International Journal of Ecology and Environmental Sciences 42 (2): 143-161, 2016
ISSN: 2320-5199 (Online)

Abundance and Habitat Use of Leopard and Lion in Gir National Park and Sanctuary, Gujarat, India

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ABSTRACT

We estimated abundance and habitat use of leopard and lion in Gir National Park and Sanctuary, Gujarat from 2009 to 2012. Direct and indirect evidence of leopard and lion were sampled on trails and roads inside the study area in western Gir for abundance estimation. The abundance of leopard outside Gir was estimated using capture-mark-recapture technique on 10×10 km grid map using data obtained from the forest department. Scats sampled on trails and roads in the study area were used to calculate scat encounter rates. Scats data were plotted on a grid system of 2 x 2 km for calculation of scat accumulation rates and defecation rates for both species in order to estimate the abundance. The direct sightings of leopard and lion were recorded for each season and data were used for calculation of densities by abundance estimation models "Royle/Nichols Heterogeneity Model (Model 1) and Royle Model w/species counts (k=200) (Model 2)" using software program PRESENCE (ver 4.0). The density of leopard was calculated as 17.8, 18.5 and 16.8 leopard/100 km^2 by indirect evidence and direct evidence data (model 1 and model 2) respectively. The values for lion were 20.1, 21.5 and 20.2 lions per100 km^2 by indirect evidence and direct evidence data (model 1 and model 2) respectively. The pattern of leopard habitat use for overall period was assessed in following order: Teak Mixed Forest > Teak *Acacia Ziziphus* Woodland > Riverine Forest >Thorn Woodland while for lion it was assessed to be Riverine Forest > Teak Mixed Forest > Teak *Acacia Zyziphus* woodland > Thorn Woodland, respectively. The estimated density values for leopard and lion by both methods were similar and therefore the sampling protocol used under the present study could be adopted by managers for regular monitoring in Gir for abundance estimation.

Key Words: Abundance Estimation; Density; Gir National Park and Sanctuary; Habitat Use; Population Size.

INTRODUCTION

Abundance estimation and understanding of habitat use pattern of large carnivores is required for long term management of such species and for taking policy decisions (Jackson and Novell 1996, Karanth and Nichols 1998). The abundance data of leopard (*Panthera pardus fusca*) in Gir National Park and Sanctuary (henceforth Gir) was based on pugmark counts and it needed validation. Use of camera trapping was desirable for such validation but due to lack of sufficient funds, camera trapping could not be used. Large number of captures of leopards from peripheral areas required that the leopard population inside Gir be estimated in order to understand its population dynamics and dispersal. The existence of a large leopard population outside Gir in agro ecosystem has been hypothesized to be linked with severe competition with lion (*Pathera leo persica*) inside Gir PA. It was therefore also necessary to obtain information on population size of lion which co-exists with leopard in Gir. This paper presents data on the habitat use and abundance of leopard and lion in Gir.

STUDY AREA

The GNPS is located at 21^0 55' to 21^0 20'N latitude and 70^0 25' to 71^0 15' E longitude and it covers an area of 1412.13 km^2 in Saurashtra region of Gujarat, India. Khan (1996) described GNPS in detail and the prevailing ecological conditions are much similar to what was reported by Khan (1996). The study was carried out in the intensive study area (ISA) of approximately 200 km^2 which was located in western part of the GNPS.

METHODOLOGY

Following two approaches were used to estimate abundance and assess habitat use pattern of leopard and lion in Gir: i) recording of direct actual sightings of both predators and ii) counting of scats on roads and trails used by both predators following (Gese 2001). Standardized protocols were followed to avoid any bias throughout the whole study period. Surveys were conducted on seasonal basis and each selected path was monitored once in each season from 2009 to 2012 at the time when leopard and lion were thought to be most active. Besides, it is based on the assumption that use of such sampling efforts relating to direct counts and inventory of indirect evidences (IEs) are reliable to monitor population status over a time in a demarcated area and compare abundance of target species between different locations or areas or even an interval of a particular time period (Gros 1996).

Survey for Indirect Evidences (Scat Count)

The survey was carried out to obtain information on presence-absence of predators and pattern of habitat use inside the intensive study area (ISA) as it was known that lion and leopard prefer to use roads and trails as travel routes and were likely to leave scats and tracks during movement. The entire road network and frequently used trails of the ISA were selected and monitored for scat sampling on seasonal basis covering summer, monsoon and winter season. The search team comprised of trained and skilled assistants who had long experience in identification of leopard and lion scats. All selected trails were monitored on foot for scat clearance carefully by the research team to enhance accuracy in estimates by recording encountered scats on prefixed time schedule. Roads were monitored with a fixed speed of 10 km^{-hrs} in open Jeep. Wherever scats were encountered, the same were first identified and recorded. Supplementary information such as date and time, location and approximate age of the scat were also recorded. Scats of leopard and lion were easily distinguishable. All selected paths were cleared from all scats first than re-monitored after fixed time interval to collect data on number of scat accumulated during that time period. Scat re-clearance was done with GPS coordinates along with each scat location and distances of monitored paths were recorded properly following Gros (1996). The clearance of scats was carried out over a period of three years surveys, over equal length sampling animal paths at the same time of the year, and with equal sampling efforts (number of days), at fixed time interval to avoid biases associated with differential prey digestibility (hence differential scat deposition rates) and seasonal changes in food items consumed (Andelt and Andelt 1984).

Survey for Direct Sightings (Predator Count)

The selected paths used for sampling of scats were also used for sampling of direct sightings of lion and leopard. This is probably simplest approach among all direct and advanced available methods (photographic capture-recapture and scat collection for DNA sampling) to estimate actual population in a given area (Harris and Rayner 1986a, Gese 2001). Under this method, registrations of all opportunistic sightings of leopard and lion were done within the ISA during the study period. For leopard, the identification of sex and age was sometimes difficult due to its cryptic nature. The assumptions of direct counts and the estimators used to determine population size were carefully followed for whole sampling period. Each sighting of lion and leopard was recorded using a GPS along with data on other necessary parameters. The population size of peripheral population of leopard was estimated by using data pertaining to leopards capture–mark-recapture which was obtained from the rescue center of Wildlife Division Sasan Gir from 2000-2012.

Habitat Use

Habitat patches intensively used by leopard and lion were surveyed. Data on habitat factors around direct sightings or indirect evidence in terms of habitat type, percentage of crown densities of trees and shrubs were recorded. The information pertaining to distance to water availability (artificial or natural) and human habitations (maldhari nesses) was also recorded to assess role of water availability and human disturbance on the distribution of leopard and lion.

Data Analysis

Abundance of Leopard and Lion Based on Indirect Evidences

All data sets of scats counting were pooled together on seasonal basis for the study period because sample of a single survey was not sufficient for analysis. The pooling was done for all summer (2009-2012) and winter (2009-2012) seasons to construct two inventories of scat counting records. Later both inventories (summer and winter) were summed up in one data set for overall abundance estimation. Distances of all monitored paths were calculated and used to calculate encounter rates for seasonal and overall periods following Sadlier et al. (2004) with the following formula:

Encounter Rate =
Total number of counted scats (N) / total distance covered in km (L).

Encounter rates were calculated for trails, roads and habitat types separately on seasonal and overall basis. Precise information on scat defecation, accumulation rates and duration are needed for reliable individual density estimation. GIS software Arc Info was used to calculate average number of scats/ km^2 for each sample of data for summer and winter season and for overall accounts. Defecation rates for targeted species were computed by following Davison (1980):

Defecation Rate = Total number of cleared scats (N) in particular time period / Total number of animal days.

Number of gap days between monitoring of predefined paths (trails or routs) was fixed as 30 days on seasonal basis. The formula for estimating population density using indirect indices (scats) was used following Roth (1973):

D = s (scat km^{-2} t^{-1} (gap days) x d (scats $animal^{-1}$ day^{-1})
where s = average number of scats km^{-2},
t = number of gap days between visits and
d = defecation rate.

This method is used widely for estimation of herbivore densities (Neff 1968) but it is being used for small to medium sized predators from fox to coyotes (Beltran et al 1991, Stoddart et al. 2001, Bartel et al. 2005, Bartel et al. 2008). Roth (1973) modified this method to estimate density of brown bear using captivity of known area for an average number of scats.

