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ORIGINAL PAPER

Home range and habitat preference of female lions (*Panthera leo persica*) in Gir forests, India

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Abstract The social organization of Asiatic lions (*Panthera leo persica*) differs from African lions (*P. l. leo*) in that breeding lionesses defend resource based territories while male coalitions maximize coverage of female groups. Thus, lion density in the Gir forests of India is dictated by female territory size. We studied the home range and habitat preference of lions using radio telemetry on seven lionesses spaced throughout the Gir between 2002 and 2005. Radio locations obtained by homing in were plotted on a classified (LISS III FCC) habitat map of Gir to obtain habitat use and availability. Habitat preference was computed using compositional analysis and Ivlev's index. Average (±SE) 100% Minimum Convex Polygon (MCP) range of six lionesses was 48.2 ± 10.6 km^2, 95% MCP was 34.7 ± 7.8 km^2 and 95% fixed kernel range size was 32.5 ± 8.2 km^2. Breeding female group density and group size was about 3 per 100 km^2 and 1.3 (0.5 SD, $n = 45$) respectively. Lions were observed to show a habitat preference ($\chi^2_{(6df)} = 11.4$, $P = 0.08$), the order of preference was Moist Mixed forests > Mixed forests > Savanna habitats > Teak-*Acacia-Zizyphus-Anogeissus* forests > *Acacia-Lannea-Boswellia* forests > Thorn and Scrub forests > Agriculture areas. Habitat preference during the day was for dense vegetation ($\chi^2_{(6df)} = 35$, $P < 0.001$). At night lions even ventured into agricultural fields. Our data

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suggests that dense habitats are preferred by lions in Gir to escape the heat of the day and to be in good cover when human activity was likely to be at its peak within forested areas.

Keywords Asiatic lion · Compositional analysis · Group Size · Ivlev's index · Lion density · Radio telemetry

Introduction

Large carnivores being at the apex of the trophic level occur at low densities and have large ranges (Schaller 1996). Therefore, they require vast tracts of habitats for maintaining viable populations (Bixby 1992). This attribute along with ecological, ethical, and symbolic reasons make them ideal flagship and umbrella species for conservation programs (Dalerum et al. 2008; Kellert et al. 1996). However, large carnivores compete and conflict with human interests (Inskip and Zimmermann 2009) making their conservation programs difficult to implement (Karanth and Chellam 2009; Weber and Rabinowitz 1996). Conservation policy and habitat management based on scientific information is important for managing protected areas for large carnivores (Karanth and Chellam 2009). When a Protected Area is home to the last free ranging population of a large carnivore as is the case of the Asiatic lion (*Panthera leo persica*) in the Gir Forests of Gujarat, western India, such information becomes crucial for management.

The Asiatic lion once had an extensive distribution ranging from Greece and Syria in the west through Iraq, Iran, Pakistan and up to India in the east (Kinnear 1920; Macdonald 1992). During the past hundred years lions were distributed throughout northern India, in the present day states of Rajasthan, Gujarat, Haryana, Punjab, Uttar Pradesh, Madhya Pradesh and Bihar (Divyabhanusinh 2005; Fenton 1908; Pocock 1930; Rangarajan 2001). Today the Asiatic lions have been reduced by hunting and habitat loss to a single population of about 350 in the Gir forests of Gujarat (Singh 2007). There is a belief among the wildlife managers that due to better protection, the forests of Gir are becoming denser and turning into non typical lion habitat; as lions are believed to prefer open forests or savanna habitat. Major wildlife habitat management has been proposed to address this natural successional habitat change (Singh and Kamboj 1996).

Since Gir has the only free ranging population of the critically endangered Asiatic lions, one of the objectives of the park management is to increase the lion population in numbers and extent. Within the past four decades, due to good protection and management, lions have increased and dispersed outside of the Protected Area extending their range to cover the forests of Girnar in the North, Mitiyala in the North East, coastal forests of Sutrapada-Kodinar and Jafarabad-Rajula, up to the Savarkundla and Palitana hills in the east, presently covering an area of approximately 10,500 km^2 including 1,883 km^{2}of the Gir forests and remaining area of approximately 8,500 km^2 of agro-pastoral landscape (Banerjee et al. in press; Singh 2007). However, the Protected Area of Gir still holds the best promise for long term conservation of the Asiatic lion due to its legal status, high prey density, good protection regime, and low human-lion conflict (Pathak 2002).

