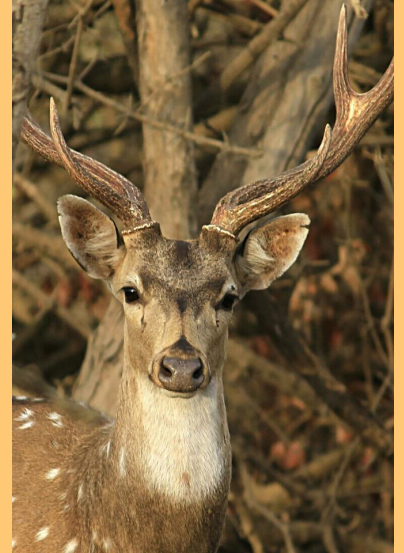


# ECOLOGY OF LION IN AGRO-PASTORAL GIR LANDSCAPE, GUJARAT

Final Project Report 2014



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- III. Name of the investigator(s):** Dr. Y.V. Jhala
- IV. Name of the research fellow(s):** Dr. Kausik Banerjee, Dr. Parabita Basu and Shri Subrata Gayen
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# Ecology of Lion in Agro-pastoral Gir Landscape, Gujarat

(FINAL PROJECT REPORT 2009-2014)

A Collaborative Research Project between

Wildlife Institute of India  
&  
Gujarat Forest Department

Wildlife Institute of India Technical Report-2014

(TR-2014/006)

Principal Investigator: Yadvendradev Jhala

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## Executive Summary

Asiatic lion (*Panthera leo persica*) is a conservation icon and elucidates India's conservation commitments. However, with single isolated population with small founder base, it typifies all the formidable challenges of global carnivore conservation. Once ranged from Persia to Palamau in eastern India, lions were almost driven to extinction by indiscriminate hunting and habitat loss. A single relict population of less than 50 lions persisted in the Gir forests of Gujarat by 1890's. With stringent protection offered by the *Nawabs* of Junagadh and subsequently by the State run Gujarat Forest department, Gir lions have increased to a current population of over 400. This also accompanied with an increase in the extent of the species. Lions were restricted to the Gir forests (1,800 km<sup>2</sup>) till the early 1980's, but have since dispersed to occupy over 10,000 km<sup>2</sup> of human dominated agro-pastoral landscape of Saurashtra. Currently lions occupy human-dominated Saurashtra landscape encompassing the Gir Protected Area (PA), 180 km<sup>2</sup> Girnar forests and over 8,000 km<sup>2</sup> of coastal scrublands and agro-pastoral landscapes of Junagadh, Amreli and Bhavnagar districts. However, the lion population is believed to be inbred and susceptible to extinction events. Moreover, with lions living in close proximity with humans, conflicts are inevitable. Long-term persistence of Gir lions is therefore possible by maintaining a metapopulation structure wherein individual lions from different breeding populations can potentially disperse among these populations. Traditional land-use pattern in Saurashtra is fast changing under urban sprawl and intensive agro-industrial infrastructural developments. Understanding these for planning conservation strategies based on lion ecology and implementing them will ensure lions' future survival in the Gir landscape. The current study investigates lion ecology with emphasis on space use, resource selection and aspects of human-lion conflicts to assist formulating a viable lion conservation strategy for future.

Wildlife Institute of India's (WII) current project in the Gir landscape has been amongst the few projects within India that has been able to sustain long-term research. On submission of first phase's findings to the Gujarat Forest Department (GFD) and WII-TRAC through technical reports, an extension for the second phase of this project aiming at studying coastal lion populations was procured in 2011. However, owing to WII's research involvement in Kuno Wildlife Sanctuary, Madhya Pradesh and input in ongoing lion reintroduction legal battle in the Supreme Court, radio-collaring lions were not permitted by GFD after 2011. Therefore, some of the research objectives of the second phase of this



project could not be achieved as proposed. However, we continued studying lion ranging and resource selection in the human-dominated Gir landscape based on radio-collared lions before 2011; achieved quantifying landscape architecture in and around Gir PA, assessed lion diet (prey abundance and preference) and evaluated aspects of lion-human conflicts during the tenure of this research project.

With lions' dispersal from the Gir PA in a highly fragmented landscape, we expected to find a gradation in sex and age composition of lions from the 'source' Gir PA to peripheral populations ('sink'). In sink populations the sex ratio and age composition would be skewed with a bias towards males, young dispersal aged lions, and old-ousted lions. We hypothesized that if the lions outside of Gir PA exist in a metapopulation structure, it is likely that sub-adult dispersal aged lions bide their time in this high risk sink habitats and those that survive return to the Gir PA to claim prime territories. Alternatively dispersing lions from the Gir PA may permanently settle down in "suitable" habitats outside the PA and form breeding populations that occasionally exchange individuals with the Gir PA. It is therefore evident that conservation of 'source' (Gir PA) alone may not be a sufficient strategy to ensure long term survival of lions; rather it is enhanced by maintaining connectivity among different metapopulations so as to permit lion movement across human-dominated areas.

Landscape architecture and variation of vegetation cover of Gir Protected Area and its surroundings: We used ordination technique (TWINSpan) and supervised and unsupervised classifications of vegetation plot data (n = 900) using cloud free LANDSAT TM satellite imageries (Bands 1-5 and 7 for the years 1998, 2002 and 2009) to identify vegetation communities within Gir PA. We quantified the rate of change in land use and vegetation patterns within Gir PA between 1998 and 2009 and based on the probability matrix obtained, we simulated land cover map for the Gir PA of 2020 (**Figure E.2**) with the cellular automata markov analysis tool (CA-MARKOV).

Ten vegetation communities were identified in the Gir PA (**Figure E.1**) i.e. *Ziziphus mauritiana-Tectona grandis* community, pure *Tectona grandis* community, mixed teak communities like *Wrightia tinctoria-Tectona grandis* community and *Tectona grandis-Wrightia tinctoria* community, *Terminalia alata-Tectona grandis-Lannea coromandelica-Acacia catechu* community, *Boswellia serrata-Acacia catechu* community, *Acacia catechu-Ziziphus mauritiana* community, *Anogeissus latifolia-Boswellia serrata* community, *Terminalia alata-Acacia leucophloea-Anogeissus latifolia-Butea monosperma* community, *Acacia nilotica-Butea monosperma-Ziziphus mauritiana* community. Quality and quantity of



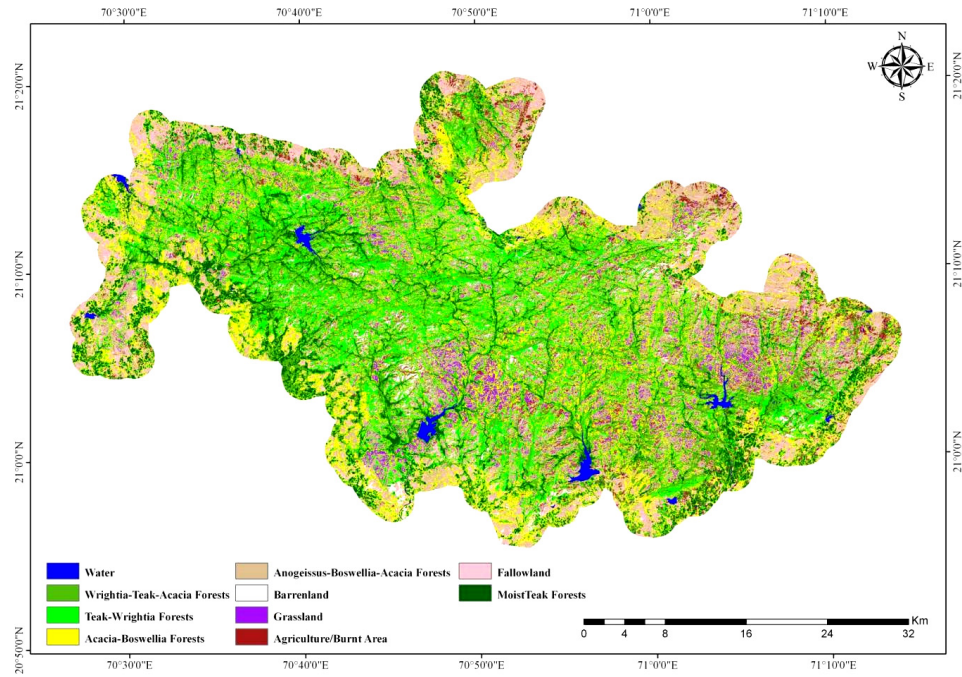
different forest types varied substantially during the time period from 1998 to 2009. The trend in land use land cover changes showed thickening of teak dominated forest types inside the Gir PA till 2002 and it might be due to a response to the canopy opening and uprooting of trees after 1984 cyclone following succession of the respective vegetation communities. Our study has demonstrated that although areas under agriculture have increased in 2009 resulting into fragmentation and patchiness of the area, the Gir PA is nevertheless effective in preserving lion's habitats against the alarming rate of forest land transformation into human conducive land use classes outside the PA boundaries.

Lion demography: An objective scientifically credible population estimation of lions using individual ID based on mark recapture framework was developed and implemented in the Gir landscape. Demographic parameters of Gir lions were deduced by intensively monitoring 75 adult lions and 91 cubs from 38 litters of 31 females using telemetry and individual lion ID profiles. Record of opportunistic mortality events ( $n = 88$ ) was used to understand the mortality causes. A population viability analysis (PVA) model was run for Girnar lions to understand the impact of various stochastic events (epidemics, loss of habitat, poaching) on their long-term persistence.

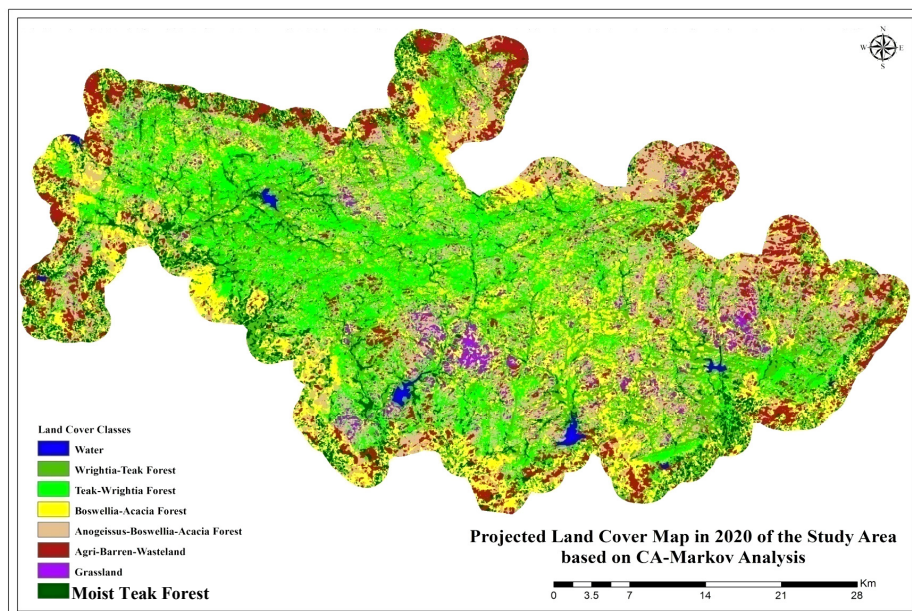
Capture probability of Girnar lions was 0.31 and the population estimate under  $M_0$  was 10 (SE 1.2) lions. Average capture probability of lions in the eastern landscape was 0.65 and the population estimate under  $M_{th}$  was 67 (SE 1.1) lions. Adult lion densities were estimated to be 5.6 (SE 0.7) lions/100 km<sup>2</sup> in Girnar and 2 (SE 0.1) lions/100 km<sup>2</sup> in the eastern landscape. Gir lions increased from about 177 in 1968 to about 411 by 2010 with an  $r = 0.022$  (SE 0.001) translated into an annual population growth of 2.2%. A large proportion of the lion population was in recruitment classes indicative of a healthy growing population. Larger proportion of adult males (43%) than adult females (26%) in the eastern landscape was probably because of male biased dispersals from the 'source' Gir PA into the 'sink' eastern landscape and lower availability of suitable habitat patches for breeding lionesses in the human-dominated landscape. Male: female ratio was 0.63 (SE 0.04) while cub: adult lioness ratio was 0.37 (SE 0.02). Mating peaked in winter while birth peaked in late summer. Average litter size was 2.39 (SE 0.12). Inter-birth interval was 1.37 (SE 0.25) years ( $n = 7$  lionesses) and was higher [2.25 (SE 0.41) years] when cubs of the previous litter survived to independence. Cub (< 1 year) survival was 0.57 (SE 0.04) while survival from cub to recruitment age (3 years) was 51% (SE 4%) with mortalities due to infanticides being 30% (SE 7 %). Juvenile (1-2 years) and sub-adult (2-3 years) survival rates were 0.87 (SE 0.04)



**Figure E.1: Land use/cover pattern of Gir PA, based on Landsat TM image of 2009**



**Figure E.2: Projected land cover map of Gir PA of the year 2020, based on CA-Markov analysis**





and 0.90 (SE 0.04), respectively. Average annual survival rate of adult lions ( $> 3$  years) was 0.9 (SE 0.12). Adult lions died primarily due to natural causes (54.5%), however, human caused mortality was substantial (43.2%) and was likely additive to natural causes. Demographic parameters of genetically less diverse Asiatic lions did not differ from those of African lions. Deleterious genes that would normally be selected against in an inbred population may continue to be propagated through ensured survival of unfit lions by health care interventions. These interventions need to be carefully evaluated for their need and effectiveness and should be scientifically implemented before being indiscriminately used in Gir.

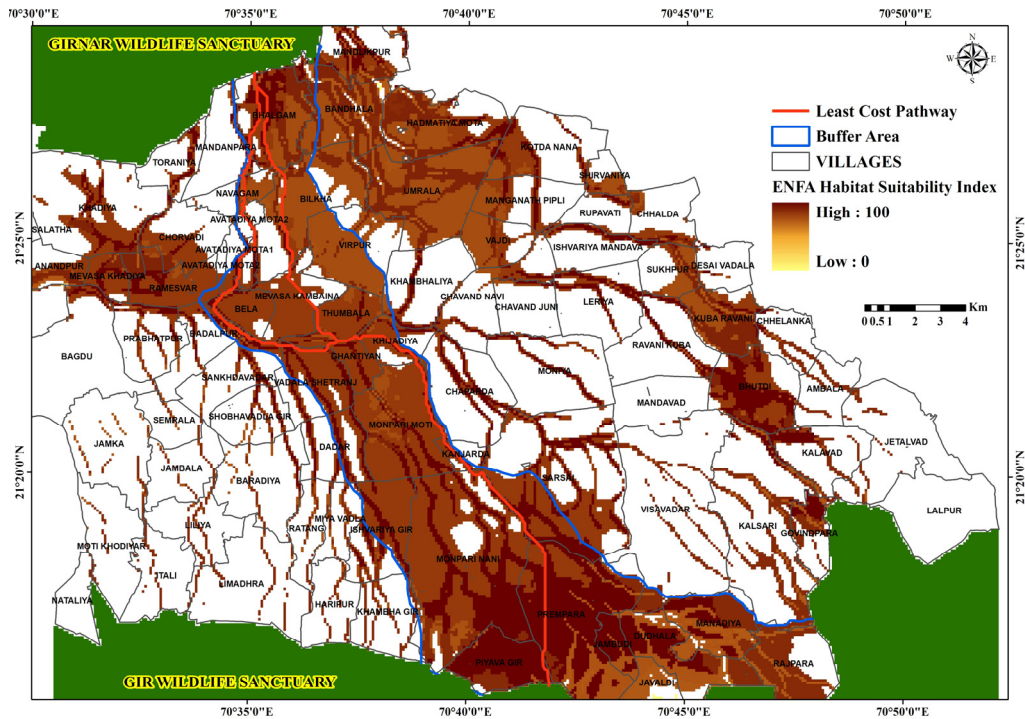
With a constant level of annual mortality, the long-term survival potential of the Girnar lions increased by 39% with habitat connectivity with the Gir PA in comparison to a non-connectivity scenario. To ensure long-term viability of Girnar lion population we delineated the potential habitat corridor between the Gir PA and Girnar (by this study, see below) and proposed the corridor to be declared and managed as 'ECOSENSITIVE' so as to curtail possible negative impacts of further developments.

Habitat suitability modeling and corridor identification between Gir and Girnar: The corridor habitat matrix between the two PAs was rapidly becoming hostile for lions and delineating the potential lion movement pathways therefore became imperative for maintaining functionality of this matrix. We performed an Ecological Niche Factor Analysis (ENFA) using GPS fixes from radio collared lions, lion signs (scats, predation events etc.) and historical *ad-libitum* lion sightings as species presence data in program Biomapper predicting lion distribution in this landscape. Outputs of ENFA was then used to calculate the resistance matrix (Habitat Suitability value) and program PATHMATRIX was used to delineate the most feasible passageway (least cost path) that lions were likely to use for movement in between these two protected areas and could be designated as functional corridor for long term sustainability of biological linkage between Gir and Girnar lion populations.

Lions exhibited preference to river channels as their passage ways. The buffered least cost pathway (**Figure E.3**) provides the minimal corridor habitat that is required to be safeguarded in a manner that its permeability to lion movement is not compromised. Wooded and shrubby vegetation functioned similarly as day *refugia* as well as passage ways for the lions in this landscape. Regular use of mango orchards and *gauchars* (pasture lands) indicated that such patches were important for lion movement in this fragmented landscape and serve as a link to other forested patches.



**Figure. E 3: Potential habitat corridor between Gir PA and Girnar Sanctuary**



As a sensible and timely attempt following the recommendations of WII, part of this corridor area (adjacent to Girnar WLS) was declared as “ECOSENSITIVE” [under The Environment (Protection) Act 1986, Government of India] by Gujarat Government with restrictions on high impact industry and mining activities. However, the other part of the corridor (bordering the Gir PA) should be made eco-sensitive urgently since key habitat connections may be lost unless they are explicitly protected. Effective land-use plans and policies that incorporate conservation principles are needed to retain landscape permeability. This would allow unaltered traditional use of gauchars (pasture lands), vidis (grasslands) and other important habitat *refugia* by local communities for livelihoods, yet their conversion into lion-hostile land uses would be regulated. The agro-pastoral Gir-Girnar corridor landscape is now being modified into towns, dams, industries and roads. Our analyses of land use and cover change processes within this corridor suggests that forested riverine patches are vanishing at an alarming rate and the remaining patches are likely to be converted to agriculture. Sustainable management of these forest fragments huddled along the riparian corridors of tributaries of the main river Ozat and other small rivers (such as Dhrafad, Ambajal, Miyaryo etc.) is urgent with a focus on lion conservation. Projected land cover



changes show a growing tendency in urban land use, threatening areas used by lions as passageways and day *refugia*. Acquiring and protecting government lands and ensuring that land-uses that act as barriers to lion movements (industry, urban sprawl, linear infrastructure like highways, high agricultural boundary walls or power fences) are discouraged or appropriately mitigated so as not to compromise the corridor value of the habitat are essential.

Lion spatial organization and resource selection: We used radio telemetry (n = 20 lions) and individual ID (n = 15 lions) to deduce lion space use, resource selection and activity patterns. A total of 5,880 hours of continuous monitoring (all occurrences) data was analyzed to understand lion activity pattern and predation. A mean of 398 (SE 124) locations/lion were used for home range analysis. Asymptotes of home range area vs. location fixes showed sample adequacy (n > 117 locations) for all lions. Non-parametric home range estimators: (a) Minimum Convex polygon (100%, 95% and 50% MCPs) and (b) Fixed Kernel (FK) contour (95%, 85% and 50%) with the reference bandwidth of a fixed proportion of 0.60 in Home Range Tools extension of Arc GIS were used to quantify annual, seasonal, diurnal and nocturnal core areas and range use by lions. Mean Utilization Distribution (UD) values were plotted on a land-use map of Global Land Cover Database to compute lion habitat use and availability. Compositional analysis was used to compute habitat preferences. Influence of different landscape variables (human habitations, cropping patterns, elevation, ruggedness, forest, major roads and river networks) on lions' selection of core areas was investigated through Analysis of Variance. Program Fragstats was used to estimate the sizes and characteristics of day refuge patch sizes for lions.

Within the Gir PA, territorial males had 2.5 times larger range (average 103 km<sup>2</sup>) than breeding females (average 40 km<sup>2</sup>) while dispersing males had about 10 times larger range (average 401 km<sup>2</sup>) than breeding females. In the eastern landscape the minimum home range size (95% FK) of territorial males [333 (SE 40) km<sup>2</sup>] was about double the size of breeding females in the landscape [193 (SE 92) km<sup>2</sup>]. Breeding lionesses within the Gir PA had five times smaller ranges than lionesses of the eastern landscape (one tailed t = 1.85, df = 14, p = 0.04). Territorial males in the eastern landscape were long ranging compared to the territorial males in the Gir PA (one tailed t = 15.57, df = 4, p < 0.001). The average core area of lions was estimated to be 166 (SE 40) km<sup>2</sup>. Average male core area [214 (SE 43)] was about 2.5 times higher than average breeding female core area [85 (SE 17)].



Average territorial tenure of males ( $n = 7$ ) was 36 (range 18 – 60) months while average estimated age at dispersal from natal pride for the sub-adult males ( $n = 6$ ) was 3.9 (SE 0.13) years. Average distances of tenure shift and dispersal of males were estimated to be 21 (SE 5) km and 16 (SE 4) km respectively. Newly established territorial males showed no or very little overlap with their natal prides, a likely mechanism to avoid inbreeding with mothers and sisters. Reduced dispersal of Gir lions compared to the Serengeti is probably because of even distribution of prey and small size of available habitats in Gir. Breeding lionesses in Gir defend resource based territories while male coalitions maximize coverage of female groups. Large coalitions may retain tenure over two or three adjacent female groups simultaneously, but sometimes abandon one female group as soon as they claim another. Thus, territorial males may be expected to maintain two or more female groups simultaneously. Old displaced males were observed to successfully re-establish territories and father cubs after spending some time as nomads. Although ranges of the adjacent female prides showed overlap [35 (SE 16) %], core areas of breeding lionesses were more or less exclusive [overlap 3 (SE 0.1) %], a pattern also observed in the Serengeti lions. Territorial overlaps between more than two male coalitions and females in Gir seem to be beneficial by reducing infanticides (confused paternity) and maximizing genetic variability of cubs. Compared to the Serengeti, Gir lions had a late activity peak (between 10:00 PM and 6:00 AM) attributable to human activities in the human-dominated landscape as well as within the Gir PA (tourism, pilgrimage, commercial activities of pastoral *Maldharis*) till late evenings. Lion hunting peak coincided with the activity peaks of wild prey [chital (*Axis axis*) and sambar (*Rusa unicolor*)] as well as with the onset and end of livestock grazing time in the agro-pastoral landscape of Gir.

Agricultural areas and dense deciduous forests composed core areas of lions in the human-dominated eastern landscape ( $\chi^2 = 23.63$ ,  $df = 5$ ,  $p < 0.001$ ). Lion core areas were observed to lie further from human disturbances [villages ( $F_{2, 1026} = 3.87$ ,  $p = 0.02$ ), townships ( $F_{2, 1026} = 3.38$ ,  $p = 0.03$ )] but were closer to forested patches of rivers ( $F_{2, 1026} = 2.86$ ,  $p = 0.05$ ), PAs ( $F_{2, 1026} = 10.97$ ,  $p < 0.001$ ) and dense vegetation ( $F_{2, 1026} = 13.17$ ,  $p < 0.001$ ). The cores were at lower elevations ( $F_{2, 1026} = 7.91$ ,  $p < 0.001$ ) and with less rugged terrains ( $F_{2, 1026} = 5.15$ ,  $p = 0.005$ ). Average day time refuge patch size of lions in the eastern landscape was estimated to be 7.5 km<sup>2</sup> (SE 0.74; range: 0.07 km<sup>2</sup> – 21.5 km<sup>2</sup>). Breeding lionesses had similar sized day refuge patches (3.8 km<sup>2</sup>, SE 1.7; range: 0.4 km<sup>2</sup> – 5.5 km<sup>2</sup>)



like adult males (7.6 km<sup>2</sup>, SE 0.77; range: 0.07 km<sup>2</sup> – 21.5 km<sup>2</sup>) [t = 0.95, p = 0.34]. Minimum patch size in which a lioness reared her cubs successfully was 4.3 km<sup>2</sup>.

The findings highlight the impact of even small vegetation patches as lion refuges. Patches greater than 4 km<sup>2</sup> were needed as breeding areas. If lions are to continue to persist in this landscape, an urgent land policy and management interventions are needed to safeguard these crucial habitats before they are removed for development as many of these patches are under private ownerships and not under the jurisdiction of the forest department.

Lion diet: Lion prey abundance in the Gir landscape was quantified through Distance sampling based on trail transects (n = 21 spatial and 60 temporal replicates; with 115 km walk effort in Girnar) and vehicle transects (n = 33 spatial and 70 temporal replicates; 941 km four-wheel drive effort in the eastern landscape). Lion feeding ecology was characterized through predation data (n = 175), scats (n = 185) and telemetry (5,880 hours of monitoring on 20 radio-collared lions) in order to address the inherent limitations of each method. Lions' food preference was computed by Jacob's Index.

Majority (70%) of kills in Girnar was composed of wild ungulates while livestock dominated (69%) the lion kills in the eastern landscape. Sambar (29%) and nilgai (*Boselaphus tragocamelus*; 29%) were predominating in lion kills in Girnar while cattle (50%) constituted majority of eastern landscape lion kills. In Girnar, percentage biomass contribution of different prey species to the lions' diet was most for nilgai (35%) followed by sambar (31%) and domestic buffaloes (20%) and lions' preferred prey as estimated by Jacob's Index was buffaloes, nilgai and cattle. In the eastern landscape, percentage biomass contribution of different prey species to the lions' diet was most for nilgai (41%) followed by cattle (33%) and domestic buffaloes (22%) and lions' preferred prey in this landscape as estimated by Jacob's Index was wild pig (*Sus scrofa*), nilgai and chital. Inter-feeding interval of lion was 3.7 (SE 0.7) days. Lions were found to feed on an average group of 2 (SE 0.22; median: 1; range 1 – 6) individuals. Telemetry data showed that livestock constituted 25% (12.5% from predation and 12.5% from scavenging) of the feeding events in Girnar while wild ungulates comprised the rest. In the eastern landscape, livestock composed 71% (20% from predation and 51% from scavenging) of lions' feeding events.

The results emphasize that despite lions' use of human dominated landscape, their dependence on productive livestock and thus conflict with local communities was minimal. Rather, lions in the human dominated landscape mostly survive by scavenging on surplus and unproductive cattle carcasses especially those from the cattle camps (*Gaushalas* and



*Panjrappoles*). Lions' dependence on nilgai in this landscape for their diet is likely to foster greater tolerance of the local farmers toward lions. Many of the cattle camps happened to be within preferred lion habitats and crucial refuge patches and thereby having higher lion densities than other parts of the landscape. Current practice of grass plantations, soil-moisture-conservation, protection from overgrazing and livestock vaccinations may be beneficial for survival of lions in this landscape.

Economics of lion-*Maldhari* coexistence: Rarely do human communities coexist in harmony with large predators. Most often communities suffer due to predation on their stock while large carnivores suffer losses and at times extirpation due to retaliation. We examine the mechanisms permitting the coexistence of Asiatic lions and pastoral communities (*Maldharis*) in the eastern part of the Gir PA. We monitored six *Maldhari* settlements during our study period to quantify seasonal livestock holding, density and losses due to predation and other causes. With free grazing rights within Gir forests, *Maldharis* offset 58 (SE 0.2) % of annual livestock rearing cost in comparison to non-forest dwelling pastoralists. With government compensation scheme for livestock predation, this profit margin augmented to 76 (SE 0.05) %. Lion density was higher in areas with *Maldhari* livestock in comparison to areas without livestock. Thus, the current lifestyles and livestock holdings of *Maldharis* seem to be beneficial to both lions and local pastoralists. Findings suggest that a combination of strict protection regime for lions, *Maldharis*' traditional reverence towards lions and the livelihood economics permit the delicate balance of lion-*Maldhari* coexistence. Indefinite increase in human and livestock population within Gir might upset this equilibrium undermining the conservation objectives. We see no end to compensation programs as they constitute a crucial element needed for human-carnivore coexistence. However, incorporating the loss in the opportunity cost within the compensation scheme may foster greater tolerance for *Maldharis*, especially of the younger generations toward lions.

Local people's perceptions to lion conservation in Gir landscape: At present Gir management and conservation communities may be overwhelmed by the success story of the lions, but this should not preclude the foresightedness in planning based on realistic future projections of conservation risks and management challenges. This necessitates an unbiased understanding of the local communities' perception towards lion conservation in the human-dominated landscape and timely revisions of the current policies whenever needed.

Based on a questionnaire survey of 680 respondents from 254 villages across the Gir landscape, the study found that attitudes to lions were more positive by younger generation



( $\chi^2 = 6.5$ ,  $df = 2$ ,  $p = 0.03$ ), economically better off ( $\chi^2 = 16.8$ ,  $df = 2$ ,  $p < 0.001$ ), farmers ( $\chi^2 = 13.1$ ,  $df = 3$ ,  $p = 0.004$ ), higher educated people ( $\chi^2 = 86.7$ ,  $df = 6$ ,  $p < 0.001$ ) and residents of Bhavnagar district ( $\chi^2 = 23.7$ ,  $df = 2$ ,  $p < 0.001$ ). Pastoralists, lower income groups, older generation, ill-educated and inhabitants of Junagadh district were more unwilling to have lions in their neighborhood in future. Economic reasons were found to be one of significant factors shaping people's attitudes about future lion conservation ( $r_s = 0.82$ ,  $p < 0.05$ ). Communities making direct and indirect economic gains from lion conservation extended more support for future lion conservation. About 10% of the respondents pointed to poaching as a probable threat to lion survival and we attribute this to their remembrance of three incidents of poaching that happened in Gir landscape in March-April 2007. Due to high price of lion body parts in international markets especially in China, the possibilities of such incident in the future cannot be overruled and respondents' opinions probably reflect this.

Our results highlight the importance of livelihood securities as major ingredient in shaping human tolerance in the Gir landscape. Since there are no tangible economic gains by living with lions in the areas outside the Gir PA, herein the Government Compensation Scheme becomes crucial in maintaining low hostility levels due to lion predation. A prompt, sensitive, and just scheme is required which addresses both capital and lost opportunity cost losses.

Lion conservation in the Gir landscape is a success story and it showcases India's conservation commitments. Over the years, Gir has become a legendary example of human-carnivore coexistence for the conservation communities around the globe. The key to such successful *model* has been effective conservation governance and traditional human values revering lions and other life forms. The current study highlights the role of an important yet hitherto overlooked ingredient of human-lion coexistence; the economics of livelihood securities. Protection and conservation of the Gir PA as the major source of lion population needs to be continued. Such strategy has already been emphasized for maintaining viable tiger populations elsewhere in India. However, in order to ensure long-term survival of lions in Saurashtra landscape the study recommends:

- i. Conservation of all vegetation patches larger than 4 km<sup>2</sup> and attempt to restore a mosaic of refuges (vegetation patches larger than 1 hectare) outside a 1 kilometer radius from villages for breeding lionesses and daytime refuge for other lions. This will minimize confrontations and potential of conflicts with humans. All identified



- core zones of lion usage in the landscape need to be offered some level of legal recognition so that they are not lost to developmental activities.
- ii. This study supported the long time debate of thickening of Gir following the cyclone of 1982 which might have happened in response to canopy opening within the protected area due to the uprooting of more than two million trees following cyclone and succession of the existing vegetation communities. This trend of increase in canopy thickening was visible till 2002, after which it stabilized.
  - iii. Girnar population of lions exists as a metapopulation sink in connection with the Gir PA. The current study delineated a corridor between Gir and Girnar used by lions primarily for movement in between these two PAs. Vegetation cover provided by drainage network, gauchar (pasture lands), farmlands and scrublands are crucial for lion refuge and movement. As a sensible attempt, part of the delineated corridor area was promptly declared as an “ECOSENSITIVE” zone under The Environment (Protection) Act 1986, Government of India by Gujarat forest department with restrictions on high impact industry and mining activities. The remaining part (towards the Gir PA) needs to be made eco-sensitive urgently.
  - iv. Riverine patches within the Gir-Girnar corridor are vanishing at an alarming rate and the remaining patches are likely to be converted to agriculture by 2020. Sustainable management of these forest fragments huddled along the riparian corridors of tributaries of the river Ozat and other small rivers is urgent with a focus on lion conservation.
  - v. Although, no study is yet conceptualized on assessing the effects of highways on the movement of lions, however, few nodes ( $n = 12$ ) have been identified, serving as bottlenecks (passageways across highways) and incorporation of crossing structures for wildlife is recommended in road-planning (widening or new road construction) in future.
  - vi. Girnar carrying capacity for lions could be enhanced by restorative management.
  - vii. *Gaushalas* and *Panjrappoles* are major food sources for lions outside the Gir PA and have significant role in minimizing conflicts with local people. Such practices need to be continued.
  - viii. Food habits of lions in the eastern landscape showed that in spite of low density of wild prey base, they form a substantial part of lions’ diet. This needs to be highlighted to gain more supports from farming communities for lion conservation.



- ix. The compensation scheme implemented in Gir for livestock depredation was good in comparison of schemes elsewhere. But regular enhancement of the scheme incorporating capital loss and lost opportunity cost should be adopted. The scheme should be streamlined with participation of NGOs for prompt and transparent implementation.
- x. Illegal practice of using electric fences by many farmers in the landscape should be addressed by introducing a compensation against crop damage. This would minimize accidental lion mortality by electrocution and reduce human-lion confrontations in the farmlands at night while farmers actively trying to defend their crops from wild ungulates.
- xi. Managing lion density below social threshold is an important issue in permitting coexistence and maintaining tolerance. Current lion density in the eastern landscape and level of conflict are well within this threshold. However, lions should be allowed to colonize new areas in Saurashtra (initially within the Forest Department owned grasslands in the areas like Gondal, Rajkot, Hingolghadh, Wankaner, Chotila, Jasdan, Rampara and up to Sayla and Muli in the north; Kutiyana, Ranavav, Barda and Porbander in the west and toward Bhal and Vallabhipur in the east) while maintaining density of about 2-4 lions/100km<sup>2</sup>.

Conserving lions as well as other wildlife in human use landscapes is essential as India does not have a land base for large PA systems that can house viable populations by themselves. Coexistence is bound to create conflict situations. Good innovative management practices to address these conflicts in a timely meaningful way so that society continues to be tolerant to large carnivore persistence in their neighborhood is the crux of large carnivore conservation in India. This study based on science will be helpful in planning development in consonance with lion conservation objectives for the general good for the society.



## CHAPTER I

### INTRODUCTION

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Global carnivores comprise of 283 extant species in 123 genera belonging to 15 families (Macdonald 2010). Large carnivores have always been a source of fascination for people and our relationships with them vary from awe and inspiration to fear and loathing. The study of carnivores has contributed substantially to our understanding of their natural history, ecological processes and human impacts on ecosystems. Conservation of large carnivores presents difficult problems as they require vast tracts of habitat due to their large ranges occurring at low densities which often competes and conflicts with other types of human interests and land uses (Schaller 1996). Over the past century, the theory and practice of conservation has evolved from strategies originally intended to preserve natural resources or awe-inspiring scenery (Callicott 1990) to an intense concern for conserving biodiversity in all its facets, including species, genetic and ecosystem diversity so as to maintain their myriad forms and interrelationships (Redford and Richter 1999). Nevertheless, our collective focus on the conservation of large predators for a complex mix of ecological, ethical and symbolic reasons has not diminished (Kellert et al. 1996). More than any other animals, carnivores have forced us to move from ecosystem theory to ecosystem management and conservation with a focal shift from species to systems and from science *vs.* management to science *and* management (Keiter and Boyce 1991). Large carnivores, thus provide the ultimate test of society's willingness to conserve wildlife (Miquelle et al. 2005) and thus have traditionally served as a charismatic flagship and umbrella species for the conservation of biodiversity worldwide (Dalerum et al. 2008).

Nevertheless, recent assessments of the conservation status of carnivores present an alarming picture of ongoing declines and range contractions, emphasizing the urgent need for informed conservation actions (Ripple et al. 2014). With the current unprecedented rate of global extinction of species being 100 times higher than natural background rates (Gittleman et al. 2001), large carnivores faced dramatic contraction in their ranges and their populations have decimated worldwide due to human population explosions and ecosystem fragmentations (Fuller 1995). For example, historically lions (*Panthera leo*) occupied a range in Africa of over 22,211,900 km<sup>2</sup> which has been currently reduced to less than 3,802,873 km<sup>2</sup> — a reduction of



83% (Ray et al. 2005; Riggio et al. 2013). Simultaneously, African lion numbers declined from little less than 100,000 in 1990 (Nowell and Jackson 1996) to a current estimate of continent-wide number of less than 40,000 (Chardonnet 2002; Bauer and Van Der Merwe 2004; Riggio et al. 2013). The situation is critical in West Africa where a recent estimate shows about 400 lions occupying about 1% of the species' historical range (Henschel et al. 2014).

Conservation scenarios become more worrying in countries like India, chiefly with an agrarian economy where conservative estimates suggest that 20% of large mammal species may face extinction, and several species have already disappeared from over 90% of their original range (Madhusudan and Mishra 2003). The pre-independence colonial policy encouraged intensive trophy and overhunting of large mammals during the 1850s to 1920s (Shakespeare 1862; Russell 1900). Situation further worsened during the two World Wars with rapid and large scale overexploitation of forest resources to meet the need of railways and telegraph systems (Divyabhanusinh 2005). With arrival of roads and firearm licenses (Champion 1934) trade in mammal body parts also expanded, and hunting became commercialized (Jepson 1937). During post-independence, India emerged as largely an agrarian country (46% of total land under cultivation) with 57% of labor force dependent on agriculture (United Nations 2006). Recent rapid economic and technological changes have improved the lives of millions but nevertheless there is tremendous political pressure to rapidly and evenly percolate those benefits among different strata of the society (Karanth and DeFries 2010). Development efforts such as large scale expansion of infrastructure, basic services such as electricity and water, urbanization, mining, dams, tourism are thus resulting in unplanned land use change and exploitation of natural resources and likely to escalate human-carnivore conflicts under different landscapes. A balanced and holistic conservation planning and habitat management based on scientific information thus becomes imperative for managing relic landscapes for conserving many of India's natural heritages including the large carnivores.

Efforts to define, predict and manage Minimum Viable Population (MVP) especially pertaining to the large carnivores have been a major focus in conservation biology in the past three decades. There are various definitions of MVP in the literature, ranging from 95% chance of persistence over several centuries (Soulé 1987) to 99% chance over 1,000 years (Shaffer 1981). A population gains more security with increasing size and number of protected demes with a MVP needing a minimal area for survival (Soulé & Simberloff 1986). This has



conservation implications in countries like India where due to high human population density and need for land, size of the Protected Areas (PA) are small in comparison to the conservation biology needs to harbor MVP of low density large carnivores. Coexistence with humans thus becomes an inevitable feature for effective conservation. When large carnivores live in proximity with humans, conflicts become unavoidable. Therefore, understanding the nature and magnitude of this conflict to design effective mitigation strategies is the essence of large carnivore conservation in India. When a Protected Area is home to the last free ranging population of an endangered large carnivore like the Asiatic lion (*Panthera leo persica*) in the Gir forests of Gujarat, western India, such information becomes extremely crucial for conservation-management, legislations and future policy makings. Currently lions occupy about 10,000 km<sup>2</sup> human-dominated landscapes with a population estimate of about 400 individuals (Singh and Gibson 2011; Banerjee and Jhala 2012). Gir PA with a lion population of about 300 is believed to have reached its carrying capacity (Singh 1997). Maintaining 500 lions as a MVP could only be achieved by protecting the source population (Gir PA) and at the same time providing dispersal opportunities by linking several metapopulations (Hanski 1994) across the agro-pastoral Gir landscape. With rapidly changing land-use pattern, ensuring long-term persistence of such meta-population framework demands robust understanding on lion ecology, conflict and socio-economic underpinnings. This long-term collaborative research project between Wildlife Institute of India and Gujarat state Forest Department has addressed some of these issues by studying ranging patterns, predation, behavior and habitat needs of Gir lions using telemetry that are likely to shape future of this endangered lion sub-species.

### **Background of the current research project**

Population decline, crisis management, stabilization, precarious recovery and sustained recovery have been described as five stages of species restoration (Linklater 2003). Currently, carnivore conservation involves a sixth stage beyond population recovery, that of managing successful recoveries of target species that exceed the carrying capacity of protected areas (Hayward et al. 2007b). During this stage, space and conflict mitigation become the principal conservation concerns (Macdonald and Sillero-Zubiri 2002; Inskip and Zimmermann 2009). Moreover, most large carnivores have low genetic diversity (Caro and Laurenson 1994). This combined with their k-selected traits such as low density, small population size, longer life histories, large ranges and fragmented habitats are considered major impediments to their conservation (Brook

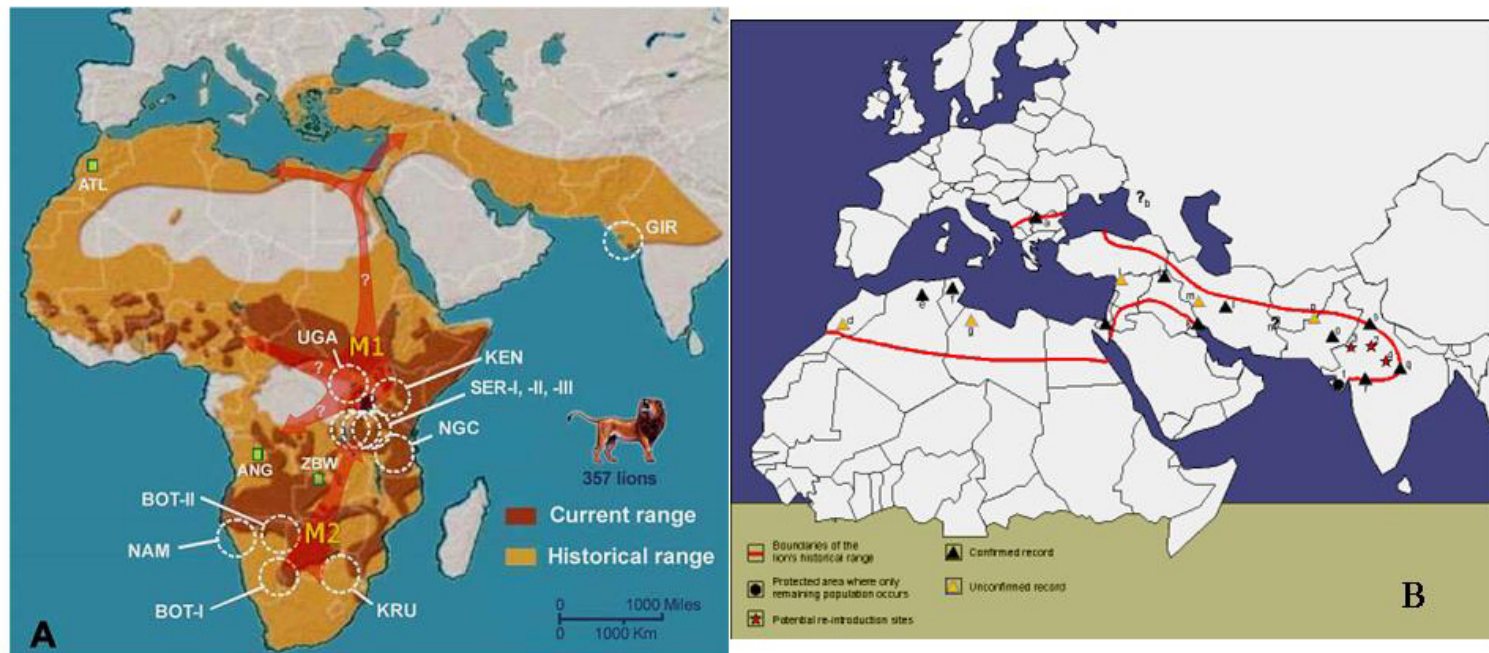


et al. 2002). The last free-ranging population of Asiatic lions exemplifies these problems (Johnsingh et al. 1998; O'Brien 2003).

With their origin in East and South Africa (**Figure 1.1**; Barnett et al. 2014; Antunes et al. 2008), Asiatic lions extended from the African Mediterranean coast into Eastern Europe, the Middle East, and into India through during the Azilian period of the Neolithic age (**Figure 1.1**; Divyabhanusinh 2005; Schnitzler 2011). Driscoll et al. (2002) suggest that about 2,680 (range 1,081 – 4,279) years ago, the Kathiawar Peninsula where the Gir forest is located was separated from mainland India by rising sea level (Gupta 1972), causing the first genetic bottleneck that isolated the founders of the present Asiatic lion population, compelling them to inbreed for several generations (O'Brien 2003). A second, less-severe bottleneck occurred at the onset of the 19<sup>th</sup> century when lions became restricted to the Gir Forests and their number declined to around 50 individuals, due to hunting and habitat loss (Edwards and Fraser 1907; Kinnear 1920; Pocock 1930; Joslin 1973). However, due to the timely and stringent protection by the Rulers of Junagadh and subsequent habitat management by the State-run forest department, Asiatic lions have increased to about 400 (**Figure 1.2**) and dispersed into a large tract of agro-pastoral landscape adjoining the Gir forests comprising of the Gir PA, Girnar Wildlife Sanctuary and vast tracts of agro-pastoral eastern landscape belonging to the revenue areas of Amreli, Bhavnagar and Junagadh districts (**Figure 1.3**; Singh and Gibson 2011; Banerjee and Jhala 2012). Drastic reduction in the numbers of isolated mammalian populations results in inbreeding which leads to an erosion of genetic diversity of the species thereby exposing it to increased risk of extinction (Terborgh and Winter 1980; Frankham et al. 2002). Apart from the negative impacts due to the loss of genetic diversity (O'Brien et al. 1987; Wildt et al. 1987) the Gir lion population also faces the multitude of threats to which small and isolated populations of endangered species restricted to a single site are subject (Gilpin and Soulé 1986).

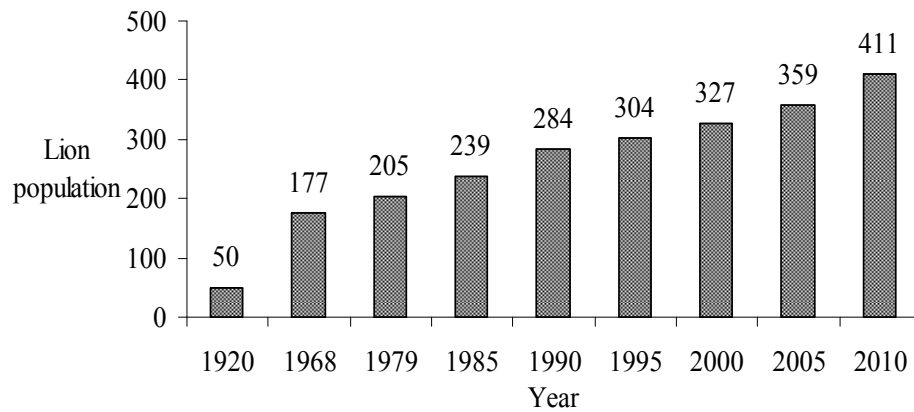


Figure 1.1 A: Historical and current geographic distribution of lion, *Panthera leo*. A three-letter code pointing to a white dotted circle represents the geographic location of the 11 lion populations GIR, Gir Forest, India; UGA, Uganda (Queen Elizabeth National Park); KEN, Kenya (Laikipia), SER, Serengeti National Park, Tanzania; NGC, Ngorongoro Crater, Tanzania; KRU, Kruger National Park, South Africa; BOT-I, southern Botswana and Kalahari, South Africa; BOT-II, northern Botswana; and NAM, Namibia. Green squares represent captive individual samples to explore the relationship of lions from more isolated/endangered/depleted areas: ATL, Morocco Atlas lions; ANG, Angola; and ZBW, Zimbabwe (reproduced from Antunes et al. 2008); B: Historical range of *Panthera leo persica* (reproduced from Nowell and Jackson 1996)





**Figure 1.2: Population trend in Asiatic lion as per census report of the Gujarat Forest Department.**



Change in traditional land-use pattern following the human population explosion in India, has taken a big toll on traditional grazing pastures and unprotected forests. In case of Gir, the forest cover had declined from 3,100 km<sup>2</sup> at the turn of the 20<sup>th</sup> century to 1,412 km<sup>2</sup> till it was declared as a Sanctuary in 1965 (Singh and Kamboj 1996). As a consequence of rapid disappearance of pasturelands, a large population of livestock nowadays thrives on protected forest areas. Prior to 1972, there were 137 pastoral settlements distributed throughout the Gir Protected Area (PA) (Berwick 1974). After creation of the Gir Sanctuary, three major ecological studies were carried out in Gir by Hodd (1970), Joslin (1973) and Berwick (1974) which were followed by several managerial inputs like removal of several pastoralist settlements, imposing a total ban on migrant livestock and creating a national park of 256 km<sup>2</sup> in the core of the Gir PA. Unfortunately, the resultant ecological change in the ecosystem was not systematically monitored on a long term basis until 1986 (Dave 2008). At this stage, Asiatic lions provided an excellent opportunity that caters to all the mandates of the Wildlife Institute of India (WII) and Gir became a research stronghold for WII almost since its inception in mid-1980s. A number of ecological researches were carried out pertaining to lion ecology, prey-habitat relationship and lion-human conflict until 2006-07 (Chellam 1993; Khan 1993; Sharma 1995; Jhala 2004; Dave 2008; Meena 2008). Information generated by WII's research projects contributed significantly in drafting various Biodiversity Management Plans for the Gir ecosystem (Singh and Kamboj 1996; Pathak et al. 2002). However until then, ecological information was still lacking on satellite lion populations. To check the potential ill-effects of rapid changes of traditional land-use patterns in the Saurashtra landscape and safeguard long-term viability of lions, formulation of a landscape



level lion conservation policy based on robust science became imperative. At this stage, WII in collaboration with Gujarat state forest department undertook the current project “Ecology of lion with emphasis on the agro-pastoral landscapes of Greater Gir ecosystem” in 2009 to investigate lion population dynamics, ranging, resource selection and aspects of human-lion conflicts in multiple-use Gir landscape.

**Research objectives:** The study primarily aimed at engendering ecological information on lion populations across Gir landscape and assist the Management to develop a regional lion conservation plan. The project objectives were therefore decided after much deliberations with the park managers. The research intended to address the following objectives:

1. Lion abundance, population structure and demography in the Gir landscape.
2. Lion ranging, dispersal and resource selection in the Gir landscape.
3. Lion diet in the Gir landscape.
4. Evaluating aspects of lion-human conflicts in the Gir landscape.
5. High resolution mapping of Gir Landscape to better understand the factors responsible for animal distribution patterns and land use patterns.
6. To develop habitat suitability models for lions and principal prey species.

The first phase of the research project was completed in 2011-12 and the project findings were communicated to Gujarat Forest Department (GFD) and Training, Research and Academic Council (TRAC) of WII through two technical reports (Jhala et al. 2011a; Jhala et al. 2012b). Findings were accepted by GFD and TRAC-WII and based on that field permissions and fund extensions were provided to study lion ranging in the coastal populations. WII had seven lion radio-collaring permits remaining out of 20 granted by the Ministry of Environment and Forests (New Delhi) and Office of the Chief Wildlife Warden, Gujarat state (Gandhinagar) in 2005. However, owing to WII’s research involvement in Kuno Wildlife Sanctuary, Madhya Pradesh and input in ongoing lion reintroduction legal battle in the Supreme Court, radio-collaring lions were not permitted at local official levels (Junagadh and Sasan) after 2011. Field works for other research components were also not facilitated. Therefore, studying the coastal lion population and estimating abundance of co-predators within the Gir Protected Area could not be accomplished as committed. However, we continued with studying lion ranging and resource selection based on already radio-collared lions before 2011 and achieved quantifying lion diet (prey abundance and preference) and aspects of lion-human conflicts during the second phase of the research project. On formal requests from the Gujarat State Lion Conservation Society and Chief Wildlife Warden, we



also addressed two additional research components during the project tenure: 1) assessment of potential habitat corridor landscape between Gir and Girnar and 2) estimation of leopard (*Panthera pardus*) abundance in Girnar Wildlife Sanctaury. The findings of those studies were already communicated to GFD through two technical reports (Jhala et al. 2012 a, c).

### **Organization of the current report**

The current report is divided into following chapters:

**Chapter 1: Introduction** – elucidates the background of the current study and highlights the research objectives.

**Chapter 2: Study Area** - illustrates the study landscape and provides relevant information about the geography, geology, climate, hydrology, ecological features and socio-economic background of the entire landscape.

**Chapter 3: Landscape architecture of Gir Protected Area and its surroundings** - describes the current landscape pattern of the Gir wildlife sanctuary. It provides detail of the vegetation community structure found in Gir and its spatial distribution.

**Chapter 4: Variations in the landscape patterns and vegetation cover in Gir PA** - details about the landscape dynamics in a ten year framework and summarizes the pattern of changes occurred in the landscape.

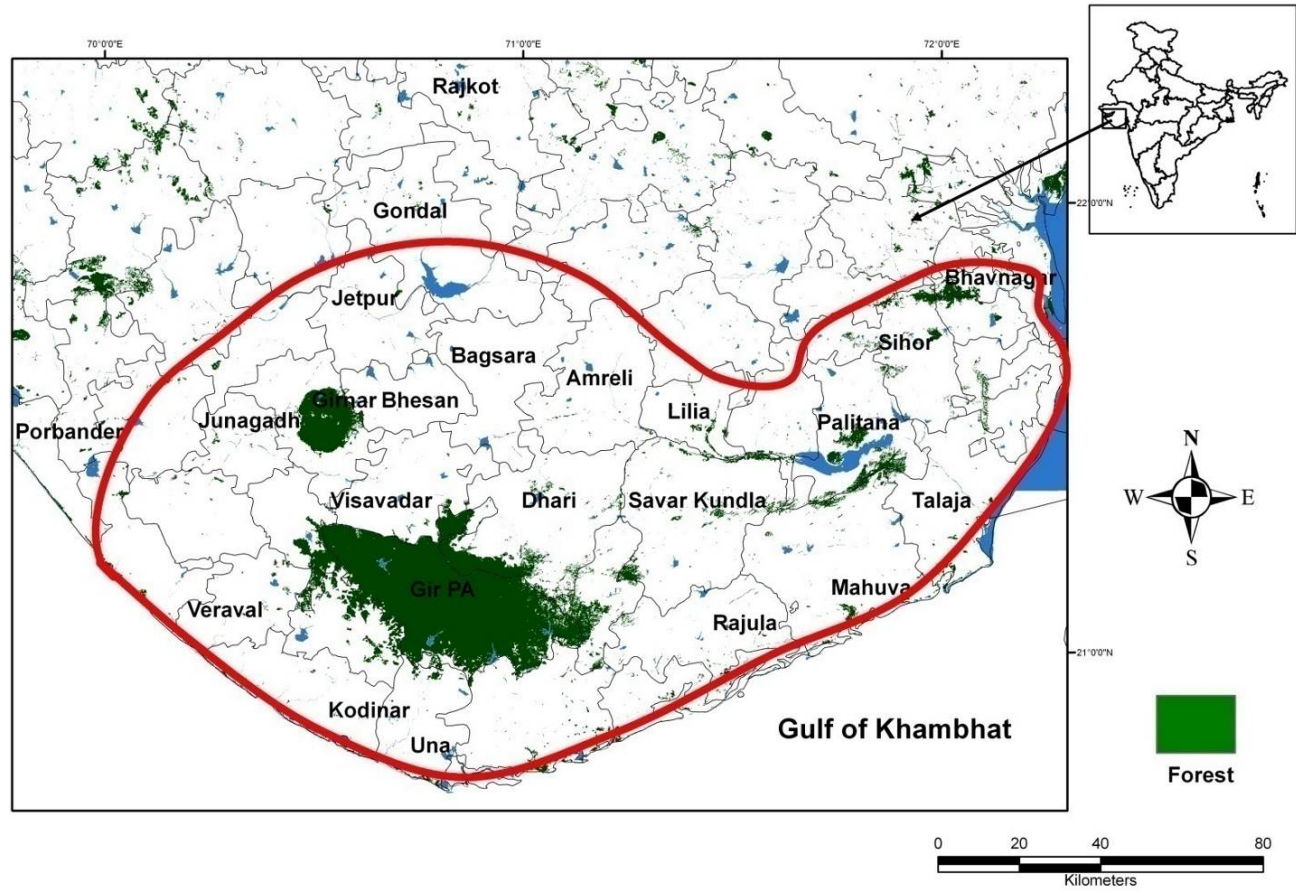
**Chapter 5: Lion abundance and population structure** - deals with estimation of lion abundance and population structure and discusses their importance in the conservation-management of the Gir lions.

**Chapter 6: Habitat suitability modeling and corridor identification between Gir and Girnar wildlife sanctuary** - describes the management of the agro-pastoral landscape between Gir and Girnar wildlife sanctuary.

**Chapter 7: Lion demography** - deals with lion demography and discusses the underlying conservation significance.



Figure 1.3: Current *tehsil* level distributions of Asiatic lion in Gujarat state, India. The map inset shows outline map of India with location of the Gir landscape. The red boundary indicates areas most frequented by lions.





**Chapter 8: Lion spatial organization** - deals with lion ranging and movement and discusses their significance in the context of mitigating conflicts.

**Chapter 9: Lion habitat use and resource selection** - deals with lion habitat usage and resource selection and emphasizes the urgent needs of conservation of the critical lion habitat patches in the Gir landscape.

**Chapter 10: Lion diet** – evaluates lions’ diet in the landscape through a combination of methods and uses this information to evaluate human-lion conflict.

**Chapter 11: Economics of living with lions** – investigates aspects of lion-human conflicts and discusses drivers behind legendary lion-*Maldhari* (pastoral communities in Gir) coexistence.

**Chapter 12: Assessment of people’s perception for lion conservation in the Gir landscape**



## CHAPTER II

### STUDY AREA

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The study was carried out in about 10,000 km<sup>2</sup> Greater Gir Landscape (**Figure 1.3**) spreading over 18 *talukas* of three districts of Saurashtra peninsula of Gujarat, western India. The entire landscape is divided into:

1. Gir Protected Area
2. Girnar Wildlife Sanctuary and
3. Agro-pastoral Eastern Landscape

#### 1. Gir Protected Area

##### *History, Location and Size*

In general, 'Gir forest' term is used synonymously with the Gir National Park and Wildlife Sanctuary, but the ecological boundaries of Gir a couple of centuries before covered half of the Saurashtra peninsula (Divyabhanusinh 2005). Due to increased cultivation and developmental activities Gir forest has shrunk to almost the legal boundaries of the protected forest areas. Gir National Park and Wildlife Sanctuary lies between 21° 20' N to 20° 40' N and 70° 30' E 71° 15' E. The total area under protection as sanctuary (1153.42 km<sup>2</sup>) and National Park (258.71 km<sup>2</sup>) is 1412.13 km<sup>2</sup> (**Figure 2.1**). Recently the Chachai-Pania wildlife sanctuary (39.64 km<sup>2</sup>) at the northern boundary of Gir PA has also been included as part of the Gir Conservation Unit (GCU). Additionally, there is a buffer area of reserved forest (245.90 km<sup>2</sup>), protected forest (107.51 km<sup>2</sup>) and unclassed forest (77.19 km<sup>2</sup>) comprising of valuable grassland and forests (Pathak et al. 2002). The Gir protected area is divided into three managerial zones viz. Sanctuary west, Sanctuary East and National Park. Due to a rainfall gradient increasing from east to west, these three zones differ ecologically which reflects in the vegetation types (Qureshi and Shah 2004) and associated productivity. The Gir reaches its greatest length of 80 km along the east-west axis, whereas north south width is 16-24 km, on an average, except eastern and western ends. Gir is located about 50 km from Junagadh in south west and 75 km from Amreli in south east, headquarters of adjacent districts. The coast line is 25 to 50 km away from southern park boundary.



Over the past 100 years the Gir has been reduced to about a third of its former size and the PA covers most of the extant forests (Government of Gujarat 1975). In a previous study, Santapau and Raizada (1956) estimated around 2560 km<sup>2</sup> area under forest cover which was significantly contributed by the revenue forests. Later, Joslin (1973) reported 87% decline in forest cover outside the sanctuary area between 1872 and 1969, mostly for cultivation purpose. Uncontrolled commercial exploitation of forest resources and increasing demand for cultivation land by the expansion of human settlement led to continuous decline in the area under the forest cover. It was not until 1920 that a small portion of Gir forest (Devalia Block in the south-western boundary of the Gir PA) declared as a lion sanctuary by the erstwhile *Nawab* of Junagadh. After independence, in 1965, the Government of Gujarat constituted the Gir Wildlife Sanctuary and later it was expanded in 1974 to present size of the PA. Subsequently, a tract of land nearly 150 km<sup>2</sup> was declared as a national park in 1975 and enlarged to its present size in 1978.

### ***Topography***

The terrain of Gir includes the undulating surface with rolling hills of low to moderate height traversed with several perennial rivers, which altogether compose a beautiful landscape for Gir. The altitude ranges from 100 m MSL to 648 m (Sarakala hill on the northern boundary of Gir PA). The Gir has undulating terrain, varying across the park. Central part of Gir has a more hilly terrain when compared to the rest of the park. The terrain has been classified into the following categories (Chellam 1993): flat plain; gentle slope; steep slope; hill top; river bed; and reservoir bed. The physiography is intersected by narrow seasonal streams. The drainage is mostly from North to South and the PA is split up by watersheds from which stream run to all points of the compass and feed the six major perennial rivers viz. Hiran, Singawada, Machhundri, Jatardi, Ghodawadi and Rawal. These rivers have a perennial supply of water and it is the abundant supply of water and grazing that have made the Gir reserve as the centre of cattle rearing and breeding. The flow of river is southward in most cases, which has made southern fringe of the Gir, the most irrigated and productive tract of the Saurashtra peninsula.

### ***Geology and Soil***

The chief geological formation of the Gir is deccan trap occurring as acidic and basic dyke formations. The formation of the hills consists of traps (basalt) of varying composition associated with granite and gneiss, overlaid by beds of calcareous sandstones, which in part assumes the nature of limestone (Santapau and Raizada 1956). In the Gir, soil ranges from lateritic in the



northern and eastern parts to black cotton in the southeast and along many of the plains. The local variations are erosion; deposition and the effect of vegetation cover have introduced many other changes, resulting in the formation of a number of intermediate types (Wynter-Blyth 1949; Puri et al. 1983). The black cotton soil, in the bottom land is the most common and suitable for dry land agriculture, as it retains moisture for a long. The red-brown soil originates from rock weathering and is found in the hills, it is poor for agriculture as it is rich in iron.

### ***Climate, Seasons and Rainfall***

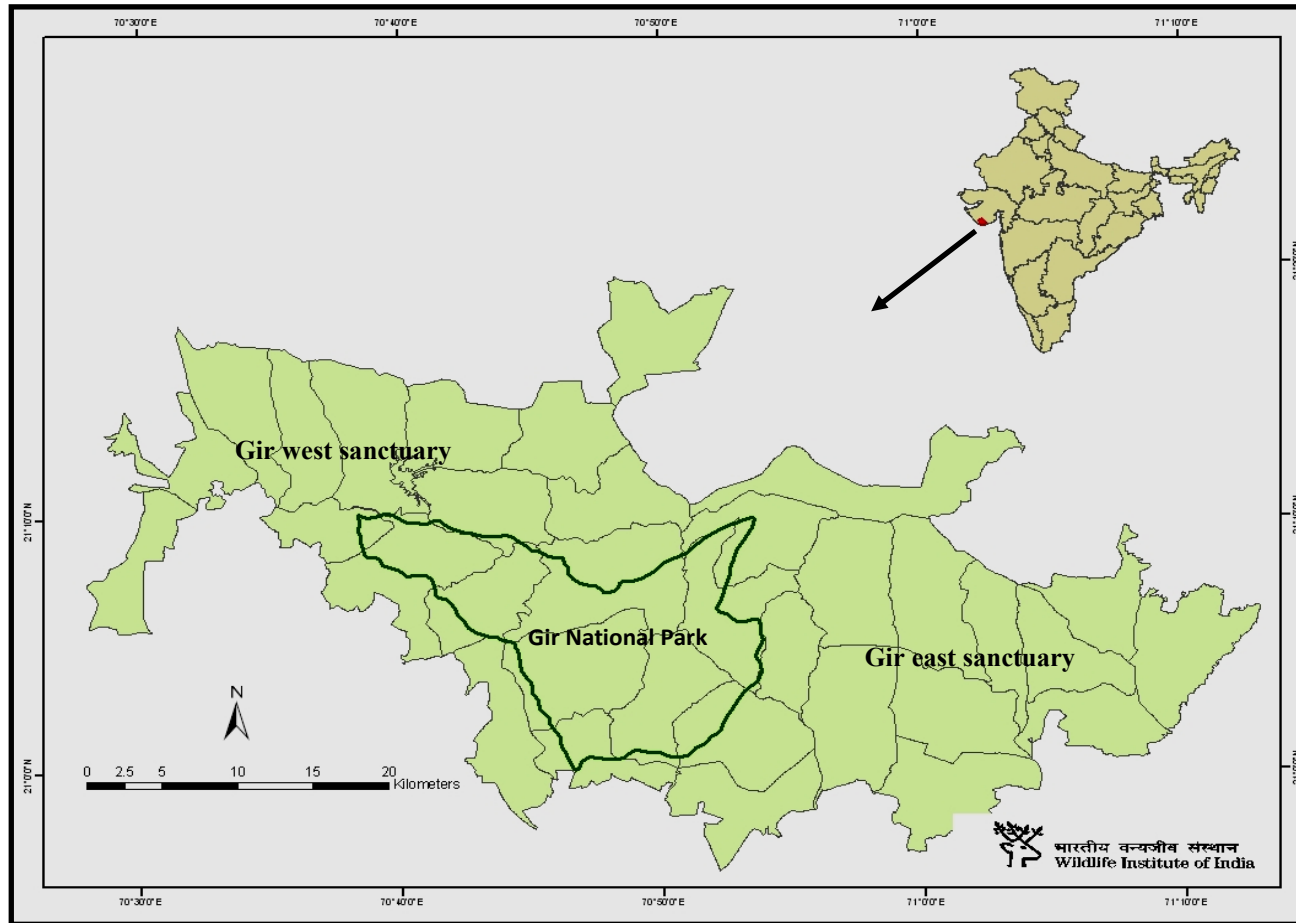
According to Koppen's (1931) classification, the area comes under 'Tropical Savanna' climate. As a whole it is hot and humid during and after monsoon season. Rainfall is brought by south-westerly winds from Arabian Sea during monsoon season between June and September. There is a distinct dry spell in winter but pretty heavy dewfall is common.

The area experiences three distinct seasons as the other part of the country. There is cool dry winter in Gir from December to March (average minimum temperature 9 °C.) followed by a hot dry season (average maximum temperature 42°C), which lasts until mid-June. The monsoon breaks in June and continues till September and is followed by a dry post monsoon season till mid-December.

The average rainfall based on the past 28 years data from the western part of the sanctuary and 10 years data from the eastern part of the sanctuary are approximately 1000 mm and 800 mm, respectively (Khan et al. 1996). The rainfall gradient increases from east (850 mm at Jasadhar) to west (1000 mm at Sasan). However, the annual variation in rainfall is large. About 94 % of the rainfall is received during monsoon, with July – August being the maximum rainy months. On an average there are 40 rainy days in a year. Long dry spell during monsoon is common. Moreover, the area is roughly affected by a 4 year drought cycle.



Figure 2.1: Gir PA comprising of Gir National Park and Wildlife Sanctuary in Gujarat, western India. The Map inset shows the geographic location of the Gir Protected Area (PA) within India.





## Vegetation

The floral wealth of the Gir forest includes some 500 flowering plant taxa (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). Gir comprises one of the largest compact tracts of dry deciduous forest, which falls under the 5A/C1b forest subtype (Champion and Seth 1968).

Gir vegetation was classified into three broad classes namely Moist Mixed vegetation, Thorn forests and Hill forests which were further divided into eight types (**Table 2.1, Figure 2.2**) (Qureshi and Shah 2004).

**Table 2.1: Percent contribution land use within Gir Protected Area (Qureshi and Shah 2004).**

Vegetation Type	Percent Area
Wetland	0.69
Moist Mixed Forest	12.76
Mixed Forest	16.95
Teak- <i>Acacia</i> - <i>Zizyphus</i>	29.71
<i>Acacia</i> (Teak)- <i>Anogeissus</i>	13.38
<i>Acacia</i> - <i>Lannea</i> - <i>Boswellia</i>	12.54
Thorn Forest	7.73
Scrublands	4.48
Savanna	1.38
Agriculture/Open Area	0.29

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*, *Zizyphus* spp., etc. The under storey 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*, *Mallotus philippinensis* etc. The under storey 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 under storey is composed of *Capparis 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).

### **Fauna**

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 lion some of the other



carnivores are leopard (*Panthera pardus*), jungle cat (*Felis chaus*), striped hyena (*Hyaena hyaena*), jackal (*Canis aureus*), Indian fox (*Vulpes benghalensis*), ratel (*Mellivora capensis*), mongoose (*Herpestes edwardsi*), small Indian civet (*Viverricula indica*) and rusty spotted cat (*Prionailurus rubiginosus*). Major herbivores include chital (*Axis axis*), sambar (*Rusa unicolor*), nilgai (*Boselaphus tragocamelus*), four horned antelope (*Tetracerus quadricornis*), langur (*Presbytis entellus*) and chinkara (*Gazella gazella*) (Singh and Kamboj 1996).

### ***People and human settlements***

The PA is subjected to biotic pressure from 97 peripheral villages (human population of approximately 150,000 and a livestock population of 95,000) (Singh and Kamboj 1996). Within the PA, there are 52 *Maldhari* settlements [*nesses*] (333 families with a human population of about 2,300 and livestock population of about 12,000) and 14 forest settlement villages (human population of 4,500, nearly 4,200 livestock) (Singh 2007). Each family rears about 20-100 regionally famous breed of livestock, primarily Jafrabadi breed of buffalo and Gir breed of cattle. Often one or two camels are also kept for carrying fuel wood and fodder. The sale of dairy products has always been the mainstay of their traditional economy (Varma 2009).

Gir forests are inhabited by trans-nomadic, multiethnic pastoral communities, called *Maldharis* for past one and a half century (Casimir 2001). Their main religion is Hinduism and they have strong religious ethics and sentiments towards nature and natural resources. *Maldhari* is not a traditional tribe but an occupational community comprising different livestock holding castes. They are kind, hospitable and courageous folk. The life of *Maldhari* is closely woven with the natural cycles, the wildlife and their cattle. Being vegetarian they cause no direct harm to wildlife (Raval 1991). Through years of close association with the wildlife they have developed a traditional way of living alongside the local wildlife. *Maldharis* live in semi temporary habitations, called '*ness*'. A *ness* is usually a small cluster of huts made out of mud and locally available timber. Usually, *nesses* are situated close to perennial water sources. The livelihood of *Maldhari* solely depends on cattle rearing. They used to sell *ghee* (purified butter) traditionally but due to recent development in transportation and increase in their access of peripheral towns, they have started selling milk to nearby towns (Berwick 1990; Varma 2009).



## 2. Girnar Wildlife Sanctuary

### *History, Location and Size*

This newly formed Protected Area (c.a. 180 km<sup>2</sup>) (Government of Gujarat 2008) of Gujarat is a famous and historical site of pilgrimage for both Hindus and Jainas and the highest hill feature in Gujarat. Mount Girnar is visited by around 0.9 million pilgrims annually (Parmar 2005). The town of Junagadh is situated practically at the foot of these hills to their west. These hills lie between the parallels of latitude 21 .25' and 21 .35' N and longitude of 70.30' and 70.40' E. Looked from above, the forest area looks like a circular disc of about 16 km (Parmar 2005) diameter (**Figure 2.3**). Locally these forests are also known as *Dungar*. Girnar forests were once part of a major forest ecosystem comprising of Gir and Girnar. Gradually the urbanization and economic activities caused by major agricultural invasion and industrialization have isolated these two forests converting Girnar as an isolated compact patch of forested habitat.

Till the year 1905, these forests were managed under “Dan” (Royalty) system, during the time of ‘Mahers’ of Padaria, Dadevadar, Derwan, Paswala and Mandalikpur villages (Dharaiya 2001). These Mahers were the retainers of the State and managed the forests by recovering “Dan” for the produce removed and in lieu thereof rendered services to the State on occasions of outlawry. The State, however, reserved to itself the sovereign right over the entire forest and the rights to remove any forest produce at any time for the purpose of the State free of “Dan”. In the year 1865 or there about, the State took over the entire management of the forest but the “Dan” system was continued for some more time (Parmar 2005). In the year 1913 erstwhile Junagadh state started the management of Girnar forest and prepared a management plan.



Figure 2.2: Vegetation types in Gir Protected Area and its 1 km surrounds (source: Qureshi and Shah 2004).

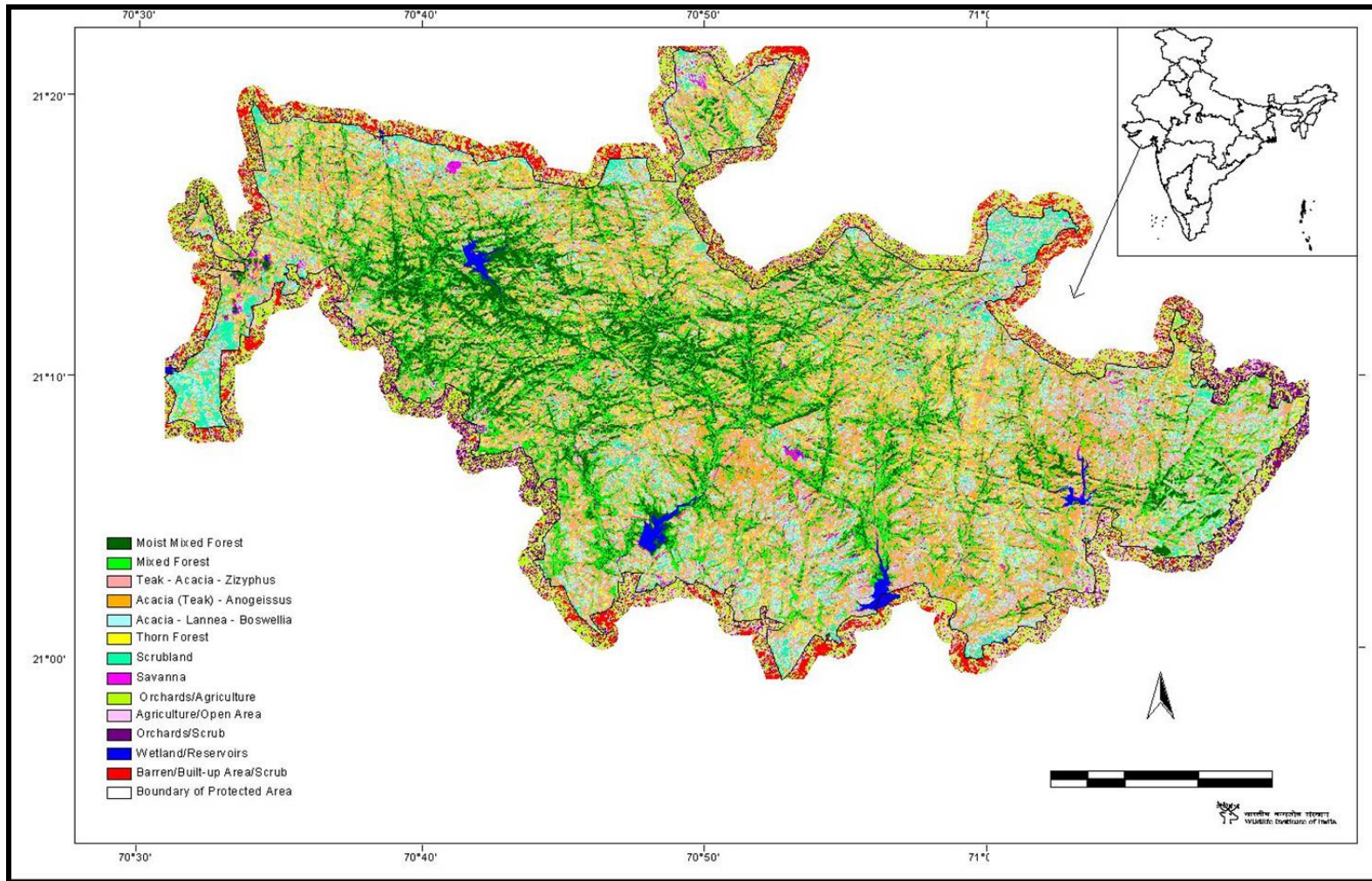
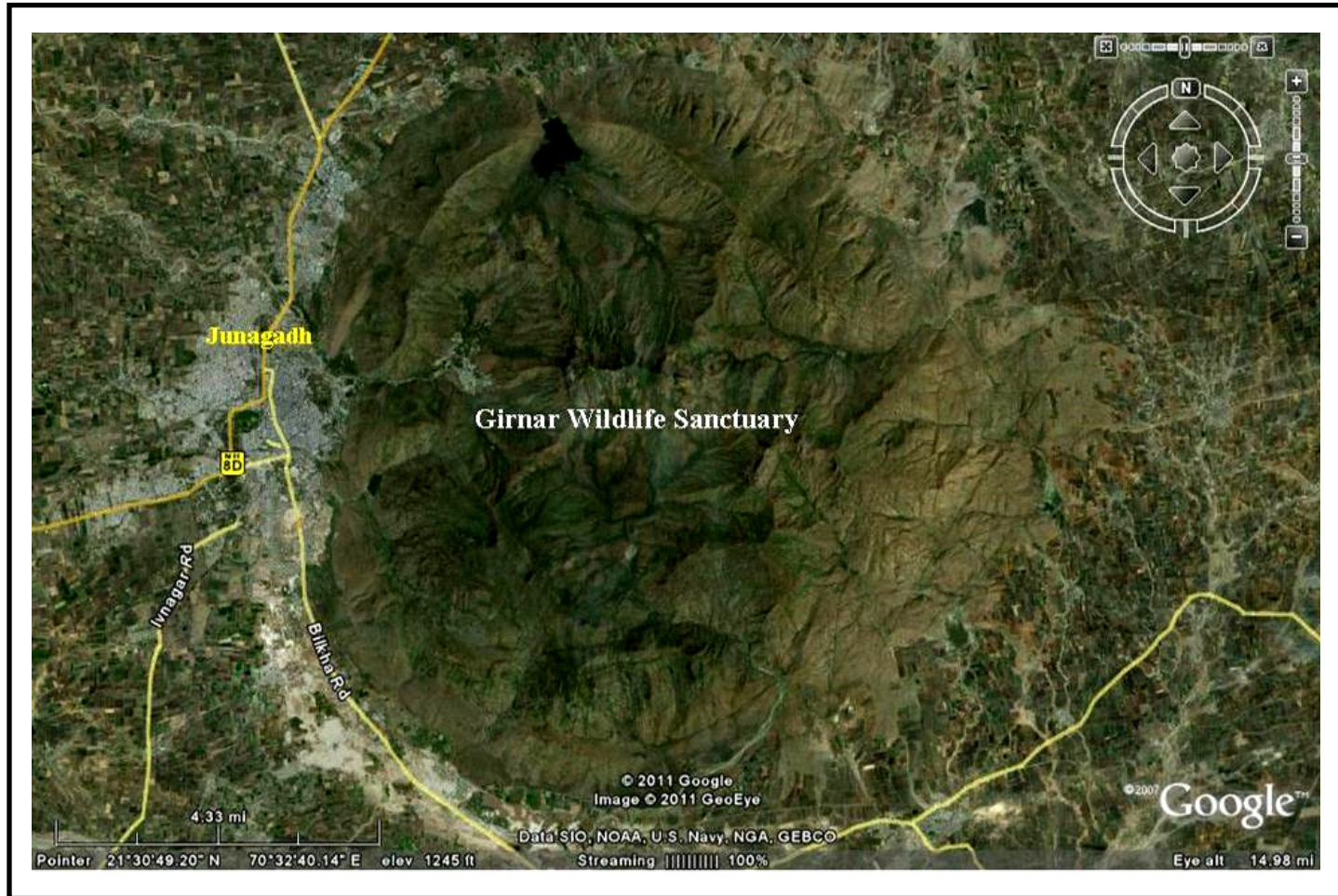




Figure 2.3: Google Earth image of the Girnar Wildlife Sanctuary. Junagadh city mark the western boundary of the sanctuary. Surrounded by human dominated landscapes from all sides, sanctuary boundary of the Girnar forms a ‘hard’ boundary (Banerjee et al. 2010).





### ***Topography and terrain***

There is very little flat or undulating area in the Girnar forests. The Ground is extremely hilly and rugged with moderate to very steep slopes. The sanctuary is surrounded by flat, arid and extensively irrigated agricultural land and forms a vital watershed in Junagadh district. Parmar 2005 roughly classified terrain as:

- Hill top
- Steep slope
- Gentle to moderate slope
- Flat plain
- River bed
- Reservoir bed

The Ground is extremely hilly and rugged with moderate to very steep slopes which frequently pass into precipitous inclines. The higher portions of the centrally situated Mount Girnar serve at places a sheer perpendicular wall. This magnificent mass rises in the center to a maximum height of 1,117.4 meters, the highest point of Gujarat and lies east-west covering a basal area of 8 Kilometers long and 2 kilometers wide. Along its east-west length lie seven famous peaks, *viz.* Uparkot, Ambaji, Gorakhnath, Oghadnath, Guru Dattatraya; Ansuya and Kalika (1,004.3 meters). Most slopes on this mount are precipitous and supporting little tree growth. It is girt by almost a broken series of smaller hills lying within a radius of 4 km from its central peak Gorakhnath.

The Surroundings hills vary in height from 460.8 meters (Dhrubakio) in the North-East to 847.0 meters (Datar Pir) in the south-west. The Prominent hills lying in this griddle are adodunger (579.1 meters) and Bhenslo of Pitalia Kotha (679.9 meters) in the north and north-east respectively; Lasa Pavan (770.2 meters) and Ranamerno-pano in the east and the south-east respectively; Gadhekot and Jogania (558.0 Meters) in the west and south-west respectively. The continuity of this griddle is broken by four gorges which form the only outlets to the drainage of the enclosed area.

This girdle is joined with the central Mount Girnar Hills by 300-450 meters high radial squares at four places deciding the circular valley lying between the central mountain and its surrounding hills into four small lays. Each valley is like a huge bowl with griddle. The radial spurs and the central mountain forming its walls. The valleys so formed are known as the



Hasnapur, Bhavnath, Bordevi and Surajkund valleys. A number of smaller valleys of Kalagadba, Mathura, Ramnath and Dungarpur are also formed on the other side of the griddle. All aspects are represented in the Girnar Hills. There is very little flat or undulating area in the Girnar forests.

The Girnar Forest has few seasonally flowing rivers, namely, the Lol, the Sonarekh of Surajkund, the Gudajali and the Sonarekh of Damodar, besides large nallas of Dhedia in the south and Kalwa in the west. Water in these nallas and rivers dries up during summer. However there are few deep water pools along their course where water lasts all the year round. Reservoirs have been created on the river Lol near Hasnapur, Wilingdon reservoir on the Kalva near Junagadh city and the Khodiyar and Sipariya reservoirs on two nallas near Datar Pir on the Datar Hills. All the reservoirs are maintained for the purpose of supply of drinking water to the town of Junagadh.

### ***Geology and Soil***

The Girnar appears to have been produced by a volcanic eruption of considerable magnitude towards the close of the Deccan trap period. The outer portions have been more readily removed by denudation, owing to the decomposition of the component materials. The central peak is formed of diorite, having much the appearance of syenite. Two other varieties of diorite occur on the basal and outer portion of the central pile. The rock occupying the valleys between the central mountain and the surrounding ranges is a third variety of diorite and is remarkably prone to decomposition.

The soil on the upper hills slope is generally shallow, very strong and of a reddish white color. Higher hill tops like the Mount Girnar are generally rocky and devoid of any soil resulting into very scanty vegetation. On the inner lower slopes and valleys fairly deep black cotton soil is found. At places soil is fairly deep supporting good forests. Red lateritic and clayey soils are found in smaller proportions. Clayey loam is also met with though in less proportions. Humus is absent except in the lower most slopes on large hills and hollows in the valleys.

### ***Climate***

Climate of the area is generally dry. The tract experiences, in fact, only two seasons hot and cold. The monsoon, which has few rainy days, merges with the hot period, which extends from the middle of February to the end of October, the remaining period from November to mid-February forming the cold season. Monsoon generally sets in by the first week of July. July and August



are the two months when maximum, three-fourths, rain falls, June and September are the marginal months. The monsoon in the area is not dependable. The distribution of rainfall and number of rainy days vary widely over years. The average rainy days in a year were 43-65. Monsoon generally breaks out by the end of June and continues up to middle of September, with maximum concentration in July and August. The monsoon is very irregular and erratic. Every fourth year is almost a year of drought. During the year 1989 to 2003 average rainfall of Junagadh was 697.11 m.m. Maximum rainfall was 1164 m.m. in the year 1994 and minimum rainfall was 299 m.m. in the year 1999. The temperature range varies greatly. The mean variation in temperature is high and the maximum temperature is 41<sup>o</sup> C and minimum 7<sup>o</sup> C, the hottest month being May-June and coldest being Dec-Jan.

### ***Vegetation***

The Forests in general, falls under Type VII-A/C-I 'Southern Tropical Dry deciduous-dry Teak forests' of Champion and Seth (1968) classification under the Biogeographic Zone 4B-Gujarat Rajputana of the semi-arid biotic province of Rodgers and Panwar 1988 Classification. They appear to be in continuation of the same type found extensively in the Gir forests. In the Past century these two forests were not separated by the present intervening agriculture expanses.

Girnar forest can further be classified into the following vegetation types (Parmar 2005) as:

**Type 1- Teak Forests:** This type occurs on the foot hills adjoining the plains and on lower slopes. The associated species include *Dispyros Melanoxylon*, *Terminalia tomentosa*, *Grewia tiliaefilia*, *Dalbergia latifolia*, *Moringa tinctoria*, *Butea monosperma*, *Albizia odoratissima* and *Albizia lebbbeck*.

**Type 2- Miscellaneous forests:** This type occurs in the eastern outer periphery of the Girnar Forests and between the altitudes of 300 meters to 600 meters. These forests are found on the lower altitudes, especially on the eastern periphery. The associated species include *Tectona grandis*, *Terminalia tomentosa*, *Diospyrous melanoxylon*, *Lanea coromandalica*, *Dalbergia latifolia*, *Emblica officinalis*, *Acacia arabica*, *Acacia catechu*, *Wrightia tinctoria* and *Dichrostachys cinerea*.

**Type 3- Scrub forests and grasslands:** This type is found all the degraded patches in the plain area on the hill tops and along the ridges. Bamboo occur scattered in pockets. *Nyctanthes arbortristia* bushes, *Strobilanthes* spp. and *Dichrostachys cinerea* are some of the typical species of the type. Along the outer boundary, *Butea monosperma* and thorny bushes are the



main species of this subtype. Along nallas compositions is remarkably different where species like *Manikara hexandra*, *Mitragyna parviflora*, *Ixora arborea*, *Gardenia resinifera* and *Moringa oleifera* occur. Thorn forests on further deterioration turns into savannah forests characterized by large grassy open blanks with very sparse and poor thorny scrub forests. Both annual and perennial grasses are found in these areas. Major grass species include *Iseilema prostratum*, *Dichanthium annulatum*, *Sehima sulcatum*, *Bothriochloa intermedia*, *Aristida funiculate*, *Iseilema laxum*, *Themeda cymbaria*, *Apluda mutica*, *Heteropogon contortus*, *Cymbopogon jawarancusa*, *Cymbopogon martinii*, and *Sorghum helepense*

### ***Fauna***

Girnar is rich in floral diversity with 537 plant species belonging to 97 families (Parmar 2005). 2010 lion census reported a resident population of 24 lions in this sanctuary (**Table 2.2**), while a mark-recapture density of 6 adult lions/100 km<sup>2</sup> was obtained in 2008 (Banerjee et al. 2010). Apart from lions, Girnar forest harbors 37 other mammalian species, 38 species of herpetofauna and more than 300 species of birds (Parmar 2005).