Abundance of Leopard and Lion Based on Direct Sighting

The demarcated study area was searched for predator sightings and for each sighting, GPS co-ordinates were recorded. The GPS co-ordinates were used to prepare thematic maps of the ISA with the help of GIS software. All data regarding large predator sightings were sorted out on seasonal basis and later summed up for the entire study period (2009-2012). Initially, the samples of sightings were plotted on ISA map having grids of 2 km×2 km to view overall distribution of recorded GPS co-ordinates and to construct matrixes for analysis purpose separately for each season. As leopard sightings were results of very rare events, the data set were tested for normal distribution as for predictive purpose as it was desirable to understand the shape of the underlying distribution. To estimate abundance from direct count, thematic maps of data samples were used to construct matrixes of each season separately in the form of presence-absence (sequence of 1's and 0's = presence and absence) at a particular site where each grid was considered as a independent site. Prepared data samples of all prefixed sites or locations with their sightings were analyzed for abundance using abundance estimation models "Royle/Nichols Heterogeneity Model and Royle Model w/species counts (k=200)".

To estimate size of predator population residing outside Gir, the collected data sets on capture–mark-recapture of leopards from 2000 to 2012 were plotted on thematic maps of peripheral villages in same way as was done for inside the park but grids size was expanded to 10 km×10 km grid system to cover entire area affected by problem leopard. About eleven thematic maps of leopard capturing-recapture cases were prepared for each year separately to construct clear sampling matrix and to find its distribution. These data samples were analyzed using only the "Royle/Nichols Heterogeneity Model".

Scat survey indices can be used to obtain population estimates if the relationship between the index of relative abundance and actual density is known. Linear regression analysis was used to evaluate the relationship between the index and actual density or abundance (Quinn and Keough 2002). Once the relationship is determined, it can be applied to results of scats surveys to extrapolate population estimates from the indices. Studies evaluating this approach have shown that indices obtained through indirect surveys can provide reasonable precise population estimates (Lariviere et al. 2000).

Habitat preference of leopard and lion was calculated using information recorded along with direct or indirect evidences on seasonal as well as overall basis for following habitat types a) Teak Mixed Forest, b) Teak-*Acacia-Ziziphus* woodland, c) Thorn Woodland and d) Riverine Forest. In case of leopard, habitat preference was also assessed using the data of radio-collared leopards by computing Bonferroni Index.

Statistical analysis was done using SPSS computer program (version 11.0). Spearman's rho test was used as it is a rank-order correlation coefficient which measures association at the ordinal level. The Kolmogorov-Smirnov Test was used to test normality in distribution through comparison of an observed cumulative distribution function to a theoretical cumulative distribution. Simple linear regression analysis was used to test associations between relative abundance index (RAI) of indirect evidences and density estimates of leopard population by direct count. The Wilcoxon Signed-Rank test was used to detect difference between sighting distribution of two season's summer viz. winter. The GIS software program "GEO MEDIA PROFESSIONAL" (version 5.0) was used to project species distribution as an event theme to display species existence. The program PRESENCE (Version 4.0, Donovan and Hines 2007) was used to analyze the abundance of leopard and lion using direct sighting data.

RESULTS

Distribution and Abundance of Leopard and Lion Using Scats

A total of 12 sampling surveys were carried out from 2009 to 2012 to derive RAI of leopard and lion based on encounter rates of scats. The distributions of leopard and lion scats are presented in Figure 1 and 2. All scats encountered were used to calculate encounter rates. Table 1 provides information pertaining to encounter rates for leopard scats. The encounter rates were 45.24 scats/100 km during summer, 38.10 scats/100 km during winter on trails and 7.21 scats/100 km during summer, 9.61 scats/100 km during winter on roads respectively. The overall encounter rates between trails and roads were 41.67/100 km for trails and 8.41/scats for roads.

Table 1. Number of leopard scats encountered, and estimates of encounter rates (ER), based on a 3-year (6 seasons) field survey covering 1836 km distance in which each trail and route was monitored six times during study period (2009-2012) in western Gir Lion Sanctuary, Gujarat.

Animal paths	Seasons	No. of scats counted	Distance covered (km)	E.R 100 km^{-1}
Trail	Overall	210	504	41.67
Trail	Summer	114	252	45.24
Trail	Winter	96	252	38.10
Roads	Overall	112	1332	8.41
Roads	Summer	48	666	7.21
Roads	Winter	64	666	9.61
Road+Trail	Overall	322	1836	17.54
Road+Trail	Summer	162	918	17.65
Road+Trail	Winter	160	918	17.43

Table 2. Number of Asiatic lion scats encountered, and resulting estimates of encounter rates (ER) derived from a 3 years (6 seasons) field survey covering 1932 km distance in which each trail and route was monitored six times during study period (2009-2012) in western Gir Lion Sanctuary, Gujarat.

Animal paths	Seasons	No. of scats counted	Distance covered (km)	E.R 100 km^{-1}
Trail	Overall	124	540	22.96
Trail	Summer	65	270	24.07
Trail	Winter	59	270	21.85
Roads	Overall	201	1332	15.09
Roads	Summer	102	666	15.32
Roads	Winter	99	666	14.86
Road+Trail	Overall	325	1932	16.82
Road+Trail	Summer	167	936	17.84
Road+Trail	Winter	158	936	16.88

There was negligible difference in the encounter rates of scats either seasonally or on overall basis on combining the values of trails and roads. These rates were (per 100 km) 17.65 scats, 17.43 scats and 17.54 scats for summer, winter and on overall basis respectively.

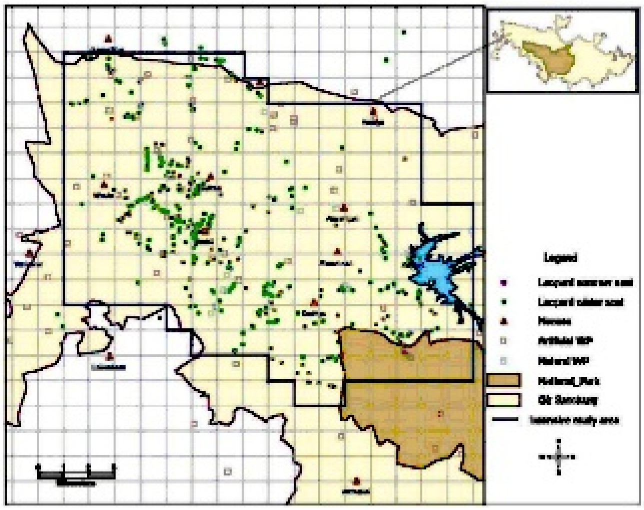

Figure 1. Distribution of leopard registered through indirect evidences on seasonal basis during 2009-2012 in Western Gir Lion Sanctuary, Gujarat.

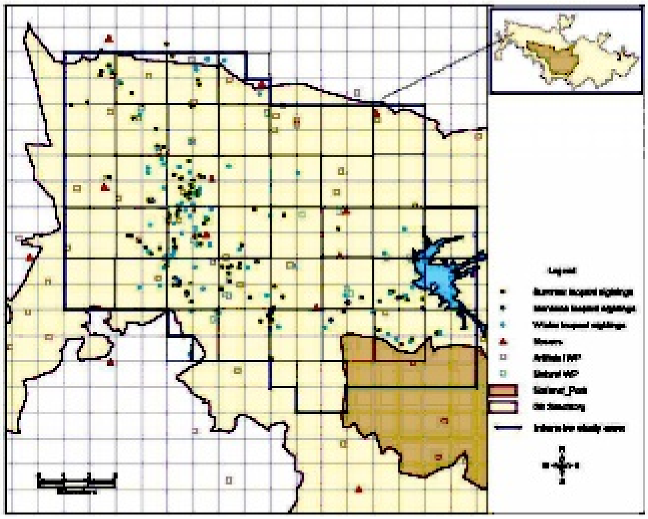

Figure 3. Distribution of leopard registered through direct sightings on seasonal basis during 2009-2012 in Western Gir Lion Sanctuary, Gujarat.

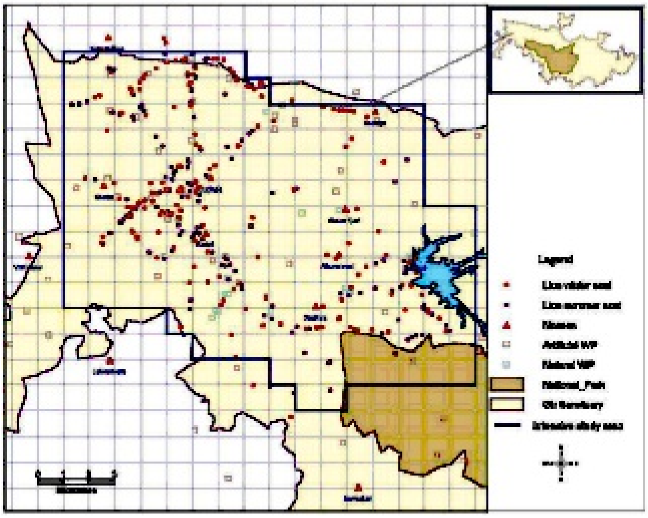

Figure 2. Distribution of Asiatic lion registered through indirect evidences on seasonal basis during 2009-2012 in Western Gir Lion Sanctuary, Gujarat.