Population density in carnivores is regulated by territory size and group size (Fuller 1989; Fuller et al. 2003; Keith 1974, 1983; Macdonald 1983; Mech and Boitani 2003; Seidensticker et al. 1973; Sunquist and Sunquist 1989). Group sizes in turn are governed by prey size (Mech 1991; Mech and Boitani 2003; Packer and Ruttan 1988) and territory size by prey density (Fuller et al. 2003; Macdonald 1983; Miquelle et al. 1999; Schaller 1972;

Seidensticker et al. 1973; Sunquist and Sunquist 1989). The social organization of lions in Gir differs from that of the Serengeti in that a group or single lioness holds resource territory while male coalitions attempt to maximize female groups within their range (Joslin 1973, Chellam 1993). Thus, lion density in Gir is determined primarily by female territory size and group size. Therefore, an understanding of territory sizes of lioness is important in managing the lion population of Gir to achieve its conservation objective.

In this paper we use radio telemetry data from seven lionesses spaced throughout Gir to estimate their home ranges and evaluate their habitat preferences. We use this information to test if lions indeed prefer open canopy habitats.

Study area

The Gir Protected Area (20°57′ to 21°20′N latitude and 70°27′ to 71°13′E longitude) lies 40 km from the coast in the Kathiawar peninsula of Gujarat, India (Fig. 1). Gir forests consist of the Gir Protected Area made up of a Sanctuary with an area of 1,412 km^2 and a central National Park with an area of 259 km^2. Besides 470 km^2 of reserve, protected and unclassified forests make a total forested habitat of 1,883 km^2 (Johnsingh et al. 1998; Singh and Kamboj 1996). Gir lies within the Afro tropical realm (Singh and Kamboj 1996) in the 4B Gujrat Rajputana biotic province of Biogeographic Classification of India (Rodgers and Panwar 1988). The area has dry deciduous forest 5A/C1b of Champion and Seth (1968) classification, with west Gir dominated by *Tectona grandis* and east Gir dominated by *Anogeissus*, *Acacia* and *Zizyphus* (Khan 1993). There is a cool dry season in Gir from December to March (average minimum temperature 9°C) followed by hot dry

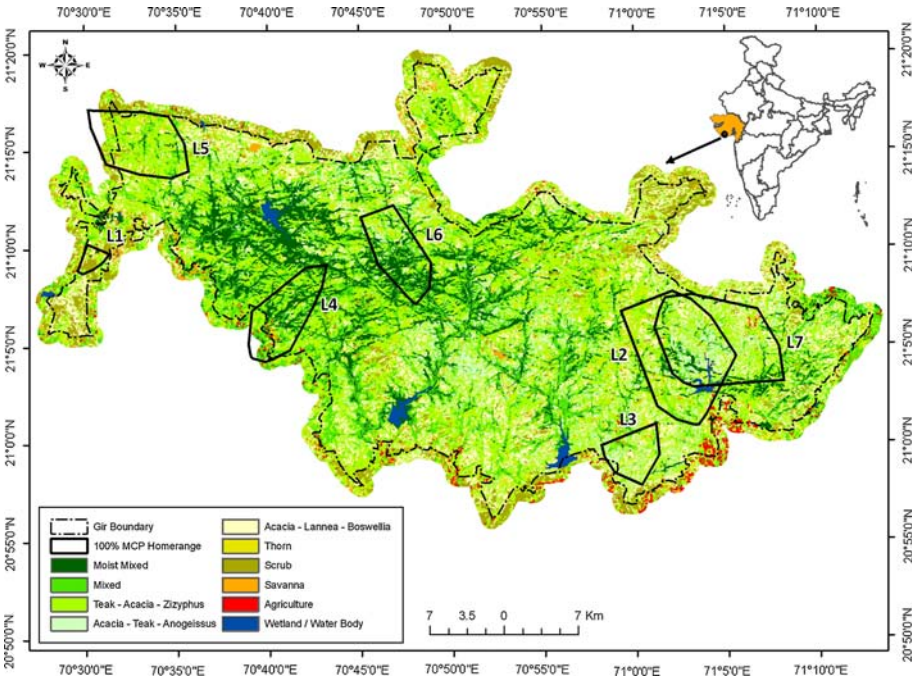

Fig. 1 Different habitat types of Gir with the 100% minimum convex polygon of seven radio-collared lionesses. Map *inset* shows the location of Gir PA within India. Habitat map modified from Qureshi and Shah 2004