### ***Religious pilgrimage***

Girnar and Datar hills are famous pilgrimages for Hindus, Jainas and Muslims. There are 19 religious places on top of the Mountain Girnar (Parmar 2005). In order to facilitate pilgrims to reach there easily, there are 9,999 stairs (locally known as *Pagathia*) from Bhavnath Taleti to climb Girnar. On an average 1,000 pilgrims climb Girnar daily, the number reaches as high as 5,000 on weekends and other holidays and a total of around 0.9 million pilgrims climb Girnar yearly (Parmar 2005). In 2009 an estimated 0.25 million pilgrims climbed Girnar during *Parikrama* (a festival held in October-November when pilgrims perambulate around the Mount Girnar in three days) and 0.15 million people visited Girnar during the *Maha Shiva Ratri Mela* (another week long big festival held during February-March) (A. Karn, Deputy Conservator of Forests-Junagadh, personal communication).

### **3. Agro-pastoral eastern landscape (EL)**

This eastern revenue belt of Savarkundla-Palitana (including Ambardi Reserve Forests and 18 km<sup>2</sup> Mitiyala Wildlife Sanctuary) is comprised of large tract of agro-pastoral landscapes of the Junagadh, Amreli and Bhavnagar districts and situated to the north, east and north-eastern part of the Gir PA. EL is located between the co-ordinates triangle of 21°30' N-70°42' E, 21°30' N-71°54' E and 21°06' N-71°12' E (between the townships of Bilkha-Visavadar-Mendarda in the



west, Palitana-Talaja-Sihor in the east, Dhari-Bagasara-Amreli in the north and Khambha-Nandivela in the south). Administratively, EL is constituted by full or partial revenue lands of 18 *Talukas* with a total area of about 7,000 km<sup>2</sup> (Gazetteer of India, Gujarat State; for more details see Singh 2007) and a rural human population of around 2 million as per 2001 Census. The entire area is predominated by flat agricultural lands interspersed with scattered hills in Mitiyala, Hipavadli and Palitana, dense *Prosopis juliflora* thickets along the river networks of Shetrunjee and Shail and private and government owned grasslands (known as *vidis*). Highest hill feature is Mount Shetrunjaya (498 meter from msl) at Palitana. EL is connected with the Gir PA by drainage networks and patches of *Acacia-Zizyphus* scrub-forests. There are two existing habitat corridors between the EL and the Gir PA used by lions: one, river networks of Shetrunjee and Sel and second, Mitiyala and low hills running along the River Shetrunjee system (Singh 2007). The major prey base of lions included blue bull (*Boselaphus tragocamelus*), wild pig (*Sus scrofa*), chital (*Axis axis*) [in the reserve grasslands] and domestic livestock. An area of about 230km<sup>2</sup> of the landscape (chiefly *vidis*) with the potential lion habitats have already been delineated and proposed to manage as a ‘Conservation Reserve’ (Wildlife Protection Act 1972; Ravenel and Redford 2005) by the Gujarat Forest Department (Singh 2007).

Land-use in this landscape is mixed and characterized mostly by private farms, orchards, industrial and pastoral lands with some government owned community grazing lands. Public lands are managed for multiple uses, including seasonal cattle grazing. Livestock grazing for dairy products, agriculture comprised of seasonal crops and horticulture are the main economics of the region. The entire landscape is interspersed by a good network of road (national and state highways, district and village level roads) and railway services. Recent lion census estimated a population count of seven lions in the Mitiyala Wildlife Sanctuary and 53 lions in the revenue areas of this landscape (Table 2.2).

**Table 2.2: Lion population estimate based on 2010 lion census (Gujarat Forest Department 2010).**

	<b>Areas</b>	<b>Total lion number</b>
1	Gir National Park, sanctuary and adjoining areas	297
2	Girnar Sanctuary	24
3	Mitiyala Sanctuary	7
4	Paniya Sanctuary	9
5	Coastal areas (Una, Kodinar, Sutrapada and Chhara)	21
6	Savarkundla, Liliya and its adjoining areas of Amreli and Bhavnagar districts	53
	<b>Total</b>	411



## *CHAPTER III*

### *LANDSCAPE ARCHITECTURE OF GIR PROTECTED AREA AND ITS SURROUNDINGS*

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#### **Introduction**

Spatial pattern of habitat governs the persistence of natural populations (Harrison et al. 1988; Vos et al. 2000) and affects the distribution of the dispersing individuals to patches (Dunning et al. 1995; Vos et al. 2002). Hence it is important in constructing ecological communities (Levins 1976), maintaining the distribution and persistence of populations (Fahrig and Paloheimo 1988) and may determine foraging (Senft et al. 1987). Differences in climate, edaphic factors, resource distribution and physical disturbances are natural factors that regulate landscape patterns (Wiens et al. 1985).

In explaining ecological problems, the necessity of the extrapolation of fine scale measurements for the analysis of broad scale phenomena and failure to account for scale-dependent patterns has confused and confounded ecological synthesis and led to many inappropriate extrapolations of research results (Wiens 1989; Gardner 1998). Therefore the progress in methods that will preserve information across scales or compute the loss of information with altering scales has become a critical task. Such methods are essential before ecological understandings can be extrapolated between spatial and temporal scales. In recent years, the importance of scale effects on spatial analysis and modeling has been progressively emphasized in light of spatial heterogeneity and hierarchy theory (Allen and Starr 1982; Wu and Levin 1994). Both theoretical and empirical approaches have confirmed relationships between spatial scale and spatial pattern (Wiens 1989) and to better understand, manage, and forecast the behavior of the complex systems that provide life on earth, we need an improved understanding of the scale-specific interactions responsible for landscape metabolism (Levin 1992), robust techniques for visualizing and interpreting multi-scale processes from patterns (Turner and Gardner 1991), and appropriate scaling strategies for linking and modeling data at multiple scales (Ehleringer and Field 1993).



### Previous vegetation studies in Gir

The Gir ecosystem falls in the biogeographic zone 4 (Rodgers and Panwar 1988) (semi-arid) (**Figure 3.1**) and biographic province 4-B (Rodgers and Panwar 1988) (**Figure 3.2**) Gujarat Rajwara of India. The semi-arid zone in numerous ways is a conversion from the western arid zone to the moister areas of the peninsula to the east.

**Figure 3.1: Bio geographic zone map of India (source: Rodgers and Panwar 1988)**

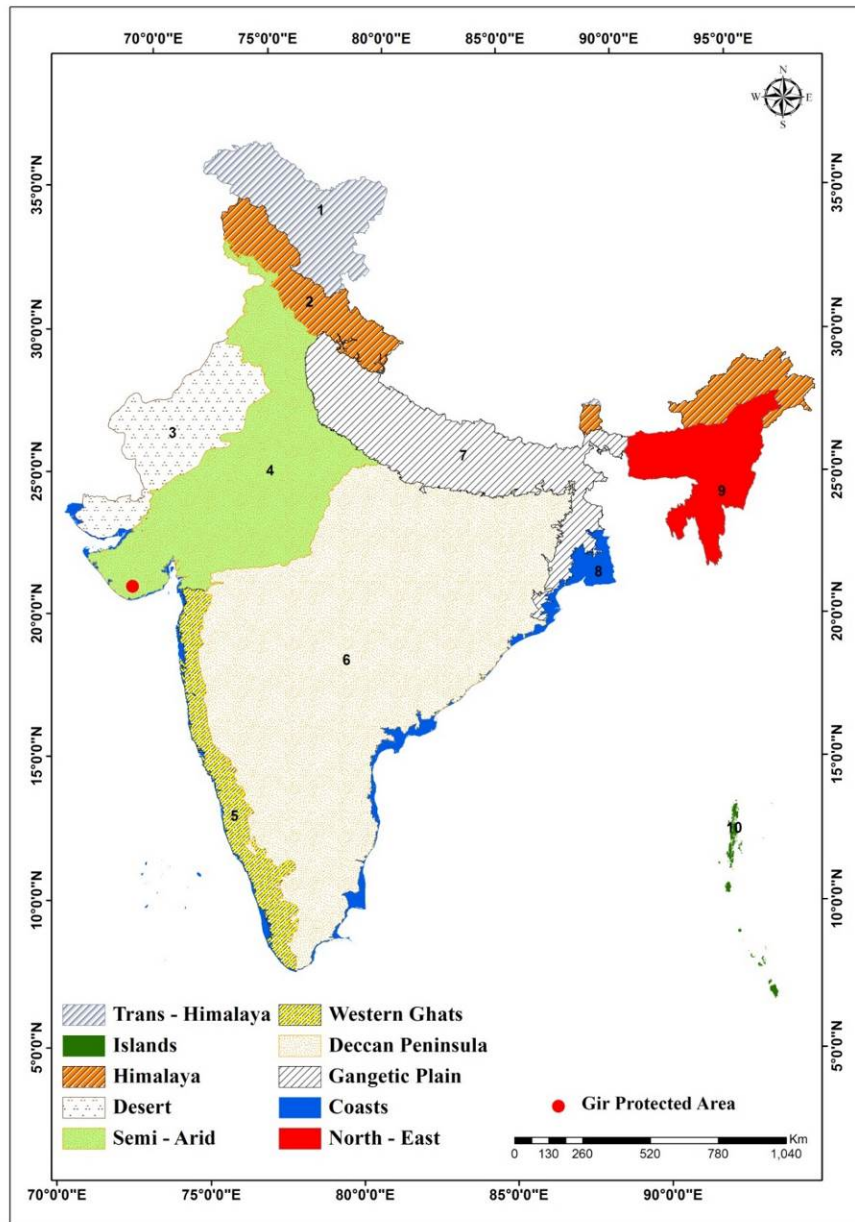
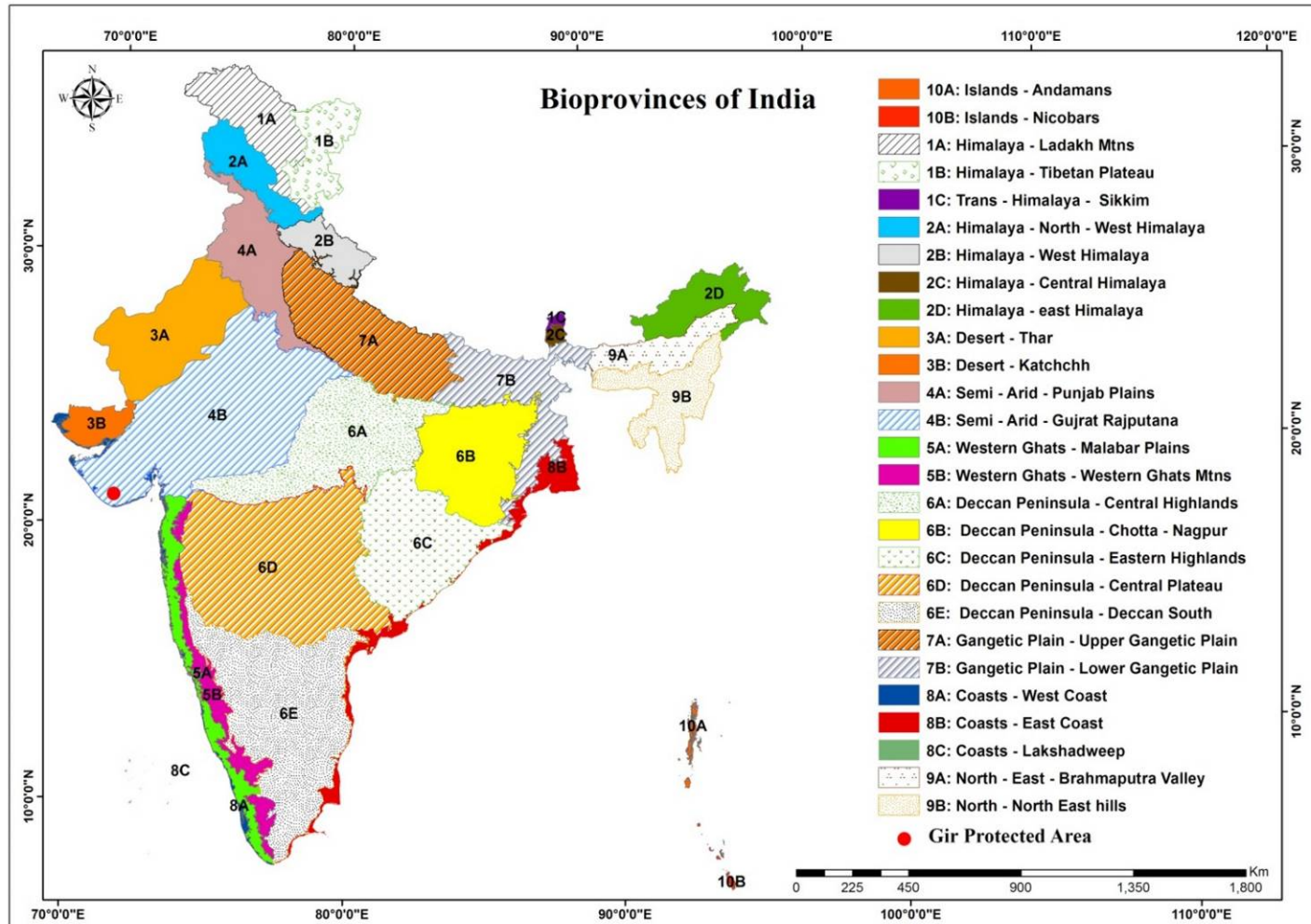




Figure 3.2: Biographic Provinces of India (source: Rodgers and Panwar 1988)





As a transition, it is fairly heterogeneous. The Gujarat-Rajwara biotic province that covers all of Kathiawar in Gujarat is typically different being drier largely *Anogeissus pendula* forests than the moist teak forests. In many parts of the world, semi-arid regions with their dominant grass and palatable shrub layers achieved some of the highest wildlife biomasses and Gir is not an exception. It harbors diverse variety of flora and fauna which comprise numerous endangered species and delivers breeding ground for numerous migratory as well as resident birds. The semi-arid zone of India has strong biological associations with western Asia (Pakistan, Iran and Middle East) and northern Africa. Many of the plants are of African affinity: *Acacia*, *Anogeissus*, *Balanites*, *Capparis*, *Grewia* etc. The Kathiawar peninsula of Gujarat is lower and has black cotton soil. French Institute of Pondicherry classified the vegetation of this region as *Acacia-Capparis* scrubland (Gaussen et al. 1968).

Dry deciduous forest of Gir has been divided into 13 sub-types ranging from riverine forest to scrub forest. The grasslands within and outside the protected area provide valuable fodder to the *panjrapoles*, *goshalas*, village *panchayats* and individuals (Srivastav 1997). According to Champion and Seth's classification of Forest types, 1968, these areas fall under the type 5A/CIa, i.e. very dry teak forests with rainfall less than 900 mm. and dry shallow soil. Teak occurs mixed with dry deciduous species. Due to heavy grazing and annual fires, ground cover is insufficient; the degradation stages of these subtypes are also met with in this tract under:

- (i) Sub-type 5/DS1: Dry deciduous scrub forests
- (ii) Sub-type 5/DS2: Dry savannah forests (locally known as *vidis*)

From the forestry point of view, the growing stock may be broadly classified into the following sub types:

- (i) Teak forests : (Type 5A/CIa)
- (ii) Non-teak forests : (Type 5/DS1 and 5/DS2)

Habitat of Gir has been studied in past, but in diverse contexts and using different methods like studies with vegetation component (Berwick 1974; Khan et al. 1990). Berwick classified habitat types subjectively, the first effort to classify the habitat/ vegetation. Earlier this, the work done was restricted to listing the flora (Santapau and Raizada 1956). The habitat of Gir was classified using quantitative analytical techniques (TWINSPAN programme) (Khan et al. 1990). They increased the number of habitat types to eleven as against four by Berwick. The study categorized 11 broad habitat types with distinctive tree species described in **Table 3.1** but



identification of a tree and/or shrub was based on its height and not on its life form. Hence larger individuals of the same species were categorized as trees and smaller individuals as shrub based on height. Later the Gir forest was broadly divided into two major vegetation types (Chellam 1993). The western two-thirds of the forest were found dominated by stunted teak, in association with various other species, chiefly *Acacia*, *Zizyphus* and *Terminalia*. The remaining eastern portion consisted of a grassland savannah interspersed with patches of thorn (*Acacia* and *Zizyphus*) and dry deciduous forests (*Anogeissus latifolia* and *Boswellia serrata*), teak was absent in this region. The understorey was often sparse in the more densely wooded areas but shrubs like *Carissa opaca*, *Capparis sepiaria*, and *Helicteres isora* along with various grass species dominated the understorey in other areas. Evergreen riverine forests were found along the banks of most of the rivers and streams. *Syzygium rubicundum*, *Derris indica*, *Manilkara hexandra* and various other species were found in the riverine tracts. The eleven broad categories classified are mentioned in **Table 3.1**. Various forest types of Gir, were classified under 13 subtypes (Chavan 1993) and later in fifteen major vegetation associations (Sharma 1995) (**Table 3.1**). Most recently the forest was classified into three major classes (Qureshi and Shah 2004) which is described in **Table 3.1**.



**Table 3.1: Previous vegetation studies in Gir**

Khan et al. 1990		Chellam 1993	Chavan 1993	Sharma 1995	Qureshi and Shah 2004		
Classes	Characteristic species	Classes	Classes	Classes	Classes	Characteristic species	
(1) Riverine Woodland	<i>S. rubicunda, P.pinnata, Manilkara hexandra, Ficus bengalensis</i>	(1) Riverine forest,	(1) Dry Teak Forest (5A/C1b)	(1) <i>Acacia catechu-Zizyphus numularia-Aristida adscensionis</i> association,	Moist mixed vegetation	Moist mixed forest	<b>Dominant species:</b> <i>Tectona grandis</i> replaced by <i>Anogeissus latifolia</i> . In Gir (east)
(2) Thorn woodland	<i>Acacia nilotica, Acacia catechu, Zizyphus mauritiana, Acacia senegal</i>	(2) Teak Forest	(2) Southern Dry Mixed Deciduous Forest (5A/C3)	(2) <i>Apluda mutica-Themeda quadrivalvis- Sehima nervosum</i> association,			<b>Associates:</b> <i>Acacia spp., Wrightia tinctoria, syzigium spp., Mitragnyna parviflora, Bauhinia racemosa, Diospyros melanoxylon and Emblica officinalis.</i>
(3) Teak-Acacia-Zizyphus woodland	<i>Tectona grandis, Acacia senegal, Zizyphus mauritiana, Acacia nilotica</i>	(3) <i>Acacia-Zizyphus</i> woodland,	(3) Northern Dry Mixed Deciduous Forest (5B/C2)	(3) <i>Anogeissus latifolia-Acacia spp-Terminalia crenulata</i> association			<b>Understorey:</b> <i>Acacia spp., Zizyphus spp.,Grewia tiliaefolia, Helecteres isora, Carissa carandas, Manilkara hexandra and ixora arborea.</i>
(4) Mixed teak woodland	<i>Tectona grandis, Terminalia crenulata, Acacia catechu, Lannea coromandelica, Boswellia serrata</i>	(4) Mixed Forest	(4) Dry Deciduous Scrub (5/DS1)	(4) <i>Anogeissus latifolia- Acacia catechu-</i> association		Mixed forest	<b>Dominant species:</b> <i>Tectona grandis</i> replaced by <i>Anogeissus latifolia</i> in Gir (east)
(5) Mixed valley community	<i>Tectona grandis, Pterocarpus marsupium, Schrebera swietenoides</i>	(5) <i>Acacia</i> Woodland	(5) Dry Savannah Forest (5/DS2)	(5) <i>Acacia spp-Zizyphus mauritiana</i> association			<b>Associates:</b> <i>Diospyros melanoxylon, Garuga pinnata, Gmelina arborea and Mallotus phillipensis.</i>
(6) Teak-Boswellia-Sterculia woodland	<i>Tectona grandis, Boswellia serrata, Sterculia urens, Lanneacoramandelic, Acacia catechu</i>	(6) Scrubland	(6) Dry Grasslands	(6) <i>Zizyphus mauritiana</i> association			Thorn forest



Khan et al. 1990		Chellam 1993	Chavan 1993	Sharma 1995	Qureshi and Shah 2004		
Classes	Characteristic species	Classes	Classes	Classes	Classes	Characteristic species	
(7) <i>Anogeissus-Boswellia-Lannea</i> woodland	<i>Anogeissus latifolia</i> , <i>Boswellia serrata</i> , <i>Sterculia urens</i> , <i>Lannea coromandelica</i> , <i>Acacia catechu</i>	(7) Teak <i>Acacia-Zizyphus</i> woodland	(7) <i>Boswellia serrata</i> forest (5/B2)	(7) <i>Acacia nilotica-Zizyphus mauritiana</i> association	Thorn forest	<b>Dominant species:</b> <i>Tectona grandis</i> replaced by <i>Anogeissus latifolia</i> . In Gir (east), <i>Acacia catechu</i> , <i>Zizyphus mauritiana</i>	
(8) <i>Anogeissus-Terminalia</i> woodland	<i>Anogeissus latifolia</i> , <i>Acacia catechu</i> , <i>Terminalia crenulata</i> , <i>Butea monosperma</i> ,	(8) Teak-Mixed Forest,	(8) Babul ( <i>Acacia nilotica</i> ) Forest (5/B3)	(8) <i>Tectona grandis-Acacia catechu-Zizyphus mauritiana</i> association		<b>Associates:</b> <i>Acacia spp.</i> , <i>Zizyphus spp.</i> , <i>Terminalia spp.</i> ,	
(9) Pure Teak woodland	<i>Tectona grandis</i>	(9) Teak- <i>Acacia</i> Woodland	(9) <i>Butea</i> ( <i>Butea monosperma</i> ) Forest (5/B5)	(9) <i>Tectona grandis-Acacia catechu-Terminalia crenulata</i> association		<b>Understorey:</b> <i>Zizyphus spp.</i> , <i>Carissa carandas</i> and <i>Capparis sepiaria</i>	
(10) Thorn savannah	<i>Acacia and Zizyphus sp.</i> , <i>Dichrostachys cineria</i>	(10) Open land	(10) Dry Tropical Riverine forest (5/1S1)	(10) <i>Tectona grandis</i> association			
(11) Thorn Bushland	<i>Zizyphus sp.</i> , <i>Dichrostachys cineria</i>	(11) Agricultural land.	(11) Southern Thorn Scrub (6A/C2/DS1)	(11) <i>Tectona grandis-Acacia catechu-Lannea coromandelica-Boswellia serrata</i> association,		<b>Acacia – Zizyphus</b>	<b>Dominant species:</b> <i>Acacia spp.</i> , <i>Zizyphus spp.</i> ,
			(12) Desert Thorn Scrub (6B/C1)	(12) <i>Tectona grandis-Acacia spp-Wrightia tinctoria</i> association			<b>Understorey:</b> <i>Carissa carandas</i> and <i>Capparis sepiaria</i>
			(13) Tropical Euphorbia Scrub (6B/DS2)	(13) <i>Tectona grandis</i> mixed association		<b>Scrubland</b>	<b>Dominant species:</b> <i>Acacia catechu</i> , <i>Acacia leucohloea</i> , <i>Zizyphus numularia</i>
				(14) Mixed association			<b>Associates:</b> <i>Zizyphus spp.</i> , <i>Capparis sepiaria</i> and <i>Balanites aegyptica</i>



Khan et al. 1990		Chellam 1993	Chavan 1993	Sharma 1995	Qureshi and Shah 2004	
Classes	Characteristic species	Classes	Classes	Classes	Classes	Characteristic species
				(15) <i>Syzygium rubicundum</i> - <i>Derris indica</i> association	Hill forest	<b>Dominant species:</b> <i>Acacia</i> spp., <i>Zizyphus</i> spp., <i>Terminalia crenulata</i> , <i>Bauhinia racemosa</i> , <i>Tectona grandis</i> , <i>Anogeissus</i> spp, <i>Boswellia serrata</i> and <i>Balanites aegyptica</i> .
						<b>Understorey grasses:</b> <i>Appluda mutica</i> , <i>Heteropogon contotus</i> , <i>Themeda quadrivalvis</i> and <i>Sehima nervosum</i>
						<b>Dominant species:</b> <i>Tectona grandis</i> replaced by <i>Anogeissus latifolia</i> . in Gir (east), <b>Associates:</b> <i>Acacia</i> spp., <i>Terminalia</i> spp., <i>Wrightia tinctora</i> , <i>Grewia tiliifolia</i> , <i>Boswellia serrata</i> , <i>Flacourtia indica</i> , <i>Bauhinia racemosa</i> and <i>Zizyphus</i> spp.,
						<i>Acacia</i> spp., <i>Lansea coromandelica</i> , <i>Boswellia serrata</i> , <i>Tectona grandis</i> , <i>Terminalia crenulata</i> , <i>Wrightia tinctora</i> , <i>Soyamida febrifuga</i> and <i>Sterculia urens</i>



## Objectives

With this context, the current chapter aims to classify and show spatial patterns of the existing vegetation of the Gir PA. The followings were the broad objectives:

- To evaluate the current landscape architecture of Gir Protected Area and its surroundings (5 km buffer around Gir Protected Area).
- To map land use/cover classes of different vegetation types, water bodies, barren areas.

## Methods

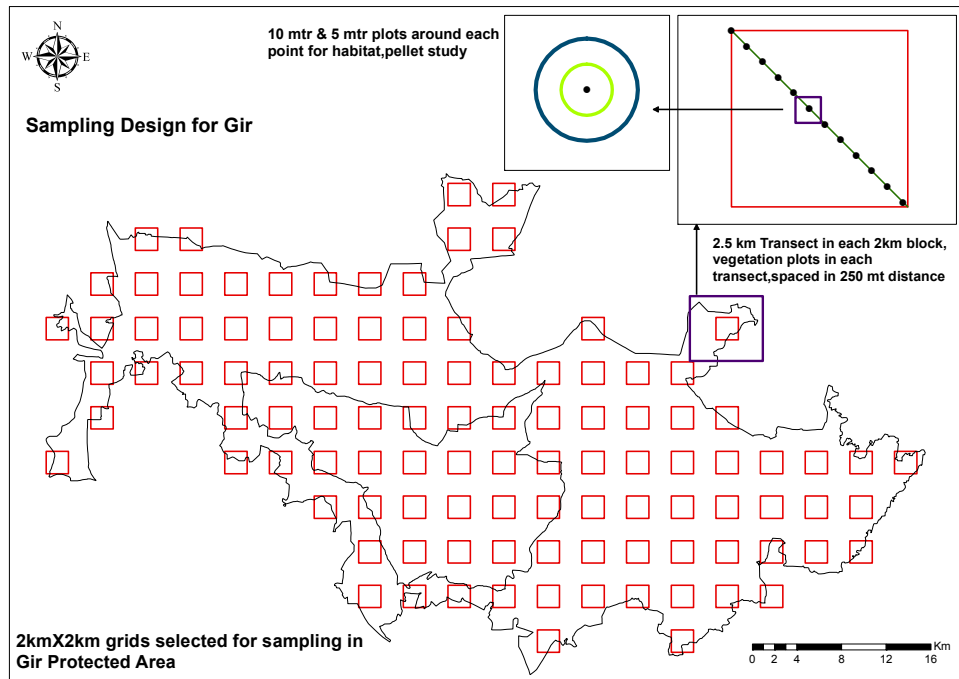
### Field Methods

#### *Stratification and Sampling Units*

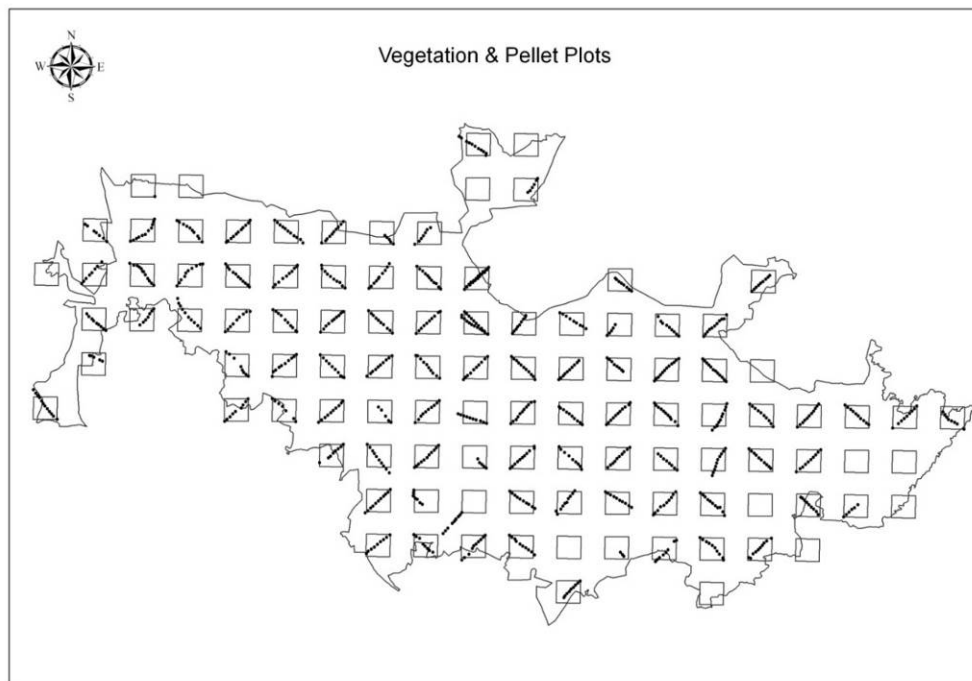
In Gir PA, precipitation determines the structure of vegetation communities. In a dry deciduous forest tract, the vegetation is almost entirely confined to watercourses. This discontinuous cover and the scattered distribution of shrubs play an important role in structuring plant communities. A vegetation survey was therefore carried out to assess the variation in vegetation structure in different habitats. The study area was explored with a view to classify the habitat focusing on the species survival. Following a systematic sampling design, the entire Gir Protected Area (Gir PA) was divided into 2 km X 2 km grids and alternatively each grid was selected as sampling grid (**Figure 3.3**). In each of these sampling grids, one 2.5 km transect was laid diagonally covering most of the area of the grid. In this transect, at 250 meter intervals, different plots were laid of 10 meter and 5 meter radius to collect phytosociological data of plants (**Figure 3.4**). Other descriptive parameters such as topography, precipitation, hydrology, vegetation structure, and human land use i.e. presence of *nesses*, cultivable lands, presence of roads inside the Gir PA were also used to differentiate habitats.



**Figure 3.3: Vegetation Sampling Design in Gir Protected Area**



**Figure 3.4: Distribution of vegetation sampling plots in Gir PA**





### ***Data Collection Protocols***

Data on species composition and structure were collected using circular plots method following Muller-Dombois and Ellenberg 1974. Circular plots are expeditious in allowing accurate area sampling with relatively less effort for plot layout (a single central marker for permanent location) and they reduce the number of edge decisions because they minimize perimeter to area ratio (Mc Cune and Grace 2002). The following details were collected from the plots:

**Tree Species:** At each sampling point, a circular plot of 10 m radius was laid for enumeration of trees. The individuals with > 20 cm girth at breast height (gbh) and height > 1.37 m with distinct bole were considered as trees (Muller-Dombois and Ellenberg 1974). In each plot, parameters like species names, number of trees, gbh and % canopy cover were recorded. Tree saplings (gbh > 10.5cm and < 20 cm; height > 30cm and < 1.37m) (Singh et al. 1995) in 5m radius nested plot were also recorded.

**Shrub Species:** Names and number of shrubs were enumerated from nested circular plot of 5m radius.

**Herb Species:** Nested 1m×1m quadrat was laid for estimation of ground vegetation. Name of species and percentage of herb cover, grass cover, litter cover, weed cover were recorded from each quadrat.

**Community structure and distribution pattern of species:** Density, frequency, abundance and dominance of constituent species were determined. We calculated the Importance Value Index (IVI) for all species by adding the relative values of frequency, density and dominance (basal area) (Curtis and McIntosh 1950; Brown and Curtis 1952). With the A/F ratio the distribution of trees was calculated which indicates regular distribution if the value is <0.025, random distribution, if it is in between 0.025 to 0.050 and contiguous distribution if > 0.050 (Curtis and Cotton 1956).

**Diversity, Richness and Evenness:** To analyze that the individuals are randomly sampled from an infinite large population and all the species from the community are included in the sample. Species diversity was computed using Shannon Wiener Index (Shannon and Weaver 1949). Richness was calculated by counting total number of species observed in each habitat. Evenness (Equability) was calculated using the Pielou's (1966) equation. Evenness ranges between 0 and 1. If the evenness value is higher, the variation in communities between the species would be less.



### Remote sensing approach

We used a cloud free LANDSAT TM scene, which was located in Path 149, Row 45 and acquired in November 2009. Bands 1-5 and 7 were utilized. The image was checked for radiometric distortions such as line striping. Using ERDAS software, the TM image was geometrically rectified using known ground control points.

To assess the potential to map forest classes, natural groupings in both the remotely-sensed and ground-collected ecological data sets were sought. The ground data ( $n > 900$  vegetation sampling plots) were grouped into ecological classes with a conventional ecological ordination technique. These data were classified according to species composition using a TWINSPLAN analysis (Hill 1979). The remotely sensed multispectral data were compressed via a principal component analysis and was grouped with an unsupervised classification approach using Erdas 10.

All bands of the TM image except the thermal band were used in Principal Component Analysis (Jolliffe 2002) to extract information and transforming a set of correlated spectral bands of image data into an equivalent set of uncorrelated components of the data. Three principal components were derived based on eigen values and eigen vectors (**Table 3.2**). The unsupervised classification was performed on the first three principal components, which accounted for more than 99% of the spectral variance in the original six LANDSAT TM5 channels.

**Table 3.2: Principal Component Analysis used for unsupervised classification**

Principal Component	1	2	3	4	5	6
Normalized Variance	0.845	0.121	0.022	0.007	0.004	0.001

These three principal components were stacked together to use for unsupervised classification. Scene classification was undertaken using a decision rule which first separated water bodies and forest-non forest areas and then classifying the forest areas into different forest types. The stacked PC layers were initially classified using the Isodata algorithm (Unsupervised classification) into 100 classes and then regrouped into the ten major classes under investigation based on the field study.

Initially classified images were evaluated visually, and the effects of topographic normalization were noted. The image was evaluated quantitatively with ground truth data points.



Several other types of ground truth maps, such as drainage network, road network, and settlement areas were included in the ground truth map. Between November 2008 and January 2011, extensive field reconnaissance trips were made throughout the study site. Vegetation composition and structure were noted and many zones of anthropogenic disturbance were mapped in the field. We assessed the accuracy of the classification using a classification error matrix. Cross-tabulations were made of sites visited in the field and the image classifications. Errors were assessed using commission error (a measure of the number of sites of other vegetation types incorrectly assigned to a particular vegetation type), omission error (a measure of the number of sites of a particular vegetation type incorrectly assigned to other vegetation types).

We delineated a one hectare quadrat plot around each of our circular vegetation plots, used in the accuracy assessment. One hectare was used as the unit because one hectare area of any forest type was assumed as minimum requirement to be specified as a patch of that forest type. As the satellite imagery used for generating vegetation map is of 30 meter resolution, we quantified the number of pixels of different vegetation types falling within the one hectare quadrat and denoted the vegetation type of the quadrat according to dominant vegetation type found in that quadrat. While doing accuracy assessment, we checked whether the vegetation type affirmed by our sampling area is same with the major vegetation type of the quadrat or not. KAPPA analysis was used to perform a classification accuracy assessment based on error matrix analysis. For the classified image, accuracy was determined based on a stratified random sample of 200 points distributed throughout the area. Kappa statistics, which assess overall accuracy by incorporating individual errors of omission and commission were also calculated (Congalton 1991) [see **Table 3.16**].



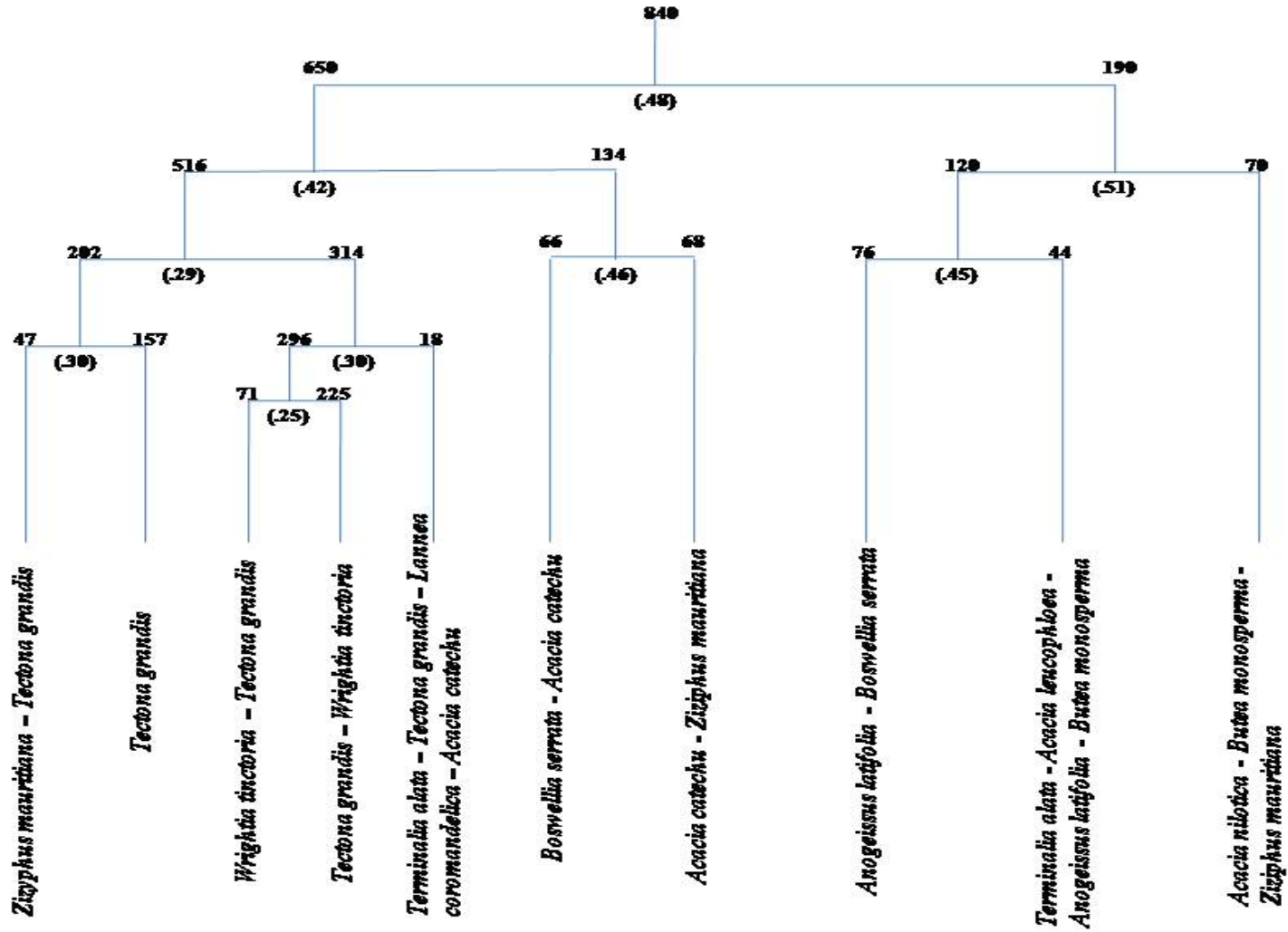
## Results

### TWINSpan Analysis

The TWINSpan classification hierarchy separated the Gir vegetation into teak associated and non-teak forests (**Table 3.3**). A total of ten communities were identified as a result of the analysis (**Figure 3.5**) i.e. *Ziziphus mauritiana-Tectona grandis* community, pure *Tectona grandis* community, mixed teak communities like *Wrightia tinctoria-Tectona grandis* community and *Tectona grandis-Wrightia tinctoria* community, *Terminalia alata-Tectona grandis-Lannea coromandelica-Acacia catechu* community, *Boswellia serrata-Acacia catechu* community, *Acacia catechu-Ziziphus mauritiana* community, *Anogeissus latifolia-Boswellia serrata* community, *Terminalia alata-Acacia leucophloea-Anogeissus latifolia-Butea monosperma* community, *Acacia nilotica-Butea monosperma-Ziziphus mauritiana* community.



Figure 3.5: Dendrogram showing vegetation communities identified through TWINSpan analysis





**Table 3.3: Community wise distribution of vegetation sampling plots, dominant species, constant species, diversity, richness and evenness**

Community	No of Plots	Name of the Community	Dominant Species (Based on IVI Value)	Constant Species (Frequency>25%)	Diversity	Richness	Evenness
1	45	<i>Ziziphus mauritiana</i> , <i>Tectona grandis</i>	<i>Ziziphus mauritiana</i> (85.00), <i>Tectona grandis</i> (81.02)	<i>Ziziphus mauritiana</i> (100.00), <i>Tectona grandis</i> (71.11), <i>Acacia catechu</i> (26.67), <i>Acacia auriculiformes</i> (26.67)	2.13	25	0.66
2	157	<i>Tectona grandis</i>	<i>Tectona grandis</i> (143.83)	<i>Tectona grandis</i> (94.90), <i>Ziziphus mauritiana</i> (37.58), <i>Acacia nilotica</i> (29.94)	2.09	51	0.53
3	71	<i>Wrightia tinctoria</i> , <i>Tectona grandis</i>	<i>Wrightia tinctoria</i> (68.11), <i>Tectona grandis</i> (46.86)	<i>Wrightia tinctoria</i> (92.96), <i>Tectona grandis</i> (59.15), <i>Acacia catechu</i> (35.21), <i>Ziziphus mauritiana</i> (38.03), <i>Bauhinia purpurea</i> (30.99)	2.84	48	0.73
4	223	<i>Tectona grandis</i> , <i>Wrightia tinctoria</i>	<i>Tectona grandis</i> (124.43), <i>Wrightia tinctoria</i> (29.12)	<i>Tectona grandis</i> (98.21), <i>Wrightia tinctoria</i> (44.39), <i>Acacia catechu</i> (27.80)	2.30	55	0.57
5	51	<i>Terminalia alata</i> , <i>Tectona grandis</i> , <i>Lannea coromandelica</i> , <i>Acacia catechu</i>	<i>Terminalia alata</i> (39.52), <i>Tectona grandis</i> (38.13), <i>Lannea coromandelica</i> (30.64), <i>Acacia catechu</i> (31.00)	<i>Terminalia alata</i> (47.06), <i>Tectona grandis</i> (45.10), <i>Lannea coromandelica</i> (45.10), <i>Acacia catechu</i> (43.14), <i>Boswellia serrata</i>	2.92	40	0.79



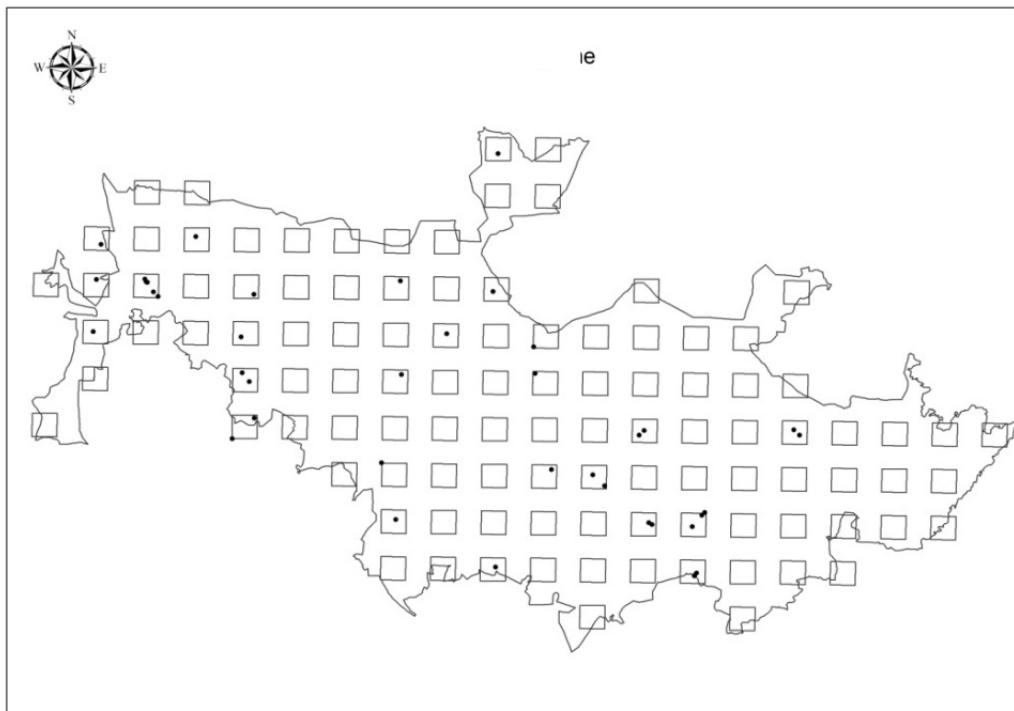
Community	No of Plots	Name of the Community	Dominant Species (Based on IVI Value)	Constant Species (Frequency>25%)	Diversity	Richness	Evenness
				(27.45), <i>Embllica officinalis</i> (25.49)			
6	31	<i>Boswellia serrata</i> , <i>Acacia catechu</i>	<i>Boswellia serrata</i> (106.51), <i>Acacia catechu</i> (41.21)	<i>Boswellia serrata</i> (90.32), <i>Acacia catechu</i> (54.84), <i>Manilkara hexandra</i> (29.03), <i>Acacia spp</i> (29.03)	2.20	20	0.73
7	66	<i>Acacia catechu</i> , <i>Ziziphus mauritiana</i>	<i>Acacia catechu</i> (131.10), <i>Ziziphus mauritiana</i> (25.10)	<i>Acacia catechu</i> (100.00)	2.16	40	0.58
8	75	<i>Anogeissus latifolia</i> , <i>Boswellia serrata</i>	<i>Anogeissus latifolia</i> (89.37), <i>Boswellia serrata</i> (26.54)	<i>Anogeissus latifolia</i> (86.67), <i>Acacia catechu</i> (30.67), <i>Acacia nilotica</i> (32.00)	2.43	34	0.69
9	44	<i>Terminalia alata</i> , <i>Acacia leucophloea</i> , <i>Anogeissus latifolia</i> , <i>Butea monosperma</i>	<i>Terminalia alata</i> (80.08), <i>Acacia leucophloea</i> (52.75), <i>Anogeissus latifolia</i> (37.46), <i>Butea monosperma</i> (27.55)	<i>Terminalia alata</i> (59.09), <i>Acacia leucophloea</i> (56.82), <i>Anogeissus latifolia</i> (25.00), <i>Butea monosperma</i> (25.00)	2.40	27	0.73
10	69	<i>Acacia nilotica</i> , <i>Butea monosperma</i> , <i>Ziziphus mauritiana</i>	<i>Acacia nilotica</i> (103.49), <i>Butea monosperma</i> (34.55), <i>Ziziphus mauritiana</i> (26.03)	<i>Acacia nilotica</i> (88.41), <i>Butea monosperma</i> (39.13), <i>Ziziphus mauritiana</i> (30.43)	2.29	30	0.67



### 1. *Ziziphus mauritiana*- *Tectona grandis* community

This vegetation community occurred in the south-western and middle part of the Gir Wildlife Sanctuary (Gir WLS). Approximately 25 species of trees were found in this community. According to IVI value, the dominant trees were *Ziziphus mauritiana* (85.00), *Tectona grandis* (81.02). The constant species with the frequency of occurrence more than 25 % were *Ziziphus mauritiana* (100.00), *Tectona grandis* (71.11), *Acacia catechu* (26.67), and *Acacia auriculiformes* (26.67). The total tree density of this vegetation type was 189.67/ha. The diversity value was 2.13 and the richness, evenness values were 25, 0.66. Details of distribution of vegetation sampling plots within this communities and species composition, status are given in **Figure 3.6** and **Table 3.4**.

**Figure 3.6: Distribution of vegetation sampling plots classified in *Ziziphus mauritiana*-*Tectona grandis* community**





**Table 3.4: Species composition and status in *Ziziphus mauritiana* - *Tectona grandis* community**

Species	Density/ha	Frequency	Basal Area	IVI	A/F Ratio
<i>Bauhinia purpurea</i>	4.95	15.56	0.03	8.44	0.06
<i>Acacia sp</i>	3.54	11.11	0.07	8.52	0.09
<i>Acacia nilotica</i>	15.57	26.67	0.13	22.36	0.07
<i>Aegle marmelos</i>	3.54	6.67	0.07	7.44	0.25
<b><i>Ziziphus mauritiana</i></b>	<b>58.03</b>	<b>100.00</b>	<b>0.51</b>	<b>85.00</b>	<b>0.02</b>
<i>Grewia tiliiaefolia</i>	2.83	6.67	0.03	4.87	0.20
<i>Wrightia tinctoria</i>	10.62	13.33	0.12	15.40	0.19
<i>Acacia senegal</i>	0.71	2.22	0.00	1.09	0.45
<i>Zizyphus xylopyra</i>	0.71	2.22	0.01	1.31	0.45
<i>Acacia leucophloea</i>	1.42	4.44	0.00	2.30	0.23
<i>Balanites aegyptiaca</i>	2.12	4.44	0.04	4.24	0.34
<i>Holarrhena pubescens</i>	0.71	2.22	0.01	1.33	0.45
<i>Acacia catechu</i>	12.03	26.67	0.21	24.74	0.05
<i>Phoenix sylvestris</i>	0.71	2.22	0.00	1.04	0.45
<i>Azadirachta indica</i>	1.42	4.44	0.02	3.18	0.23
<i>Flacourtia indica</i>	0.71	2.22	0.02	2.06	0.45
<i>Dichrostachys cinerea</i>	2.83	8.89	0.00	4.33	0.11
<i>Lannea coromandelica</i>	1.42	4.44	0.05	4.62	0.23
<i>Grewia asiatica</i>	0.71	2.22	0.00	1.19	0.45
<i>Morinda pubescens</i>	0.71	2.22	0.03	2.63	0.45
<b><i>Tectona grandis</i></b>	<b>55.91</b>	<b>71.11</b>	<b>0.62</b>	<b>81.02</b>	<b>0.03</b>
<i>Terminalia alata</i>	1.42	4.44	0.00	2.06	0.23
<i>Boswellia serrata</i>	4.25	6.67	0.01	4.82	0.30
<i>Schleichera oleosa</i>	1.42	4.44	0.01	2.64	0.23
<i>Ficus glomerata</i>	1.42	4.44	0.02	3.18	0.23

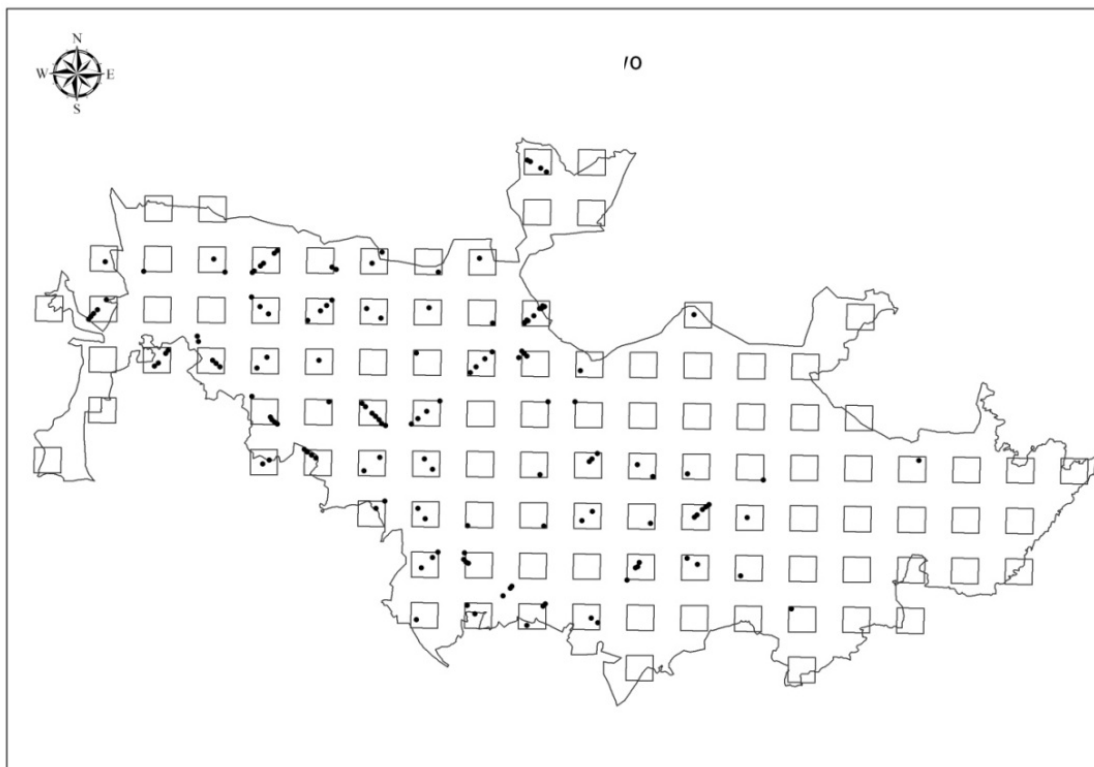
## 2. *Tectona grandis* Community

This vegetation community occurred in the western and central part of the Gir WLS. About 51 species of trees were found in this community. *Tectona grandis* (143.83) was found as the dominant species. Other constant species with the occurrence value more than 25% were *Tectona grandis* (94.90), *Ziziphus mauritiana* (37.58), and *Acacia nilotica* (29.94). The total tree density of this vegetation type was 266.75/ha. Diversity value was 2.09, richness and evenness values



were 51 and 0.53. Details of distribution of vegetation sampling plots within this communities and species composition, status are given in **Figure 3.7** and **Table 3.5**.

**Figure 3.7: Distribution of vegetation sampling plots classified in *Tectona grandis* community**



**Table 3.5: Species composition and status in community *Tectona grandis***

Species	Density/ha	Frequency %	TBA	IVI	A/F Ratio
<i>Bauhinia racemosa</i>	0.20	0.64	0.00	0.28	1.57
<i>Bauhinia purpurea</i>	4.67	13.38	0.05	6.26	0.08
<i>Emblca officinalis</i>	1.83	5.10	0.05	2.83	0.22
<i>Phyllanthus emblica</i>	1.22	3.82	0.06	2.44	0.26
<i>Tamarindus indica</i>	2.03	3.18	0.10	3.14	0.63
<i>Asparagus dumosus</i>	0.20	0.64	0.00	0.31	1.57
<i>Acacia sp</i>	3.45	8.28	0.07	4.72	0.16
<i>Terminalia bellirica</i>	0.20	0.64	0.00	0.27	1.57
<i>Acacia nilotica</i>	12.98	29.94	0.17	15.73	0.05
<i>Aegle marmelos</i>	2.03	3.82	0.05	2.54	0.44
<i>Pterocarpus marsupium</i>	0.20	0.64	0.00	0.27	1.57
<i>Ziziphus mauritiana</i>	14.81	37.58	0.28	20.17	0.03
<i>Grewia tiliiaefolia</i>	6.69	11.46	0.08	6.86	0.16



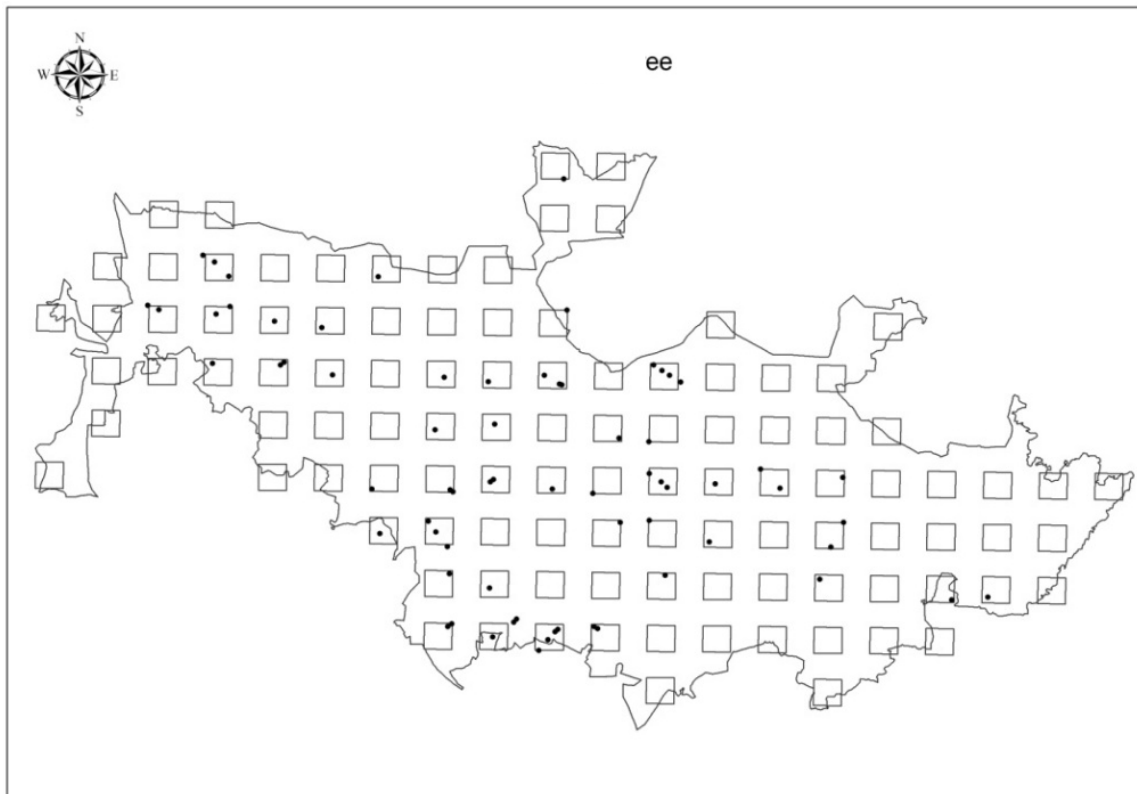
Species	Density/ha	Frequency %	TBA	IVI	A/F Ratio
<i>Anogeissus latifolia</i>	0.81	0.64	0.02	0.79	6.28
<i>Wrightia tinctoria</i>	3.85	8.28	0.08	4.97	0.18
<i>Grewia tenax</i>	1.42	4.46	0.01	1.89	0.22
<i>Cassia fistula</i>	2.03	5.73	0.02	2.66	0.19
<i>Acacia senegal</i>	2.84	5.10	0.06	3.33	0.34
<i>Zizyphus xylopyra</i>	3.25	7.01	0.04	3.71	0.21
<i>Haldinia cordifolia</i>	0.20	0.64	0.01	0.40	1.57
<i>Acacia leucophloea</i>	5.88	14.01	0.09	7.45	0.09
<i>Balanites aegyptiaca</i>	1.22	3.18	0.02	1.62	0.38
<i>Syzygium cumini</i>	0.81	0.64	0.17	3.11	6.28
<i>Holarrhena pubescens</i>	4.06	8.28	0.03	4.26	0.19
<i>Sterculia urens</i>	0.41	1.27	0.02	0.84	0.79
<i>Mallotus philippinensis</i>	0.81	2.55	0.02	1.26	0.39
<i>Mitragyna parvifolia</i>	0.20	0.64	0.01	0.34	1.57
<i>Derris indica</i>	0.20	0.64	0.02	0.54	1.57
<i>Acacia catechu</i>	7.91	15.29	0.13	9.17	0.11
<i>Butea monosperma</i>	9.53	24.84	0.21	13.67	0.05
<i>Azadirachta indica</i>	0.61	1.91	0.01	0.98	0.52
<i>Flacourtia indica</i>	0.81	1.91	0.01	0.95	0.70
<i>Dichrostachys cinerea</i>	1.22	1.91	0.01	1.21	1.05
<i>Catunaregam spinosa</i>	2.64	6.37	0.02	2.98	0.20
<i>Lannea coromandelica</i>	1.22	3.82	0.04	2.14	0.26
<i>Ficus arnottiana</i>	0.20	0.64	0.25	4.15	1.57
<i>Soymida febrifuga</i>	0.20	0.64	0.01	0.38	1.57
<i>Parkinsonia aculeata</i>	0.41	1.27	0.01	0.58	0.79
<i>Manilkara hexandra</i>	1.01	2.55	0.03	1.54	0.49
<i>Morinda pubescens</i>	2.84	5.73	0.05	3.46	0.27
<b><i>Tectona grandis</i></b>	<b>151.73</b>	<b>94.90</b>	<b>3.84</b>	<b>143.83</b>	<b>0.05</b>
<i>Terminalia alata</i>	2.03	5.73	0.03	2.77	0.19
<i>Boswellia serrata</i>	0.41	1.27	0.02	0.74	0.79
<i>Delonix elata</i>	0.41	1.27	0.01	0.59	0.79
<i>Holoptelia integrifolia</i>	0.20	0.64	0.01	0.35	1.57
<i>Dalbergia latifolia</i>	0.20	0.64	0.00	0.28	1.57
<i>Bombax ceiba</i>	0.41	1.27	0.01	0.67	0.79
<i>Diospyros melanoxylon</i>	2.03	5.73	0.07	3.45	0.19
<i>Schleichera oleosa</i>	0.61	1.27	0.02	0.89	1.18
<i>Ficus glomerata</i>	1.01	3.18	0.01	1.39	0.31
<i>Ehretia laevis</i>	0.61	1.91	0.00	0.82	0.52



### 3. *Wrightia tinctoria*-*Tectona grandis* Community

This type of vegetation occurred in the south-western and middle part of the Gir WLS. Approximately 48 tree species were found in this community. The dominant species were *Wrightia tinctoria* (68.11), *Tectona grandis* (46.86) and the constant species were with the occurrence value more than 25 % *Wrightia tinctoria* (92.96), *Tectona grandis* (59.15), *Acacia catechu* (35.21), *Ziziphus mauritiana* (38.03), *Bauhinia purpurea* (30.99). The total tree density of this vegetation type was 252.98/ha. The diversity value of this vegetation type was 2.84/ha. The richness and evenness values of this vegetation type were 48 and 0.73. Details of distribution of vegetation sampling plots within this communities and species composition, status are given in **Figure 3.8** and **Table 3.6**.

**Figure 3.8: Distribution of vegetation sampling plots classified in *Wrightia tinctoria*-*Tectona grandis* community**





**Table 3.6: Species composition and status in *Wrightia tinctoria*-*Tectona grandis* community**

Species	Density/ha	Frequency %	TBA	IVI	A/F Ratio
<i>Bauhinia purpurea</i>	10.77	30.99	0.22	14.37	0.04
<i>Embllica officinalis</i>	0.90	2.82	0.03	1.37	0.36
<i>Phyllanthus emblica</i>	2.69	5.63	0.09	3.75	0.27
<i>Asparagus dumosus</i>	0.45	1.41	0.00	0.52	0.71
<i>Alangium salvifolium</i>	0.45	1.41	0.00	0.53	0.71
<i>Acacia sp</i>	1.79	5.63	0.04	2.48	0.18
<i>Hymenodyctyon orixense</i>	0.45	1.41	0.01	0.59	0.71
<i>Terminalia bellirica</i>	0.45	1.41	0.08	1.91	0.71
<i>Acacia nilotica</i>	1.35	4.23	0.02	1.80	0.24
<i>Aegle marmelos</i>	5.38	8.45	0.08	5.18	0.24
<i>Pterocarpus marsupium</i>	1.35	4.23	0.11	3.31	0.24
<i>Ziziphus mauritiana</i>	15.70	38.03	0.19	17.28	0.03
<i>Grewia tiliiaefolia</i>	3.14	7.04	0.04	3.35	0.20
<i>Anogeissus latifolia</i>	1.35	2.82	0.07	2.33	0.53
<b><i>Wrightia tinctoria</i></b>	<b>67.28</b>	<b>92.96</b>	<b>1.30</b>	<b>68.11</b>	<b>0.02</b>
<i>Grewia tenax</i>	0.90	2.82	0.01	1.07	0.36
<i>Cassia fistula</i>	1.35	2.82	0.02	1.42	0.53
<i>Acacia leucophloea</i>	6.28	15.49	0.19	8.97	0.08
<i>Balanites aegyptiaca</i>	0.90	1.41	0.01	0.75	1.42
<i>Holarrhena pubescens</i>	1.79	5.63	0.02	2.15	0.18
<i>Sterculia urens</i>	2.24	5.63	0.16	4.84	0.22
<i>Mallotus philippinensis</i>	3.14	9.86	0.07	4.52	0.10
<i>Mitragyna parvifolia</i>	0.45	1.41	0.03	0.97	0.71
<i>Derris indica</i>	1.79	4.23	0.04	2.21	0.32
<i>Capparis sepiaria</i>	0.45	1.41	0.01	0.56	0.71
<i>Acacia catechu</i>	20.63	35.21	0.34	21.12	0.05
<i>Butea monosperma</i>	3.59	8.45	0.12	5.30	0.16
<i>Azadirachta indica</i>	2.24	5.63	0.06	3.00	0.22
<i>Flacourtia indica</i>	1.79	4.23	0.01	1.78	0.32
<i>Dichrostachys cinerea</i>	1.79	4.23	0.01	1.77	0.32
<i>Catunaregam spinosa</i>	4.04	8.45	0.02	3.70	0.18
<i>Schrebera swietenioides</i>	1.35	1.41	0.07	2.12	2.13
<i>Lannea coromandelica</i>	4.04	11.27	0.13	6.13	0.10
<i>Schrebera swietenioides</i>	0.45	1.41	0.01	0.68	0.71
<i>Ficus arnottiana</i>	0.45	1.41	0.01	0.61	0.71
<i>Manilkara hexandra</i>	5.38	14.08	0.17	7.94	0.09
<i>Morinda pubescens</i>	0.45	1.41	0.01	0.62	0.71
<b><i>Tectona grandis</i></b>	<b>40.82</b>	<b>59.15</b>	<b>1.07</b>	<b>46.86</b>	<b>0.04</b>



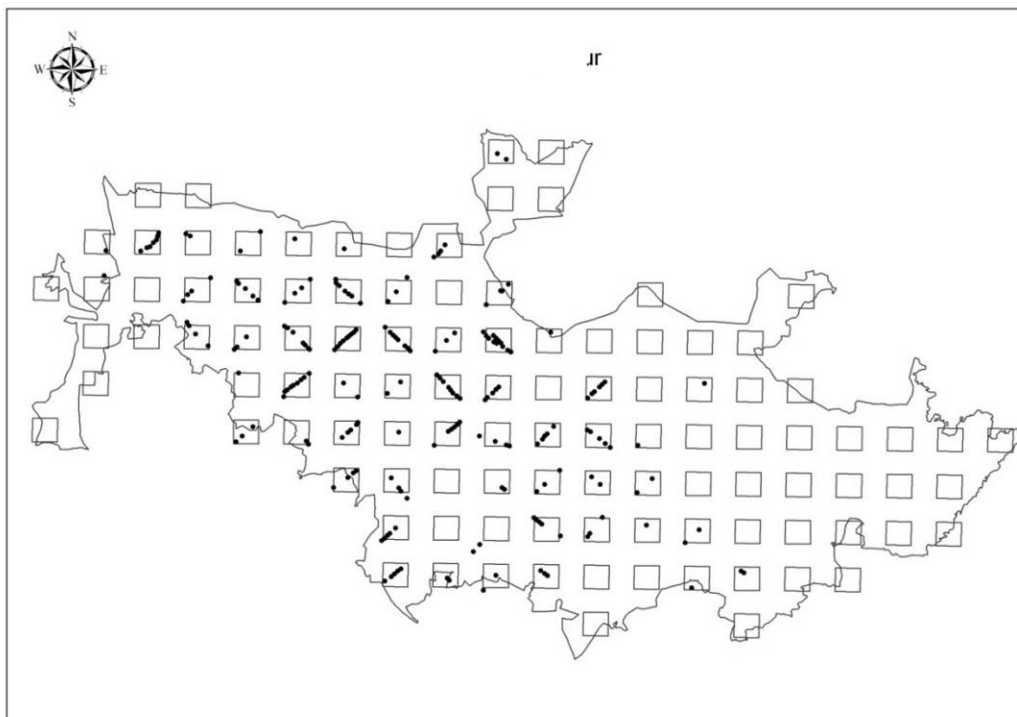
Species	Density/ha	Frequency %	TBA	IVI	A/F Ratio
<i>Terminalia alata</i>	1.35	2.82	0.05	1.90	0.53
<i>Boswellia serrata</i>	3.59	8.45	0.18	6.20	0.16
<i>Holoptelia integrifolia</i>	2.69	8.45	0.04	3.49	0.12
<i>Dalbergia latifolia</i>	1.79	5.63	0.03	2.42	0.18
<i>Bombax ceiba</i>	0.90	2.82	0.04	1.54	0.36
<i>Diospyros melanoxylon</i>	12.56	23.94	0.22	13.60	0.07
<i>Schleichera oleosa</i>	1.35	4.23	0.01	1.57	0.24
<i>Ficus glomerata</i>	5.83	14.08	0.19	8.52	0.09
<i>Ehretia laevis</i>	1.79	5.63	0.01	2.09	0.18
<i>Moringa oleifera</i>	1.35	4.23	0.07	2.69	0.24

#### 4. *Tectona grandis*-*Wrightia tinctoria* community

This vegetation type occurred in the western part of the Gir WLS. Approximately 55 different tree species were found in this community. *Tectona grandis* (124.43), *Wrightia tinctoria* (29.12) were the dominant species. The other constant species with more than 25% occurrence values were *Tectona grandis* (98.21), *Wrightia tinctoria* (44.39), and *Acacia catechu* (27.80). The total tree density of this vegetation type was 238.64/ha. The diversity value is 2.30 and richness, evenness values were 55, 0.57. Details of distribution of vegetation sampling plots within this communities and species composition, status are given in **Figure 3.9** and **Table 3.7**.



**Figure 3.9: Distribution of vegetation sampling plots classified in *Tectona grandis*-*Wrightia tinctoria* Community**



**Table 3.7: Species composition and status in *Tectona grandis*-*Wrightia tinctoria* Community**

Species	Density/ha	Frequency %	TBA	IVI	A/F ratio
<i>Bauhinia racemosa</i>	0.14	0.45	0.00	0.21	2.23
<i>Polyalthia longifolia</i>	0.14	0.45	0.00	0.22	2.23
<i>Bauhinia purpurea</i>	5.71	15.25	0.07	7.48	0.08
<i>Emblica officinalis</i>	1.57	3.59	0.03	2.05	0.38
<i>Phyllanthus emblica</i>	3.14	8.52	0.08	4.97	0.14
<i>Tamarindus indica</i>	0.14	0.45	0.01	0.35	2.23
<i>Asparagus dumosus</i>	0.29	0.45	0.01	0.37	4.46
<i>Sapindus emarginatus</i>	0.14	0.45	0.00	0.19	2.23
<i>Acacia sp</i>	5.28	13.90	0.13	8.02	0.09
<i>Terminalia bellirica</i>	1.29	3.59	0.05	2.29	0.31
<i>Acacia nilotica</i>	1.14	2.24	0.01	1.27	0.71
<i>Aegle marmelos</i>	3.00	6.28	0.04	3.59	0.24
<i>Pterocarpus marsupium</i>	1.14	3.59	0.04	2.01	0.28
<i>Ziziphus mauritiana</i>	0.86	2.69	0.01	1.22	0.37
<i>Grewia tiliiaefolia</i>	8.00	19.28	0.10	9.96	0.07
<i>Anogeissus latifolia</i>	0.14	0.45	0.00	0.21	2.23



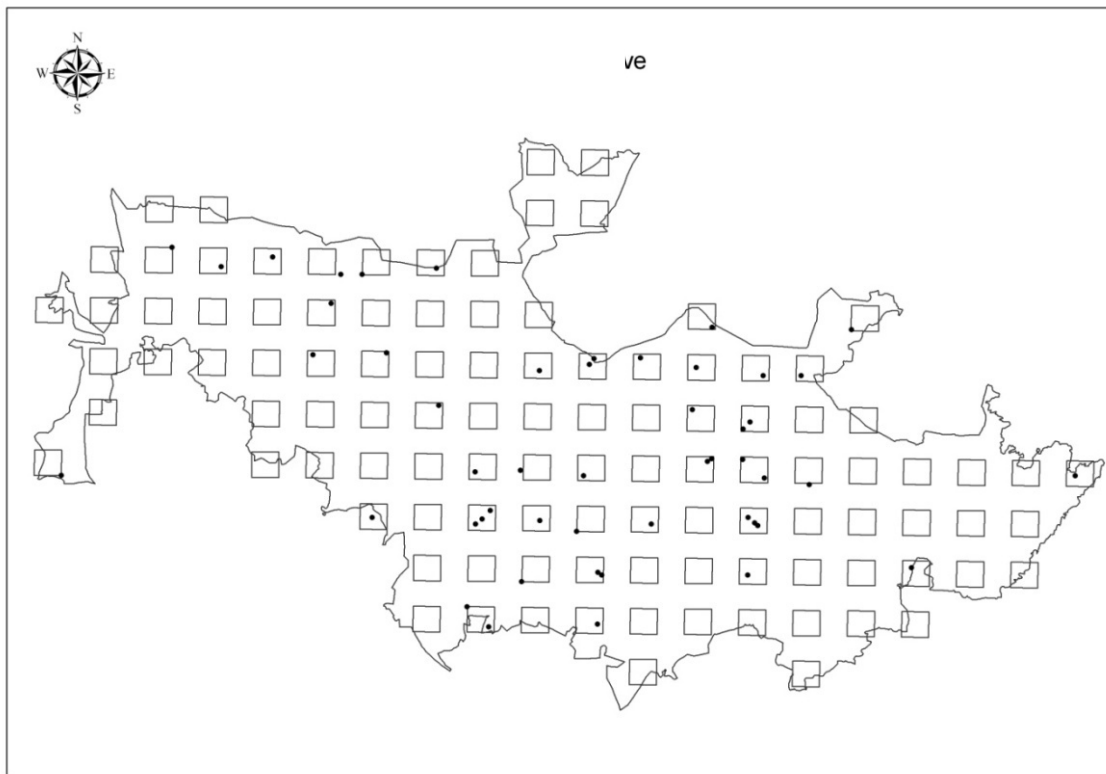
Species	Density/ha	Frequency %	TBA	IVI	A/F ratio
<i>Wrightia tinctoria</i>	<b>24.28</b>	<b>44.39</b>	<b>0.43</b>	<b>29.12</b>	<b>0.04</b>
<i>Grewia tenax</i>	0.14	0.45	0.00	0.19	2.23
<i>Cassia fistula</i>	1.43	4.48	0.02	2.10	0.22
<i>Acacia senegal</i>	0.57	1.79	0.02	0.99	0.56
<i>Zizyphus xylopyra</i>	1.71	4.48	0.01	2.11	0.27
<i>Haldinia cordifolia</i>	0.14	0.45	0.09	1.74	2.23
<i>Acacia leucophloea</i>	4.57	13.00	0.09	6.78	0.08
<i>Syzygium cumini</i>	0.14	0.45	0.02	0.57	2.23
<i>Holarrhena pubescens</i>	3.00	6.73	0.02	3.41	0.21
<i>Sterculia urens</i>	2.14	5.83	0.17	5.42	0.20
<i>Mallotus philippinensis</i>	1.57	3.59	0.04	2.28	0.38
<i>Derris indica</i>	0.14	0.45	0.00	0.21	2.23
<i>Capparis sepiaria</i>	0.14	0.45	0.00	0.19	2.23
<i>Acacia catechu</i>	15.42	27.80	0.29	18.66	0.06
<i>Butea monosperma</i>	2.14	6.73	0.04	3.38	0.15
<i>Azadirachta indica</i>	0.29	0.90	0.01	0.46	1.12
<i>Dichrostachys cinerea</i>	0.14	0.45	0.00	0.18	2.23
<i>Catunaregam spinosa</i>	1.29	3.59	0.01	1.69	0.31
<i>Lannea coromandelica</i>	5.14	12.11	0.11	7.24	0.11
<i>Schrebera seietenioides</i>	0.43	1.35	0.01	0.65	0.74
<i>Ficus arnottiana</i>	0.14	0.45	0.00	0.25	2.23
<i>Grewia asiatica</i>	0.14	0.45	0.00	0.23	2.23
<i>Manilkara hexandra</i>	2.43	5.83	0.09	4.06	0.22
<i>Morinda pubescens</i>	1.29	4.04	0.05	2.36	0.25
<b><i>Tectona grandis</i></b>	<b>114.25</b>	<b>98.21</b>	<b>2.93</b>	<b>124.43</b>	<b>0.04</b>
<i>Terminalia alata</i>	6.43	17.94	0.15	9.94	0.06
<i>Boswellia serrata</i>	3.28	6.73	0.13	5.43	0.23
<i>Delonix elata</i>	0.14	0.45	0.00	0.20	2.23
<i>Holoptelia integrifolia</i>	0.57	1.79	0.01	0.95	0.56
<i>Dalbergia latifolia</i>	2.43	6.73	0.05	3.70	0.17
<i>Bombax ceiba</i>	0.14	0.45	0.00	0.21	2.23
<i>Diospyros melanoxylon</i>	7.43	18.39	0.19	11.06	0.07
<i>Ficus racemosa</i>	0.14	0.45	0.01	0.32	2.23
<i>Schleichera oleosa</i>	0.43	0.90	0.02	0.75	1.67
<i>Ficus glomerata</i>	1.43	4.48	0.04	2.39	0.22
<i>Ficus benghalensis</i>	0.43	1.35	0.04	1.15	0.74
<i>Ehretia laevis</i>	0.14	0.45	0.00	0.20	2.23
<i>Moringa oleifera</i>	0.14	0.45	0.00	0.19	2.23
<i>Gmelina arborea</i>	0.29	0.90	0.00	0.42	1.12



### 5. *Terminalia alata*-*Tectona grandis*-*Lannea coromandelica*-*Acacia catechu* Community

This type of vegetation community occurred in the National Park and central east part of the Gir WLS. More than 40 different species of trees were found in this vegetation type. *Terminalia alata* (39.52), *Tectona grandis* (38.13), *Lannea coromandelica* (30.64), *Acacia catechu* (31.00) were the dominant trees of this community. The other constant species with the occurrence value more than 25% were *Terminalia alata* (47.06), *Tectona grandis* (45.10), *Lannea coromandelica* (45.10), *Acacia catechu* (43.14), *Boswellia serrata* (27.45), *Emblica officinalis* (25.49). The total tree density of this vegetation type was 179.84/ha. The diversity value was 2.92 and the richness, evenness values were 40, 0.79. Details of distribution of vegetation sampling plots within this communities and species composition, status are given in **Figure 3.10** and **Table 3.8**.

**Figure 3.10: Distribution of vegetation sampling plots classified in *Terminalia alata*-*Tectona grandis*-*Lannea coromandelica*-*Acacia catechu* Community**





**Table 3.8: Species composition and status in *Terminalia alata*-*Tectona grandis*-*Lannea coromandelica*-*Acacia catechu* Community**

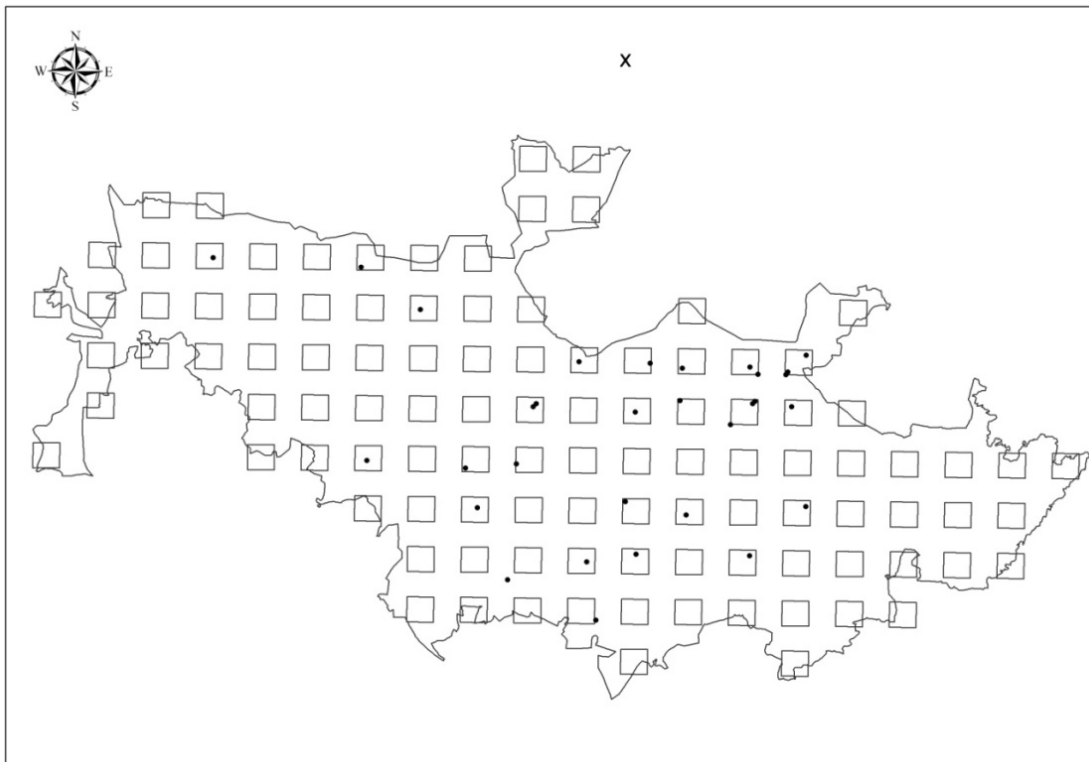
Species	Density/ha	Frequency %	TBA	IVI	A/F ratio
<i>Emblica officinalis</i>	12.49	25.49	0.19	17.99	0.06
<i>Phyllanthus emblica</i>	3.75	7.84	0.07	5.67	0.19
<i>Tamarindus indica</i>	1.25	3.92	0.03	2.48	0.26
<i>Sapindus emarginatus</i>	0.62	1.96	0.00	0.95	0.51
<i>Acacia sp</i>	2.50	7.84	0.03	4.07	0.13
<i>Terminalia bellirica</i>	2.50	7.84	0.21	8.64	0.13
<i>Aegle marmelos</i>	2.50	1.96	0.06	3.45	2.04
<i>Pterocarpus marsupium</i>	0.62	1.96	0.00	0.95	0.51
<i>Ziziphus mauritiana</i>	0.62	1.96	0.01	1.03	0.51
<i>Grewia tiliiaefolia</i>	2.50	5.88	0.02	3.22	0.23
<i>Anogeissus latifolia</i>	1.87	3.92	0.04	2.90	0.38
<i>Wrightia tinctoria</i>	1.25	3.92	0.02	2.08	0.26
<i>Grewia tenax</i>	1.25	3.92	0.01	1.97	0.26
<i>Cassia fistula</i>	0.62	1.96	0.01	0.99	0.51
<i>Acacia senegal</i>	1.25	1.96	0.02	1.74	1.02
<i>Acacia leucophloea</i>	0.62	1.96	0.05	2.17	0.51
<i>Syzygium cumini</i>	0.62	1.96	0.00	0.88	0.51
<i>Holarrhena pubescens</i>	0.62	1.96	0.00	0.88	0.51
<i>Sterculia urens</i>	0.62	1.96	0.00	0.91	0.51
<i>Mallotus philippinensis</i>	1.87	5.88	0.03	3.18	0.17
<i>Mitragyna parvifolia</i>	2.50	7.84	0.11	6.15	0.13
<i>Derris indica</i>	0.62	1.96	0.01	1.14	0.51
<i>Acacia catechu</i>	23.10	43.14	0.30	31.00	0.04
<i>Butea monosperma</i>	1.25	3.92	0.01	1.93	0.26
<i>Azadirachta indica</i>	1.25	3.92	0.02	2.29	0.26
<i>Flacourtia indica</i>	1.87	5.88	0.01	2.85	0.17
<i>Dichrostachys cinerea</i>	0.62	1.96	0.00	0.95	0.51
<i>Catunaregam spinosa</i>	5.00	5.88	0.07	5.90	0.45
<b><i>Lannea coromandelica</i></b>	<b>16.24</b>	<b>45.10</b>	<b>0.42</b>	<b>30.64</b>	<b>0.03</b>
<i>Manilkara hexandra</i>	7.49	21.57	0.34	17.84	0.05
<b><i>Tectona grandis</i></b>	<b>23.73</b>	<b>45.10</b>	<b>0.55</b>	<b>38.13</b>	<b>0.04</b>
<b><i>Terminalia alata</i></b>	<b>24.35</b>	<b>47.06</b>	<b>0.58</b>	<b>39.52</b>	<b>0.03</b>
<i>Boswellia serrata</i>	13.74	27.45	0.39	24.18	0.06
<i>Dalbergia latifolia</i>	2.50	7.84	0.07	5.05	0.13
<i>Diospyros melanoxylon</i>	10.62	21.57	0.26	17.74	0.07
<i>Schleichera oleosa</i>	1.25	3.92	0.03	2.35	0.26
<i>Ficus glomerata</i>	1.87	5.88	0.02	2.98	0.17
<i>Ficus benghalensis</i>	0.62	1.96	0.02	1.22	0.51
<i>Sterculia villosa</i>	0.62	1.96	0.00	0.92	0.51
<i>Gmelina arborea</i>	0.62	1.96	0.01	1.08	0.51



### 6. *Boswellia serrata*-*Acacia catechu* Community

This type of vegetation community occurred in the central part of the Gir WLS. Twenty different tree species were observed in this community. *Boswellia serrata* (106.51), *Acacia catechu* (41.21) were the two most dominant species of trees found in this vegetation type. Other constant species with the occurrence value more than 25% were *Boswellia serrata* (90.32), *Acacia catechu* (54.84), *Manilkara hexandra* (29.03), and *Acacia spp* (29.03). The total tree density was 173.62/ha. The diversity value was 2.20 and the richness, evenness values were 20, 0.73. Details of distribution of vegetation sampling plots within this communities and species composition, status are given in **Figure 3.11** and **Table 3.9**.

**Figure 3.11: Distribution of vegetation sampling plots classified in *Boswellia serrata*-*Acacia catechu* community**





**Table 3.9: Species composition and status in *Boswellia serrata*-*Acacia catechu* community**

Species	Density/Ha	Frequency %	TBA	IVI	A/F Ratio
<i>Bauhinia purpurea</i>	6.16	16.13	0.09	10.66	0.07
<i>Emblica officinalis</i>	2.05	6.45	0.03	3.76	0.16
<i>Phyllanthus emblica</i>	1.03	3.23	0.01	1.75	0.31
<i>Asparagus dumosus</i>	4.11	3.23	0.03	4.15	1.24
<i>Acacia sp</i>	11.30	29.03	0.17	19.30	0.04
<i>Ziziphus mauritiana</i>	1.03	3.23	0.01	1.75	0.31
<i>Anogeissus latifolia</i>	1.03	3.23	0.01	1.72	0.31
<i>Wrightia tinctoria</i>	9.25	19.35	0.18	15.70	0.08
<i>Sterculia urens</i>	4.11	12.90	0.39	16.05	0.08
<i>Mitragyna parvifolia</i>	1.03	3.23	0.03	2.29	0.31
<b><i>Acacia catechu</i></b>	<b>28.77</b>	<b>54.84</b>	<b>0.33</b>	<b>41.21</b>	<b>0.03</b>
<i>Lannea coromandelica</i>	7.19	16.13	0.15	12.78	0.09
<i>Ficus arnottiana</i>	2.05	3.23	0.09	4.34	0.62
<i>Manilkara hexandra</i>	12.33	29.03	0.34	24.41	0.05
<i>Tectona grandis</i>	6.16	16.13	0.18	12.89	0.07
<i>Terminalia alata</i>	5.14	16.13	0.08	9.62	0.06
<b><i>Boswellia serrata</i></b>	<b>65.75</b>	<b>90.32</b>	<b>1.64</b>	<b>106.51</b>	<b>0.03</b>
<i>Dalbergia latifolia</i>	3.08	9.68	0.05	5.94	0.10
<i>Diospyros melanoxylon</i>	1.03	3.23	0.06	3.06	0.31
<i>Moringa oleifera</i>	1.03	3.23	0.02	2.13	0.31

### 7. *Acacia catechu*-*Ziziphus mauritiana* community

This type of vegetation community occurred in the central, northern, central east part of the Gir WLS. More than 40 tree species were observed in this community. *Acacia catechu* (131.10), *Ziziphus mauritiana* (25.10) were the dominant species of this community. *Acacia catechu* (100.00) was considered to be the most constant species of this community. The total tree density of this vegetation type was 176.61/ha. The diversity value was 2.16 and the richness, evenness values were 40, 0.58. Details of distribution of vegetation sampling plots within this communities and species composition, status are given in **Figure 3.12** and **Table 3.10**.