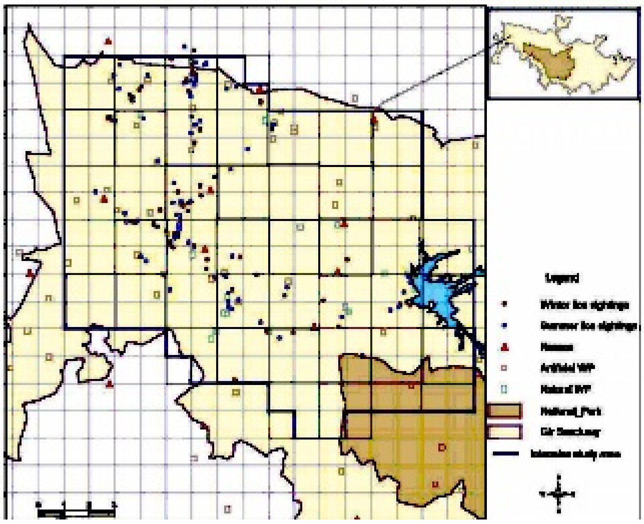

Figure 4. Distribution of Asiatic lion registered through direct sightings on seasonal basis during 2009-2012 in Western Gir Lion Sanctuary, Gujarat.

Table 2 provides data on encounter rates for lion. The encounter rates of scats (per 100 km) for lion were: 24.07 scats and 21.85 scats in summer and winter on trails while encounter rates on roads were 15.32 scats in summer and 14.86 scats in winter. The overall encounter rates between trails and roads were considerably different (22.96 scats/100 km and 15.09 scats/100 km). The overall encounter rates (trail + roads combined) was 16.82 scats/100 km and it did not differ seasonally between summer and winter (17.84 scats per100 km and 16.88 scats per 100 km respectively).

The distribution of encounter rates of leopard and lion scats resembled a normal distribution (K-S = 0.863, $p > \alpha^{*\ lion}$ and K-S = 0.847, $p > \alpha^{*\ leopard}$) where large significance values indicated that the observed distribution corresponds to the theoretical distribution and the same data were used for estimation of density of leopard and lion.

Table 3 provides the data on scat accumulation rates for leopard and lion. The scat accumulation rate was ca. 2.2 scats km^{-2} during winter season and 2.3 scats km^{-2} during summer season. The overall scat accumulation

Table 3. Density estimates of leopard and Asiatic lion derived from indirect evidences (scat count) during the study period (2009-2012) in western Gir Lion Sanctuary, Gujarat. A= Accumulation rate, DR = Defecation rate.

Predator	Season	Scats (A) No. km^{-2}	Scat DR	Predators/ 100 km^2	Abundance in ISA
Leopard	Winter	2.2	3.56	17.38	32
	Summer	2.3	3.60	18.40	34
	Overall	4.5	3.58	17.89	33
Lion	Winter	2.34	3.51	18.26	33
	Summer	2.6	3.71	21.44	39
	Overall	5.01	3.61	20.10	37

rate was estimated to be ca.4.5 scats km^{-2}. The average defecation rate calculated was ca.3.56 and 3.60 scats per leopard per day for winter and summer respectively whereas the overall rate was ca. 3.58 scats per leopard per day. The scat accumulation rate for lion was ca. 2.6 scats km^{-2} during summer season and 2.3 scats km^{-2} during winter season and the overall estimate was ca. 5.01scats km^{-2} . The defecation rates calculated were ca. 3.5 and 3.7 scats per lion per day for winter and summer respectively whereas the overall estimate was ca. 3.61. The density of leopard was estimated to be 18.4 leopards per 100 km^2 for summer season and 17.38 leopards peer 100 km^2 in winter season. The overall density for entire period was estimated at 17.89 leopards per 100 km^2 . The density of lion was estimated higher for summer season (21.44 lions per 100 km^2) than in winter season (18.26 lions per100 km^2) while for overall period it was estimated at about 20.10 lions per 100 km^2 . According to current estimates, the ISA (180 km^2) was used by ca. 34 leopards and 39 lions during summer season and by 32 leopards and 33 lions during winter season simultaneously. On an average ca. 33 leopards and 37 lions used the ISA intensively during the study period (2009-2012).

Distribution and Abundance of Leopard and Lion Using Direct Sightings Data

The distribution of direct sightings of leopard and lion is presented in Figure 3 and 4. The sighting matrixes were analyzed using 42 fixed grids of 2×2 km on seasonal basis for leopard and lion. The distribution and occupancy of large predators were monitored using 16 monitoring (16 for lions and 16 for leopards) for each site or locations systematically from 2009-2012. A total of 136 sightings of leopard and 154 sightings of lion were used for analysis simultaneously. Distribution and occupancy data of leopard and lion were analyzed on seasonal basis which were later pooled together for overall calculation. Seventy sightings of leopard and 80 sightings of lion were registered during summer season while 66 sightings of leopard and 74 sightings of lion were registered during winter season (Figure 3 and 4). There was significant difference in distributions of two co-existing large predators on seasonal basis using direct sightings between summer and winter ($Z = -1.515$, $p< 0.05^{leopards}$ and $Z = -2.349$, $p<0.05^{lions}$) respectively. In case of peripheral population of leopard, 1156 cases of leopard's registrations using capture-mark-recapture technique during study period were recorded between 2001-2012.

The mean values of different attributes calculated by Royle/Nichols Heterogeneity Model for summer, winter and overall data sets to estimate abundance are presented in Table 4. The mean value for leopard number per grid was high in summer season ($\lambda = 0.87\pm0.20$, $r = 0.157\pm0.027$) as compared to winter ($\lambda = 0.66\pm0.17$, $r = 0.144 \pm 0.028$) whereas the overall value for entire period was $\lambda = 0.86 \pm0.19$, $r = 0.111 \pm0.017$. The occupancy rates were higher for summer season than winter season ($\Psi = 0.58\pm0.083 > 0.48 \pm0.087$), whilst it was similar to summer season for the entire period ($\Psi= 0.58\pm0.079$). Using Royle Model w/species counts (k=200), the mean number of leopard/grid was calculated with respect to summer and winter season (Table 5). The summer season value was higher again than winter season at a given site or location with high probability of sighting for summer ($\lambda = 0.73 \pm 0.17$, $c = 0.174 \pm 0.029$, compared to winter ($\lambda = 0.72 \pm 0.18$, $c = 0.132 \pm 0.027$) whereas the overall value was similar to summer ($\lambda = 0.74\pm0.16$, $c = 0.125 \pm 0.018$). The occupancy rates were approximately identical for summer, winter season and overall data ('Ψ' = 0.519 ± 0.079, 0.514 ± 0.088 and 0.522 ± 0.077) respectively. The estimates of leopard density (leopard/100 km^2) are provided in Table 5. The overall estimate of leopard density was 18.5 and 16.8 by Mo1 and Mo2 respectively. The leopard density estimates differed between summer and winter season in Mo1 but the values in Mo2 were almost identical in both seasons.

In case of lions, seasonal means of abundance per grid were estimated (Table 6) and the same had high probability of sighting for summer ($\lambda = 1.07 \pm0.21$, $r = 0.227 \pm0.031$) compared with winter ($\lambda = 0.80\pm0.25$, r =

Table 4. Estimates of leopard abundance using Royle/Nichols Heterogeneity Model during study period (2009-2012) in western Gir Lion Sanctuary. [Untransformed estimates of coefficients for covariates (Beta's)]. N = No. of sites, S.O.=Sampling occasions.

