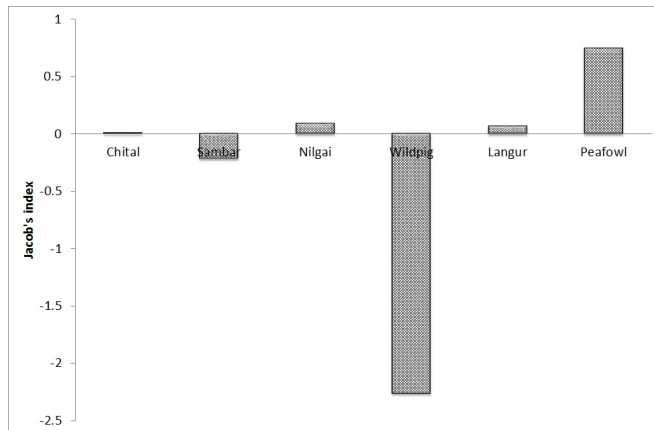


Figure 5. Selection and avoidance of different prey species by leopard in ISA of Gir National Park and Sanctuary, Gujarat.

## DISCUSSION

### Status and Distribution

Combined large carnivores density (leopard and lion) from the present study produced to be 38.5 individuals/100 km<sup>2</sup> (Zehra et al. 2016, Alam et al. 2011). Leopard density is relatively higher in GNPS compared to other sites in and outside India (Zehra et al. 2016). Resource abundance in terms of prey biomass seems to affect the densities of carnivores (Kale et al. 2011). Densities of African lions and leopards were related to the prey biomass (Hanby et al. 1995, Stander et al. 1997). Demographic parameters such as litter size, productive females and offspring survival should be higher when prey is abundant (Fuller and Sievert 2001). GNPS in the earlier past has come up with significant increase in prey densities (Khan et al. 1996, Zehra et al. 2016) especially of chital which is principal prey of both leopard and lion. Being a less K selective species compared to other large carnivores and generalist in diet, leopard in GNPS seems to have benefitted from an increase in prey populations during the last two decades.

Human caused mortality such as poaching has profound effects on large carnivore population as in case of tigers in India. However, apart from the prey base increase, protection measures taken in GNPS due to keystone “Asiatic lion” have further benefited the leopard population. Lion population has also increased substantially and seems to have reached the carrying capacity in GNPS as indicated by high infant mortality (Banerjee and Jhala 2012). The increase in leopard and lion population in GNPS is also the result of intensive management of lion population by forest department (FD) and resource subsidies in the form of livestock. FD has been regularly treating the sick and injured trapped leopards from outside GNPS due to leopard human conflict (LHC) and their release in central forest has resulted in increased survival probabilities. Resource subsidies affect large predator ecology in various ways. It may result in an increase in predator abundance, fecundity, and survival (Newsome et al. 2014). Livestock is one of the heavily utilized food by top predators and most widespread resource subsidies available to predators across the globe (Newsome et al. 2014) and also constitute considerable part of the diet of lion in GNPS (Meena et al. 2011). Further, Banerjee and Jhala (2012) found that this was also not the actual predation upon the livestock, but at about half of the feeding events were of scavenging of already dead livestock. Latter food is available at the rate of very much less energy expense while the predation of livestock needs less energy expenditure as compared to wild prey. Further, our results also showed high levels of kill thefts by lions from leopards (about 41%) which switch on leopards towards supplementary prey items (i.e. rodents, birds, hare, mongoose etc.; Zehra et al. 2017).

### Home Range and Movement Pattern

Home ranges of leopard in GNPS are smaller compared to studies conducted in the Asian continents (Odden and Wegge 2005, Karanth and Sunquist 2000) but larger than other two studies (Rabinowitz 1989, Grassman 1999). A larger home ranges have been documented from the African continent (Norton and Lowson 1985, Bothma et al. 1997, Jenny 1996, Stander et al. 1997). Several Studies have shown the inverse relationship between space use and food availability (Litvaitis et al. 1987, Saitoh 1991). The larger home ranges in Africa are reported from drier and sparse prey base areas where as smaller home ranges are reported from humid and prey rich habitats (Odden and Wegge 2005). Individual uses