Figure 3.12: Distribution of vegetation sampling plots classified in *Acacia catechu- Ziziphus mauritiana* Community

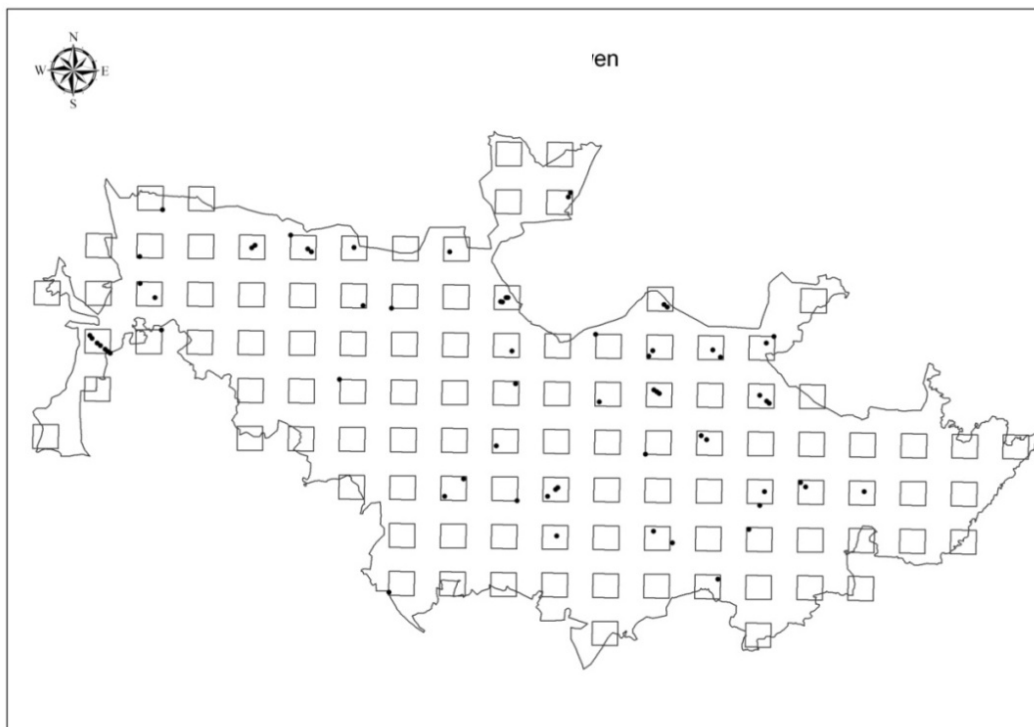


Table 3.10: Species status and composition in *Acacia catechu- Ziziphus mauritiana* Community

Species	Density/Ha	Frequency %	TBA	IVI	A/F Ratio
<i>Bauhinia purpurea</i>	1.45	4.55	0.03	3.27	0.22
<i>Embllica officinalis</i>	2.90	6.06	0.08	6.42	0.25
<i>Acacia sp</i>	0.97	3.03	0.01	2.09	0.33
<i>Hymenodyctyon orixense</i>	1.45	1.52	0.03	2.33	1.98
<i>Terminalia bellirica</i>	0.48	1.52	0.04	2.11	0.66
<i>Acacia nilotica</i>	3.38	7.58	0.06	6.47	0.18
<i>Aegle marmelos</i>	0.97	1.52	0.02	1.65	1.32
<b><i>Ziziphus mauritiana</i></b>	<b>16.41</b>	<b>22.73</b>	<b>0.23</b>	<b>25.10</b>	<b>0.10</b>
<i>Grewia tiliiaefolia</i>	1.45	3.03	0.02	2.70	0.50
<i>Anogeissus latifolia</i>	3.86	7.58	0.04	6.31	0.21
<i>Wrightia tinctoria</i>	0.97	3.03	0.01	1.85	0.33
<i>Grewia tenax</i>	0.48	1.52	0.00	0.91	0.66
<i>Acacia senegal</i>	1.45	4.55	0.03	3.46	0.22
<i>Zizyphus xylopyra</i>	2.41	7.58	0.02	4.71	0.13
<i>Haldinia cordifolia</i>	0.48	1.52	0.01	1.13	0.66
<i>Acacia leucophloea</i>	2.41	7.58	0.04	5.28	0.13
<i>Balanites aegyptiaca</i>	0.97	3.03	0.00	1.77	0.33
<i>Holarrhena pubescens</i>	0.97	3.03	0.01	1.93	0.33
<i>Mallotus philippinensis</i>	0.48	1.52	0.01	1.01	0.66
<i>Derris indica</i>	0.97	1.52	0.01	1.28	1.32



Species	Density/Ha	Frequency %	TBA	IVI	A/F Ratio
<i>Acacia catechu</i>	95.06	100.00	1.24	131.10	0.03
<i>Butea monosperma</i>	1.93	6.06	0.05	4.86	0.17
<i>Azadirachta indica</i>	0.48	1.52	0.01	1.20	0.66
<i>Dichrostachys cinerea</i>	1.93	4.55	0.02	3.26	0.29
<i>Catunaregam spinosa</i>	0.97	3.03	0.01	1.85	0.33
<i>Lannea coromandelica</i>	2.90	9.09	0.06	6.85	0.11
<i>Grewia asiatica</i>	0.97	3.03	0.01	1.99	0.33
<i>Parkinsonia aculeata</i>	0.48	1.52	0.02	1.36	0.66
<i>Manilkara hexandra</i>	0.48	1.52	0.11	4.58	0.66
<i>Morinda pubescens</i>	2.90	6.06	0.06	5.76	0.25
<i>Tectona grandis</i>	4.83	10.61	0.17	12.28	0.13
<i>Terminalia alata</i>	5.79	15.15	0.13	13.15	0.08
<i>Boswellia serrata</i>	5.31	9.09	0.20	13.00	0.20
<i>Delonix elata</i>	0.48	1.52	0.03	1.77	0.66
<i>Holoptelia integrifolia</i>	0.48	1.52	0.01	1.08	0.66
<i>Dalbergia latifolia</i>	0.48	1.52	0.01	0.99	0.66
<i>Diospyros melanoxylon</i>	2.90	6.06	0.06	5.70	0.25
<i>Schleichera oleosa</i>	0.97	1.52	0.02	1.65	1.32
<i>Ficus glomerata</i>	1.45	4.55	0.04	3.66	0.22
<i>Moringa oleifera</i>	0.97	3.03	0.02	2.13	0.33

### 8. *Anogeissus latifolia*, *Boswellia serrata* Community

This type of vegetation community occurred in the Gir east part. Thirty four different tree species belong to this community. The dominant species were *Anogeissus latifolia* (89.37), *Boswellia serrata* (26.54). The other constant species with the more than 25 % occurrence value were *Anogeissus latifolia* (86.67), *Acacia catechu* (30.67), and *Acacia nilotica* (32.00). The total tree density was 189.79/ha whereas the diversity value was 2.43. The richness and evenness values were 34 and 0.69. Details of distribution of vegetation sampling plots within this communities and species composition, status are given in **Figure 3.13** and **Table 3.11**.



Figure 3.13: Distribution of vegetation sampling plots classified in *Anogeissus latifolia*, *Boswellia serrata* Community

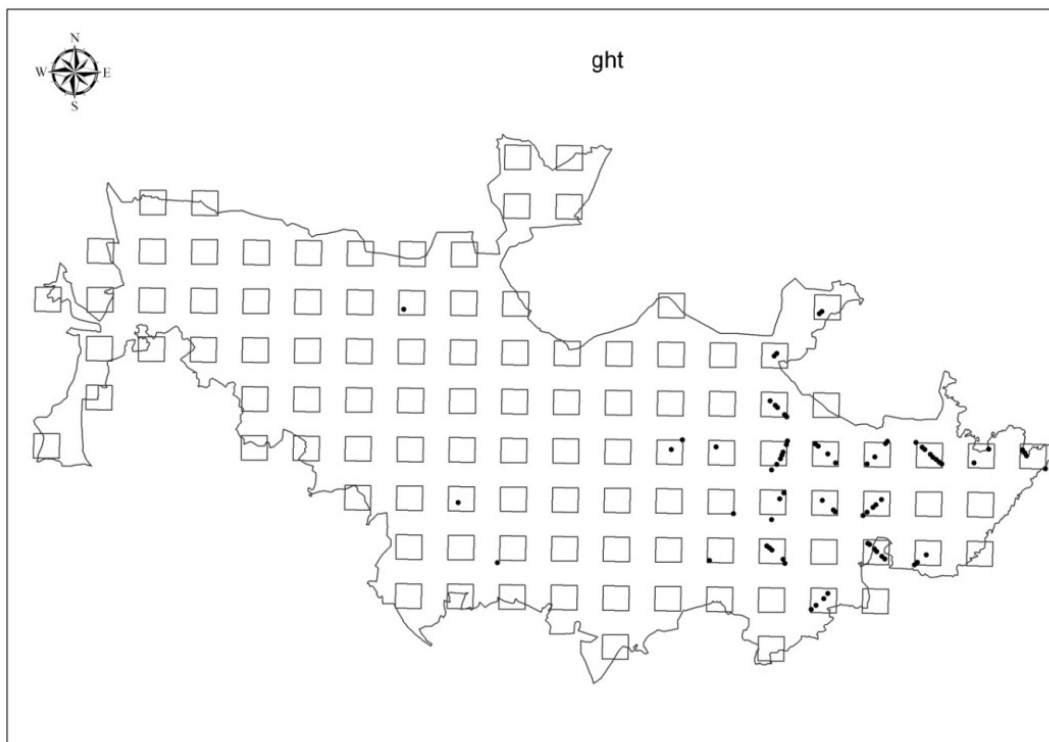


Table 3.11: Species composition and status in *Anogeissus latifolia*, *Boswellia serrata* Community

Species	Density/Ha	Frequency %	TBA	IVI	A/F Ratio
<i>Bauhinia purpurea</i>	1.70	5.33	0.03	3.20	0.19
<i>Emblica officinalis</i>	1.28	4.00	0.02	2.36	0.25
<i>Acacia sp</i>	0.43	1.33	0.00	0.63	0.75
<i>Acacia nilotica</i>	15.74	32.00	0.28	24.06	0.05
<i>Ziziphus mauritiana</i>	2.55	8.00	0.02	4.15	0.13
<b><i>Anogeissus latifolia</i></b>	<b>70.21</b>	<b>86.67</b>	<b>1.13</b>	<b>89.37</b>	<b>0.03</b>
<i>Wrightia tinctoria</i>	2.55	8.00	0.08	5.52	0.13
<i>Grewia tenax</i>	0.43	1.33	0.00	0.65	0.75
<i>Acacia senegal</i>	15.32	22.67	0.26	20.84	0.09
<i>Acacia leucophloea</i>	6.81	18.67	0.10	11.19	0.06
<i>Balanites aegyptiaca</i>	0.85	2.67	0.00	1.27	0.38
<i>Sterculia urens</i>	0.43	1.33	0.03	1.36	0.75
<i>Mitragyna parvifolia</i>	0.43	1.33	0.00	0.63	0.75
<i>Acacia catechu</i>	16.17	30.67	0.32	24.95	0.05
<i>Phoenix sylvestris</i>	0.85	1.33	0.02	1.20	1.50



Species	Density/Ha	Frequency %	TBA	IVI	A/F Ratio
<i>Butea monosperma</i>	2.98	9.33	0.04	5.25	0.11
<i>Azadirachta indica</i>	2.55	8.00	0.06	4.96	0.13
<i>Dichrostachys cinerea</i>	2.13	5.33	0.02	3.11	0.23
<i>Catunaregam spinosa</i>	0.43	1.33	0.00	0.63	0.75
<i>Lannea coromandelica</i>	4.68	12.00	0.14	9.41	0.10
<i>Schrebera seietenioides</i>	0.85	2.67	0.02	1.64	0.38
<i>Grewia asiatica</i>	0.43	1.33	0.02	1.03	0.75
<i>Manilkara hexandra</i>	8.09	21.33	0.22	15.75	0.06
<i>Morinda pubescens</i>	1.28	4.00	0.02	2.26	0.25
<i>Tectona grandis</i>	1.28	4.00	0.03	2.59	0.25
<i>Terminalia alata</i>	6.81	18.67	0.18	13.16	0.06
<b><i>Boswellia serrata</i></b>	<b>13.19</b>	<b>24.00</b>	<b>0.52</b>	<b>26.54</b>	<b>0.07</b>
<i>Delonix elata</i>	0.85	2.67	0.20	6.11	0.38
<i>Holoptelia integrifolia</i>	0.43	1.33	0.01	0.80	0.75
<i>Dalbergia latifolia</i>	0.43	1.33	0.01	0.73	0.75
<i>Annona squamosa</i>	0.43	1.33	0.00	0.65	0.75
<i>Diospyros melanoxylon</i>	6.38	16.00	0.18	12.36	0.08
<i>Schleichera oleosa</i>	0.43	1.33	0.01	0.86	0.75
<i>Moringa oleifera</i>	0.43	1.33	0.01	0.80	0.75

### 9. *Terminalia alata*, *Acacia leucophloea*, *Anogeissus latifolia*, *Butea monosperma* Community

This type of community occurred in the north-eastern part of the Gir WLS. Twenty seven different tree species were found in this vegetation type. *Terminalia alata* (80.08), *Acacia leucophloea* (52.75), *Anogeissus latifolia* (37.46), *Butea monosperma* (27.55) were the dominant species found in this community. Other constant species with more than 25% of occurrence values were *Terminalia alata* (59.09), *Acacia leucophloea* (56.82), *Anogeissus latifolia* (25.00), *Butea monosperma* (25.00). The total tree density of this vegetation type was 127.39/ha. The diversity value was 2.40. The richness and evenness values were 27 and 0.73. Details of distribution of vegetation sampling plots within this communities and other statistical analysis are given in **Figure 3.14** and **Table 3.12**.



Figure 3.14: Distribution of vegetation sampling plots classified in *Terminalia alata*, *Acacia leucophloea*, *Anogeissus latifolia*, *Butea monosperma* Community

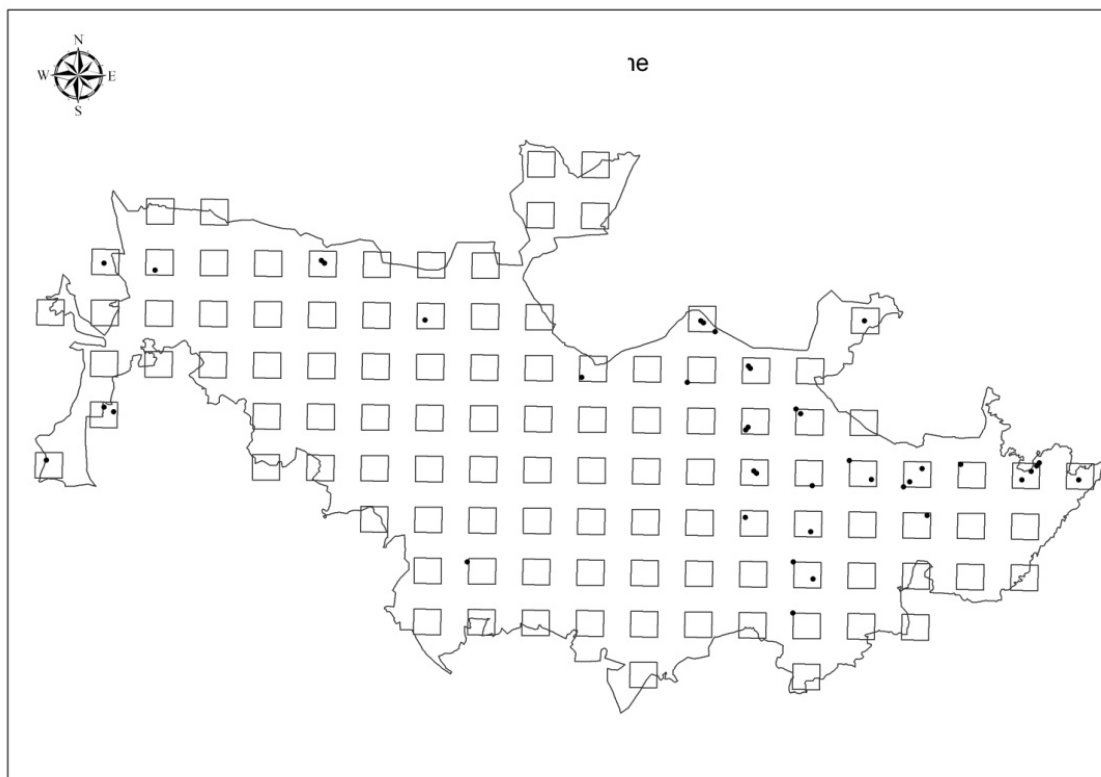


Table 3.12: Species composition and status in *Terminalia alata*, *Acacia leucophloea*, *Anogeissus latifolia*, *Butea monosperma* Community

Species	Density/Ha	Frequency %	TBA	IVI	A/F Ratio
<i>Bauhinia purpurea</i>	1.45	4.55	0.02	3.94	0.22
<i>Emblica officinalis</i>	3.62	11.36	0.04	9.00	0.09
<i>Acacia nilotica</i>	9.41	18.18	0.09	18.66	0.09
<i>Ziziphus mauritiana</i>	2.17	4.55	0.03	4.67	0.33
<i>Grewia tiliiaefolia</i>	1.45	4.55	0.01	3.32	0.22
<b><i>Anogeissus latifolia</i></b>	<b>19.54</b>	<b>25.00</b>	<b>0.25</b>	<b>37.46</b>	<b>0.10</b>
<i>Grewia tenax</i>	0.72	2.27	0.01	1.66	0.44
<i>Acacia senegal</i>	1.45	4.55	0.02	4.07	0.22
<i>Zizyphus xylopyra</i>	0.72	2.27	0.01	2.14	0.44
<b><i>Acacia leucophloea</i></b>	<b>23.89</b>	<b>56.82</b>	<b>0.26</b>	<b>52.75</b>	<b>0.02</b>
<i>Balanites aegyptiaca</i>	0.72	2.27	0.01	1.87	0.44
<i>Mallotus philippinensis</i>	0.72	2.27	0.02	2.29	0.44
<i>Capparis sepiaria</i>	0.72	2.27	0.01	1.66	0.44
<i>Acacia catechu</i>	3.62	11.36	0.05	9.59	0.09



Species	Density/Ha	Frequency %	TBA	IVI	A/F Ratio
<b><i>Butea monosperma</i></b>	<b>10.13</b>	<b>25.00</b>	<b>0.20</b>	<b>27.55</b>	<b>0.05</b>
<i>Flacourtia indica</i>	1.45	4.55	0.01	3.32	0.22
<i>Dichrostachys cinerea</i>	0.72	2.27	0.00	1.58	0.44
<i>Lannea coromandelica</i>	0.72	2.27	0.01	1.87	0.44
<i>Manilkara hexandra</i>	5.07	11.36	0.07	11.55	0.12
<i>Tectona grandis</i>	0.72	2.27	0.03	2.89	0.44
<b><i>Terminalia alata</i></b>	<b>32.57</b>	<b>59.09</b>	<b>0.64</b>	<b>80.08</b>	<b>0.03</b>
<i>Boswellia serrata</i>	0.72	2.27	0.00	1.58	0.44
<i>Holoptelia integrifolia</i>	0.72	2.27	0.01	2.11	0.44
<i>Dalbergia latifolia</i>	1.45	4.55	0.02	3.74	0.22
<i>Annona squamosa</i>	0.72	2.27	0.00	1.58	0.44
<i>Schleichera oleosa</i>	0.72	2.27	0.01	2.14	0.44
<i>Ficus benghalensis</i>	1.45	2.27	0.10	6.93	0.88

#### 10. *Acacia nilotica*, *Butea monosperma*, *Ziziphus mauritiana* Community

This type of vegetation community was mainly found in the eastern part of the Gir WLS. The dominant species were *Acacia nilotica* (103.49), *Butea monosperma* (34.55), *Ziziphus mauritiana* (26.03). The constant species with the more than 25% occurrence values were *Acacia nilotica* (88.41), *Butea monosperma* (39.13), *Ziziphus mauritiana* (30.43). The total tree density of this vegetation type was 196.62/ha. The diversity value was 2.29. The richness and evenness values were 30 and 0.67. Details of distribution of vegetation sampling plots within this communities and species composition, status are given in **Figure 3.15** and **Table 3.13**.



Figure 3.15: Distribution of vegetation sampling plots classified in *Acacia nilotica*, *Butea monosperma*, *Ziziphus mauritiana* Community

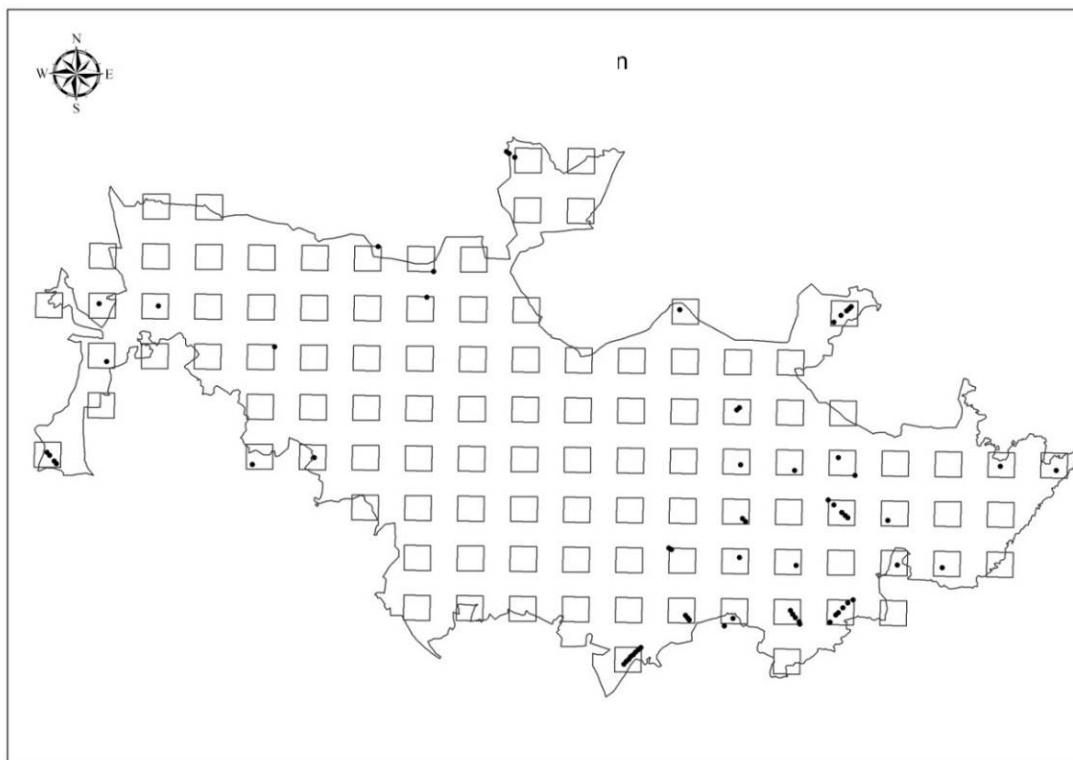


Table 3.13: Species status and composition in *Acacia nilotica*, *Butea monosperma*, *Ziziphus mauritiana* Community

Species	Density/Ha	Frequency %	TBA	IVI	A/F Ratio
<i>Bauhinia purpurea</i>	4.62	14.49	0.05	7.96	0.07
<i>Acacia sp</i>	1.38	4.35	0.06	3.66	0.23
<b><i>Acacia nilotica</i></b>	<b>77.08</b>	<b>88.41</b>	<b>1.42</b>	<b>103.49</b>	<b>0.03</b>
<b><i>Ziziphus mauritiana</i></b>	<b>18.46</b>	<b>30.43</b>	<b>0.28</b>	<b>26.03</b>	<b>0.06</b>
<i>Grewia tiliiaefolia</i>	0.92	2.90	0.02	1.84	0.35
<i>Anogeissus latifolia</i>	4.15	7.25	0.17	8.89	0.25
<i>Cassia fistula</i>	0.46	1.45	0.00	0.76	0.69
<i>Acacia senegal</i>	15.23	24.64	0.31	23.41	0.08
<i>Acacia leucophloea</i>	9.23	24.64	0.14	15.78	0.05
<i>Balanites aegyptiaca</i>	0.46	1.45	0.00	0.76	0.69
<i>Syzygium cumini</i>	2.31	1.45	0.04	2.80	3.45
<i>Mallotus philippinensis</i>	0.46	1.45	0.01	1.02	0.69
<i>Capparis sepiaria</i>	0.46	1.45	0.01	0.91	0.69
<i>Acacia catechu</i>	6.92	13.04	0.08	9.68	0.13



Species	Density/Ha	Frequency %	TBA	IVI	A/F Ratio
<i>Phoenix sylvestris</i>	0.46	1.45	0.00	0.76	0.69
<b><i>Butea monosperma</i></b>	<b>24.46</b>	<b>39.13</b>	<b>0.39</b>	<b>34.55</b>	<b>0.05</b>
<i>Azadirachta indica</i>	6.00	14.49	0.13	10.82	0.09
<i>Flacourtia indica</i>	0.92	2.90	0.01	1.73	0.35
<i>Dichrostachys cinerea</i>	5.08	10.14	0.04	6.76	0.15
<i>Lannea coromandelica</i>	1.38	2.90	0.01	1.97	0.52
<i>Schrebera seietenioides</i>	0.92	2.90	0.01	1.65	0.35
<i>Ficus arnottiana</i>	0.92	2.90	0.23	7.35	0.35
<i>Manilkara hexandra</i>	0.92	2.90	0.02	1.88	0.35
<i>Morinda pubescens</i>	1.38	4.35	0.02	2.62	0.23
<i>Tectona grandis</i>	0.46	1.45	0.01	0.87	0.69
<i>Terminalia alata</i>	1.85	4.35	0.04	3.22	0.31
<i>Delonix elata</i>	0.46	1.45	0.01	1.02	0.69
<i>Holoptelia integrifolia</i>	2.31	7.25	0.06	4.93	0.14
<i>Diospyros melanoxylon</i>	5.54	13.04	0.10	9.33	0.10
<i>Ficus benghalensis</i>	1.38	4.35	0.06	3.58	0.23

## Remote Sensing Approach

**Image Classification:** The unsupervised classification of the remotely-sensed data indicated that a high degree of inter-class separability was not present and only a few useful groupings could be identified. To assess the degree of correspondence between the ecological classes identified by the TWINSpan analysis and those identifiable in the remotely-sensed data attention was therefore focused on only the classification producing up to five groups. The first three groups essentially separated pure teak and teak associated forest classes from other forest classes. The other two forest classes were non teak bearing forest classes. The three teak bearing forest classes were Moist Teak forests; *Wrightia*-Teak forests where *Wrightia* were dominated than Teak, Teak-*Wrightia* forests where teak dominated *Wrightia* presence. Other forest classes were *Boswellia*-*Acacia* forest, *Anogeissus*-*Boswellia*-*Acacia* forests.

The class groupings identified from the unsupervised classifications of the remotely sensed data therefore to some extent, resembled those derived from the TWINSpan analysis. Together these results indicated that some 4-5 groups of forest classes were separable in the remotely sensed data set and that these groups corresponded broadly to the ecological groups identified from the TWINSpan analysis. From both sets of classifications it was apparent that



Teak associated forests, *Boswellia-Acacia* forests, and *Anogeissus-Boswellia-Acacia* forests were separable to reasonable levels but further inter-class discrimination was unlikely.

On the basis of these results an attempt was made to map ecological groups which might assist lion conservation at the site from the Landsat TM image. For this it was, however necessary to accommodate the other classes present in the image. These classes were water bodies, barren land, grassland, agricultural or burnt area, and fallow land. All these classes were spectrally distinct from the others and so could be classified accurately. The 10 classification categories (**Figure 3.16**) consisted of:

1. Moist Teak Forests,
2. *Wrightia*- Teak- *Acacia nilotica* Forests,
3. Teak- *Wrightia* Forests,
4. *Accacia-Boswellia* Forests,
5. *Anogeissus-Boswellia-Accacia* Forests,
6. Bare land representing soil that has almost no vegetation,
7. Water, where this class mainly represents water stored behind dams,
8. Agriculture land including crop and fallow land as well as rainfed and irrigated land.
9. Grassland.
10. Fallow land.

The dominant and constant species of each of these vegetation types are given in **Table 3.14**.

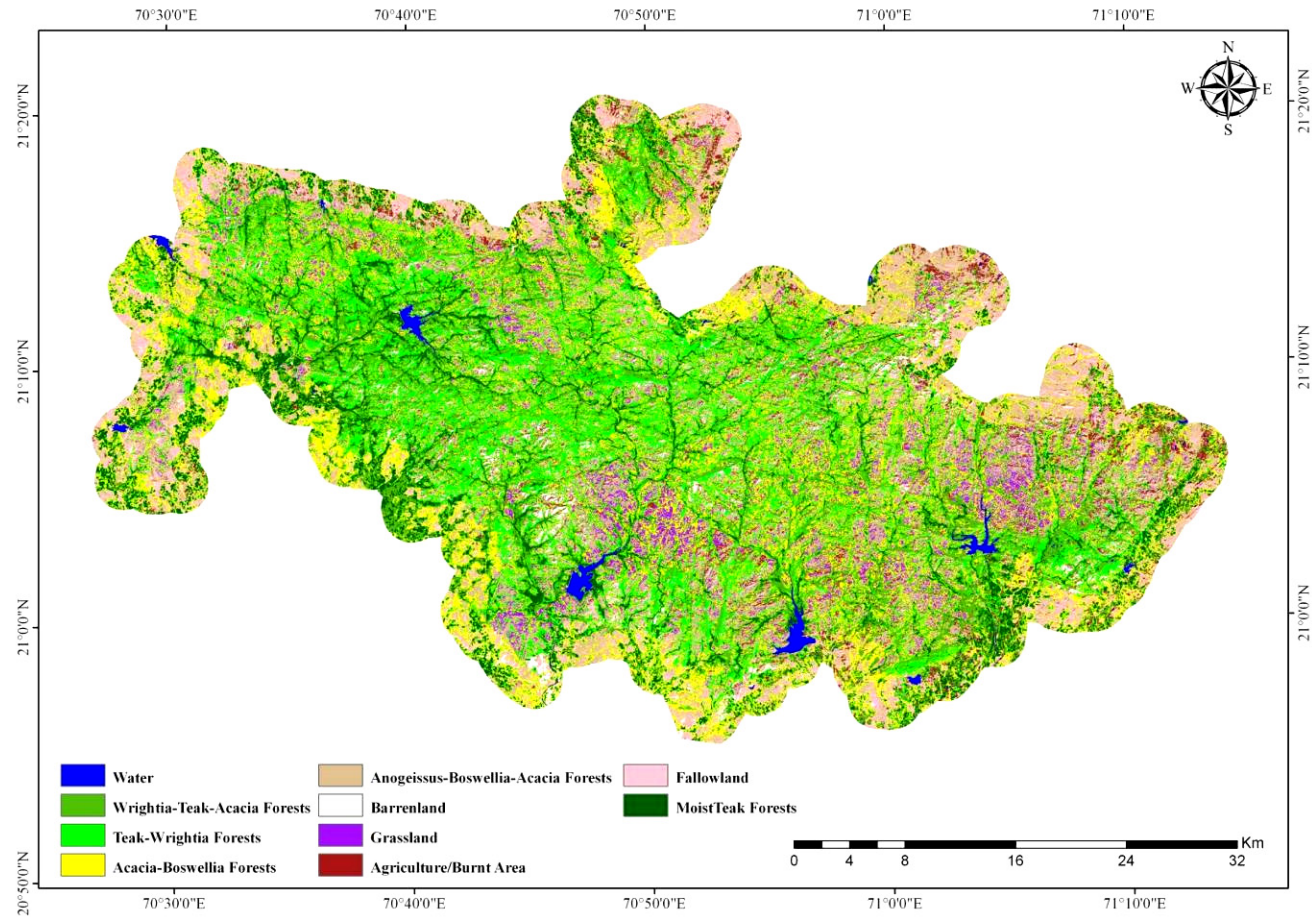


**Table 3.14: Dominant and constant species of major vegetation types in Gir Protected Area**

<b>Forest Type</b>	<b>Dominant Species (Based on IVI Value)</b>	<b>Constant Species (Frequency&gt;25%)</b>
<b>Moist Teak</b>	<i>Tectona grandis, Ziziphus mauritiana</i>	<i>Ziziphus mauritiana, Tectona grandis, Acacia nilotica, Acacia catechu, Acacia auriculiformes</i>
<b><i>Wrightia-Teak- Acacia nilotica</i></b>	<i>Wrightia tinctoria, Tectona grandis, Acacia nilotica, Butea monosperma, Ziziphus mauritiana</i>	<i>Wrightia tinctoria, Acacia nilotica, Tectona grandis, Butea monosperma, Ziziphus mauritiana, Acacia catechu, Bauhinia purpurea, Ziziphus mauritiana</i>
<b>Teak-<i>Wrightia</i></b>	<i>Tectona grandis, Wrightia tinctoria</i>	<i>Tectona grandis, Wrightia tinctoria, Acacia catechu</i>
<b><i>Acacia-Boswellia</i></b>	<i>Acacia catechu, Boswellia serrata, Terminalia alata, Tectona grandis, Lannea coromandelica, Ziziphus mauritiana</i>	<i>Acacia catechu, Boswellia serrata, Terminalia alata, Tectona grandis, Lannea coromandelica, Emblica officinalis, Manilkara hexandra</i>
<b><i>Anogeissus-Boswellia- Accacia</i></b>	<i>Anogeissus latifolia, Boswellia serrata, Terminalia alata, Acacia leucophloea, Anogeissus latifolia, Butea monosperma</i>	<i>Anogeissus latifolia, Acacia catechu, Acacia nilotica, Terminalia alata, Acacia leucophloea, Anogeissus latifolia, Butea monosperma</i>



Figure 3.16: Land use/cover pattern of Gir protected area, based on Landsat TM image of 2009





Detailed descriptions of the above five vegetation types and other land use/cover classes are as follows:

### **1. Moist Teak Forests**

This forest type was represented by two different communities of trees, *Ziziphus mauritiana*-*Tectona grandis* community and *Tectona grandis* Community. More than 50 different trees were found in this forest type. Teak (*Tectona grandis*) was the most dominant tree species of this forest type and distribution of teak was governed by the precipitation. Other dominating trees found were *Ziziphus mauritiana*, *Acacia catechu*, *Acacia auriculiformes*, and *Acacia nilotica*. Throughout its stretch from west to east within the sanctuary, teak was dominating in the western and central part of the sanctuary. *Ziziphus mauritiana* was distributed all over the stretch while presence of *Acacia auriculiformes* was mainly found in central-eastern part of the sanctuary and *Acacia nilotica* was dominating in eastern part of the sanctuary where teak was totally absent.

### **2. Wrightia-Teak- Acacia nilotica Forests**

This forest type was represented by two different vegetation communities, *Wrightia tinctoria*-*Tectona grandis* Community and *Acacia nilotica*, *Butea monosperma*, *Ziziphus mauritiana* community. More than 50 tree species were found in this forest type. While the *Wrightia tinctoria*-*Tectona grandis* Community mainly found in the western and central part of the sanctuary, the *Acacia nilotica*, *Butea monosperma*, *Ziziphus mauritiana* Community was distributed in the eastern part of the sanctuary. In the western part, this forest type was dominated by *Wrightia tinctoria*, *Tectona grandis* and other constant species were *Acacia catechu* and *Bauhinia purpurea*. In the eastern part, this forest type was dominated by *Acacia nilotica*, *Butea monosperma*. *Ziziphus mauritiana* was found all over this forest type.

### **3. Teak-Wrightia Forests**

This forest type was spread throughout the sanctuary but more area in western part of the sanctuary was under this forest type than in the eastern part. Approximately 55 different tree species occurred in this forest type. *Tectona grandis*, *Wrightia tinctoria* were the dominant species in the western and central part of the sanctuary while in the eastern part of the sanctuary *Acacia catechu* was the most common species.

### **4. Acacia-Boswellia Forests**

This forest type was patchily distributed in National Park area, central part of the sanctuary, fringes area and represented by three different vegetation communities namely, *Terminalia alata*-*Tectona grandis*-*Lannea coromandelica*-*Acacia catechu* community, *Boswellia serrata*-*Acacia catechu* community, *Acacia catechu*-*Ziziphus mauritiana* community. More



than 50 different tree species occurred in this forest type. In the national park area and few places in the central part of the sanctuary *Terminalia alata*, *Tectona grandis*, *Lannea coromandelica* were the dominant tree species while *Boswellia serrata*, *Acacia catechu* dominated in the central part of the sanctuary and in the central-east portion of the sanctuary *Acacia catechu* was the dominant species.

### 5. *Anogeissus-Boswellia-Acacia* Forests

This forest type was found in the eastern and north eastern portion of the sanctuary and it was patchily distributed. More than 40 different tree species were found in this forest type. The most dominating tree species of this forest type was *Anogeissus latifolia*, distribution of which was totally restricted to the eastern Gir. Other dominating species were *Boswellia serrata*, *Terminalia alata*, *Butea monosperma*. Different *Acacia spp* were also found in this forest type and they were spatially distributed separately from west to east. *Acacia catechu* was distributed all over the sanctuary while distribution of *Acacia leucophloea* was mostly found in the central part and *Acacia nilotica* was found in the eastern part of the sanctuary.

Kappa statistic used to measure classification accuracy was found to be 0.82 (**Table 3.15**), showing significant amount of agreement between the actual and classified vegetation map.

**Table 3.15: Kappa statistics showing accuracy of the image classification**

Symmetric Measures					
		Value	Asymp. Std. Error	Approx. T	Approx. Sig.
Measure of Agreement	Kappa	<b>0.821</b>	0.032	21.654	.000
N of Valid Cases		200			

## Discussions

LANDSAT provided scientific researchers with a valuable imagery that can be utilized for detecting terrestrial land cover conditions, and tracking land vegetation, agricultural activity, urban growth, and surface hydrology (Cohen and Goward 2004) and proved to be valuable in qualitative and quantitative terrestrial land cover changes (Coppin and Bauer 1994; Woodcock et al. 2001). Multiple images were used in identifying and monitoring reclaimed lands (Pax Lenney et al. 1996) and helped to avoid confusion between fallow and barren lands in delta regions. Multivariate discriminant function was applied to Landsat images which allowed six major land cover classes to be classified to an accuracy of 87% (Wood and



Foody 1989). The spectral and segment based classification levels of Landsat TM was merged to generate a land use maps with enhanced accuracy up to 78% (Guindon et al. 2004)

Despite the heterogeneity of the landscape from the precipitation and vegetation point of view, especially from west to east corner of the Gir protected area, Landsat images were found to be efficient in delineating the major landscape classes. Accuracy levels of more than 80% are considered adequate enough for reliable classification of land use/cover types (Sabins 1997). Importantly, areas of different classes on the study area were estimated. The use of automated signature building method such as the Isodata algorithm based on statistical differences might fail to capture the difference between different vegetation communities but supplemented by representative field data improved the ability to discriminate between these classes, but on the expense of higher cost. Other landscape elements can be easily discriminated using automated signature building algorithms. Thus collecting field data on these classes is not cost effective. Agricultural land extends from irrigated, rainfed areas followed by completely irrigated dryland farms. Mango orchards also extend over a wide range of landscapes with varying types of associated farming practices. Sometimes, the distinction between scrubland and forestland was vague where some of the so called forests are no more than a dense scrubland. On the other hand reflectance of old mango orchard and canopies of bigger trees were similar in reflectance increasing probability of classifying mango orchard as forestland. It was difficult to discriminate between pastureland and agricultural lands because of the marginal to semi dryness of the area while some agricultural lands especially fallow lands were being mistakenly identified as pastureland.

The final map assessment demonstrated satisfactory accuracy figures. An important validating element of the classification obtained was the result derived from the multivariate analysis of the phytosociological relevés. In all cases the various plant communities obtained through the TWINSpan classification corresponded to one of the final classes obtained in the digital classification. However even when the procedures proved adequate for the definition of broad land cover types along the study area, it should be noted that some floristic differences shown by the TWINSpan analysis were not represented on the final map include forest communities sharing similar to identical physiognomic characteristics. This problem already addressed by many authors in different sites (Singh 1987; Tuomisto et al. 1994) was due to the fact that satellite sensor systems measure reflected and emitted radiation from plants and from the ground surface (given a clean atmosphere) which may be shared by various vegetation types as long as they show a similar structure and plants show similar spectral signatures (Wilkie and Finn 1996).



## *CHAPTER IV*

### *VARIATIONS IN THE LANDSCAPE PATTERNS & VEGETATION COVER IN GIR PA BETWEEN 1998 & 2009*

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#### **Introduction**

Habitat loss and fragmentation beside other issues such as climate change, invasive species, disease, and overexploitation produce detrimental effects on species and ecosystems (Ewers and Didham 2006) and are the primary causes of declines in biological diversity worldwide (Wilcove et al. 1998). Hence, assessing and monitoring the state of the earth surface is a basic requirement for global change research (Jung et al. 2006). In the last two decades, increased understanding of ongoing and emerging environmental issues and the prerequisite to attempt for sustainable management of natural resources have engrossed the attention of the scientific community and International and regional organizations to assess and monitor such changes on a regular basis (DeFries et al. 2002). The study of Land Use and Land Cover Change (LUCC) is a joint core project of the International Geosphere-Biosphere Program (IGBP) and the International Human Dimensions of Global Environmental Change Programme (IHDP) (IGBP 1993; Ojima et al. 1994; IGBP/IHDP 1995). Many nations and International organizations have dedicated considerable attention to LUCC (IIASA 1998; Kuninori 1999), including International organizations such as the United Nations Environment Programme (UNEP), United Nations Food and Agriculture Organization (UN/FAO), International Institute of Applied Systems Analysis (IIASA) and International Geographical Union (IGU).

Increasing human activity across the globe has rapidly accelerated the pace of land cover/use change, resulting in extensive changes in the spatial arrangement of native habitats and biodiversity loss (Collinge 1996). Habitat modification (including habitat loss, degradation and fragmentation) is now considered as the major threats of ecosystem degradation by human activities (Whitfield et al. 2002). Recent changes in agricultural management and strengthening have altered the equilibria between biota and patterns in both farmed and natural landscapes (Poudevigne et al. 2002). More land was turned into cropland in the 30 years after 1950 than in the 150 years between 1700 and 1850 (Millenium Ecosystem Assessment 2005). Most of the world's biomes have experienced a 20%-50% conversion to human use (Collinge 2009). Worldwide, about 50% of tropical dry forests were transformed to other uses by 1950, and another 10% was lost between 1950 and 1990. Nearly 70% of the natural cover of temperate grasslands disappeared by 1950, and an additional 15%



has vanished since then (Collinge 2009). As a consequence, efforts to protect biological diversity have shifted from protection of distinct threatened species to unified strategies that protect ecosystems or habitats (McNeely et al. 1990; Lauver and Whistler 1993). The signing of the biodiversity Convention at the Rio “Earth Summit” Conference in 1992, by a number of countries, establishes the global political assurance of retaining biodiversity (Ledoux et al. 2000).

Changes in landscape patterns are reliant on the spatial and temporal scales of observation (Meentemeyer and Box 1987) which happens over long periods of time as an outcome of changes in population (Turner et al. 1993). These changes are driven by seasonal and inter-annual climatic disparities, long term climatic shifts, vegetation succession and human or natural instabilities (Hobbs 1990). The interaction between these changes leads to explicit landscape dynamics. The monitoring of landscape spatial pattern at a variety of temporal scales has several applications (Turner 1989) and as land transformation patterns vary in their spatial patterns, they may also change significantly in their impact on vital ecological processes (Fahrig 2003). Environments within regenerating stands change quickly and therefore, stand condition information must be updated occasionally. A thorough understanding of the patterns, the reasons and both the social and ecological consequences of historical changes improve our ability to predict future landscape dynamics and design more effective landscape management approaches (Kienast 1993).

### **Background information of Forest Dynamics and Management Systems of Gir (1878 – 2009)**

Gir forests comprise of forest areas of both the ex-Junagadh and ex-Baroda states (Divyabhanusinh 2005). The past history for those two tracts is therefore somewhat different (Joshi and Karamchandani 1976).

#### **Junagadh Gir Forests**

**1878-1914:** The forests were managed by the revenue department. A permit holder on payment of prescribed fees was allowed to cut the material in any manner he liked from a given area. As a result, all the best trees were removed leaving behind stunted, hollow trees.

**1915-1934:** As per the plan by Ratnagar in 1920, the area was divided into two working circles. Western working circle retained mixed deciduous forests with teak forming 80% of the crop. The coppice with standard system, with a rotation of 30 years and a closure of 10 years for the exploited coupes was recommended with no cleanings and thinning. Eastern working circle retained non-teak areas bearing mainly thorny species and large grassy blanks.



A sanctuary for lions was formed into Devalia block and Ronia vidi in Malpara block was worked for hay collection.

**1935-1954:** The simple coppice system i.e. clear felling with reservation of fruit trees e.g. rayan, ambo, amli, arithi was introduced. The closure period was reduced to 3 years and *rab* method was introduced for regeneration. This system was followed till 1952, and the number of fruit tree species was increased to cover ambo, amli, rayan, ravano, aritha, simlo, vad, papal, bahedo, jambu, pipalo, khair.

**1965-1972:** Acharya revised the working plan of Gir forests for the period from 1954-55 onwards and his working plan was continued. Five different working circles were created as under.

**Superior Teak Working Circle:** Well stocked good quality teak areas were included in this working circle. Rotation of 40 years was fixed. Modified clear felling with certain reservations was prescribed. This was supplemented with 5 percent artificial regeneration, cleaning in 5<sup>th</sup> year and thinning in 15<sup>th</sup> and 25<sup>th</sup> years with a closure for 6 years.

**Inferior Teak Working Circle:** Open and poor teak forests were involved in this circle, with a rotation of 30 years. Modified clear felling with reservation was prescribed. Most of the prescriptions of superior working circle were made applicable except that only one thinning in 10<sup>th</sup> year was prescribed.

**Improvement Working Circle:** All the open scrub type non-teak forests (except *vidis*) were included in this circle. Light and conservative “Improvement felling system” with felling cycle of 20 years, soil conservation measures with 5 percent plantation and closure of 10 years was prescribed.

**Grass (Fodder) Working Cycle:** Tree growth was worked on a felling cycle of 10 years. Artificial regeneration of fruit, fodder and shade trees in percent of coupe area was prescribed.

**Sarasia Gir Forests:** During the period from 1884-1894, when the management of forests was with the Revenue department, misuse was permitted through contractors on permit system. As a result, serious damage to forests intensified. The protection was poor and fire conservancy was not known. During the period of ex-Baroda state, Sarasia Gir was treated as grazing ground and the main item of revenue was grazing fees and sale of grass. As a result of this, damage to fodder trees happened because of extensive lopping. From the year 1954-55 these forests were brought under Acharya’s working plan.

**Joshi Plan (1976 to 1985):** The Acharya plan was revised in 1969 to change traditional method of working of forests to wildlife management and the revision work was completed in



1976. The entire working plan of the Gir forests was based on the concept of biodiversity conservation and improvement of habitat in favour of wildlife. Most of the Sanctuary and National Park area was managed under National Park Habitat Improvement Working Circle and the Watershed Conservation Working Circle. The rest of the area excluding forest settlement, protected forests and reservoirs were included in Grasslands and Coastal Plantation Working Circle.

The total area under the Joshi plan was 1602.6 sq km. In order to fulfill the objects of management, an area of 258.71 sq km. has been constituted as “National Park”. A buffer zone of a width of about 1 km was left undisturbed all around the area of the National Park. Total area of this buffer zone was 100.86 sq km. The remaining area was constituted into the following working Circles.

**Habitat Improvement Working Circle:** The area allotted to this working circle was 292.41sq km. It included all the teak bearing areas with teak forming more than 10% of the growing stock. The entire crop was of coppice origin with a large proportion of old and mature trees. The forest was worked mainly with the idea of preservation and improvement of habitat.

**Watershed Conservation Working Circle:** The area allotted to this working Circle was 704.10 sq km. This working circle included all areas containing sparse growth of non teak species and formed catchment areas of many rivers flowing throughout this region. These forests were worked mainly with the idea of soil and moisture conservation and practically no exploitation was prescribed.

**Grass-land Working Circle:** The working circle comprised of 164.58 sq km of grass producing areas locally known as *vidis*. Improvement measures for reserve *vidis* were prescribed for 10 years.

**Plantation Working Circle:** The area allotted to the working circle was 20.086 sq km. It included all the areas wherein plantations had been carried out in past along the coastal border in Gir East and Gir West Divisions and all other such areas (in charge of Forest Department) proposed to be covered by such plantations in future.

**Recreation (Overlapping) Working Circle:** The entire area of the Gir Sanctuary i.e. 1,412 sq km was covered by this working circle. The special object of management was to create conditions for the development of Wildlife tourism.

### **Objectives**

To date, there have been very few studies of landscape pattern or change for the Gir PA. Qureshi et al. 2004 used LISS III imagery to classify forests. The current study represents the



first landscape change analysis using remotely sensed data in the Gir wildlife sanctuary. The objectives of this research are:

1. To assess the rate of change in land use and vegetation patterns over a 10-year period and to consider the implications of the rates and patterns of change on future ecological conditions.

Main questions of interest were the following:

- (a) What is the pattern of change in the landscape?
- (b) What habitat types are vulnerable to change and why?

### **Hypothesis for the objective**

**H<sub>0</sub>:** Land use cover changes over years are similar across different habitat types or random.

**H<sub>a</sub>:** Human driven land uses or land cover increases with time.

### **Methodology**

The post-classification comparison approach was employed for detection of land use/cover changes, by comparing independently produced classified land use/cover maps. The main advantage of this method was its capability to provide descriptive information on the nature of changes that occurs. The following approaches were considered appropriate to fulfill above objectives. Field data was collected in a systematic manner, described in chapter three. Landsat TM satellite imageries were obtained of different years to understand the temporal changes occurred in the place. The spatial distributions of each of the classes were extracted from each of the land use/cover maps by means of GIS functions. Change Vector Analysis (Malila 1980) was used to check the direction and magnitude of the change. Markov analysis (Eastman 2000) was also applied to understand the probability of changes of one land cover type to other. For this study, we used Cellular Automata (CA)-Markov Chain analysis modeling technique, embedded in IDRISI Andes software (Eastman 2000) for predicting future landscape pattern.

The Markov Chain analysis model was executed using the Markov module. The first step in the model was to develop a transition probability matrix for each of the land cover classes between the years 1998 and 2002, and this in turn was used as an input for modeling land cover change for 2009. Based on the probability matrix obtained from Markov analysis, simulated land cover map of 2009 was created with the cellular automata markov analysis tool (CA-MARKOV). The validation of the result obtained from this technique was done using the actual classified image of 2009 with the simulated image of 2009. CA analysis was



carried out with the CA-Markov module, which uses the output from the above stated Markov Chain analysis and transition suitability image collection, and applies a contiguity filter. Later images of 1998 and 2009 was analyzed using Markov Change Analysis and based on the probability matrix obtained, simulated land cover map of 2020 was created with the cellular automata markov analysis tool (CA-MARKOV). First the probability matrix was obtained from Markov analysis and then assuming the transition probability matrix remain unchanged, simulated land cover map of 2020 was produced. FRAGSTAT (McGarigal and Marks 1995) was run on the classified image of 1998, 2002 and 2009. The trend of change observed in values of different indices with the change of land cover type is discussed.

The techniques applied to classify individual scene is discussed in chapter 3.

### **Strategies used for Land use/cover change detection**

#### ***Satellite Images and Reference Data***

Three satellite images from the Landsat program (path-row 149/45) were used in this study. All these images were acquired by Landsat 5 Thematic Mapper (TM) sensor on 17<sup>th</sup> November, 1998, 4<sup>th</sup> November, 2002 and 1<sup>st</sup> December, 2009. These images were cloud free over the study area. Observations at anniversary dates were selected because by using non-anniversary dates into consideration, the number of possible combinations of observation dates increases dramatically and the range of change magnitudes for different combination of dates is much wider than for anniversary dates. Thus the comparison of anniversary dates does indeed provide some control over seasonal variations.

During the post monsoon season in 2010 (November – January, 2011), we gathered ground reference data from more than 900 plots. We recorded vegetation structure and composition, slope and aspect for all of these reference sites. The location of these sites recorded with a GPS (Garmin 72) (see Chapter 3 for more details).

#### ***Classification of the 1998, 2002 and 2009 TM scene***

All bands of the TM image except the thermal band were used in PCA to extract information and transforming a set of correlated spectral bands of image data into an equivalent set of uncorrelated components of the data. The stacked PC layers were initially classified using the Isodata algorithm (Unsupervised classification) into 100 classes and then regrouped into the ten major classes under investigation based on the field study (see chapter three for details).

The 10 classification categories consisted of:

1. Moist Teak Forests.
2. *Wrightia*- Teak Forests



3. Teak-*Wrightia* Forests
4. *Boswellia*-*Acacia* Forests
5. *Anogeissus*-*Boswellia*-*Acacia* Forests
6. Bare land representing soil that has almost no vegetation.
7. Water, where this class mainly represents water stored behind dams.
8. Agriculture land including crop and fallow land as well as rainfed and irrigated land.
9. Grassland.
10. Fallow land

### ***Classification accuracy analysis***

Accuracy assessment was performed for 1998, 2002 and 2009 land cover maps using topographical maps, local knowledge, and systematic sampling design. Initially classified images were evaluated visually, and the effects of topographic normalization were noted. The image was evaluated quantitatively with ground truth data points. Several other types of ground truth maps, such as drainage network, road network, and settlement areas were included in the ground truth map. For the classified image of 2009, accuracy was determined based on a stratified random sample of 200 (out of total 900 points) points distributed throughout the area. Kappa statistics (Landis and Koch 1977), which assess overall accuracy by incorporating individual errors of omission and commission, were also calculated (**Table 3.15, Chapter 3**).

Identification of respective land use/cover classes and the accuracy of the classified images of 1998 and 2002 were assessed by identifying bigger patches (more than 1 ha) and using ground truth points of 2009, distributed in those bigger patches. A detailed literature review of past vegetation studies and management plans assured that in last ten years, main forest types in the area did not change so much but area under one forest type might have changed to other forest type, following process of succession or human disturbance. Use of satellite images of the same season every year assured the same reflectance values of respective forest types.

Landscape pattern analysis was performed on the raster coverages with FRAGSTATS v2.0. (McGarigal and Marks 1995). Numerous indices of landscape pattern were calculated. FRAGSTATS calculated a number of spatial metrics for each patch, for each cover class and for the entire landscape. We analyzed all metrics for the land cover classes of all dates (1998, 2002 and 2009) but selective results showing significant changes over time are presented here.



The following indices are presented here:

- (1) **The total number of landscape patches** was used as an overall measure of landscape fragmentation. This index exhibits a unimodal relationship with land cover proportions because maximum patch number occurs at intermediate levels and decreases at both high and low cover proportions (Gustafson and Parker 1992).
- (2) **Mean patch size** (Area mean) is a similar measure of fragmentation but one that exhibits a pattern opposite to that of patch number because patch size is usually largest in homogeneous landscapes.
- (3) **Total landscape edge** was calculated by summing the length of all patch boundaries in the landscape. Both the number of patches in a landscape and the complexity of patch boundaries influence the amount of edge in a landscape.
- (4) **Patch density** is a limited, but fundamental, aspect of landscape pattern. Patch density has the same basic utility as number of patches as an index, except that it expresses number of patches on a per unit area basis that facilitates comparisons among landscapes of varying size. Of course, if total landscape area is held constant, then patch density and number of patches convey the same information. Like number of patches, patch density often has limited interpretive value by itself because it conveys no information about the sizes and spatial distribution of patches.

## **Results**

The classified land use/cover maps for the study area in 1998, 2002 and 2009 are shown in **Figures 4.1, 4.2 and 4.3**. The trends in all the land use/cover changes are summarized in **Table 4.1**. Viewed as a time series, the quality and quantity of different forest types have substantially varied during the 11-year period from 1998 to 2009.



**Table 4.1: Land use/cover changes for Gir PA, as extracted from Landsat images, 1998-2009**

Land use/cover types	1998		2002		2009	
	Area in Hectare	Percentage (%)	Area in Hectare	Percentage (%)	Area in Hectare	Percentage (%)
<b>Water</b>	2443.59	1.69	728.28	0.50	1168.47	0.81
<b><i>Wrightia</i>-Teak Forests</b>	60255.09	41.67	35870.67	24.81	33278.67	23.02
<b>Teak-<i>Wrightia</i> Forests</b>	9589.50	6.63	35061.75	24.25	29277.45	20.25
<b><i>Boswellia</i>-<i>Acacia</i> Forests</b>	36483.66	25.23	35671.32	24.67	27719.46	19.17
<b><i>Anogeissus</i>-<i>Boswellia</i>-<i>Acacia</i> Forests</b>	17050.05	11.79	18121.59	12.53	25652.25	17.74
<b>Agri-Barren-Fallow land</b>	1766.25	1.22	3744.09	2.59	8651.43	5.98
<b>Grassland</b>	8838.09	6.11	7686.00	5.32	9794.61	6.77
<b>Moist Teak Forests</b>	8166.51	5.65	7709.04	5.33	9050.40	6.26

Teak-*Wrightia* forests increased in 2002 four times from its initial coverage of area in 1998, and covered approximately the same area in 2009. The *Wrightia*-Teak forest areas covered 60255 ha in 1998 and decreased to 33278 ha in 2009. On the other hand Teak-*Wrightia* forests increased substantially from 9589 ha in 1998 to 29277 ha in 2009. The *Boswellia*-*Acacia* forests occupied 36483 ha in 1998 and decreased to 27719 ha in 2009. The agriculture, Barren and fallow land jointly occupied 1766 ha in 1998 that increased to 8651 ha in 2009. Though there was not substantially increase in grassland and moist teak forest area but area of both the land cover types increased in 2009. The trends in land use/cover changes for all the classes are shown in **Figure 4.4**.

*Wrightia*-Teak forest type has decreased by 26976 ha during the period 1998-2009 while the Teak-*Wrightia* forests increased by the area of 19688 ha. Comparison of transition probabilities of these three main succession stages of teak associated forests is described in **Figure 4.5**. The probability of switching towards a more dense community is indicated from this analysis.



Figure 4.1: Land use/cover map of Gir PA in1998

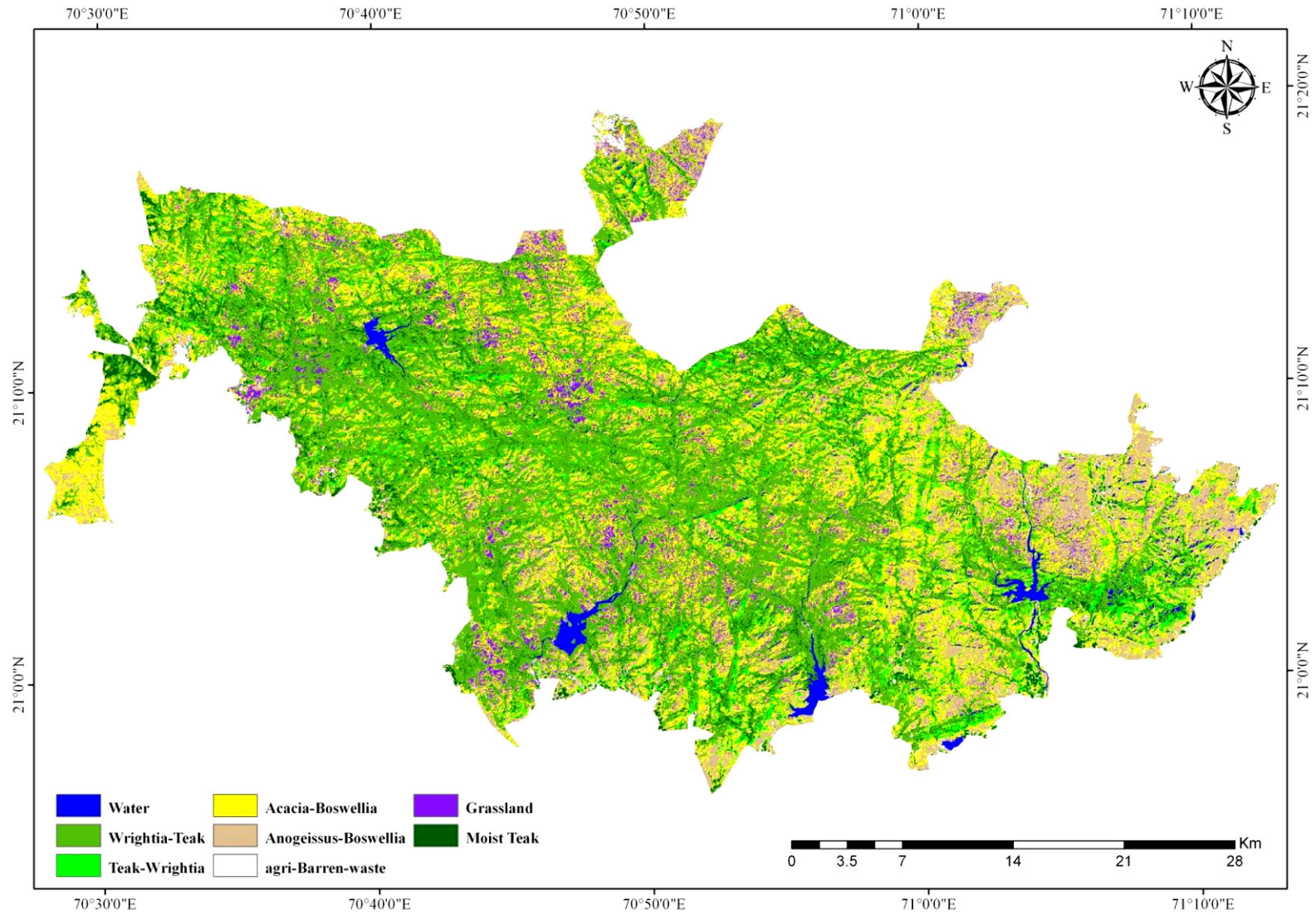
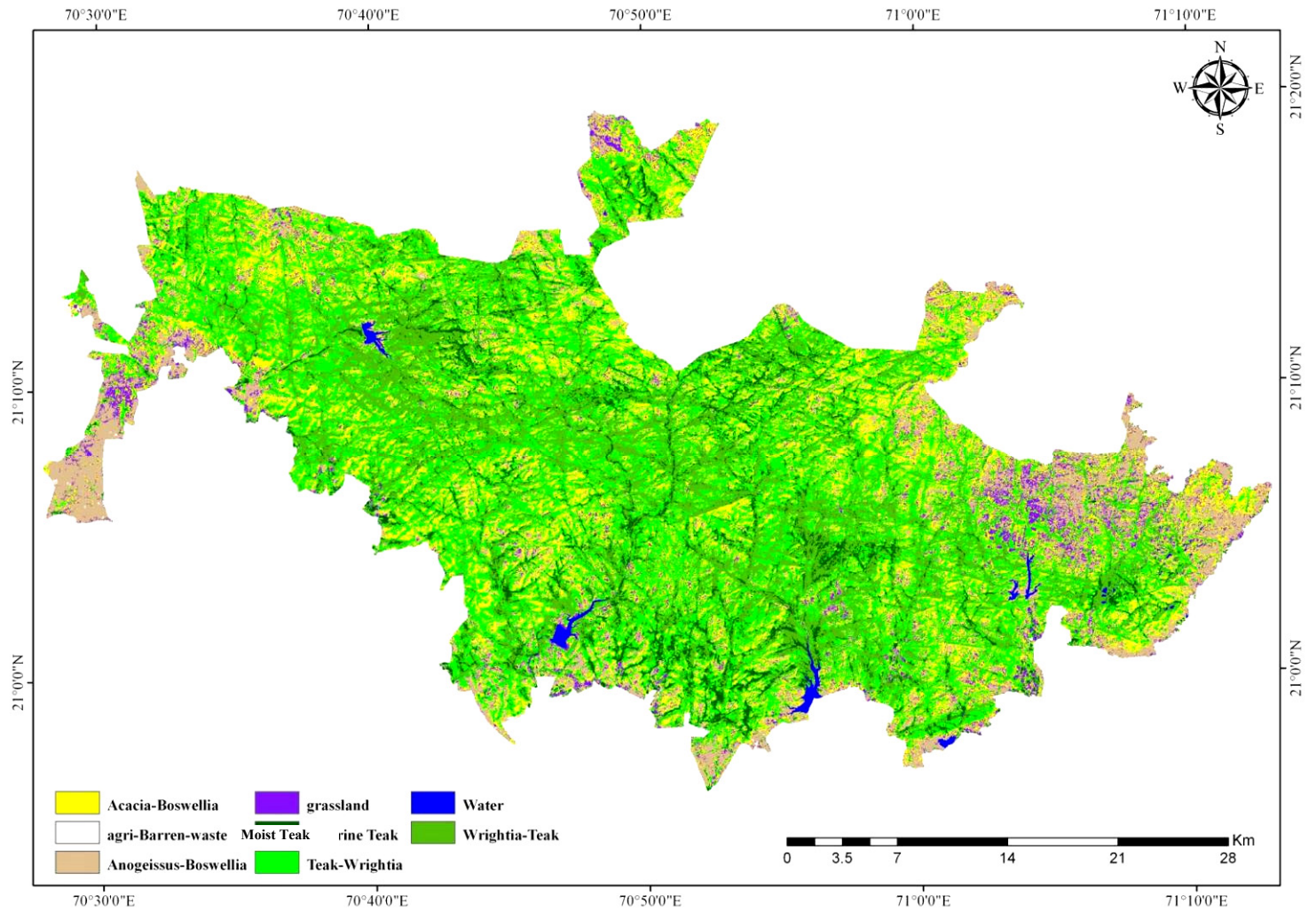


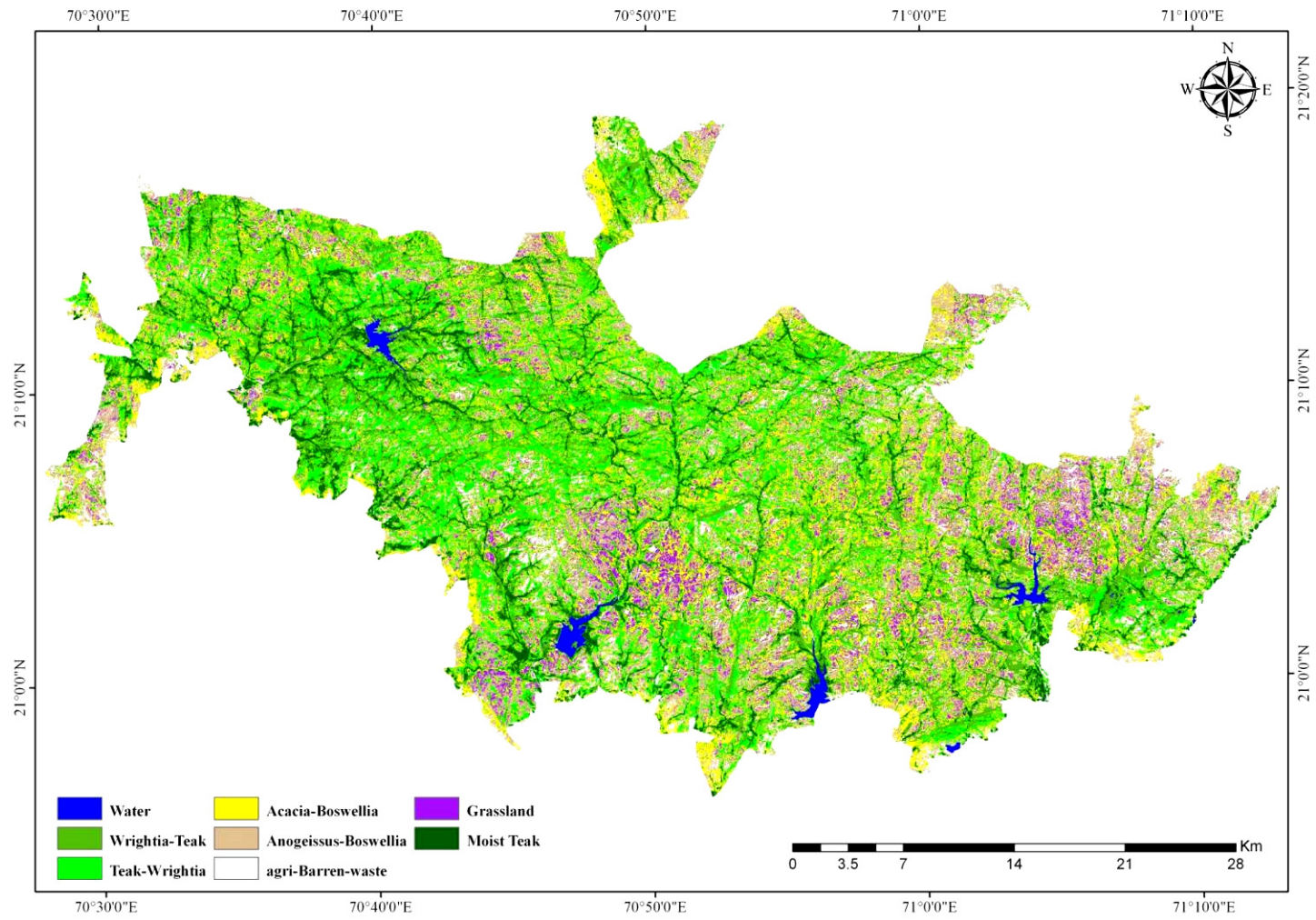


Figure 4.2: Land use/cover map of Gir PA in 2002



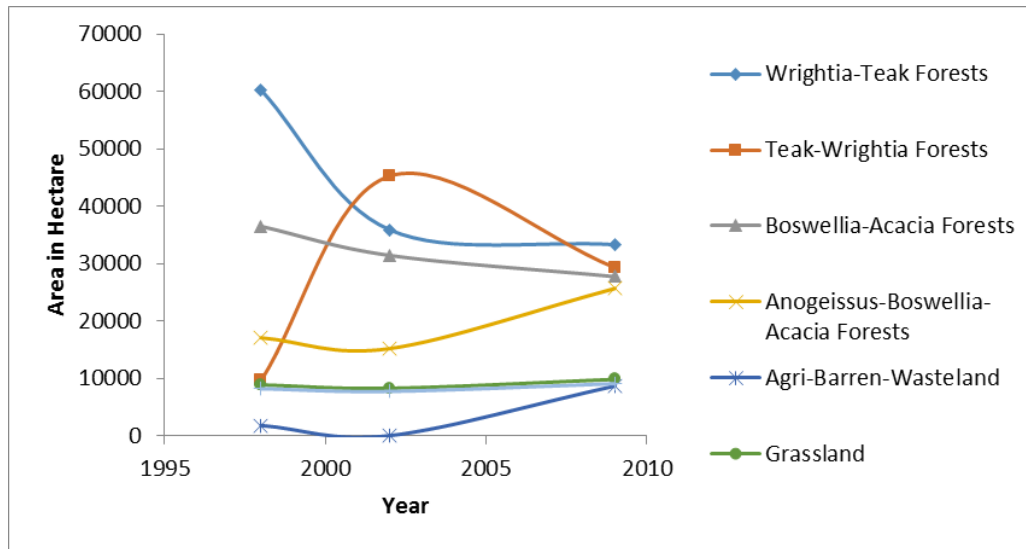


**Figure 4.3: Land use/cover map of Gir PA in 2009**

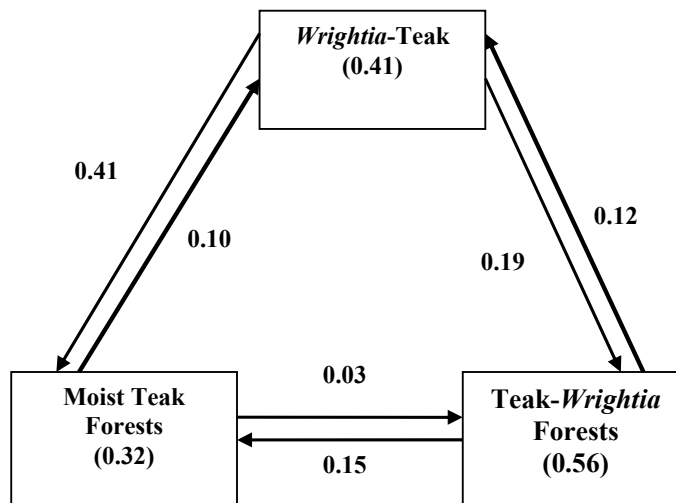




**Figure 4.4: Trends in different land use/cover changes of Gir PA from 1998-2009.**



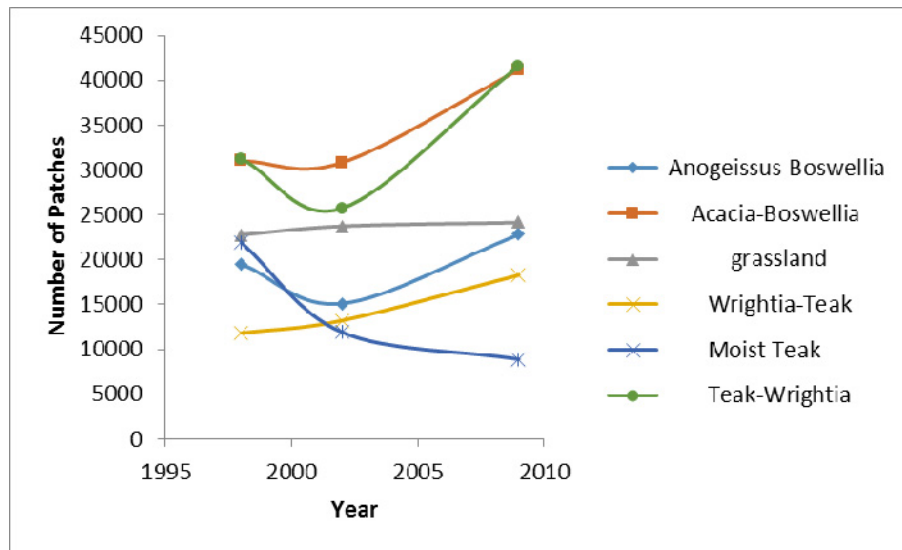
**Figure 4.5: Box and arrow diagram illustrating land cover transition probabilities for the Gir PA from 1998-2009. Values within boxes are self replacement probabilities, whereas values positioned on arrows are transition probabilities.**



The pattern of changes observed in teak associated forest types had effect on spatial distribution of forest too. As the moist teak forests became denser, number of patches of this forest type decreased while number of patches increased for the *Wrightia*-Teak forest type and remained almost constant for the *Teak-Wrightia* forest type (Figure 4.6).



Figure 4.6: Changes in number of patches in Gir PA from 1998-2009

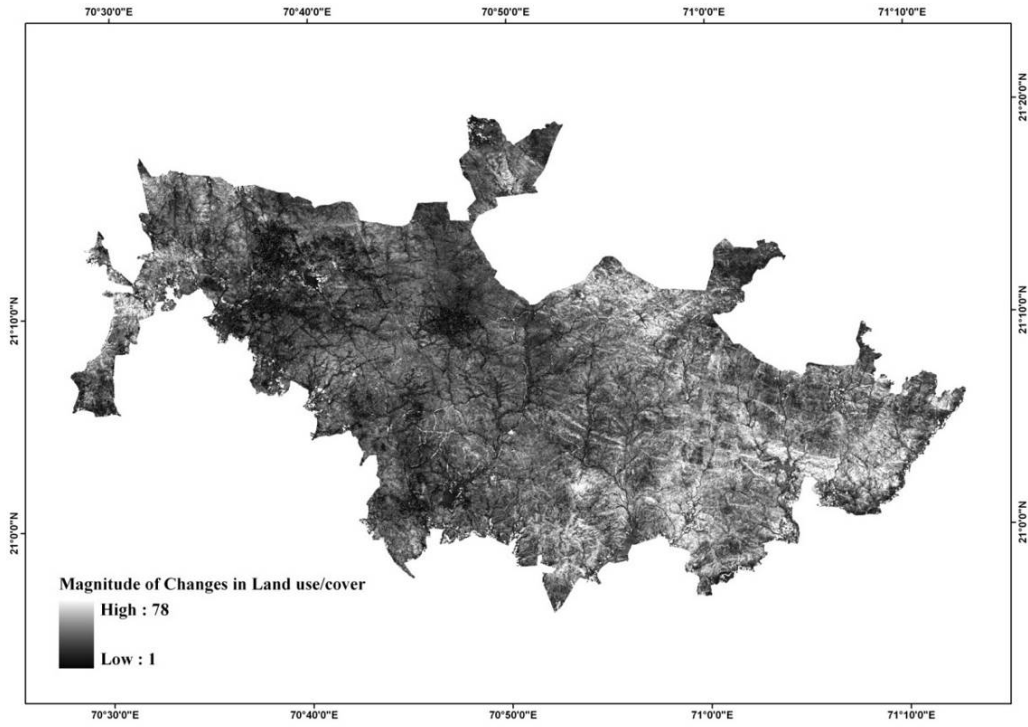


The change has not taken place in all directions but mainly around river channels or water bodies in western part of the Gir. The distribution of these forests from river channels are like moist teak forests to *Wrightia*-teak forests then to teak-*Wrightia* forests. Direction of change image obtained from CVA strongly supports this view with higher values in areas under these forest types around river channels in western Gir mainly (**Figure 4.7**).

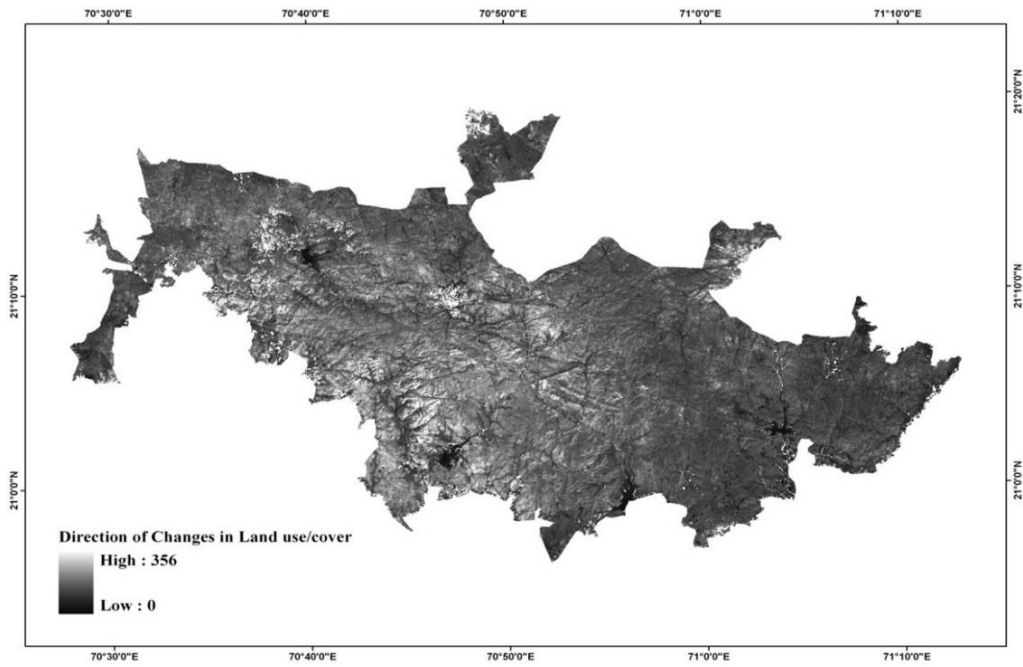
Other notable land cover changes include the increase in *Anogeissus-Boswellia-Acacia* forests type from 17050 ha in 1998 to 25652 ha in 2009 with its spatial distribution mainly in eastern portion of the study area where teak associated forest types are less common or absent. The gradual changes in vegetation pattern in eastern Gir, where *Anogeissus-Boswellia-Acacia* forests increased and *Acacia-Boswellia* forests decreased over time are also visible from the magnitude of changes image obtained from CVA (**Figure 4.8**).



**Figure 4.7: Direction of changes in land use/cover obtained from CVA of images of 1998 and 2009**



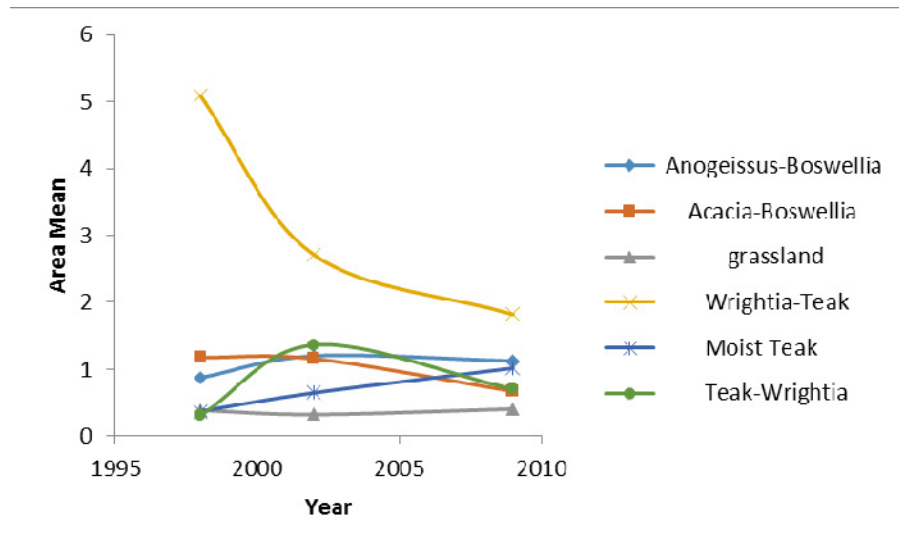
**Figure 4.8: Magnitude of changes obtained from CVA of images of 1998 and 2009**





Number of patches increased for both the forest types during the study period (**Figure 4.6**) but the mean patch size decreased for *Acacia-Boswellia* whereas it almost remained same for *Anogeissus-Boswellia* forest type (**Figure 4.9**). Average patch size increased for the moist teak forest type as small patches begin to coalesce into larger ones and decreased for the *Wrightia-Teak* forest types as the area under this forest type reduced following succession (**Figure 4.9**).

**Figure 4.9: Changes in average size of patches from 1998-2009**

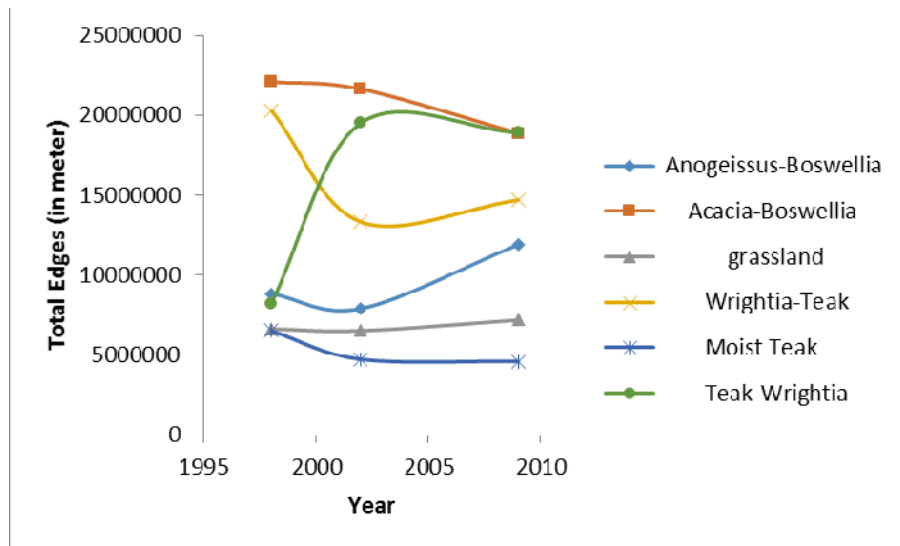


The rate of agricultural encroachment and the amount of open area have substantially increased in 2009 increasing the fragmentation and patchiness of the area with an uneven spatial direction. Total edges for *Anogeissus-Boswellia* forest types increased during the study period as a result of spread of both of these forest types over the study period (**Figure 4.10**) whereas for all other forest types it decreased following the decrease in area under these forest types over time.

Changes in patch density of different forest types occurred as an accumulated effect of increase of area under specific vegetation type as it happened in case of increase of patch density of *Anogeissus-Boswellia* forests, result of succession of *Wrightia-Teak* to *Teak-Wrightia* and moist teak forests where patch density decreased in the *Wrightia-Teak* forest whereas it increased in the later teak associated forest types. Clearance of vegetative patches of *Acacia-Boswellia* showed decrease in patch density too (**Figure 4.11**).

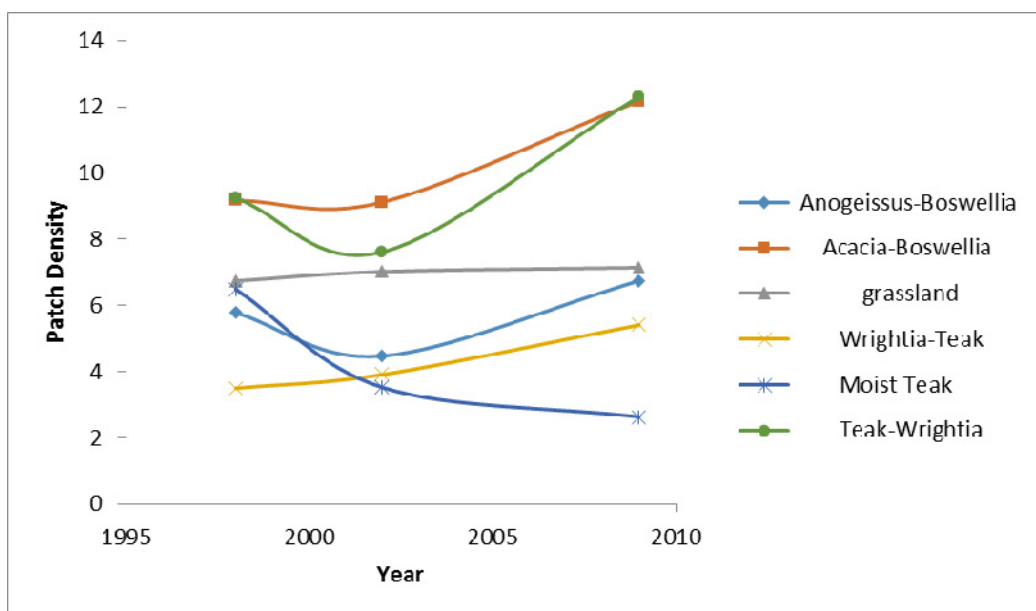


**Figure 4.10: Changes in total edges from 1998-2009**



Visual interpretation of the land cover modeling results showed that the simulated map (Figure 4.12) for the year 2009 is reasonably similar to the actual classified map of that year. A more detailed analysis was accomplished using the Kappa variations. The closer the values of these indices are to 100%, the stronger the agreement is between two maps. The  $K_{no}$ , which also gives the overall accuracy of simulation, is calculated to be 70%.

**Figure 4.11: Changes in patch density from 1998-2009**





The model performed well in the ability to specify location correctly ( $K_{location} = 71\%$ ), and also in the ability to specify quantity ( $K_{quantity} = 71\%$ ). Thus the classified map of 2009 was used for the future projection of 2020 (**Figure 4.13**). A cross-tabulation that describes the changes in land cover classes included in the study is given in **Table 4.2**. CA-Markov has the ability to simulate transition among any number of classes and the nature of the simulation is bidirectional. The table shown above demonstrates the number of pixels that are expected to change from 2009 to 2020. The diagonal of the matrix indicates the number of pixels that have persisted during the simulation, while the off-diagonal shows the number pixels that changed class.

## Discussions

Land cover changes can influence ecosystems and regional sustainable development directly and/or indirectly by affecting a wide range of processes, such as the movement of nutrients through plants, soils, water and the atmosphere as well as greenhouse gasses and the movement of soil and water within catchments. It is thus very important for governmental decision making at local, national and regional scales to obtain real time information on land cover and its temporal and spatial changes.