Version 4.1_120214; Bootstraps=1000 for each one Royle/Nichols Heterogeneity Model

Duration	N	S.O	AIC	Estimated Factor	Estimation	S.E	95% CI	
							LB	UB
Winter	41	16	375.749	-2log (likelihood)	371.749	-	-	-
				(Beta's) (`λ) and (Beta's) ( `r)	-0.412 and -1.77	0.256 and 0.231	-	-
				avg. Abundance (λ)	0.66	0.17	0.40	1.09
				sighting probability (r)	0.144	0.028	0.096	0.210
				Occupancy (psi =Ψ)	0.484	0.087	0.330	0.665
				Total abundance (N)	27.15	6.96	16.42	44.89
Summer	41	16	452.969	-2log (likelihood)	448.969	-	-	-
				(Beta's) (`λ) and (Beta's) ( `r)	-0.140 and -1.681	0.229 and 0.209	-	-
				avg. Abundance (λ)	0.87	0.20	0.55	1.36
				sighting probability (r)	0.157	0.027	0.110	0.219
				Occupancy (psi=Ψ)	0.580	0.083	0.425	0.744
				Total abundance (N)	34.62	8.19	22.70	55.89
2009-12 Overall	41	32	733.614	-2log (likelihood)	729.614	-	-	-
				(Beta's) (`λ) and (Beta's) (`r)	-0.145 and -2.073	0.218 and 0.176	-	-
				avg. Abundance (λ)	0.86	0.19	0.56	1.33
				sighting probability (r)	0.111	0.017	0.081	0.150
				Occupancy (psi = Ψ)	0.58	0.079	0.430	0.734
				Total abundance (N)	33.45	7.76	23.09	54.44

Table 5. Estimates of leopard abundance using Royle Model w/species counts (k=200) during study period (2009-2012) in western Gir Lion Sanctuary. [Untransformed Estimates of coefficients for covariates (Beta's)]. N = No. of sites, S.O.=Sampling occasions.

Version 4.1_120214; Bootstraps=1000 for each one Royle Model

Duration	N	S.O	AIC	Estimated Factor	Estimation	S.E	95% CI	
							LB	UB
Winter	41	16	397.484	-2log(likelihood)	393.484	-	-	-
				(Beta's) (`λ) & (Beta's) (``p)	-0.324 & -1.875	0.253 & 0.242	-	-
				avg. Abundance (λ)	0.72	0.18	0.44	1.19
				sighting probability (c)	0.132	0.027	0.087	0.197
				Occupancy (psi= Ψ)	0.514	0.088	0.355	0.694
				Total abundance (N)	29.63	7.50	18.03	48.67
Summer	41	16	462.206	-2log (likelihood)	458.206	-	-	-
				(Beta's) (`λ) & (Beta's) (``p)	-0.311 & -1.551	0.226 & 0.201	-	-
				avg. Abundance (λ)	0.73	0.17	0.47	1.14
				sighting probability (c)	0.174	0.029	0.125	0.239
				Occupancy (psi= Ψ)	0.519	0.079	0.375	0.680
				Total abundance (N)	30.03	6.79	19.28	46.76
2009-12 Overall	41	32	741.60	-2log (likelihood)	737.60	-	-	-
				(Beta's) (`λ) & (Beta's) (``p)	-0.301 & -1.938	0.218 & 0.169	-	-
				avg. Abundance (λ)	0.74	0.16	0.48	1.13
				sighting probability (c)	0.125	0.018	0.093	0.167
				Occupancy (psi= Ψ)	0.522	0.077	0.382	0.678
				Total abundance (N)	30.31	6.63	19.75	46.53

Table 6. Estimates of Asiatic Lion abundance using Royle/Nichols Heterogeneity Model during study period (2009-2012) in western Gir Lion Sanctuary. [Untransformed estimates of coefficients for covariates (Beta's)]. N = No. of sites, S.O.=Sampling occasions.

Version 4.1_120214; Bootstraps=1000 for each one Royle/Nichols Heterogeneity Model

Duration	N	S.O	AIC	Estimated Factor	Estimation	S.E	95% CI	
							LB	UB
Winter	41	16	334.842	-2log (likelihood)	330.842	-	-	-
				(Beta's) (`λ) and (Beta's) ( `r)	-0.229 and -2.235	0.310 and 0.311	-	-
				avg. Abundance (λ)	0.80	0.25	0.43	1.46
				sighting probability (r)	0.096	0.027	0.054	0.164
				Occupancy (psi =Ψ)	0.548	0.111	0.351	0.767
				Total abundance (N)	32.60	10.11	17.75	59.88
Summer	41	16	390.969	-2log (likelihood)	386.969	-	-	-
				(Beta's) (`λ) and (Beta's) ( `r)	0.068 and -1.22	0.192 and 0.178	-	-
				avg. Abundance (λ)	1.07	0.21	0.73	1.56
				sighting probability (r)	0.227	0.031	0.172	0.295
				Occupancy (psi=Ψ)	0.657	0.070	0.520	0.790
				Total abundance (N)	35.92	7.45	30.13	64.03
2009-2012	41	32	605.958	-2log (likelihood)	601.958	-	-	-
Overall				(Beta's) (`λ) and (Beta's) (`r)	-0.011 and -1.962	0.217 and 0.190	-	-
				avg. Abundance (λ)	0.99	0.21	0.65	1.51
				sighting probability (r)	0.123	0.020	0.088	0.169
				Occupancy (psi = Ψ)	0.627	0.079	0.560	0.834
				Total abundance (N)	38.85	8.81	26.48	62.05

Table 7. Estimates of Asiatic Lion abundance using Royle Model w/species counts (k=200) during study period (2009-2012) in western Gir Lion Sanctuary. [Untransformed Estimates of coefficients for covariates (Beta's)]. N = No. of sites, S.O.=Sampling occasions.

Version 4.1_120214; Bootstraps=1000 for each one Royle/Nichols Heterogeneity Model

Duration	N	S.O	AIC	Estimated Factor	Estimation	S.E	95% CI	
							LB	UB
Winter	41	16	337.357	-2log (likelihood)	333.357	-	-	-
				(Beta's) (`λ) and (Beta's) (``p)	-0.340 and -2.142	0.289 and 0.290	-	-
				avg. Abundance (λ)	0.71	0.21	0.40	0.40
				sighting probability (c)	0.105	0.027	0.062	0.171
				Occupancy (psi= Ψ)	0.509	0.101	0.332	0.714
				Total abundance (N)	29.16	8.43	16.55	51.39
Summer	41	16	507.32	-2log (likelihood)	503.327	-	-	-
				(Beta's) (λ) and (Beta's) (p)	-0.304 and -1.357	0.217 and 0.187	-	-
				avg. Abundance (λ)	0.74	0.16	0.48	1.13
				sighting probability (c)	0.204	0.030	0.151	0.270
				Occupancy (psi= Ψ)	0.521	0.076	0.382	0.676
				Total abundance (N)	33.24	6.57	19.75	46.29
2009-2012	41	32	800.523	-2log (likelihood)	796.523	-	-	-
				(Beta's) (λ) and (Beta's) (p)	-0.143 and -2.01	0.207 and 0.165	-	-
				avg. Abundance (λ)	0.87	0.18	0.58	1.30
				sighting probability (c)	0.117	0.017	0.088	0.156
				Occupancy (psi= Ψ)	0.579	0.075	0.438	0.727
				Total abundance (N)	36.52	7.36	23.66	53.30

0.096 ±0.027) whereas the overall estimate was in between the seasonal values (λ = 0.99±0.21, r = 0.123 ± 0.020). The occupancy rate was higher for summer season (Ψ = 0.657±0.070 > 0.548±0.111) and the overall estimate was also similar to summer season (Ψ = 0.627 ± 0.079). The average number of lion abundance per grid was also calculated using the Royle Model w/ species counts (k=200) on seasonal basis (Table 7). The summer season had higher mean values than winter season but probability of sighting at a given site or location was higher for winter season (summer λ = 0.74±0.16, c = 0.204±0.030, winter λ = 0.71±0.21, c = 0.105±0.027), while the overall matrix of presence-absence data produced λ = 0.87±0.18, c = 0.117±0.017 respectively. The occupancy rates were high for summer season rather than winter (summer 'Ψ' = 0.521±0.076, winter 'Ψ' = 0.509±0.101), whilst for overall period it was 'Ψ' = 0.579±0.075. The overall lion density was 21.5 and 20.2 lion/100km^2 by Mo1 and Mo2 respectively. The seasonal estimates for lion density were lower than the overall lion density and lacked any seasonal variation (Table 9). Both models "Royle/ Nichols Heterogeneity Model and Royle Model w/ species counts (k=200)" (henceforth Mo1 and Mo2) have provided relatively similar population estimates (Table 4 and 5) for the study area. The estimate of leopard abundance for summer season was 34.62 ±8.19 using Mo1 model and 30.03 ±6.79 using Mo2 model and it was 27.15±6.96 using Mo1 model and 29.63±7.50 using Mo2 model for winter season respectively. The overall estimate was 33.43 ±7.76 using Mo1 model and 30.31 ± 6.63 using Mo2 model respectively. The estimates for lion abundance were calculated as 35.92±7.45 using Mo1 model and 33.34 ± 6.57 using Mo2 model during summer season and 32.60 ± 10.11 using Mo1 model and 29.16±8.43 using Mo2 model during winter season while the overall abundance was calculated to 38.85±8.81 using Mo1 model and 36.52 ±7.36 using Mo2 model respectively (Table 6 and 7).