season (average maximum temperature 42°C) till mid-June. The South-west monsoon normally arrives in Gir around mid June and rains continue till October. Average rainy days per year were 45, with an average annual rainfall of 980 mm (Singh and Kamboj 1996). Rugged hilly terrain of Gir forms catchment of seven perennial rivers. The vegetation in Gir is largely influenced by natural calamities like cyclones and droughts. Cyclone of 1983 uprooted hundreds of thousands of trees and created canopy openings. Subsequently regeneration of species and coppice crop again improved the density of the area (Singh and Kamboj 1996).

The protected area is subjected to biotic pressure from the 97 peripheral villages having a human population of approximately 152,000 from over 26,200 families and a livestock population of 95,000 (Singh 2007). Within the Protected Area there are 54 pastoral settlements (*Nesses*) of local communities called *Maldharis*. The total population size of these *Maldhari*s is roughly more than 2,280 individuals from 333 families, and together they own around 12,330 livestock (cattle and buffaloes). In addition, there are 14 forest settlement villages with a human population of 4,500 individuals and nearly 4,240 livestock within the Protected Area (Singh 2007).

The Gir forest has a diverse assemblage of wild fauna harboring about 32 species of mammals, 26 species of reptiles and over 300 species of birds. Apart from the Asiatic lions other carnivores include leopard (*Panthera pardus*), jungle cat (*Felis chaus*), striped hyena (*Hyaena hyaena*), jackal (*Canis aureus*), Indian fox (*Vulpes benghalensis*), ratel (*Mellivora capensis*), mongoose (*Herpestes edwardsi*), and rusty spotted cat (*Prionailurus rubiginosus*). Major herbivores include chital (*Axis axis*), sambar (*Cervus unicolor*), nilgai (*Boselaphus tragocamelus*), four horned antelope (*Tetracerus quadricornis*), langur (*Presbytis entellus*) and chinkara (*Gazella gazella*) (Singh and Kamboj 1996).

Materials and methods

Lion capture and radio-telemetry

Seven lionesses ranging approximately between 2.5 and 12 years, from seven different prides spaced throughout Gir Protected Area were captured and radio collared. Lions were anaesthetized using a combination of 2.4 (range 2.03–3.09) mg/kg Ketamine hydrochloride and 0.04 (range 0.03–0.07) mg/kg Meditomedine (Jalanka and Roeken 1990; Kreeger 1996) injected intramuscularly using a gas powered projectile Teleinject™ dart delivery system. The extremely specific antidote Atipamezole resulted in the total recovery of anaesthetized lionesses within 3–10 min. Lionesses were equipped with a MOD 500 Telonics™ or Wildlife Material™ activity radio collars. The collar weights were <1% of the body weight of the lion. Lion locations were obtained at different times of the day and night, primarily by homing in and sighting the animal. In some cases (especially areas with dense thickets) the collared lion's location was determined by circling around it from a distance of roughly 40–60 m. All telemetry work was done from the ground either using a four wheel drive vehicle, or on foot using a three element Yagi antenna. Once the location of the lion was confirmed a hand held GPS unit was used to record its coordinates.

Group size

A systematic search for lions was done throughout Gir PA and data on group size was obtained from 45 different female groups. Individual lions in these groups were identified

uniquely from their vibrissae patterns and permanent body markings (Jhala et al. 1999; Jhala et al. 2004; Pennycuick and Rudnai 1970).