The land cover in the study area was found to have changed over the study period; in particular, the areas under teak associated vegetation types found in western, central portion of the Gir PA, as well as areas under *Anogeissus-Boswellia-Acacia* forest, *Acacia-Boswellia* forest types. Land use/cover maps of the study area for the years 1998, 2002 and 2009 were obtained using an object-oriented approach and the derived maps provided new information on spatio-temporal distributions of vegetation types. Results obtained from classification were validated and employed for further change analysis and modeling. A critical analysis of the nature of land use/cover change was addressed and quantified using landscape metrics. Each of the metrics provided information on the nature of each index for the study site. The spatial simulation technique employed, produced satisfactory results that were confirmed by various Kappa summaries. This allowed us to project land change until the year 2020. Future projections presented an acceptable output for short term forecasting. This study has contributed to the understanding of spatial and temporal dynamics of vegetation growth of the Gir protected area and will form a basis for better planning.



Figure 4.12: Projected land cover map of the study area of the year 2009, based on CA-Markov analysis

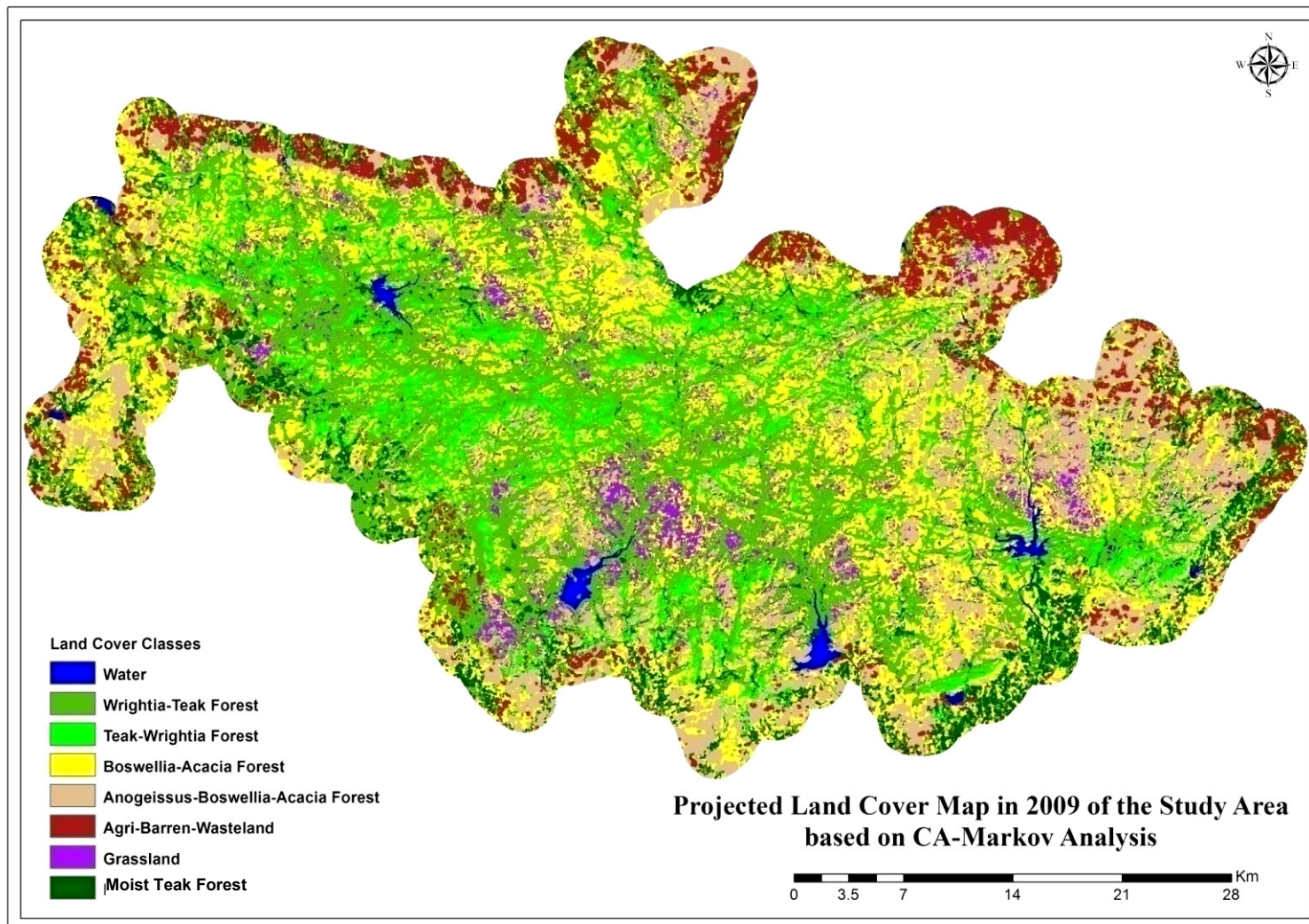




Figure 4.13: Projected land cover map of the study area of the year 2020, based on CA-Markov analysis

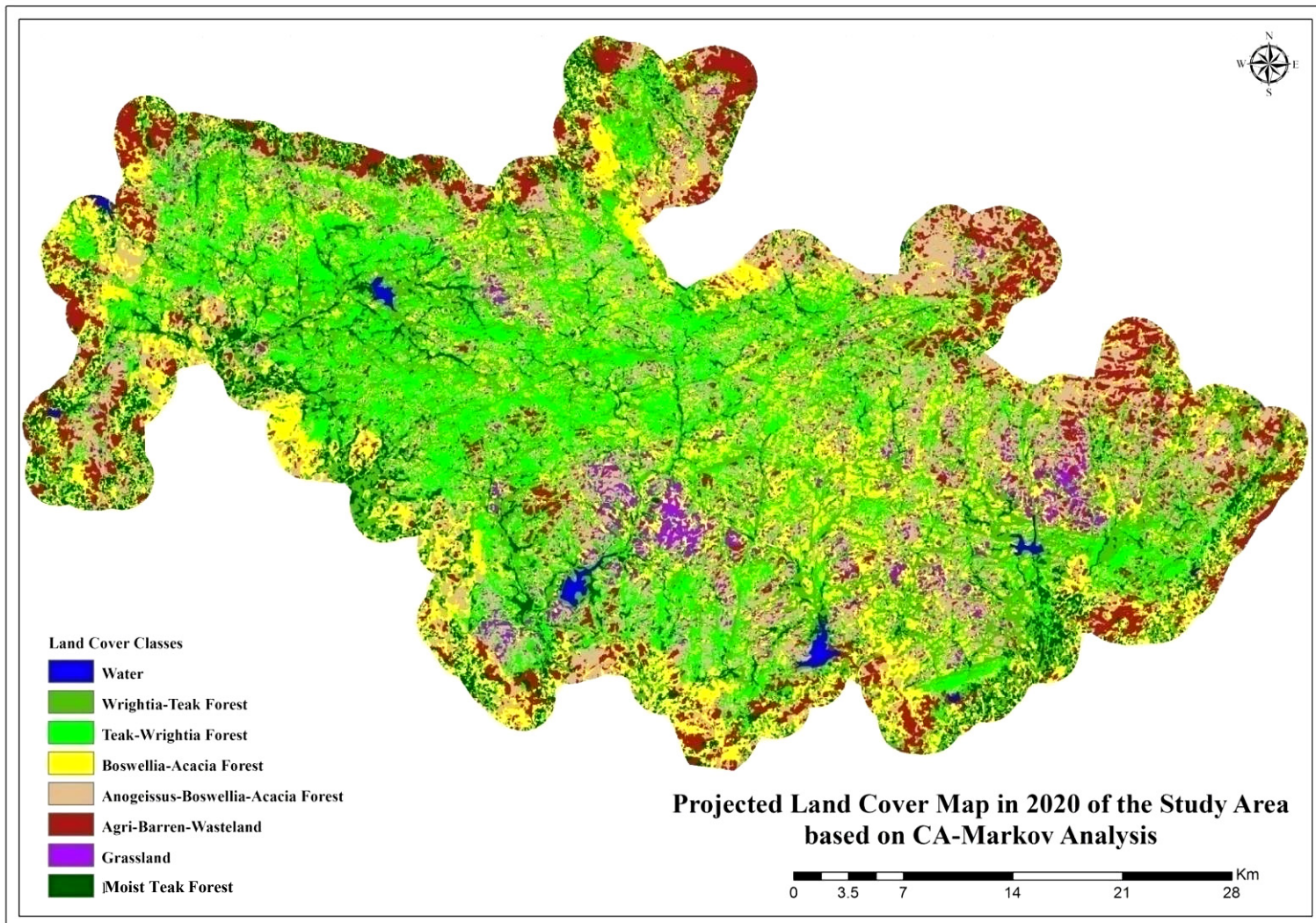




Table 4.2: Cross tabulation of simulated land cover map of 2020 with actual land cover map of 2009 (number of pixels)

Simulated Land Cover Map 2020	Actual Land Cover Map 2009										
	Classes	No Data	Water	<i>Wrightia-Teak Forests</i>	<i>Teak-Wrightia Forests</i>	<i>Boswellia-Acacia Forests</i>	<i>Anogeissus-Boswellia-Acacia Forests</i>	<i>Agri-Barren-Fallowland</i>	Grassland	Moist-Teak Forests	Total
	No Data	1966538	0	0	0	0	0	0	0	0	1966538
	Water	153	11909	6	0	0	0	36	0	0	12104
	<i>Wrightia-Teak Forests</i>	0	5343	345442	3378	1694	234	34439	89	30010	420629
	<i>Teak-Wrightia Forests</i>	0	0	52606	340612	27157	713	444	300	15191	437023
	<i>Boswellia-Acacia Forests</i>	0	0	83038	24379	308211	6009	13938	3895	2562	442032
	<i>Anogeissus-Boswellia-Acacia Forests</i>	0	0	0	977	102767	360723	14244	16206	0	494917
	<i>Agri-Barren-Fallowland</i>	0	1047	170	0	6563	100205	146251	4243	0	258479
	Grassland	0	0	184	0	14649	5456	0	87934	0	108223
	Moist Teak Forests	0	0	8396	177	263	187	31417	1256	131454	173150
	<b>Total</b>	1966691	18299	489842	369523	461304	473527	240769	113923	179217	4313095



A cyclone that swept through Gir in November 1982, uprooted about 2.8 million trees (Daniel 1984; Singh and Kamboj 1996), and the extraction of these trees continued for a few years, disturbing the harmony of Gir. Literature review stated that the forest cover which was receding in the 1960's and 70's, has consistently improved. Dense foliage has increased across Gir throughout the last two decades and in the time period (1985-2005) forest cover has improved in the forest and a large portion of land became dense or moderately dense forest (Singh 2007). Though any record is absent of the extent of the different qualities of forests before 1960, but records of the last five decades shown that Gir was never as dense as it is today. The trend in land use/cover changes observed in this study supported the ongoing debate of thickening of teak dominated forests type in the study area. The increase in the area of Teak dominated forests resulted from the transition of *Wrightia*-Teak forests into both Teak-*Wrightia* and moist teak forests as almost half of the area under cover type of *Wrightia*-Teak disappeared from this landscape during the study period. The spatial patterns of Teak-*Wrightia* forests expansion indicated the gradual shift of the *Wrightia*-Teak forests type with *Wrightia* domination to the Teak-*Wrightia* forests type with Teak domination. The direction of this change was mainly in central and western part of the study area where teak dominates rather than the eastern part of the sanctuary. The management plan (Singh and Kamboj 1996) prescribed the thinning of forests on an experimental basis; but no action has been taken since the felling of trees in the sanctuary is a highly delicate matter.

This study demonstrated that Gir WLS is effective in preserving dry deciduous forests and lion's habitat against the alarming rate of transformation of forests into human conducive land use classes outside protected area (Jhala et al. 2012a). Results were similar to those reported from many protected areas throughout the tropics. Bruner et al. 2001 showed that 93 protected areas in tropical forests were successful in slowing forest loss when the surrounding landscapes were largely deforested. Similar results were presented by a land cover change study of 198 tropical protected areas (DeFries et al. 2005) and a detailed study of deforestation in the Sarapiquí region in Costa Rica (Sánchez-Azofeifa et al. 2005). In all of these studies the protected areas were surrounded by rapidly changing landscapes. Although they became increasingly more isolated, they maintained high forest cover within their boundaries, potentially providing strongholds for species and biodiversity conservation (Songer et al. 2009).



## CHAPTER V

### ***LION ABUNDANCE AND POPULATION STRUCTURE IN GIR LANDSCAPE***

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#### **Introduction**

Abundance (relative population size) can be expressed as absolute density, relative density and also as total counts of the individuals in a population (Lancia et al. 1996). Abundance is a state variable of primary interest to wildlife scientists, managers and conservationists because of its decisive influence on ecological and behavioral attributes, and, thus the potential viability of any animal population (Gibbs et al. 1999; Williams et al. 2002). Precise and unbiased estimates of animal population abundance is essential for monitoring and evaluating conservation programs and is *prima facie* for policy formulation, prioritization of resource allocation and often political decision making (Karanth 2003; Jhala et al. 2011 b, c). In the absence of measured abundance information, conservation management decisions are often based on crude estimates, expert opinion or educated guesses, which may result in erroneous decisions that can be counterproductive for conservation (Blake and Hedges 2004). This becomes even more crucial when one is conserving the only free-ranging population of Endangered (Breitenmoser et al. 2008) Asiatic lion in the Gir forests of Gujarat, western India.

Most populations of large carnivores across the globe come into conflict with humans for their basic ecological needs and are therefore threatened (Woodroffe and Ginsberg 1998; Karanth and Chellam 2009). Therefore, understanding the ecology of large carnivores and monitoring their populations are important for their conservation needs. In addressing these challenges, biologists have only recently started to employ modern animal population sampling methods. Sampling protocols typically focus on estimating one or more ‘system state variables’ (e.g. population size, Williams et al. 2002) at different points in space and/or time. Monitoring programs are frequently designed with the intention of documenting variation of such quantities over time, space and associated environmental and management variables.

Caughley (1994) identified two paradigms in conservation biology: i) the small-population paradigm which deals with the effect of smallness on the persistence of a population, and ii) the declining population paradigm which deals with the cause of smallness and its cure. The processes relevant to the small-population paradigm are amenable to theoretical examination



because they generalize across species and are subsumed by an inclusive higher category: stochasticity. Monitoring wildlife populations with an appropriate design incorporating scientific technique, appropriate periodicity and subsequent analyses is thus important for ensuring the long-term conservation of endangered carnivores that are vulnerable to environmental stochasticity (Loveridge et al. 2001). Inbreeding can impair the reproductive capacity and may be reflected in compromised population vital rates (O'Brien 2003). Demographic vigour of a population (defined as its level of well being in terms of fecundity and survival) is often measured in terms of realized rate of population growth (Caughley 1977). A healthy demographic structure would thus be defined by stable survival rates and population numbers, adult sex ratio and with a substantial proportion of the population in the breeding and recruitment stage. Population decline, crisis management, stabilization, precarious recovery and sustained recovery have been described as five stages of a species restoration (Linklater 2003). Currently, carnivore conservation involves a sixth stage beyond population recovery, that of managing successful recoveries of target species that exceed the carrying capacity of protected areas (Hayward et al. 2007b). During this stage, space and conflict mitigation become the principal conservation concerns (Inskip and Zimmermann 2009). Regular assessment of carnivore populations therefore becomes imperative so as to enable the conservation managers to monitor the population fluctuations and formulate conflict mitigation strategies by active management of problem individuals.

Gir lions exemplify both of the above scenarios. With their origin in East and South Africa (Antunes et al. 2008), Asiatic lions extended from the African Mediterranean coast into Eastern Europe, the Middle East and into India sometime between 3000 and 2000 BCE (Divyabhanusinh 2005). O'Brien (2003) suggests that about 2,500 years ago, the Kathiawar peninsula was separated from the mainland India by rising sea level causing the first genetic bottleneck that isolated the founders of the present Asiatic lion population compelling them to inbreed for several generations. A second less severe bottleneck happened at the onset of the nineteenth century when lions became restricted to the Gir forests and their numbers declined to around 50 individuals due to hunting and habitat loss (Edwards and Fraser 1907; Kinnear 1920; Pocock 1930). Owing to the protection by the Junagadh *Nawabs* and the management interventions by the state forest department in India's post-independent era (after 1947, lion population increased and the current population is at a little over than 400 (Singh and Gibson



2011; Banerjee and Jhala 2012). Gir Protected Area (PA) is believed to have reached its carrying capacity in terms of lion numbers (Singh 1997) causing dispersal of lions outside the Gir PA into the Girnar forests, coastal scrub and about 6,000 km<sup>2</sup> agro-pastoral landscapes of Junagadh, Amreli and Bhavnagar districts (Banerjee et al. 2010; Singh and Gibson 2011). Lions outside the PA come in conflict with human interests by preying on livestock, causing occasional injury and loss of human lives (Saberwal et al. 1994). Although the sentiment of the majority of the local people is in favor of lion conservation, there are occasional incidents of retaliation (Pathak et al. 2002). Lions also get killed as non-target species by electrocution (when they come in contact with live wires placed illegally around agricultural fields to prevent crop damage by wild ungulates) or by falling into open agricultural irrigation wells (Pathak et al. 2002; Banerjee and Jhala 2012; Meena and Kumar 2012). Moreover, it becomes a challenge for the management to protect lions from international wildlife poaching gangs in a multiple use landscape where lion conservation is not a primary objective (Singh 2007; Fair 2009). Regular landscape level lion population monitoring through precise population estimation and continuous assessment of its demographic parameters become crucial for formulating management strategies that ensures the long term persistence of lions in the Gir landscape.

Assessing the abundance of low density, wide-ranging and cryptic carnivore species is extremely demanding in terms of time and resources (Garshelis 1992). Several approaches have been tried for estimating large carnivore numbers. These include a) total counts without correcting for detection bias (Choudhury 1970; Panwar 1980; Fuller 1989; Gore et al. 1993; Smallwood and Fitzbugh 1995; Rishi 1997), b) indices for relative abundance (Knowlton and Tzilkowski 1979; Palomares et al. 1996; Stander 1998; Houser et al. 2009; Funston et al. 2010), c) indirect methods of scaling and predicting (Carbone and Gittleman 2002; Karanth et al. 2004; Hayward et al. 2007a) and d) modern approaches to abundance estimation incorporating detection probabilities (Karanth 1995; Karanth and Nichols 1998; Garshelis et al. 1999; Grogan and Lindzey 1999; Poole et al. 2001; Soisalo and Cavalcanti 2006; Jhala et al. 2008; Kelly et al. 2008; Mondol et al. 2009; Sharma et al. 2010). Techniques used to date for abundance estimation of lions included mark recapture (Smuts 1976; Jhala et al. 1999, 2004; Ogutu et al. 2006; Banerjee et al. 2010) through individual lion identification (Pennycuik and Rudnai 1970), playback surveys (Ogutu and Dublin 1998; Mills et al. 2001; Ogutu et al. 2005) fecal DNA sampling (Tende et al. 2010) and helicopter surveys (Packer 2006). However, the methods for



estimating endangered carnivores need to be practical and cost effective. Helicopter surveys are expensive and cannot be applicable for lion population estimation in the Gir landscape. Track counts (Sharma et al. 2005) although providing inexpensive measures of population estimation, this method cannot be applied in group living species like lions owing to the difficulty in identifying individual pugmarks. The potential variability of individual lions in their response to call-up sounds and other factors, however, need careful examination for a playback survey (Loveridge et al. 2001).

**Total Counts of Gir lions:** Since 1963, the Gujarat Forest Department has censused lions about every five years by a labor-intensive method using live baits for three days, until 1995 when this met with social and ethical opposition (Singh 2007). Most lions in Gir were familiar with killing livestock and readily approached buffalo bait. A daily record was kept of all lions that visited the baits. After accounting for possible double counts, the maximum number of lions recorded on any single day was considered to be the total population. Total counts are error prone as they lack measures of detection probabilities; require a careful sampling design, trained field staff and intensive field efforts (Williams et al. 2002). Two counts can be compared as an index only if detection remains constant. In Gir PA, the total count of lions obtained by the management using buffalo baits was lower than the mark-recapture population estimate (Singh 1997; Jhala et al. 1999). This suggests that total counts were likely underestimates. However, since there was no objective way to determine the proportion of lions missed or counted multiple times, the total count method needs to be modified to incorporate detection probability of lions based on sampling (Karanth et al. 2003). The prevailing census method of the forest department by intensive search for lions can only be used to formulate a good index for lion numbers, provided it is calibrated against the more robust mark-recapture population estimation in a double sampling framework (Jhala et al. 2011b). The combination of individual identification by standardized protocols based on vibrissae patterns and permanent natural markings (Jhala et al. 1999, 2004), in a capture-recapture framework (Pollock et al. 1990) if done during the exercise of total counts, would estimate the lion population in a more robust manner.

Given the global importance of this single population of the endangered Asiatic lion, it is crucial that the population be regularly monitored using modern scientific methodologies, and its demographic parameters assessed for long term persistence. This chapter deals with capture-recapture population and density estimation of lions in the Girnar Wildlife Sanctuary and the



human-dominated eastern landscapes of the Junagadh, Amreli and Bhavnagar districts. We deduced the demographic parameters of Asiatic lions (through telemetry and reported as a separate chapter — Chapter 7) and used this data to parameterize a population viability analysis (Burgman et al. 1993; Akçakaya and Sjögren-Gulve 2000) incorporating realistic scenarios of catastrophe, poaching, and reduction in carrying capacity of habitat to assess and evaluate the long term survival prospects of the Girnar lions.

## **Methodology**

### **Field method for individual identification of lions**

For estimating the lion population in Girnar Wildlife Sanctuary and the eastern landscape; closed-population mark-recapture (Pollock et al. 1990) was used. We attempted to address limitations of random sampling imposed by the territorial and group-living nature of lions (Schaller 1972; Joslin 1973) by randomly and systematically distributing the search effort across space in a landscape. Lions were intensively searched on foot and by vehicle systematically in different areas of the lion habitats of these study sites. Various cues, including tracks, roars and alert behavior of prey, information from local people were used to locate lions. Lions were approached within 10-30 meters to determine their whisker spot patterns with binoculars, and by a 15 to 60 X spotting scope. Lions (>1.5 year) were individually identified from their unique whisker spot patterns and other permanent unique marks (Pennycuick and Rudnai 1970; Jhala et al. 2004). Close-up color photographs using an 80-400 mm zoom lens were taken of both sides of the face and a full-face view to supplement field drawings (Jhala et al. 1999).

On observing a lion's face at a right angle, several rows on its upper lip from which vibrissae (whiskers) emerge could be seen. The whisker rows that were used for individual identification were the top 3 rows; A, B and C (**Figure 5.1**). Spots were counted from nose to eye direction in both left and right sides. Row B can have anywhere between 5 to 9 spots. Rows A and C are not complete rows but consist of sporadic occurrence of spots. Row A consists of spots above row B. The spots in the above row A are defined in relation to their position to spots in row B (**Figure 5.1**). Thus there are potentially 17 positions for spots to occur in row A. Similarly, row C also has a potential of 17 positions below row B.



Data on the location of the lion, age group, sex, pride composition and interaction and any additional identifiable marks on the body like ear notches (both left and right), permanent scars or spots on the body were recorded on a data sheet (**Figure 5.1 ii**; Jhala et al. 2004; Banerjee et al. 2010). Identity cards were made for each individual lion encountered using the photo-identification technique and have been maintained in a database program LION vers. 1.0 (**Figure 5.1 i**; Badoni et al. 2005). Considering the long lifespan (average of 15 – 16 years) of lions (Schaller 1972) in comparison to our short sampling duration we assumed a demographic closure and formally tested for it using the program CloseTest (Stanley and Burnham 1999).

### **Data analysis**

Sampling adequacy was ascertained by plotting the number of unique lions sighted against cumulative lion sightings and on examining if they reached an asymptote. The capture histories of individual lions generated from the sample survey were used to make an X matrix (Pollock et al. 1990). We systematically summarized field results of lions to cover the entire lion habitats in a 3-4 day period within the Girnar forests and a five day period in the eastern landscape which represented respective single sessions. Data was analyzed using discrete-time capture-recapture experimental design (Chao and Huggins 2005) using model selection procedure built in program CAPTURE-2 (Rexstad and Burnham 1991) that uses a series of goodness of fit tests followed by discriminant function analysis to decide between the null (Mo), heterogeneity (Mh), behaviour (Mb), time effects (Mt) and combination of these models (Otis et al. 1978; White et al. 1982) for determining the best model fit for our data.



Figure 5.1: i. Individual lion identification through vibrissae pattern and additional permanent body marks using the photo-identification technique and maintaining the profiles in an automated database program LION (Badoni et al. 2005).

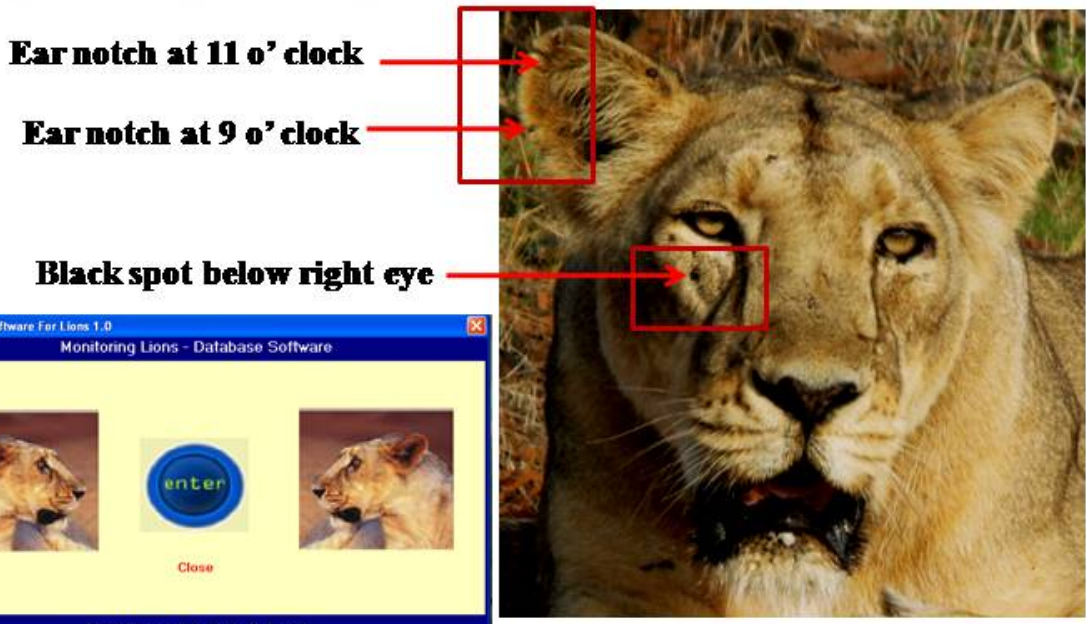
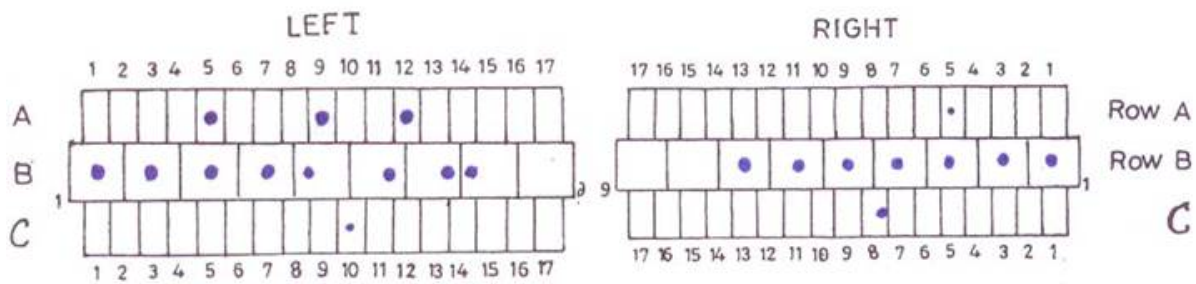




Figure 5.1: ii. Performa of the data sheet used in the field for individual lion identification. Vibrissae patterns are calibrated on a graph paper and position of additional body marks are recorded. (Source: Jhala et al. 2004).

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Lion Identification Data Sheets

11.6.2010 Dhasowala Gali, Patwon, Girner GTS: 21°33'48.5" / 76°04'42.2"  
 8:00 hrs Prime Adult ♀

LEFT

Row A	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
Row B	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Row C																															

RIGHT

Row A	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
Row B	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Row C																															

NOTES

Left Row:

A = 3, 5, 6 1/2

B = 8 (large gap between spots 5 & 6. Spots 7 & 8 closer)

C = 5 1/2 (very faint spot)

Right Row:

A = 3 (faint spot)

B = 7

C = 4 1/2

NOTES

Habitat: Teak mixed.

Associated Animals: Four (4) Small cubs (< 6 months), One (1) large cub (> 6 months)



The null model ( $N_0$ ) assumes that there is equal “catchability” (i.e. equal probability of working on the whisker patterns) of all lions. This model is biologically unrealistic since lions differed in their probability of being “captured”. Some were shy and difficult to work with while others were quite complacent. The heterogeneity (Mh) model assumes that each lion has its own unique capture probability (i.e. probability of working on the whisker patterns). Models Mb and Mt consider ‘trap’ or ‘time’ responses respectively when lions may become habituated or shy to the method of data collection.

### **Lion density estimation**

Lion density in the eastern landscape was estimated as the population size divided by the effectively sampled area estimated by creating a minimum convex polygon over the lion capture points and a buffer width estimated as half the mean maximum distance moved ( $1/2$  MMDM) by recaptured lions added to the polygon (Karanth and Nichols 1998). Since lions even ventured inside the villages at nights in search of food; therefore village areas were not excluded from our analysis in the eastern landscape. However, townships (with a human population of  $> 50,000$ ) and large permanent water reservoirs (Palitana Dam and Dhari Dam) were excluded from the eastern landscape lion density analysis. Girnar Wildlife Sanctuary, on the contrary, is surrounded by human habitations and private farmlands. Lions were observed to venture into the agricultural areas at night but seldom spent the daylight hours outside of the Girnar forests. We therefore considered the forested boundary ( $180 \text{ km}^2$ ) as a “hard edged boundary” while calculating lion density for Girnar (Banerjee et al. 2010) [Figures 5.2 and 5.3].

### **Lion population structure**

Data on the location coordinates; age group, gender, and group composition were recorded for all *ad libitum* lion sightings. Lions were classified into six age categories (Jhala et al. 2004) based on body size, coloration, secondary sexual characteristics, tooth eruption and wear (Schaller 1972) as cubs ( $< 1$  year), juveniles (1 - 2 years), sub-adults (2 - 3 years), young adults (3 - 5 years), prime adults (5 - 10 years) and old adults ( $> 10$  years). Average and typical group sizes (Jarman 1974) were computed.

### **Population Viability Analysis (PVA) of Girnar lions**

The examination and the analysis of the interacting factors that place a population or a species at risk is called population viability analysis or PVA (Burgman et al. 1993). PVA was carried out to identify the threats faced by the Girnar lions and to evaluate the likelihood that it will persist for



a given time into the future. This type of analysis is often oriented towards the conservation and management of rare and threatened species, with the goal of applying the principles of population ecology to improve their chances of survival. PVA contributes in the two broad objectives of the threatened species management; i) the short term objective of minimizing extinction risks and ii) the long-term objective of promoting conditions in which species retain their potential for evolutionary change without intensive management (Lacy 1993).

Lion life history parameters were obtained either from the current study or published literature (Schaller 1972; Joslin 1973; Chellam 1993). Five hundred simulations for combinations of each of the stochastic scenario given in **Table 5.1** were run in program VORTEX 9.99 (Lacy et al. 2009). Various combinations of such scenarios assisted in judging the relative contribution of different environmental/management factors towards long-term viability of Girnar lion population. All scenarios were run with the default inbreeding depression and density dependence option provided in VORTEX 9.99 wherein density dependence was modeled by limiting the breeding of lionesses to 40% at carrying capacity (Kissui and Packer 2004; Trinkel et al. 2010). We defined *quasi-extinction* at the critical lion population size below 10 individuals.

Relative densities using prey biomass can be used to estimate ecological carrying capacity of a site which can be used in a PVA (Van Orsdol et al. 1985; Gros et al. 1996; Carbone and Gittleman 2002; Hayward et al. 2007a). The carnivore density derived from this relationship works as long as no other mechanisms limit a carnivore population. Prey biomass was used for predicting lion carrying capacity in Girnar as other top-down limiting factors like trophy hunting and incidence of epizootics (Kissui and Packer 2004; Whitman et al. 2007) were not prevalent in Girnar (Pathak et al. 2002; Singh 2007). Predictive model suggested by Hayward et al. (2007a) based on lions' preferred prey species (chital, sambar, nilgai, cattle and buffalo) was used to estimate the ecological carrying capacity of Girnar for lions. The equation was  $y = -2.158 + 0.377x$  ( $r^2 = 0.71$ ,  $n = 23$ ) where  $y$  is the  $\log_{10}$  of lion density and  $x$  is the  $\log_{10}$  of biomass of significantly preferred prey. Prey biomass were obtained from density estimates based on distance sampling (Buckland et al. 2001) done during the current study and deduced by multiplying unit body weights of various prey species taken from literature (chapter 10 for more details). Since all the domestic livestock were not available for lion predation, therefore a conservative proportion (24%) of the biomass of domestic livestock obtained from my estimates



of the proportion of the vulnerable livestock to lion predation in the Gir (Banerjee et al. 2013) was incorporated in the model.

Under the PVA models, population persistence (probability of extinction), median time to extinction, mean final population size and stochastic rate of increase ( $r$ ) were evaluated.



**Table 5.1: Rationale behind Population Viability Analysis (PVA) models used in Program VORTEX for the Girnar lion population**

Modeled Scenario	Rationale
<b>Scenario 1:</b> No harvest (poaching and accidents), no catastrophe, habitat linkage between Gir PA and Girnar	
<b>Scenario 2:</b> No harvest, mild catastrophe, habitat linkage between Gir PA and Girnar	Modeled a mild catastrophe frequency of one in 10 years, wherein reproduction was depressed by 50% and survival by 25% (Ashraf et al. 1995). This catastrophe depicts a scenario wherein severe drought that occurs often in Saurashtra peninsula. Under such conditions, in the past, pastoralists along with their cattle from the surrounding regions have invaded Saurashtra thereby escalating human-lion conflict and subsequent increase in lion mortality (Saberwal et al. 1994).
<b>Scenario 3:</b> No harvest, mild and severe catastrophes, habitat linkage between Gir PA and Girnar	Built in a severe catastrophe mimicking the epidemic of canine distemper virus that caused catastrophic mortality in the Serengeti lions (Roelke-Parker et al. 1996). In this model a severe catastrophe occurred with a frequency of one in 50 years, wherein reproduction was depressed by 80% and survival by 60% in addition to a mild catastrophe of the same scale in the scenario 2.
<b>Scenario 4:</b> No harvest, mild and severe catastrophes, no habitat linkage between Gir PA and Girnar	This model assumed a habitat connectivity of the Girnar lions with the ‘source’ Gir PA population permitting exchange of individuals (Singh 2007). With the rapidly changing land-use pattern in the Gir landscape, a conservative scenario of loss of habitat connectivity was modeled preventing exchange of at least one breeding male, two sub-adult males and two non-breeding females every alternative year.
<b>Scenario 5:</b> Every year harvest, both catastrophes, habitat linkage between Gir PA and Girnar	Poaching was incorporated into the models to mimic those that occurred in 2007 wherein about 8 to 10 lions were poached (Singh 2007; Fair 2009). In this scenario, three lions (one breeding male, one breeding female and one sub-adult male) were conservatively removed every year from the population to model the threat of poaching and human-induced mortalities.
<b>Scenario 6:</b> Every year harvest, both catastrophes, no habitat linkage between Gir PA and Girnar	This model once again considered the loss of habitat connectivity between the two Protected Areas in an every year poaching scenario.
<b>Scenario 7:</b> Every alternative year harvest, both catastrophes, habitat linkage between Gir PA and Girnar	We incorporated a less severe harvest scenario where three lions were removed every alternate year.
<b>Scenario 8:</b> Every alternative year harvest, both catastrophes, no habitat linkage between Gir PA and Girnar	



Figure 5.2: Lion sighting points in Girnar Wildlife Sanctuary. Potential habitat corridor linking Girnar to Gir Protected Area proposed as an Eco-sensitive Zone is shown.

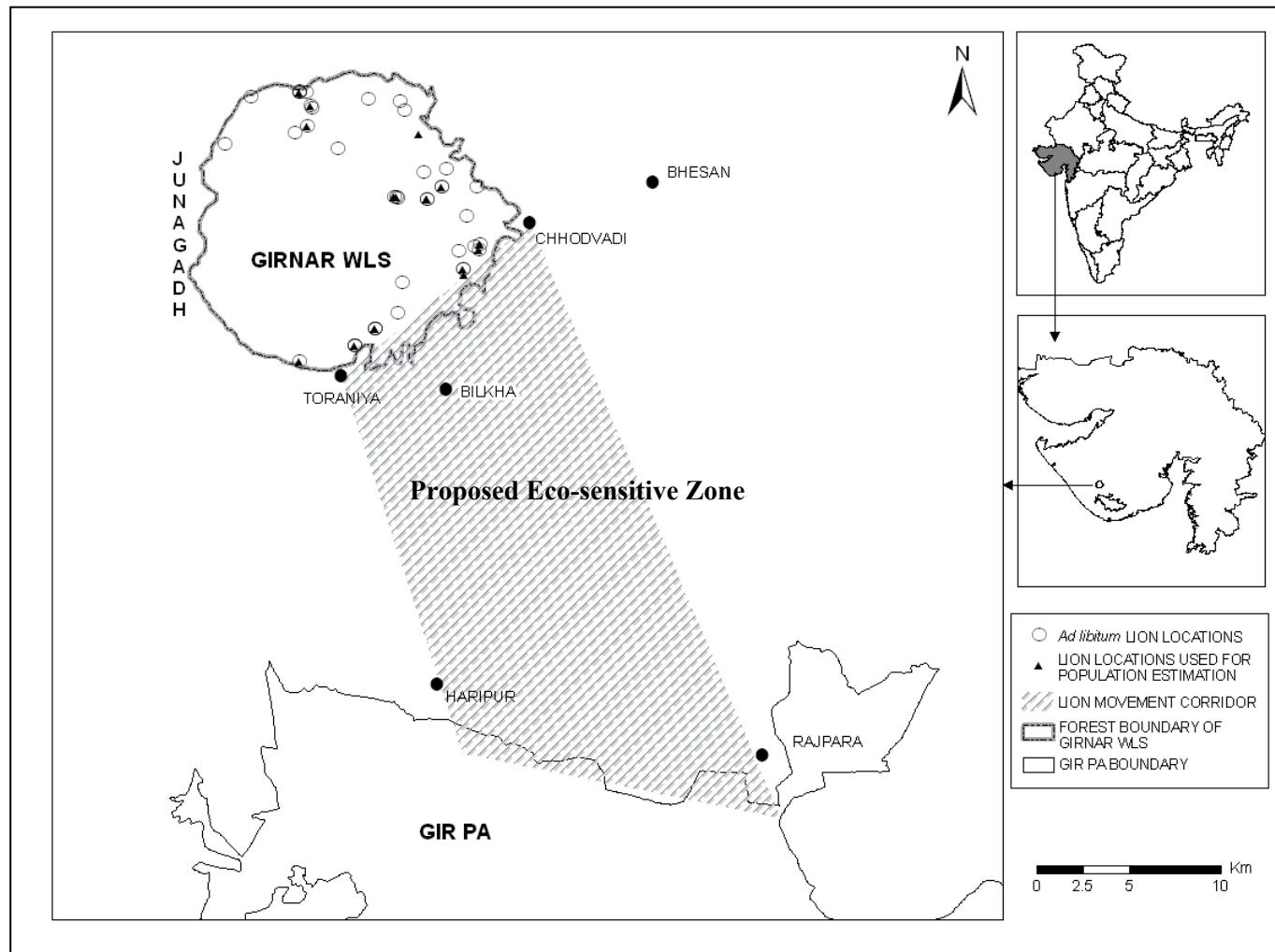
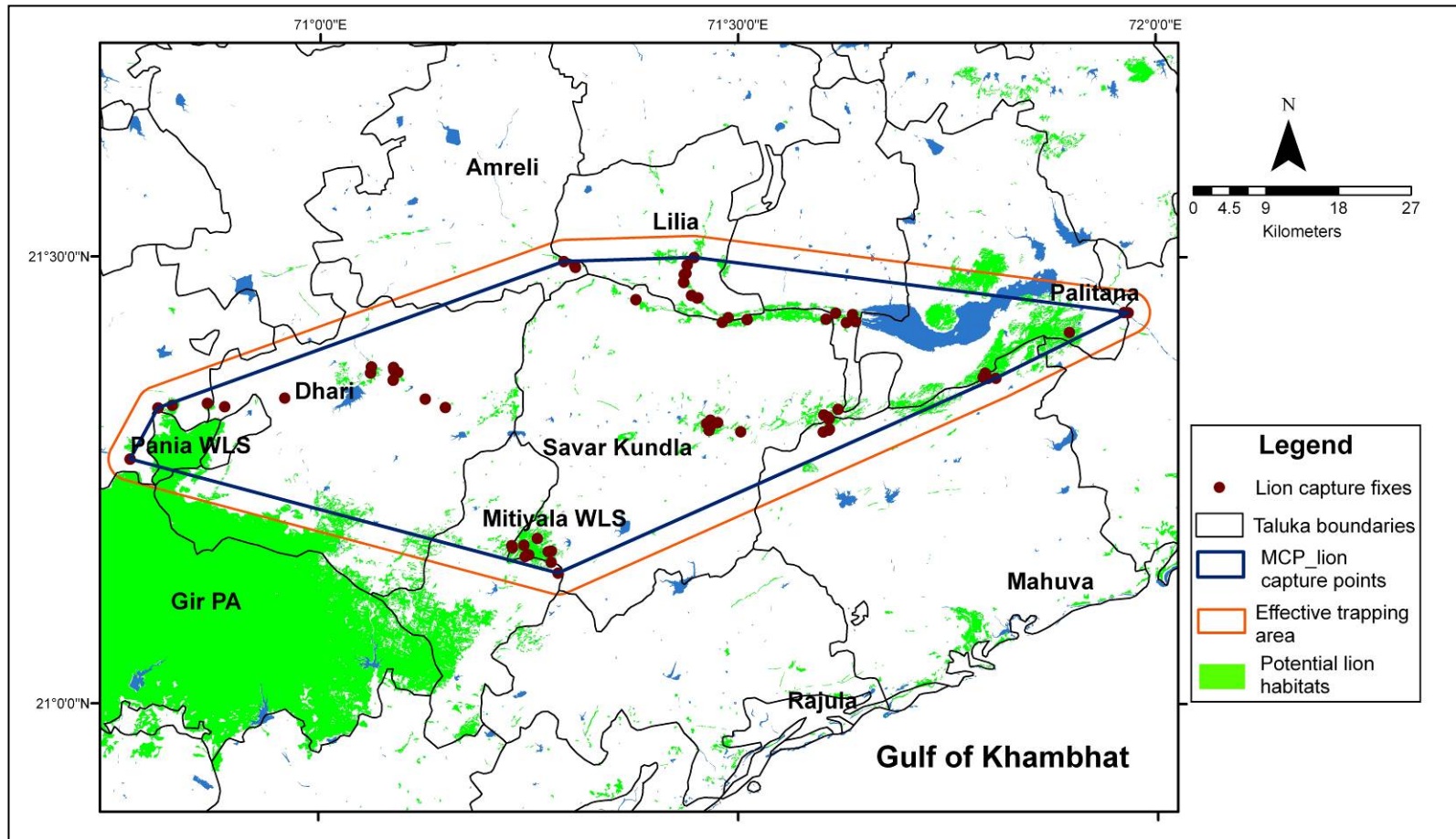




Figure 5.3: Minimum convex polygon defining lion search within the potential lion habitats of the Eastern landscape, buffered with half MMDM





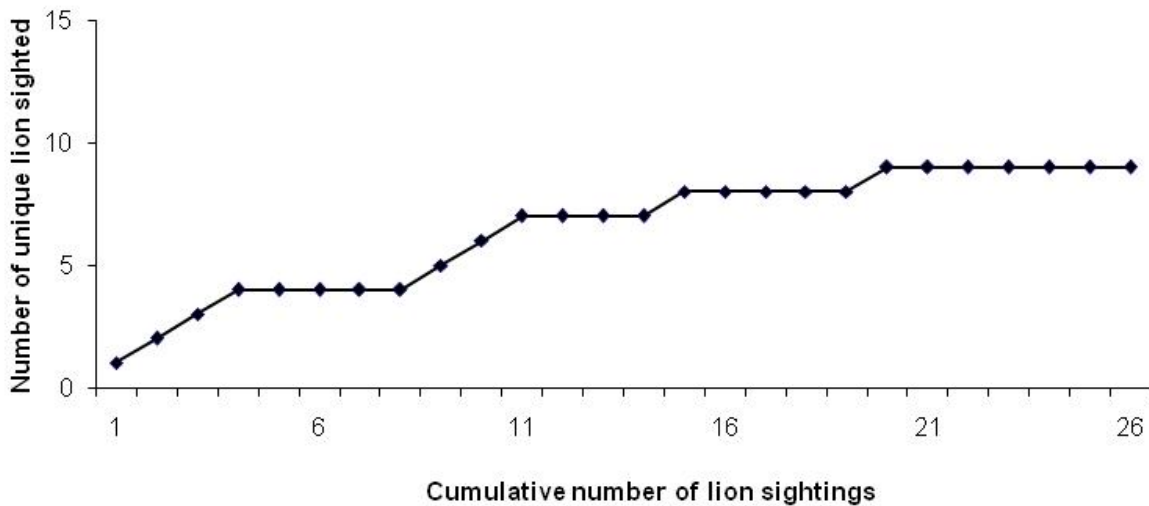
## Results:

### Lion population and density estimation

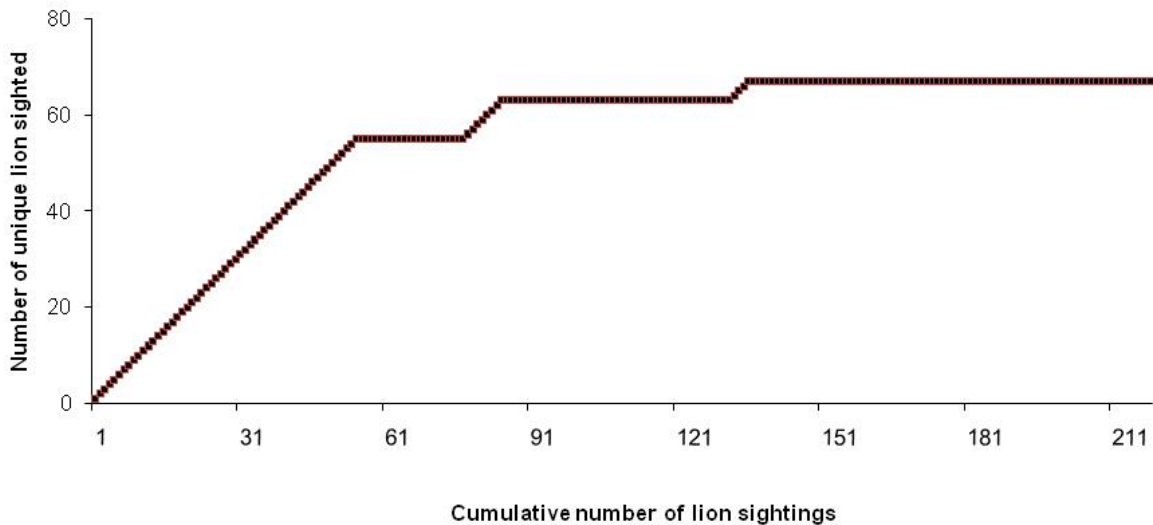
Number of unique lions sighted when plotted against cumulative lion sightings, reached an asymptote suggesting adequacy of sampling and population closure (**Figure 5.4**).

**Figure 5.4: Saturation curves for lion captures during mark recapture session in i) Girnar Wildlife Sanctuary and ii) the eastern landscape.**

i)



ii)



During the capture-recapture exercises, 26 sightings of 9 individual lions were obtained in Girnar while 219 sightings of 67 individual lions were obtained in the eastern landscape



(Table 5.2). Program CloseTest supported population closure ( $\chi^2_{df 4} = 6.16, p = 0.18$ ) in the Girnar forests while did not support a population closure ( $\chi^2_{df 4} = 10.4, p = 0.03$ ) in the eastern landscape. Also, there were no evidence of either a behavioural response ( $M_o$  vs  $M_b$ ;  $\chi^2_{df 1} = 0.58, p = 0.44$ ) or a temporal variation ( $M_o$  vs  $M_t$ ;  $\chi^2_{df 5} = 6.62, p = 0.25$ ) in Girnar. The model selection procedure of program CAPTURE-2 selected the null model ( $M_o$ , scored at 1), followed by model incorporating individual heterogeneity in capture probabilities ( $M_h$ , scored at 0.77) in Girnar. Capture probability of lions in Girnar was 0.31 and the population estimate under  $M_o$  was 10 (SE 1.2) lions (Table 5.3). In the eastern landscape the test for a behavioural response was negative ( $M_o$  vs  $M_b$ ;  $\chi^2_{df 1} = 1.52, p = 0.21$ ). However, there was evidence for variation in capture probabilities among the captured lions ( $M_o$  vs  $M_h$ ;  $\chi^2_{df 2} = 24.03, p < 0.01$ ) and temporal variation ( $M_o$  vs  $M_t$ ;  $\chi^2_{df 4} = 17.68, p < 0.01$ ). In the eastern landscape, program CAPTURE-2 selected the model incorporating time variation and individual heterogeneity ( $M_{th}$ , scored at 1). Average capture probability of lions in the eastern landscape was 0.65 and the population estimate under  $M_{th}$  was 67 (SE 1.1) lions (Table 5.3).

Density of lions (> 1.5 years) was estimated to be 5.6 or about 6 (SE 0.7) lions/100 km<sup>2</sup> in Girnar Wildlife Sanctuary (Table 5.2). In the eastern landscape, the polygon formed by the outermost lion locations measured 2,599 km<sup>2</sup>. Using the ½ MMDM approach, a buffer width [W (SE)] of 2.7 (0.1) km and an effectively sampled area A (SE) of 3,700 (25) km<sup>2</sup> were estimated. The area masked was 408 km<sup>2</sup> making a final effectively sampled area of 3,292 (SE 34) km<sup>2</sup>. Adult lion (>1.5 years) density (D (SE^D) obtained by dividing the estimated population size (N) by the effectively sampled area (A) was 2 (SE 0.1) lions/100 km<sup>2</sup> (Table 5.2).

**Table 5.2: Summary of lion density (lion/100 km<sup>2</sup>) estimation in Girnar forests and the human-dominated eastern landscape.**

Area	Sampling period	Number of distinct lions	Number of total lion sightings	Number of capture occasions	Population estimates (SE)	Effective sampling area (km <sup>2</sup> )	Lion Density (SE)
Girnar WLS	2008	9	26	6*	10 (1.2)	180	6 (0.7)
Eastern Landscape	2010	67	219	5**	67 (1.1)	3,292	2 (0.1)

\* 3-4 days marked single session, \*\* 5 days marked single session



**Table 5.3: Lion population estimates in i) the Girnar Wildlife Sanctuary and ii) the human-dominated eastern landscape using various estimators in Program CAPTURE.**

**i) Girnar Wildlife Sanctuary**

Model	Population estimate	SE	95% CI	Model selection criteria score
M <sub>0</sub>	10	1.2	9 – 14	1.00
M <sub>h</sub>	9	0.3	9 - 11	0.77
M <sub>t</sub>	9	0.6	9 - 13	0.00
M <sub>b</sub>	9	0.9	9 - 17	0.28
M <sub>th</sub>	8	0.0	9 - 9	0.51
M <sub>bh</sub>	9	0.5	9 - 11	0.65
M <sub>tb</sub>	9	0.4	9 - 11	0.25

**ii) Eastern Landscape**

Model	Population estimate	SE	95% CI	Model selection criteria score
M <sub>0</sub>	67	0.6	67 - 68	0.37
M <sub>h</sub>	68	5.2	68 - 103	0.47
M <sub>t</sub>	67	0	67 - 67	0.48
M <sub>b</sub>	67	0.6	67 - 68	0.10
M <sub>th</sub>	67	1.1	67 - 74	1.00
M <sub>bh</sub>	67	0.4	67 - 68	0.50
M <sub>tb</sub>	67	0.4	67 - 68	0.00

Details of the estimators are available in White et al. 1978 and Chao and Huggins 2005

**Lion population structure**

In Gir PA *ad libitum* sightings of 281 lion groups consisting of 652 lions; in Girnar Wildlife Sanctuary, *ad libitum* sightings of 40 lion groups consisting of 81 lions and in the eastern landscape, 66 *ad libitum* lion group sightings consisting of 172 lions were obtained.

In the Gir PA, cubs constituted 16% of the population, lionesses in the reproductive age group comprised 34% of the population while recruitment aged lions comprised 41% of the total sightings. In Girnar Wildlife Sanctuary, cubs (< 1 year) comprised 14% of the population while lionesses in the reproductive age group comprised 20%, sub-adults (between 1-3 years) constituted 43% of the population. In the eastern landscape, breeding lionesses comprised 30% of the population while recruitment aged lions comprised 34% of the total sightings (**Figure 5.5**).



In Gir PA, average group size (including cubs) was 1.98 (SE 0.11), while adult (excluding cubs) group size was 1.71 (SE 0.1), group size of females (> 2 years) was 1.52 (SE 0.07) and males (> 2 years) was 1.42 (SE 0.05). Typical group size, the size of a group in which a lion is typically found was 3.67 (including cubs), for adult lions it was 3.1, for lionesses it was 2, and for males it was 2.28 (**Figure 5.6**).

In Girnar, average group size (including cubs) was 3.04 (SE 0.31), while adult (excluding cubs) group size was 2.73 (SE 0.32), group size of females (> 2 years) was 1.85 (SE 0.34) and males (>2 years) was 1.44 (SE 0.17). Typical group size was 4.37 (including cubs), for adult lions it was 4.26, for lionesses it was 2.69, and for males it was 1.61 (**Figure 5.6**).

In the eastern landscape, average group size (including cubs) was 2.85 (SE 0.23), while adult (excluding cubs) group size was 2.10 (SE 0.18), group size of females (> 2 years) was 1.62 (SE 0.12) and males (>2 years) was 1.64 (SE 0.08). Typical group size was 4.5 (including cubs), for adult lions it was 3.4, for lionesses it was 2.37, and for males it was 2.05 (**Figure 5.6**).

### **Population Viability Analysis of Girnar lions**

The carrying capacity of Girnar for lions was estimated to be 9 lions/100 km<sup>2</sup> which translated into about 16 lions in the sanctuary.

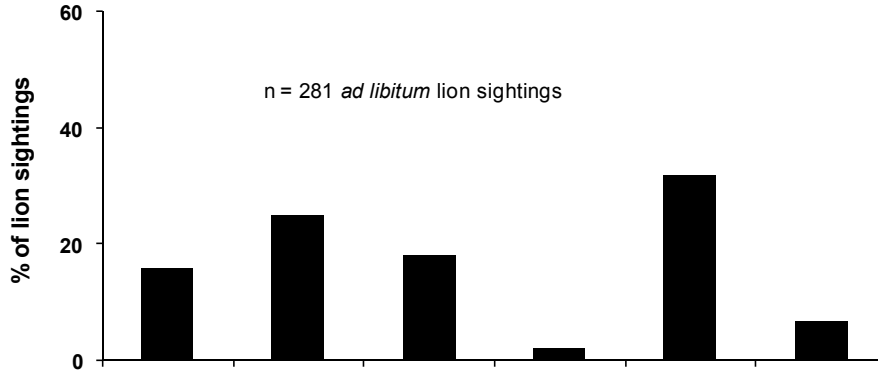
**Effect of catastrophe:** The two realistic but extreme scenarios of catastrophes modeled did not have significant effect on the persistence probability of the Girnar lion population unless there is habitat linkage with the Gir PA and no harvest in terms of poaching or accidents. In all these simulations probability of extinction for the next 100 years was close to zero. Catastrophes were included in all subsequent scenarios as they depicted a realistic risk.

**Effect of habitat linkage with the Gir PA:** Girnar lions were found to be extremely sensitive to the habitat linkage with the Gir PA. In the absence of any poaching episode or accident, the long-term (100 years) survival probability of Girnar lions increased by 39% in comparison to scenario wherein there was no habitat linkage i.e. no immigration (**Table 5.4, Figure 5.7**). With lion poaching incident every year and with both the catastrophes; the median time to extinction of Girnar lions was 130 years when both the PAs were connected

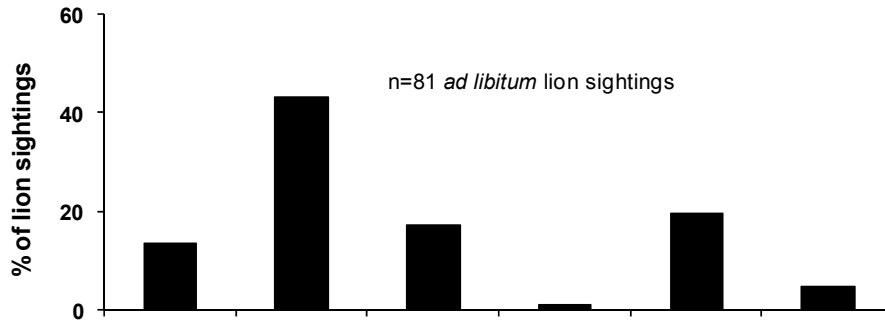


Figure 5.5: Age and sex composition of Asiatic lions in i) Gir PA, ii) Girnar forests and iii) the eastern landscape.

i)



ii)



iii)

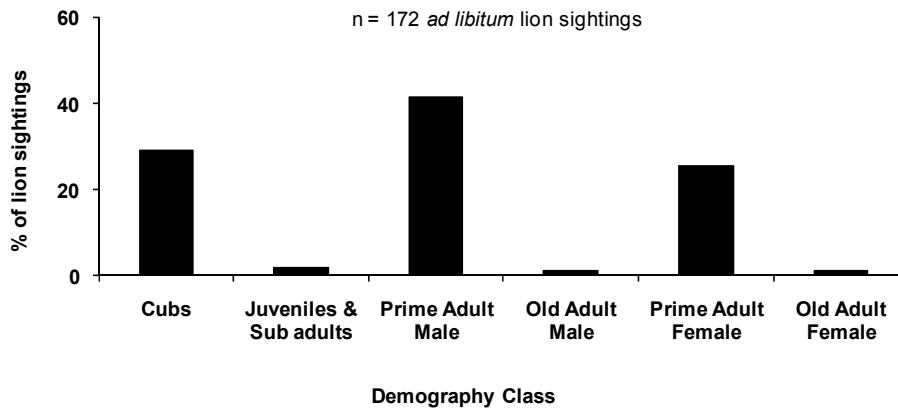
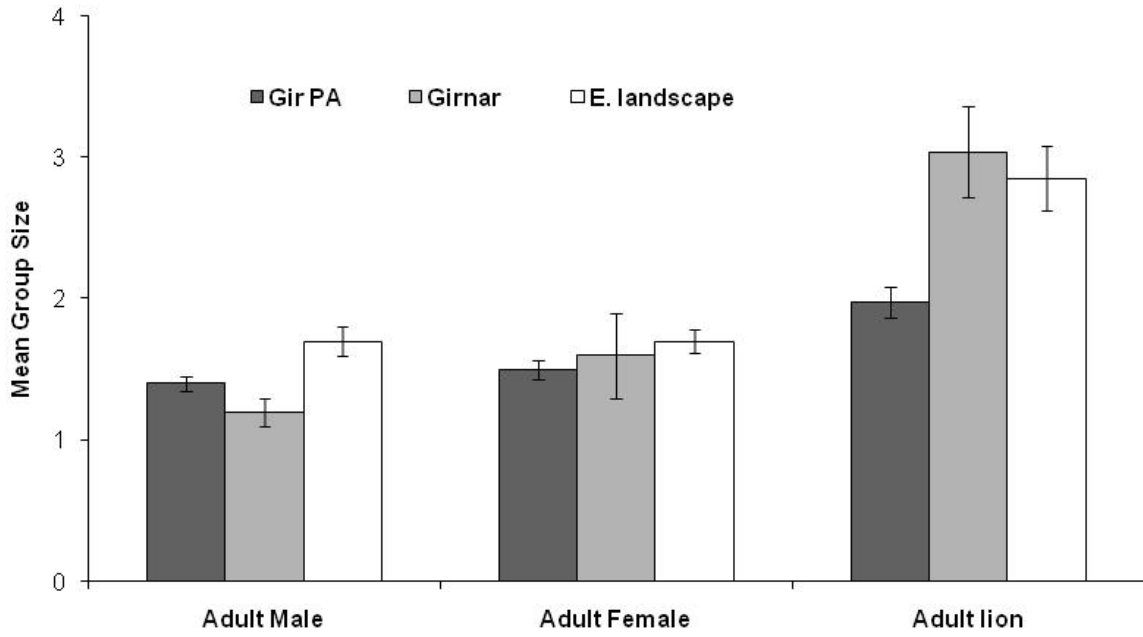


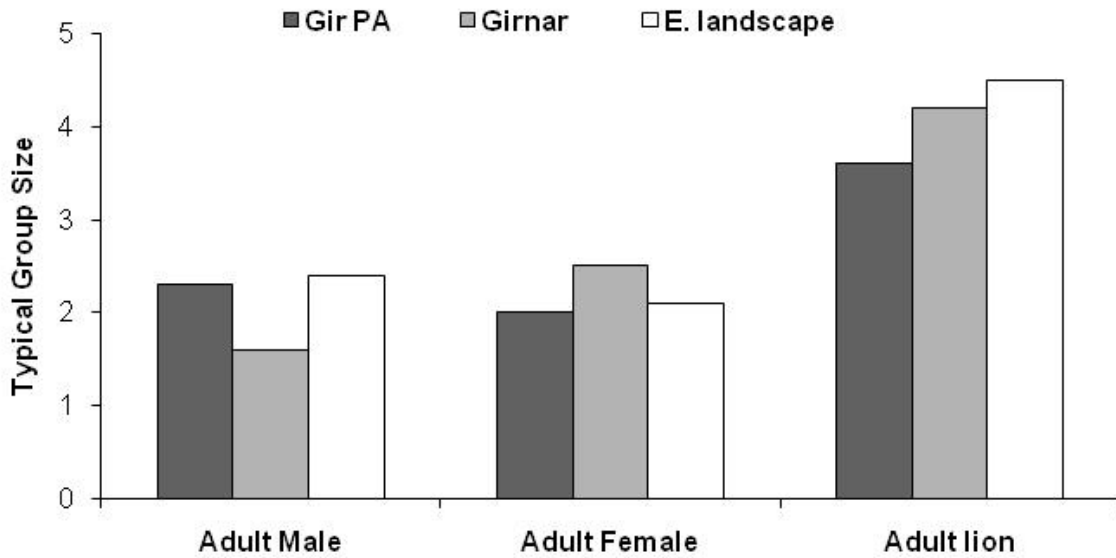


Figure 5.6: i) Mean group size (including cubs) and ii) Typical group size (including cubs) of Asiatic lions in the Gir PA, Girnar forests and the eastern landscape

i)



ii)





in comparison to the median time to extinction of 3 years in the absence of such habitat linkage (Table 5.4).

**Effect of poaching and accidents:** Girnar lion population persistence was sensitive to harvest due to poaching and accidents; but not to the extent that it was due to habitat linkage with the Gir PA. With the worst case scenario wherein three lions were poached annually and with no habitat linkage with the Gir PA, the Girnar lions were found to survive for only three years. With the same level of harvest every alternative year, lions survived for five years but the population would not persist in long term (Table 5.4).

The average stochastic rate of increase ( $r$ ) of the lion population for all scenarios that had a persistence probability greater than 90% was 7.3 (SD 0.2) % (Figure 5.8).

**Table 5.4: Population viability model predictions for Girnar lions under various combinations of stochastic events for the next 100 years.**

Modeled scenario	Extinction probability (SE)				Median time of extinction (year)
	25 year	50 year	75 year	100 year	
Scenario 1: No harvest_no catastrophe_habitat linkage	0	0	0	0	0
Scenario 2: No harvest_mild catastrophe_habitat linkage	0	0	0	0	0
Scenario 3: No harvest_both catastrophes_habitat linkage	0	0	0	0	0
Scenario 4: No harvest_both catastrophes_no habitat linkage	0.08 (0.01)	0.27 (0.02)	0.43 (0.02)	0.61 (0.02)	57
Scenario 5: Every year harvest_both catastrophes_habitat linkage	0.05 (0.01)	0.09 (0.01)	0.11 (0.01)	0.20 (0.01)	130
Scenario 6: Every year harvest_both catastrophes_no habitat linkage	1	1	1	1	3
Scenario 7: Every alternative year harvest_both catastrophes_habitat linkage	0	0	0	0	0
Scenario 8: Every alternative year harvest_both catastrophes_no habitat linkage	0.99 (0.01)	1	1	1	5



Figure 5.7: Long-term (100 years) extinction probability of Girnar lion population under different modelled stochastic scenarios in VORTEX. A – H correspond to the eight scenarios explained in Table 5.1. N = population size. I. Mean survival probability of Girnar lions under different modelled scenarios

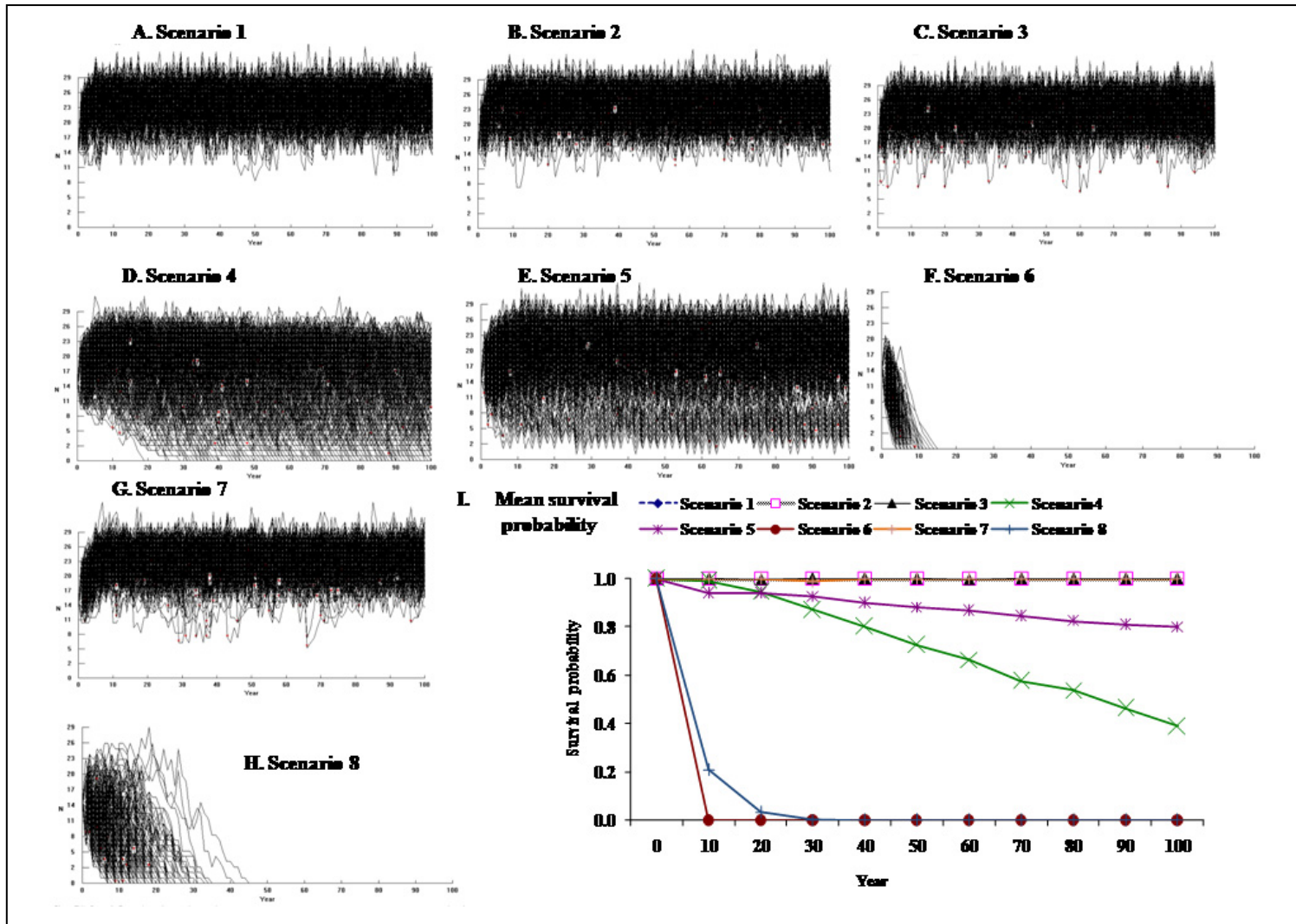
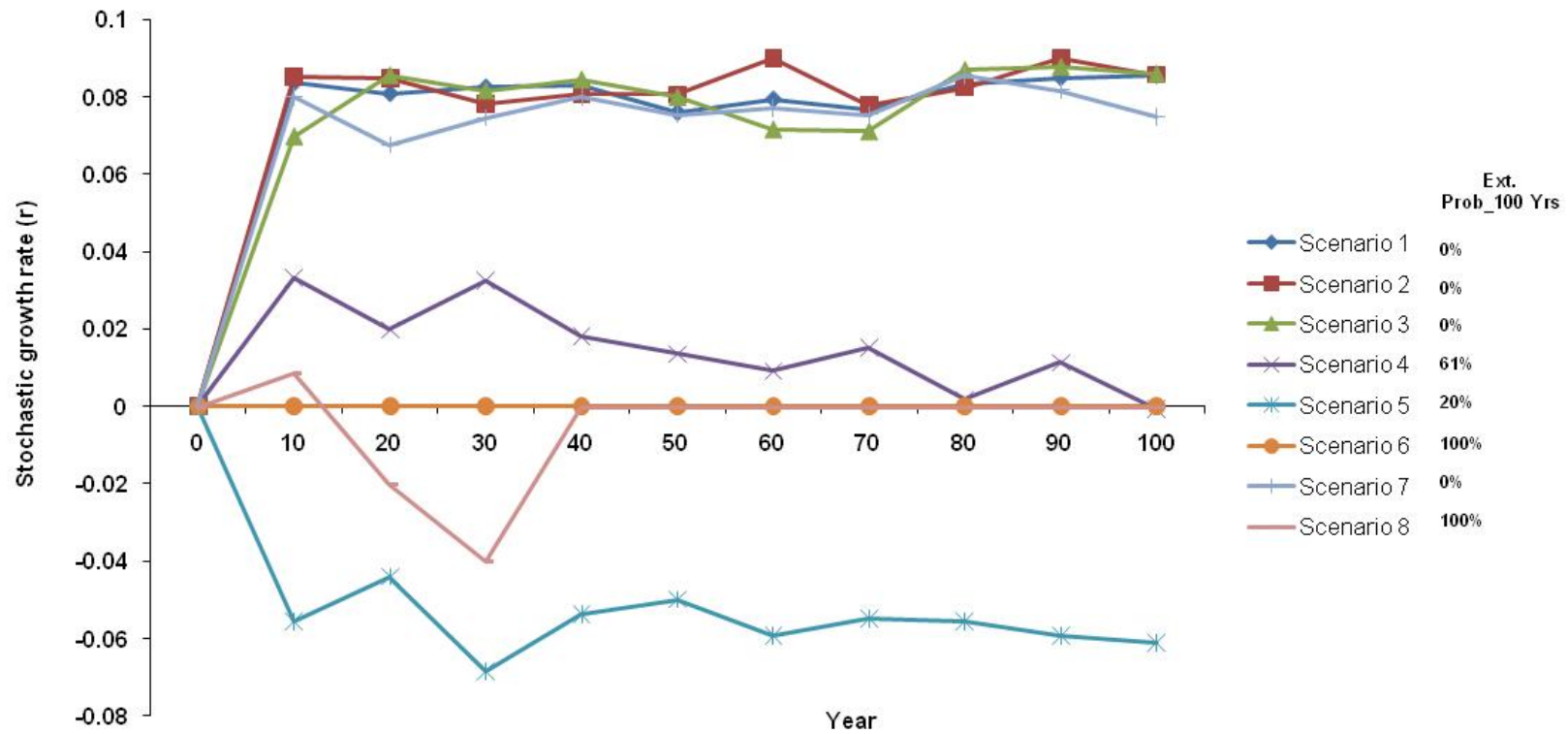




Figure 5.8: Mean stochastic growth rate ( $r$ ) of the Girnar lion population under different modeled scenarios. Details of the scenarios are explained in Table 5.1





## Discussions

### Population estimation and density

White et al. 1982 suggested a minimal capture probability of  $> 0.3$  so as to ensure that CV% of  $\leq 20\%$  from the dataset and able to detect variation in capture probability for populations less than 100. Pollock et al. (1990) stated that this level of precision is adequate for management purposes. In the current study, the estimated average capture probabilities (0.31 in Girnar and 0.65 in the eastern landscape) were fairly good and were higher than the minimal capture probability required to generate reliable population estimates (Harmsen et al. 2010). A significant proportion of the overall lion population was represented in the sampling as  $M_{t+1} > 90\%$  of the population estimates.

Most capture–recapture studies are inherently spatial in nature, with capture probabilities depending on the location of traps relative to animals (Borchers and Efford 2008). The need for a spatial component in models arises from the fact that territorial animals located closer to traps tend to be more likely to be captured and animals far from the traps may not be captured. Spatially explicit capture–recapture (SECR) methods incorporate the spatial information in inference. In the current study ‘traps’ were not fixed and all the potential lion habitats were systematically sampled during field work. Since following this approach, all the lions within the study area had equal likelihood of getting captured and SECR models were not used for the analysis.

A population is closed if it remains effectively unchanged in the course of investigation through such processes as birth, death or migration; otherwise it is open (Seber 1982). Karanth et al. (2002) recommended a sampling duration of about 45–60 days to avoid violation of closure. The sampling durations in Girnar (19 days) and in the eastern landscape (25 days) during the current study was relatively short compared to the average lifespan of lions. Covering a very large area in the eastern landscape encompassing the entire target lion population over a very short duration ensured ecological closure in my model and provided a scope of estimating the abundance of a ‘superpopulation’ (Kendall 1999). Moreover, the closure test in Program CAPTURE is a weak test because a failure of closure cannot be distinguished from changes in capture probabilities because of behavioral responses and insensitivity to temporary emigration occurring at the middle of the study period or from certain patterns of time-trends in capture probabilities and is only valid if  $M_h$  or  $M_o$  is selected as the most appropriate model (Otis et al.



1978; Amstrup et al. 2005). It was, therefore, beyond one's limits to ascertain if the violation of closure in the population estimation of the eastern landscape (with  $M_{th}$  as best selected model) in spite of brief sampling period of 25 days was due to demographic or geographic openness or a sampling artifact.

Total counts can be biased by observability that varies, in turn, with vegetation cover, activity schedule, body size, group size and population size of the vertebrates (Seber 1982). The most likely source of duplicate counting is failure to recognize known lions. Eastern landscape lion population estimates were close, but higher than the total count of 54 lions conducted by the state forest department around the same period (Singh and Gibson 2011) and a similar pattern was reported for the Gir PA in 1995 (Jhala et al. 1999). This affirms that total counts were likely underestimates. However, since there was no objective way to determine the proportion of lions missed out or counted multiple times, the total count method needs to be modified to incorporate detection probability of lions based on sampling (Karanth et al. 2003; Jhala et al. 2004). This can be achieved in a double sampling framework by combining individual identification of lions based on vibrissae patterns and permanent natural markings (Jhala et al. 1999, 2004) in a capture-recapture framework (Pollock et al. 1990) done during the exercise of total counts. The lion monitoring protocol should be precise, unbiased and have the statistical power of detecting slight changes in the population (Taylor and Gerrodette 1993). Such a monitoring program would enable timely management inputs in the form of rectifying measures for control of poaching, disease and other sources of mortality.

Gir PA holds the maximum potential for being a lion stronghold with a much higher lion density in comparison to the Girnar forest and the eastern landscape (Jhala et al. 2004; 2006; **Table 5.5**). Prey density is one of the key determinants of large felid abundance (Karanth et al. 2004). Lion density has a positive linear correlation with prey abundance (Van Orsdol et al. 1985; Carbone and Gittleman 2002; Hayward et al. 2007a). However, the current study did not find any significant correlation between lion abundance and prey biomass in different parts of the Gir landscape suggesting that there were other limiting factors.



**Table 5.5: Lion density and prey biomass density from different Protected Areas across the World**

Lion Reserve	Country	Reserve area (km <sup>2</sup> )	Lion density (lion/km <sup>2</sup> )	Prey biomass density (kg/km <sup>2</sup> )	Average adult male group size	Average adult female group size	Source
Kruger National Park	South Africa	235	0.11	246	2.1	4.5	East 1984; Funston et al. 2003
Waza National Park	Cameroon	1,700	0.02	600	1.2	1.6	Bauer and De Iongh 2005; Tumenta et al. 2009
Selous National Park	Tanzania	2,600	0.16	1,874	2.4	3.4	Caro et al. 1998; Spong 2002
Etosha National Park	Namibia	22,270	0.02	283	1.5	4.8	East 1984; Stander 1991
Serengeti	Tanzania	40,000	0.12	970	3.1	5.4	Hanby et al. 1995
Masai Mara NP	Kenya	1,530	0.35	18,213	2.4	9.2	Ogutu and Dublin 2002
Ngorongoro Crater	Tanzania	260	0.40	15,660	3.2	3.5	Hanby et al. 1995
Gir PA	India	1,888	0.15	8,511	1.4	1.5	Jhala et al. 2004; Dave 2008
<b>Girnar forest</b>	<b>India</b>	<b>180</b>	<b>0.06</b>	<b>953</b>	<b>1.4</b>	<b>1.9</b>	<b>Banerjee 2012; Current study</b>
<b>Human dominated eastern landscape</b>	<b>India</b>	<b>3,292</b>	<b>0.02</b>	<b>98</b>	<b>1.6</b>	<b>1.6</b>	<b>Banerjee 2012; Current study</b>



### **Lion population structure**

A large proportion of the lion population (41% in the Gir PA, 56% in the Girnar forest and 31% in the eastern landscape) was in the recruitment class indicative of a healthy growing population (Caughley 1977). The eastern landscape lion population had a higher proportion of adult males (43%) than adult females (26%); indicative of male biased dispersal (Schaller 1972) from the 'source' Gir PA into the 'sink' eastern landscape (Hanski and Gilpin 1997). Fewer females were recorded compared to males in the eastern landscape and this could also be attributed to lower availability of suitable habitat patches for breeding lionesses in this human-dominated landscape.

Prey body size, prey density and prey capture efficiency were found to be the major ecological determinants of group sizes in social carnivores (Krukk 1972; Schaller 1972; Caraco and Wolf 1975; Zimen 1976; Griffiths 1980). Lions display a 'fusion-fission' grouping pattern which is functionally identical to sociality in other social carnivores like spotted hyenas *Crocuta crocuta* (Krukk 1972), wolves *Canis lupus* (Mech 1970) or coyotes *Canis latrans* (Camenzind 1978). Individual fitness in lions is enhanced by the formation of large foraging groups due to increased capture efficiency (Schaller 1972; Van Orsdol 1981), improved protection of the carcasses against the interspecific competitors (Schaller 1972) and increased reproductive success of females in rearing cubs communally by reducing infanticides (Bertram 1975). However, these benefits are partially offset by the costs of living in large groups and specifically increased competition at the feeding sites (Packer and Ruttan 1988). Lions of Queen Elizabeth National Park, Uganda showed association pattern partially determined by the pride demographic characteristics (Van Orsdol 1981). Thus it becomes difficult to evaluate all the social factors determining lion congregation pattern.

In areas where small to medium sized prey are consumed, such as in the Kalahari, lions exist in small group sizes or are solitary (Eloff 1973). In Etosha, lion group sizes fluctuate seasonally with respect to changes in prey availability (Stander 1991). The optimum foraging group size is a pair of lions for prey < 50 kg available during dry season whereas, in wet season higher density of wild prey resulted in larger hunting groups (Stander 1991). In the case of open areas with seasonal migratory prey, lions adapt to fluctuations in prey biomass as well as absence of preferred prey during some periods of the year (Hanby et al. 1995). Prey selection varies between sexes where the male-female social bonding is weak, with females preferring medium sized prey and males going for larger sized prey (Scheel and Packer 1995).



Lion group sizes in the Gir PA estimated in the present study were small in comparison to earlier reports (Joslin 1973; Chellam 1993; Singh 2007). This is likely due to a major shift in the modal prey size from large bodied cattle (> 300 kg) in 1960's to 1980's to a medium size chital (60 kg) in 2000's (Meena et al. 2011; Banerjee 2012; Banerjee et al. 2013). This observation is also supported by the smaller group size of lions observed in the Gir PA where there are less livestock available in comparison to larger lion groups observed in the Girnar Sanctuary and the agro-pastoral eastern landscape which have more livestock. Lions in the eastern landscape were known to predate and scavenge livestock (primarily cattle) from several villages and the poor condition cattle kept at the charity of various cattle camps (*Panjrappoles* and *Gaushalas*) and temples spread across the landscape.

### **Population Viability Analysis of Girnar lions**

The simulation scenarios modeled were realistic and conservative with respect to the situation likely to exist in Girnar. The stochastic population growth rate observed for all scenarios with greater than 90% persistence probability for 100 years was 7.3 (SD 0.2)% and comparable to that computed for the Girnar lion population (total count by the Forest Department) between 2000 to 2010 ( $r = 7.2\%$ ), lending support to the parameterization of the PVA models. The estimate of the carrying capacity of Girnar for lions was conservative based on lion densities observed in the Gir PA (Jhala et al. 2004; 2006). The wild ungulate population has been increasing since the early 1990's (Dharaiya 2001) and therefore the food based carrying capacity of Girnar is likely to increase in the future. The Gir region is prone to droughts and cyclones, such events could cause decline of wild ungulate populations, increase in livestock and human invasion into the Gir PA thereby increasing human-lion conflict (Saberwal et al. 1994), Such a catastrophe in a worst case scenario would result in depression of reproduction (by 50%) and survival (by 25%) and occur once in every 10 years. We also modeled a severe depression in survival and fecundity caused due to calamities like disease epidemics (Roelke-Parker et al. 1996; Kissui and Packer 2004). This severe catastrophe had a probability of occurring twice within a span of 100 years - an extremely conservative scenario (Kohlmann et al. 2005). All simulations were modeled with density dependence where only 40% of lionesses bred at carrying capacity (more conservative than suggested by field data, Kissui and Packer 2004) and with the default setting of inbreeding depression available in VORTEX.

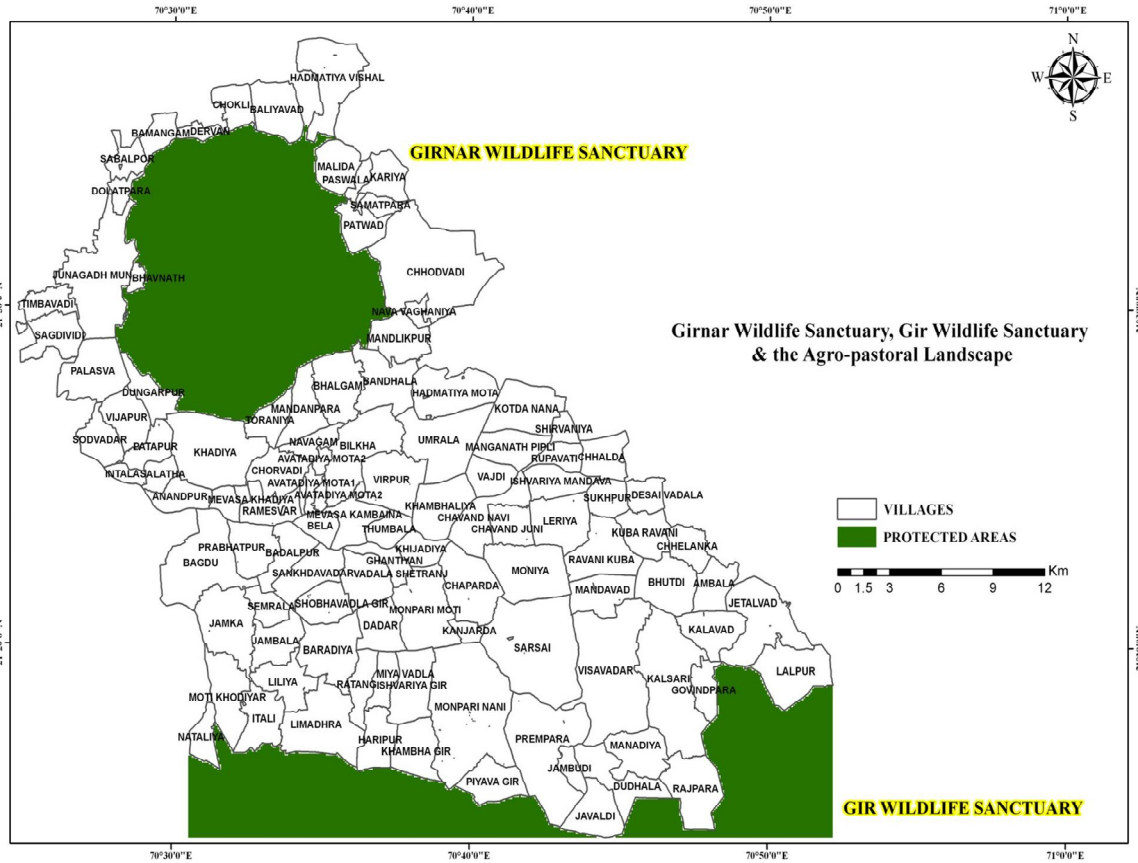


Persistence of the modeled Girnar lion population was very sensitive to i) habitat linkage of Girnar with the Gir PA allowing regular exchange of genetic material and ii) harvest of lions from the population. With a constant level of annual harvest, the long-term survival potential of the Girnar lions increased by 39% with habitat connectivity with the Gir PA in comparison to a non-connectivity scenario (Banerjee et al. 2010). Besides, with high demand of lion body parts like that of tigers in the international market (Gratwicke et al. 2008; Fair 2009) poaching of lions has become extremely profitable for international commercial poaching gangs. Moreover, poaching lions is comparatively easy in comparison to tigers due to formers' habitat, behavior, and group living behavior (Rice 1884; Singh 2007; Fair 2009). Human caused accidents (road accidents, falling in open irrigation wells, electrocution etc.) attributed 43% of lion mortalities in the Gir landscape (Banerjee and Jhala 2012). We, however, did not include the behavioral and social aspects induced by harvest, such as infanticide that would subsequently occur as a direct consequence of removal of dominant males (allee effect; Woodroffe and Frank 2005) or the probability of population *quasi-extinction* by high level of female harvest in the PVA models. These, when considered, would be additive to the negative impacts of loss of habitat linkage with the Gir PA and harvest on long-term persistence of small Girnar lion population.

The traditional land-use pattern in the Gir landscape is changing at an unprecedented rate. Agricultural intensification, sedentarization of pastoralism, diversification of livelihoods and land fragmentation through privatization of land tenure necessitate urgent strategic management interventions and legislations integrating the social, cultural and economic welfare of the region while simultaneously incorporating conservation of lions as an important goal in this landscape. The lion population is well protected within the Gir PA but its recent recolonization of human dominated landscape areas around the Gir PA has been a matter of concern as conservation is not the major land-use objective in these areas. A 1,400 km<sup>2</sup> habitat corridor landscape on the eastern and south-eastern fringes of the Girnar Sanctuary including the revenue lands of approximately 90 villages (belonging to Junagadh, Mendarda, Visavadar, Bhesan and Dhari *talukas*) has been identified (**Figure 5.9**; Jhala et al. 2012a and chapter 6 of the current report) and has been proposed to manage as an '**eco-sensitive area**' (The Environment Protection Act 1986, Ministry of Environment and Forests, Govt. of India) so as to curtail adverse conversion of land uses to prevent further deterioration of this corridor habitat (Banerjee et al. 2010).