The abundance of leopard in peripheral areas was estimated to be 265.13±29.30 leopards using Mo1 model (Table 8). The mean number of leopard per grid was estimated as 3.47±0.28 (r = 0.206±0.020) along-with occupancy rate (Ψ) which was found to be 0.915 ±0.024 leopards per grid.

The relationship between relative abundance of indirect evidences and density calculated from direct evidence was tested between encounter rates of scats which was used as relative abundance index (RAI) with two different sets of density estimates by performing simple linear regression analysis. In case of leopard, the coefficient of determination (R^2) explained about 86.41% variation (R=0.930, R^2 = 0.864 ± 1.163), (F=6.361, p=0.240) between RAI of indirect evidences and estimated density set (A) using Mo1 and about 33.25% variation (R=0.577, R^2 = 0.332 ± 0.220), (F=0.498, p=0.609) between RAI of indirect evidences and estimated density set (B) using Mo2. The regression equation appeared to be very useful for making predictions since the value of R^2 is very close to 1. Whilst for lions, the coefficient of determinations (R^2) explained 82.40% variation (R=0.908[a], R^2 = 0.824 ± .030), (F=4.682, p=0.276) between RAI of indirect evidences and estimated density set (A) using Mo1, about 84.27% variation (R =0.918, R^2= 0.843 ± 1.149), (F=5.360, p =0.260) between RAI of indirect evidences and estimated density set (B) using Mo2 respectively. All provided combinations of relative abundance index (RAI) and actual density estimated using direct sightings have provided positive and strong correlation, where models have fitted data well but lacked significance.

The normal P-p plot of the residuals exhibited the points close to diagonal line; thus residuals appeared to be approximately normally distributed and met the assumptions for regression analysis at 95% confidence zone. The standardized residual plots exhibited a random scatter of points (independence) with a constant spread (constant variance) with no values beyond the ±2 standard deviation reference lines (Figure 5 and 6). Moreover, linear analysis did not detect any variation between independent variable (scat ERs) and dependent variable (density/km^2) significantly. The correlation between densities of leopard viz. summer, winter and overall period (calculated by scat count) and number of direct sightings of leopards for same time frame were statistically significant ($r = 0.03$, $p < 0.05$, N=3).

Habitat Use by Leopard and Lion

The habitat use by leopard and lion was assessed using percentage use of each habitat type. In case of leopard, habitat use pattern using indirect evidences (scats) on seasonal basis was as follows: Teak-*Acacia- Ziziphus* woodland>Teak Mixed Forest > Riverine Forest >Thorn Woodland with following order of use 47.9> 35.4> 12.1> 4.5 during summer season, Teak Mixed Forest > Teak-*Acacia-Ziziphus* woodland >Riverine Forest> Thorn Woodland with following order of use 52.9> 25.9> 20.7> 0.4 during winter season and the overall use for entire study period was same as that of winter season with following proportions 44.4> 36.6> 16.50> 2.4 respectively. Using direct sightings the pattern of habitat

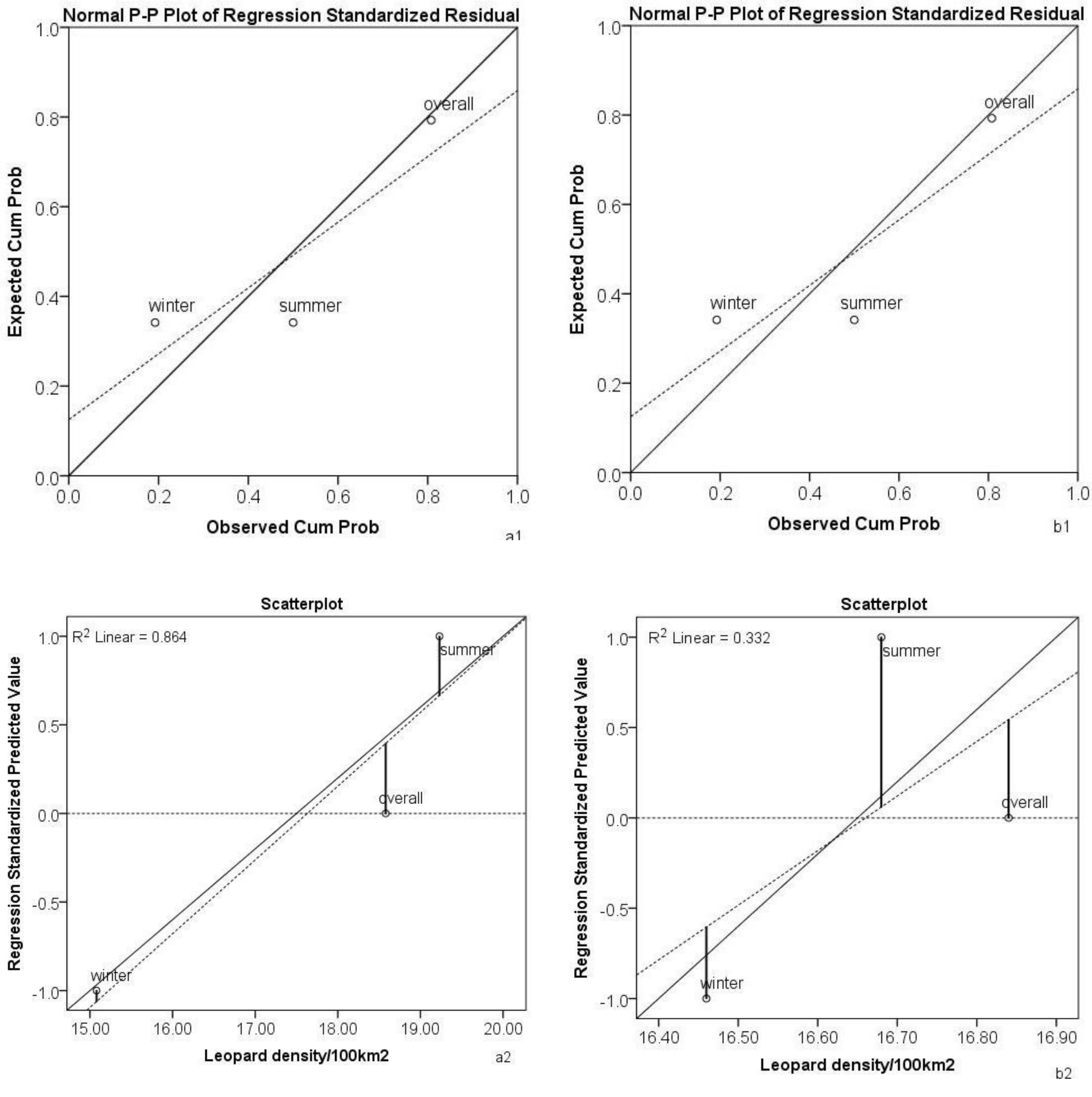

Figure 5. Associations between RAI and estimated density of leopard. a1 and b1 (above) represent normality of residuals (model fit), at 95% CI by saying that the slope of the true regression line is outward somewhere from confidence zone and a 2 and b 2 (below) represent S.D. reference lines for potential outliers.