smaller home ranges, possibly when they can acquire the necessary energy for survival (Tufto et al. 1996). High prey abundance seems to be responsible for smaller home ranges of leopards in GNPS. Seasonal differences in home ranges were found as summer home ranges were smaller and both M1 and M2 RC leopards and expended it in monsoon season. Simcharoen et al. (2008) also documented an increase in home ranges of male leopards in tropical forest of Huai Kha Khaeng Wildlife Sanctuary, Thailand. Grassman (1999) found that the relative diffused distribution of prey due to increase in food abundance is responsible for the increase in home ranges of leopards. Bailey (1993) demonstrated spatio-temporal changes in prey distribution and movement patterns which affected the movement pattern of leopards. Prey distribution and abundance in GNPS vary spatially as well as temporally (Khan 1993). Availability of water affected the distribution of prey in semi-arid conditions of GNPS during summer. Prey populations exhibited clumped distribution in areas around water holes and leopard movement remained focussed around these areas resulting in smaller home ranges in summer. However, the rains in monsoon season changes distribution of prey populations as food and water become evenly available in GNPS resulting in expansion of leopard home ranges. Prey availability and abundance also facilitated the employment of different topographic features in the survey region. High use of riveluts in the present study by leopards was primarily in order to attain cover for hunting prey species such as langurs which have restricted distribution in riverine habitat, hiding the prey and also avoiding high temperature during hot hours of the day. Roads also played an important role since leopard used them to traverse and mark their territories (Bailey 1993). Overlap in home ranges in the present study is comparable from studies in the African ecosystem (Cristescu et al. 2013). Latter study also showed considerable overlap between the home ranges of lion and leopards (12.2%) but minimal overlap in the core area use of lions which indicates avoidance of lion space use by leopards. Vanak et al. (2013) found that leopards avoided the recent locations of lions in Karongwe Game Reserve while Du Preez et al. (2015) found that leopards increased their speed of movement when in close proximity to lions. In the present study despite considerable overlap between lion and leopard home ranges, leopard used different behavioural tactics to avoid a lion at fine scale (Krebs and Davies 1979).

### Activity Pattern and Habitat Use

Theory of an Activity pattern of large predators revolves around two process i.e. bottom up and top down (Hayward and Slotow 2009). Bottom up process concentrates on foraging success by large predator while top down concentrates on avoidance of dominant predator. Habitat selection is also a hierarchical process (Johnson 1980). The results in present study showed that leopards spent considerable time in walking and or moving which could be largely attributed to prey searching behaviour in response of feeding competition. Large scale movement of leopard was also documented by Karanth and Sunquist (1995) as compared to other dominant predators i.e. tiger and dhole. The generalist behaviour of leopards in terms of diet might be the cause for high movement activity. Since only large kills are detectable during the tracking of leopards, a certain number of small prey species may have been missed which can further add to low activity of hunting. We found two peaks in the activity of leopards from 06:00 to 12:00 hrs and from 17:00-20:00 hrs. Earlier findings also supported such crepuscular activity of leopards (Hayward and Slotow 2009, Ramesh et al. 2012, Selvan 2013). High activity of leopards during the dawn and dusk seems to follow their key prey activity peaks i.e. chital. Dave (2008) also found two activity peaks in activity of chital (06:00-10:00 hrs and 14:00 to 20:00 hrs) in GNPS. Being active at the same time of chital, leopard seems to maximize their encounter rates during searching which seems to support the bottom up process of activity pattern. Abiotic environmental factors such as light and temperature may influence optimum daily activity patterns (e.g., Nielsen 1983, Patterson et al. 1999). Low activity of leopards during afternoon hours might be to avoid high temperature in GNPS. Asiatic lions are less active as compared to leopard since they spend most of the time in resting as compared to other activities (Meena 2008, Banerjee and Jhala 2012). Predators in response to resource subsidies decrease their activity up to 36% (Newsome et al. 2014). Lions in GNPS obtain much of their food from livestock and kleptoparasitism which may have resulted in decreased activity of this large predator (Zehra et al. 2013). Most of the studies about habitat selection by leopard have been confined to the African continent (Bailey 1993, Marker and Dickman 2005, Balme et al. 2007) while few studies address this issue in the case of the Asian continent (Simcharoen et al. 2008, Kittle et al. 2014). Leopard used TMF and RF mostly followed by