**Figure 5.9: Location of Gir PA, Girnar forest and the connecting habitat corridor across the agro-pastoral landscape proposed as an eco-sensitive area**



The study recommends that the corridor area needs to be declared as ‘ECOSENSITIVE’ urgently with restrictions on high impact industry and mining activities. Infrastructure development needs to be kept at minimal and when essential should be mitigated with appropriate investments e.g. highways, roads, and railways need appropriately designed underpasses for wildlife, with funneling fences, sound and light barriers at strategic passage ways. Assistance of professional wildlife scientists and engineers is required for location, design and construction. Private property needs to remain permeable to wildlife movement, thus high walls, electric fences need to be restricted or designed for permeability of target species. Urban sprawl is difficult to regulate and can reduce the viability of the corridor significantly. Urbanization is associated with developmental activities and curtailing these within the corridor habitat will discourage nuclear human settlements. This could be addressed by providing the local communities with appropriate mitigations and incentives so as to ensure the long term viability of Girnar lion population.



## CHAPTER VI

# *HABITAT SUITABILITY MODELING AND IDENTIFICATION OF POTENTIAL HABITAT CORRIDOR LANDSCAPE BETWEEN GIR AND GIRNAR*

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### **Introduction**

Habitat fragmentation is widely recognized as one of the primary threats to biological diversity (Groom et al. 2005). Urbanization is the main cause of habitat fragmentation, threatening carnivore persistence around the world (Ferrerias et al. 1992). The degree of anthropogenic alteration fragmented the landscape within the present distribution range of Asiatic lion. The area of Gir forest, spread over an area of 5,000 km<sup>2</sup>, two centuries ago, gradually shrank with steady deforestation. The earlier existent corridors connecting hills, forests and the lion's habitat in the form of protected and un-classed forests have almost been transformed to the agriculture and human settlements (Johnsingh et al. 1998). Highways and expressways have been widened and are now filled by speeding vehicles, making it difficult for animals to safely cross them. A large track of grazing pastures and wastelands, which were used by both wildlife and livestock, have been transformed to other uses.

Girnar WLS, one of few small breeding units, recolonized by dispersing lions from Gir protected area in mid 1980s (Singh 2007), is bordered on three sides by townships of Junagadh, Bilkha and Bhesan (Parmar 2005). The small lion population of Girnar exists as a separate but connected with the lion population of Gir Protected area. Occasional exchange of lions between the two populations is crucial for sustaining long-term demographic and genetic viability of the Girnar lion population. Functional connectivity, defined as the degree to which inter-fragment landscape facilitates or impedes the movement of individuals between patches, encapsulate the combined effects of matrix structure and its influence on the movement of a particular species (Taylor et al. 1993; Tischendorf and Fahrig 2000). Understanding how this spatial heterogeneity impacts lion's dispersal, and hence persistence of populations in this fragmented landscape, aid in the identification and subsequent preservation of critical habitat.

The increasing lion population of Girnar (Banerjee et al. 2010) uses definite areas within the sanctuary avoiding of rugged terrain of Girnar (Banerjee 2012). In addition the sacred nature of this forest, dotted with many Hindu and Jain temples and visited by hundreds of thousands of



pilgrims each year, reduce the amount of available habitat for this increasing lion population. The approximate carrying capacity of Girnar as 25 individuals (a conservative estimate based on lion densities in Gir Protected Area; Jhala et al. 1999, 2004), natural barriers, anthropogenic disturbances within the sanctuary, the traditional land use changes outside protected area in this region (Banerjee et al. 2010; Basu 2013), claimed a study identifying functional corridors joining Gir and Girnar protected area and recommending management interventions, safeguarding the corridor.

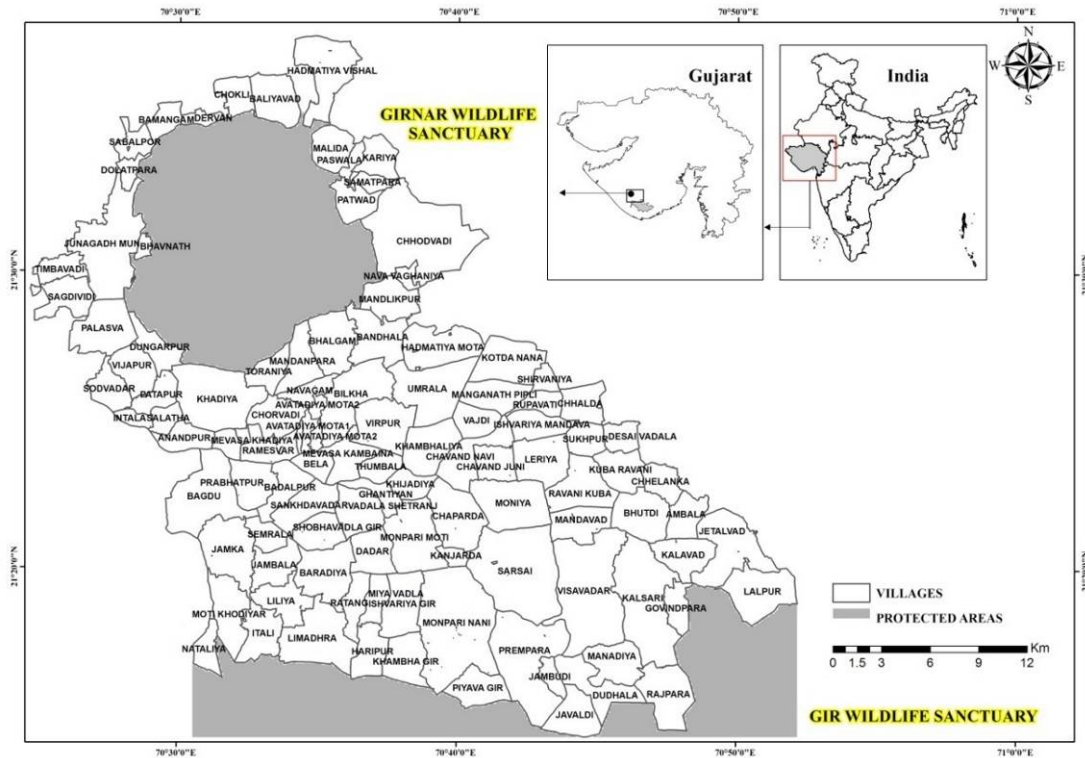
With the advent of Global Positioning System (GPS) technology it was possible to gain new insights into lion dispersal and connectivity among disjoint lion populations. Analysis of detailed GPS revealed dispersal paths provided information on how animal perceives and moves through this landscape. We used data from radio collared lions ( $n = 9$ ) to develop habitat suitability model (Hirzel et al. 2001). Output of habitat suitability was then used in PATHMATRIX (Ray 2005) to delineate the least cost pathway between Gir PA and Girnar to spatially define the corridor habitat between the two lion populations.

### **Study Area**

This landscape includes the revenue lands of approximately 90 villages (**Figure 6.1**), consists of broken topography, small drainage systems, Government and privately owned wastelands, fallow lands and is predominantly agricultural with seasonal crops and fruit (mango) orchards (**Figure 6.1**). This area is exhibiting rapid growth, yet there are still many natural areas interspersed among human development. Climate is generally dry with two main seasons' viz. summer and winter. The monsoon which has few rainy days fuses with the summer period. The area is interwoven with road and rail networks. All villages are connected with each other with a very good road network. There are four major state highways and three metre gauge railways going through the study area. The principal rivers flowing through the area under study are Ozat and Gundajali. Gundajali merge with the river Ozat, together forming the main water source of the area. Several small rivers, joining and originating from these two main rivers, used by lions as passage ways.



Figure 6.1: The location of Girnar Wildlife Sanctuary with reference to the Gir PA and the potential habitat corridor linking Girnar to Gir PA



## Methods

We used data from radio collared lions ( $n = 9$ ) as species presence data to be used in Biomapper (Hirzel et al. 2006) predicting lion distribution in this landscape, identifying areas appropriate as passageways for the species in this sub optimal habitat. Biomapper uses ecological niche factor analysis (ENFA) to compute habitat suitability (HS) maps, and define the niche of a respective species based on few important habitat variables (Hirzel et al. 2002). The program has been used in studies on some terrestrial vertebrates (Dettki et al. 2003; Reutter et al. 2003; Brotons et al. 2004). We superimposed a 100m X 100m grid on the study area. The environmental variables in GIS format all pertain to the same geographic area, were extracted to grids to be useful in modeling method to predict environmental suitability for the species as a function of the given environmental variables. The grid size was considered suitable to obtain and understand habitat choice by lions and being sufficiently large to enable us to use freely available data sets on environmental variables without compromising on spatial resolution. We extracted data of different eco-geographical variables such as Digital Elevation Model (DEM), Normalized



Differential Vegetation Index (NDVI), Euclidean distance to available water sources, considering both the major rivers and dry river channels and Euclidean distance to major roadways as a disturbance factor to animal movement to model lion habitat use pattern and identifying crucial areas for corridor.

The output of ENFA was then used to calculate the resistance matrix (1-Habitat Suitability value) and PATHMATRIX (Ray 2005) was used to delineate the most feasible passageway that lions use for movement in between two protected areas and could be designated as functional corridor for long term sustainability of biological linkage between these two protected areas. This algorithm computes a least-cost path between a source population and a target population by using a friction (or resistance) layer. The friction layer is a raster map where each cell (landscape unit) expresses the relative difficulty (or cost) of moving through that cell for a given species. A least-cost path minimizes the sum of frictions of all cells along the path, and this sum is the least-cost distance.

## Results

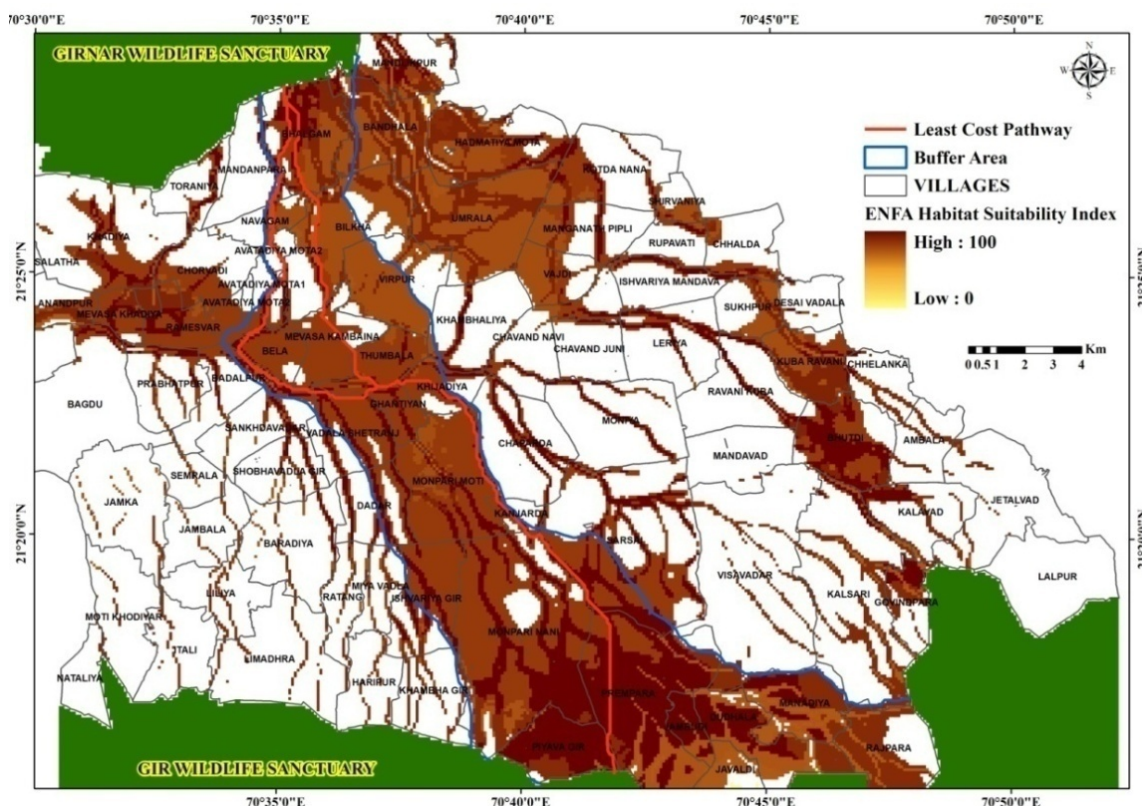
Results of ENFA suggest that, lions have exhibited preference to dry river channels as their passage ways (**Figure 6.2**). The areas with higher elevation were not preferred by lions. The marginality factor was explained by euclidean distance to rivers and dry river channels (0.61) and the specialization factor 1 (9%) was explained by DEM (0.71), specialization factor 2 (5%) was explained by euclidean distance to major roadways (0.66) and specialization factor 3 (3%) was explained by euclidean distance to rivers and dry river channels (0.74).

The identified corridor (**Figure 6.2**) between Gir and Girnar, cut across 28 villages (**Table 6.1**). The use of least cost algorithm accounts for the resistance implied by the landscape on animals, and the output follows the least resistant grids from animal's perspective. A buffer of 1.5 km, necessary for safeguarding the corridor, with modifications in some places, for incorporating administrative boundaries or excluding unsuitable areas resulted in an area of 200 sq km as functional corridor. Lions tended to venture into developed areas mostly late at night. The majority of radio locations at dusk were in interior habitat, and locations in development were mostly at night, possibly in search of easy prey such as livestock. Therefore, although the species venture into development, they are less likely to do so during times of high human



activity and occurred frequently in corridors, showing behavioral adjustments to habitat fragmentation and human activities.

**Figure 6.2: Lions habitat suitability, least cost pathway with buffer around showing the functional corridor in Gir-Girnar landscape**



**Table 6.1: List of villages within Gir-Girnar habitat corridor landscape**

AVATADIYA MOTA	MEVASA KAMBAINA	ISHVARIYA GIR	MONPARI NANI
AVATADIYA NANA	NAVAGAM	JAMBUDI	PIYAVA GIR
BADALPUR	SANKHDAVADAR	JAVALDI	PREMPARA
BANDHALA	THUMBALA	KANJARDA	RAJPARA
BELA	DADAR	KHIJADIYA	SARSAI
BHALGAM	DUDHALA	MANADIYA	VADALA SHETRANJ
BILKHA	GHANTIYAN	MONPARI MOTI	VIRPUR



## Discussions

Conservation biology theory recommends that building of linkage structures for wildlife between isolated habitat patches may increase or at least maintain levels of interpatch dispersal, thus sustaining gene flow and supporting population viability of target species (Kozakiewicz 1993; Forman and Alexander 1998). Gir protected area is at its carrying capacity for lions (Singh 1997), constructive changes in the environment may improve this figure slightly, but for the sustenance of increasing lion population, habitat upgradation in new areas naturally colonized by the lions and preserving the linkages in between these areas are essential (Pathak et al. 2002; Singh 2007; Banerjee 2012). Variation in the landscape can influence the movement of individuals through the matrix and therefore the prospect of habitat patch occupancy (Wiens 1997; Ricketts 2001). The valley portion and foot hills of Girnar are used by lion as major part of Girnar is not suitable for them (Banerjee 2012). The animals use peripheral villages which are integral part of the habitat as the lions prey on livestock at night in these bordering villages (Singh 2007; Banerjee 2012).

The human dominated landscape between Gir and Girnar is used by lions primarily for movement purpose. Distance of Girnar from the nearest boundary of the Gir sanctuary (W) Division is about 22 km. Lions use streams, barren land, *gauchar*, agricultural field and scrubland for movement and also for shelter when it becomes necessary (Basu 2013). Though few patches exist, where there is a possibility of finding resident animals (unpublished data) but very small such patches, surrounded by human settlements and timely occupancy by animals, don't show potential as strong lion hold in near future, until and unless they get protection.

The provisioning of landscape corridors has often been recommended as mitigation for the isolation effect of fragmentation (Saunders et al. 1991). Several studies supported that the presence of a corridor improves population density relative to isolated patches (Fahrig and Merriam 1985; Haddad and Baum 1999). An understanding of how species move through fragmented landscapes, by means of elements such as corridors and stepping stones, is vital for species management at a landscape-scale (Bowne and Bowers 2004).

The behaviour of species moving through the corridor within agricultural landscapes is expected to be influenced by the nature of the matrix, the type and spatial distribution of adjacent habitats, season, and interaction between same and other species. Wooded and shrubby vegetation together with the corridor functioned as day *refugia* as well as passage ways for lions,



signifying their importance to lion's movement in this landscape. Regular use of mango orchards and *gauchar* (pasture land) indicated that such patches are important for movement in fragmented landscape and serve as a link to other forested patches. Agricultural intensification, and the associated loss due to explosion of urbanization, has resulted in riverine forest patches acting an important contributor to biodiversity conservation in this agricultural landscape (Jhala et al. 2012 a, b). These biological corridors may alleviate negative impacts of habitat fragmentation by permitting movement between large areas of suitable habitat for the species. Use of the same riverine patches by animals; for it's to and fro movement between two protected areas confirmed the importance of these patches as functional corridor. Some of the cultivated lands which are not suitable for agriculture may be reverted back under pasture or thorn forest for multiple uses. Barren lands, riverbeds, and some of the private lands may be acquired or purchased and the corridor area should be afforested by suitable species to allow free movement of lions between the two areas.

Analyses of land use and cover change processes within the Gir-Girnar corridors suggested that riverine patches are vanishing at an alarming rate and the remaining patches are likely to be converted to agriculture. Sustainable management of these forest fragments huddled along the riparian corridors of tributaries of the main river Ozat and other small rivers is urgent with a focus on biodiversity. The corridor passes through the lands of villages given in Table 6.1. It is important to provide incentives and safeguards to the livelihood needs of local communities of these villages while ensuring that the conservation values of the corridor are not compromised. This could be done by implementing several Government funded rural development schemes through the civil administration and by ecodevelopment activities in a manner that the communities do not suffer economically due to development restrictions needed for conserving the corridor values of their lands.

Gir PA is likely to be an unabated lion stronghold in the future owing to its large size and strong protection regime. However, a broader rural support base has to be generated in this human-dominated landscape where conservation is not a major land-use objective. With the traditional land-use pattern in the Gir landscape changing at an alarming rate and the tendency of increasing urban sprawl, the crucial Gir-Girnar habitat corridor delineated herein needs to be secured. Acquiring and protecting government lands and ensuring that land-uses that act as barriers to lion movements (industry, urban sprawl, linear infrastructure like highways, high



agricultural boundary walls or power fences) are discouraged or appropriately mitigated so as not to compromise the corridor value of the habitat are essential. It would not be prudent to declare the corridor habitat as a Protected Area due to local livelihood dependencies, and it may not be needed, since lions are tolerant to traditional land-use practices. **However, as a sensible and timely attempt, based on WII's recommendations (Banerjee et al. 2010; Jhala et al. 2012a), some part of the corridor area is declared as "ECOSENSITIVE" (under The Environment Protection Act 1986, by Gujarat Forest Department** with restrictions on high impact industry and mining activities. Infrastructure development needs to be kept at minimal and when essential should be mitigated with appropriate investments e.g. highways, roads, and railways need appropriately designed underpasses for wildlife, with funneling fences, sound and light barriers at strategic passage ways. Private property needs to remain permeable to wildlife movement, thus high walls, electric fences need to be restricted or designed for permeability of target species. Urban sprawl is difficult to regulate and can reduce the viability of the corridor significantly. The least cost corridor habitat currently passes through areas that have the least resistance to lion movement, declaring this as ecosensitive and by providing appropriate mitigation and incentives to local communities should assist in maintaining its permeability for future generations ensuring the metapopulation structure of lions in this landscape.



## *CHAPTER VII*

### *LION DEMOGRAPHY*

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#### **Introduction**

Most large carnivores have low genetic diversity (Caro and Laurenson 1994; O'Brien 2003). This coupled with their low density, small population size and fragmented habitats are considered major impediments to their conservation (Brook et al. 2002). The last free-ranging population of Asiatic lions in the Gir forests of western India exemplifies these problems (Johnsingh et al. 1998; O'Brien 2003).

With their origin in East and South Africa (Antunes et al. 2008), Asiatic lions extended from the African Mediterranean coast into Eastern Europe, the Middle East and into India sometime between 3000 and 2000 BCE (Divyabhanusinh 2005). O'Brien (2003) suggests that about 2,500 years ago, the Kathiawar peninsula was separated from the mainland India by rising sea level causing the first genetic bottleneck that isolated the founders of the present Asiatic lion population compelling them to inbreed for several generations (O'Brien 2003). A second less severe bottleneck happened at the onset of the nineteenth century when lions became restricted to the Gir forests and their number declined to around 50 individuals due to hunting and habitat loss (Edwards and Fraser 1907; Kinnear 1920; Pocock 1930).

Allozyme and microsatellite studies indicate that the Asiatic lion population is genetically monomorphic, attributed to an isolated inbred population with a small founder base, (Wildt et al. 1987; Shankaranarayanan et al. 1997; O'Brien 2003) although, RAPD analysis showed some level of polymorphism in Asiatic lions (Shankaranarayanan et al. 1997). Though the extent of inbreeding and homozygosity in Gir lion population is debatable, there is little doubt that they have decreased heterozygosity in comparison to African lions. Decreased heterozygosity likely diminishes reproductive vigor and survival and is believed to impair a population's long-term viability (Foose 1977; O'Brien et al. 1986; Packer et al. 1991; Björklund 2003).

Due to the timely and stringent protection by the Rulers of Junagadh and subsequently during post-independence by the State-run forest department, Asiatic lions have increased to about 400 (Gujarat Forest Department 2010) and dispersed into a large tract of agro-pastoral



landscape adjoining the Gir forests (Banerjee et al. 2010; Singh and Gibson 2011). Vital rates of an animal population determine its size and composition, and represent the aggregate life-history performances of its constituents (Robinson et al. 2008). It is widely believed that the effects of inbreeding and subsequent low genetic diversity should manifest in poor population vital rates (Frankham et al. 2002). Yet declines in large carnivore populations are most often attributed due to causes other than lack of measured genetic diversity and subsequent depression of population vital rates (Caughley 1994; Altizer et al. 2003). We collected twelve years' data from free ranging Asiatic lions on survival, litter size, inter litter interval, and rate of population increase by radio-telemetry on 20 lions and individual monitoring of 55 lions and compared these with genetically more diverse African lion (*Panthera leo leo*) populations to determine if the demography of the Gir lions was compromised due to inbreeding depression.

## **Methodology**

### **Data collection**

Twenty lions (10 males, 10 females) ranging between approximately 2.5 and 12 years, from different prides spaced throughout the Gir Landscape, were radio-collared (11 lions in Gir PA, 4 lions in Girnar, and 5 lions in the eastern landscape; **Figure 7.1**). Lions were anaesthetized using a combination of Ketamine hydrochloride (2.5-3 mg/kg body weight) and Medetomidine (0.04-0.06 mg/kg body weight; Kreeger 1996) injected intramuscularly using a gas powered projectile (Telinject Inc., CA, USA) dart delivery system. Reversal agent Atipamezole (0.05-0.1 mg/kg body weight) was used resulting in the total recovery of anaesthetized lions within 3–10 min. Each sedated lion was sexed, aged, measured, weighed, ecto-parasites collected and photographed according to standard protocol. Lions were equipped with combination of VHF (n = 10; Telonics Inc., Arizona, USA and Wildlife Materials Inc. Illinois, USA), GPS (n = 5; HABIT Research Ltd., Victoria, Canada and Vectronics Aerospace GmbH, Berlin, Germany) and GPS Plus -satellite (n = 1; Vectronics Aerospace GmbH, Berlin, Germany) radio-collars. The collar weights were <1% of the body weight of the lions. Collared lions were monitored from the ground either using a four-wheel drive vehicle, or on foot using a 3-element Yagi antenna and a hand-held receiver (HABIT receiver model HR 2600 and Vectronics GPS Plus Handheld Terminal Unit). Considering the vastness of the landscape, we attempted to locate every collared lion at least bi-weekly and every non-collared known lion at least once in 2 months. Once activated, GPS and GPS-satellite collars provided 6-8 daily locations either via IRIDIUM



(Iridium Communications Inc., McLean, VA, USA) two-way satellite network using low earth orbit satellites or via UHF (ultra high frequency) based ground download facility.

Lions were classified into 7 age categories (Jhala et al. 2004) based on body size, coloration, secondary sexual characteristics, tooth eruption and wear (Schaller 1972) as small cubs (<6 months), large cubs (6 months-1 year), juveniles (1-2 years), sub-adults (2-3 years), young adults (3-5 years), prime adults (5-10 years) and old adults (>10 years). Our research team first practiced and compared our age category classification skills on known age captive and free ranging lions for consistency and accuracy. We could accurately and consistently age lions up to the age of five years. Variability between observers ranged between 1-3 years for age estimation of lions greater than 5 years. We therefore used a consensus age (year) estimate for lions older than 5 years between two or more observers. Due to small sample sizes in each age group and to avoid errors of estimating exact age from biasing our survival estimates, we report stage specific rates (averaged across all ages within that stage) and not age specific rates.

We individually identified and intensively monitored 55 lions (37 males and 18 females between approximate age of 1.5 to 13 years) between 2005 and 2010 across the entire landscape based on their unique vibrissae patterns and additional body marks (Pennycuik and Rudnai 1970; Jhala et al. 1999) and by maintaining their individual profiles based on repeated sightings in a database program LION version 1.0 (Badoni et al. 2005) [see chapter 5 for more details on individual lion identification technique].

### **Sex ratio**

We used 412 opportunistic lion sightings (281 in Gir PA, 41 in the Girnar and 90 in the eastern landscape) across the Gir landscape to deduce sex ratios reported as ratio of adult males to adult females. There was a possibility of sampling individuals more than once because not all lions observed were able to be individually identified. Therefore, a single sample survey with replacement model was used to compute the adult sex ratio (Skalski et al. 2005).

### **Reproduction and cub survival**

Seasonality of mating was deduced from direct sightings ( $n = 29$  mating events). We accounted for varying search effort in different seasons by dividing the number of mating events recorded by the number of field days spent searching for lions in that season. The young: adult lioness ratio was calculated as ratio of cubs and juveniles to breeding lionesses ( $n = 215$ ) in the population using single survey without replacement model (Skalski et al. 2005) since all mothers

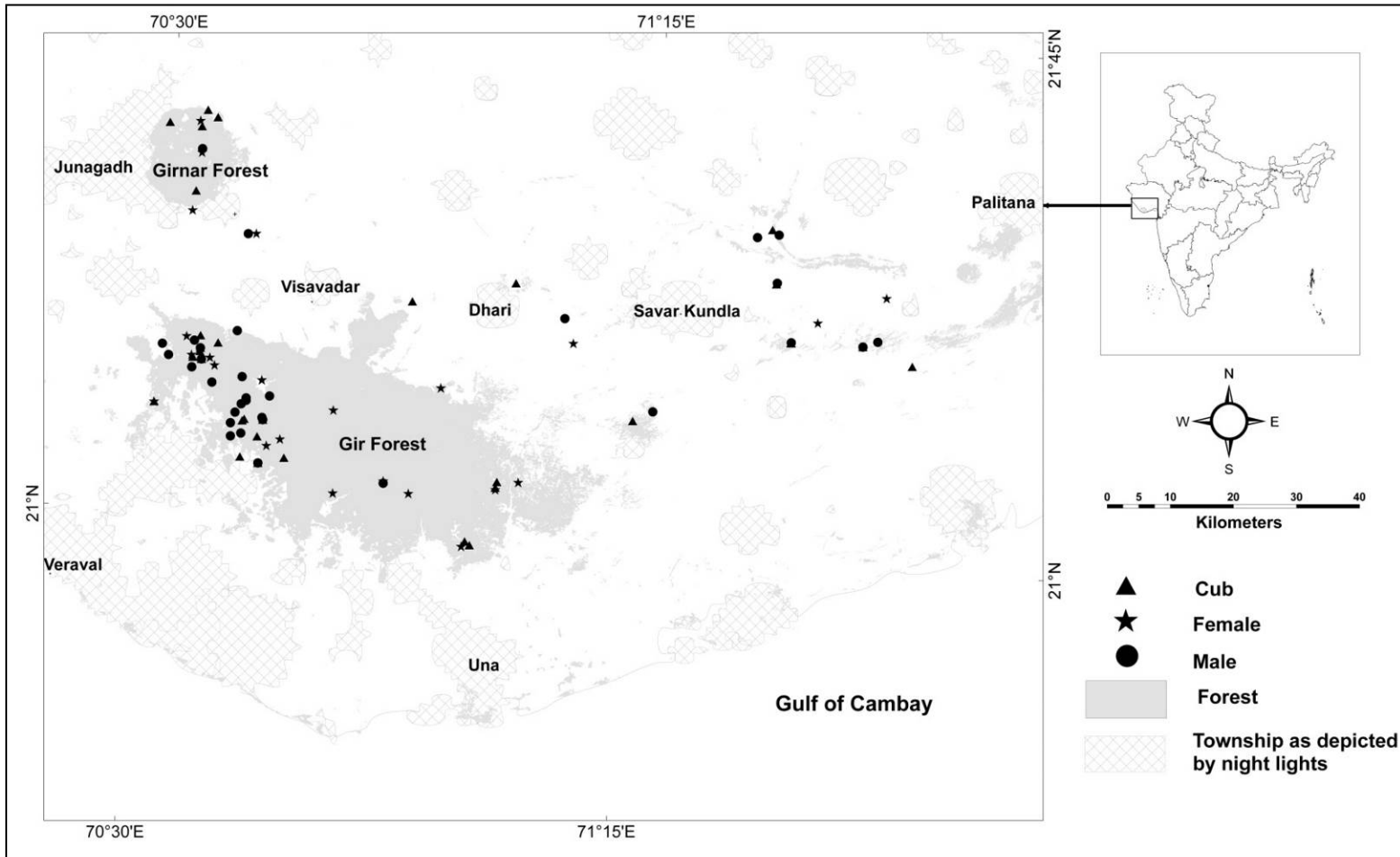


were individually identified and their young were counted a single time in our analyses. Ninety one cubs from 38 litters of 31 females across the Gir Landscape between 2005 and 2010 (55 cubs in 23 litters from 18 females in Gir PA, 11 cubs in five litters from five females in Girnar and 25 cubs in 10 litters from eight females in the eastern landscape) were monitored to estimate litter size and cub survival rate. Litter size and cub mortality until about one month, could not be ascertained because of observational difficulties, therefore, survival rates have been calculated from one month of age when cubs start movement with lionesses. Cub recruitment was calculated as the proportion of cubs reaching young adult stage (3 years). Most of the cub mortalities were recorded when found dead; however, all carcasses could not be detected. Therefore, a cub was considered dead if it was not observed with the pride on 2-3 subsequent observations and not seen thereafter (Goodrich et al. 2008). Whenever possible, causes of cub mortality were classified into four categories: (1) infanticide by adult males, (2) other natural causes such as rejection by mother, diseases and injury, (3) anthropogenic (e.g., falling into open irrigation wells, road kills, electrocution by live wires illegally set around agriculture fields to deter crop damage by wild herbivores and poaching), and (4) unknown. Program MICROMORT (Heisey and Fuller 1985) was used to compute cause-specific cub mortality.

Inter-litter interval was calculated as the time interval between successive litters of a lioness (Packer et al. 1988). We measured reproductive success of lionesses as percent of cubs that survived to adulthood by a female (Kelly et al. 1998) during the study period.



Figure 7.1: Location centroids of study lions and location of litters used in the analysis of survivorship. Map inset shows the location of Gir Landscape in the Gujarat province, India. Night light satellite data was used for mapping human habitations (Elvidge et al. 1997) in the Greater Gir Landscape. LISS-III sensor data of IRS-1C satellite was used to map extent of forest cover.





### **Adult survivorship and annual mortality rate**

We primarily detected mortality of radio-collared lions when radio-collars went into mortality mode and investigated the site to determine cause of death. For non-collared animals, all births and mortality events were recorded as far as possible due to scheduled fieldwork combined with exchange of information with the park authorities, local tourist guides and villagers. The causes of lion mortalities were rarely ambiguous as we collected the information in a combination of ways: direct inspection of the site within 24 - 36 h, information gathered from the park authorities with verification from the veterinary officer, inspection of post mortem reports and by interviewing local witnesses. Adult lion mortality ( $n = 88$ ) events were primarily categorized into natural mortality (intraspecific strife, disease, old age, snake bites and flash flood) human caused mortality (falling in irrigation wells of farmlands, road accidents, poaching and electrocution) and unknown causes.

Stage specific annual and span survival probability of adult lions was estimated using a known-fate model (Skalski et al. 2005) in Program MARK (White and Burnham 1999) using the staggered entry design (Pollock et al. 1989; Hayward et al. 2005). This technique can be used where fate of an identifiable individual is known with certainty and independently. Mortality dates of all study lions were known within 5 days of occurrence. We grouped encounter histories of the lions into time intervals of 6 months each and created a live-dead matrix where '10' meant the individual lived through the interval, an '11' meant the individual died during the interval and '00' meant censoring the individual (when unaware about the fate; Cooch and White 2009). For the survivorship analysis, we right censored surviving lions in our sample at the end of December 2010. Lions monitored before adulthood, and that lived long enough to enter the next stage class, were included in all appropriate stage classes with the assumption that survival rates in different age classes of an animal were independent. We estimated adult lion survival by monitoring 68 lions (13 radio-collared and 55 non-collared) where stage specific sample sizes were juvenile  $n = 56$ , sub-adult  $n = 42$ , young adult male  $n = 28$ , young adult female  $n = 15$ , prime adult male  $n = 28$ , prime adult female  $n = 24$ , old adult male  $n = 15$  and old adult female  $n = 15$ . We also estimated cause-specific mortality using program MICROMORT (Heisey and Fuller 1985) according to the total number of monitoring days and death of monitored lions occurring in the interval covered (Trent and Rongstad 1974). We generated 95% confidence



intervals on survival rates (Zar 2010); non-overlapping confidence intervals on survival estimates were considered significantly different.

### **Realized rate of increase of Asiatic lion population**

Since 1963, the Gujarat Forest Department has estimated lion numbers about every 5 years by a labor-intensive total count of lions using live baits for 3 days (Jhala et al. 1999; Singh 2007). Most lions in Gir were used to killing livestock and readily approached buffalo bait. A daily record was kept of all lions that visited the baits. Lions feeding on the bait remained stationary in the vicinity of the bait for 3-4 days. If however, lions moved away to another bait site a record of this movement was kept and accounted for while computing total number of lions so as to minimize double counts. The maximum number of lions recorded on any single day was considered to be the total population. The data for the population estimates used for the analysis of population trend were obtained from literature and reports (Divyabhanusinh 2005; Singh 2007). Though total counts are known to be error prone in population estimation (Williams et al. 2002), in case of Gir lions they provided a reasonably reliable index of population trends as the same method and effort have been used since 1968. We used this information to compute the realized rate of increase for lion population by regressing natural logarithm-transformed total counts against time (Caughley 1977).

### **Comparing demographic parameters of African and Asiatic lions**

We surveyed published literature and obtained information from 19 studies on various demographic parameters of African lions. 95% confidence intervals on demographic parameters of Asiatic and African lions were constructed and considered them to be similar if the confidence intervals overlapped.

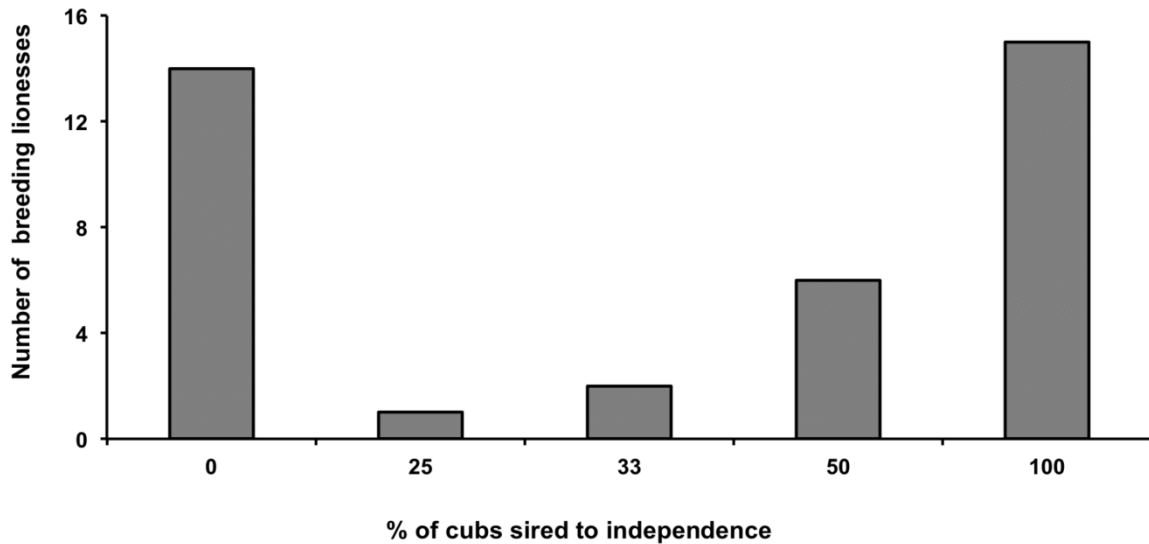
## **Results**

The adult sex ratio (male: female) was female biased 0.52 (SE 0.04) in Gir PA and 0.70 (SE 0.13) in Girnar Wildlife Sanctuary while it was male biased 1.21 (SE 0.17) in the eastern landscape. The overall adult sex ratio in the Gir Landscape was 0.63 (SE 0.04). The cub to adult lioness ratio was 0.37 (SE 0.02) while the juvenile to adult lioness ratio was 0.23 (SE 0.01), and the overall young: lioness ratio was 0.60 (SE 0.01). Mating occurred throughout the year but mostly (56%) in winter followed by summer (25%) and monsoon (19%;  $\chi^2_{df 2} = 23.68$ ,  $P < 0.001$ ). Cub births peaked in summer (57%) followed by winter (37%) and monsoon (6%;  $\chi^2_{df 2} = 39.66$ ,  $P < 0.001$ ). We could confirm age of first litter in seven lionesses which ranged from 4 to



5 years with an average age of 4.39 (SE 0.17) years. Of the 38 litters for which litter size was recorded with reasonable certainty, 12.7% had one cub, 50.9% had two cubs, 29.1% had three cubs, and 7.3% had four cubs. The average litter size was 2.39 (SE 0.12). Several lionesses were not successful at raising cubs to adulthood, while a few raised many (**Figure 7.2**).

**Figure 7.2: Reproductive success of Asiatic lioness (91 cubs from 38 lionesses) measured as percentage of cubs that survived to adulthood.**

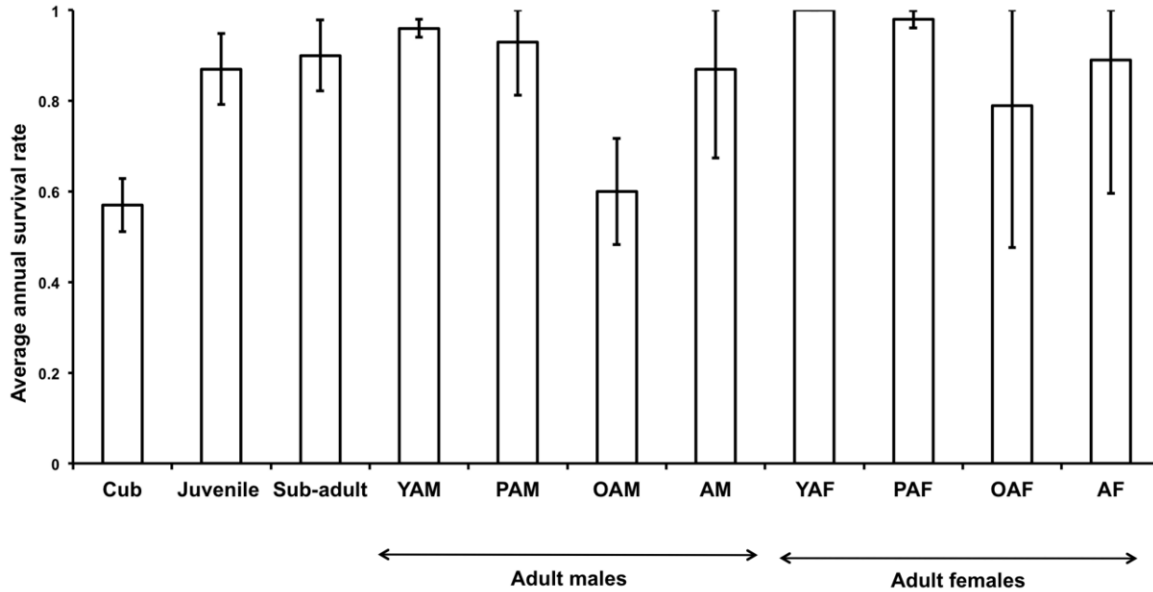


Infanticide due to territorial takeovers by adult males was found to be the major cause of cub mortality (**Table 7.1**). Annual cub survival rate was lower (0.57, SE 0.03) than juvenile (0.87, SE 0.04) and sub-adult (0.90, SE 0.04) survival rates which were similar (**Figure 7.3**). Overall recruitment (survival from young cub to adult stage) was 51% (SE 4%). Annual survival rates for young and prime adult males were higher than old adult males, while survival was similar across all adult stages amongst females (**Figure 7.3**). The overall average annual survival rate of adult lions (> 3 years) was 0.90 (SE 0.12).

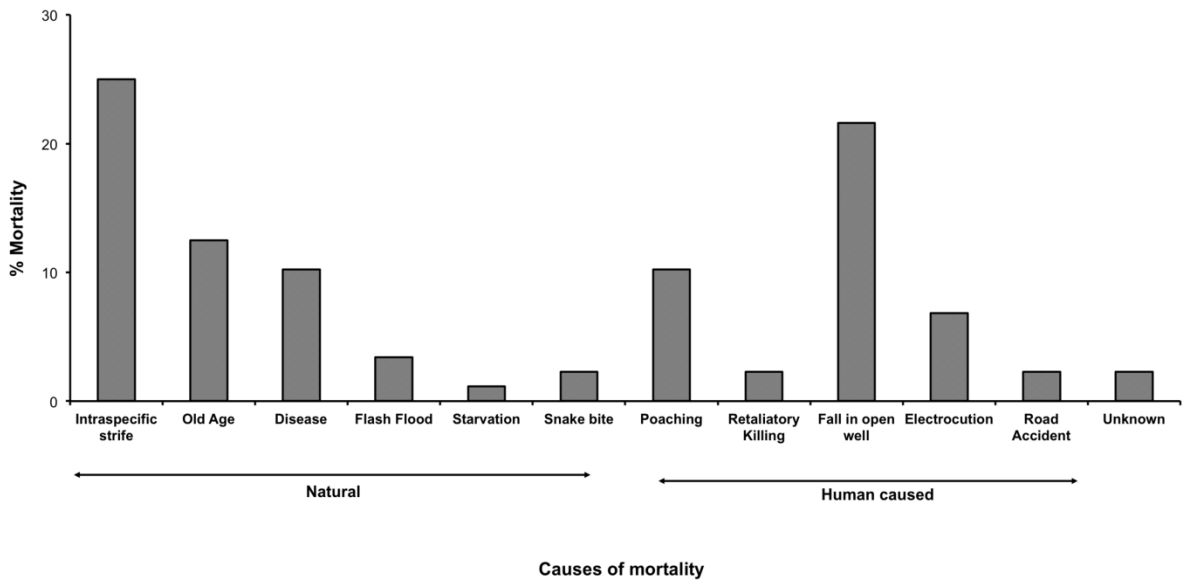
Mortality of radio-collared lions (n = 8) was primarily natural (87.5%), mostly due to old age (50%) or intraspecific strife (33.3%). One radio-collared lioness died due to human causes (12.5%). Out of the 88 observed mortalities across the Gir Landscape inclusive of collared and non-collared lions, 54.5% were due to natural causes, 43.2% were due to human causes while the remaining 2.3% were due to unknown causes. A single episode of commercial poaching was responsible for 10.2% of the observed mortality while we observed retaliatory killing of lions due to livestock depredation twice (2.3%; **Figure 7.4**).



**Figure 7.3: Comparison of stage specific average annual survival rates of Gir lions. YAM = young adult male, PAM = prime adult male, OAM = old adult male, AM = adult male, YAF = young adult female, PAF = prime adult female, OAF = old adult female and AF = adult female. Error bars are 95% confidence intervals.**



**Figure 7.4: Cause specific mortality in Asiatic lions (n = 88) in the Gir Landscape between 2006 and 2010**





**Table 7.1: Survival rates and cause specific mortality of Asiatic lions between 2000 and 2010 in the Gir Landscape, India.**

Demographic Stage	Sample size	Average Annual Survival Rate (SE)	Annual Mortality Rates (SE)				Cohort-specific Span Survival Rate (SE)	Span Mortality Rates (SE)			
			Infanticides	Other natural causes	Human caused	Unknown		Infanticides	Other natural causes	Human caused	Unknown
Small cub (<6 m)	91	-	-	-	-	-	0.90 (0.03)	0.04 (0.01)	0.03 (0.01)	0.03 (0.01)	0
Large cub (6 m - 1 y)	83	-	-	-	-	-	0.63 (0.06)	0.27 (0.05)	0.07 (0.03)	0	0.03 (0.01)
Cub (1m - 1 y)	91	0.57 (0.03)	0.28 (0.05)	0.10 (0.03)	0.03 (0.01)	0.02 (0.01)	-	-	-	-	-
Juvenile (1-2 y)	56	0.87 (0.04)	0.09 (0.04)	0	0.04 (0.02)	-	-	-	-	-	-
Sub-adult (2-3 y)	42	0.90 (0.04)	0.05 (0.03)	0.03 (0.02)	0.02 (0.01)	-	-	-	-	-	-
Cub recruitment (birth-3 y)		0.51 (0.04)	0.30 (0.07)	0.13 (0.05)	0.06 (0.02)	-	-	-	-	-	-
Young adult male (3-5 y)	28	0.96 (0.01)	-	0.04 (0.01)	0	-	0.93 (0.004)	-	0.07 (0.001)	0	-
Young adult female (3-5 y)	15	1.00	-	0	0	-	1.00	-	0	0	-
Prime adult male (5-10 y)	28	0.93 (0.06)	-	0.05 (0.001)	0.02 (0.001)	-	0.66 (0.01)	-	0.29 (0.01)	0.05 (0.002)	-
Prime adult female (5-10 y)	24	0.98 (0.01)	-	0.01 (0.001)	0.01 (0.001)	-	0.93 (0.03)	-	0.035 (0.003)	0.035 (0.003)	-
Old adult male (> 10 y)	15	0.60 (0.06)	-	0.40 (0.007)	0	-	0.06 (0.007)	-	0.94 (0.007)	0	-
Old adult	15	0.79	-	0.21	0	-	0.20	-	0.80	0	-



female (>10 y)		(0.16)		(0.009)			(0.03)		(0.03)		
Adult male (>3 y)	47	0.87 (0.10)	-	0.12 (0.005)	0.01 (0.001)	-	0.13 (0.02)	-	0.82 (0.02)	0.05 (0.002)	-
Adult female (>3 y)	28	0.89 (0.15)	-	0.10 (0.005)	0.01 (0.001)	-	0.15 (0.01)	-	0.78 (0.02)	0.07 (0.002)	-
Adult lion	75	0.90 (0.12)	-	0.08 (0.003)	0.02 (0.001)	-	0.27 (0.02)	-	0.67 (0.02)	0.06 (0.001)	-



After territorial takeovers and infanticides, females mated within an average 4.80 (SE 0.66) months ( $n = 5$  lionesses). Average inter-birth interval was estimated to be 1.37 (SE 0.25) years ( $n = 7$  lionesses). However, when cubs of the previous litter survived to independence, the inter-birth interval was higher [2.25 (SE 0.41) years;  $n = 2$  lionesses] than when all the cubs of the previous litter died [1.02 (SE 0.06) years;  $n = 5$  lionesses,  $t_5 = 5.1$ ,  $P < 0.01$ ].

The Asiatic lion population was increasing with a realized rate of increase ( $r$ ) of 0.022 (SE 0.001,  $\lambda = e^r = 1.0222$ ) for the past 42 years ( $F_{1, 7} = 416.3$ ,  $P < 0.001$ ,  $R^2 = 0.98$ ) with an initial population of about 177 in 1968 that increased to about 411 by 2010.

All the demographic parameters of free ranging Asiatic lions were within 95% confidence limits of African lion population parameters (**Table 7.2**).

## Discussions

O'Brien et al. (1987) and Wildt et al. (1987) found that, Asiatic lions and the cheetahs (*Acinonyx jubatus*) showed a high incidence of morphologically abnormal spermatozoa (79% and 71%, respectively) when compared to free-ranging African lions (25-61%) and other species such as bulls and dogs (20-30%). The serum testosterone (a critical hormone for spermatogenesis) was low and Asiatic lions had lower variability in major histocompatibility complex (MHC) gene responsible for body immunity in comparison with those of populations of African lions (Wildt et al. 1987; O'Brien 2003). These traits were believed to impair their reproductive vigor and population vital rates and were attributed to low genetic variation. Todd (1965) attributed dentition abnormalities in Asiatic lions to inbreeding depression. Brook et al. (2002) estimated that with the prevailing inbreeding depression and subsequently compromised demography, the mean time to extinction of Gir lions with an initial population size of 250 individuals was likely to be 39.3 years. It is possible that harmful effects of inbreeding on Asiatic lion may diminish as deleterious recessive genes are purged from the population by selection (Keane et al. 1996; Tanaka 1998; Frankham et al. 2002) resulting in comparable population growth rate and vital rates to genetically diverse lion populations. The results of the current study suggest that the vital rates of Asiatic lions are similar to those of other free-ranging lion populations from Africa and no evidence was found to suggest that the Asiatic lions' demographic parameters were depressed in comparison to other lion populations.



**Table 7.2: Comparison of demographic parameters of free ranging Asiatic lions with those of African lion populations obtained from published studies.**

Location	Population Growth Rate ( $\lambda$ )	Litter Size	Cub Survival	Adult Survival	Inter-birth Interval (year)	Adult Sex Ratio (male: female)	Cub: female Ratio	Reference
Serengeti, Tanzania		2.1	0.3	0.9	0.8	0.5	0.4	Schaller (1972)
Nairobi National Park, Nairobi			0.8			0.4		Rudnai (1973)
Serengeti National Park, Tanzania		2.5	0.1		1.6			Bertram (1975)
Ngorongoro crater, Tanzania			0.6			1.1		Elliott and Cowan (1978)
Kalahari Gemsbok National Park, South Africa			0.1			0.5		Eloff (1980)
Ishasha, Queen Elizabeth National Park, Uganda		2.6	0.8			0.2		Van Orsdol et al. (1985)
Mweya, Queen Elizabeth National Park, Uganda		2.3	0.4			0.5		Van Orsdol et al. (1985)
Ngorongoro crater, Tanzania		2.8	0.7					Hanby et al. (1995)
Serengeti plains, Tanzania		2.7	0.2					Hanby et al. (1995)
Etosha National Park, Namibia	0.97							Berry et al. (1997)
Maasai Mara National Park, Kenya			0.7			1	0.4	Ogotu and Dublin (2002)
Tarangire National Park, Tanzania		1.9	0.7			0.3	0.7	Ryen and Soressina (2003)



Kruger National park, South Africa			0.8		3.3	0.4	0.6	Funston et al. (2003)
Laikipia district, Kenya	0.95	2.2	0.7	0.8				Woodroffe and Frank (2005)
Kunene region, Namibia	1.16		0.8	0.7	2.1	1		Stander (2006)
Serengeti, Tanzania	1.08							Chauvenet (2009)
Madikwe Game Reserve, South Africa	1.38	3.0			2.0			Trinkel et al. (2010)
<b>Mean (95% CI)</b>	<b>1.06 (0.98-2.05)</b>	<b>2.45 (2.33-2.57)</b>	<b>0.55 (0.47-0.62)</b>	<b>0.8 (0.7-0.9)</b>	<b>1.9 (1.2-2.6)</b>	<b>0.59 (0.48-0.69)</b>	<b>0.5 (0.3-0.7)</b>	
Gir, India		2.1	0.4	0.9	1.2	0.9		Joslin (1973)
Gir, India		2.3				0.4		Chellam and Johnsingh (1993)
Gir, India	1.02							Jhala et al. (1999)
Gir, India						0.4	0.6	Jhala et al. (2004)
<b>Gir Landscape, India (95% CI)</b>	<b>1.022 (1.02-1.024)</b>	<b>2.39 (2.2-2.6)</b>	<b>0.57 (0.49-0.64)</b>	<b>0.90 (0.66-1.00)</b>	<b>1.37 (0.88-1.86)</b>	<b>0.63 (0.55-0.70)</b>	<b>0.37 (0.33-0.40)</b>	<b>Banerjee &amp; Jhala 2012; Present study</b>



Adult sex ratio in free-ranging lion populations are generally female biased (Schaller 1972; Joslin 1973; Packer et al. 1988; Chellam and Johnsingh 1993; Banerjee et al. 2010). In populations with selective harvest and trophy hunting of adult male lions, adult sex ratios are highly skewed in favor of females (Cooper 1991; Yamazaki 1996; Loveridge et al. 2007). The finding of male skewed sex ratio in the eastern landscape in the current study suggests a male biased dispersal (Schaller 1972) from the ‘source’ Gir PA into the ‘sink’ eastern landscape (Hanski and Gilpin 1997) which is further supported by the current study (see chapter 5). Fewer females were recorded compared to males in the eastern landscape and this could also be attributed to lower availability of suitable habitat patches for breeding lionesses in this human-dominated landscape. The ratio of cubs to adult lionesses was indicative of births every other year and high infant mortality as expected in lion populations at carrying capacity (Schaller 1972; Kissui and Packer 2004).

Most mating occurred during late winter (January) and with an average gestation period of 110 days (Cooper 1942), cub birth showed a peak during summer (April-May). Lion reproduction coincides either with the fawning peak of chital (*Axis axis*) in December – January or with the rutting season of chital and fawning peak of sambar (*Cervus unicolor*) during May-June (Lydekker 1916; Dunbar-Brander 1923; Schaller 1967; Prater 1971; Ables 1974). Chital and sambar form the major prey for lions in the Gir forests (Chellam and Johnsingh 1993; Dave and Jhala 2011; Meena et al. 2011) with fawns and rutting males most vulnerable to predation (Hornocker 1970; Johnsingh 1983). Moreover, during summer most of the domestic livestock are in poor body condition making them more vulnerable to natural death and lion predation (Jhala et al. 2006). Thus, food availability increases during late winter to summer and breeding lionesses cue into this increased resource to time births for maximizing survival of their young.

Joslin (1973) estimated an annual adult mortality rate of approximately 2% in Gir (n =16 lions). The current estimates of Gir lion survival rates were similar to those observed for African lions (**Table 7.2**). However, for the past decade lion populations within the Gir landscape have been intensively managed. The wildlife managers intervene by treating sick and injured lions either *in-situ* or by temporary translocation to a health care facility within the protected area (Pathak et al. 2002). We truncated nine lions in the survival analysis at dates when these lions were captured for treatment, since they were unlikely to have survived in the wild if left untreated. Current estimates of survival are still somewhat confounded with the management



intervention of minor treatments to some of the intensively monitored lions. Other demographic parameters such as litter sizes, cub survival, inter litter interval, and age of first litter, were not likely to be affected by this management intervention. Such management interventions, though well intentioned, interfere with the natural processes of selection and social dynamics (Whitman et al. 2004; Packer et al. 2010). Deleterious genes that would normally be selected against in an inbred population may continue to be propagated through ensured survival of unfit lions by health care interventions (Keller and Waller 2002). In the case of endangered species that are highly visible, it is often difficult to refrain from treating sick and injured individuals due to public perception (Rolston 1992; Karesh 1995). Such interventions may be essential when population numbers are extremely small and survival of each individual is crucial to ensure population persistence (Leroy et al. 2004; Smith and Almberg 2007; Nellemann et al. 2010), but these interventions need to be carefully evaluated for their need and effectiveness and should be scientifically implemented (Burrows 1992; Burrows et al. 1994). However, in the case of the Asiatic lions the population is reasonably large and increasing. It is therefore recommended that diseased lions, even if treated, should not be released back into the wild, as a precaution, in case susceptibility to the infection has a genetic basis (Keller and Waller 2002; Michel et al. 2006). Such interventions are also at odds with the guiding philosophy of managing protected areas (Lockwood et al. 2006; Gore et al. 2011) and should therefore be kept to a minimum. Data shows infanticide as a major cause of mortality amongst cubs; this could probably be due to a disruption of social dominance and territoriality of male coalitions (Whitman et al. 2004) by such managerial interventions by taking out the coalition partners temporarily for treatment of minor ailments and injuries.

The current telemetry study shows that male lion coalitions in the Gir Landscape have large ranges approximately 8-10 times larger than that of females (Jhala et al. 2006, 2009; more details in Chapter 5 of this thesis). This makes males more vulnerable to anthropogenic threats. Juveniles and sub-adult lions had high survival rates in comparison to cubs; this was likely due to their mobility and ability to avoid contact with infanticidal males owing to the dense habitats of Gir (Jhala et al. 2009). They also adopted a strategy of staying with the natal pride for a prolonged duration. These patterns were similar to those observed in Kruger where lions live in habitats comparable to Gir (Funston et al. 2003).



Infanticide by adult males, synchronous with pride takeovers (Packer and Pusey 1983a) was found to be most significant cause of cub mortality. By infanticide, incoming males speed up females' return to estrous (Packer and Pusey 1983b) by an average of approximately 5 months (SE 0.66) in Gir lions. Starvation in lean seasons, disease, abandonment by mother, predation by other predators and snakebites were some of the major documented causes of cub mortality as also observed in Africa (Guggisberg 1961; Schaller 1972; Joslin 1973; Eloff 1980).

Retaliatory killing of lions was not a major source of mortality in the Gir landscape due to cultural reverence by local communities and strict legal enforcement by the management (Pathak et al. 2002). However, with a fast changing land-use pattern and commercialization of natural resources, such societal values are rapidly eroding. Local communities' apathy towards lion conservation resulting from livestock depredation by carnivores (lions and leopards, *Panthera pardus*) is likely to lead to complacency towards professional lion poachers (Singh 2007; Fair 2009). Outside of the protected area, lion conservation is not the prime objective for land management, and tolerance towards livestock depredation by communities is less. To ensure the persistence of lions in this human dominated landscape it is essential to manage lion densities within social and economically acceptable levels (Treves et al. 2006).

This study suggests that the genetically depauperate Asiatic lion population does not suffer from depressed demographic parameters. However, small populations that are isolated and genetically less diverse are more vulnerable to environmental and demographic stochasticity making them prone to local extinction events (Frankham 1995). Since Asiatic lions currently exist as a single population that is vulnerable to local extinction processes, establishing other free ranging populations geographically distant from Gir (Johnsingh et al. 1998) should be considered a conservation priority. Human causes were a significant source of lion mortality in the Gir Landscape. Since human caused mortality is not directed to old and young lions that have higher chances of dying from natural causes, this mortality is likely to be additive to natural causes. Though currently lions continue to expand their range and density, it seems that in the future human-caused mortality is likely to increase due to enhanced human-lion conflict and become a major concern for lion persistence in the Gir Landscape. It would, therefore, be prudent to plan mitigation measures to manage conflict so as to minimize human-caused lion mortality for ensuring the long-term survival of this endangered lion sub-species in the Gir Landscape.



## *CHAPTER VIII*

### *LION SPATIAL ORGANIZATION*

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#### **Introduction**

Large carnivores and people have a complex and often paradoxical relationship which probably dates back to the pre-historic age (Loveridge et al. 2010). On the one hand, human kind reveres and admires carnivores for aesthetic, symbolic, spiritual, ethical, utilitarian and ecological reasons. On the other, human conflict with wild carnivores, overexploitation of carnivore and prey populations, habitat loss and fragmentation have extirpated carnivore populations and still threaten many more (Woodroffe 2000). The current global landscape is increasingly human-dominated where every ecosystem on the Earth's surface has been impacted by human activities in some form (Vitousek et al. 1997). Ecological processes, biogeochemical cycles, and biodiversity have been imperiled and the landscape structures have been altered. With changing land use and altered natural habitats much of the world's remaining biodiversity have become increasingly restricted to small, fragmented patches within a matrix of human-dominated landscapes (Laurance and Bierregaard 1997). This intensifies the interactions and the potential conflicts between conservation and development.

Although some wildlife species appear to be able to withstand these pressures of habitat loss and changing land use relatively well (Nee and May 1992; Anderson 1997; Purvis et al. 2001), others are often particularly threatened by such environmental changes (Belovsky 1987; Woodroffe 2000; Gittleman et al. 2001). Certain biological characteristics (k-selected traits) make species more vulnerable to extinction, including large body size, complex social behaviour, low population density, specialized niche requirements, high trophic level and large home range size (Terborgh 1974; Diamond 1984; McKinney 1997; Purvis et al. 2001). These k-selected traits are inherent to many large carnivores (Gittleman et al. 2001; Sunkist and Sunkist 2001), making them particularly vulnerable to habitat loss and environmental change, and intensifying conservation concern for such taxa as human domination of ecosystems escalates further.

Large carnivores are especially sensitive to human activity; because their requirements often conflict with those of local people. Predators have been actively persecuted in most regions of the world. Persecution is widespread, ranging in scale from the occasional poisoning of



hyaenas (*Crocuta crocuta*) by African pastoralists, to the government-sponsored eradication of wolves (*Canis lupus*) in the United States of America in the 19<sup>th</sup> and 20<sup>th</sup> centuries (Mech 1970). As a result of such conflicts, killing by people remains the greatest threat to the persistence of many large carnivores (Woodroffe and Ginsberg 1998). Even nominally protected populations may be at risk: contact with people at reserve borders is a major cause of mortality, which may cause local population extinctions where reserves are too small to enclose the home ranges of the animals that inhabit them (Woodroffe and Ginsberg 1998). These observations indicate that future conservation efforts depend upon understanding the carnivores' space use, food habits and interactions with local folk. The aforesaid situations become more intense in an economically progressive state like Gujarat and such understanding forms a vital component in conservation-management of the endangered Asiatic lions in the Gir landscape. In this chapter we investigate ranging, movement and activity pattern of Gir lions and discuss their underlying ecological implications for long-term lion conservation.

### **Hypotheses and background of the chapter**

Successful conservation policies have resulted in recovery of several previously endangered species (Singh and Gibson 2011) often leading into their population spill over outside the formal Protected Areas (Karanth and DeFries 2010). The fundamental question regarding the presence of wildlife in human-dominated landscapes is whether they are attracted to human activities and somehow benefit from agro-pastoral areas [synanthropic species] (Johnston 2001), or alternatively occur in such areas despite possible negative impacts of human-dominated areas, and thereby require habitat fragments protected from development. Large carnivores can not persist in human modified landscapes where habitat fragmentation is extensive and human-carnivore conflicts are acute (Woodroffe 2000; Cardillo et al. 2004; but see Linnell et al. 2001). Currently Gir lion populations are characterized by source-sink dynamics (Pulliam 1988; Hanski 1994) with the Gir Protected Area serving as a source to populate and maintain lion occupancy of sink habitats (Girnar sanctuary, coastal forests and agro-pastoral eastern landscape). The Protected Area of Gir still holds the best promise for the long-term lion conservation due to its legal status, high prey density, good protection regime and lower human-lion conflicts (Pathak et al. 2002). However, future survival of the Gir lions could only be secured in a metapopulation framework by protecting the source population (Gir PA) and at the same time providing dispersal opportunities by linking various satellite populations (Linkie et al. 2006). Gujarat is an economic



progressive state with the annual growth rate of Gross Domestic Product being about 21% in the year 2011-12 (higher than India's national average of 7%) (<http://planningcommission.nic.in>, accessed August, 2012). The traditional land use pattern in the Gir landscape is changing at an unprecedented rate due to lopsided developments, agricultural intensifications, sedentarization of pastoralism and privatization of land ownerships. Understanding lion space use therefore becomes a significant tool for mitigating conflicts and planning long-term lion conservation policy (Gibbs et al. 1999).

Since lion spatial organization is interwoven with the distribution and availability of resources, we expect that there will be significant difference between males and females and lions from different parts of the Gir landscape in terms of their space use. Forested area within the Gir PA is expected to be more suitable for lions with a higher prey base in comparison to the agro-pastoral eastern landscape. This difference is likely to be reflected in lions having larger home ranges and movement in the 'resource-poor' agro-pastoral landscapes. Moreover, rainfall has significant impact on the semi-arid landscape of Saurashtra (Singh and Kamboj 1996). Within the Gir PA, the wild prey congregates themselves near the water sources during the summer while in monsoon their distribution becomes more random and uniform. The grazing area of *Maldhari* livestock inside Gir is reduced during monsoon due to higher availability of fodder (Dave 2008). Monsoon is also the primary farming season outside Gir where most of the croplands are guarded from wild ungulates. In accordance, we also expect seasonal fluctuations in lion space use and investigated the following in the current chapter:

- Pattern of range use, movement and activity by Gir lions.
- What is the variation of lion space use in terms of gender?
- What and how are variations of lion space use in terms of resource availability (i.e. different parts of the Gir landscape)? and
- How does seasonality influence lion space use in the Gir landscape?



## Methodology

### Field methods

#### Lion telemetry

Radio-telemetry is an indispensable modern technological tool that enables collecting biological data that are either extremely difficult or otherwise resource intensive to obtain (Jhala et al. 2004). It is extremely important to obtain information from individually known animals at precise predetermined time dictated by an experimental design to answer many ecological questions such as vital rates, space use, behavior, predation etc. Radio-telemetry is an effective tool that assists in collecting this information which would otherwise not be possible to procure.

Ten lions (seven males, three females) ranging between approximately 2.5 and 12 years, from different prides spaced throughout the Gir Landscape, were radio-collared (one lion in the Gir PA, four lions in the Girnar Wildlife Sanctuary and five lions in the eastern landscape) in between 2008 and 2010 (**Figure 8.1**). Necessary permissions for radio-collaring lions were procured from the Director, Wildlife Preservation, Government of India and Office of the Chief Wildlife Warden, Gujarat state. We also monitored three additional radio-collared male lions (M2, M7 and M10; **Table 8.2**) from December 2005 onwards as a part of an earlier WII research on social organization and dispersal of Asiatic lions (Jhala et al. 2011a, 2012b) and included GPS fixes obtained from them for the current study. We also re-analyzed data from seven additional lionesses radio-collared within the Gir PA during a previous study on lion population monitoring (Jhala et al. 2009). Lions were anaesthetized using a combination of Ketamine hydrochloride (2.5 - 3 mg/kg body weight) and Medetomidine (0.04 - 0.06 mg/kg body weight; Kreeger 1996) injected intramuscularly using a gas powered projectile (Telinject Inc., CA, USA) dart delivery system. Reversal agent Atipamezole (0.05 - 0.1 mg/kg body weight) was used resulting in the total recovery of anaesthetized lions within 3 – 10 min. Anaesthetized lions were shaded or swabbed with water to prevent hyperthermia. Each lion's head was covered with a cloth to prevent damage to its dilated pupils and to minimize stress related to human presence. Each sedated lion was sexed, aged, measured, weighed, ecto-parasites collected and photographed according to standard protocol. Females were examined for evidence of recent lactation, as indicated by large pigmented nipples. Lions were classified into seven age categories (Jhala et al. 2004) based on body size, coloration, secondary sexual characteristics, tooth eruption and wear (Schaller 1972) [for detail see chapter 7 of the current report].



Lions were equipped with combination of VHF (n = 5; Telonics Inc., Arizona, USA and n = 2 Wildlife Materials Inc. Illinois, USA), GPS (n = 5; HABIT Research Ltd., Victoria, Canada and Vecronics Aerospace GmbH, Berlin, Germany) and GPS Plus satellite (n = 1; Vecronics Aerospace GmbH, Berlin, Germany) radio collars. The collar weights were <1% of the body weight of the lions.

### **Data collection**

The radio collared lions were tracked and monitored on a fixed schedule to cover all time periods of the day either on foot or from a motorcycle or from a four wheel vehicle. As there was considerable distance between each of the satellite pockets and Gir, we spent a week in each month in each population and in Gir. The lions were tracked with the help of a hand held directional 3-element Yagi directional antennae with radio receivers (HABIT receiver model HR 2600, Telonics TR 2 receiver, and Vecronics GPS Plus Handheld Terminal Unit) (**Figure 8.1**). Attempts were made to locate at least one and when possible two animals on a daily basis. GPS fixes were recorded for locations of every lion. Lions were primarily located by homing in and direct sightings. Once activated, GPS and GPS-satellite collars provided 6-8 daily locations either via IRIDIUM (Iridium Communications Inc., McLean, VA, USA) two-way satellite network using low earth orbit satellites or via UHF (ultra high frequency) based ground download facility. The data from the GPS collars were downloaded at fixed intervals (generally once bi-weekly).

### **Monitoring individually known (non-collared) lions**

Additionally, we individually identified and monitored 15 lions (5 males and 10 females between approximate age of 2 to 13 years) between 2005 and 2011 across the Gir landscape based on their unique vibrissae patterns and additional body marks (Pennycuik and Rudnai 1970; Jhala et al. 1999) and by maintaining their individual profiles based on repeated sightings in a database program LION version 1.0 (Badoni et al. 2005). These lions were located by intensive search based on various cues (e.g. vocalization, direct/indirect signs, prey alarm call, kills and secondary information sources). Once located, the identity of the lion was confirmed from its vibrissae patterns and other permanent marks on its body (Pennycuick and Rudnai 1970; Jhala et al. 1999) and GPS fixes were recorded. Data from non-collared identified lions with number of GPS fixes exceeding the minimum required fix for home range calculation (*vide* sub-section on minimum sample size requirement in the data analysis section of this chapter for more details)



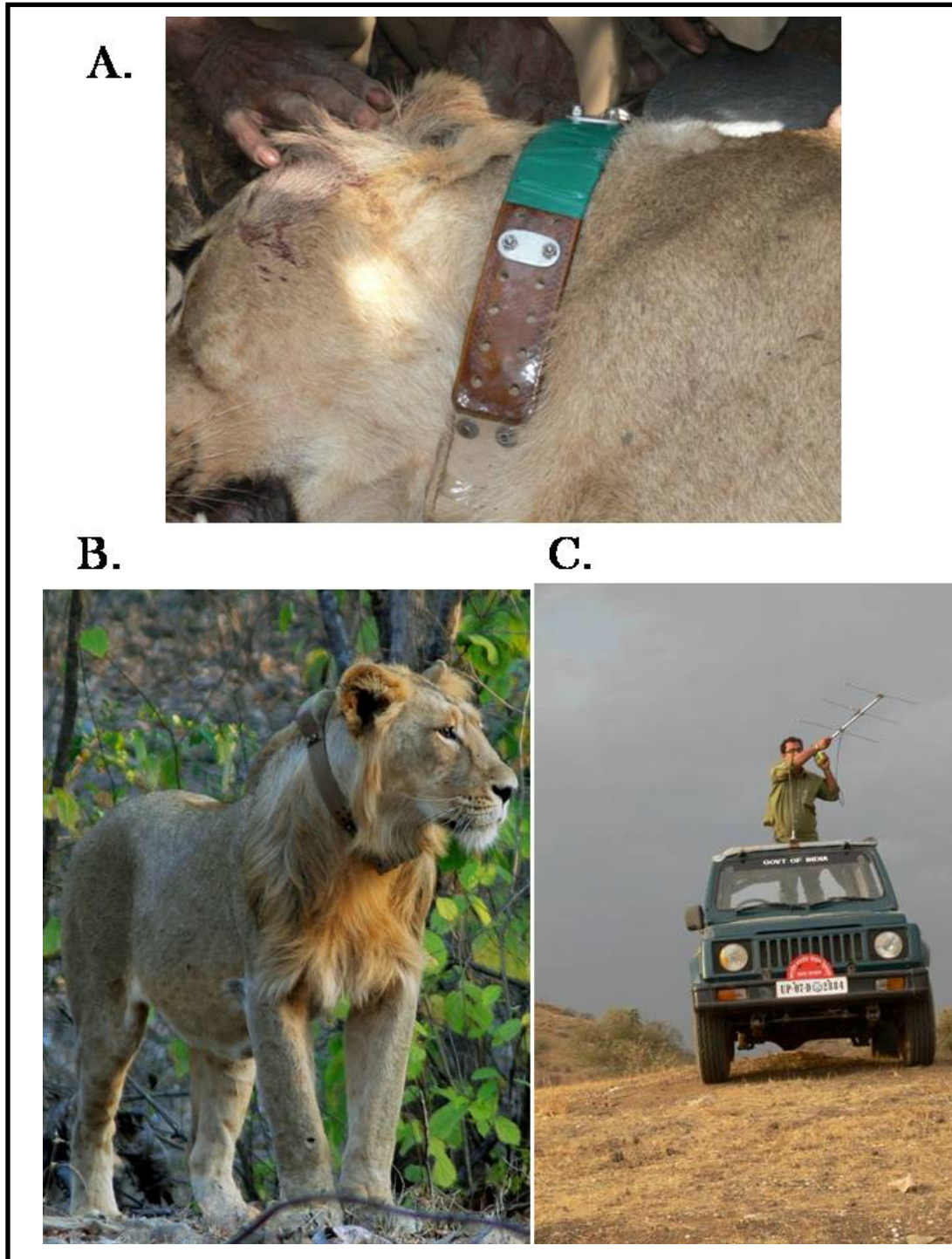
were used for analysis. These non-collared identified lions were regularly located across the landscape for quantifying population size, density, demographic parameters and for recording conflict and predation. Therefore, individually identified lions had a good opportunity of being sampled anywhere i.e. even outside their ‘normal’ home ranges. In the absence of radio-collars it was not possible to always know of the sudden occasional forays typical of lion movement pattern and we could not collect data in a predetermined sampling scheme from these lions. Nevertheless, an unbiased and fairly accurate representation of the ‘minimum range area’ was obtained.

### **Continuous monitoring**

We monitored each radio-collared lion continuously on foot and/or four-wheel drive for 30 sessions ranging from continuous 120 hours to 360 hours per session, seasonally. A total of 5,880 hours of monitoring data was analyzed to understand lion activity pattern and related ranging and movements. This methodology was similar to the all-occurrences sampling methodology (Altmann 1974) where specific animals were observed during 24- hour periods to record various ‘states’ and ‘events’. We defined a state (like moving, resting, sleeping, feeding, patrolling etc.) as any activity > 2 minute duration and measured them in time duration. We measured events (like urination, defecations, scent marking, roaring etc.) as frequencies. Although continuous monitoring was difficult to execute, it could be an efficient method to study feeding and consumption rates and behavior of large carnivores exhibiting a ‘starve-feed’ cycle of several days (Schaller 1972; Jethva and Jhala 2004). During this duration, we kept lions in view or within 100 m during the day and night. Lions were initially habituated for 1-3 days prior to data collection and care was taken not to disturb the ‘normal’ behavior of the lions. The observation teams were relayed so that everyone in the team got sufficient rest. We chose a continuous period of 10-12 days to incorporate ‘starve-feed’ cycle of large predators giving lions enough time to make/scavenge at least three major kills. We hoped to obtain data on at least two large kills and the associated behaviors and movement during this period, besides being able to get data on the smaller kills and be able to differentiate between predation, scavenging, and kleptoparasitism.



Figure 8.1: A. Lion radio collaring, B. A radio-collared male lion after revival from the anesthesia, C. Radio-tracking lions from a vehicle.





## **Data analysis**

### **Initial data screening and classification**

We use the term nocturnal and night to indicate the time span starting from sunset (18:00 hrs) and ending at sunrise (6:00 hrs), diurnal to indicate the time from sunrise (6:00 hrs) to sunset (18:00 hrs), and diel to indicate a 24 hour time span. We assumed that the lion ranging and movement will differ with differential distribution of water, prey and refuge before and after rainfall in the semi-arid Gir landscape. We, therefore defined two annual seasons based on precipitation and resource availability for lions as dry (October 16 – June 14) and wet (June 15 – October 15) [see climate, season and rainfall section of chapter 2 for more details].

### **Minimum Sample size requirement and effects of autocorrelation**

The minimum number of fixes required and whether or not it is necessary to avoid autocorrelation of fixes has been debated in the literature (Millspaugh and Marzluff 2001). Several authors have used field data and computer simulations to determine how home range estimators perform under varying sample sizes (Boulanger and White 1990; Worton 1995; Seaman and Powell 1996). Seaman and Powell (1996) suggested that to maximize the effectiveness of the kernel utilization distribution method, at least 100 fixes should be obtained, if possible. By contrast, Börger et al. (2006) recommended a minimum of 10 fixes per month. To determine if sufficient radio-locations were obtained to provide adequate representation of home range size, we examined 100% MCP home ranges of each radio-collared lion using area accumulation plot (also referred as incremental area analysis). Using this method, home range size was plotted against the number of locations used; with sample size regarded as adequate when the accumulation plot reached an asymptote (Harris et al. 1990; White and Garrot 1990; Kernohan et al. 2001). For 100% MCP sample size estimation, we randomized the locations and added 10 locations at every increment (Harris et al. 1990). We also computed the sample size adequacy for non-collared lions for estimating home range size.

The main debate related to the effects of autocorrelation on home range estimates is that autocorrelated observations yield less information than independent observations (Swihart and Slade 1985 a, b). When data are autocorrelated, the distance moved between consecutive observations decreases resulting in a lower proportion of the home range traversed. This causes an underestimation of home range size and movement rates. Most of the early literatures asserted independence of observations for an unbiased estimate of the Utilization Distribution (Worton



1987; Harris et al. 1990; White and Garrott 1990; Cresswell and Smith 1992; Kenward 1992). However, there is an unavoidable trade-off between sampling interval and sample size (Hansteen et al. 1997). As the time between locations becomes longer and data presumably become more useful for home range estimation, the number of locations that may be collected is inherently reduced. Since most of the telemetry studies are subject to fiscal and manpower constraints, an optimum combination of the number of animals (N) and the number of locations recorded per animal (n) should be conceived (Otis and White 1999). Eliminating autocorrelated fixes from the data set not only reduces the sample size, but may also limit the biological significance of the analysis (Reynolds and Laundre 1990). More recently it has been argued that in using only one fix per day, a great deal of biologically valuable information is lost (Börger et al. 2006). de Solla et al. (1999) emphasized that as long as the sampling remains systematic with the time interval between successive observations remaining relatively constant, autocorrelation should not reduce the validity of home range estimate. They further argued that with non-random fashion of movement of animals (Lair 1987), areas with autocorrelated observations are often associated with important resources (Weatherhead and Robertson 1990) and thus autocorrelated data are often required to sufficiently model animal movement and space use (Goodrich et al. 2010). In the current study along with home range estimates for lions, other ecological information like movement, feeding events and social behavior were inferred from the radio fixes. Therefore, we used all the GPS fixes from the GPS and satellite collars as they were recorded systematically at regular intervals causing no bias of higher or lower sampling by time on location. The sub-sampling was done only with the continuous monitoring dataset as spells of short interval locations gave higher weightage of space use (fixed kernels) during this period compared to other locations.

The average lion home range (100% MCP) size was 308 km<sup>2</sup> (**Table 8.2**). Diameter estimated after converting this into an equivalent sized circle was 19.8 km. Travelling with an average speed of 1.2 km/hr, it will take 16.5 hours by lions to traverse the entire home range from one end to other. We reanalyzed this after excluding all the lions outside the Gir PA and dispersing males within the Gir PA. The average home range size was estimated to be 63 km<sup>2</sup> and had a diameter of 8.9 km. Travelling with an average speed of 1.2 km/hr, it will take 7.9 hours by lions to traverse their entire home ranges within the Gir PA from one end to other. Considering locations either at 16.5 or 7.9 hour interval was impractical; as substantial numbers



of the study lions would have had deficient number of locations compelling their exclusion from the analysis, resulting in unrealistic values and loss of information. Therefore for our continuous monitoring dataset, we chose the fixed interval of three hours for diurnal fixes and two hours for the nocturnal locations for all subsequent analyses (de Solla et al. 1999).

### **Home range estimators**

We used two non-parametric home range estimators: (a) Minimum Convex Polygon (b) Fixed Kernel contour. A minimum Convex Polygon (MCP) home range is the area contained within the smallest possible convex polygon joining the outermost location of an animal movement (Mohr 1947). This is conceptually simple, easy to draw, reflects the exploratory behaviour of animals, most widely used comparable between studies (Worton 1987; White and Garrot 1990; Harris et al. 1990). The main disadvantages of the MCP method are that it is sensitive to the number of radio locations used (Anderson 1982), it provides no indication of the intensity with which an animal uses different parts of its range, and home range size is strongly influenced by the peripheral locations (van Winkle 1975; Powell 1987; White and Garrot 1990; Seaman 1993; Kernohan et al. 1998; Kenward et al. 2001). Herein, we present the 100% MCP for comparison with past studies. To remove the effect of exploratory movements, outlying fixes and indicate core areas of home ranges, we also computed the 95% MCP and 50% MCP home ranges for all lions.

Recent advances in home range modeling culminated in the use of contouring methods for estimating complex probability density distributions (Dixon and Chapman 1980; Worton 1989). Kernel density estimation (KDE) is widely viewed as the most reliable contouring method currently used in ecology (Powell 2000; Kernohan et al. 2001). KDE creates isopleths of intensity of home-range utilization (e.g. 95%) by calculating the mean influence of data points at a series of grid intersections. Two major subdivisions of the general kernel technique are the fixed and adaptive kernel methods (Worton 1989). With the fixed kernel method the same bandwidth is used over the entire evaluation area while with the adaptive kernel method a local bandwidth is selected for each observation (Kernohan et al. 2001). Despite the close relationship between fixed and adaptive kernel methods, the adaptive kernel estimators performed slightly worse than the fixed kernel estimators, apparently through overestimation of peripheral use (Seaman 1993; Seaman and Powell 1996; Seaman et al. 1999).



Therefore in the current study we also calculated lion home ranges using Fixed Kernels (FK) [also called Utilization Distribution, UD] methods. In the absence of any single home range estimator to every situation, the FK method has consistently performed when compared with other commonly used home range estimators (Worton 1995; Kernohan et al. 2001). This technique has also been applied in several studies reporting lion home range sizes from Africa and in Gir (Funston et al. 2003; Hemson et al. 2005; Lehmann et al. 2008; Jhala et al. 2009; Banerjee 2012).

The most important consideration when using the Kernel method is selecting an appropriate smoothing parameter  $h$ ; as under smoothing produces highly fragmented results that are difficult to interpret, while over smoothing removes important details to internal home range features (Worton 1989; Powell 2000). No single best method of choosing a bandwidth *a priori* exists (Worton 1989). Common approaches to selecting a fixed value of  $h$  are to use the reference bandwidth  $h_{ref}$  (derived from variance in the coordinates of fixes), or least squares cross validated (LSCV) multiplier of  $h_{ref}$  (Silverman 1986; Worton 1995). Least-squares cross-validation, however, tends to be especially sensitive to sample size (Seaman and Powell 1996). A compromise is to reduce the reference bandwidth to a fixed proportion (such as 0.70 or 0.80), thereby reducing over-smoothing (Bertrand et al. 1996; Kie and Boroski 1996; Kie et al. 2002; Osborne and Sua´rez-Seoane 2002). If the objective is to estimate a contiguous home-range boundary, it is possible to reduce the reference bandwidth just prior to the point where that estimate starts to fragment into multiple polygons (Berger and Gese 2007; Jacques et al. 2009). In this study, for choosing the smoothing parameter; we used fixed kernel by increasing the proportion of the generated smoothing parameters (starting at  $0.1 \times h_{ref}$  and then increased at 0.1 increments) until a single polygon home range (subjectivity by eye) was evident (Kie et al. 2010; Rodgers and Kie 2010). Thus, the reference bandwidth was reduced to a fixed proportion of 0.60 in the current study for fixed kernel estimates.

We used Home Range Tools (HRT; Rodgers and Kie 2010) in ARCGIS 9.3 (ESRI, Redlands, CA: Environmental Systems Research Institute, USA) to calculate annual, diurnal, nocturnal and seasonal MCP and Fixed Kernel home ranges. Data from continuous monitoring on radio-collared lions and GPS fixes obtained from satellite/GPS collars at fixed intervals were analyzed to arrive at diurnal and nocturnal range use patterns. One-way ANOVA and t-tests were used to test the significance of differences in home range sizes between time of the day, seasons



and gender (Zar 2010). Lions have been observed to venture inside villages at night. Therefore we did not exclude village areas from the home range calculation. However, townships with a human population of over 50,000 were subtracted from the analysis using habitat masking operation available in the GIS package.

### **Lion Core area estimation**

Core has been defined as particular areas of an animal's home range which are more important than others. A core is therefore used more heavily than the apparent clumps of heavy use that occur from uniform random use of space within a home range and may not be strictly determined by home range area (Powell 2000). Most definitions of cores have been ad hoc or subjective. Many define the core as the smallest area with an arbitrary probability of use (e.g. 89% of authors defined a core area by the 50% KDE isopleths; Laver and Kelly 2008). Given that different processes underlie space use patterns for different individuals and species, it is probably not valid to assume that an arbitrary rule will adequately define a core area. Rather, methods used to delineate animal space use patterns should have logic (Samuel et al. 1985). We used fixed kernel home ranges with isopleths at 5% increments from 5% to 100% (Powell 2000). We created area/probability curves by plotting the home range area within each isopleth as a function of the isopleth. Area/probability curves are typically concave, indicating clustered use of space (Bingham and Noon 1997; Seaman and Powell 1990; Burdett et al. 2007). The point at which inflection of line (slope) changed was identified as the core area (Powell 2000).

### **Lion land tenure system**

We monitored seven adult males and three sub-adult males (including non-collared lions) for studying territorial shift and dispersal. We defined a territorial shift when the male was never located in the previous (or natal for sub-adults) area. We calculated tenure duration for territorial males and average estimated age at dispersal from natal pride for the sub-adult males. Average territorial shift and average dispersal were calculated as distance shift between the location centroids (centroid to centroid) of the successive range areas.

### **Quantifying lion territoriality**

Home ranges of conspecifics often overlap, sometimes extensively. Subsets of a population may exhibit different patterns of simultaneous use. Relatives, for example, may use their areas of overlap more than expected from random use, whereas nonrelatives may avoid each other and use areas of overlap less than expected. For large carnivores, territory defense is difficult or



impossible to document but patterns of home range overlap can be documented (Mech 1970; Nicholson et al. 2011). Such patterns of overlap can often be used to deduce territorial behavior (Powell 2000).

In the current study, we define pride members based on social interactions among different individuals. Lions; sharing kills, playing, allogrooming and being comfortable with each other and their cubs were considered to be of the same pride/group. Home range overlap was calculated only for contemporaneous lions having adjacent home ranges (95% MCP and core area) overlapped in time and space. Percent overlap between adjacent home ranges was computed as the average proportion of overlap between two home ranges (Mizutani and Jewell 1998; Kernohan et al. 2001; Jhala et al. 2009).

### **Lion movement**

Distance moved between two successive locations (separated by 3 hours) were estimated by using Home Range Tool in ArcGIS 9.3 (Rodgers and Kie 2010). For distance calculations, the same dataset (continuous monitoring of radio collared lions and fixes downloaded from GPS/IRIDIUM collars) was used as for the calculations for home range and no data reduction was needed. For each day, the distances between subsequent GPS fixes were added up to calculate daily travelled distance. We calculated average travel distances, average travel time and speed of movement for nocturnal (6 PM – 6 AM), diurnal (6 AM – 6 PM) and diel (24 hrs) periods for both males and females and compared between genders, periods of the day and landscape part.