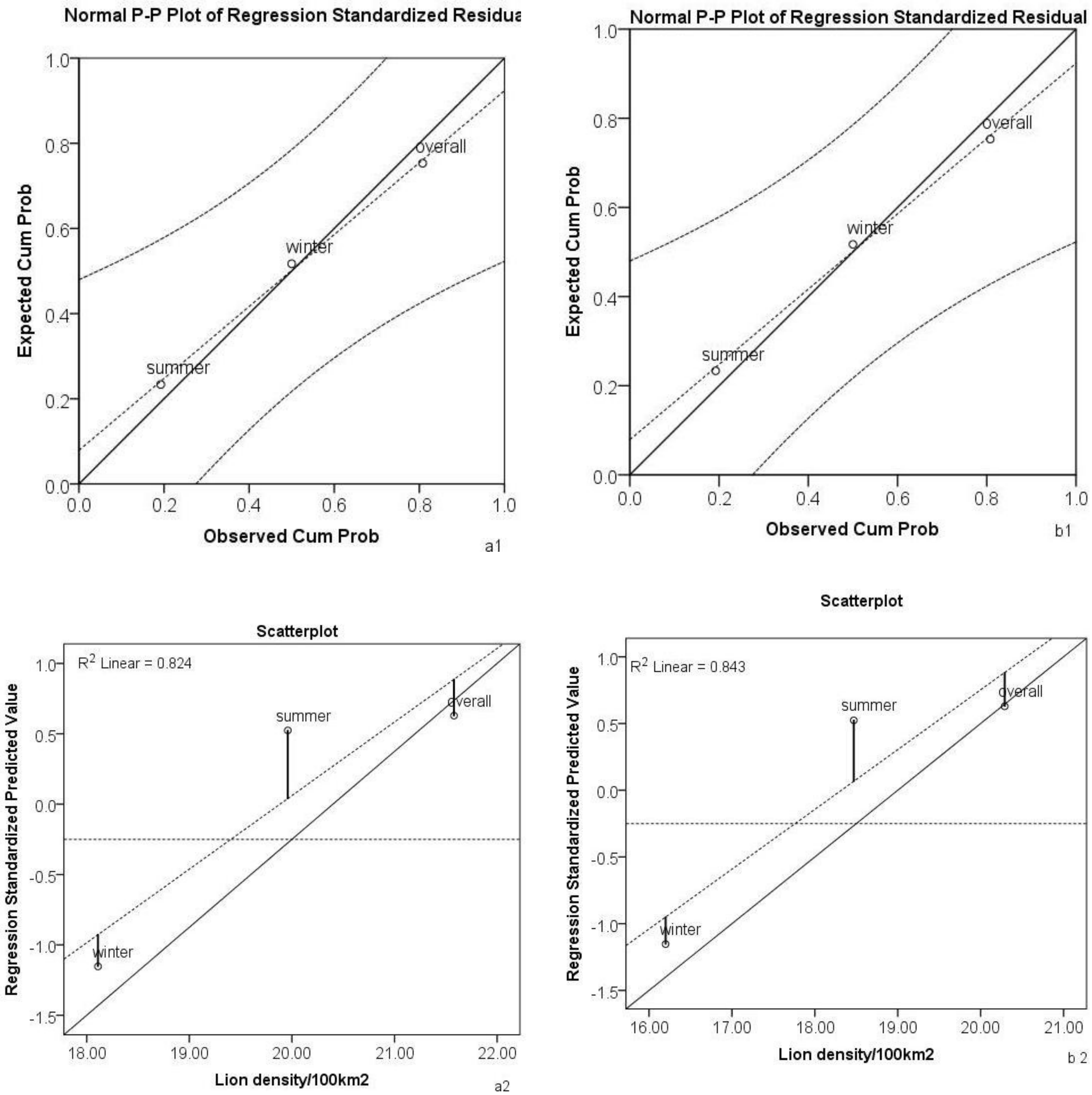

Figure 6. Associations between RAI and estimated density of lion. a1 and b1 are representing normality of residuals (model fit), at 95% CI by saying that the slope of the true regression line is between somewhere in confidence zone and a 2 and b 2 are representing S.D. reference lines for potential outliers.

use emerged as Riverine Forest > Teak Mixed Forest > Thorn Woodland> Teak-*Acacia-Ziziphus* Woodland with following proportions 52.5>37.5> 6.25> 3.7 during summer season, Teak Mixed Forest > Riverine Forest > Teak-*Acacia-Ziziphus* woodland > Thorn Woodland with following proportions 53.5> 28.1> 14.1> 4.2 during monsoon season, Teak Mixed Forest > Riverine Forest >Teak-*Acacia-Ziziphus* Woodland > Thorn Woodland with following proportions (%) 41.6> 29.1> 25.0> 4.1 during winter season, whereas for overall study period, it was as Teak Mixed Forest > Riverine Forest > Teak-*Acacia-Ziziphus* Woodland > Thorn Woodland with following propor-tions 53.5> 28.1> 14.1> 4.2 respectively (Figure 7). The difference in habitat use was confirmed using habitat selection indices of radio collared leopard recorded during the study period within the ISA. Bonferroni indices were significantly different ($F_{3, 16}$ = 3.316, p = 0.047) between Riverine Forest and Thorn Woodland habitat use (0.3495 LL - 70.2595 UL) at 95% confidence interval.

In case of lion, the habitat use pattern using indirect evidences (scats) on seasonal basis was as follows: Riverine Forest >Teak Mixed Forest > Teak-*Acacia-Ziziphus* woodland > Thorn Woodland with the proportions 53.9>27.2>14.64>4.1 during summer season; Teak Mixed Forest> Teak-*Acacia-Ziziphus* Woodland> Riverine Forest> Thorn Woodland with the proportions 64.4>16.5>12.8>6.1 during winter season whilst for the entire study period it was Teak Mixed Forest > Riverine Forest> Teak-*Acacia-Ziziphus* woodland> Thorn Woodland with the proportions 42.2>37.3>15.4>4.9 respectively. Using direct evidence, the habitat use pattern emerged as Riverine Forest > Teak Mixed Forest > Teak-*Acacia-Ziziphus* woodland > Thorn Woodland with following proportions 47.5>28.7>18.7>5.0 during summer season, Teak Mixed Forest > Riverine Forest > Teak-*Acacia-Ziziphus* woodland>Thorn Woodland with following proportions 46.1>30.7>23.1 during monsoon season, Riverine Forest > Teak Mixed Forest > Teak-*Acacia -Ziziphus* woodland > Thorn Woodland with following proportions 50.8>32.2>11.8>5.0 during winter season whilst for overall study period, it was as Teak Mixed Forest > Riverine Forest > Teak-*Acacia-Ziziphus* Woodland> Thorn Woodland with following proportions 45.6>39.1>10.5>4.6 respectively (Figure 8). Leopard used areas with medium tree cover density (92.8%) with

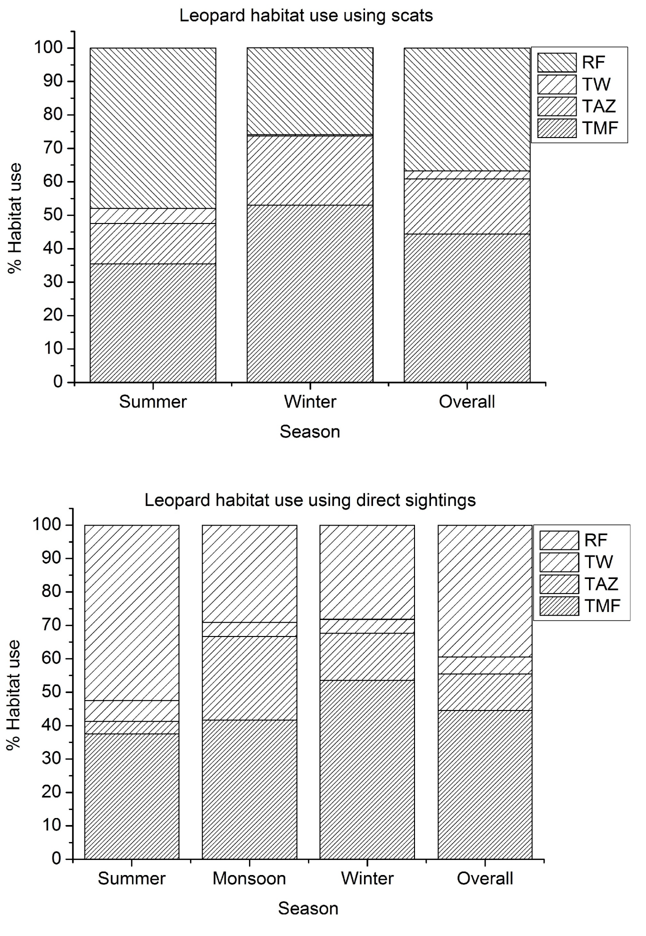

Figure 7. Habitat use (% of locations in each habitat type) by leopard using direct and indirect evidences during 2009-2012 in western Gir Lion Sanctuary, Gujarat.

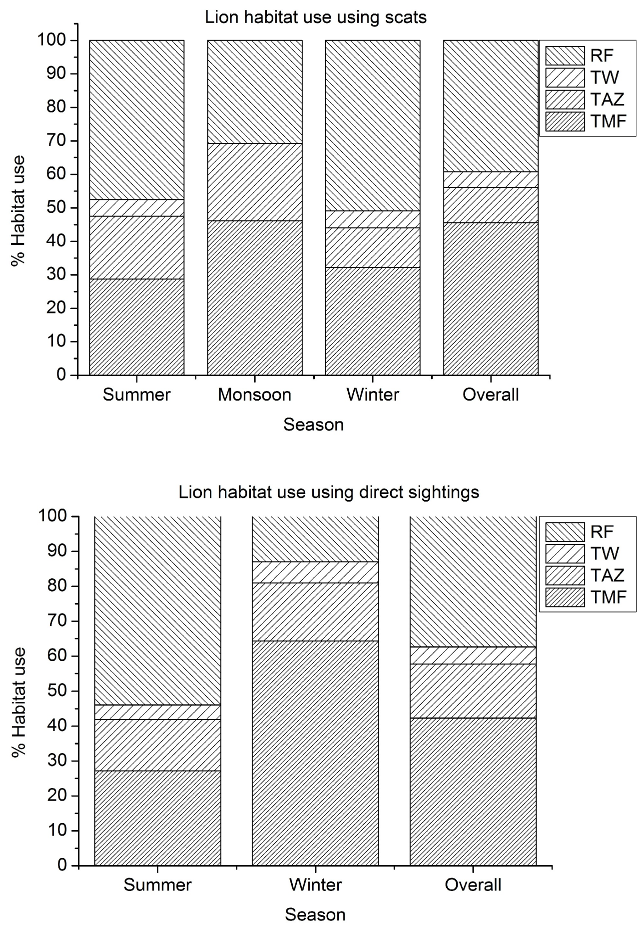

Figure 8. Habitat use (% of locations in each habitat type) by lion using direct and indirect evidences during 2009-2012 in western Gir Lion Sanctuary, Gujarat.