Habitat classification

We used Indian Remote Sensing Satellite (IRS-ID/LISS III) with four bands (blue, green, infrared and near infrared) that was classified into ten habitat types (Qureshi and Shah 2004). These habitat types were reclassified into seven categories that were relevant in terms of lion habitat use. These were:

1. Moist mixed forest: It includes the riverine habitats of Gir. The dominant species are *Tectona grandis* in the Gir west which was replaced by *Anogeissus* spp. and *Acacia* spp. in the Gir east and to a larger extent in Central Gir. The species associated are *Wrightia tinctoria, Syzigium* spp., *Mitragyna parviflora, Diospyros melanoxylon, Emblica officinalis* and *Zizyphus* spp. The understory is comprised of *Carissa carandas, Capparis sepiaria, Helecteres isora* etc. This habitat type is the densest and has the highest canopy cover.
2. Mixed forest: The dominant species are *Tectona grandis* in the Gir west which was replaced by *Anogeissus* spp. and *Acacia* spp. in the Gir east and to a larger extent in Central Gir. The associated species are *Diospyros melanoxylon, Gmelina arborea* and *Mallotus phillipinensis*. The understory is comprised of *Zizyphus* spp., *Wrightia tinctoria, Grewia tiliaefolia, Manilkara hexandra* and *Capparis sepiaria*. This habitat type is dense with good canopy cover.
3. Teak-*Acacia-Zizyphus-Anogeissus* forest: The dominant species are *Tectona grandis* in the west which was replaced by *Anogeissus* spp. and *Acacia* spp. in the east and to a larger extent in Central Gir. The co-associates are *Zizyphus* spp., *Acacia* spp., and *Terminalia* spp. The understory is composed of *Cappparis sepiaria* and *Carissa carandas*. This habitat type is moderately dense with sparse canopy cover.
4. *Acacia-Lannea-Boswellia* forest: This forest type is found in hilly areas of Gir. The association is characterized by *Acacia* spp., *Boswellia serrata, Lannea coromandelica, Tectona grandis, Terminalia crenulata, Soyamida febrifuga, Wrightia tinctoria* and *Sterculea urens*. This habitat type is moderately open with sparse canopy cover.
5. Thorn and scrubland: This association was characterized by patchy and stunted growth of scrub species like *Acacia catechu, Acacia leucophloea, Zizyphus numularia* and *Balanites aegyptica*. This habitat type is quite open with sparse to moderate cover.
6. Savanna: It had scattered growth of trees like *Acacia* spp., *Terminalia crenulata, Tectona grandis, Bauhinia racemosa, Anogeissus* spp., *Boswellia serrata* and *Balanites aegyptica.* The grasses like *Apluda mutica, Heteropogon contotus*, *Themeda quadrivalvis* and *Sehima nervosum* formed the ground layer. This habitat type has very poor canopy cover.
7. Agriculture: It includes the open agricultural fields, open grass meadows and wasteland patches in and around Gir Protected Area (Qureshi and Shah 2004).

Home range analysis

Lion home range sizes were generated using an Arc-View™ extension package Animal Movement (Hooge and Eicnehlaub 2000) and Program CALHOME (Kie et al. 1994). Minimum Convex Polygon (MCP) home ranges obtained by ten cumulative sequential samples were plotted versus number of locations to determine the adequacy of sample size

of radio locations for home range estimation (Harris et al. 1990; Kernohan et al. 2001; White and Garrot 1990). Two non-parametric methods, the minimum convex polygon (MCP) (Mohr 1947) and the fixed kernel (Worton 1989) were used to estimate home range size. The 100% MCP method is most widely used (Harris et al. 1990) and is presented for comparison with other studies. To remove the effect of exploratory movements and outlying fixes we computed the 95% MCP and 95% fixed kernel (Kernohan et al. 2001; Mizutani and Jewell 1998; White and Garrott 1990). The fixed kernel is rated as one of the most robust and least biased estimator of home range considering its performance with small sample sizes, auto-correlated data, shape of underlying utilization distribution, outlier data and comparability between different studies (Jaremovic and Croft 1987; Kernohan et al. 2001; Worton 1995). The smoothing parameter of the 95% fixed kernel was chosen using the Least Square Cross Validation (LSCV) procedure (Kernohan et al. 2001; Silverman 1986). Percent overlap between adjacent home ranges was computed as the average proportion of overlap between two home ranges (Kernohan et al. 2001; Mizutani and Jewell 1998).