### **Lion activity pattern**

We used 5,880 hours of day and night continuous monitoring (30 sessions ranging from 120 hours to 360 hours) data on 20 radio-collared lions to understand lion time budget pattern. All-occurrence behaviour states (any mutually exclusive activity continuing for more than 2 minutes) and events (**Table 8.1**) of lions were recorded. The time of the day was divided into eight periods of three hours each and proportional time spent in different activities was calculated for each period. We also calculated the percentage of time spent by lions in different activities. The circular statistics software for Windows, Program Oriana version 3.0 (Andersen et al. 2000) was used to compute mean (95% CI) peak time for different activities. Comparisons were made among different lion demography classes and across seasons (dry and wet). We performed Rayleigh's uniformity test and Rao's spacing test (Mardia and Jupp 2000) to calculate the



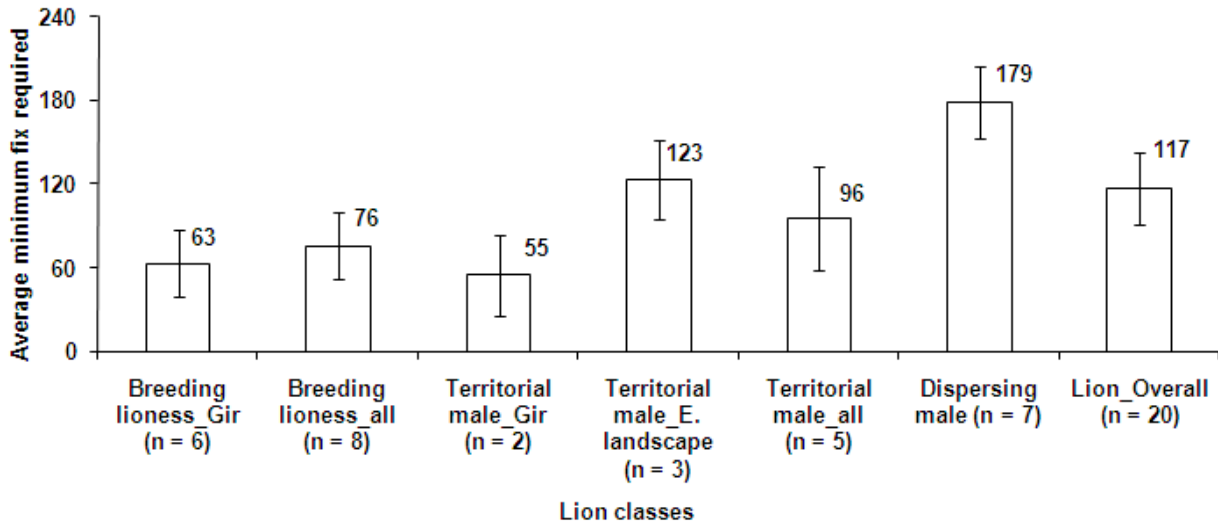
probability of the null hypothesis that the data is uniformly distributed across time intervals. A probability less than 0.05 indicated that the data showed a preferred time period.

## Results

### Sample Size Adequacy for Home Range Analysis

The plots of 100% MCP ranges versus sample sizes stabilized for all lions. The home ranges of individual lions reached asymptote at different sample size (**Figure 8.2**) reflecting greater exploratory movements and tenure shifts of male lions. Overall lion home range size asymptotes were reached in 117 (95% CI 91 – 143; range: 20 - 220) fixes. In the Gir PA, territorial males and breeding females required the same sample sizes (one tailed  $t = 0.34$ ,  $df = 6$ ,  $p = 0.37$ ). Overall, males and females (all life history stages) required similar sample size (one tailed  $t = 0.92$ ,  $df = 11$ ,  $p = 0.20$ ). Dispersing males required larger sample sizes than breeding females (one tailed  $t = 5.68$ ,  $df = 13$ ,  $p < 0.001$ ) and territorial males (one tailed  $t = 3.69$ ,  $df = 10$ ,  $p = 0.004$ ). Territorial males in the eastern landscape also required larger sample sizes than territorial males in Gir to reach an asymptote (one tailed  $t = 3.12$ ,  $df = 3$ ,  $p = 0.02$ ).

**Figure 8.2: Average minimum number of fixes required for adequacy of home range (100% MCP) analysis of different demography classes of Asiatic lions. Error bars are 95% CIs; n = sample sizes for different lion classes.**





**Table 8.1: Definition of different key activities (ethogram) used in the study for calculating time budget pattern in Gir lions (modified after Schaller 1972; Bertram 1978).**

Behaviour states and events	Definition
<b>States</b>	
Moving	Displacing between locations mostly in search of a prey. Travelling in an irregular line or loosely scattered with the cubs trailing behind or occasionally running beside and around the adults. Lions during movement are with relaxed open-mouth faces and are mostly silent except for occasional hum.
Patrolling	Mostly moving with alert face and with territorial advertisements like roaring, spray marking by urination, tree clawing etc.
Resting	Sitting or lying in a usual relaxed posture with the head pointing downwards, the ears at a medium angle and the mouth either loosely closed or lower jaw drooping. The standard resting posture was ‘Tail-end Lying Front Sphinxed’ (Bertram 1978) with both hind legs lying on one side of the body but the front end resting symmetrically on elbows and forearms. Head may be held up (alert) or drooping (relaxed). The commonest lying posture is flat on one side with flank, head and legs resting limply on ground.
Feeding	Includes feeding on carcass (predated or scavenged) assessed either by direct observation or by hearing sound of crushing and chewing bones. Also includes drinking by lapping as in domestic cats. It was difficult to ascertain how often lions drank as they could easily go to water briefly my being aware of it. But generally in Africa, lions drink twice; once in the morning (8 AM – 8:30 AM) and late night (10 PM – 11 PM) when water was readily available (Schaller 1972). I remained especially alert during this time to see if lions drank or not.
Hunting	Predating and includes stalking walk, crouching walk and crouching with alert face and body held rigid; either lying, sitting or moving.
Mating	Includes sniffing vulva, mounting, courtship and copulation.
<b>Events</b>	
Roaring	A vocalization with slightly raised muzzles and relaxed eyes and ears and includes woofing, grunting, soft and loud roaring.
Spraying	Stopping at intervals while walking by vegetation and rubbing faces in it and thereafter swiveling around with the tail raised and followed by ejecting fluid from caudally directed penis (Schaller 1972).
Scraping	Raking the ground with hind paws after hunching the back slightly and lowering the rump.
Tree clawing	Squatting or standing on hindfeet, hooking the claws into the bark and pulling them down slowly.



## Lion home ranges

A mean of 398 (SE 124) locations (range 64 – 2,776 from  $n = 13$  collared and 15 non-collared identified lions) was used in each home range analysis (**Table 8.2**). Since non-collared lion ranges were likely underestimated, we checked for biases by comparing them with telemetered lions in the same gender/stage class. The average home range (95% FK) size of overall (all gender and life history stages) collared and non-collared lions were similar (one tailed  $t = 1.70$ ,  $df = 34$ ,  $p = 0.49$ ). Collared and non-collared breeding females had equal range sizes in the Gir PA (one tailed  $t = 2.09$ ,  $df = 10$ ,  $p = 0.15$ ) and in the eastern landscape (one tailed  $t = 1.49$ ,  $df = 4$ ,  $p = 0.18$ ) and thus were pooled together for estimating home range sizes. Within the Gir PA, non-collared territorial males had similar range size [95% FK home range size: 106 (95% CI 66 – 147)  $\text{km}^2$ ] with that of radio-collared territorial male ( $n = 1$ ; 95% FK home range: 95  $\text{km}^2$ ) and pooled together to estimate home range size. However territorial collared males in the eastern landscape had higher ranges than non-collared territorial males (one tailed  $t = 7.28$ ,  $df = 2$ ,  $p = 0.01$ ) and thus ranges of non-collared territorial males in the eastern landscape were used to understand the ‘minimum home range area’. We did not have any non collared lions in Girnar, non-collared dispersing males in Gir PA and eastern landscape for home range analysis.

In the Gir PA, territorial males had 2.5 times larger range (average 103  $\text{km}^2$ ) than breeding females (average 40  $\text{km}^2$ ; one tailed  $t = 3.66$ ,  $df = 12$ ,  $p = 0.006$ ) while dispersing males had 10 times larger range (average 401  $\text{km}^2$ ) than breeding females (one tailed  $t = 5.71$ ,  $df = 11$ ,  $p < 0.001$ ; **Figure 8.3**). In the eastern landscape the minimum home range size (95% FK) of territorial males [333 (SE 40)  $\text{km}^2$ ] was about 2 times larger than that of breeding females [193 (SE 92)  $\text{km}^2$ ] (one tailed  $t = 8.05$ ,  $df = 5$ ,  $p = 0.005$ ). Dispersing males had higher home ranges in comparison to the territorial males in the Gir PA (one tailed  $t = 3.22$ ,  $df = 5$ ,  $p = 0.02$ ) but smaller home ranges compared to the territorial males in the eastern landscape (one tailed  $t = 2.29$ ,  $df = 3$ ,  $p = 0.05$ ). Breeding lionesses within the PAs (Gir and Girnar) had smaller ranges than lionesses of the eastern landscape (one tailed  $t = 1.85$ ,  $df = 14$ ,  $p = 0.04$ ). Territorial males in the eastern landscape were long ranging compared to the territorial males in the Gir PA (one tailed  $t = 15.57$ ,  $df = 4$ ,  $p < 0.001$ ).

The average single day home range (95% FK) size [10.4 (SE 3.2)  $\text{km}^2$ ] was almost 3.5 times smaller than the average single night range sizes [36.2 (SE 12.4)  $\text{km}^2$ ] ( $t = 2.36$ ,  $df = 13$ ,  $p$



= 0.03; **Table 8.3**). Territorial males had larger night range sizes compared to day range sizes (**Table 8.3**) while breeding females and dispersing males had similar day and night ranges.

Gir lions had similar dry season [325.6 (SE 110.8) km<sup>2</sup>] and wet season [255.3 (SE 76.6) km<sup>2</sup>] home ranges ( $t = 0.97$ ,  $df = 12$ ,  $p = 0.34$ ; **Table 8.4**). In Gir PA, lion range size during wet season was found to be higher than that of dry season ( $p = 0.45$ ) while in Girnar and the eastern landscape, dry season home range sizes were higher compared to wet season ranges (**Table 8.4**). Overall male lions had higher dry season ( $t = 2.74$ ,  $df = 11$ ,  $p = 0.01$ ) and wet season home ranges ( $t = 3.11$ ,  $df = 11$ ,  $p = 0.009$ ) in comparison to the breeding females.

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**Table 8.2: Estimated annual home ranges (km<sup>2</sup>) of Asiatic lions in Gir landscape, India. MCP = minimum convex polygon, FK = fixed kernel.**

Lion ID	Collared/Non collared	Demography Class	Part of the landscape	Collaring/ start of monitoring	Date of last tracking/ monitoring	100% MCP	95% MCP	50% MCP	95% FK	85% FK	Number of fixes (n)	Fate
M1	Collared	Young Adult Male_Dispersing	Eastern landscape	January 2010	March 2010	374	121	69	195	108	386	Dead
M2		Prime Adult Male_Dispersing	Gir PA	December 2005	January 2009	410	375	32	355	214	183	Dead
M3		Old Adult Male_Dispersing	Eastern landscape	March 2008	May 2010	1,626	1,349	210	866	469	1,216	Dead
M4		Prime Adult Male_Territorial	Eastern landscape	June 2008	November 2009	907	875	119	991	558	168	Dead
M5		Young Adult Male_Territorial	Girnar	January 2009	June 2010	243	219	63	222	138	337	Collar stopped working, currently alive
M6		Sub-adult Male_Dispersing	Gir PA	January 2010	September 2011	940	537	148	638	333	2,776	Collar stopped working, currently alive
M7		Prime Adult Male_Territorial	Gir PA	January 2006	February 2012	74	70	7	95	51	140	Dead
M10		Sub-adult Male_Dispersing	Gir PA	January 2006	October 2011	380	350	29	211	120	382	Collar stopped working, currently alive
M11		Young Adult Male_Dispersing	Girnar	January 2011	January 2012	1,126	342	100	270	191	2,362	Collar stopped working, currently alive
M12		Prime Adult Male_Territorial	Eastern landscape	March 2008	January 2011	1,817	790	22	1,182	488	230	Collar stopped working, fate unknown
F2		Prime Adult Female	Girnar	June 2008	November 2011	137	119	19	132	84	166	Collar stopped working, currently alive
F5		Prime Adult Female	Eastern landscape	September 2008	August 2011	417	312	128	377	216	153	Collar stopped working, currently alive
F11		Young Adult Female	Girnar	January 2010	March 2012	203	144	127	217	153	180	Collar stopped working, currently alive

**Table 5.2 continued**



M8	<b>Non-collared, individually identified</b>	Prime Adult Male Territorial	Gir PA	January 2006	August 2011	118	98	35	123	117	90	Still alive
M9		Prime Adult Male Territorial	Gir PA	January 2006	December 2010	56	44	5	65	42	80	Dead
M13		Prime Adult Male Territorial	Eastern landscape	December 2009	September 2011	550	274	126	293	157	257	Still alive
M14		Prime Adult Male Territorial	Eastern landscape	May 2008	October 2011	404	253	94	372	134	242	Still alive
M15		Young Adult Male Territorial	Gir PA	March 2006	September 2011	91	80	22	131	88	78	Still alive
F1		Prime Adult Female	Eastern landscape	October 2008	September 2011	53	40	6	88	58	68	Still alive
F3		Prime Adult Female	Gir PA	February 2006	July 2009	31	16	2	26	17	71	Unknown
F7		Prime Adult Female	Gir PA	April 2006	February 2010	124	115	41	122	81	477	Dead
F8		Sub-adult Female	Gir PA	May 2007	January 2011	317	279	107	343	179	554	Unknown
F9		Old Adult Female	Gir PA	February 2007	March 2010	68	54	15	93	65	66	Dead
F12		Prime Adult Female	Eastern landscape	March 2008	September 2011	16	8	5	7	6	97	Still alive
F14		Prime Adult Female	Gir PA	January 2007	February 2012	70	52	12	59	53	112	Still alive
F15		Prime Adult Female	Gir PA	November 2006	May 2010	136	85	27	142	89	89	Dead
F17		Prime Adult Female	Eastern landscape	April 2008	June 2010	73	70	2	114	72	64	Unknown
F18		Prime Adult Female	Gir PA	January 2007	April 2011	46	31	10	32	30	128	Still alive



**Table 8.3: Diurnal (single day) and nocturnal (single night) home range sizes of Asiatic lions in Gir landscape, Gujarat, India. n = sample sizes of different lion demography classes used for analysis. Figures within parentheses are standard errors.**

Lion demography class	Diurnal home range (km <sup>2</sup> )		n (diurnal)	Nocturnal home range (km <sup>2</sup> )		n (nocturnal)	Significance (* = significant)
	95 FK	85 FK		95 FK	85 FK		
Breeding lioness	9 (5)	6 (3)	8 lionesses, 79 days	22 (12)	17 (10)	8 lionesses, 70 nights	t = 1.93, df = 7, p = 0.09
Territorial males	17 (2)	13 (1)	3 lions, 50 days	100 (37)	65 (24)	3 lions, 61 nights	t = 19.01, df = 1, p = 0.03*
Dispersing males	10 (3)	7 (2)	5 lions, 443 days	40 (26)	26 (17)	5 lions, 505 days	t = 1.37, df = 4, p = 0.23
Overall lion	10 (3)	7 (2)	16 lions, 572 days	36 (12)	26 (9)	16 lions, 636 nights	t = 2.36, df = 13, p = 0.03*



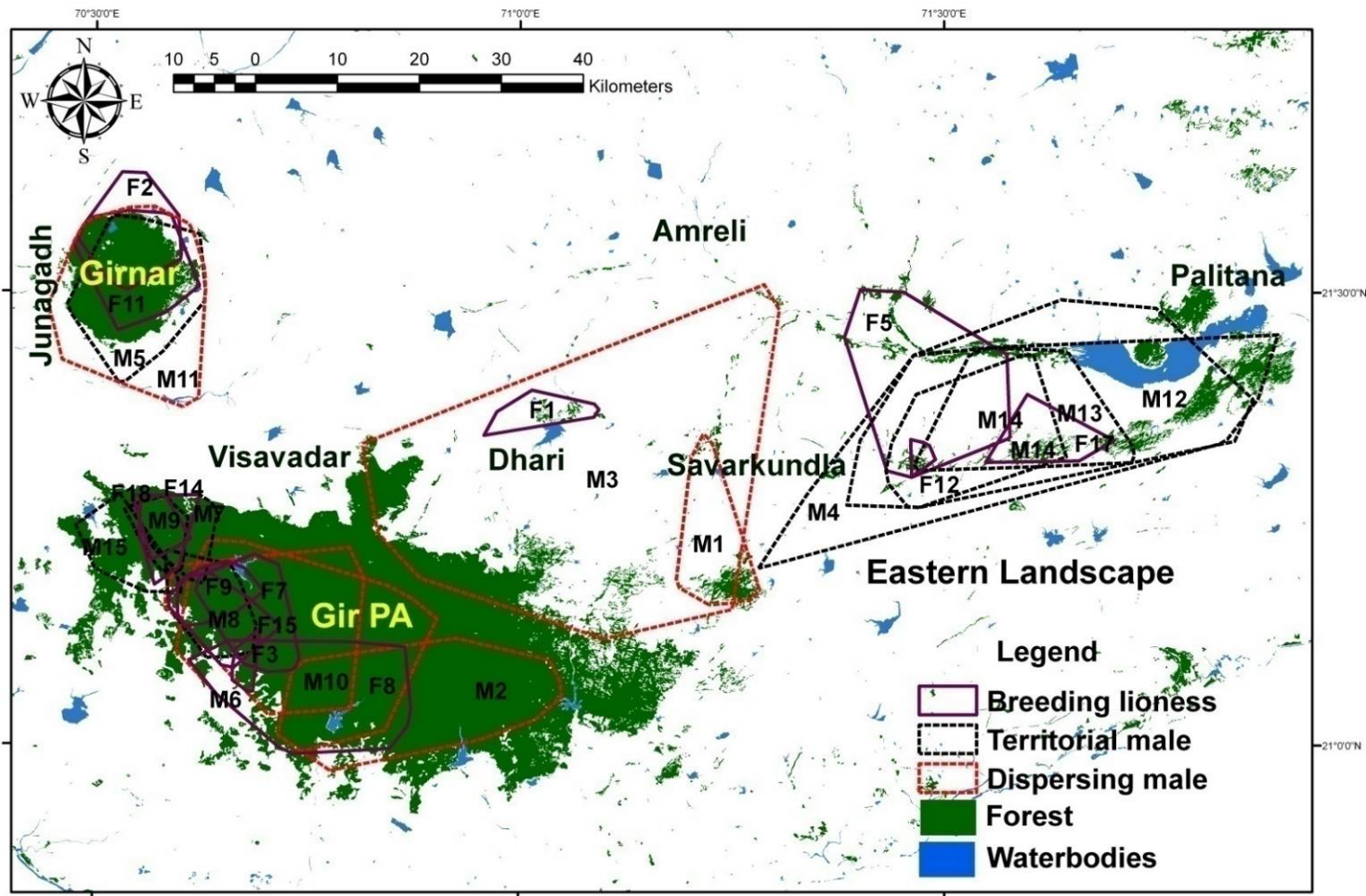
**Table 8.4: Seasonal home range sizes (km<sup>2</sup>) of Asiatic lions in Gir landscape, Gujarat, India. Lion IDs are same as in Table 8.2. Figures within parentheses are standard errors.**

Lion ID	Part of the Landscape	Dry season (16 October – 14 June)			Wet season (15 June – 15 October)			* = significant
		100 MCP	95 FK	85 FK	100 MCP	95 FK	85 FK	
M3	Eastern landscape	696	612	389	881	678	643	--
M4	Eastern landscape	851	1,392	931	523	480	287	--
M5	Girnar	243	224	138	98	181	123	--
F2	Girnar	130	151	102	59	68	44	--
F11	Girnar	204	207	143	26	83	54	--
F5	Eastern landscape	170	267	232	169	326	302	--
M6	Gir PA	599	378	338	314	410	365	--
M7	Gir PA	54	79	70	68	101	92	--
M12	Eastern landscape	1,690	798	720	1,226	861	783	--
<b>Average</b>	<b>Overall</b>	<b>368 (135)</b>	<b>326 (111)</b>	<b>244 (80)</b>	<b>267 (107)</b>	<b>255 (78)</b>	<b>216 (70)</b>	<b>t = 0.97, df = 12, p = 0.34</b>
<b>Average</b>	<b>Gir PA</b>	<b>133 (94)</b>	<b>97 (58)</b>	<b>85 (52)</b>	<b>82 (47)</b>	<b>107 (62)</b>	<b>95 (55)</b>	<b>t = 0.82, df = 5, p = 0.45</b>
<b>Average</b>	<b>Girnar</b>	<b>192 (33)</b>	<b>194 (22)</b>	<b>128 (13)</b>	<b>61 (21)</b>	<b>111 (36)</b>	<b>74 (25)</b>	<b>t = 3.51, df = 2, p = 0.07</b>
<b>Average</b>	<b>Eastern landscape</b>	<b>852 (315)</b>	<b>767 (236)</b>	<b>568 (158)</b>	<b>700 (228)</b>	<b>586 (117)</b>	<b>504 (124)</b>	<b>t = 0.74, df = 3, p = 0.51</b>
<b>Average</b>	<b>Male lion</b>	<b>689 (234)</b>	<b>580 (194)</b>	<b>431 (137)</b>	<b>519 (187)</b>	<b>452 (118)</b>	<b>382 (114)</b>	<b>t = 0.81, df = 5, p = 0.45</b>
<b>Average</b>	<b>Breeding lioness</b>	<b>92 (29)</b>	<b>107 (39)</b>	<b>83 (32)</b>	<b>52 (20)</b>	<b>87 (41)</b>	<b>73 (39)</b>	<b>t = 0.79, df = 6, p = 0.45</b>

\*Based on 95% FK kernel seasonal range sizes



Figure 8.3: 95% MCP home ranges (km<sup>2</sup>) of Asiatic lions (n = 28) across the agro-pastoral Gir landscape, Gujarat, India.

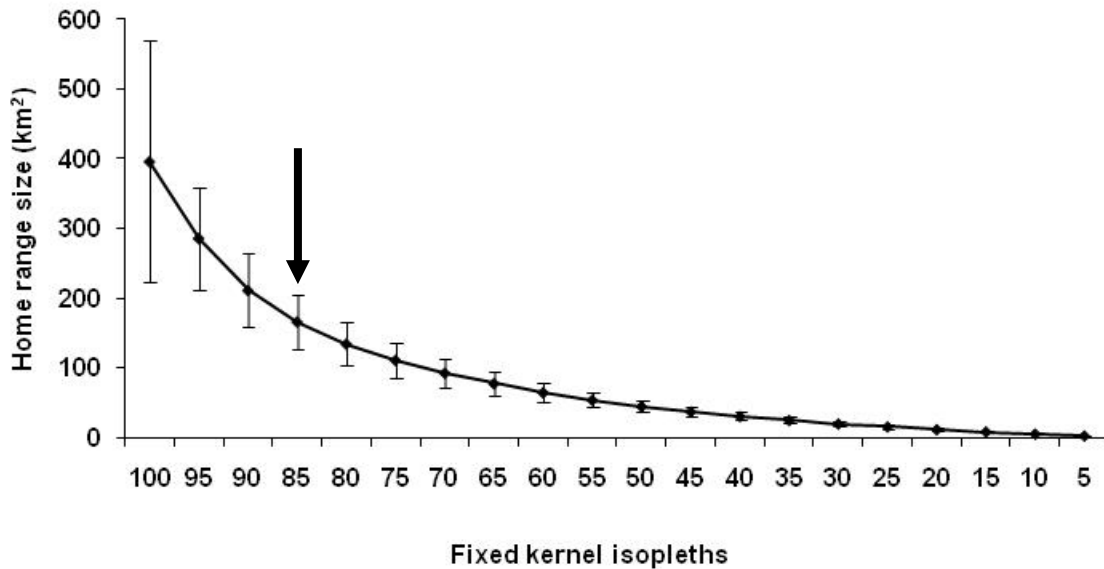




### Core area estimation

The point of inflexion in the home range size vs. Fixed Kernel isopleths graph suggests that at 85% FK the home range reduction was less in comparison to the changes in the isopleths and beyond it the increase was rapid (**Figure 8.4**). Hence 85% fixed kernel was chosen to estimate lion core areas.

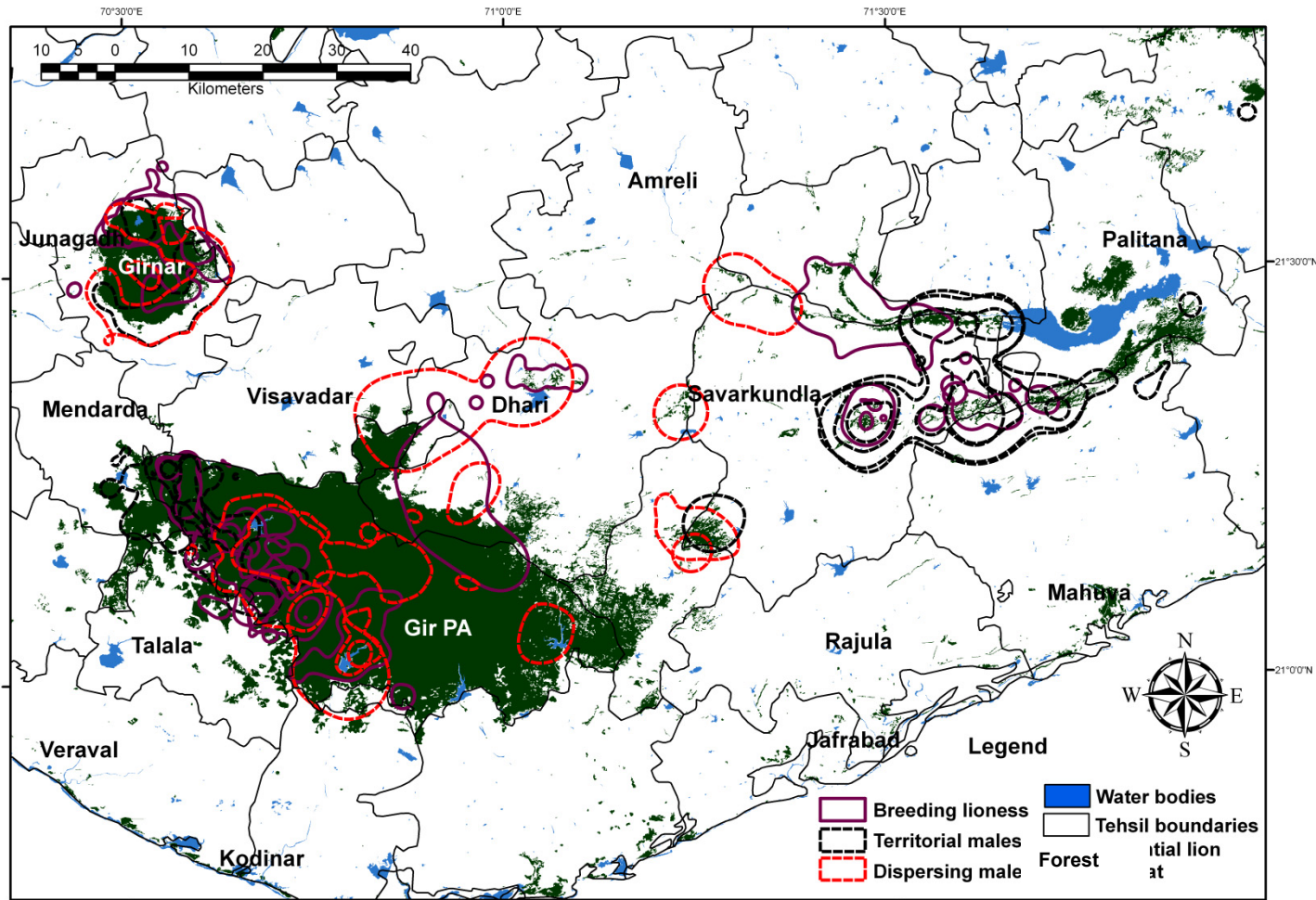
**Figure 8.4:** Area/Probability curve estimating core areas of lions in Gir landscape, Gujarat, India. Arrow depicts inflection point of curve and depicting core area (85% isopleths) as area of uniform use among lions.



The average (SE) core area of Gir lions was estimated to be 166 (40) km<sup>2</sup> (**Figure 8.5, Table 8.2**). Average male core area [214 (SE 43)] was higher than average breeding female core area [85 (SE 17)] (one tailed  $t = 2.62$ ,  $df = 26$ ,  $p = 0.01$ ). Average core area of territorial males within protected areas (Gir and Girnar) [87 (SE 18)] km<sup>2</sup> was smaller in comparison to that of the eastern landscape [334 (SE 110)] km<sup>2</sup> (one tailed  $t = 2.49$ ,  $df = 7$ ,  $p = 0.04$ ). Average core area of breeding females in the eastern landscape [88 (SE 45)] km<sup>2</sup> was found to be larger than average core area of breeding females within the protected areas [60 (SE 28)] km<sup>2</sup> (one tailed  $t = 0.79$ ,  $df = 9$ ,  $p = 0.44$ ).



Figure 8.5: Core areas (km<sup>2</sup>) 85% fixed kernels of Asiatic lions in the Gir landscape, Gujarat, India.





Average diurnal core area of lions [7 (SE 2) km<sup>2</sup>] was lower than average nocturnal core [26 (SE 9) km<sup>2</sup>] ( $t = 2.4$ ,  $df = 14$ ,  $p = 0.03$ ) [**Table 8.3**]. There was no effect of time on core area size for breeding females, territorial males and dispersing males (diurnal core:  $F = 0.60$ ,  $df = 14$ ,  $p = 0.56$ ; nocturnal core:  $F = 2.12$ ,  $df = 15$ ,  $p = 0.15$ ). Breeding lionesses within protected areas (Gir and Girnar) had a significantly smaller diurnal [2.4 (95% CI 1.2 – 3.5) km<sup>2</sup>] and nocturnal [6.9 (95% CI 3.1 – 10.7) km<sup>2</sup>] core areas than lionesses of the eastern landscape [ $n = 1$ , diurnal 30 km<sup>2</sup> and nocturnal 89 km<sup>2</sup>]. Dispersing males in the eastern landscape had smaller diurnal cores in comparison to nocturnal cores ( $t = 23$ ,  $df = 2$ ,  $p = 0.02$ ; **Table 8.3**).

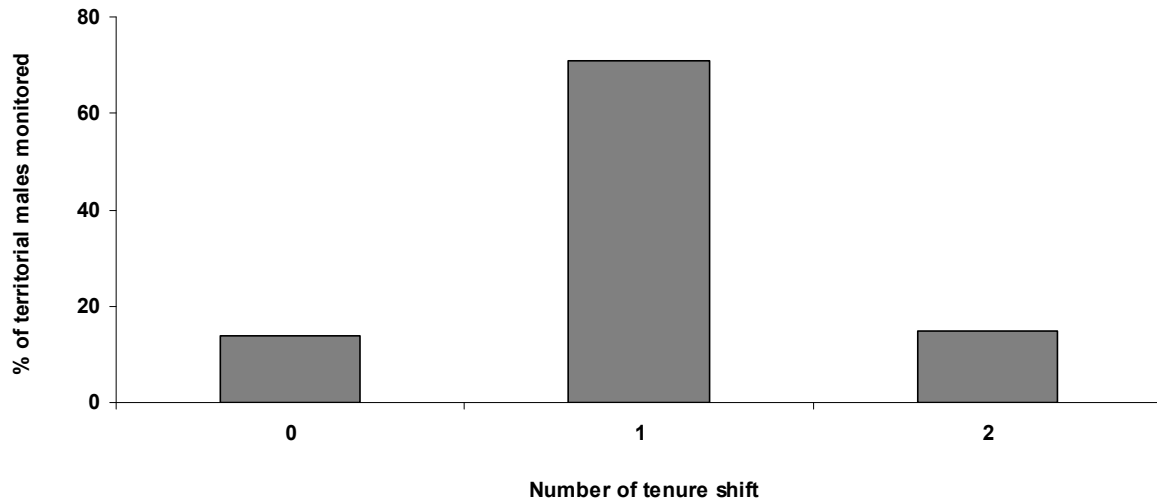
We did not find any seasonal difference in lions' average core area ( $t = 0.50$ ,  $df = 13$ ,  $p = 0.60$ ; **Table 8.4**). Dry season ( $t = 4.18$ ,  $df = 11$ ,  $p = 0.002$ ) and wet season ( $t = 4.31$ ,  $df = 11$ ,  $p = 0.001$ ) core area of lions within protected areas were larger than that of eastern landscape lions. Dry ( $t = 2.48$ ,  $df = 11$ ,  $p = 0.003$ ) and wet season ( $t = 2.57$ ,  $df = 11$ ,  $p = 0.02$ ) core areas of male lions were significantly larger than those of breeding lionesses.

### **Lion land tenure system**

Among the territorial males of the Gir landscape monitored during my study period, tenure shift was recorded for once in 71% ( $n = 5$ ) of the territorial males and for twice in 15% ( $n = 1$ ) of territorial males (**Figure 8.6**). One male (M14) did not shift his territory even once during the monitoring period of 56 months. Average land tenure duration of male Asiatic lion was estimated to be of 36 (range: 18 - 60) months (**Table 8.5**). Territorial lions of the Gir PA had a longer tenure [39 (range: 23- 60) months] than lions of the eastern landscape [33 (range: 18 - 56) months] (one tailed  $t = 0.58$ ,  $df = 12$ ,  $p = 0.24$ ). Average distance of tenure shift of male Asiatic lion was estimated to be 21 (SE 5) km and was higher for lions in the eastern landscape [31 (SE 8) km] than lions within the Gir PA [12 (SE 4) km] (one tailed  $t = 2.35$ ,  $df = 6$ ,  $p = 0.03$ ).



**Figure 8.6: Distribution of observed tenure shift in territorial male Asiatic lions (n = 7) between 2006 and 2012**



Average estimated age of sub adult males (n = 6) at dispersal was 3.9 (SE 0.13) years. Average dispersal distance of sub-adult males was estimated to be 16 (SE 4) km (**Table 8.6**). Average age of territory acquisition was estimated to be 4.3 (SE 0.16) years.



**Table 8.5: Land tenure duration and distances between successive territories of adult male Asiatic lions.**

Male ID	Part of the landscape	Tenure I duration (months)	Distance (km) between Tenure I & Tenure II	Minimum number of Cubs successfully sired to sub-adult stage	Tenure II duration (months)	Distance (km) between Tenure II & Tenure III	Minimum number of Cubs successfully sired to sub-adult stage	Tenure III duration (months)	Minimum number of Cubs successfully sired to sub-adult stage
M2	Gir PA	23	22.8	3	30	--	4	--	--
M3	Eastern landscape	29	40.4	0	14**	--	5**	--	--
M7	Gir PA	44	7.5	5	10***	9.2	--	60	12
M8	Gir PA	29	8.3	3	48	--	10	--	--
M12	Eastern landscape	43	44.1	4	24	--	0****	--	--
M13	Eastern landscape	29	27.1	2	18	30.5	4	7*****	--
M14	Eastern landscape	56	--	5	--	--	--	--	--

\*\*M3 was a nomad during his tenure I and later became a territorial male mating with lionesses in Ambardi. However, he died due to old age within 14 months and so number of cubs indicates only the juveniles. Tenure II duration has not been included for the calculation of average land tenure duration. \*\*\*M7 had a range expansion during tenure II when he continued to be with the same group of lionesses of his tenure I for 10 months. This has not been included for the analysis of land tenure duration. \*\*\*\*M12 became a nomad during his tenure II after losing a territorial strife with M13 and losing his coalition partner and could not further breed with lionesses until he died after 24 months. \*\*\*\*\*M13's second tenure shift happened recently (January 2012) and therefore data could not be collected on his further social status.



**Table 8.6: Dispersal age and dispersal distance of sub-adult male Asiatic lions in the Gir landscape, India.**

Male ID	Part of landscape	Age (year) at dispersal	Dispersal distance (km)	Age (year) of 1 <sup>st</sup> reproduction
M5	Girnar	3.7	9.9	4
M6	Gir PA	4	25.7	4.5
M10	Gir PA	4.2	12.3	4.5

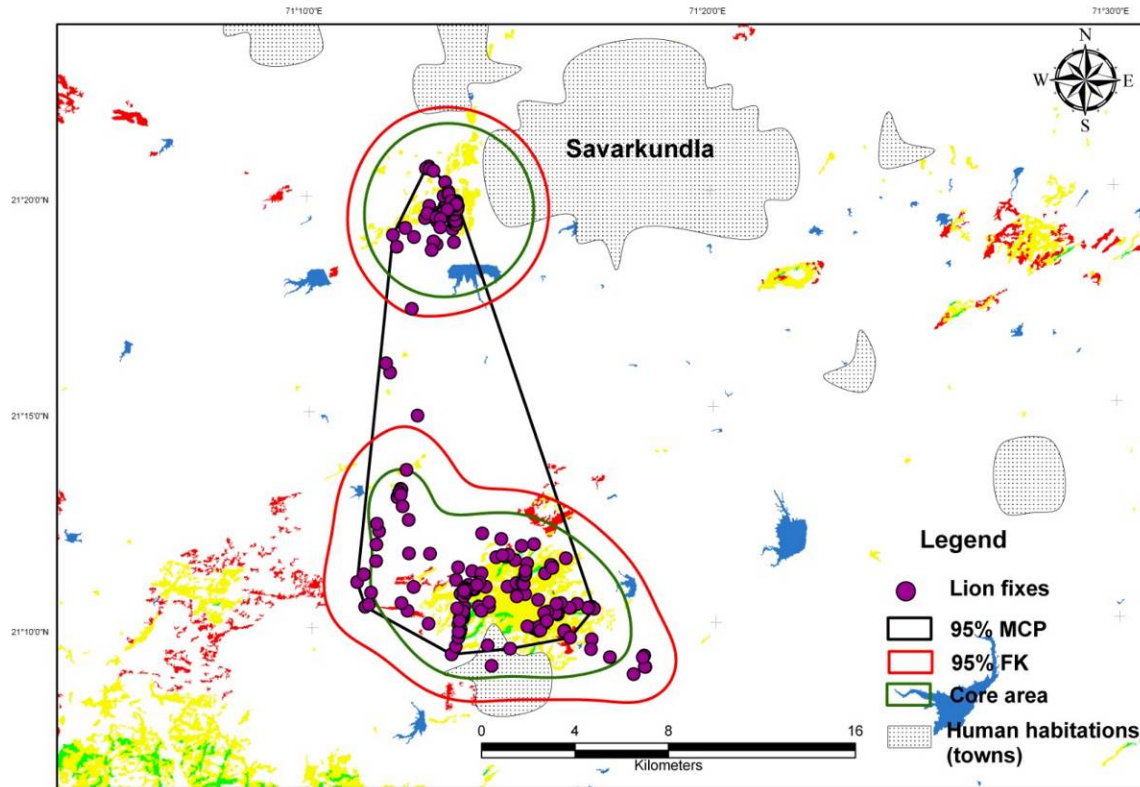
Herein, we discuss the ranging and land tenure system of some of the radio-collared and intensively monitored (non-collared) lions.

### **Male ranging and land tenure system**

**M1:** This was a young adult male about 5 years old in the eastern landscape. The male was fitted with a satellite collar with IRIDIUM uplink on 7<sup>th</sup> January 2010 in the Ambardi Reserve forest, Dhari. The male mostly ranged in the Ambardi Reserve Forest, Mitiyala Wildlife Sanctuary and *Prosopis* dominated agro-pastoral areas and mango orchards of Dhari, Chalala, Khambha, and Savarkundla (**Figure 8.7**). The male was part of a three male coalition. The range size (95%FK) of the male was estimated to be 374 km<sup>2</sup> (**Table 8.2**) and showed range overlap with other radio-collared lions of the region. The male sustained a severe injury on his face and leg in March 2010 due to territorial fight with other two males of another coalition and was taken to Sakkarbaug Zoo, Junagadh for treatment but succumbed to his injuries on 23<sup>rd</sup> March, 2010.



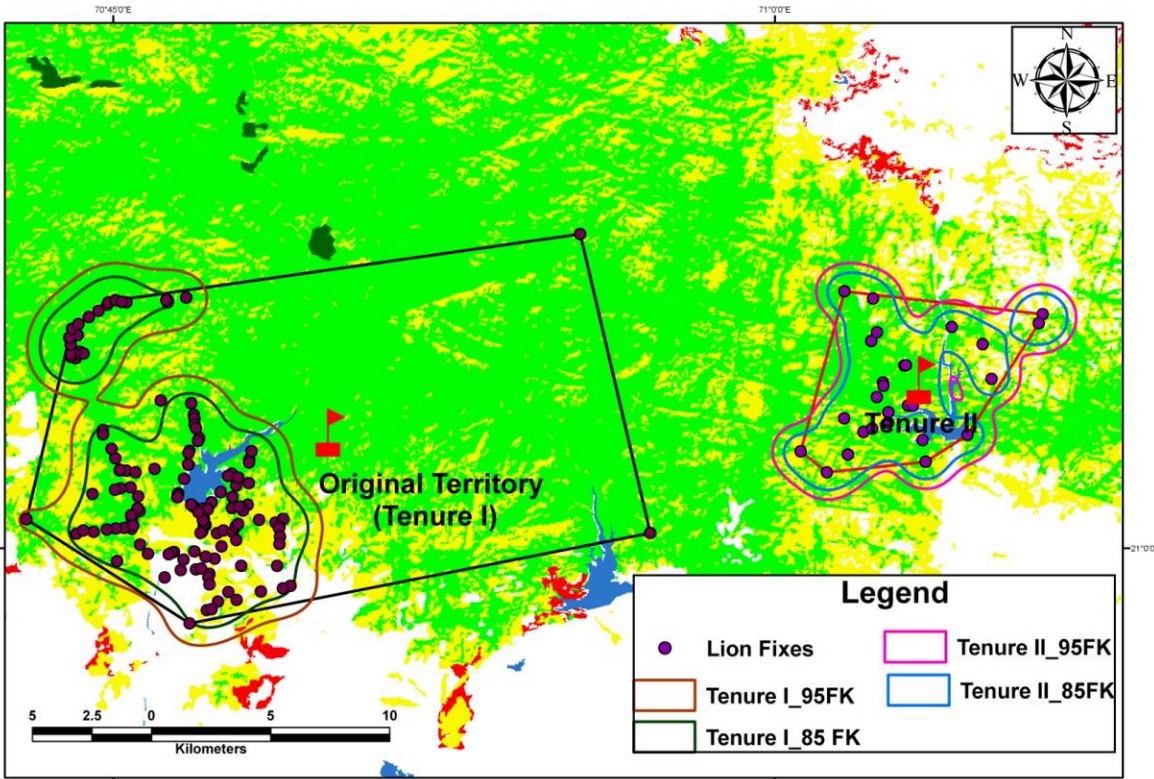
**Figure 8.7: Ranging pattern of radio-collared male M1. Extent of major human habitations demarcated by using night light satellite data.**



**M2:** M2 male was a part of a two male (prime adult, approximate age 7 years) coalitions radio-collared (VHF) in the central part of the Gir PA in December 2005. The male coalition ranged mostly in the Gir National Park areas of Kankai, Jamvala, Bantha, Banej, Janvadla and Chhodavadi and occasionally ranged in the southern peripheral villages of the Gir PA (Bamnasa, Javantri, Ghatvad, Thordi, Bakha and Babaria) and was found to sire at least three cubs to sub-adulthood. In June 2006 the coalition male went missing and M2 started nomadic movement. In April 2007 the male permanently dispersed to the eastern part of the Gir sanctuary and roamed mostly in and Tulsishyam and Jasadhar areas. It often ranged in the revenue areas of Khambha and Dhokadwa (**Figure 8.8**). After spending few months of nomadic life, M2 further dispersed to the north-eastern part of the sanctuary (Hadala, Bankajambu) and once again became territorial. On one occasion the male was even observed to share a kill with three other males. During his tenure II, M2 sired at least four cubs successfully to sub-adulthood near Bhimchas, Hadala part. The male died of old age in winter 2009 (**Table 8.5**).



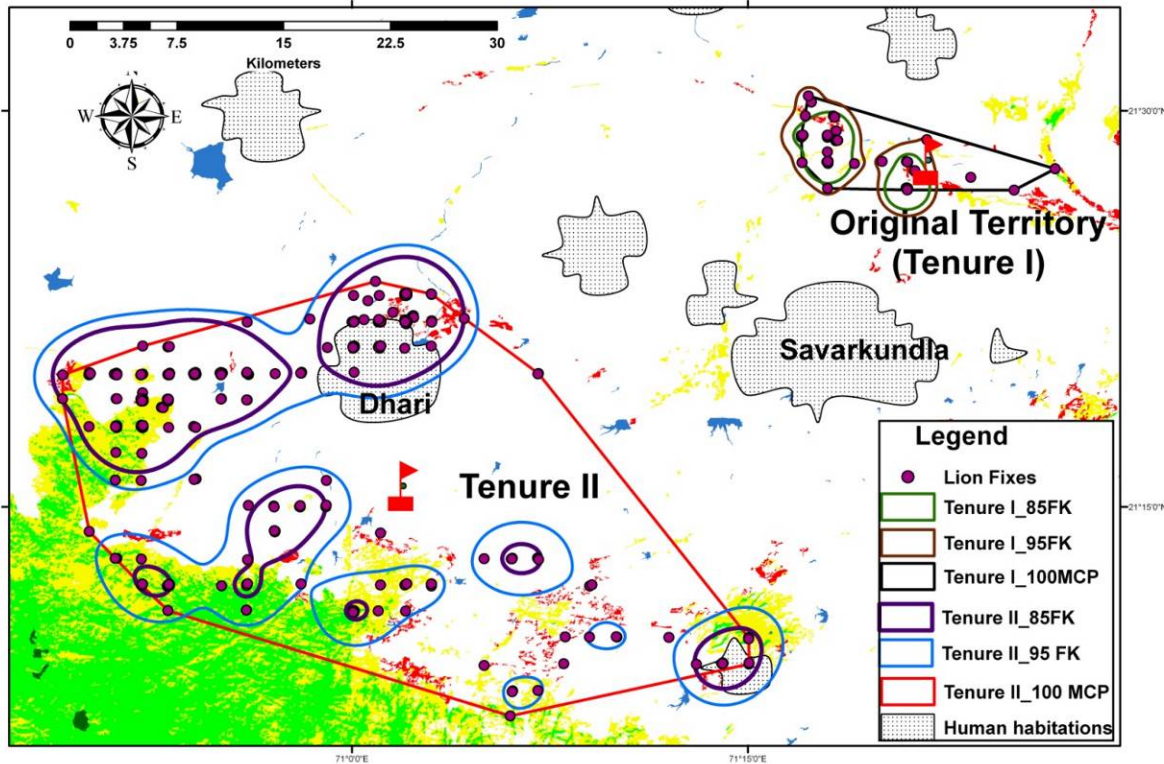
Figure 8.8: Tenure shift of prime adult male M2 in the Gir PA, India. Tenure centroids shown by flags.



**M3:** This male was an old adult male (approximately 11 years old) fitted with a combination of GPS/VHF radio collar on 27<sup>th</sup> March 2008 in the outskirts of village Chandgadh, Amreli. The male was long ranging (**Table 8.2, Figure 8.9**) with regular movement to the Gir PA. The male ranged in the human-dominated landscape of Amreli, Savarkundla, Chalala, Khambha, Dhari and Visavadar. The landscape was characterized by farmlands, human settlements, industry, mining and government wastelands. The male after dispersing to Dhari and Visvadar (Tenure II) became territorial as he settled down with Ambardi pride, mated and gave birth to cubs. The male was seen with five cubs regularly during 2009-2010 (**Table 8.5**). The collar failed in August 2009 and the male died due to old age in May 2010 at the Jasadhar Animal Rescue Centre when the cubs were juveniles and all surviving.



**Figure 8.9: Tenure shift of old adult male M3 in the eastern landscape. Tenure centroids shown by flags. Extent of major human habitations demarcated by night lights.**



**M4, M12 and M14:** These males were part of a three male coalition in the eastern landscape. M12 was the first lion to be radio collared (GPS/VHF combination) outside the Gir PA on 24<sup>th</sup> March, 2008. He was a prime adult territorial male (approximately 8 years old) which was collared at Ranigalo Reserve *vidi* near Nangarla *Gaushala* (cattle camp for ill and feral livestock), Jesar, Mahuva. The GPS collar failed within a month due to some technical fault but the VHF worked for 2.25 years. The coalition partner (M4), a prime adult male (approximately 8 years old) was fitted with VHF collar in June 2008 near Dholikui Forest Quarter, Jesar. He succumbed to his injuries in November 2009 that resulted from a territorial strife with two adult males (M13 and his partner). M14 was a non-collared prime adult male (approximately 7 years old) whom we monitored for four years on the basis of vibrissae pattern. These males had large territories ranging from Mitiyala to Palitana along the private and government owned grasslands and revenue village lands of Khambha, Savarkundla, Palitana, Mahuva and Gariadhar talukas of Amreli and Bhavnagar districts (**Table 8.2, Figure 8.10**). M4 and M12 stayed together for most of the time and had 64% overlap of their range and 100% overlap of their core areas. M14 on the



other hand ranged mostly in the Nani Vadal *vidi* near Savarkundla. M4 and M12 successfully sired four cubs to sub-adulthood while M14 successfully sired five cubs to sub-adulthood. After losing his coalition partner M4, M12 dispersed from Ranigalo-Dholikui Reserve Forest further north-east in the revenue landscapes of Bagdana and Talaja and finally to the areas of Sihor and Songadh (**Figure 8.11**). We lost contact with M12 in February 2011. However, M14 continued to range in the Nani Vadal area for quite sometime.

**Figure 8.10: Ranging of coalition males M4, M12 and M14 across the human-dominated eastern landscape. Human habitations demarcated by using night light satellite data.**

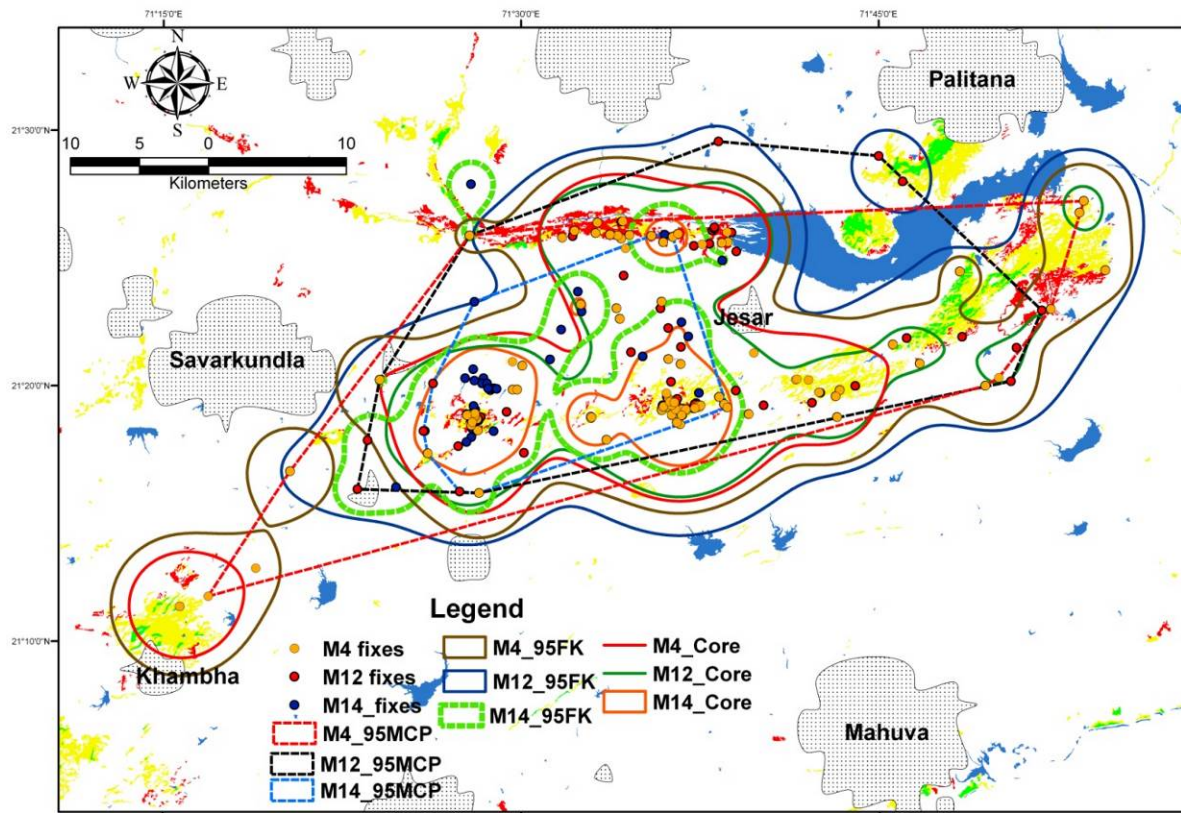
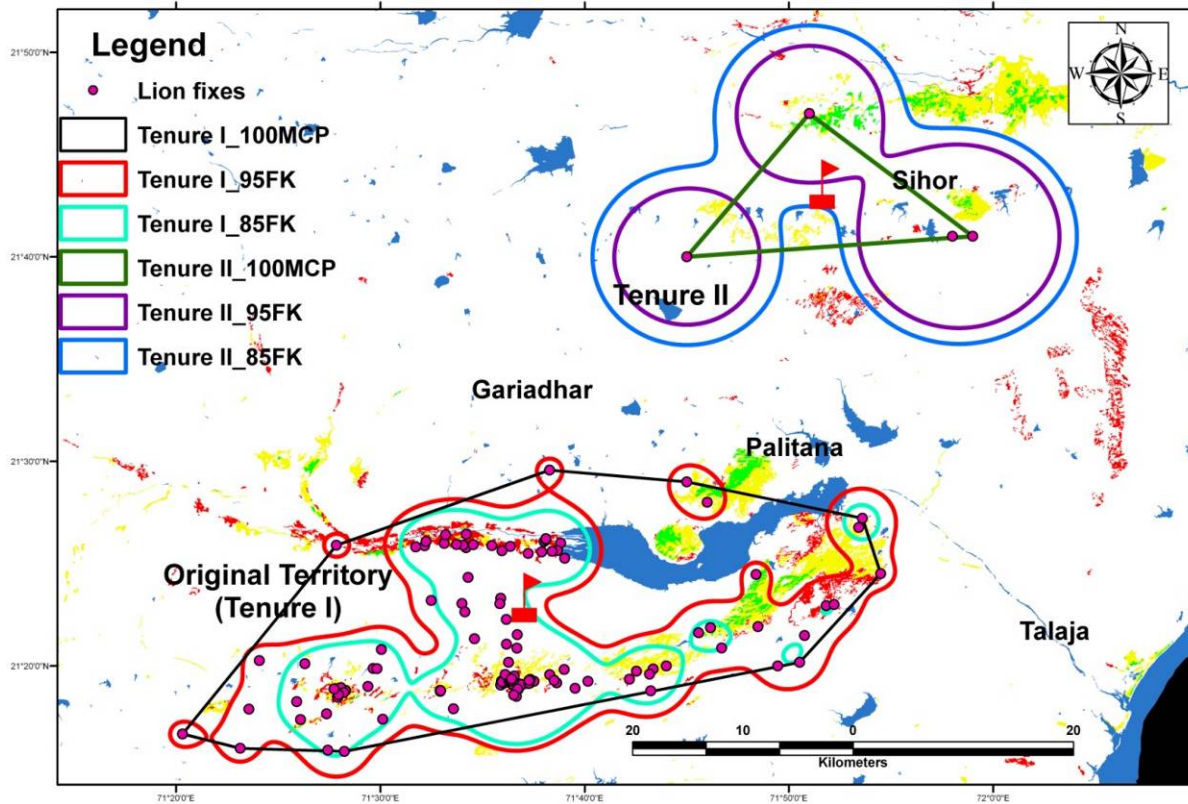




Figure 8.11: Tenure shift of prime adult male M12 in the eastern landscape. Tenure centroids shown by flags.



**M5:** M5 was a sub adult male (approximately 3.5 years old) fitted with GPS/VHF collar in the Girnar Wildlife Sanctuary on 3<sup>rd</sup> January 2009. GPS transmitter failed within a week and VHF monitoring of the male was done till January 2012. The male mostly ranged inside the Girnar Wildlife Sanctuary. It dispersed from his natal group soon after the collaring and along with the coalition partner (M11) established territory in the south-eastern part of the sanctuary (**Figure 8.12**). The dispersal distance was estimated to be 10 km (**Table 8.6**). The male often ventured into the revenue areas of Junagadh, Visavdar, Bhesan and Mendarda talukas.

**M6:** M6 was the part of a sub-adult male (approximately 4 years old) coalition of two males and fitted with a GPS/VHF radio-collar in January 2010 near Kamleshwar dam, western part of the Gir sanctuary. During collaring, the male was with his natal pride (one prime adult female, one sub-adult male and one sub-adult female). The prime adult lioness (supposed to be his mother)



died because of infection of wounds on 12<sup>th</sup> February, 2010. Before her death, the group mostly ranged in the National Park area of the Gir PA but later the movement of the group became nomadic and mostly restricted to the central Gir (Kankai, Rampari, Bantha, Umadvidi, Chhodavadi, Dabhala and Banej). The male was last seen with the sub-adult female in May 2010. On 15<sup>th</sup> June, 2010 the male showed a nomadic movement to south (revenue areas of Talala taluka) of the Gir PA and further east and reached Pachpachia village of Khambha taluka on 19<sup>th</sup> June, 2010 (**Figure 8.13**). M6 and his coalition partners dispersed about 26 km from their natal territory and established new territory in central and eastern Gir (**Figure 8.14**). The collar stopped working in August 2010. However occasional monitoring of the male was continued until January 2012.

**Figure 8.12: Tenure shift of young adult male M5 in Girnar. Tenure centroids shown by flags.**

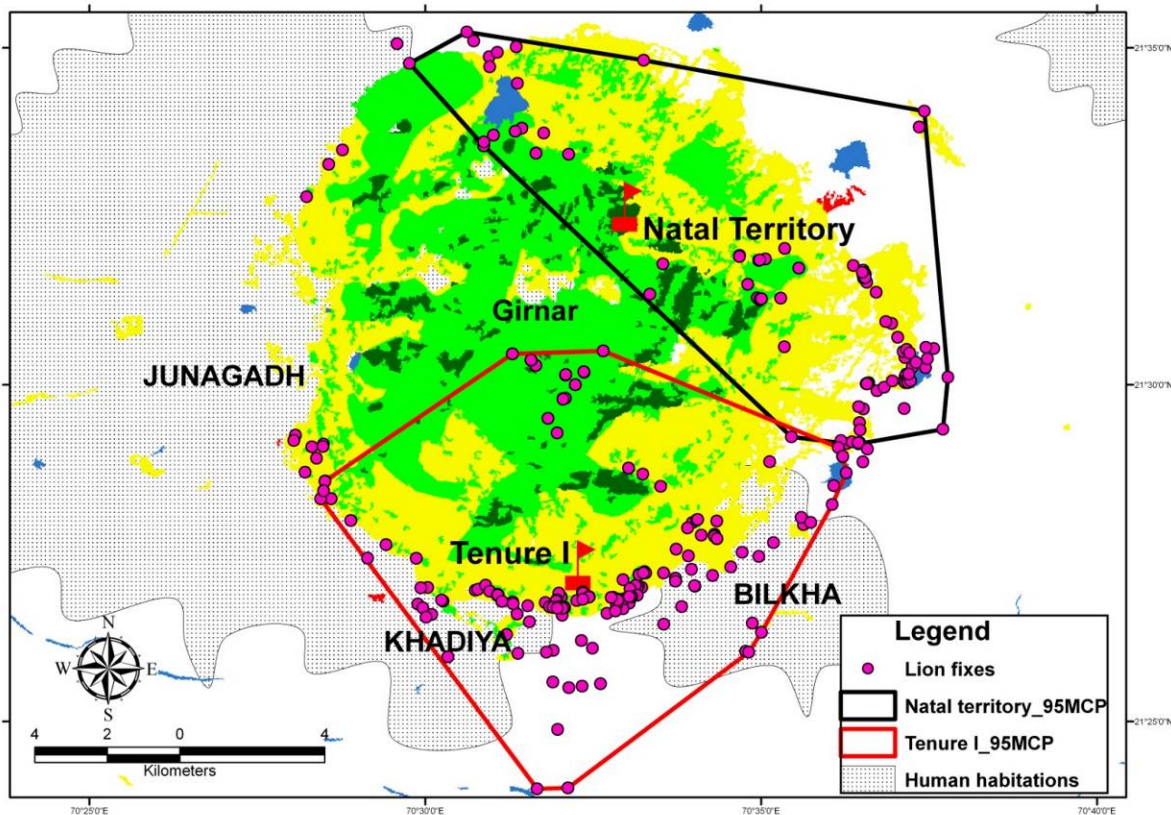




Figure 8.13: Range use and dispersal of M6 within the Gir PA, India.

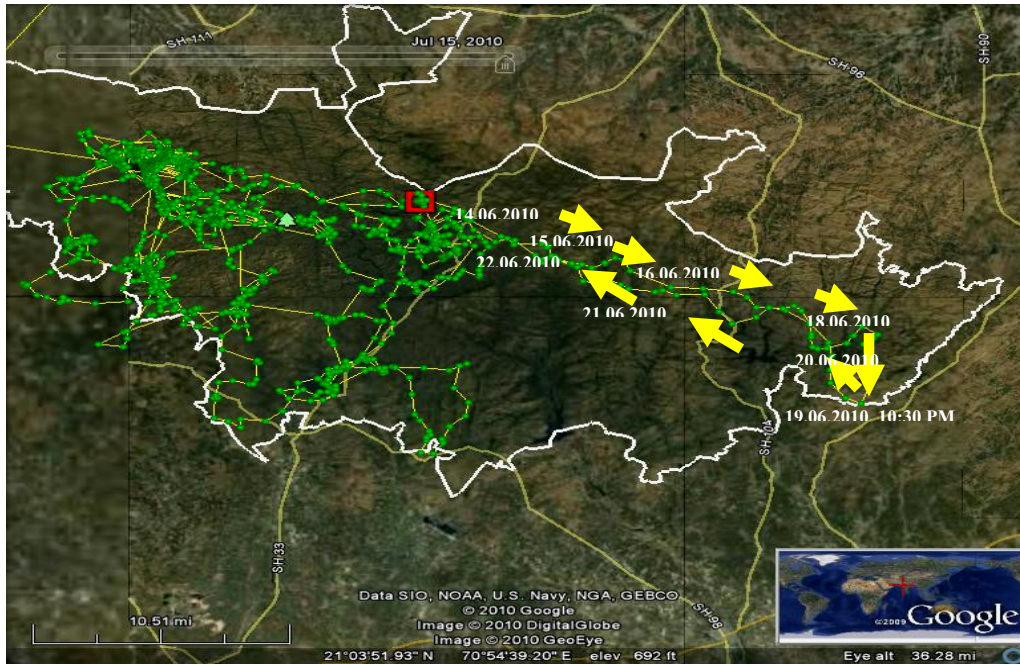
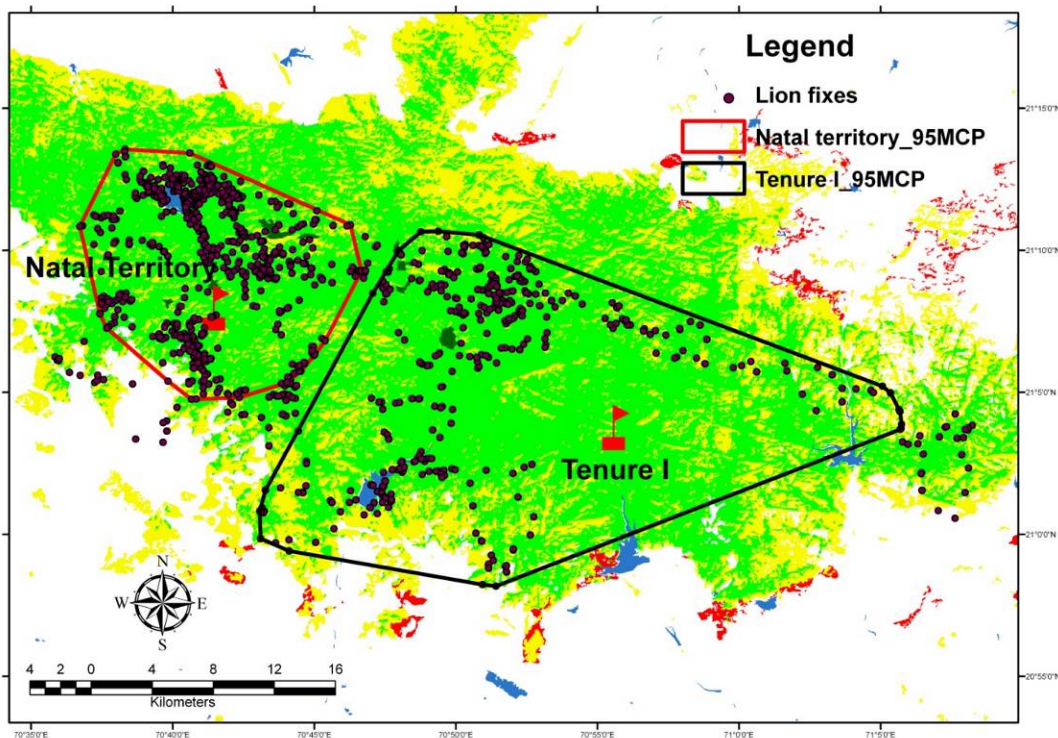


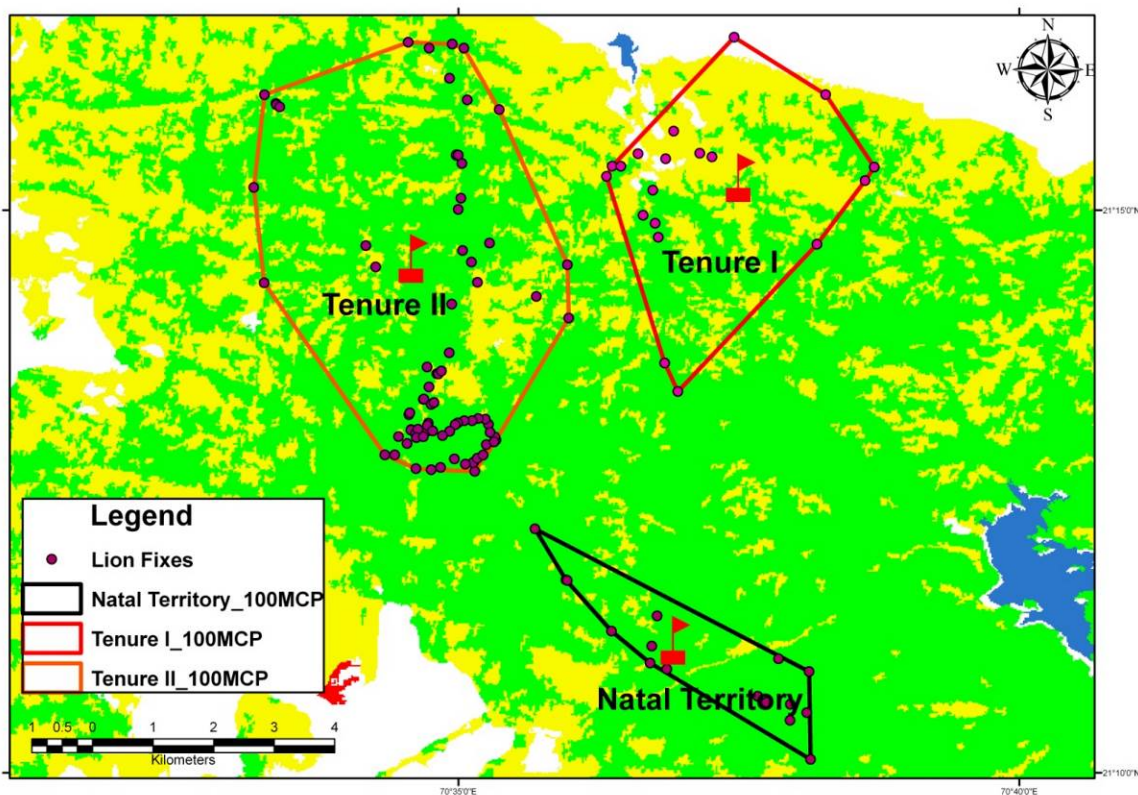
Figure 8.14: Dispersal of sub-adult male M6 in Gir PA. Tenure centroids shown by flags.





**M7:** M7 and his coalition partner had a natal territory near Kamleshwar dam of the western part of the Gir sanctuary. The male was fitted with a VHF radio in January 2006. We monitored the male until the male died because of old age in June 2012. Immediately after the collaring the male shifted 7.5 km north and established his territory near Barwania and Kashia parts. In January 2007 the male shifted his territory about 9 km west in the tourism zone of the Gir forest (Raidi, Dudhala, Kherambha, Dedakadi; **Figure 8.15**). The coalition held this territory continuously for a period of more than five years (**Table 8.5**).

**Figure 8.15: Tenure shift of prime adult male M7 in Gir PA. Tenure centroids shown by flags.**

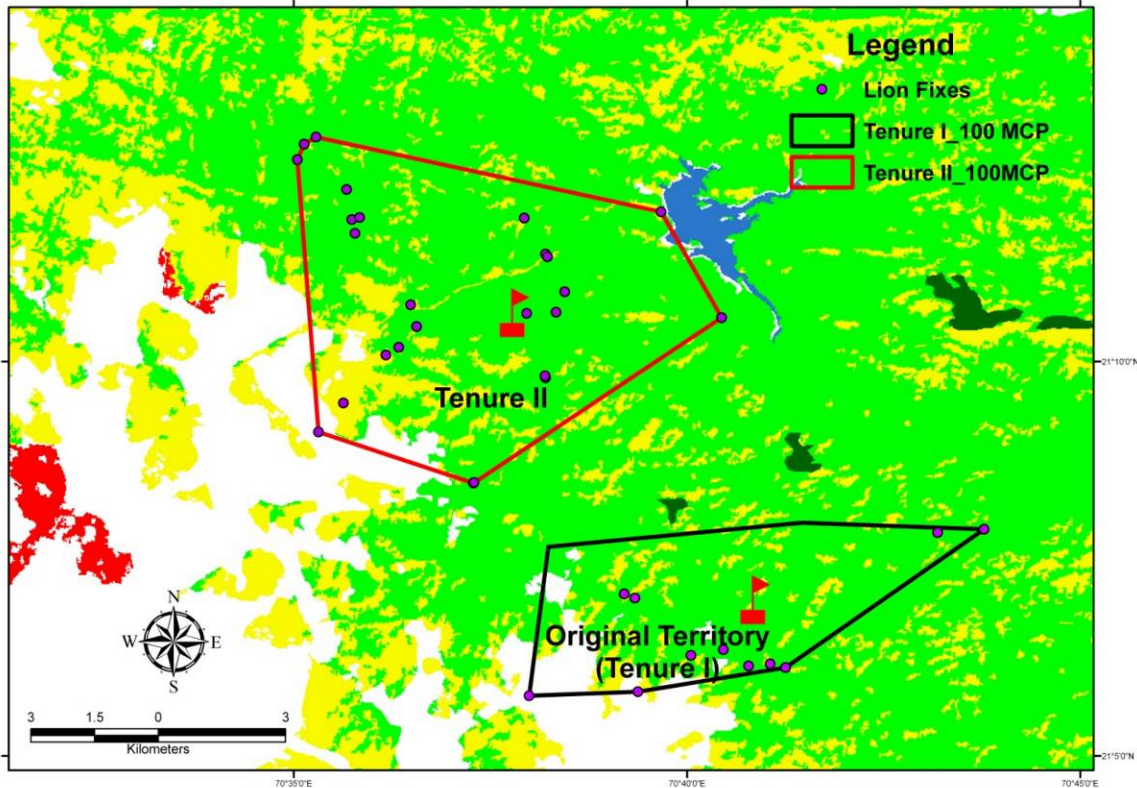


**M8:** We have been monitoring this non-collared prime adult male (about 6 years old) since January 2006 on the basis of vibrissae pattern. The male had a coalition partner which died in 2005. The male had an earlier territory (Tenure I) in the south-western part of the Gir PA (Sirwan, Kapuria, Khokhra). In December 2007 the male had a territorial strife and shifted his



territory 8 km west (near Sasan, Kamleshwar and Amla hill parts; **Figure 8.16**) and still holds the tenure.

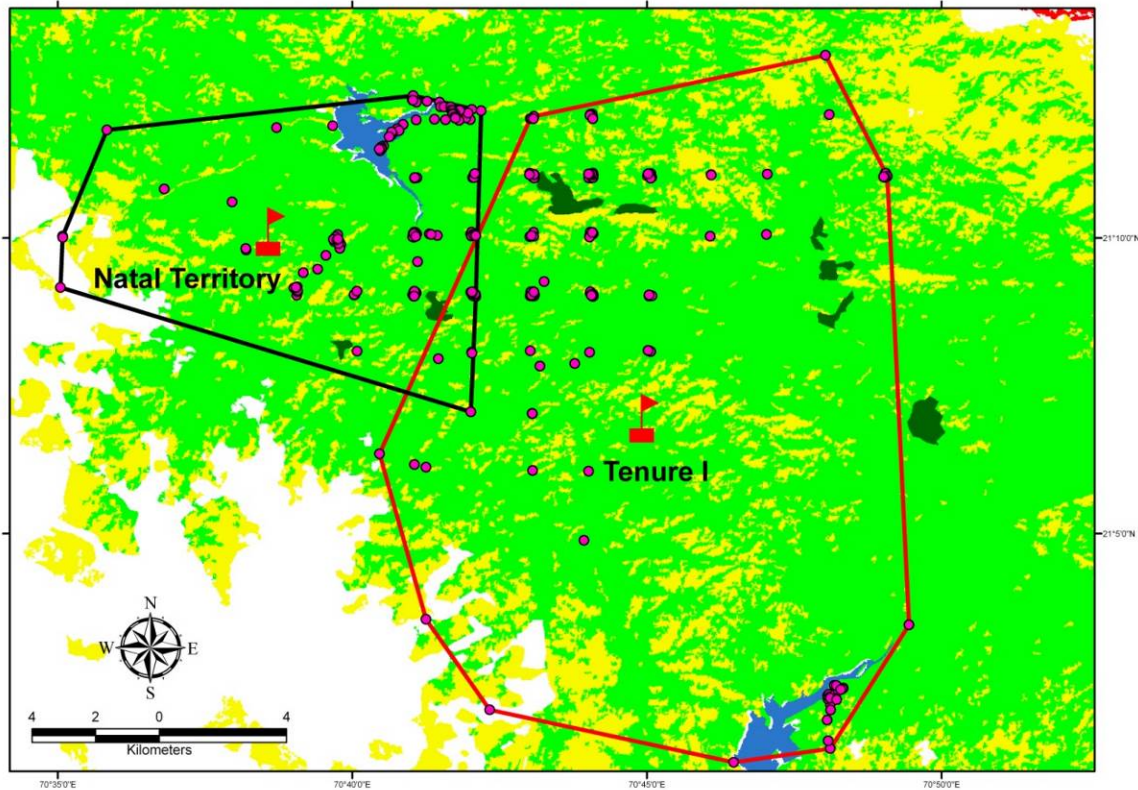
**Figure 8.16: Tenure shift of prime adult male M8 in Gir PA. Tenure centroids shown by flags.**



**M10:** M10 and his coalition partners were sub-adult males (about 3 year age) having a natal territory in the Gir National Park (Patararia, Kankai, Karamdadi, Vadvangra areas). The males were with their mother (prime adult lioness) and one of the males was collared in December 2005 as a part of the previous study on male reproductive strategy. The lioness died in summer 2006 due to infection from porcupine quills and the males became nomads. Initially they expanded their territory to west and mostly ranged near Kamleshwar dam and part of the tourism zone in the western part of the Gir sanctuary. Finally they dispersed about 12 km from their natal territory to the east and established their new territory in the central Gir (**Figure 8.17**).



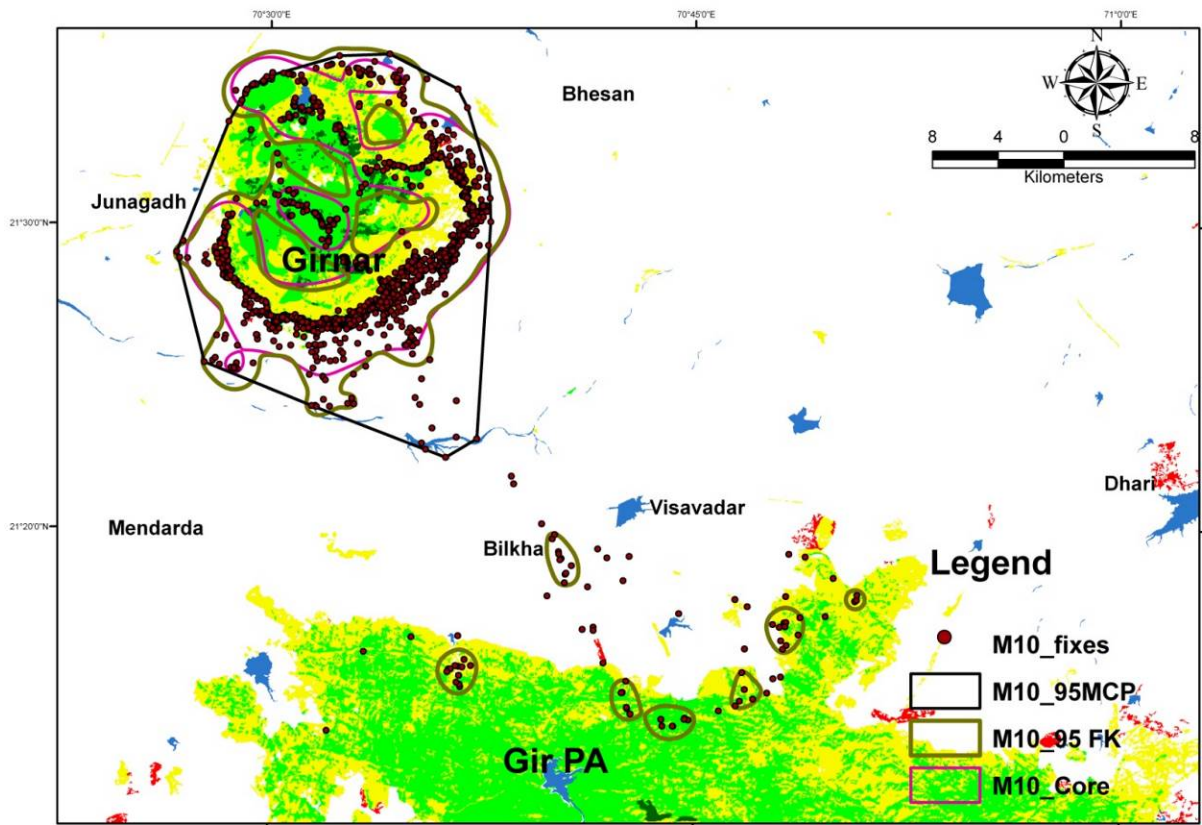
Figure 8.17: Dispersal of sub-adult male M10 in Gir PA. Tenure centroids shown by flags.



**M11:** This male was a sub-adult male (about 4 years old) fitted with a GPS/VHF collar in January 2010 near Ramnath temple in Girnar. This male provided an important insight into lion movements of between the Gir PA and the Girnar Wildlife Sanctuary (**Figure 8.18**). The male ranged Girnar and agro-pastoral tracts of Junagadh, Mendarda, Bhesan and Visavadar talukas. The collar stopped functioning in November 2010 when the male was located with two prime adult females near Dedakadi, western part of the Gir sanctuary. After that, the male was located several times by me and my research assistants in the revenue areas of Sasan, Bhalchhel, Chitrod, Haripur and Chitravad.



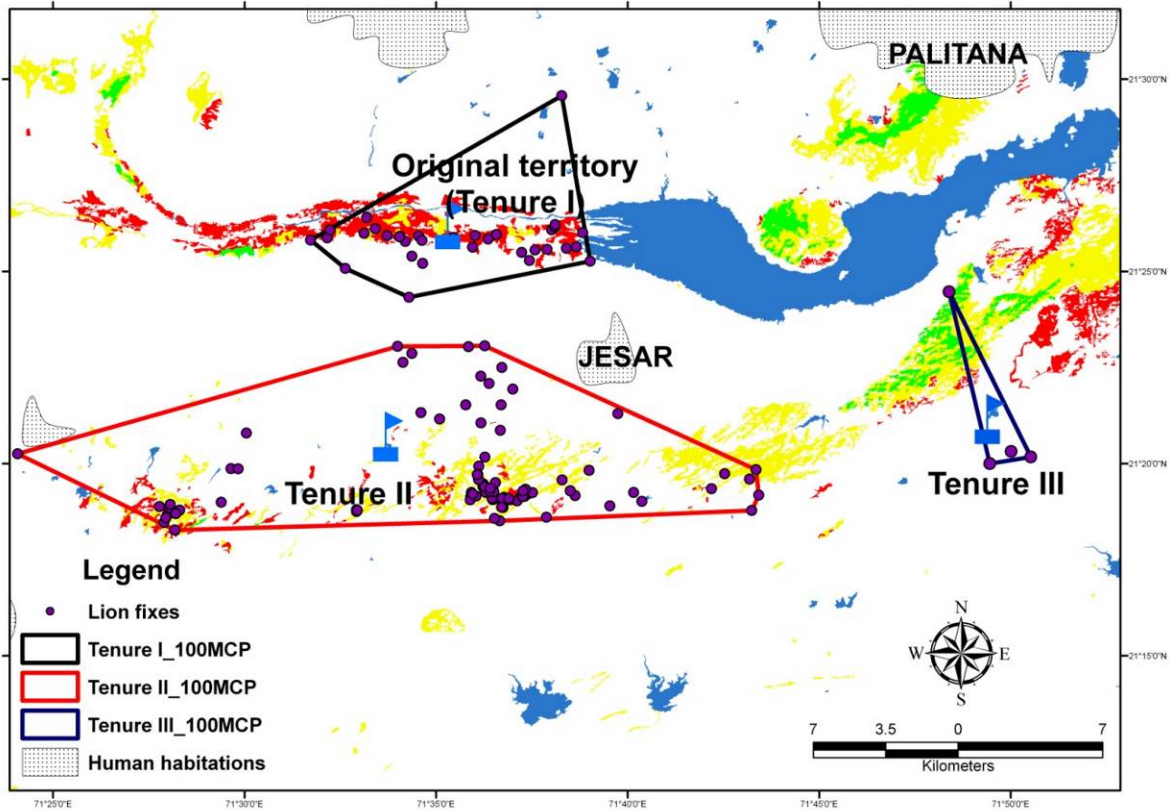
Figure 8.18: Ranging pattern of young-adult male M11 between Gir and Girnar.



**M13:** M13 and his coalition partner (two prime adult males of about 8 years old) had a breeding territory (tenure I) near lower Shetrunjee basin. The males were non-collared whom we monitored on the basis of vibrissae pattern. The males ranged mostly in the *Prosopis juliflora* dominated patches on the banks of Shetrunjee and Shail rivers of Lilia, Gariadhar, Savarkundla and Palitana talukas. They dispersed from their original territory (tenure I) in November 2009 and had a territorial strife with M4 and M12 in Dholikui. M4 died and M12 dispersed from his territory. M13 and his partner established their new territory (tenure II) about 27 km away from their original territory in the Ranigalo-Dholikui area (**Table 8.5; Figure 8.19**). In May 2011 these two males were outweighed in a territorial strife with two other prime adult males and shifted their tenure (tenure III) about 30 km further east from Ranigalo (in the *vidis* of Bagdana and Talaja; **Table 8.5**).



Figure 8.19: Tenure shift of prime adult male M13 in the eastern landscape. Tenure centroids shown by flags. Extent of major human habitations demarcated by night light satellite data.



## Female ranging

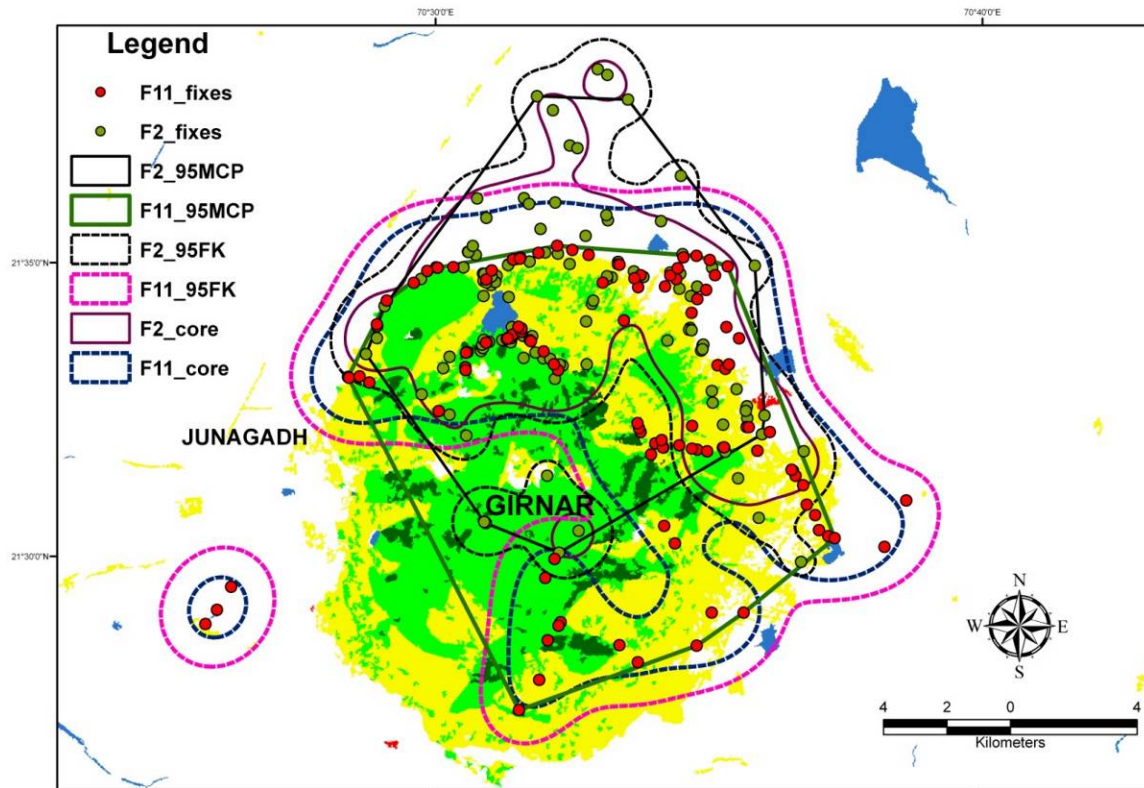
**F2 and F11:** Females F2 and F11 belonged to the same pride in the Girnar sanctuary. F2, a prime adult female (about 6 years old) in the Girnar Wildlife Sanctuary was fitted with VHF radio collar in July 2008 in Sakkarbaug Zoo, Junagadh and released back to the sanctuary. The female was found to be interacting with her own group of lionesses and two males till December 2008 and was found to be ranging almost the entire lion habitats of the Girnar and adjoining village lands of Junagadh, Jetpur and Bhesan talukas (**Figure 8.20**). During our study period in between 2008 and 2012 she littered thrice and successfully raised two cubs.

F11 was a sub adult female (about 3 years old) fitted with GPS/VHF collar in the Girnar Wildlife Sanctuary during January 2009. She ranged mostly within the lion habitats of the Girnar though occasionally frequented to the adjacent revenue areas of Junagadh, Bhesan and Bilkha



(Figure 8.20). She stayed mostly with her natal group, littered twice successfully raising two cubs during my study.