Table 8. Estimates of leopard abundance during study period (2000-2012) at periphery of Gir PA using Royle/Nichols Heterogeneity Model. [Untransformed estimates of coefficients for covariates (Beta's)]. N = No. of sites, S.O.=Sampling occasions.

Version 4.1_120214; Bootstraps=1000 for each one				Royle/Nichols Heterogeneity Model			
Duration	N	S.O	Estimated Factor	Estimation	S.E	95% CI LB	95% CI UB
2001-2012	40	11	-2log (likelihood)	1330.646	-	-	-
			(Beta's)(`λ)	0.903	0.115	-	-
			(Beta's) (`r)	-1.345	0.126	-	-
			avg. Abundance (λ)	3.47	0.28	1.97	3.09
			sighting probability (r)	0.206	0.020	0.168	0.250
			Occupancy (psi = Ψ)	0.915	0.024	0.860	0.954
			Total abundance (N)	265.13	29.30	202.72	318.58

Note: Data used for population estimation of leopard at periphery of Gir Lion Sanctuary obtained from rescue department in form of year-wise no. of rescued leopards from 2001-2012.

Table 9. Comparative estimates of leopard and lion population (number per 100 km^2) in the study area in western Gir Lion Sanctuary, Gujarat. A = Estimation by indirect evidences, B and C = Estimation by direct evidences and analyzed by model Mo1 and Mo2 respectively.

	Leopards (A)	Leopards (B)	Leopards (C)	Lions (A)	Lions (B)	Lions (C)
Winter	17.38	15.08	16.46	18.26	18.11	16.20
Summer	18.40	19.23	16.68	21.44	19.96	18.47
Overall	17.89	18.58	16.84	20.10	21.58	20.29

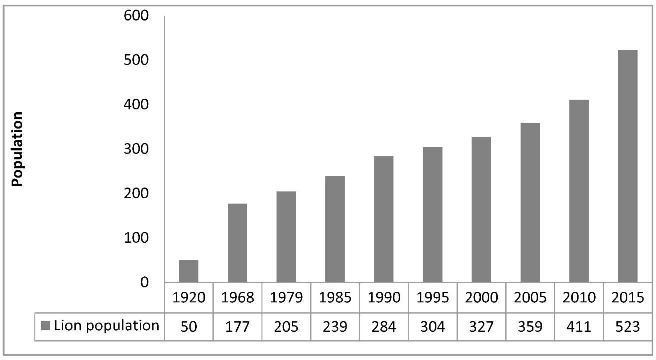

Figure 9. The trend of lion population in Gir Lion Sanctuary, Gujarat, India. Estimation was done using total count method for over three days by the forest department.

low shrub cover (86.67%). Lion used areas with medium tree cover density (80.9%) with low shrub cover (89.91%). In relation to water availability maximum sightings were observed within 100 m distance while impact of human disturbance kept predators at a distance of 1-1.5 km respectively.

DISCUSSION

Most carnivore species are secretive and occur relatively in low densities due to which accurate abundance estimates are difficult and expensive to obtain (Stander 1998). The methodologies which have been used to determine population size of large predators are diverse (Gese 2001) and all have associated advantages and disadvantages which have to be evaluated according to the conditions of the study area. Biologists have relied on estimation of abundance of carnivores using methods based on indirect evidences such as scats, scraps, spoors etc and direct evidences i.e. actual sightings. Surveys using indirect evidences are commonly useful in monitoring of relative abundance of targeted species (VanDyke et al. 1986, Smallwood and Fitzhugh 1995) as well as for evaluating trends in population size. Therefore large number of studies on different carnivore species have used methods based on indirect evidences. Recently, this methodology has been reviewed by Gese (2001) following studies on red fox (Beltran et al. 1991), coyotes (Davison 1980, Andelt and Andelt 1984, Bartel et al. 2008) and wolves (Crete and Messier 1987).

Table 10. Comparative estimates of leopard population density from different sites in and outside India

Study Sites	Area (km^2)	Density 100 km^{-2}	Authors
Western Gir Lion Sanctuary, Gujarat, India	1412.13	18.58	Present study
Sariska Tiger Reserve, Rajasthan, India	273.80	10.7	Mondal (2011)
Satpura National Park, MP, India	524.37	7-8	Edgaonkar (2008)
Rajaji National Park (West) foot hills of Himalaya, India	820.42	9.8	Mondal (2006)
Rajaji National Park (East)	820.42	14.9	Harihar et al. (2009)
Mudumalai Tiger Resrve, Tamil Nadu, India	321.55	14.9	Kale et al. (2011)
Mera Poh, Malayasia	4,343	6	Kawanishi and Sanquist (2004)
Phinda Reserve, South Africa	220	9.27	Balme et al. (2009)
Mkhuze Reserve, South Africa	400	10.7	Balme et al. (2009)
Bamu National Park, Iran	480	1.9	Khorozyan (2008)
Jabal Samhan Nature Reserve, Oman	4500	0.4	Spalton et al. (2006)

Table 11. Comparative estimate of Asiatic lion population density from different protected areas worldwide.

Study Site	Area (km^2)	Density 100 km^{-2}	Authors
Western Gir Lion Sanctuary , Gujarat, India	1412.13	21.58	Present study
Gir National Park and Sanctuary, Gujarat, India	-do-	15	Jhala (2004)
Kruger National Park, South Africa	235	13	Funston et al. (2003)
Selous Game Reserve, Tanzania	2,600	8-13	Creel and Creel (19970
Etosha National Park, Namibia	22,270	2	Stander (1991)
Serengeti National Park, Tanzania	40,000	6.3	Hanby et al. (1995)
Luangwa Valley, Zambia	355	13.8	Yamazaki (1996)
Masai Mara National Park, Kenya	1,530	35.8	Ogutu and Dublin (2002)
Ngorongoro Crater, Tanzania	260	20.4	Hanby et al. (1995)
Chobe National Park,	11,700	1.8	Cooper (1991)
Hwange National Park, Zimbabwe	14,600	2.7	Loveridge, et al. (2007)
Waza National Park, Cameroon	1,700	1.5	Tumenta et al. (2009)
Kunene National Park, Namibia	51,380	0.05-0.62	Stander (2006)
Tarangire National Park, Tanzania	2,600	11.5	Ryen and Soressina (2003)
Phinda R, South Africa	220	12.90	Balme et al. (2009)

The estimation of population size or densities of large cats has been a challenging task in India. Few studies have been carried out in Indian-sub continent on population size estimation of carnivores and managers have traditionally relied on pug mark census for tigers and leopard and total count in case of lions in Gir. Recent studies on tiger and leopard have used camera trapping for abundance estimation in different protected areas (e.g. Karanth and Stith 1999, Karanth et al. 2003, Sharma et al. 2005, Mondal 2006, Harihar et al. 2009). However, the use of camera trapping for abundance estimation has limitations as it is costly and it requires large manpower. There is also possibility of theft and vandalism and in some areas low capture rates in photographic capture-recapture is an issue to be dealt with (Beltran et al. 1991, Cavallini 1994, Gros et al. 1996, Stephens et al. 2006, Wilting et al. 2006). On the other hand, abundance estimation using indirect evidence such as scats is less expansive and require less manpower and as studies have demonstrated that estimates obtained are equally reliable. There are no or few field trials available where density estimation of large carnivores has been attempted using scat surveys or direct sightings. Hence, scat count was used together with sampling of direct sightings. Both methods were easy to use, fiscally cheap, required limited manpower and could be applied in different habitats of intensive study area.