Habitat use analysis

Three thousand and fifty-nine radio telemetry locations from seven radio collared lionesses for the period of 2002–2005 spaced throughout Gir Protected Area at different times of the day were analyzed to evaluate habitat use patterns. Lion locations were plotted on the classified LISS-III imagery of Gir Protected Area. Habitat use by lions was estimated as the percent number of locations in each habitat type (Aebischer et al. 1993; White and Garrot 1990). The 100% MCP home range represents the total area from within which an animal has the opportunity to choose different habitat types. Therefore, availability of different habitat types to a lion was computed as the area of a habitat within its 100% MCP home range in a GIS domain (Hooge and Eicnehlaub 2000). Habitat preference of lions was computed using compositional analysis (Aebischer et al. 1993) and Ivlev's electivity Index (Ivlev 1961). Each lion was considered as a sample for statistical analysis (Garton et al. 2001). Habitat use was investigated at the following levels for each individual lion (Palomares and Delibes 1992):

1. All radio locations (overall) within 100% Minimum Convex Polygon as compared to habitat availability.
2. Habitat selection during day (day locations) within 100% Minimum Convex Polygon.
3. Habitat selection during night time (night locations) within 100% Minimum Convex Polygon.

Results

Plots of 100% MCP range sizes versus sample sizes stabilized for all lions showing adequacy of sampling. Lioness L3 was tracked only for a short duration of 6 months after which her collar malfunctioned. Remaining lionesses were tracked between 2 and 3 years. Home range of the lioness L1 was exceptionally small as her range was primarily restricted within Devalia Safari Park, a fenced off area of about 4 km^2 in the westernmost part of Gir. Though the lioness had learnt to negotiate the predator proof fencing of the safari park, her cubs were confined within the safari park. We excluded her home range from computing the average values. Lionesses in Gir had an average 100% MCP home range of 48.2

Table 1 Home range estimates of seven radio collared lionesses in Gir Protected Area, India

Lioness ID	100% MCP home range (km^2)	95% MCP home range (km^2)	95% Fixed kernel home range (km^2)	Number of locations	Group size of adult females
L1[a]	4.2	3.8	6.7	37	1
L2	78.9	54.4	34.4	159	4
L3	18.8	12.6	16.7	79	2
L4	35.2	22.3	33.2	226	2
L5	43.7	37.4	22.0	113	1
L6	31.6	21.6	18.4	75	2
L7	81.2	60	70.7	196	1
Average (SE)	48.2 (10.6)	34.7 (7.8)	32.5 (8.2)	141 (26)	1.8 (0.4)

[a] Not used for average computations

(± 10.6 SE) km^2, 95% MCP home range of 34.7 (± 7.8) km^2 and 95% kernel home range of 32.5(± 8.2) km^2 (Fig. 1, Table 1). Percent overlap between the adjacent ranges of lionesses L2 and L7 was 51.9%.

Adult female group size of radio collared lionesses ranged between 1 and 4 (Table 1) with an average adult female group size for the Gir PA of 1.3 (SD 0.51, $n = 45$ groups).

Overall, the lionesses were found to use Teak-*Acacia-Zizyphus-Anogeissus* habitat the most and the agricultural areas the least. During day time the most used habitat was Teak-*Acacia-Zizyphus-Anogeissus* habitat followed by the moist mixed forest type. Lions were not observed in agricultural fields during the day. During night, lions were found using Teak-*Acacia-Zizyphus-Anogeissus* habitat the most and even ventured into agricultural fields. The Teak-*Acacia-Zizyphus-Anogeissus* habitat type also had the maximum extent comprising over 40% of Gir (Qureshi and Shah 2004).

Results of compositional analysis showed that the lionesses seemed to exhibit preferences for certain habitats ($\chi^2_{(6df)} = 11.4$, $P = 0.08$). The order of habitat preference being Moist Mixed forests > Mixed forests > Savanna habitat > Teak-*Acacia-Zizyphus-Anogeissus* forests > *Acacia-Lannea-Boswellia* forests > Thorn and Scrub forests > Agriculture areas.

During the day lions were found to have a preference for dense canopy forests ($\chi^2_{(6df)} = 35.0073$, $P < 0.001$). The order of habitat preference being Moist Mixed forests > Mixed forests > Teak-*Acacia-Zizyphus-Anogeissus* forests > Savanna habitat > *Acacia-Lannea-Boswellia* forests > Thorn and scrub forests > Agriculture areas.

The order of habitat preference by lions during night ($\chi^2_{(6df)} = 36.6$, $P = 0.035$) was Mixed forests > Moist Mixed forests > *Acacia-Lannea-Boswellia* forests > Teak-*Acacia-Zizyphus-Anogeissus* forests > Savanna habitat > Thorn and scrub forests > Agriculture areas.