TAZ and TW at third order habitat selection (selection of specific habitats within home range). Habitat selection among carnivores also revolves around prey catch ability hypothesis. Further third order habitats are considered as the foraging areas. Use of TM and RF mostly by leopard reflected the importance of cover along with effect of abiotic factors on leopard, since both RF and MF in GNPS are dense and has highest canopy cover respectively as compared to TAZ and TW which are moderately dense and have sparse canopy. Despite a high abundance of prey in TAZ habitat in GNPS, it was less selected by leopards compared to RF due to prevailing habitat features mentioned above which makes leopard easily detected by prey along with that RF in the hottest hours of the day. Earlier studies also found the use of dense areas by a leopard at the third level of habitat selection (Simcharoen et al. 2008). At finer levels leopard used dense patches of *Carrisa conjesta* and *Lantana camara* within the habitats. Since leopard requires at least 20cm of cover for concealment (Bothma and LeRiche 1984) therefore apart from avoidance of interface with lions and humans during daytime, these dense patches of vegetation also provided hide from an ambush predator. Our results strongly indicated that leopard foraged in patches which were both prey abundance and also provided ample cover to decrease the probability of being detected by prey as well as to avoid interface with lion. At level 4 of habitat selection leopard made most of the kills in the medium canopy with a low shrub cover which is consistent with earlier findings (Karanth and Sunquist 2000). Balme et al. (2007) also found that leopard hunted in habitats where it can strike a balance between encounter rates of prey and sufficient cover to hunt. Leopard used RF mostly as a consumption sites. The understory of this habitat comprised of *Carissa carandas*, *Capparis sepiaria*, *Helecteres isora* etc. which are very dense. When scavenger densities are low very few carcasses are taken up the trees (Bothma and Le Riche 1984). In the present study large numbers of kills were recorded upon the trees which indicated high pressure of kill theft by lion on leopard. Water resources form passive traps and contribute to the structure of predators foraging behaviour (Davidson et al. 2013). Water is an important factor affecting the distribution of prey in semi-arid conditions. Many of the kills recorded near the waterholes are the results of aggregation of ungulates near water points which increased the probability of prey being found further increasing the predation success respectively.

### Prey Availability and Utilization

GNPS possess overall high density of ungulates when compared with other tropical sites (Zehra et al. 2016). It probably depends upon the high habitat heterogeneity condition (Eisenberg and Seidensticker 1976). GNPS is dominated by a fairly open canopy with habitat heterogeneity ranging from dense riverine patches to thorn woodland. This condition might be favourable to harbour high densities of ungulate population in GNPS. Mixed feeders contribute maximum to the overall percentage of terrestrial mammalian biomass in any habitat (Eisenberg and Seidensticker 1976). This seems to work well in GNPS where densities of chital are fairly high, whereas densities of some large sized prey i.e. sambar and Nilgai were fairly low in the study area. Chital density has risen fairly during last two decades. Decrease in grazing pressure due to removal of settlements and presence of flat areas has contributed this increase in population along with the presence of heterogeneous habitat which further benefits a mixed feeder. Sambar density is consistently low when compared to earlier studies in GNPS (Khan et al. 1996) and from other sites in India (eg. Sariska, Nagarhole, Bandipur). Low sambar densities can be attributed to couple of factor. Sambar prefers hilly terrain and dense shrub cover (Johnsingh 1983, Khan 1993). Both western and eastern part of GNPS consisted of fairly open canopy area whereas only National Park area with dense canopy and hilly terrain provided suitable habitat for sambar and apart from that sambar is one of the most preferred prey in the diet of lion (Meena 2008). The absence of suitable habitat and high predation pressure seem to be governing the low densities of sambar in GNPS. Nilgai prefer to use open area. A significant increase in tree cover and shrub density in National Park and Sanctuary west has been observed during the past in GNPS (Khan et al. 1996). Peafowl, langur and wild pig densities are low as compared to other studies (Karanth and Sunquist 1995, Mondal et al. 2011).