Encounter rates showed that trails were used more than roads by leopard and lion for fulfilling their day today ecological and biological requirements while they used roads just to cross different areas or habitats. The encounter rates for both large predators were higher in summer season compared to winter season which was perhaps due to significant changes in distribution of both predators as prey populations concentrate around limited water availability inside the study area. Drastic reduction in cover condition open up habitats leading to higher detections of both predators during summer season and therefore the high encounter rates. Defecation rates may fluctuate due to numerous factors such as prey availability, animal body weight, age structure of the population of targeted predator and weather conditions (Schaller 1963, Tutin et al. 1991, Beltran et al. 1991). Mean defecation rates of leopard and lion were higher in wild (3.58 d^{-1} and 3.61 d^{-1} respectively) compared to captivity (2.5 d^{-1} and 2.7 d^{-1}). Defecation rates in captivity were computed based on 3 months monitoring of ex-situ leopard and lion kept at the Rescue Center, Sasan Gir. Roth (1973) reported defecation rates for brown bear to be 5.0 d^{-1} for adult males and 6.0 d^{-1} for both sexes. Andelt and Andelt (1984) reported that seasonal changes also influence the defecation rates of an animal. Leopard density estimated using scats defecation rate and accumulation rates were lower than lions.

Population size obtained by direct sightings were remarkably close to the estimates obtained by indirect evidences. Among total monitored sites, about 73.81% sites were occupied by leopard and 61.36% sites were occupied by lion prides. Modeling of direct count data in the form of presence–absence is a widely used approach to estimate abundance particularly of cryptic species. For direct count, GIS technique was used and grid size was opted according to ranging pattern of leopard and lion to avoid false absence at the site as conceptualized in the theory of occupancy by MacKenzie et al. (2006). In the light of ever increasing costs of wildlife research and conservation, in-expensive methods like this have always warranted special attention (Tosh et al. 2004). Detection probabilities and occupancy rates have been verified for a variety of taxa including tiger *(Panthera tigris)* in India and Malaysia (MacKenzie and Royle 2005, MacKenzie and Bailey 2004, Linkie et al. 2007, Stainley and Royle 2005). Under this model, the distribution is predicted by each sighting or number of sightings or time period independently of every other sighting or number of sightings or time period respectively.

The single-season model estimated the detection probability in order to estimate the number of sites that were truly occupied by targeted predator species even if there were no detections (MacKenzie et al. 2002). Lamda (λ) depicts bias is generally rare over the range of situations considered in the simulations but perform very well under the right circumstances. For example, larger values of R (sites) and T (time) provide more favorable conditions for estimating λ. The estimates of predator detection probability exhibited accuracy of the estimates as for winter sample, $r > 0.1$. For summer and overall samples r is slightly above from 0.1. In such cases, the bias is typically; 10–15% which is not unexpected because λ is not as small. The probability of detection of targeted species at any site is a function of the abundance of individuals there. Usually all animals have some inherent detection probability that is independent of abundance where some species are easy to find and locate (e.g. lion) while others are quite difficult (e.g. leopard, cougars etc.). In contrary probability vary species-wise but remain constant for all individuals of a species. Detection probability of cougars is estimated $r = 0.1$ (Anderson Jr. 2003). Population estimates provided by indirect evidences were slightly low in comparison to estimates provided by direct count. It was expected because in direct count some data were added from all the three seasons (summer, monsoon, and winter) whereas scats were counted during two seasons only.

However, both methods were quite useful and have provided reasonable precision in estimates of leopard and lion in the ISA where encounter rates could successfully be used as RAI to correlate with densities estimated by direct counts. Because, an understanding of the statistical relationship between indirect RAI's and true density is of primary importance when implementing a measure of indirect evidences for population estimation as it improves reliability of cheaper indirect sampling method (Eberhardt and Simmonsm 1987). Karanth et al. (2003) reviewed 30 years of pugmark census data to estimate abundance of tigers in India but estimates lacked statistical significance which decreased the reliability of the estimates. Hence, the density estimates calculated through indirect evidences were positively correlated with density estimates calculated through direct sightings (Figure 3 and 4) which suggests that scat encounter rates can be used as a surrogate of predator densities throughout the species distribution range (Table 1 and Figure 1 and 2). Diefenbach et al. (1994) applied it on Bobcat *(Lynx rufus)* in Georgia and found positive relationship between two estimates. Schauster et al. (2002) reported positive relationship between scent mark station estimates and swift fox density within Colorado. Knowlton (1984) tested this correlation on coyotes and reported positive correlation (R^2 = 0.79) between scent stations and Coyote *(C. latrans)* population size and same year on same species, it was reported (R^2 = 0.97) between scat deposition rates and densities estimated by mark-recapture method. Crete and Messier (1987) found positive correlation (R^2 = 0.90) between RAI's and actual density estimates of Wolf *(Canis lupus)*. Whilst, some studies (Smith et al. 1994) did not find any such correlation between RAIs and their true densities. Few studies have tested such associations within and between different habitats and found differences in the relationship between RAIs of indirect evidences and actual densities (Niebauer and Rongstad 1977, Stoddart et al. 2001, Bartel et al. 2005).

Density estimates of large predators are reportedly varied between study sites and regions owing variation in habitat types, topography and prey availability. Leopard density was estimated comparatively higher (Table 10) from other sites (Karanth et al. 2004, Khorozyan et al. 2008, Paviolo et al. 2008) presumably because of higher carrying capacity of west Gir and habitat use of leopards and their potential prey species are correlated positively but lacked significance. Lion density was also higher as compared to past estimates from Gir WLS which is due to continuous increase in population size (Figure 9). On comparison of lion estimates from other studies worldwide, the lion population density was found to be lower than lion densities in Masai Mara National Park (Table 11). The lion population in Gir has been steadily rising and it remains to be seen where the population density of lion in Gir will stabilize. Karanth et al. (2004) suggested that if prey availability exceeds the actual estimates of targeted predator, it is a significant sign of healthy predator population (Khorozyan et al. 2008, Paviolo et al. 2008). This appears to be the case in Gir as the prey population is abundant and it perhaps exceeds the annual requirement of lion and leopard considering the fact that domestic livestock also contributes to the available biomass.

Leopard and lion in Gir predominately occupy Teak Mixed Forest habitat as perhaps diversity in plant species composition of habitat attracts more prey. Predators get opportunities for regular sequential hunting (personal observation) and they rest around the kill until it is not fully consumed (Bailey 2005, Balme et al. 2007). Leopard used all identified habitat types significantly but difference was detected between Riverine Forest and Thorn Woodland which indicate that Thorn Woodland was not used as intensively as riverine belts. Kumar et al. (2002) reported significant differences in major habitat use of large carnivores but low occurrence of leopard in rainforest and deciduous forest in comparison to others. In case of forest canopy use, it is assumed that ideal habitat of lion is with open canopy savannah forest (Schaller 1972, Singh 2005) while under this study lion utilized medium canopy cover over relatively dense canopy cover. Jhala et al. (2009) also reported a similar habitat use pattern of lion in Gir .

There is direct association between prey species and their particular habitat types which fluctuate seasonally (Crawshaw and Quigley 1991, Khan 1993, Imcharoen et al. 2008) and lead to habitat selection by large predators following optical foraging theory (Pyke 1984). Balme et al. (2007) concluded that large predators prefer habitats where hunting is easier rather than prey abundance. Although close associations of large predators to watering sites have been described widely as a key hunting point (Crashaw and Quigley 1991) and the same has been found in present study.

CONCLUSION

The population density values for leopard and lion estimated using scat as indirect evidence and direct sightings provided reasonable abundance figures for both species and both methods provided similar estimates. Therefore the methods and sampling protocol used under the present study could be a very useful tool to monitor population status and distribution of leopard and lion in future if it is adopted by the managers and implemented for whole of Gir. Being inexpensive method, it is much easier to carry out periodically and it can provide much information compared to other expansive methods. In fact, the process of scat count from the area will alternatively provide the material of food habit analysis if done systematically with minimum bias. The use of both types of methods (direct and indirect) is recommended.

ACKNOWLEDGEMENTS

We are grateful to the University Grant Commission, Ministry of Environment, Forests and Climate Change and PURSE-I initiative of the Department of Science and Technology for providing funding support to carry out research in Gir. We wish to place on record our sincere thanks and gratitude to the PCCF (Wildlife), Gujarat State for his kind permission to work in Gir. The Wildlife Division, Sasan Gir and the office of the Chief Conservator of Forests (Wildlife), Junagadh Circle provided excellent logistic support and help to Nazneen Zehra and Jamal A Khan during the fieldwork and both sincerely thank the two offices and the staff of the Gir National Park and Sanctuary. Lastly all field assistants are thanked for their dedication and support during the study.

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Received 21 May 2016
Accepted 19 June 2016