Ivlev's Index (Fig. 2) gave identical results as compositional analysis except for night time preference where Agriculture areas were shown to be preferred by lions.

Discussion

In Serengeti, home ranges of pride lionesses have been observed to range between 20 and 400 km^2 (Schaller 1972). In Gir, Joslin (1973) estimated the female home range sizes

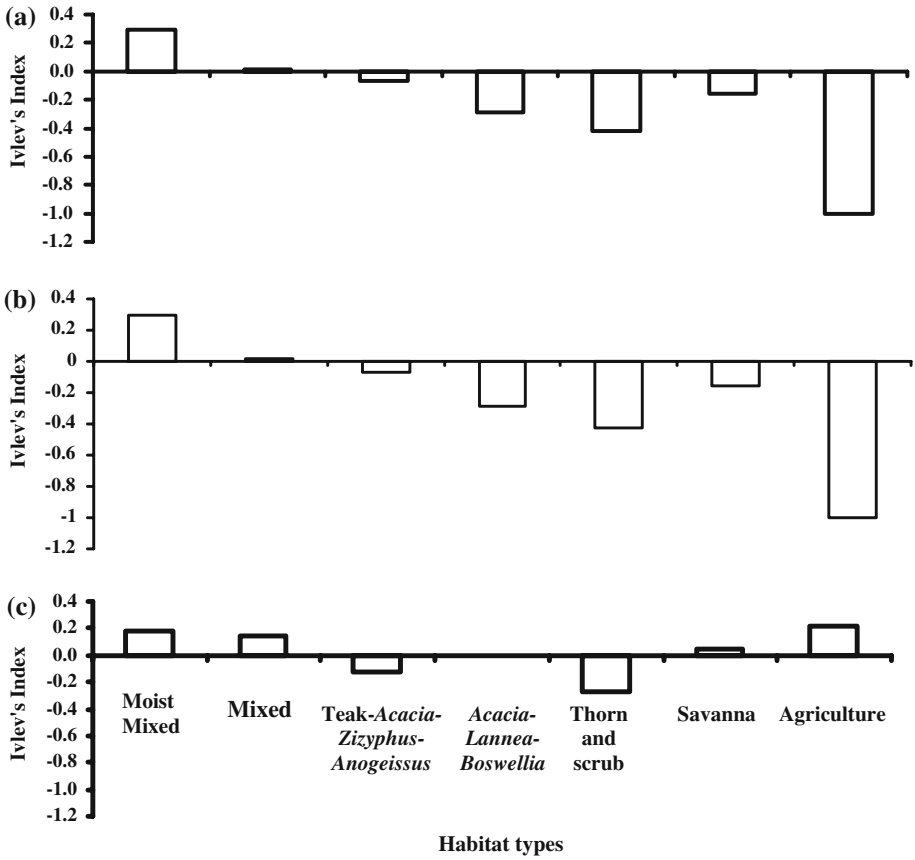

Fig. 2 Ivlev's index of habitat preference by radio collared lionesses in Gir Protected Area. **a** Overall preference considering day and night lion locations; **b** day time preference; **c** night time preference. Availability of habitat types was obtained from 100% Minimum convex polygon home range

between 72 and 81 km^2 while Chellam (1993) reported the 100% MCP range size of a single female to be 121 km^2. Radio collared lionesses in the current study were either lone individuals (e.g., lioness L6) or associated with groups ranging from 2 to 11 individual lions. The home range size of the lioness L1 was small as she tended to use the fenced off area of Devalia Safari Park. The safari park offered protection from predators, infanticidal male lions, as well as occasional food provisioning. Due to the artificial nature of her range we excluded her sample from our computations.

The percent overlap of home ranges of adjacent lionesses was substantial. One of this pair of lionesses (L2) was a sub-adult at the time of radio collaring and belonged to a group of 11 lions, while the other was a lone lioness (L7) with three 5-month old cubs. During the first year, while her cubs were small, this lioness had a smaller range (16.9 km^2) which overlapped 72% with the range of L2's group. During the next year L7's range increased almost threefold as her cubs, now over 1.5 years could move with her. The overlap between L2 and L7 decreased during the second year to 10%. Though both the groups of L2 and L7 shared the prime habitat around the perennial rivers of Jamri and Raval, they were not observed to interact socially or share kills. Thus, it appears that even with

significant area overlap these lionesses maintained temporal territoriality (Kortello et al. 2007).