**Figure 8.20: Ranging patterns of lionesses F2 and F11 in Girnar Wildlife Sanctuary.**

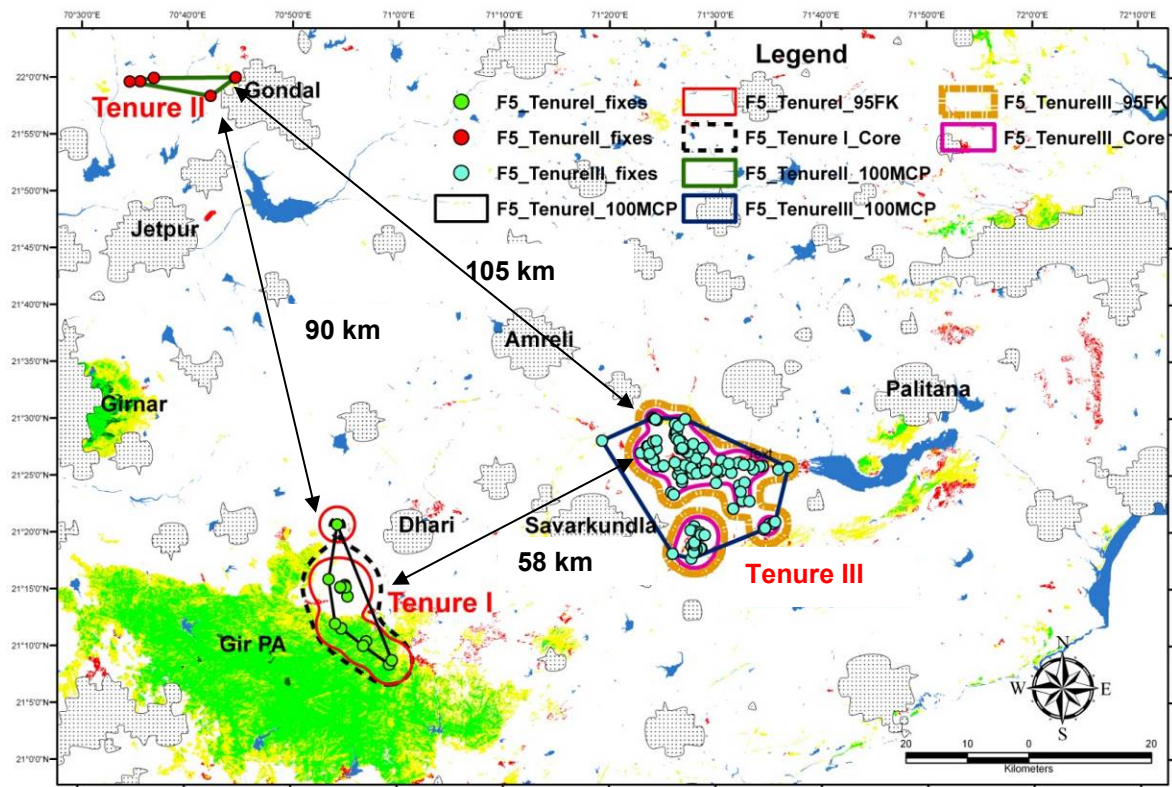


**F5:** F5 was a prime adult female (approximately 7 years old) with three small cubs (3-4 months) and had a natal area near lower Shetrunjee basin (Krakanch, Lilia, Ghoba area). She was captured by the Gujarat Forest Department in anticipation of danger from flashfloods within her territory at the onset of monsoon 2008. The lioness was fitted with VHF radio collar in July 2008 prior to her release. However, she was released 58 km from her natal territory near Hadala, north-eastern boundary of the Gir PA (Tenure I). She stayed inside the Gir PA for a week, moved out and started ranging in the revenue areas of Dalkhaniya and Mithapur villages of Dhari and Visavadar talukas. She made a kill there and was last seen near Molvel village of Visavadar. Subsequently the female was lost and located almost a month after near Gondal city, 50 km from Rajkot (Tenure II; **Figure 8.21**). The linear distance was found to be 89.5 km from her tenure I and 105 km from the original territory (tenure II range use of 27 km<sup>2</sup>). Her cubs were with her and she made two kills. They were captured by the department staff and brought back to the



Sakkarbaug Zoo, Junagadh. In February 2009, F5 along with her cubs was released back at her original territory (Tenure III). The female lost two of her cubs in April 2009 due to an infanticidal resident male. Thereafter, she littered thrice during our study period till 2012 and successfully raised three cubs. The female was long ranging. In 2011 she expanded her territory further east and ranged in the revenue areas of Savarkundla, Jesar and occasionally reaching near Ranigalo *vidi*.

**Figure 8.21: Ranging pattern and dispersal of prime adult female F5. Human habitations demarcated by night light satellite data.**



### Lion territoriality

We examined home range overlap for pairs of same pride/coalition and neighboring lions ( $n = 3$  pairs of same pride females,  $n = 3$  pairs of neighboring females,  $n = 4$  pairs of coalition males,  $n = 14$  pairs of neighboring males,  $n = 16$  pairs of coalition male-females and  $n = 14$  pairs of neighboring male-females). Lionesses had a higher range overlap with their pride females than neighboring females ( $t = 0.7$ ,  $df = 4$ ,  $p = 0.51$ ). Average core area overlap of pride females [61 (SE 18) %] was much higher than that with neighboring females [3.5 (SE 0.05) %] ( $t = 3.32$ ,  $df =$



3,  $p = 0.04$ ; **Table 8.7**). Coalition males had a higher overlap of range ( $t = 5.98$ ,  $df = 14$ ,  $p < 0.001$ ) as well as of core area ( $t = 6.19$ ,  $df = 18$ ,  $p < 0.001$ ) than neighboring males (**Table 8.7**). Male home ranges overlapped extensively with those of sympatric females [mean: 63 (SE 3) %], but little with neighboring females [mean: 18 (SE 6) %] ( $t = 6.91$ ,  $df = 26$ ,  $p < 0.001$ ). Male ranges overlapped in the areas where female cores were concentrated (**Figure 8.22**).

**Table 8.7: Overlap (mean) of home ranges and core areas (85% FK) of lions in the Gir landscape between 2005 and 2012. Figures within parentheses are standard errors.**

Lion categories	% overlap	
	95% MCP	Core area
Females (same pride)	51 (18)	61 (18)
Females (neighboring)	35 (16)	3 (0.05)
Coalition males	74 (5)	73 (6)
Neighboring males	20 (7)	21 (6)
Male-female (same pride)	63 (3)	56 (3)
Male-female (neighboring)	17 (6)	20 (3)

### Lion movement

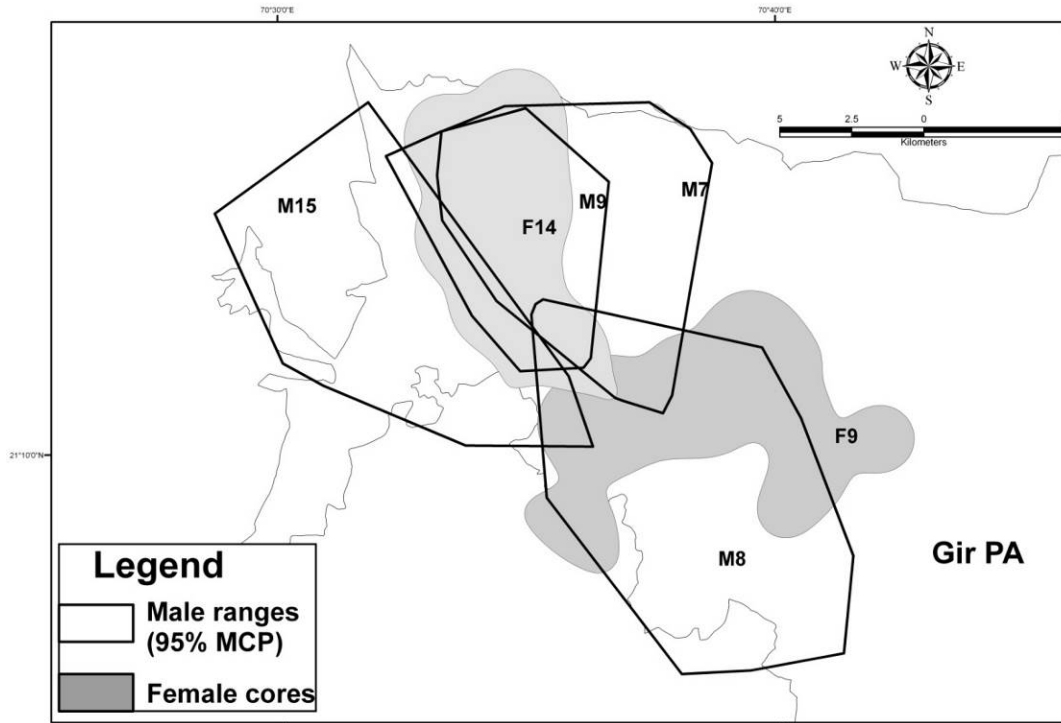
The average diurnal distance travelled by lions [2.3 (SE 0.4) km] was smaller than the average nocturnal distance traversed [7.1 (SE 2) km] ( $t = 2.56$ ,  $df = 17$ ,  $p = 0.02$ ; **Table 5.8**). Males travelled more during night than day time ( $t = 14.62$ ,  $df = 9$ ,  $p = 0.05$ ). The same pattern was observed in females ( $t = 3.94$ ,  $df = 8$ ,  $p = 0.01$ ). Diurnal [ $F = 1.17$ ,  $df = 8$ ,  $p = 0.37$ ] and nocturnal [ $F = 1.88$ ,  $df = 8$ ,  $p = 0.23$ ] distances travelled by male lions in Gir, Girnar and the eastern landscape were similar. In Girnar, males showed larger movements during the night ( $t = 26.5$ ,  $df = 2$ ,  $p = 0.02$ ).

Girnar male M11 moved between the Gir PA and the Girnar Wildlife Sanctuary thrice in between January 2010 and October 2010 (**Figure 8.23**). Dispersing sub-adult male M6 moved from the western part to the eastern part of the Gir PA (**Figure 8.24**).

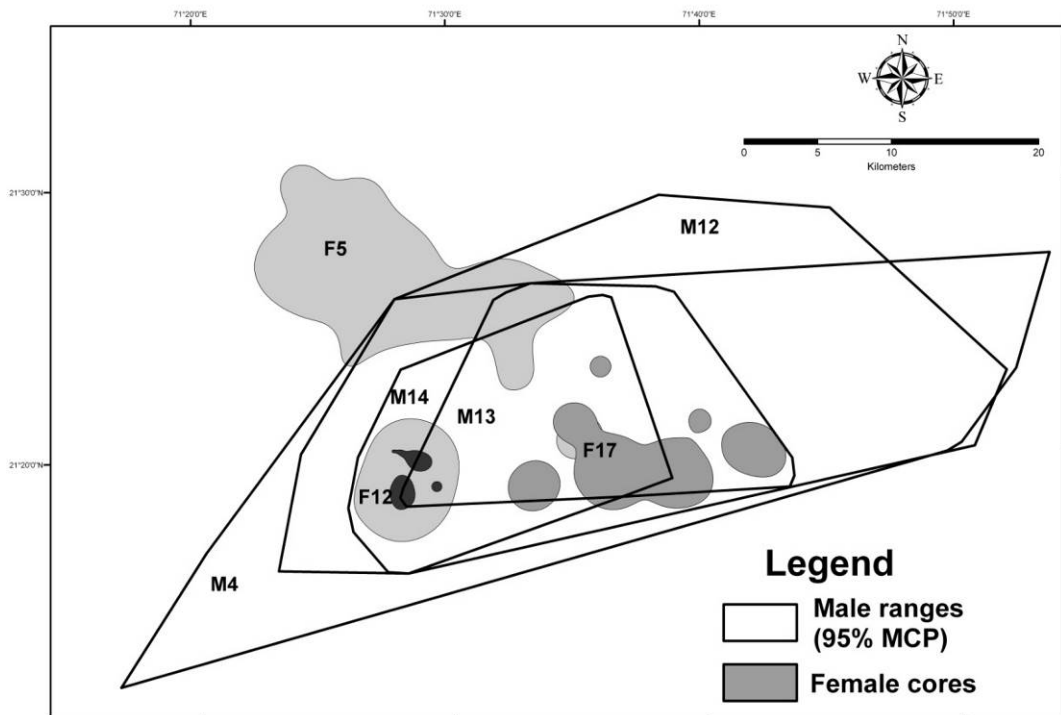


Figure 8.22: Male range and female core area (85% FK) overlap in i) Gir PA and ii) eastern landscape.

i)



ii)





**Table 8.8: Average movement parameters of Asiatic lion in the Gir landscape. Figures within parentheses are standard errors.**

Lion ID	Diurnal				Nocturnal			
	n (day)	Distance travelled (km)	Hour	Speed (km/hr)	n (night)	Distance travelled (km)	Hour	Speed (km/hr)
F2	14	1.16	4.69	1.11	15	5.50	6.54	0.80
F5	11	1.68	4.75	0.75	11	3.48	2.41	1.61
F11	10	3.57	4.75	0.89	12	7.64	6.90	1.19
M1	26	1.93	9.22	0.21	26	3.99	9.30	0.44
M2	21	5.86	8.16	0.64	22	3.63	7.85	0.67
M3	114	3.39	10.30	0.40	112	9.04	9.17	1.10
M4	18	1.11	8.07	0.17	20	31.75	9.19	3.53
M5	15	1.14	4.83	0.51	19	5.40	5.50	0.91
M6	186	2.36	9.50	0.24	187	3.12	9.70	0.31
M10	63	2.14	9.10	0.23	61	2.55	3.86	0.65
M11	157	2.62	9.00	0.31	158	6.57	9.66	0.70
M12	32	0.39	4.12	0.36	37	15.68	7.47	1.88
<b>Overall lion</b>	42 (16)	2.30 (0.39)	6.96 (0.59)	0.51 (0.08)	42 (16)	7.05 (2.00)	6.95 (0.77)	1.07 (0.22)
<b>Male Overall</b>	70 (22)	2.32 (0.53)	8.03 (0.71)	0.34 (0.05)	71 (22)	9.08 (3.14)	7.96 (0.68)	1.13 (0.33)
<b>Female Overall</b>	9 (1)	2.28 (0.45)	5.75 (0.52)	0.70 (0.11)	9 (1)	4.77 (0.76)	5.81 (1.11)	1.02 (0.19)
<b>Gir Males</b>	90 (50)	3.45 (1.21)	8.92 (0.40)	0.37 (0.14)	90 (50)	3.10 (0.31)	7.14 (1.72)	0.54 (0.12)
<b>Girnar males</b>	86 (71)	1.88 (0.74)	6.92 (2.09)	0.41 (0.10)	89 (70)	5.99 (0.59)	7.58 (2.08)	0.81 (0.11)
<b>Eastern landscape males</b>	48 (22)	1.71 (0.64)	7.93 (1.35)	0.29 (0.06)	49 (21)	15.12 (6.04)	8.78 (0.44)	1.74 (0.67)
<b>Gir lioness</b>	8 (1)	2.37 (0.62)	6.37 (0.70)	0.57 (0.14)	7 (1)	4.31 (1.03)	6.13 (1.66)	0.90 (0.27)
<b>Girnar lioness</b>	12 (2)	2.37 (1.21)	4.72 (0.03)	1.00 (0.11)	14 (2)	6.57 (1.07)	6.72 (0.18)	1.00 (0.20)



Figure 8.23: Movement of M11 between Gir PA and Girnar Wildlife Sanctuary.

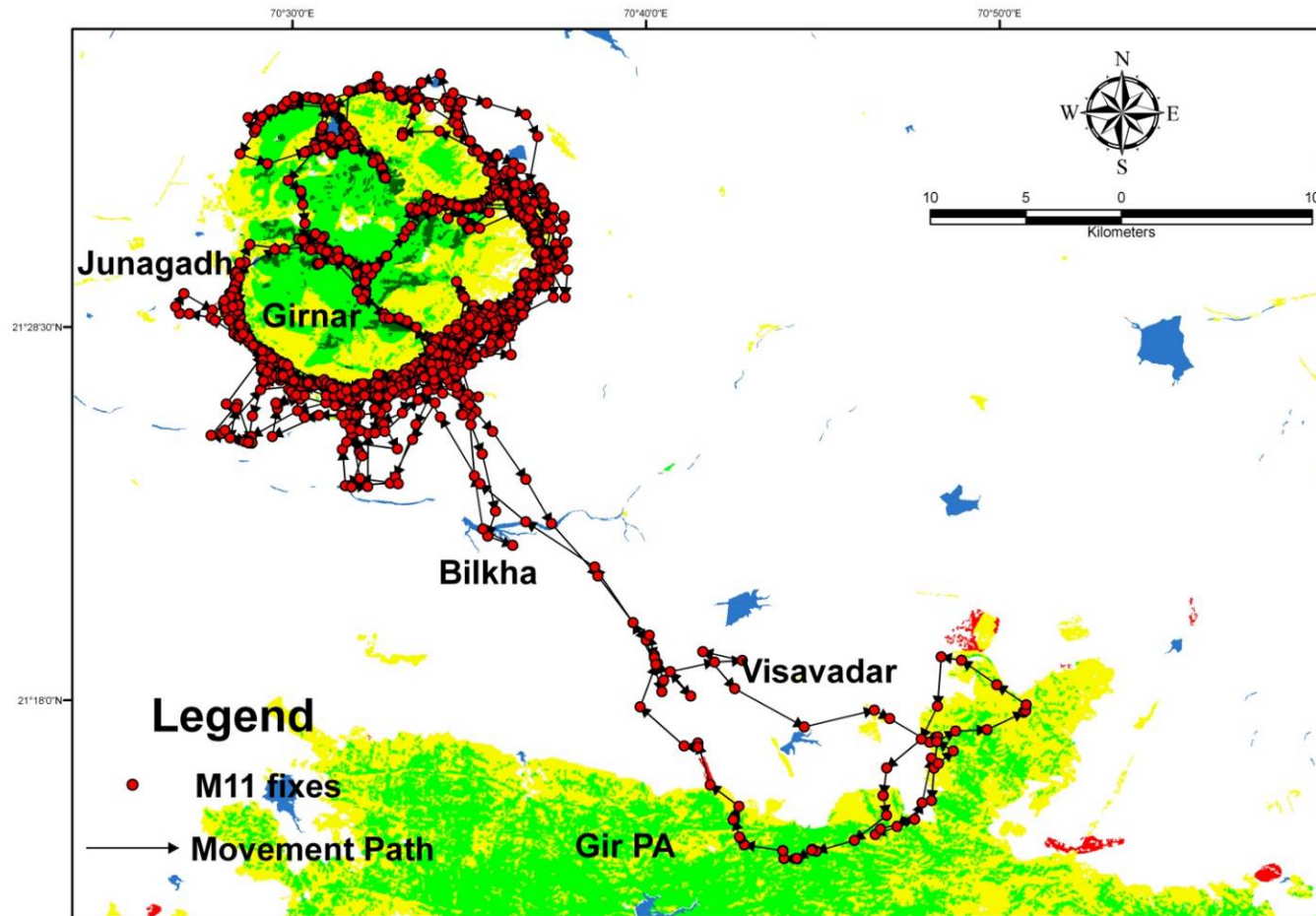
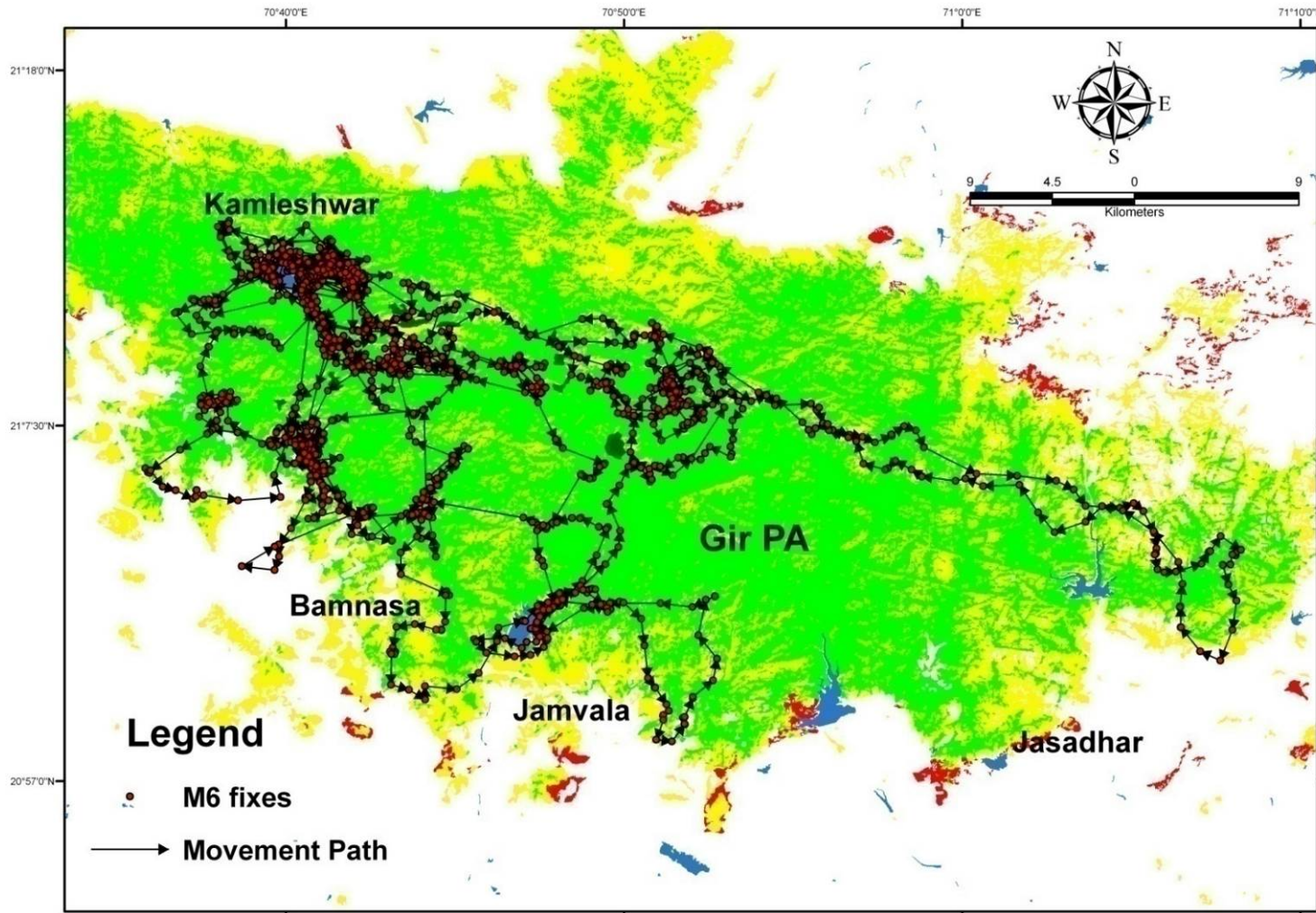




Figure 8.24: Movement of M6 from western Gir to eastern Gir.





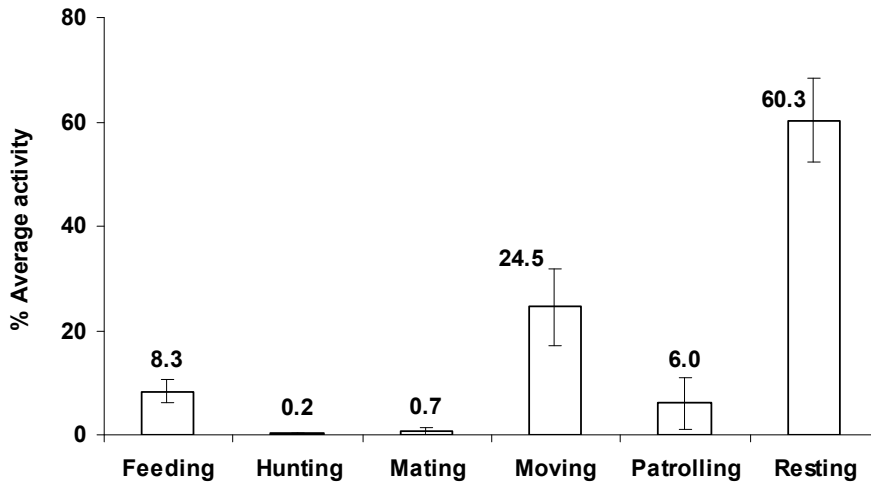
### Lion time budget and activity pattern

Overall lions spent a majority of their time resting (60%) followed by moving (24%) and we found no seasonal (wet and dry) variation ( $\chi^2 = 6.13$ ,  $df = 5$ ,  $p = 0.29$ , **Figure 8.25**). Males also spent majority of their time resting (62%) followed by moving (17%) and patrolling (13%) and no seasonal variation was observed ( $\chi^2 = 3.81$ ,  $df = 5$ ,  $p = 0.57$ , **Figure 8.26**). Females spent most on resting (59%) and no seasonal variation was recorded ( $\chi^2 = 5.07$ ,  $df = 5$ ,  $p = 0.40$ , **Figure 8.27**). However there was a significant difference of time invested in different activities by males and females ( $\chi^2 = 16.74$ ,  $df = 5$ ,  $p = 0.005$ ; **Figure 8.26 and 8.27**) with males spending greater time than females in patrolling their territories ( $t = 3.16$ ,  $df = 14$ ,  $p = 0.006$ ). Time invested in different activities by territorial males and dispersing males were similar ( $\chi^2 = 7.86$ ,  $df = 5$ ,  $p = 0.16$ , **Figure 8.28**).

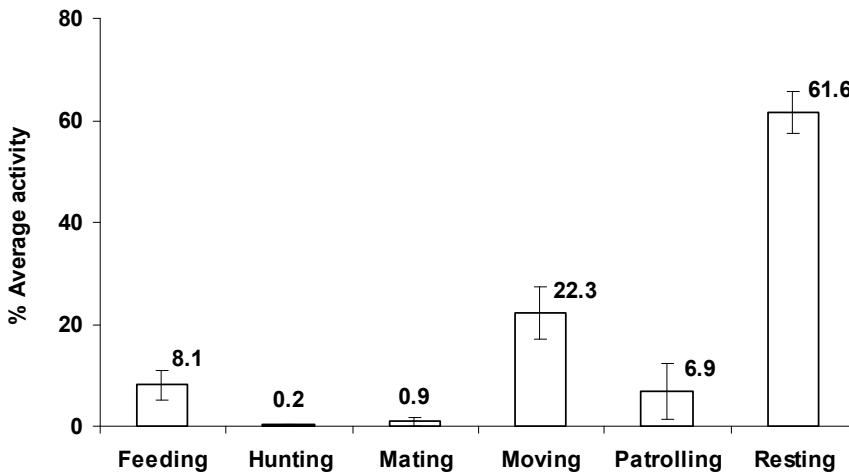


Figure 8.25: Time invested by lions (males and females) in different activities during continuous monitoring session i) overall, ii) dry season and iii) wet season. Error bars = 95% CI.

i)



ii)



iii)

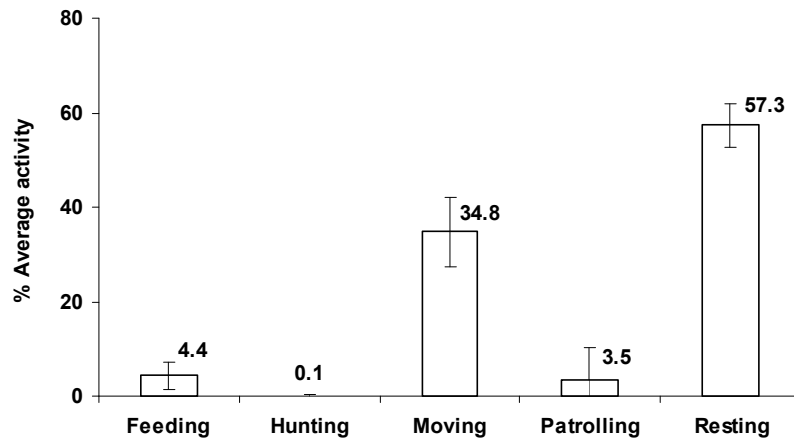
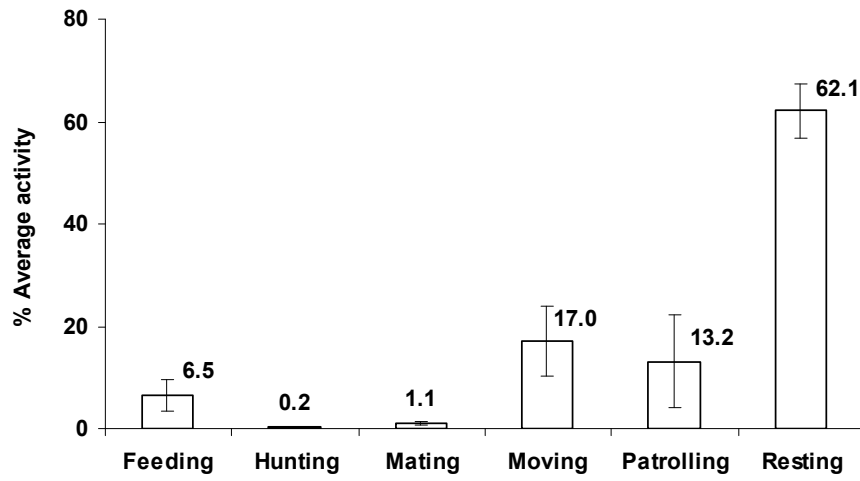


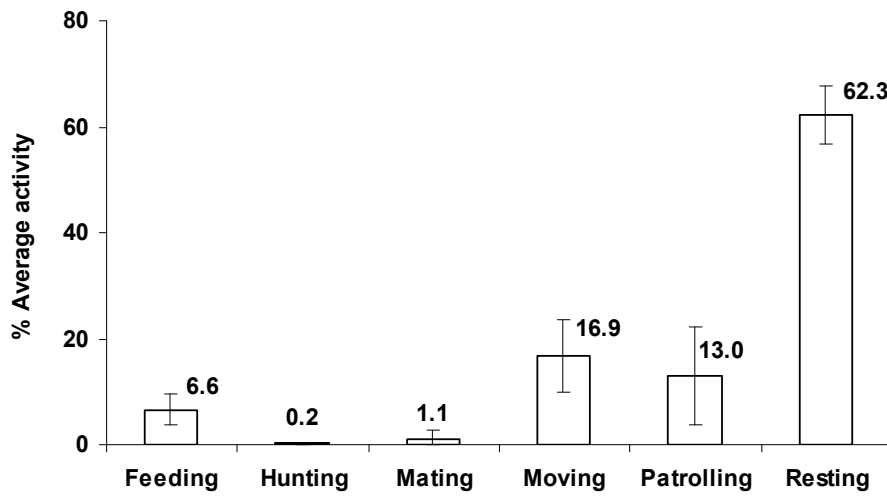


Figure 8.26: Time invested by male lions in different activities during continuous monitoring session i) overall, ii) dry season and iii) wet season. Error bars = 95% CI.

i)



ii)



iii)

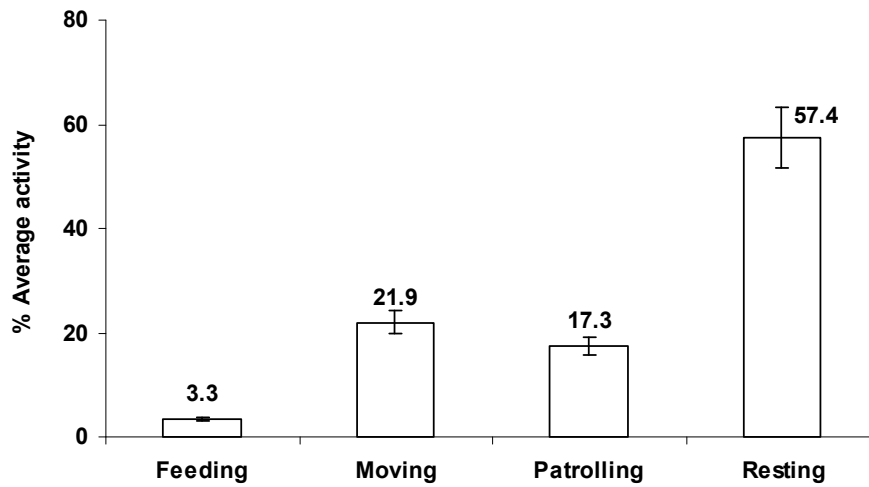
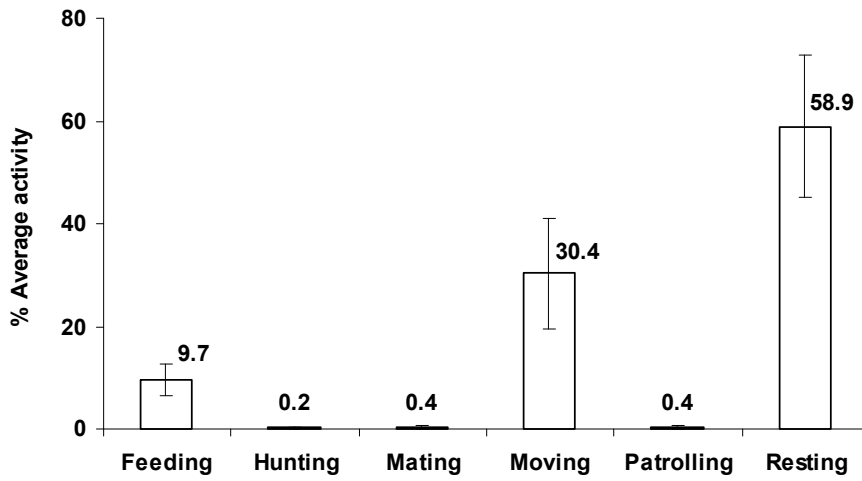


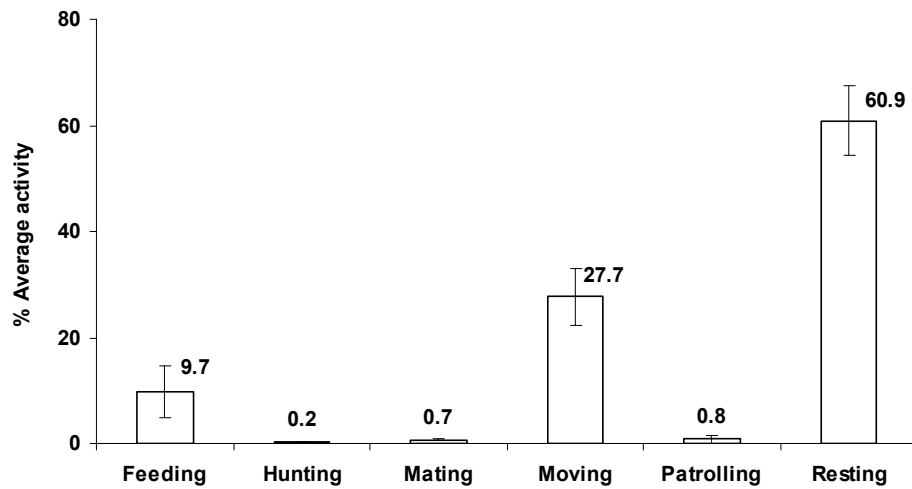


Figure 8.27: Time invested by female lions in different activities during continuous monitoring session i) overall, ii) dry season and iii) wet season. Error bars = 95% CI.

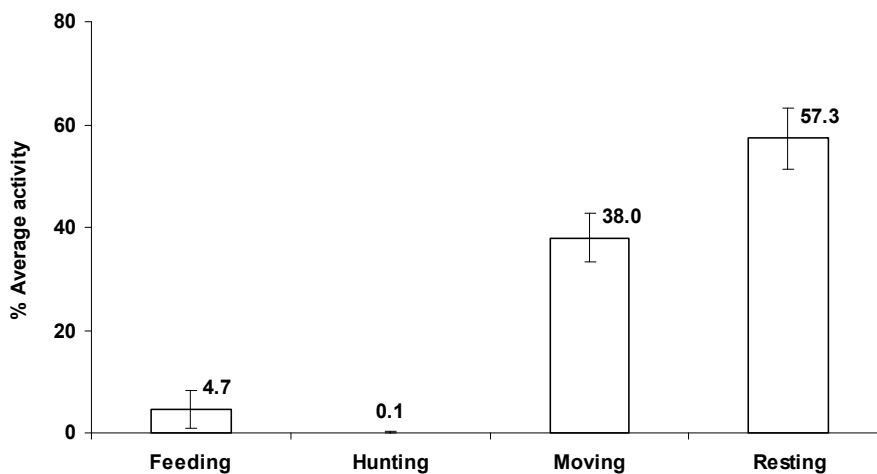
i)



ii)

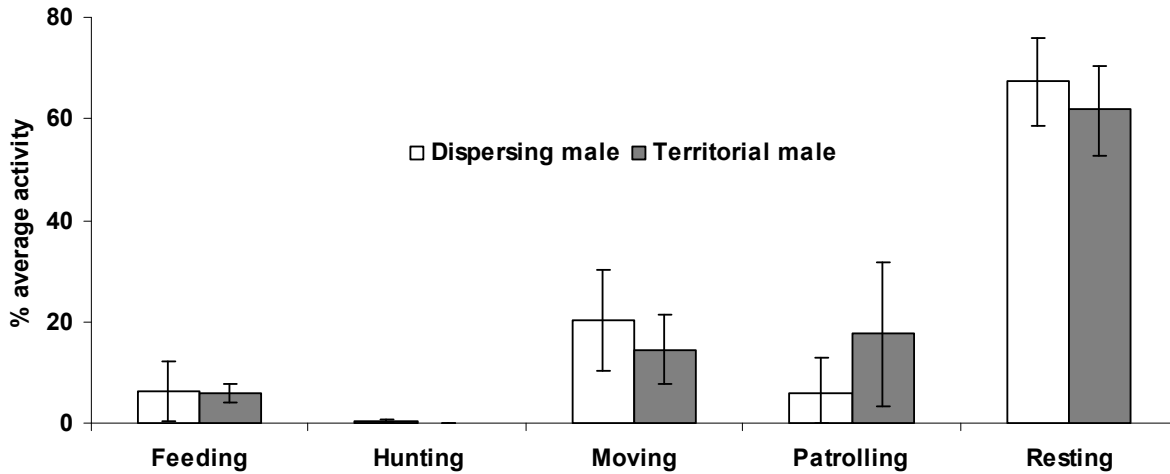


iii)





**Figure 8.28: Time invested by territorial males and dispersing males in different activities. Error bars = 95% CI.**



Lions were mostly active during night (moving and patrolling) while most of the day was spent in resting (**Table 8.9, Figures 8.29 - 8.39**). Feeding peak was at midnight while the hunting peak was during the early morning. However, during wet season the feeding peak was delayed by about 2 hours. Male feeding peak was before midnight while female feeding peak was found to be after midnight. Males were found hunting mostly during dawn while females were found to hunt mostly during dusk (**Table 8.9**). Patrolling peak for territorial males was found to be at late night (2:20 AM) while for dispersing males the patrolling peak was dawn (4 AM). No seasonal variation among activity peaks was observed for males or females. **Figures 8.29 - 8.39** show proportional time spent by lions in different activities during different times of the day and the related activity peaks.

Males roared at a rate of 2/hour (SE 0.17) (n = 90) and there could be a maximum four vocalization events per hour. Males scent marked (n = 76) at a rate of 2.2 scent marks/hour (SE 0.28). Scent marking was largely (92.1%) by urinating on bushes, trees and ground and to a smaller extent (7.9%) by tree clawing (here we assume that tree clawing is a sign of marking. It can actually have several functions as seen in domestic cats).



**Table 8:9: Activity statistics of lions in different seasons deduced by the program Oriana. \* indicates significant probability of directionality of data at  $\alpha = 0.05$ . \*\*\*\* indicates that the estimates could not be calculated due to lower sample sizes. Times are in Indian Standard Time (IST = GMT + 5:30 hours).**

Activity	Median	95% CI	Rayleigh Z statistics	Rayleigh p value	Rao spacing test (U)	Rao spacing test (p)
<b>Lion overall</b>						
Feeding	12:40 AM	11:56 PM – 1:18 AM	57.2	< 0.0001*	325.8	< 0.01*
Hunting	6:40 AM	5:28 AM – 7:18 AM	0.05	0.95	122.9	0.90 > p > 0.50
Mating	1: 00 AM	11:54 PM – 2:09 AM	17.2	<0.0001*	189.1	< 0.01*
Moving	1:35 AM	1:20 AM – 1:50 AM	418.9	<0.0001*	349.5	< 0.01*
Patrolling	2:20 AM	1:43 AM – 2:26 AM	176.9	<0.0001*	325.1	< 0.01*
Resting	1:35 PM	1:19 PM – 1:51 PM	369.8	<0.0001*	355.9	< 0.01*
<b>Lion dry season</b>						
Feeding	12:20 AM	11:39 PM – 1:14 AM	43.5	<0.0001*	321.6	< 0.01*
Hunting	5:40 AM	1:56 AM – 7:39 AM	3.1	0.04*	177.5	<0.05*
Mating	1:00 AM	11:54 PM – 2:09 AM	17.2	<0.0001*	189.1	< 0.01*
Moving	1:40 AM	1:38 AM – 2:12 AM	328.4	<0.0001*	347.5	< 0.01*
Patrolling	2:20 AM	1:44 AM – 2:31 AM	146.8	<0.0001*	320.0	< 0.01*
Resting	1:39 PM	1:20 PM – 1:58 PM	273.8	<0.0001*	355.3	< 0.01*
<b>Lion wet season</b>						
Feeding	2:00 AM	12:03 AM – 2:32 AM	16.1	<0.0001*	187.2	< 0.01*
Hunting	****	****	****	****	****	****
Mating	****	****	****	****	****	****
Moving	12:00 AM	11:53 PM – 12:51 AM	103.8	<0.0001*	313.2	< 0.01*
Patrolling	2:00 AM	12:58 AM – 2:34 AM	31.1	<0.0001*	169.1	< 0.01*
Resting	1:40 PM	12:51 PM – 1:49 PM	112.0	<0.0001*	328.8	< 0.01*
<b>Male overall</b>						
Feeding	10:40 PM	9:52 PM – 11:51 PM	27.2	<0.0001*	282.4	< 0.01*
Hunting	5:50 AM	3:34 AM – 9:24 AM	3.5	0.02*	210	< 0.01*
Mating	11:20 PM	9:53 PM – 12:56 AM	9.7	<0.0001*	190.5	< 0.01*
Moving	1:25 AM	1:06 AM – 1:43 AM	261.9	<0.0001*	339.9	< 0.01*
Patrolling	2:20 AM	1:43 AM – 2:27 AM	169.1	<0.0001*	324.4	< 0.01*
Resting	1:00 PM	12:55 PM – 1:36 PM	238.1	<0.0001*	352.5	< 0.01*



Male dry season						
Feeding	10:40 PM	9:47 PM – 11:50 PM	25.3	<0.0001*	278.6	< 0.01*
Hunting	5:50 AM	3:34 AM – 9:24 AM	3.5	0.02*	210	< 0.01*
Mating	11:20 PM	9:53 PM – 12:56 AM	9.7	<0.0001*	190.5	< 0.01*
Moving	1:20 AM	1:14 AM – 1:53 AM	231.2	<0.0001*	338.1	< 0.01*
Patrolling	2:20 AM	1:44 AM – 2:33 AM	139.1	<0.0001*	319	< 0.01*
Resting	1:00 PM	12:56 PM – 1:41 PM	189.8	<0.0001*	351.9	< 0.01*
Male wet season						
Feeding	11:00 PM	7:38 PM – 3:46 AM	1.9	0.13	204.2	< 0.01*
Hunting	****	****	****	****	****	****
Mating	****	****	****	****	****	****
Moving	12:00 AM	11:23 PM – 12:55 AM	35.9	<0.0001*	196.7	< 0.01*
Patrolling	2:00 AM	12:58 AM – 2:34 AM	31.1	<0.0001*	169.1	< 0.01*
Resting	1:00 PM	12:21 PM – 1:30 PM	68.8	<0.0001*	278.4	< 0.01*
Female overall						
Feeding	1:40 AM	12:54 AM – 2:34 AM	38.6	<0.0001*	305.6	< 0.01*
Hunting	5:20 PM	12:50 PM – 10:54 PM	1.4	0.23	104	0.90 > p > 0.50
Mating	3:00 AM	2:11 AM – 3:48 AM	12.9	<0.0001*	266	< 0.01*
Moving	1:40 AM	1:23 AM – 2:09 AM	173.5	<0.0001*	342.3	< 0.01*
Patrolling	2:40 AM	11:57 PM – 3:15 AM	7.9	0.0001*	203	< 0.01*
Resting	2:00 PM	1:37 PM – 2:30 PM	139.1	<0.0001*	351.2	< 0.01*
Female dry season						
Feeding	1:40 AM	12:44 AM – 2:47 AM	25.7	<0.0001*	296	< 0.01*
Hunting	1:30 AM	8:38 PM – 8:21 AM	1.2	0.30	161	0.50 > p > 0.10
Mating	3:00 AM	2:11 AM – 3:48 AM	12.9	<0.0001*	266	< 0.01*
Moving	2:20 AM	1:54 AM – 2:52 AM	115.2	<0.0001*	336.5	< 0.01*
Patrolling	2:40 AM	11:57 PM – 3:15 AM	7.9	0.0001*	203	< 0.01*
Resting	2:00 PM	1:41 PM – 2:47 PM	90.5	<0.0001*	348.9	< 0.01*
Female wet season						
Feeding	2:20 AM	12:16 AM – 2:51 AM	14.6	<0.0001*	200.1	< 0.01*
Hunting	4:40 AM	****	****	0.51	****	****
Mating	****	****	****	****	****	****
Moving	12:20 AM	11:51 PM – 1:02 AM	71.3	<0.0001*	302.9	< 0.01*
Patrolling	****	****	****	****	****	****
Resting	2:00 PM	12:55 PM – 2:19 PM	54.5	<0.0001*	317.2	< 0.01*



<b>Territorial male</b>						
Feeding	10:20 PM	9:57 PM – 11:30 PM	42.1	<0.0001*	257.6	< 0.01*
Hunting	6:40 AM	2:05 AM – 1:22 PM	1	0.39	****	****
Mating	11:10 PM	9:20 PM – 1:38 AM	5.2	0.0004*	201	< 0.01*
Moving	1:20 AM	1:13 AM – 2:00 AM	160.2	<0.0001*	332.2	< 0.01*
Patrolling	2:20 AM	1:35 AM – 2:20 AM	158.2	<0.0001*	323.3	< 0.01*
Resting	1:00 PM	12:47 PM – 1:30 PM	209.5	<0.0001*	350.1	< 0.01*
<b>Dispersing male</b>						
Feeding	9:04 AM	2:54 AM – 3:13 PM	0.73	0.47	190	< 0.01*
Hunting	5:40 AM	5:25 AM – 6:07 AM	2.9	0.03*	****	****
Mating	12:00 AM	8:56 PM – 1:38 AM	4.8	0.005*	210	< 0.01*
Moving	12:40 AM	12:35 AM – 1:31 AM	105.5	<0.0001*	301.9	< 0.01*
Patrolling	4:00 AM	2:31 AM – 5:03 AM	13.5	<0.0001*	214.1	< 0.01*
Resting	1:20 PM	12:53 PM – 2:41 PM	33.6	<0.0001*	328.5	< 0.01*

Larger value of Z means greater concentration of the data around the mean, and thus less likelihood of the data being uniformly distributed.



Figure 8.29: Proportional time spent by lions (males and females) in different activities during different times of the day and the related activity peaks deduced by program Oriana.

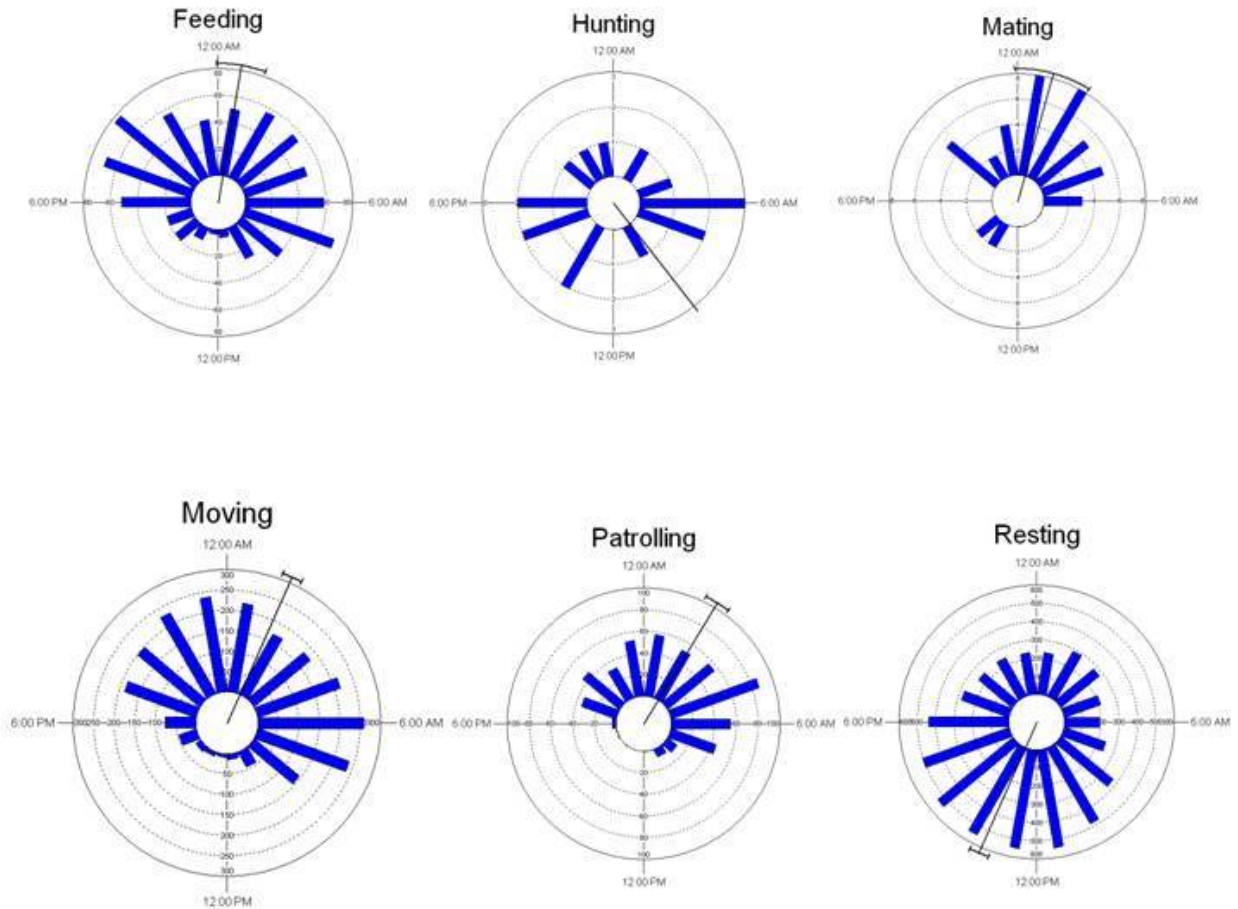
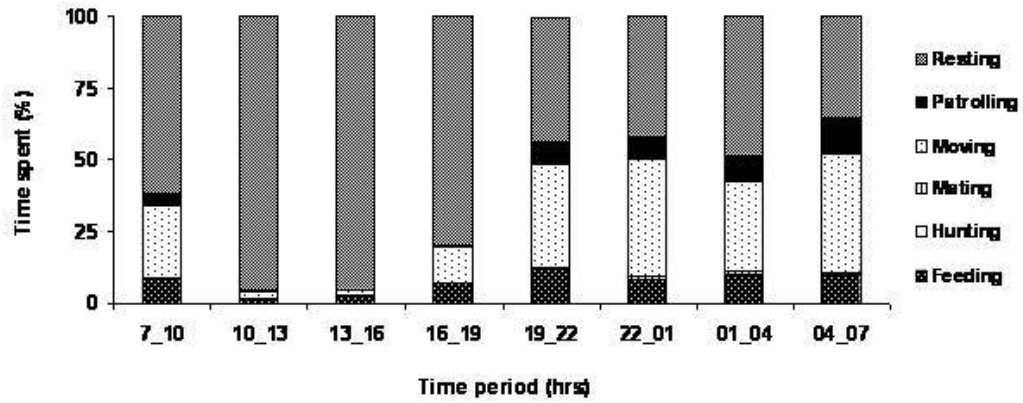




Figure 8.30: Proportional time spent by lions (males and females) in dry season in different activities during different times of the day and the related activity peaks deduced by program Oriana.

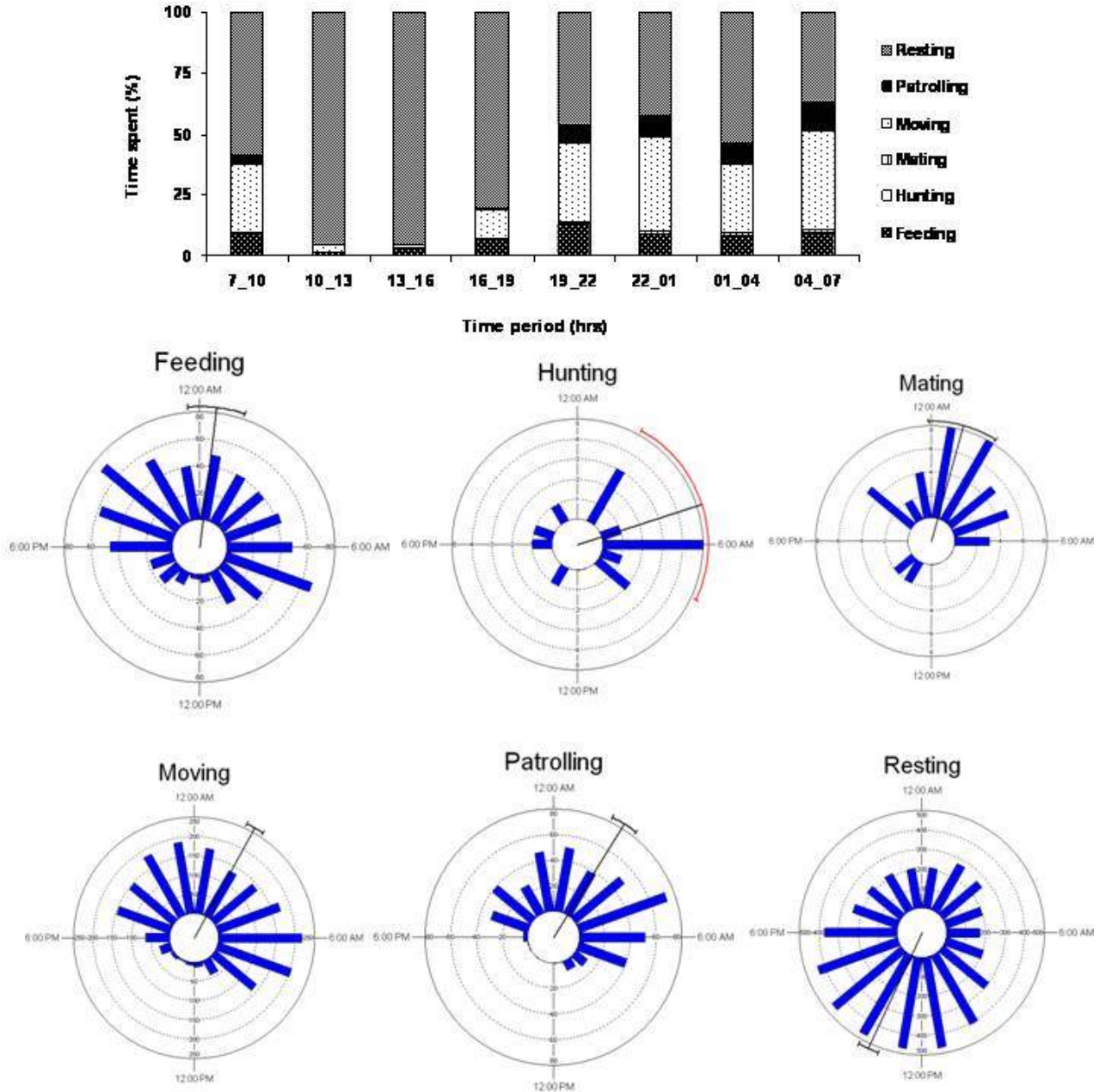
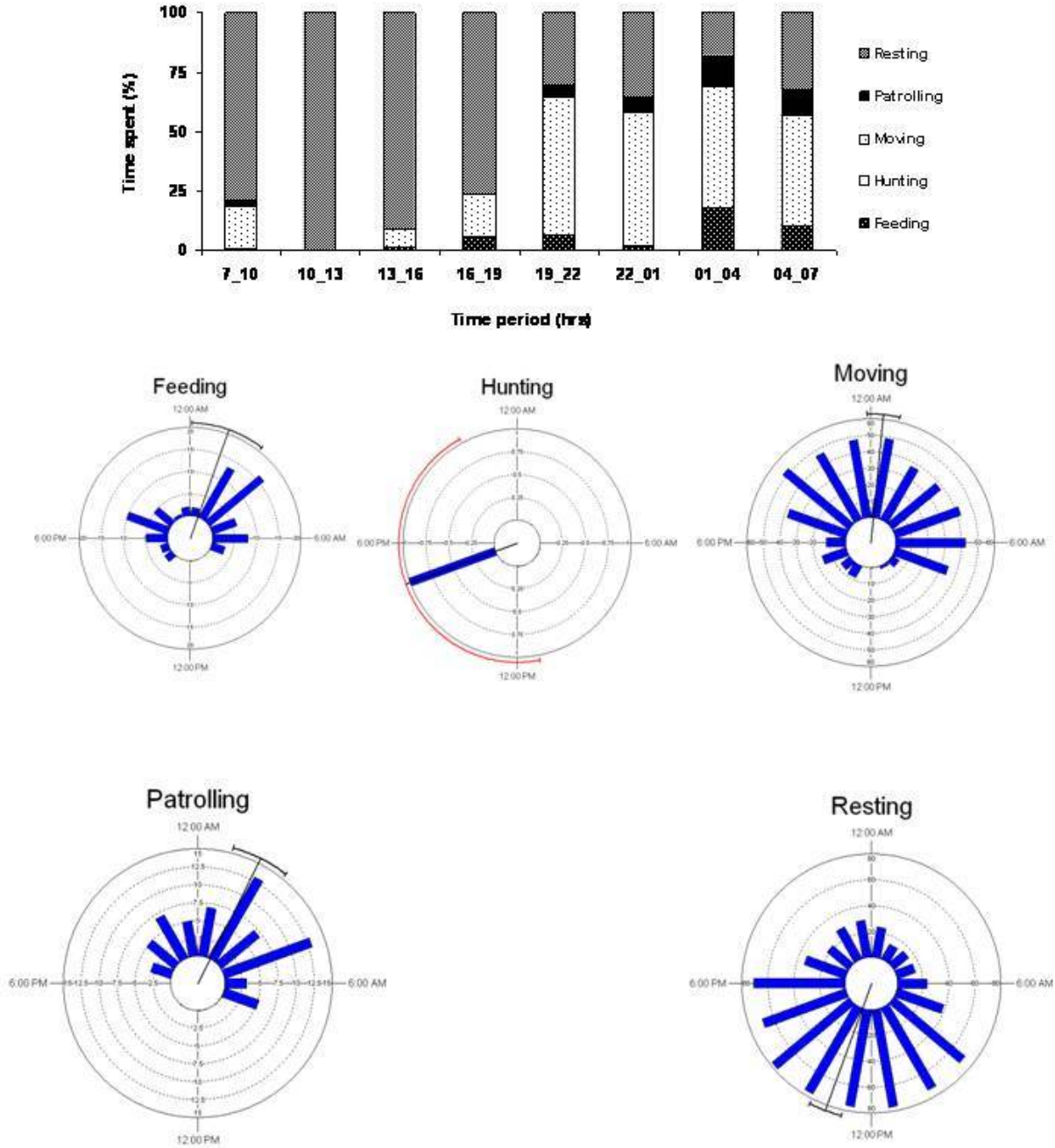




Figure 8.31: Proportional time spent by lions (males and females) in wet season in different activities during different times of the day and the related activity peaks deduced by program Oriana.





**Figure 8.32: Proportional time spent by male lions in different activities during different times of the day and the related activity peaks deduced by program Oriana.**

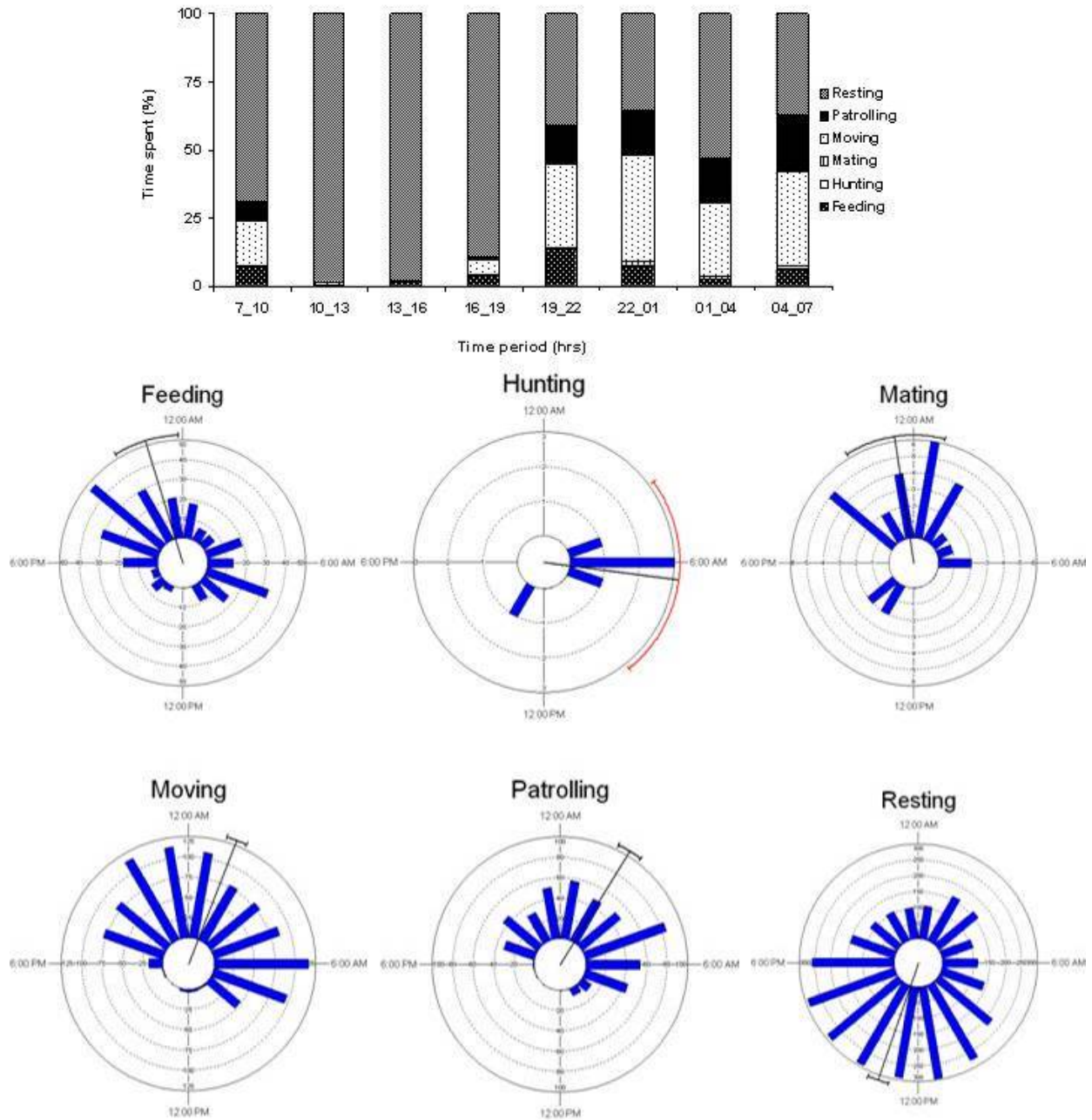




Figure 8.33: Proportional time spent by male lions in dry season in different activities during different times of the day and the related activity peaks deduced by program Oriana.

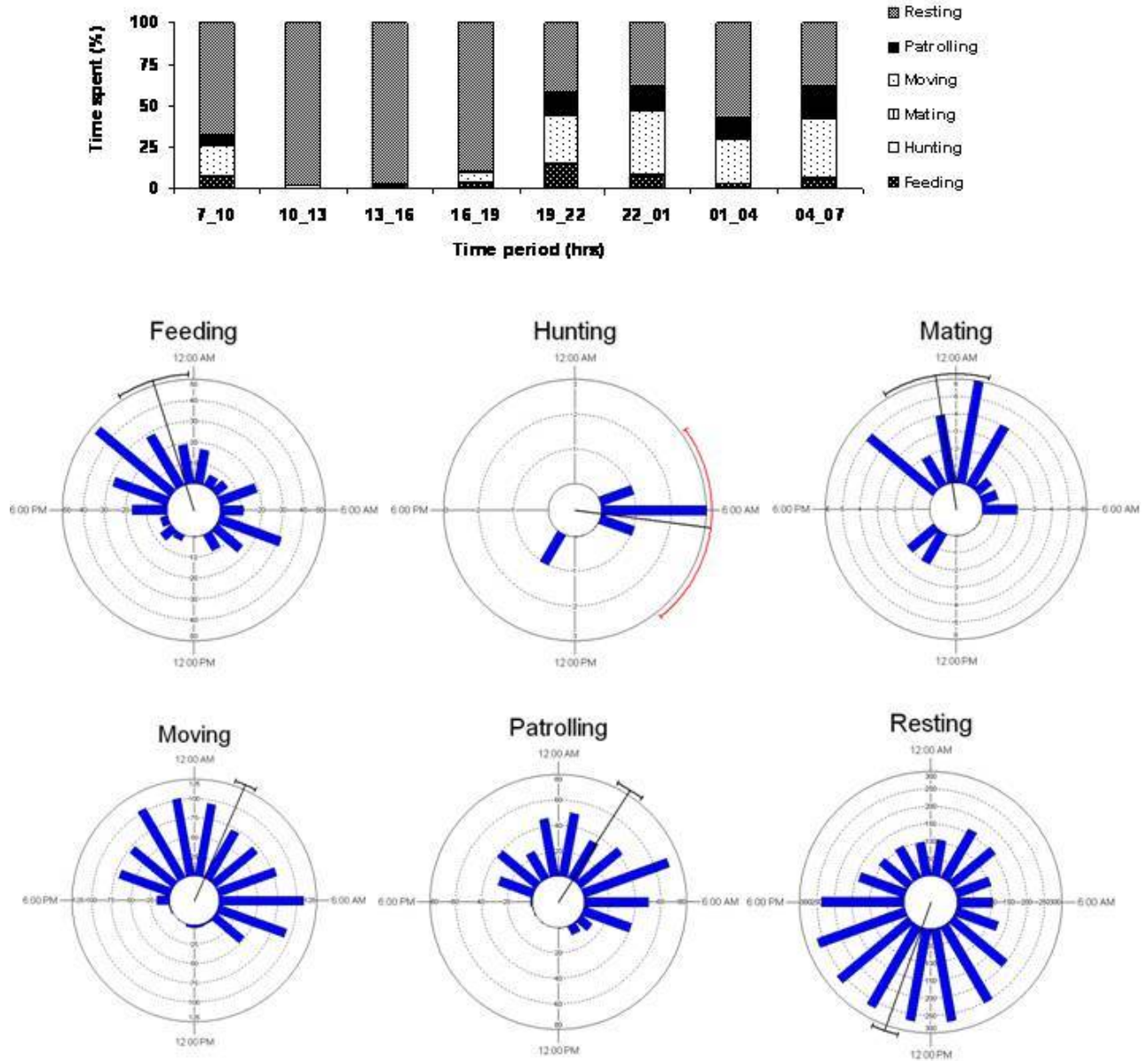




Figure 8.34: Proportional time spent by male lions in wet season in different activities during different times of the day and the related activity peaks deduced by program Oriana.

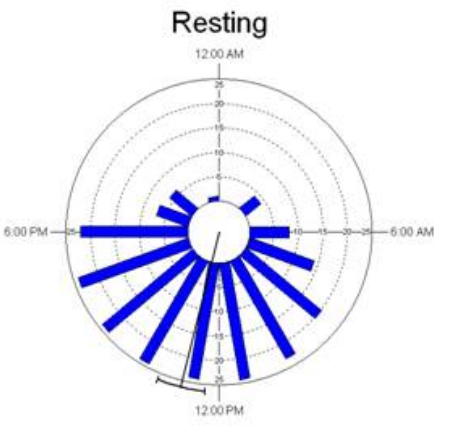
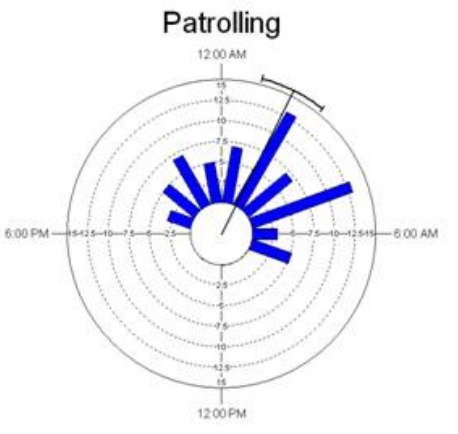
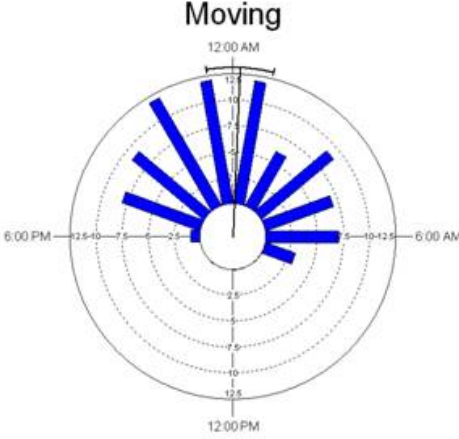
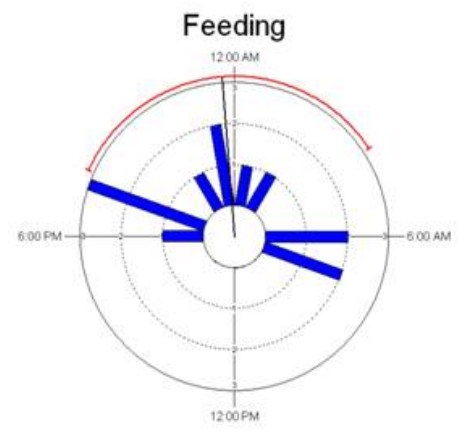
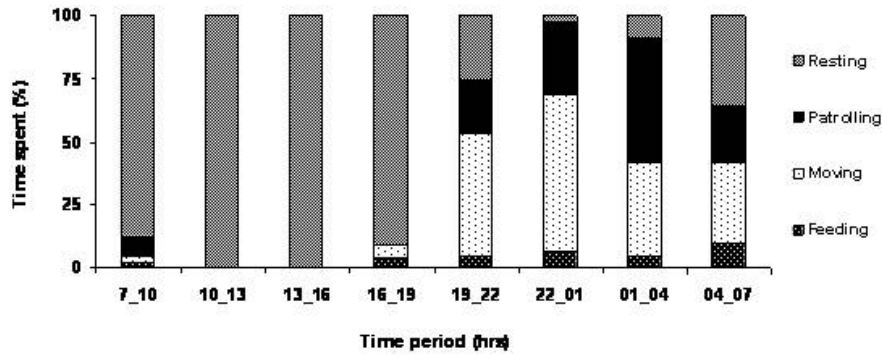
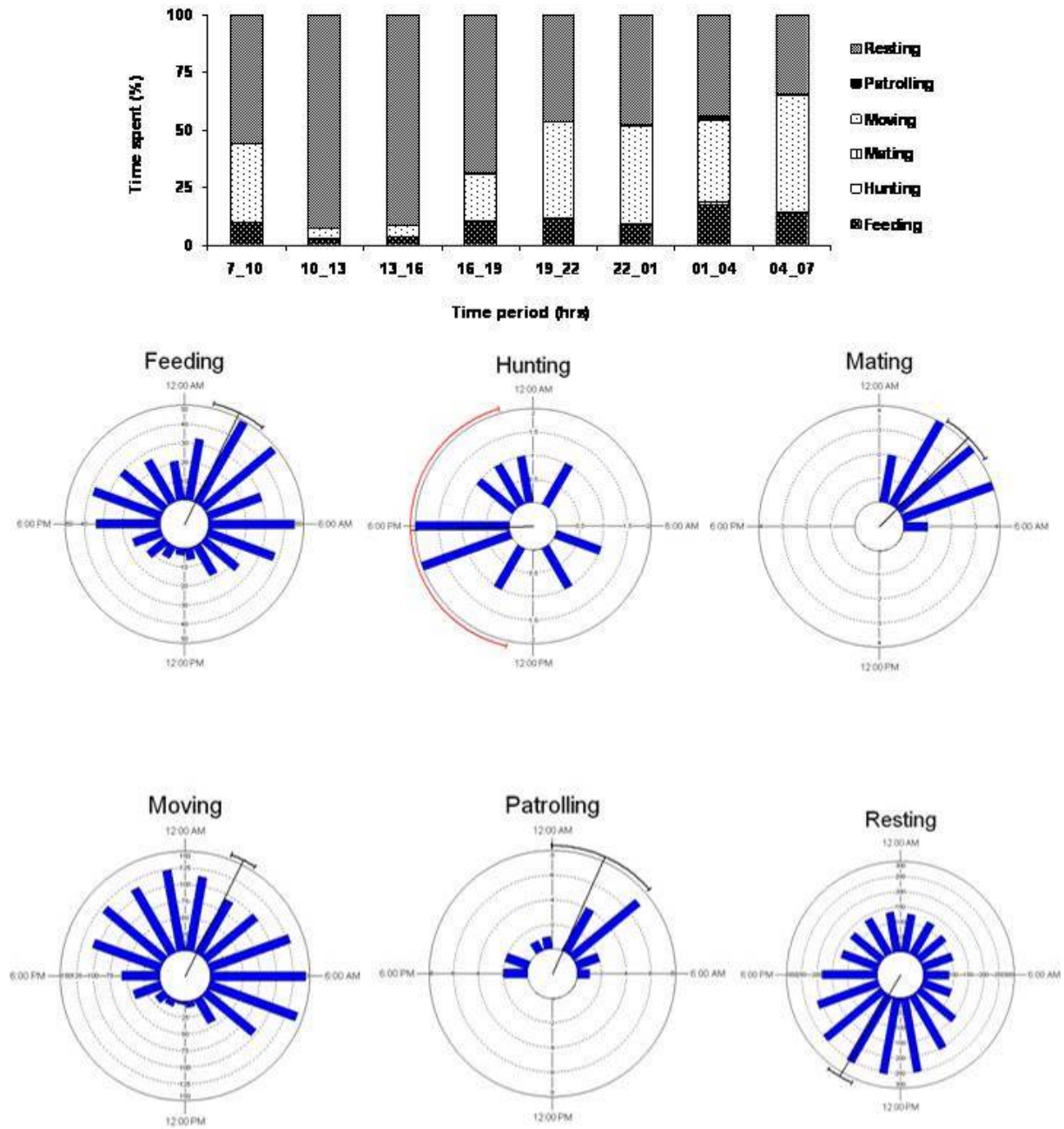




Figure 8.35: Proportional time spent by female lions in different activities during different times of the day and the related activity peaks deduced by program Oriana.





**Figure 8.36: Proportional time spent by female lions in dry season in different activities during different times of the day and the related activity peaks deduced by program Oriana.**

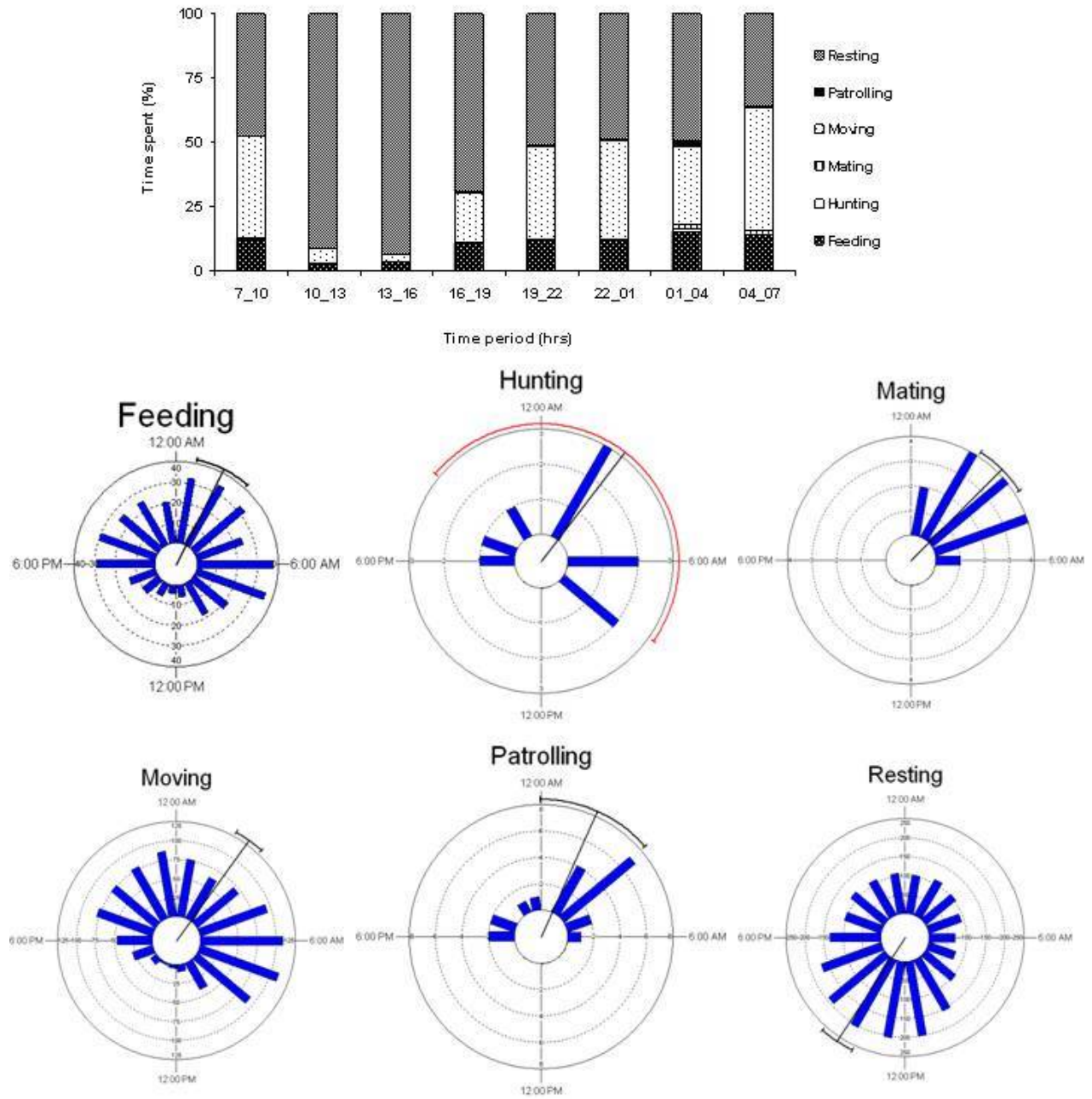




Figure 8.37: Proportional time spent by female lions in wet season in different activities during different times of the day and the related activity peaks deduced by program Oriana.

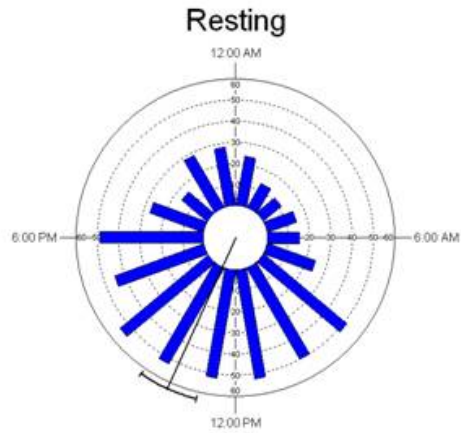
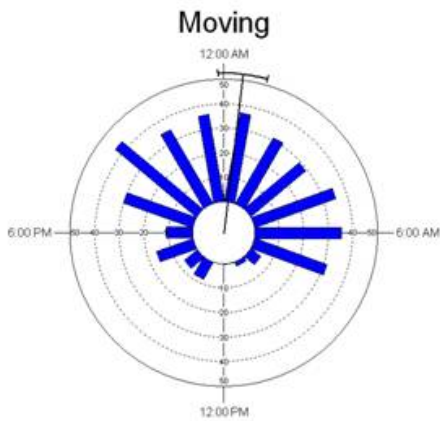
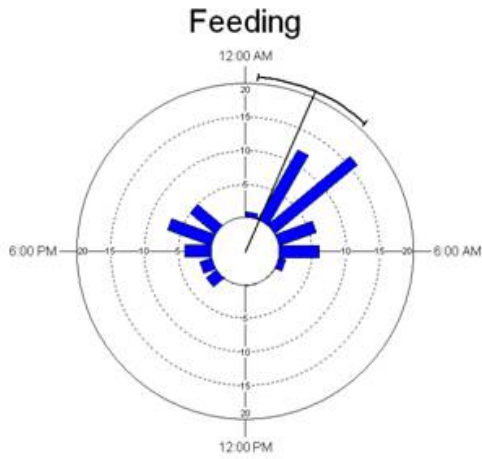
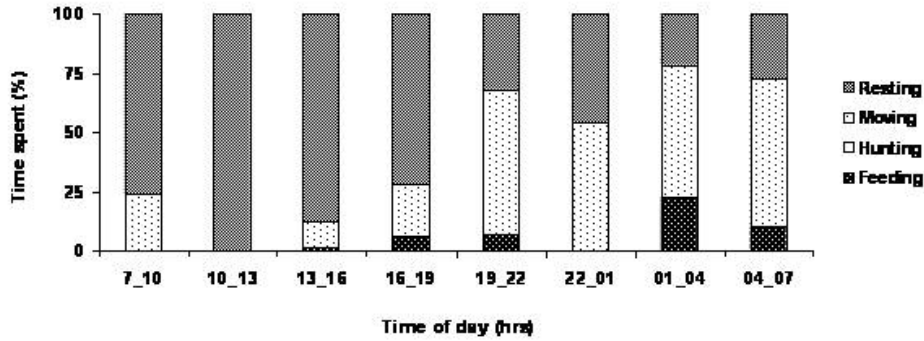




Figure 8.38: Proportional time spent by territorial males in different activities during different times of the day and the related activity peaks deduced by program Oriana.

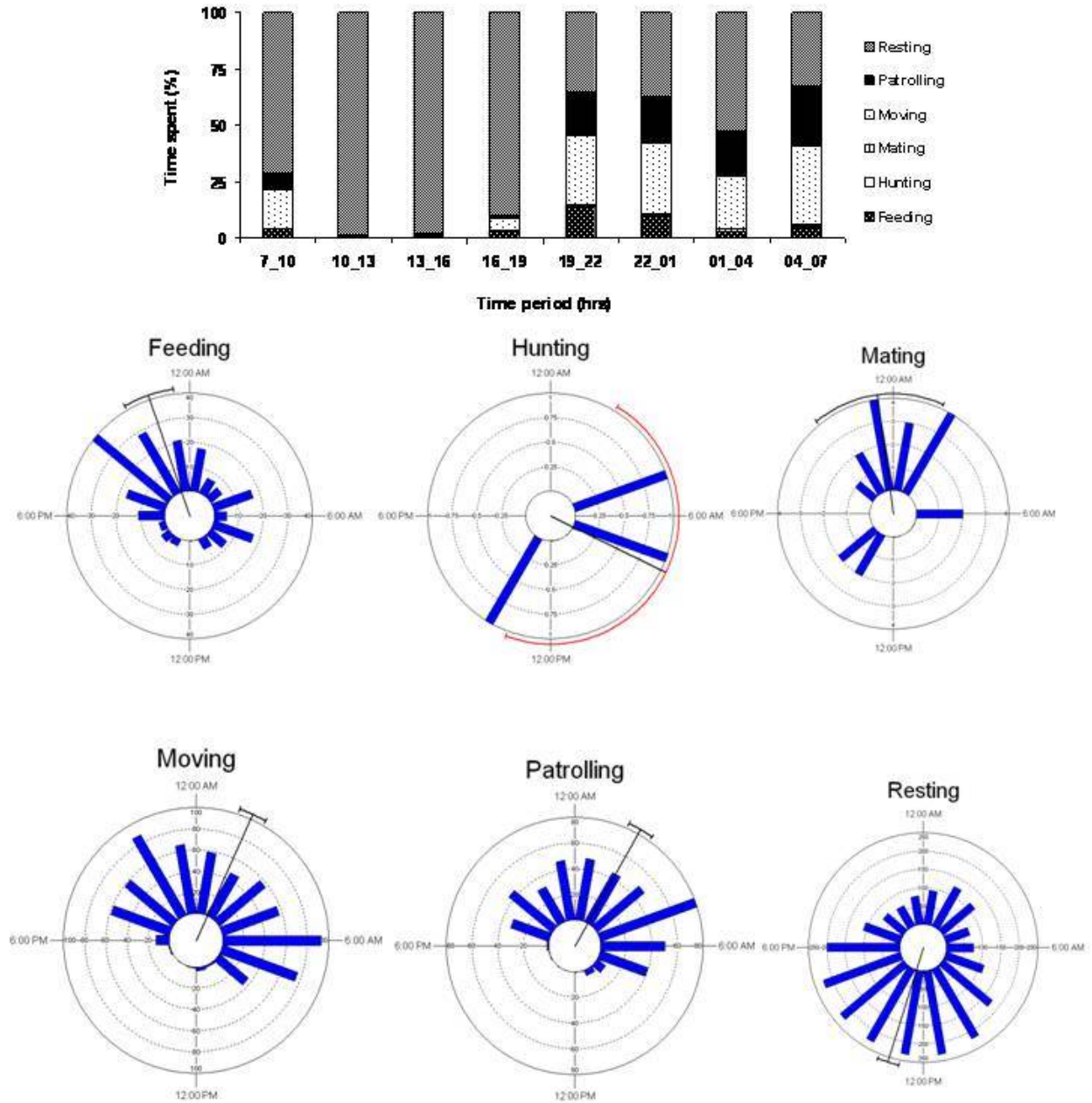
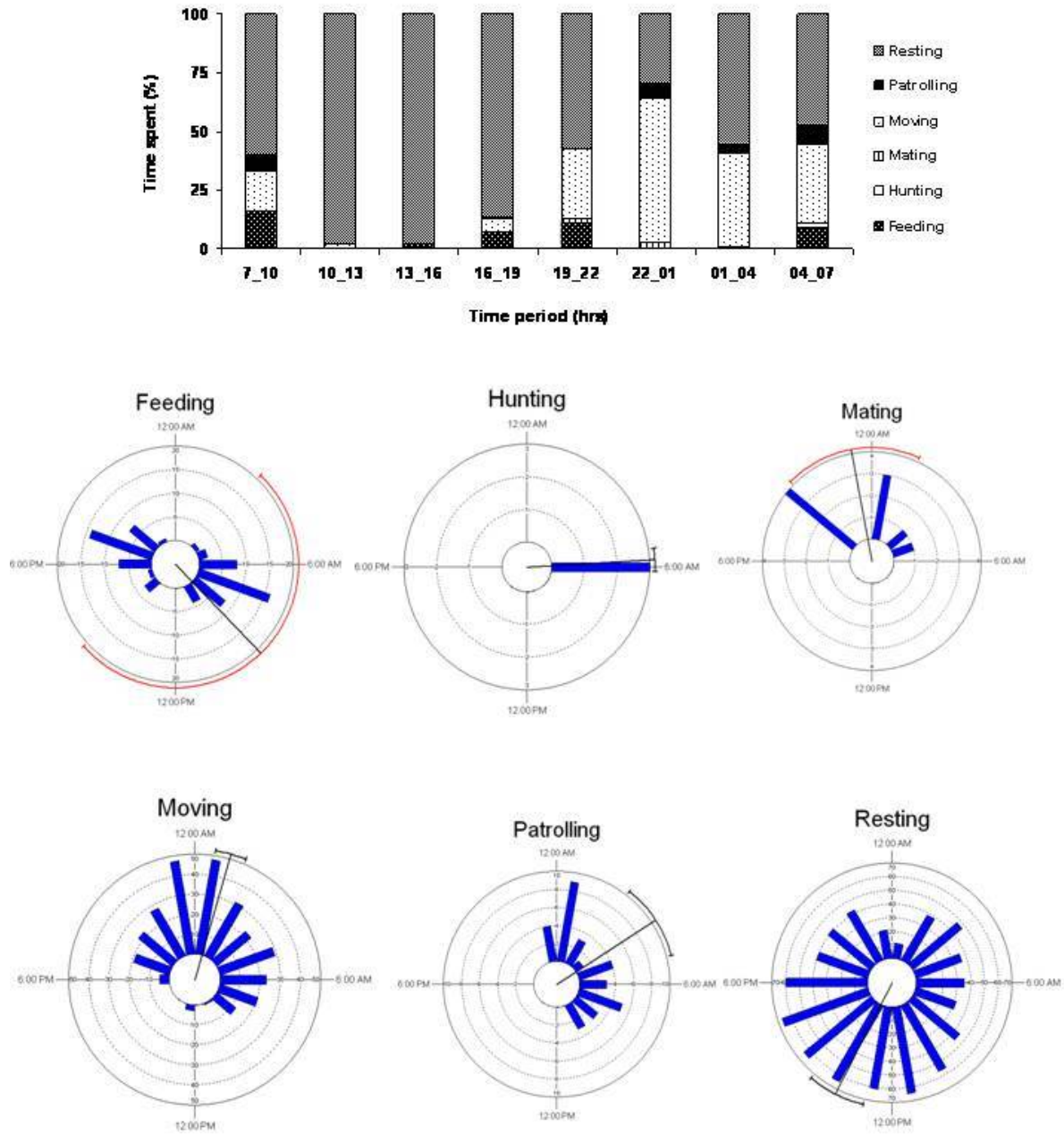




Figure 8.39: Proportional time spent by dispersing males in different activities during different times of the day and the related activity peaks deduced by program Oriana.