Distribution, abundance, habitat type and risk of injuries from prey seem to affect the predation rates of carnivores (Breuer 2005, Hayward et al. 2006b, Mondal et al. 2011, Mukherjee and Heithaus 2013). Leopard is a generalist predator and prefers to feed on common prey between 10-40 kg (Hayward et al. 2006b) while in the absence of large ungulate prey its diet consists of smaller prey ranging from hares to rodents (Zehra et al. 2017). Present study results follow the same pattern where most abundant species were consumed more by leopard with

the body weight ranging from 4-45 kg. The mean range of prey size can increase with the predator size (Wilson et al. 1995). Lion diet found dominated by large prey size (>200 kg, 41%; Zehra et al. 2017) which is consistent with some of earlier findings (Hayward and Kerley 2005). Chital dominated the diet of leopards as well as lion in GNPS. Chital was consumed in proportion to its availability along with langur by leopard. The dominance of chital and langur in the diet of leopard has been documented in earlier studies also (Karanth and Sunquist 1995, Andheria et al. 2007, Ramesh et al. 2009, Lovari et al. 2014). Leopards proportionally preyed on chital finding it abundant and widely distributed species which even associated with high detection rates particularly chitals of adult age. High abundance and detection rate of chital coupled with a preference of flat and open areas of GNPS may contribute to greater capture success since leopard prefers to hunt in the less dense canopy. Despite of restricted distribution of langurs in riverine patches of GNPS (Khan 1993), the arboreal behaviour of leopards makes langur vulnerable to predation. The dominance of chital in the diet of the lion is also consistent with some earlier findings in GNPS (Meena et al. 2011) and this is also due to kleptoparasitism by lion on leopard fresh kills as >47% of chital kills of leopard were kleptoparasitised by lion. Peafowl and Nilgai were consumed more than their availability by a leopard. Peafowl being largely ground dwelling with limited flight capability makes it more vulnerable to predation by leopard whereas in case of the nilgai role of habitat is important since nilgai utilised open and flat areas of GNPS may facilitate the predation by a leopard. Sambar and wild pig contributed less to the diet of leopard as compared to some other studies (Kumaraguru et al. 2011, Mondal et al. 2011, Selvan 2013) and these species were utilised less than their availability in the study area. Sambar, being distributed mainly in dense hilly areas (Khan 1993), with its low abundance and encounter rate results in low predation upon sambar by a leopard. Avoidance of wild pig by leopard was due to its inability to tackle aggressive prey (Ramakrishnan et al. 1999, Karanth and Sunquist 1995).

Leopard prey killing rates in GNPS is comparable to earlier studies (Bothma and Le Riche 1986, Baily 1993, Stander et al. 1997, Odden and Wegge 2009) and were low except in case of study conducted by Bothma and Le Riche (1986). Prey availability in terms of encounter rate and group size affect the kill rates (Odden and Wegge 2009). High encounter rate of chital and large mean group size as a consequence form the bulk of

leopard diet in GNPS. By feeding on large sized prey such as chital compared to smaller prey species (peafowl, langur, rodents etc.), leopard maximizes on energy demands using the least kills in GNPS. Higher predation rate by leopards during winter season may be attributed to the higher encounter rate and large group size in winter season respectively.

Kleptoparasitism has reported from Africa and it is much pronounced in spotted hyenas, which kleptoparasitize on the kills of at least seven predators (Curio 1976). Lion in GNPS kleptoparasitized highly on kills of leopard. Ecological conditions affect the kleptoparasitism including foraging behaviour of kleptoparasite, habitat use by both kleptoparasite and host, cost and gain included in kleptoparasitism (Brockmann and Barnard 1979). Open habitat conditions in GNPS increase the detectability of kills which coupled with the dominance of lions on leopards in GNPS leads to large scale Kleptoparasitism. Leopard being small in size is not able to defend their kills from lions since small size in felids results in an inability to defend their prey from bigger predators (Durant 2000). Impact of kill theft depends upon the foraging behaviour of sufferer species. For example, wild dogs hunt on their physiological tolerance and if 25% of their food is lost in Kleptoparasitism to hyenas, they will have to hunt again for 10-12 hours while cheetahs just have to hunt for 1.1 hours per day more if the kill gets stolen (Scantlebury et al. 2014). How much this will affect leopards in GNPS is a question for research.

## CONCLUSION

Ecological studies of leopard in India are few and most common focused aspect has remained diet. While leopard population estimation, distribution, movement and ranging pattern have less studied compared to other aspect. Most studies have been concentrated where leopards occur sympatrically with tigers. Whereas this study accumulated baseline information on leopard ecology in the Asiatic lion habitat. Present study show leopards coexist with lions successfully in Gir as indicated by high densities of leopards. This could be possible due to high prey availability and high habitat heterogeneity of Gir.

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**Author contributions:** JA Khan and N Zehra conceived and designed the study, NZ performed the experiments and analysed the data, and all three authors contributed to preparation of the manuscript.

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