Though the sample size of radio-collared lionesses was small, we had representative home range data from across the Gir Protected Area (see Fig. 1) with all lionesses except L6 (very old single lioness) belonging to breeding groups. Subsequent research on collared lions since 2005 suggests that 95% Fixed Kernel represents mostly areas of exclusive use (Jhala unpublished data). Hence, we used this estimate to compute the density of breeding units of lionesses in the Gir PA. Considering an average territory size of a breeding group of lionesses to be 33 km^2 (95% Fixed Kernel), Gir Protected Area could support about 58 breeding units (46–76 standard error range) having a density of about three breeding groups per 100 km^2. With an average adult lioness group size of 1.3 (Std 0.5), Gir PA was likely to support about 76 breeding lionesses. Joslin (1973) reported female group sizes to range from 1 to 11 with average group size being 2.1, while Chellam (1993) reported the mean group-size for females to be between 1 and 11 and the average group size to be 4.5 in Gir PA. Chital (*Axis axis*), a medium size cervid weighing on the average around 50 kg comprised over 93% of the total wild ungulate abundance in Gir (Khan et al. 1996). A prey of this size would be barely sufficient for a lioness and her cubs resulting in dispersal of subordinate lionesses and small group sizes as observed in this study (Bertram 1975; Packer and Ruttan 1988).

With the limited sample size it was not possible to statistically establish a relationship between territory size and prey density, but both breeding groups of lionesses in Gir east (L2 and L7) where prey densities were low (Dave and Jhala Unpublished data) had the largest range sizes.

Public perception of lions and their habitats are vastly influenced by wildlife films made in East Africa as well as the pioneering research done in the Serengeti (Heinsohn and Packer 1995; Ogutu and Dublin 2002; Packer and Ruttan 1988; Packer et al. 1990; Rudnai 1979; Schaller 1972). These depict lions as inhabitants of open savannah in contrast to Gir where lions live in forested habitats. Divyabhanusinh (2005) too attributes the occupancy of the northern and western India by lions to the loss of tropical forests by environmental changes caused due to prolonged drought as well as the impact of human settlements. Such accounts of lion habitat have given birth to a view that the current habitat in Gir is not ideal for lions and some management interventions may be needed to open up the forest canopy for creating conditions similar to savannahs of East Africa. Our data and analysis suggest just the reverse, as lions were observed to prefer the most mesic and thick canopy forest available to them in the dry deciduous forests of Gir. Lions also inhabit and thrive in the forested areas of south and west Africa (Bauer et al. 2003; Funston et al. 2003; Smuts 1978; Yamazaki 1996) which are similar to Gir forests. Similar to our observations on Gir lions, Bissett and Bernard (2007) found cheetah (*Acinonyx jubatus*) in South Africa preferring thicket vegetation contrary to the popular belief of cheetahs being savanna specialists. Funston et al. (2003) report lions having a social organization similar to that of Gir, which perhaps is a manifestation of lions living in forested habitats. Our studies and results as those of Bissett and Bernard (2007) and Funston et al. (2003), highlight the behavioral and adaptive plasticity of large carnivores.

During day, lions seek moist shady habitats that provide respite from the heat as well as cover to hide in when human activities in the form of livestock grazing, fuel wood, and fodder collection are maximum in the Gir forests. At night lions even ventured into agricultural fields in search of livestock. Our analysis suggests that moist mixed and mixed forest habitats are critical lion habitats in Gir as they are limited in their availability and provide the much needed cover during the most stressful time of the day. Our data does not

lend support to management practices that aim at manipulating dense habitats into savanna habitats. However, some parts of Gir have monoculture plantations of teak (*Tectona grandis*) done earlier for timber production. These could be selectively thinned and planted with miscellaneous species like *Zizyphus* spp, *Carissa conjesta*, *Acacia* spp, *Terminalia* spp, etc. that have forage value for wild ungulates. This will likely increase the nutritional carrying capacity for native wild ungulates which in turn will be beneficial for lions.

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