## Discussions

The current study gives an idea about lion home range sizes in an agro-pastoral ecosystem outside the Gir PA based on data collected by radio telemetry method. Shapes of the home-range area by number of observations curve varied between sexes. The home ranges of lions reached asymptote at different stages according to their social status, tenure durations and movement patterns. Estimates for individual home ranges reach asymptotes at different values and with a variety of curves, depending on the pattern of home range utilization and range size for that particular individual (Harris et al. 1990). Some lions reached an asymptote at a higher fix size; this may occur when the individual is a transient adult, a dispersing sub-adult, or when the time interval for calculating the home range is inappropriate (Harris et al. 1990). Sample size adequacy results showed that 117 (95% CI 91 – 143) locations for 100% MCP are needed to model lion space use area (**Figure 8.2**). This figure was higher than that (50 fixes) reported in an earlier study on the Asiatic lion (Meena 2008).

Dispersing young adult male M11 in Girnar had larger 100% MCP home range when compared to the mature females in Girnar but 95% MCP home ranges and core areas of M11 were within the range of the females (**Table 8.2**), suggesting that exploratory long distance dispersal movement outliers was well captured by 100% MCP estimators (eventually this individual dispersed into Gir PA).

Home range in carnivores is mainly influenced by prey and water availability (Gittleman and Harvey 1982; Van Orsdol et al. 1985; Viljoen 1993; Adams 2001). Lion home range size is negatively correlated with prey abundance during periods of prey scarcity (Van Orsdol et al. 1985) and this relationship is not linear (Carbone and Gittleman 2002); rather is exponential (Hemson 2003). Dispersion of prey and their spatial and temporal distribution are the important correlates of lion home range (Hemson 2003). However, these relationships may not apply when predation is related to preferred prey (Hemson 2003) or related to presence of competing species and anthropogenic factors (Bailey 1993; Caro 1994; Loveridge and Macdonald 2002). The Gir PA has a high density wild prey population (Dave and Jhala 2011) and about 23,000 livestock resident within the park and 95,000 in the periphery of the park (Singh and Gibson 2011). Therefore, drastic seasonal shifts in the lion ranges are not expected in the Gir PA. The relatively small home ranges of lions within the Gir PA in the dry season might furthermore be explained



by the high number and congregation of wild herbivores around the natural and forest department managed waterholes which retain water at this period and lions tend to stay around these waterholes. In the wet season, most of the rivers within Gir get fully or partially flooded. This brings the waterhole limitations of wild herbivores to an end and results in a widely dispersion of herbivores throughout and even outside the park causing a relatively larger lion range size. This finding is in accordance with a previous study (Meena 2008). However, Chellam (1993) did show a marginal difference in the lion ranges between the dry and wet season within the Gir PA. Seasonal variation in lion range sizes have been reported from many parts of Africa (Schaller 1972; Hunter 1998; Ogutu and Dublin 2004; Patterson et al. 2004; Van Rijssel et al. 2008; Visser et al. 2009).

On the contrary, water becomes a major limitation in the larger eastern landscape during dry season. With the landscape being human dominated and lower number of accessible water points by wildlife; lions tend to move more in search of water and prey resulting into larger range size during dry season. During wet season water in the landscape becomes uniformly distributed causing a reduction in lion range.

Lion home range size was large in agro-pastoral eastern landscape than the Gir PA likely due to the high prey abundance in the Gir PA. Relationship between home range size and food availability have widely been reported for lions and other mammalian carnivores (Gittleman and Harvey 1982; Van Orsdol et al. 1985; Viljoen 1993; Adams 2001). Gir PA had a higher wild ungulate [48 (SE 6)]/km<sup>2</sup> and livestock [25-31]/km<sup>2</sup> densities (Dave 2008) compared to Girnar [9 (SE 1)]/km<sup>2</sup> and the eastern landscape [19 (SE 1)] /km<sup>2</sup> (Banerjee 2012; Chapter 10, current report).

Protected areas (PA) offer the best the prospects for conserving viable populations of large carnivores. However owing to their large ranges carnivores have an increased probability of coming in conflict with humans; especially at the PA boundaries which often leads to their local extirpation (edge effect; Woodroffe and Ginsberg 1998). This is particularly true for reserves like the Gir PA (1880 km<sup>2</sup>) and Girnar (180 km<sup>2</sup>) that have high lion densities and are small in comparison to the resident lions' home ranges. This instigates lions outweighed in a territorial strife or the dispersing individuals to the human-dominated landscape and enhances the conservation significance of habitat refuges and connectivity (habitat corridors) in this larger landscape (see chapter 6 for more details) permitting long-term persistence of viable lion



population in a metapopulation framework. Information on lion core areas herein becomes valuable conservation tool as they represent the most intensively used portions of a lion home range (Bingham and Noon 1997; Seaman et al. 1999). The 85% fixed-kernel isopleths provided a reasonable generalized prediction for core areas of lion in the semi-arid Gir landscape. Average core area of Gir lions was estimated to be 166 (SE 40) km<sup>2</sup> and that of breeding lionesses was 85 (SE 17) km<sup>2</sup>. Most biologists acknowledge that reserves for wide-ranging carnivores should be large (Soulé and Simberloff 1986), but how large is difficult to say without case-specific information on habitat quality, distribution, prey populations, management practices and other human activities (Noss 1996). As a rule of the thumb, the minimum size of a conservation area must accommodate at least 20 breeding females' core areas joined in a metapopulation framework for ensuring a viable population (Funston 2002). Currently the Gujarat Forest Department has a proposal to develop a conservation reserve (IUCN category V) in the sub-optimal habitat types of the eastern landscape (Pathak et al. 2002; Singh 2007). Since the Gir landscape is predominantly human-dominated with land use priorities other than conservation, such well intentioned approaches are always fraught with oppositions from other lobbies and often end up compromising on conservation issues. The current study shows the distribution and size of the lion core areas and highlights their ranging across the entire Gir landscape. Information on these and lion habitat preference (Banerjee 2012; Basu 2013; Chapter 9, current report) therefore becomes useful tool for the management to delineate the parts of the landscape which need conservation priorities in terms of lion conservation.

Lions in the present study showed general behaviour with respect to range size comparable to those reported in previous studies in the Gir PA and elsewhere in Africa (**Table 8.11**). Joslin (1973) based on sightings of his study prides estimated the male (n = 2) ranges to be 131 km<sup>2</sup> and female ranges to be 77 km<sup>2</sup> within Gir PA. Chellam (1993) estimated average annual male (n = 2) range to be 217 km<sup>2</sup> and female range to be 122 km<sup>2</sup>. Meena (2008) estimated average male (n = 7) 100% MCP range area to be 74 km<sup>2</sup> and core area (50% FK) as 10 km<sup>2</sup> in Gir. Females (n = 4) had an average range (100% MCP) size of 34 km<sup>2</sup> and core area of 5 km<sup>2</sup>. Jhala et al. (2009) estimated average breeding lioness range (100% MCP) in Gir PA as 48 (SE 10) km<sup>2</sup>. The current study estimated the average 100% MCP home ranges of territorial males, females and dispersing males within the Gir PA as 84 (SE 13) km<sup>2</sup>, 56 (SE 12) km<sup>2</sup> and 577 (SE 182) km<sup>2</sup> respectively. In the larger landscape lion range sizes were larger but they are



within the range of reported lion range sizes from various parts of Africa (**Table 8.10**). Macdonald (1983) suggested that carnivores maintain a home range that is sufficient to provide necessary resources and this is the most likely single explanation for the variation in space use by lions in Gir and across Africa.

Female home ranges from neighbouring groups were relatively more exclusive compared to territorial male home ranges which overlapped. The land tenure systems of felids – whether they maintain exclusive or overlapping ranges – are highly varied (Sunquist 1981). In a situation where prey are widely distributed or tend to make extensive seasonal movements, carnivore ranges would likely to overlap with conspecifics. This is because the cost of maintaining exclusive rights to a large area becomes uneconomical (Schaller 1972; Hanby et al. 1995). Territorial males need to stay with a pride until their cubs are successfully sired to sub-adulthood and are no longer at high risk of being killed by other incoming males. Land tenure duration of male lions in Gir was about three years and is lower than lions in Serengeti (six years, Schaller 1972). This could be attributed to higher lion density (15/100 km<sup>2</sup> in the Gir PA, Jhala et al. 2004 and 12/100 km<sup>2</sup> in Serengeti, Hanby et al. 1995) and population turnover of resident males in the Gir PA. Moreover, the resident prey base in Gir compared to the migratory system in the Serengeti seems to promote high cub survival (chapter 4), and the dense vegetation offers numerous safe den sites and seems to assist pride females in avoiding foreign infanticidal males (Funston et al. 1998). This probably contributes to the lower land tenure duration of Gir lions in comparison with Serengeti males.

After successfully gaining a pride territory and fathering a cohort of cubs, male coalitions only retain possession for a few years before they are either driven out by another coalition, or give up their pride. Large coalitions may retain tenure over two or three adjacent prides simultaneously, but sometimes abandon one pride as soon as they claim another (Schaller 1972; Pusey and Packer 1987). Thus, territorial males may be expected to maintain two or more prides simultaneously, and most Gir coalitions did so as suggested from their range overlap with female cores from the adjacent prides. Old male lions in the Gir have been found to become territorial and father cohorts of cubs even after spending the whole life as nomads. In Gir, male ranges showed remarkable overlap (25% range overlap and 20% core overlap) in the case of two pairs of neighboring coalitions. Although ranges of the adjacent female prides showed overlap, Gir lionesses were more exclusive in defending their core area (**Figure 8.22**), a pattern also observed



**Table 8.10: Lion home ranges (100% MCP unless otherwise mentioned) and prey biomass density from different Protected Areas of Africa and previous studies in Gir PA.**

Lion reserve	Country	Lion home range size (km <sup>2</sup> )	Prey biomass density (kg/km <sup>2</sup> )	Study
Serengeti	Tanzania	Female pride: 20 – 400 Male: 39 - 275	4,222	Schaller 1972
Etosha National Park	Namibia	600	283	Stander 1991
Chobe National Park	Botswana	1,000	11,693	Cooper 1991
Serengeti	Tanzania	200	970	Hanby et al. 1995
Ngorongoro crater	Tanzania	45	15,660	Hanby et al. 1995
Selous Game Reserve	Tanzania	52	1,874	Caro et al. 1998; Spong 2002
Kruger National Park	South Africa	90% Adaptive kernel: 150	246	Funston et al. 2003
Makalali Conservancy	South Africa	95% FK: 25 - 107	2,888	Druce et al. 2004
Waza National Park	Cameroon	628	600	Bauer and De Iongh 2005
Karongwe Game Reserve	South Africa	95% FK: 76	5,225	Lehmann et al. 2008
Waza National Park	Cameroon	1,043	274	Van Rijssel et al. 2008
Hwange National Park	Zimbabwe	90% FK: Male: 478, Female: 388	2,312	Loveridge et al. 2007
Gir Protected Area	India	Male: 131, Female: 77	3,876*	Joslin 1973
Gir Protected Area	India	Male: 217, Female: 122	20,389; 7,506 (wild ungulates) **	Chellam 1993
Gir Protected Area	India	Male: 74, Female: 34	8,511***	Meena 2008
Gir Protected Area	India	Male: 84, Female: 56	8,511***	Present study; Banerjee 2012
Girnar	India	Male: 243, Female: 170	953	Present study; Banerjee 2012
Eastern landscape	India	Male: 621, Female: 129	1,212 (including domestic prey)	Present study; Banerjee 2012

\*estimates from Berwick 1974, \*\*estimates from Khan et al. 1996, \*\*\*estimates from Dave 2008



in the Serengeti lions (Schaller 1972), Kenyan leopards (Mizutani and Jewell 1998) and Namibian cheetahs (Marker et al. 2008). As female lions rear young by themselves, their reproductive success is closely correlated with the amount of energy they can allocate to reproduction and this is dictated by the food resources available during the rearing period. Therefore, food is the most important resource for females, and females will use space so as to maximize their chances of securing food resources. By contrast, the space used by male lions overlaps that of several females so as to maximize mating opportunities. Therefore male ranges will be larger than the space used by females. Since the space used by females has been selected based at least in part on food availability, the same space will also hold sufficient food for the male lions.

Distribution of conspecifics is known to influence ranging patterns as much as the habitat characteristic, dispersion and availability of prey (Sunquist 1981). This was evident in the Gir PA and the eastern landscape where areas occupied by males till mid-phase of my study period were later occupied by other males. This happened mostly because of the change in the social status of the resident males (either loss of coalition partner or dispersal or range restriction). Thus, home range is influenced by prey, female resource and presence of conspecifics for male lions. Although the concepts of territory and home range are applicable to lions, they are useful only if the complexities of male and female systems and the variation between prides are taken into account as the land tenure pattern of some females and all males change during the course of their lives (Schaller 1972).

Lion space use has a significant role in the mitigation of lion-human conflicts outside the Gir PA. Average farm size of the study area was  $0.1 \text{ km}^2$  ( $38 \text{ bigha} = 88,426 \text{ sq. meter}$  ( $@ 2,327 \text{ m}^2/\text{bigha}$ ) =  $0.1 \text{ km}^2$ ; see chapter 8 of the current thesis for more details). The mean annual home range size of lions in the agro-pastoral landscape was  $575 \text{ km}^2$ . Each home range could thus well incorporate 5,750 different farms during the course of the year. Considering an average group size of 1.6 (chapter 5, present report), this would lead to an estimate of 9,200 ‘lion-farm encounters’ in one home range alone. Bearing in mind the degree of female range overlap (30%), this would rise to about 12,000 ‘lion-farm encounters’ within one home range annually. Sightings of lions on multiple, discontinuous farms could mistakenly be taken as evidence for many lions in an area, whereas it could easily be the same lion or group of lions simply moving



through its range. It would overestimate local lion population numbers to the farmers based on their encounter rates. Farmers in the Gir landscape were often found to sight ‘many’ lions during their nocturnal farming activities and expressed antagonism against lion conservation (Banerjee 2012). Understanding the space use mechanism by lions in the agro-pastoral Gir landscape may assist the park managers to mitigate such conflict; real or perceived.

The conservation implication is not in home range size *per se* rather the constant turnover of range establishment and strife. These result in dispersal of lions from one area to another. The term “dispersal” includes both sub-adults establishing their territories as well as adult males dispersing and establishing to new areas. Dispersal has been identified to have three phases, namely, emigration (leaving the social group or natal territory), a transient phase of traveling through unfamiliar territory and immigration (establishing in a new place) (Wolff 1994). In the Serengeti it has been suggested coalitions disperse considerable distances (120km) (Schaller 1972; Bertram 1978; Hanby and Bygott 1987; Pusey and Packer 1987) while in the wooded environments they settle closer to their natal range (Funston et al. 2003). In Gir PA, the dispersal distance records were 16.5 km from centre of natal territory to area of initial dispersal and a distance of 37 km from centre of natal home range (Chellam 1993). Meena (2008) found dispersal distances due to shifts or establishment of a new territory for male lions ranged between 20 and 30 km. The current study found that the average distance of tenure shift was 21 (SE 5) km and was higher for lions in the eastern landscape [31 (SE 8) km] than lions within the Gir PA [11 (SE 4) km]. Reduced dispersal in Gir lions in comparison with the Serengeti lions can again be attributed to an even distribution of resident prey within the Gir PA. Long-term dispersal by males would be a costlier alternative for the Gir lions reliant on limited resources that are evenly distributed. On the other hand, since the eastern landscape is patchier in terms of resources (refuge and prey) therefore lions in this landscape showed relatively longer dispersion from their natal territories in comparison to the lions of the Gir PA. Average dispersal distance of the sub-adult males was 16 (SE 4) km. Considering the size of the Gir PA (20 km breadth and 70 km length) and high lion density within the PA it is evident that many of the dispersing lions are prone to establish their territories in the human dominated landscape making them more susceptible to anthropogenic pressures. Lions would therefore be expected to adapt by having smaller ranges, ranges with a greater overlap or exhibit increased dispersal outside the protected area. It is evident yet again that sub optimal habitats are very important for survival of the Asiatic



lions as shown in other studies (Hanby et al. 1995) and thus understanding spatial ecology (ranging patterns and dispersal events) is fundamental to effectively managing male lions that are transient associates of a pride.

The general mechanisms that decrease inbreeding (described by Pusey and Packer 1987) seem to be maintained in Gir lions even though males do not disperse far. All the sub-adult males during my study showed no or very little overlap with their natal territories. This becomes crucial in minimizing inbreeding with mothers and sisters in a genetically depauperate population like Gir lions.

The distance covered by lions in a single day varies in different areas. In areas of higher prey abundance, daily distance moved by lions belonging to prides varies from 5 to 7 km per day (Van Rijssel et al. 2008; Visser et al. 2009). However, in Kalahari, where prey density is low, lions move about 11 – 26 km per day (Eloff 1984). In Etosha, where there is seasonal variation in prey availability, lions walked an average of 13.2 km per day (Stander 1991). Social status of the lion is another factor determining movement of lions. In Serengeti, nomads were less sedentary than residents (Schaller 1972) and covered an average of 12 km per day. In areas where male lions are not constrained by the presence of other adjacent coalition males they tend to roam and cover large distances (Loveridge 2002). They are known to cover as much as 80 km in two days (Loveridge 2002). An earlier study of the Asiatic lion, assessed movement and home range of lions based on intensive monitoring of two prides and one male (Sinha 1987). Two prides consisting of four and three lionesses respectively were each associated with a two male coalition (Sinha 1987). Approximate estimate of movement and range of individually identified animals showed that adult males covered a maximum of 15 km in a day and an average distance of 3 km per day while adult females covered a maximum of 12 km in a day and an average distance of 2 km per day (Sinha 1987). Meena (2008) found that the territorial male in the Gir PA covered a maximum distance of 4.5 km in a single patrolling event. Sub-adults covered up to 13 km in a day. The current study estimated average nocturnal distance moved by lions as 7 (SE 2) km. Males moved more than females reflecting no territorial maintenance by females. Males and females in the eastern landscape moved greater distances than their Gir counterparts. This could be attributed to patchiness (lower availability) of appropriate refuge habitats (day time *refugias*) in the sub-optimal eastern landscape compared to the Gir PA.



Although, lions are considered to be nocturnal predators (Kingdon 1997; Stuart and Stuart 1997), few studies have been published so far on lion activity (Schaller 1972; Mills and Biggs 1993; Hayward and Hayward 2007; Van Rijjssel et al. 2008; Visser et al. 2009). Schaller (1972) reported that the activity patterns of both nomadic lions and pride members are remarkably similar. It peaks between 17.00h and 8.00h, although hunting, feeding and mating may occur at all times of the day (Schaller 1972). According to Schaller (1972) lions spent on average, two hours a day walking and 40 to 50 minutes of a day are spent eating. The rest of the day, between 20 to 21 hours, the lions are largely inactive (Schaller 1972). Hayward and Hayward (2007) found that lions were active throughout the day with crepuscular peaks around sunrise and sunset. They reported a lion activity of 41% during the day and hypothesized this high percentage to be caused by the lack of a pride. Gir lions spent majority (60%) of their time in resting and remained active for the rest 40% of the time. No seasonal difference was observed among lion activities. Males expectedly patrolled more than females. Hunting peaks of males and females coincided with the activity peaks of chital and sambar (Schaller 1967); two most preferred prey species of lions in the Gir PA. Moreover it also coincided with the onset and end of livestock grazing time in Gir. Livestock constituted a significant part of the Gir lions' diet (Banerjee 2012; Banerjee et al. 2013). *Maldharis* corral their livestock for night inside the nesses and livestock herds start grazing in the forest in the early morning. Lions mostly attacked grazing herds during this period as most of the livestock remained relatively inactive and herders remained unprepared. Again, during evenings some livestock became tired after whole day grazing and trailed behind the herd providing with the hunting opportunity for lions. The separated hunting peaks of males (early mornings) and females (evenings) (**Figures 8.32 and 8.35**) is likely to have evolved in the Gir lions so as to reduce kleptoparasitism as observed in the Serengeti cheetahs (Schaller 1972).

In a contradiction with Schaller (1972) we found a late activity peak (between 10:00 PM and 6:00 AM) in Gir lions. Movements and activity have been reduced or eliminated among carnivores living in urban, semi-urban or human dominated landscapes (Ciucci et al. 1997; McClennen et al. 2001) and this could be one of the reasons attributable to late activity peak in Gir lions. Even inside some parts of the Gir PA human activities (tourism, pilgrimage, commercial activities of pastoral *Maldharis*) continued till late evenings. Knowledge on lion activity pattern would thus be helpful in formulating future management policies aimed at



regulation of human activities within the Gir PA. In the larger landscape this has immense contribution in understanding spatio-temporal patterns of conflicts, especially lion attacks on humans (Banerjee 2012).

Studies on big cats have shown that the identification and protection of core areas alone is an insufficient strategy to ensure long-term species conservation; rather, long-term survival of populations of large carnivores is achieved in a metapopulation framework by protecting source populations (core areas) and at the same time providing dispersal opportunities by linking these populations (Hanski 1994). Connectivity between core areas ensures species survival through maintaining genetic variability and providing a source of individuals to offset losses caused by poaching, predation and accidents (Linkie et al. 2006; Jhala et al. 2011c). An economic progressive state like Gujarat is deficient in forests. Per capita forest area in Gujarat is 0.04 hectare compared to the national average of 0.07 hectare (Gujarat Finance Department 2008). The land-use pattern in the Gir landscape is changing at an unprecedented rate. Agricultural intensification, sedentarization of pastoralism, diversification of livelihoods and land fragmentation through privatization of land tenure are driven by dynamic socio-political, demographic and economic pressures. These resulted in the decline of the state's forest cover (of the state's geographical area) in the past one decade from 9.7% in 2001 to 7.46% in 2011 ([www.censusofindia.com](http://www.censusofindia.com)). These necessitate urgent strategic management interventions and legislations integrating the social, cultural and economic welfare of the region incorporating conservation of lions as an important goal in this landscape. If we intend to conserve lions in their natural habitats; holistic and innovative approaches to land use planning by considering Gir landscape as unit of conservation management that maintain connectivity between source lion populations is the need of the hour. The current chapter and information on lion resource selection (Chapter 9) are likely to have immense management significance. Robust and unbiased understanding of the lion space use, territoriality, movement and activity would surely help the park managers to formulate a future viable conservation policy for the Asiatic lions in a landscape of conflict and I see no end to the importance of such information in the conservation-management of many endangered carnivores in India and elsewhere on the globe.



## *CHAPTER IX*

### *LION HABITAT USE & RESOURCE SELECTION*

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#### **Introduction**

Understanding habitat use and the resulting spatial and temporal distribution of species along environmental gradients have repeatedly been topics of human interest. Historically, when human survival depended on hunting, predicting the presence of animals was crucial in order for a hunt to be efficient and successful (Lack 1933; Morrison et al. 2006). Nowadays, there is the desire to attain meaningful biological information to understand the underlying ecological mechanisms that affect species survival (Chefaoui et al. 2005). Where does a species occur and where could it occur are the two initial questions in wildlife conservation planning (Peterson and Dunham 2003).

During the past century human population has had an important role in the modification of environment, ecosystems and life-processes (William and Turner 1992; Turner 1996; Matson et al. 1997; Noble and Dirzo 1997; Sanderson et al. 2002; Wright 2005). It is often misconstrued among wildlife managers and certain groups of conservationists that most of the tropical biodiversity exists within its protected areas. Protected areas, on the contrary occupy less than 10% of the total area and a substantial amount of biodiversity still exists outside these (Schmitt et al. 2008; Gardner et al. 2009). Most protected areas in the tropics are either embedded in a heterogeneous matrix of land-uses or have human-modified landscapes within their boundaries (Bennett and Robinson 2000). Human-modified landscapes also serve as vital corridors for animal movement by connecting two distant and otherwise isolated protected areas while acting as buffers to the others (Bhagwat et al. 2008). In the landscapes lacking protected areas, these human-modified landscapes often provide critical habitats, and refuges for biodiversity (Petit and Petit 2003; Kumar et al. 2004; Bennett et al. 2006; Harvey et al. 2006; Raman 2006; Chazdon et al. 2009). As protected areas continue to shrink and human-modified landscapes continue to expand, conservation and research attention must be increasingly directed towards these heterogeneous landscapes if we are to conserve a substantial amount of biodiversity present on these lands (Vandermeer and Perfecto 2007). Such measures become imperative to balance between conservation goals and livelihood needs in an agrarian country like India having a



substantial amount of biodiversity in the human-dominated landscapes (DeFries et al. 2010; Karanth and DeFries 2010).

Habitat loss has been attributed as a major factor contributing toward the range shrinkage of the Asiatic lions during late 1800s. Since Gir PA had the only free ranging population of the endangered Asiatic lions, one of the objectives of the park management had been to increase the lion population in numbers and extent (Jhala et al. 2009). Owing to good protection and management, the lion population has increased at an annual rate of 2% during past four decades and increased their range to about 9,000 km<sup>2</sup> human dominated landscape (Singh and Gibson 2011; Banerjee and Jhala 2012). 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 (Jhala et al. 2004; 2009). The current study has already highlighted the importance of the agro-pastoral landscape as a potential habitat corridor for the future persistence of viable lion population in Girnar (Chapter 5) and proposed its management as an eco-sensitive zone (Banerjee et al. 2010). Moreover, my findings on lion space use have shown movement of lions in between the Gir PA, Girnar and other parts of the landscape (Chapter 8). It emphasizes that long-term survival of Gir lions can be achieved in the existing metapopulation framework by protecting source populations (Gir PA) and at the same time providing dispersal opportunities by linking these populations (Hanski 1994). This ensures lions' survival through maintaining genetic variability and providing a source of individuals to offset losses caused by stochastic events (Linkie et al. 2006).

Gir landscape is typically characterized by mosaic of farmlands, orchards, grasslands, fallow and waste lands interspersed with drainage, road and rail network. Land ownership is mixed with majority of the productive lands are private while the waste and fallow lands are chiefly government owned. Success of lion conservation in terms of increase in the species' extent has often been ascribed to the available refuge patches (grasslands, drainage cover and *Prosopis juliflora* thickets in the farmlands) in the region (Singh 2007; Singh and Gibson 2011). However, the traditional land-use pattern in the Gir landscape is changing at an unprecedented rate. With intense human population pressure in the region, vast chunks of refuge habitat patches, primarily the waste and fallow lands, are rapidly succumbing to the agricultural, industrial and eco-tourism needs. All these alter the fluidity of lion movements from Gir PA to other populations by fragmenting the landscape. Moreover, a decrease in suitable habitats in the landscape forces the



inferior competitors (sub-adults and old adult male lions) into sub-optimal habitats exposing them more toward anthropogenic threats. Currently the Gujarat Forest Department is planning to legally protect the landscape through designing Conservation Reserves and Eco-sensitive zones. Since conservation is not a major land-use objective in this human dominated landscape, therefore, such planning often gets into conflict with other powerful lobbies (like agriculture, mining, tourism) and results into a compromised implementation of the original proposed design. In the current chapter, we examined lion habitat use and resource selection at multiple scales in Girnar and the human dominated eastern landscape. Information generated herein will be of crucial importance for the management in planning land allocation for future lion conservation in the Gir landscape.

Global studies have identified the important roles of daytime habitat refuge patches in the conservation planning for an endangered carnivore (Gehrt et al. 2010). Availability, distribution and size of such refuges dictate carnivore movements and likelihood of conflicts with humans. With the recent escalated habitat fragmentation in the Gir landscape this spatial information becomes extremely crucial for future lion conservation. Since these patches are mostly embedded within inhospitable matrix of land-use patterns (human habitations, industries, roads, railways etc.) with all sorts of anthropogenic disturbances, therefore they are likely to enhance the probability of lion-human conflicts in the Gir landscape. In the current chapter we also deduced the daytime refuge habitat patch sizes for the Asiatic lions in the Gir landscape and attempted to understand their significance in the management of lions outside the Gir PA. We hypothesized that although lions could potentially range across all the habitat types, the core areas of their home ranges should act as refuges from human disturbances and have special characteristics that permit them to use a persist in the human-dominated Gir landscape. We also hypothesized that lions would require a larger day refuge patch in proximity to human habitations in order to avoid anthropogenic activities at the patch edges. Current chapter thus provides the biological basis for defining requirements of lions in terms of day light refuge as well as minimal patch sizes and their choice by breeding lionesses in 'sink' habitats. Based on the findings, land-use policies and viable lion conservation management planning can be designed and implemented.



## Methodology

### Field Methods and Analyses

We used radio-telemetry data to evaluate lion habitat use and resource selection in the Gir landscape (data collection methods described in details in chapter 8). Five thousand eight hundred and eighty four lion locations from nine radio-collared lions spaced across the landscape were used for habitat use analysis. To determine differential characteristics of habitat variables between intensively used core areas of lion ranges and general land use, we used ANOVA ( $\alpha = 0.05$ ; Zar 2010) on each of the variable with a 5 km<sup>2</sup> grid as the sampling unit. The main effects of ANOVA were the locations of the grid with a) inner core (50% FK), b) outer core (85% FK) and c) outside the core but within lions' home range. We used following eco-geographic variables for the analysis;

### Habitat and landscape data:

Information on environmental features was gathered from Geographic Information System (GIS) maps which were obtained from various sources.

*Habitat types:* For delineation of major habitat types in the Gir landscape, we used the Joint European Commission's Global Land Cover Database (GLC) for the year 2000 accessed from <http://www.gvm.jrc.it/glc2000> and (<http://www.gvm.jrc.it/glc2000/Products/fullproduct.asp> which was made freely available by CNES (Centre National d'Études Spatiales).

Vegetation instrument onboard Spot 4 satellite with four spectral bands blue (0.43-0.47mm), red (0.61-0.68mm), infrared (0.78-0.89mm) and short wave infrared (1.58-1.75mm) at a spatial resolution of 1 km and temporal resolution of 1 day were used for vegetation mapping at a continental scale. For India, a mosaic of 18 land use/land cover (LULC) classes was prepared by the Indian Institute of Remote Sensing. We followed this and reclassified these LULC classes which are applicable for the Gir region and relevant for lion conservation (**Figure 9.1**). These are:

#### A. **Tree Cover, broadleaved, deciduous, closed (abbreviated as closed deciduous):**

Represented mostly by riparian habitats in Girnar and plantations and government nurseries. The dominant species is *Tectona grandis* with association of *Anogeissus latifolia*, *Dendrocalamus strictus*, *Butea monosperma*, *Mitragyna parviflora*, *Syzigium cumini*, *Terminalia* spp., *Dalbergia* spp., *Ficus* spp. and *Diospyros melanoxylon*. The understory is dense and mainly composed of *Helicteres isora*, *Carissa carandas*, *Capparis sepiaria* etc. This LULC class is the densest and has the highest canopy cover.



- B. Tree Cover, broadleaved, deciduous, open (abbreviated as open deciduous):** Represented by *Acacia nilotica*, *Acacia senegal*, *Acacia catechu* and *Acacia leucophloea* with association of *Ziziphus* spp., *Sterculia urens*, *Lannea coromandalica*, *Pongamia pinnata*, *Holeptelia intigrifolia*, *Boswellia serrata* and *Terminalia* spp occurring in Girnar, Mitiyala, Pania sanctuaries and reserve forests in the landscape.
- C. Scrubland:** Represented by thorny woodlands and scrublands in the landscape. This LULC class is mostly dominated by *Zizyphus nummularia*, *Acacia senegal* and *Prosopis juliflora* occurring in the reserve forests and their peripheries, wastelands and fallow lands of the landscape.
- D. Grasslands:** Represented by government and private owned *vidis* in the landscape. The major grass species include *Sehima sulcatum*, *Apluda mutia*, *Heteropogon contortus* and *Cymbopogon* spp.
- E. Agriculture:** Represented by irrigated and rainfed agricultural lands and natural vegetation outside a PA. This is the major land-use pattern in the landscape characterized by sparsely covered seasonal crops and orchards. Main crops include ground nut, cotton seed, wheat, sugarcane, pulses and spices. Saurashtra is famous for indigenous *Keshar* breed of mangoes and these orchards however provide good refuge covers. In some part of the landscape (Shail and Shetrunjee basins) most of the agricultural lands are fallow as farming becomes expensive for farmers due to lower rainfall and lack of proper irrigational facilities. These farmlands are chiefly dominated by *Prosopis juliflora* thickets which are used for charcoal manufacturing and serve as good refuge for lions.
- F. Barren lands:** Includes rocks and escarpments is mostly represented by the limestone mines in the landscape. Abandoned mines are often known to provide shelter to lions and other wildlife in the Gir landscape.

The percentage available area of each land-use type was calculated for each grid in the landscape.

*AVHRR-NDVI*: Normalized difference vegetation index (NDVI) composites with a 10 day interval were derived from a the 1 kilometer advanced very high resolution radiometer (AVHRR) data acquired by National Oceanic and Atmospheric Administration's (NOAA) Television Infrared Observation Satellite (TIROS; Townsend 1994). The relationship between NDVI and photosynthesizing vegetation is well documented (Eidenshink 1992). NDVI has been



used to monitor vegetation response and to determine changes in vegetation cover over time. NDVI maps have been used to locate urbanizations, forests, vegetation phenology, crop cycles, and agricultural practices.

Gir is a typical agro-pastoral landscape where the major economy is farming. Cropping pattern in the region mostly depends on rainfalls during monsoon. Different crops on the other hand serve differently as habitat refuge for lions in the landscape. To understand the impact of cropping pattern in the region on lion habitat use, we extracted the mean value of pre-monsoon (April and May) and post-monsoon (September and October) NDVI for each grid.

*Digital elevation model (DEM):* The Shuttle Radar Topography Mission produced the most complete, highest resolution digital elevation model of the Earth (Rodriguez et al. 2005). It used dual radar antennas to acquire interferometric radar data, processed to digital topographic data at 1 arc-sec (approximately 30m X 30m) resolution. The data has linear vertical absolute height error of less than 16 meter (Rodriguez et al. 2005). We used DEM data (mean and variance of elevation) from the website [www.glcf.umiacs.umd.edu/data/srtm](http://www.glcf.umiacs.umd.edu/data/srtm) and extracted in Arc GIS in order to understand the influence of elevation and ruggedness in lions' resource selection in the Gir landscape.

*Night light data for delineating human habitations:* Night light data was obtained from NOAA/NGDC and used to delineate human habitations in the landscape. Data was collected by Defense Meteorological Satellite Program's Operational Line Scan System (DMSP/OLS) for a pixel size of 2.7 km X 2.7 km. The visible (0.47 – 0.95  $\mu\text{m}$ ) and near infrared (VNIR) spectral bands which are sensitive to the night-time lights of cities, towns, fires, lightings etc. are useful in mapping human habitations (Elvidge et al. 1997). The high contrast between lit and unlit areas and the sensor's spatial resolution makes it an ideal tool to identify regions with intense human activity.

*Roads and drainages:* The major roads and drainage maps of the digital chart of the world (ESRI 1992) for the landscape at a scale of 1: 1000,000 were used. Euclidean distances from lion locations were generated using Arc GIS.

*Protected Areas:* The locations of the Protected Areas, National Parks and Sanctuaries were obtained from the Wildlife Database cell of the Wildlife Institute of India (<http://www2.wii.gov.in/nwdc/index.html>). Euclidean distances from PAs were generated using Arc GIS.



### **Compositional analysis**

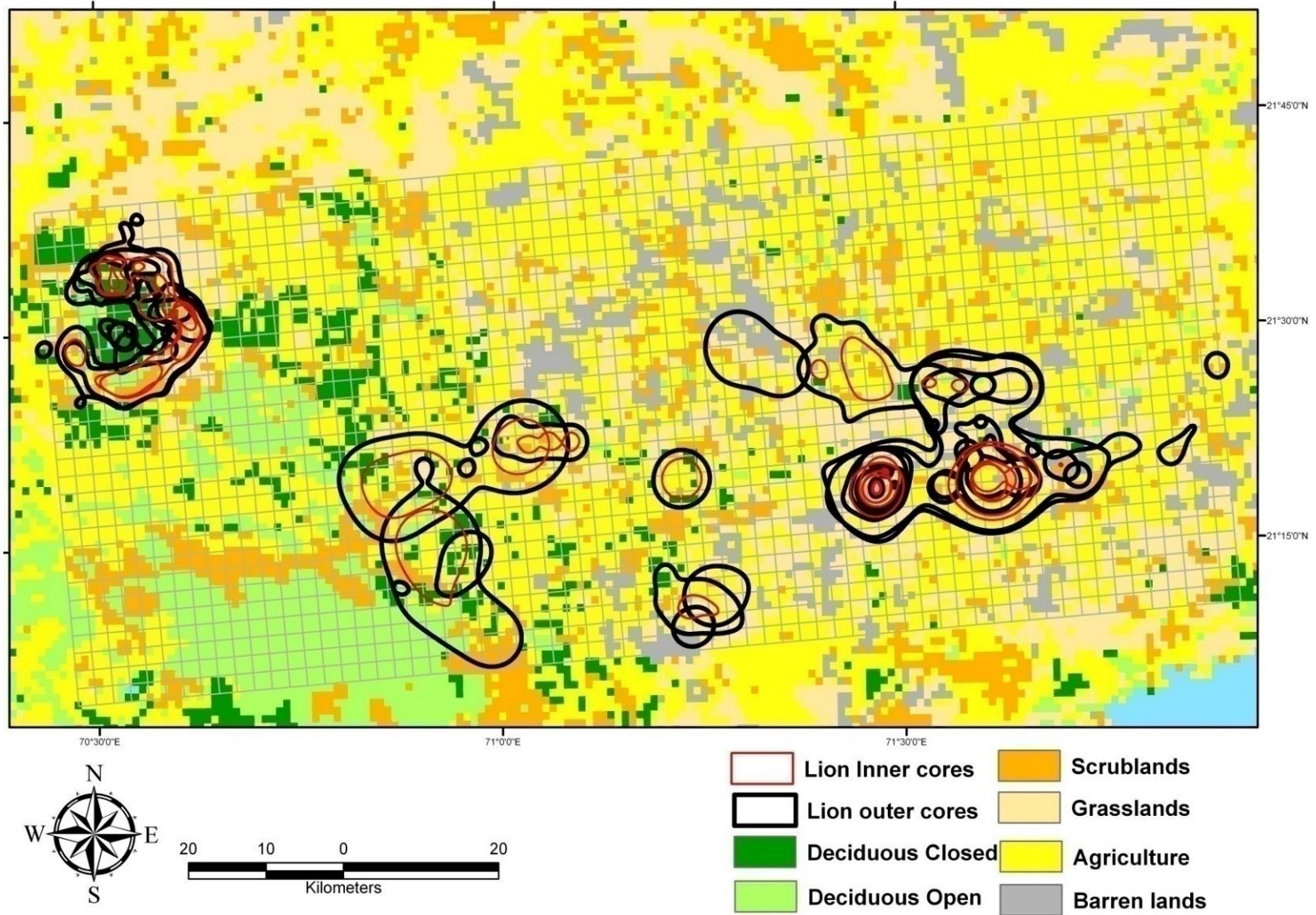
Second order resource selection function was used to understand the habitat selection of lions in the study area. We defined the extent of my study area in the Gir landscape by plotting a minimum convex polygon around the 100% MCP home ranges of all the study lions. Compositional analysis (Aebischer et al. 1993) was followed to determine the resource selection of lion in the study area at the levels of inner core and outer core, but with a modification that assigns values based on the UD of each animal in the study area (Millsaugh et al. 2006). In this way, an individual's use of the habitat is defined by the proportion of mean UD volume in each habitat type within the overall study area combining the home ranges of all lions (Millsaugh et al. 2006). A Resource Selection program for Windows (RSW; Leban 1999) was used to conduct the compositional analysis.

### **Estimating lion refuge patch size**

Day time lion locations were plotted on a GIS map and program Fragstats version 3.3 (McGarigal and Marks 1995) was used to estimate the mean refuge patch sizes. A cell size of 100 meter was chosen and patch neighbor was fixed at 4 in order to allow the program to scan at a higher resolution for contiguous forest patches. Patch sizes were deduced for male lions, breeding lionesses and overall lions. We compared the mean patch sizes for locations proximal ( $< 1$  km) to human habitation centroids with patch sizes for distant ( $> 1$  km) locations by non-parametric tests.



Figure 9.1: Various land-use classes in the Gir landscape showing distribution of lion core areas (85%FK and 50% FK).



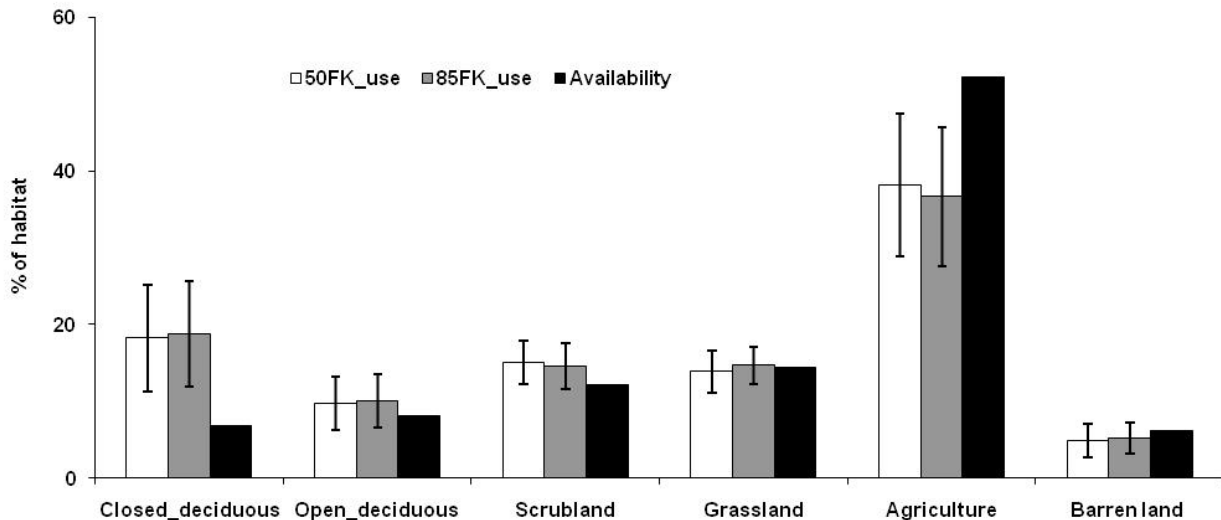


## Results

### Compositional Analysis

The total area of available lion geographic range was estimated to be 5,475 km<sup>2</sup> in the Gir landscape. Lions in the Gir landscape mostly used agriculture followed by closed deciduous forests within their inner and outer cores (**Figure 9.2**). Results of the compositional analysis showed that lions seemed to exhibit preference for certain habitats for inner cores ( $\chi^2 = 23.63$ ,  $df = 5$ ,  $p < 0.001$ ) as well as for the outer cores ( $\chi^2 = 41.92$ ,  $df = 5$ ,  $p < 0.001$ ). The order of habitat preference for both the inner and outer cores was scrublands > grasslands > deciduous closed forests > agriculture > deciduous open forests > barren lands.

**Figure 9.2: Use and availability of different land-use types for lions' core areas in the Gir landscape. Error bars are standard errors.**

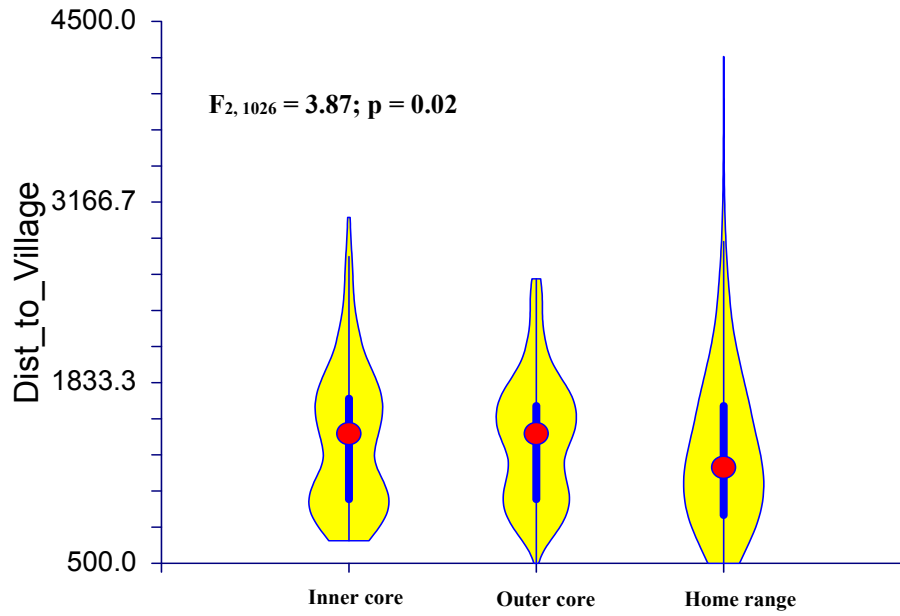


### Influence of different habitat variables on lions' core area selection

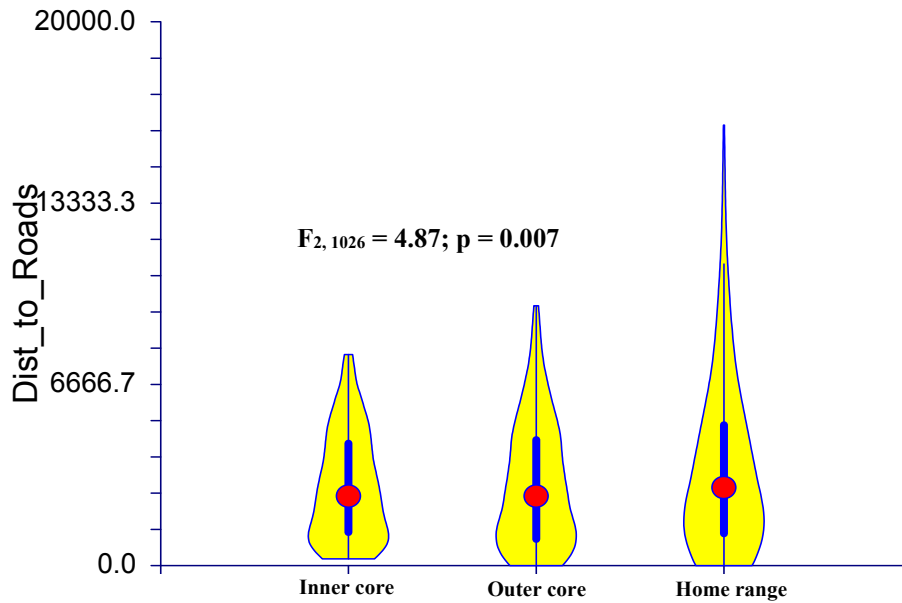
All the landscape variables were found to be significantly contributing toward lions' choice of home ranges and cores within the Gir landscape. Lion core areas were further from villages and townships but were closer to drainages, protected areas and denser vegetations (**Figure 9.3 – 9.8**). The cores were at higher elevations but with less rugged terrain (**Figure 9.9 and 9.10**).



**Figure 9.3: Influence of villages explaining lions' core selection in the Gir landscape.**

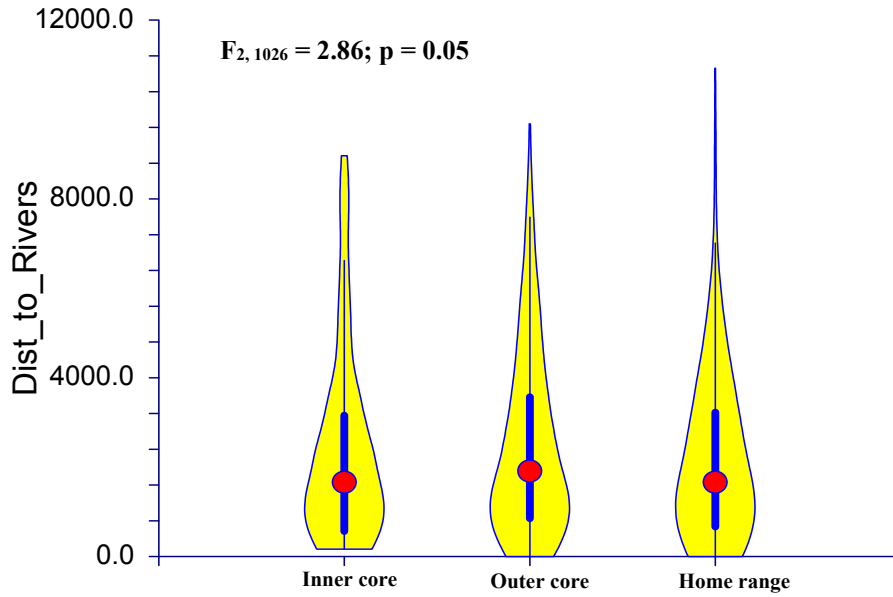


**Figure 9.4: Influence of roads explaining lions' core selection in the Gir landscape.**





**Figure 9.5: Influence of rivers explaining lions' core selection in the Gir landscape.**



**Figure 9.6: Influence of human habitations (delineated by night lights) explaining lions' core selection in the Gir landscape.**

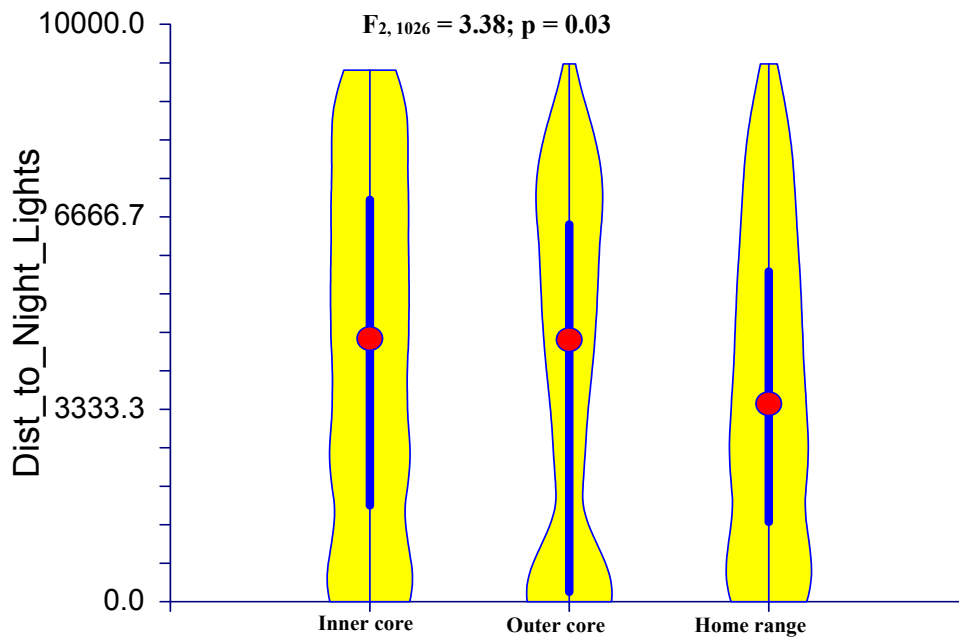




Figure 9.7: Influence of Protected Areas explaining lions' core selection in the Gir landscape.

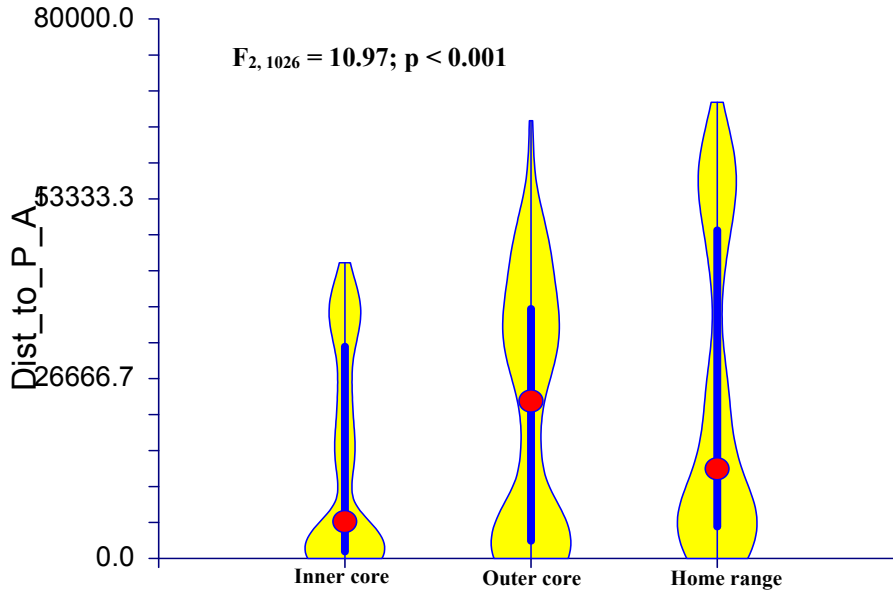
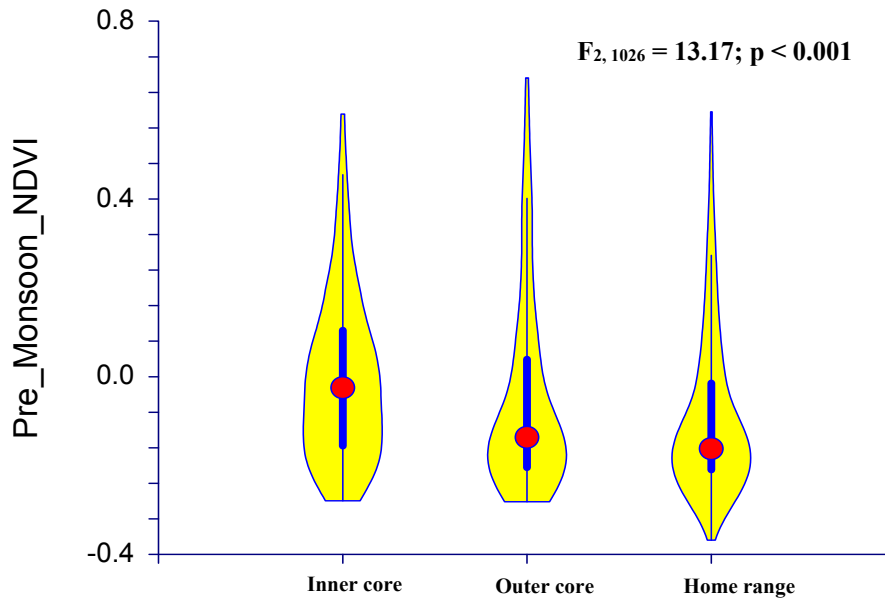
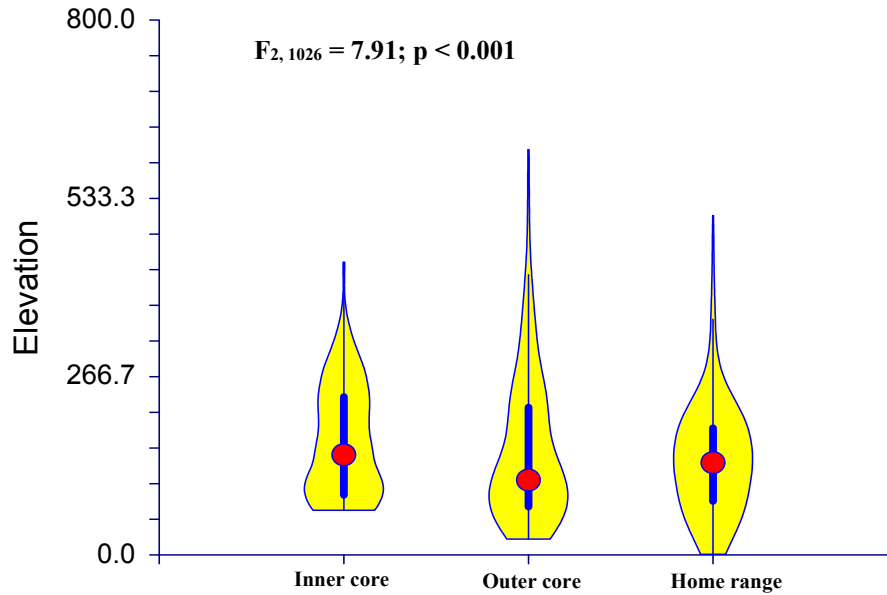


Figure 9.8: Influence of pre-monsoon NDVI explaining lions' core selection in the Gir landscape.

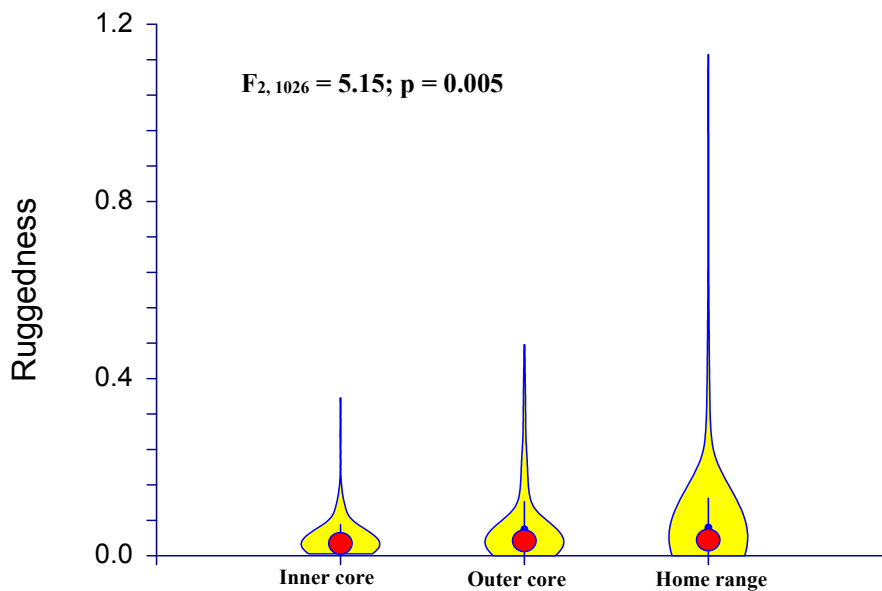




**Figure 9.9: Influence of elevations explaining lions' core selection in the Gir landscape.**



**Figure 9.10: Influence of terrain ruggedness explaining lions' core selection in the Gir landscape.**



**Lion day time refuge patches size:** Average day refuge patch size of lions in the eastern landscape was estimated to be 7.5 km<sup>2</sup> (SE 0.74; range: 0.07 km<sup>2</sup> – 21.5 km<sup>2</sup>). Breeding lionesses had similar sized day refuge patches (3.8 km<sup>2</sup>, SE 1.7; range: 0.4 km<sup>2</sup> – 5.5 km<sup>2</sup>) like adult males (7.6 km<sup>2</sup>, SE 0.77; range: 0.07 km<sup>2</sup> – 21.5 km<sup>2</sup>) [ $t = 0.95, p = 0.34$ ]. Minimum patch



size in which a lioness reared her cubs successfully was 4.3 km<sup>2</sup>. Refuge patch size did not vary in size for lion locations proximal (9.5 km<sup>2</sup>, SE 1.71; range: 0.33 km<sup>2</sup> – 21.5 km<sup>2</sup>) or distant (7 km<sup>2</sup>, SE 0.82; range: 0.07 km<sup>2</sup> – 21.5 km<sup>2</sup>) to human habitations ( $t = 1.25$ ,  $p = 0.21$ ). **Figure 9.11** shows the smallest day time refuge patch size of lions near Savarkundla and Chalala while the largest day time refuge patch was represented by Mitiyala wildlife sanctuary near Khambha (**Figure 9.12**).

## Discussions

The resource selection analysis was done by a second order compositional analysis (Vanak and Gompper 2010) and also related to Johnson's (1980) rank based method. Agriculture was found to be the most available land-use type for lions (52%) in the landscape and lions are also found to use agricultural areas substantially (36-38% of UD-weighted selected habitats). A similar pattern has been reported by Jhala et al. (2009) where breeding lionesses in the Gir PA were found to venture into peripheral farmlands at nights in search of livestock. Compositional analysis is a comparison of used habitat types against available habitats. The areas of *Prosopis* scrublands and grasslands are less in the total available habitat for lions in the Gir landscape, but considering kernel utilization distribution these land-use types are used more than their availability, thereby ranked as most preferred habitat by lion in the study area.

The study highlights the importance of dense canopied forest in the dry deciduous forest of Girnar (**Figure 9.2**). The submergence areas of the water reservoirs in Girnar (Hasnapur, Datar, Rawatsagar, Maccharia and Passwala) are dry during summers providing lions with the most mesic and thick canopied habitats as day time shelter from scorching sun. This is in contrast with the lions in the East African plains where they are mostly open savanna specialists (Schaller 1972). However, a similar pattern of habitat preference has been observed in the Gir PA (Chellam 1993; Meena 2008; Jhala et al. 2009) and elsewhere from South and West Africa (Smuts 1978; Yamazaki 1996; Funston et al. 2003) where lions mostly preferred riverine patches. Dense habitat types of Girnar are chiefly offshoots of plantation works (and till date continued) initiated by the forest department in mid 1980s aiming at the eco-restoration of the degraded habitats (Lal 2000; Parmar 2005) within Girnar. Area of dense forests in Girnar has increased from 32% of the park's area in 1986 to 74% of the park's area in 1997 (Lal 2000) and



Figure 9.11: Minimum day time habitat refuge patch (0.07 km<sup>2</sup>) for lions in the Gir landscape embedded within human habitations, road network and rivers.

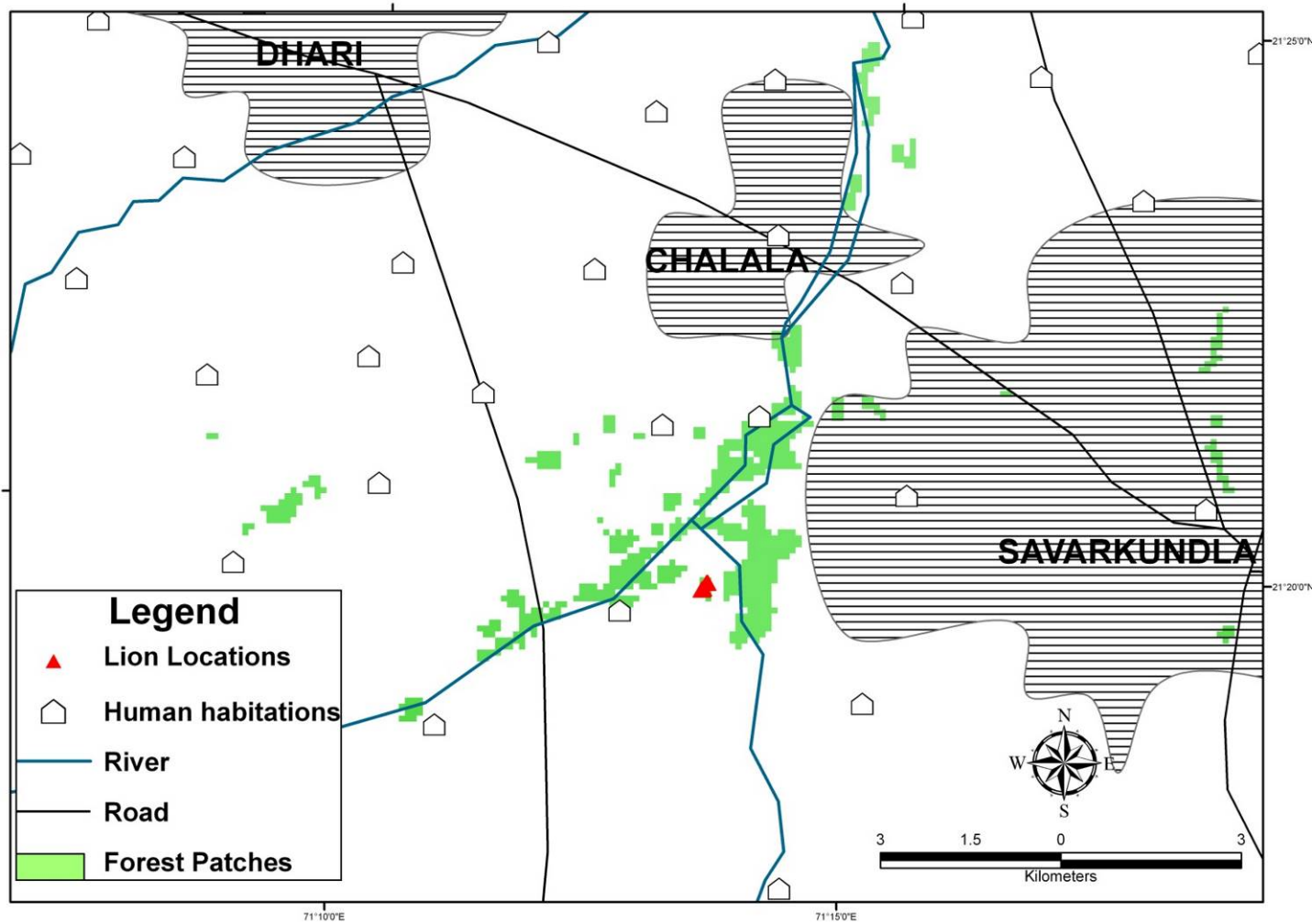
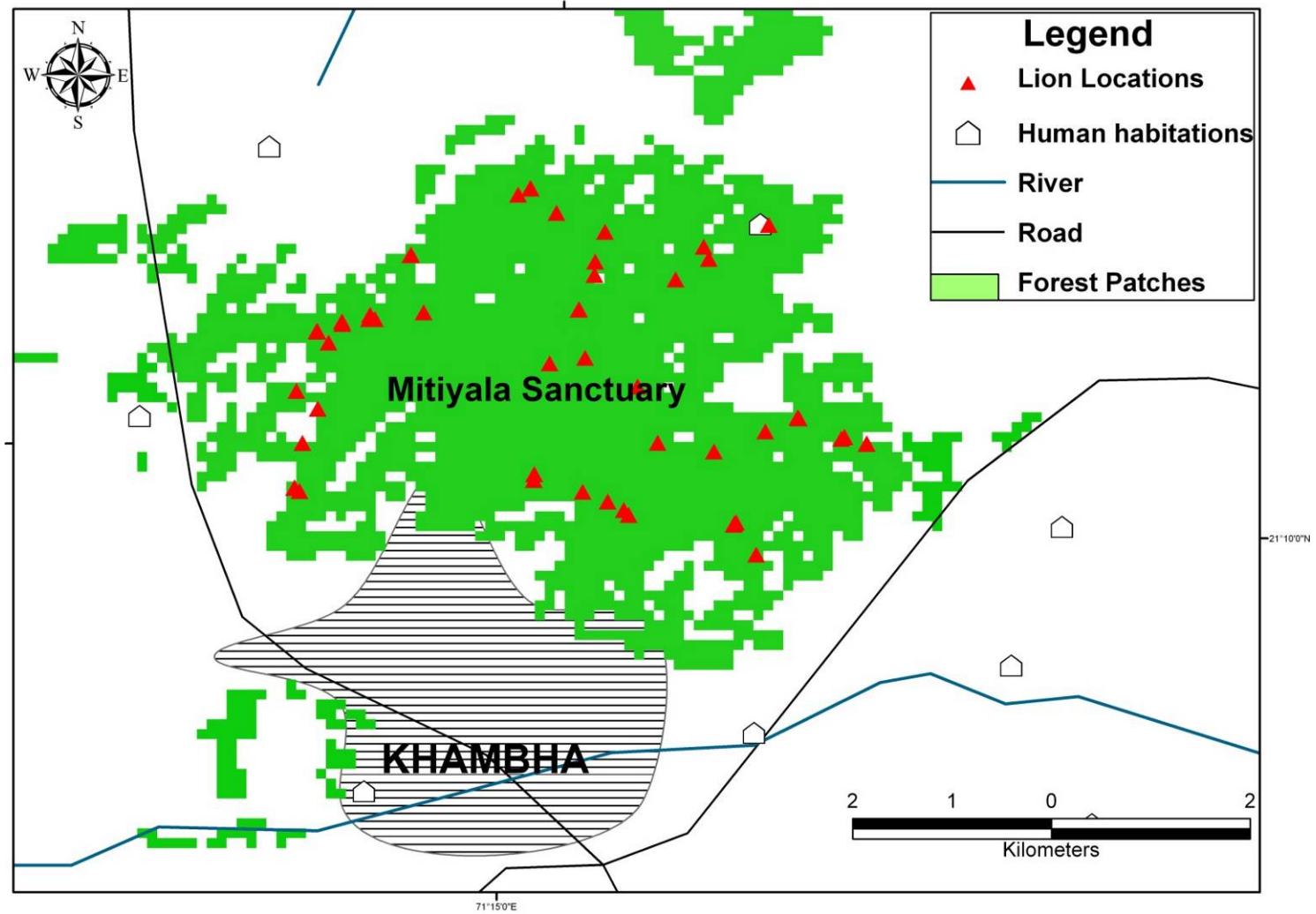




Figure 9.12: Largest day time refuge patch (21.5 km<sup>2</sup>) of lions in the Gir landscape represented by Mitiyala Sanctuary.





the current study showed the importance of this forest type in lions' habitat use. Leopards in Girnar also showed a significant correlation with these dense canopied forests (Basu 2012).

Considering the high biodiversity value and ecological role of this forest type, we recommend conserving this land-cover type against all possible threats. However, dense habitat types in Girnar could be planted with miscellaneous species like *Zizyphus* spp., *Acacia* spp. and *Terminalia* spp, having 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 and leopards.

Open woodlands characterized by *Acacia* spp. were also found to be used extensively by Girnar lions. This could be because of higher encounter rates of wild ungulates species in open forests and scrublands in the southern and eastern peripheries of Girnar (more details in chapter 10). Wild ungulates form the majority of lion's kills in Girnar (chapter 10 for more details). Although sambar population in Girnar has increased in the past one decade (chapter 10 for more details) in comparison to an earlier study (Dharaiya 2001); density of other wild ungulates are still low. Girnar has high lion (6/100 km<sup>2</sup>; Banerjee et al. 2010) and leopard (19/100 km<sup>2</sup>; Basu 2012) densities. At near carrying capacities, lack of sufficient wild prey in Girnar is likely to compel lions and leopards to raid livestock from the peripheral villages thereby increasing conflicts with humans. Gujarat forest department had initiated a restocking program from the Junagadh-Sakkarbaug Zoo for wild ungulates in Girnar which was later suspended abruptly. We propose a resumption of the restocking program (especially chital and sambar) in order to assist the wild prey population in Girnar to build up. However, such program should be reinitiated only after carefully scrutinizing the carrying capacity of various habitat types in Girnar for different wild and domestic ungulate species and a good health check programs for animals to be restocked.

Scrublands and grasslands played important ecological roles for lion resource selection in the Gir landscape. The *Zizyphus* patches allow a number of good palatable grasses to grow under it, such as *Heteropogon contortus* and *Cynodon dactylon*. These grass species along with fallen *Zizyphus mauritiana* leaves and fruits which contain high protein (Sankar 1994), influenced assemblage of a number of prey species of lion (chital, sambar and nilgai). *Prosopis juliflora* thickets in the fallow lands, waste lands and pasture lands and the grasslands (*vidis*) embedded



within the human-dominated landscape act as important day refuge patches for the wild ungulates and eventually to lions.

Topological feature like elevation and ruggedness in Girnar probably served as important niche separation mechanisms between high density lions and leopards. The current study showed that lions in Girnar avoid rugged terrains and mostly use valleys whereas leopards in Girnar were found to use all degrees of elevations (Basu 2011). Even other studies have also identified leopards using higher elevations (Schaller 1967; Mondal 2011). In the larger landscape too, ruggedness depicted by broken terrain and relief networks was found to be influential behind lions' choice of cores. This was further supported by nearer distances of lions' cores to rivers in comparison to their overall home ranges. However in the eastern landscape impact of elevation on lion resource selection may be limited by resolution of the DEM dataset (30 meter). Most of the reliefs in this landscape were less than 20-25 meters in elevation and therefore may not get reflected in the current analysis.

In the Gir landscape, lions' inner cores were nearer to the PAs (forests) while further from human habitations in comparison to their overall home ranges. Inner core is an area within a lion's home range exclusively maintained for breeding and cub rearing. Human disturbances may have detrimental effect on cub survival by enhancing the likelihood of conflict and cub mortalities. Moreover, major prey species of lions in the Gir landscape (nilgai and wild pigs) are 'edge' living during daytime while raiding the croplands at nights. Lions' selection of inner cores near forests increases breeding lionesses' chance of predating these species and enhance their reproductive success.

However, lions' home ranges were closer to human habitations. This might be because of higher scavenging opportunities near the villages. Nilgai are mostly found in the agricultural lands at nights while domestic prey is found in the villages. Domestic ungulates are always more vulnerable to lion predation (Banerjee et al. 2013). This often proves profitable for lions maximizing prey capture per unit effort. Moreover, my study area within the eastern landscape has several cattle camps (*Gaushalas* and *Panjrapoles*) housing thousands of ill and abandoned cattle and lions obtained a substantial part of their diet by scavenging the carcasses (chapter 10 for more details). Large sized domestic prey like buffaloes and cattle also provided lions with sufficient food for maintaining the group sizes and social organization in comparison with



smaller sized wild ungulates. All these explain lions' choice of areas near human habitations for their ranging.

Cropping pattern in the Gir landscape was also found to be influencing lions' resource selection. As suggested by NDVI data, during dry season lions were found to select croplands providing higher cover to avoid scorching daytime heat. In the Gir landscape, these croplands are mostly mango orchards and sugarcane farms. During summer (April-May) human activities in the mango orchards reach at peaks owing to the main harvest season for mangoes. This often instigates conflicts in these orchards where lions are found to attack humans (Banerjee 2012).

The study identifies the day patch requirement of lions in the human dominated eastern landscape and has immense management significance. These patches are predominantly represented by *Prosopis* thickets, *Acacia senegal* and *Zizyphus mauritiana* scrublands and orchards. Although small in size, these patches have great conservation value as they dictate lion movement and likelihood of conflict with humans. The characteristics of the patch also determine its use by lions. For instance, even smaller patches of *Prosopis juliflora* thickets may serve the purpose as they are impenetrable for humans while sparser vegetation (like *Acacia senegal*) patches need to be larger. Lions that cannot find a suitable habitat refuge by 7 AM- 8 AM in the morning are likely to confront people resulting in a conflict situation. On the contrary lions within a refuge patch may lie peacefully for the whole day with all sorts of human activities around and often without humans being aware of lions. For example, one of the radio-collared lionesses (F2) in Girnar regularly ventured into agricultural fields and human habitations in the eastern and north-eastern directions of the sanctuary (parts of Bhesan *tehsil*) at nights in search of food and used to return to Girnar or take shelter in some refuge patches by early morning. However on one occasion on 23<sup>rd</sup> January, 2009 night F2 ventured villages (about 20 kilometer from Girnar) in the northern and north-western sides of Girnar (Akald, Kathrota, Chok villages of Jetpur and Junagadh *tehsils*). F2 and another prime adult lioness killed seven livestock (mostly bullocks) one by one during that night but were not allowed to feed on any of the carcass and were rather pushed off by villagers. The lionesses got delayed until morning and in absence of any suitable refuge patches they came into confrontation with local people injuring two people. By the time forest staff intervened it became more delayed and the lionesses sat on a highway (9 AM), five kilometer from Girnar forest. Being agitated by the crowd, they started moving to



Girnar across an agricultural field and injured two agricultural labors engaged in sowing in the field. Finally at 10:30 AM the lionesses were able to get inside the Girnar Sanctuary.

The minimum patch size in which lions took daytime refuge was found to be as small as 0.07 km<sup>2</sup> whilst the largest forested area was represented by Mitiyala wildlife sanctuary (21.5 km<sup>2</sup>). Mitiyala is a legally protected sanctuary which would likely to continue to exist even in future. However, most of the other small refuge patches in the landscape are unprotected, without any legal status and are mostly under private ownerships. Loss of such patches, however small they may be, will compel lions to move more across the human-dominated landscape in search of an appropriate refuge thereby exposing them more toward conflict. With intense pressures of human population explosion and urban sprawls and resulting political pressures, the traditional land-use pattern in the Gir landscape is changing at an alarming rate. In order to cater for local people's better livelihood securities huge chunks of lands are getting converted for agricultural, mining, industry and tourism purposes. During my study period, this has been specially observed in the areas like Shivatali and Hothalio-Monvel (*Visavadar tehsil*), Dhari and Dholilui-Nal-Rabarika (*Savarkundla tehsil*) where vast tract of waste lands and community lands have been converted for agricultural purposes. Without any clear state level wildlife tourism policy, the situation is more worrying near Sasan (*Talala tehsil*) where new resorts are coming up almost every day. Upcoming lion safari park at the Ambardi Reserve Forest also resulted into construction of resorts and hotels near Dhari causing loss of such refuge patches. Gujarat forest department's proposal on Ambardi safari park is welcoming as it is likely to reduce tourism pressures on the park's current tourism zone at Sasan. But Ambardi acts as a significant refuge patch for lions (**Figure 9.13**) and a habitat corridor between Visavadar, Dhari and Khambha. We also observed consistent use of this patch by a resident group of about 12-15 lions during my study period. Fencing a substantial part of this crucial habitat patch may have detrimental effect on the demography, population dynamics, behaviour and survival of the resident lions. This could be partially addressed by compensatory afforestation (Forest Conservation Act 1988) on nearby government wastelands which would potentially act as refuge habitat patches for lions in future.

Like many parts of Gujarat, Saurashtra is a producer of charcoal. Charcoal is generally produced from *Prosopis juliflora* and has a good market price and creates local employment. Moreover, *Prosopis juliflora* is a chief source of fuelwood in majority of the agro-pastoral



systems in the semi-arid landscapes of India (Mann and Shankarnarayan 1980) and regarded as a weed. These have led to the uncontrolled destruction of huge *Prosopis* dominated patches in recent past in Saurashtra along with many other parts of Gujarat (Shah 2006). Charcoal extraction has been identified as one of the major factors for ecosystem degradation in semi-arid parts of Africa (Lusambo et al. 2007). In the Gir landscape this may have negative impact on lion movement and accelerate future lion-human conflict in the landscape.

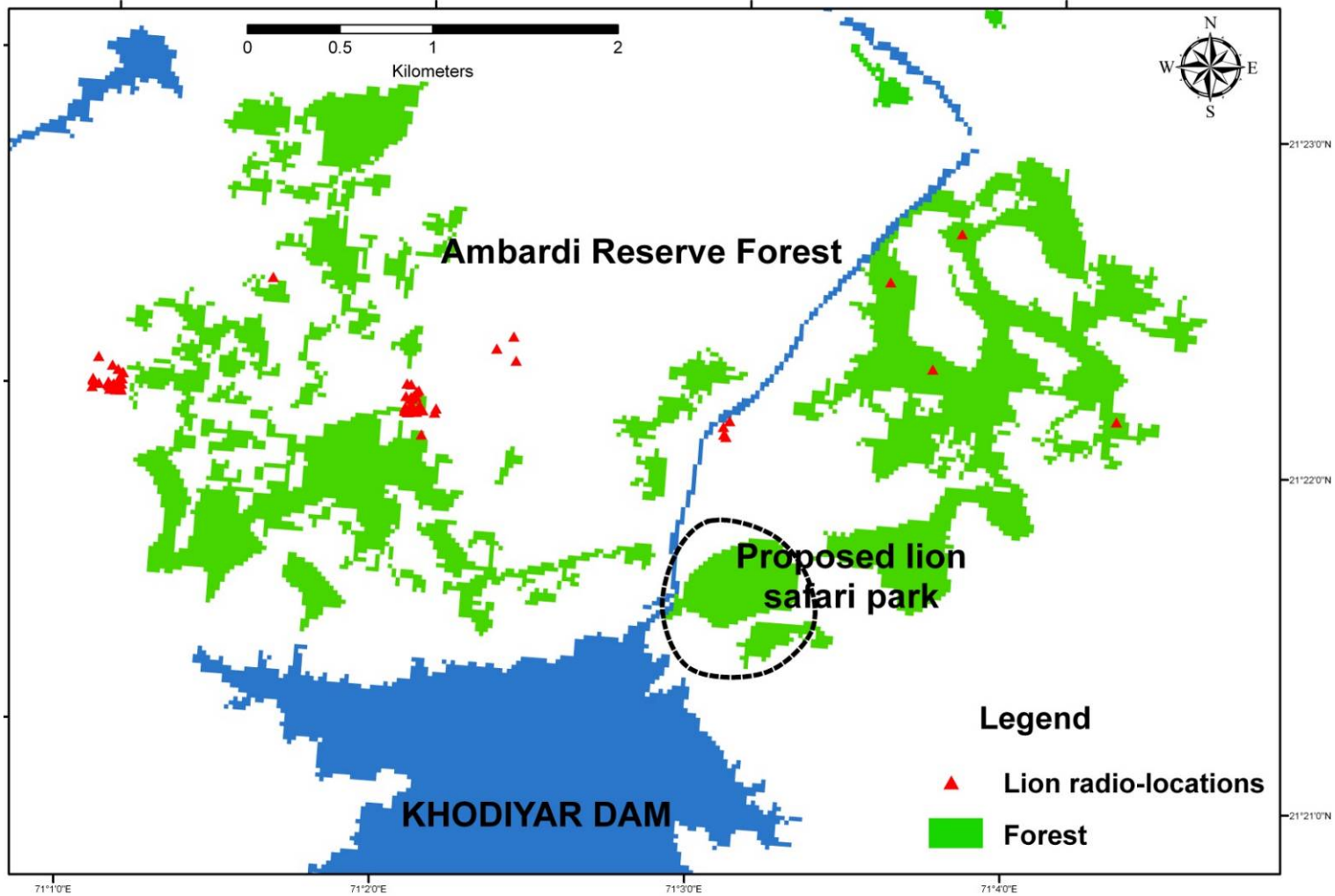
Since land ownership in the Gir landscape is mixed and issues of local livelihood are attached the Government has little control over loss of many potential lion habitats in the Gir landscape. However, community lands and fallow lands could be acquired fast even at a higher market price and be legally protected before they go in the hands of land mafias. Conservation of all vegetation patches larger than 4 km<sup>2</sup> and attempt to restore a mosaic of refuges (vegetation patches larger than one hectare) outside one kilometer radius from villages for breeding lionesses and daytime refuge for other lions will minimize confrontations and potential of conflicts with humans. All identified core zones of lion usage need to be offered some level of legal recognition so that they are not lost to developmental activities. Since the future of smaller refuge patches embedded in a hostile sub-optimal land-use matrix is uncertain, attempts should be made to secure the larger habitat patches under the government ownership. For example, network of government owned grasslands (*vidis*) and Reserve Forests in Dhari, Khambha, Nani Vadal, Hipavadli, Ranigalo, Dholikui, Kantrodi, Jesar, Bagdana and Talaja of Amreli and Bhavnagar districts should immediately be declared as ‘conservation reserves’ and managed through eco-restorative measures so as to enhance their capacity of supporting more lions in future. Similarly, potential lion habitats and refuge patches surrounding the major river basins in the region should be declared as ‘eco-sensitive zones’ so as to curb any further habitat deterioration. An innovative land-use policy should be introduced wherein local people should be given incentives for maintaining traditional land-use patterns. A stringent and transparent tourism policy curtailing any development within five km from forest boundaries should be considered. Compensation to the local farmers for crop depredation by wild ungulates should be immediately introduced as it will prevent decline of the wild ungulate densities in the larger landscape and help in future lion conservation. Dispersal of daytime habitat refuges within the larger landscape and education campaigns for local people not to enter into such thickets would benefit both lions and humans by reducing conflicts. To ensure lion conservation in a



metapopulation framework, a landscape level policy with a concerted amalgamation of the state's land, agriculture, industry, tourism and forest policies with lion conservation being a prime land-use objective is the need of the hour.



Figure 9.13: Ambardi Reserve forest (RF) at Dhari as a potential lion refuge patch. The map also shows the proposed part of the RF to be fenced for proposed lion safari park.





## CHAPTER X

### *LION'S DIET IN THE GIR LANDSCAPE*

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#### **Introduction**

Carnivore diet and the availability of these primary resources govern a number of life history strategies like habitat selection, reproductive success, dispersal patterns, movement, social organization, ranging and territoriality (Macdonald 1983; Krebs 1994; Packer and Pusey 1995; Miquelle et al. 1996; Johnson et al. 2002; Hayward et al. 2009). For ensuring long-term survival of top predators like the Asiatic lions, a thorough assessment of their diets becomes a necessity since lions' food habits and prey selection may have strong cascading effects on the different trophic levels (Keiter and Boyce 1991; Gittleman 1996; Clark et al. 1999) and population dynamics of prey species (Keith 1974).

In India, livestock predation by large carnivores is variable (Mukherjee and Mishra 2001; Biswas and Sankar 2002; Bagchi et al. 2003; Andheria et al. 2007; Meena et al. 2011; Mondal et al. 2011; Banerjee et al. 2013) and governed by availability and vulnerability of livestock and wild ungulates. In areas of substantial wild ungulate densities, large cats consumed smaller proportions of livestock (Biswas and Sankar 2002; Andheria et al. 2007) while in other areas, in spite of high prey abundance, they consumed considerable numbers of livestock that were readily available within the protected area (Mukherjee and Mishra 2001; Bagchi et al. 2003). In wild prey-deficient habitats of Satpura Tiger Reserve of India, while leopards switched to a diet of domestic prey in some areas, tigers preferentially killed smaller wild prey and avoided killing livestock in spite of their availability within the park (Edgaonkar 2008). Availability of livestock in a protected area thus does not necessarily represent the magnitude of conflict between carnivores and local communities. Instead, examination of predator diet and expression as proportion of livestock and wild prey consumed would be a better indicator and also help to overcome the difficulty of quantifying 'availability' of domestic prey.

Livestock has always been an important part of lion's diet in the Gir PA ranging between 83 to 25% (Joslin 1973; Sinha 1987; Chellam 1993; Meena 2008; Banerjee et al. 2013). This has often led to raging debates amongst various conservation lobbies about the role of livestock depredation by lions in the economic marginalization of the local pastoralists (*Maldharis*; more



detail in chapter 11). In the larger human-dominated landscape of Gir, this becomes even more crucial as lions live in close proximity with humans (chapters 8 and 9) enhancing the likelihood of conflicts predominantly by stock raiding. In the absence of any scientific information on lions' food habits outside the Gir PA, it often becomes difficult for the managers to defend the polarized conservation arguments by the pro-people lobbies mostly based on assumptions and hypotheses. Such contentious issues easily get support from the local political groups and may have significant role in shaping local communities' attitudes toward lions; by large negatively. With globalization; human values, people's custodian role for nature and natural resources and levels of tolerance toward damage caused by wild animals may lose irrevocably. All these may even lead to extirpations of lion populations in small pockets of the Gir landscape; as happened with many carnivore populations elsewhere in the world (Treves and Karanth 2003). Information on i) what are the food habits of lion populations in the Gir landscape, ii) how often do lions predate on livestock and iii) what part of a lion's diet is actually obtained by predating livestock and what proportion by scavenging dead livestock therefore becomes crucial for ensuring long-term survival of the Gir lions by minimizing conflicts. Herein, we evaluate lion food habit in Girnar and human-dominated eastern landscape based on scat analysis, telemetry and information on predation. We use this knowledge to assist the management in developing a conflict mitigation strategy for lions in the Gir landscape.

## **Methodology**

### **Lion prey base estimation in Girnar**

For estimation of lion prey abundance in the Girnar Wildlife Sanctuary, we used distance sampling on systematic trail transects (TT,  $n = 21$  spatial and 60 temporal replicates; with 115.47 km walk effort) spaced throughout the sanctuary (**Figure 10.1**). The terrain in Girnar is extremely hilly and rugged with moderate to very steep slopes (Parmar 2005) making it difficult to lay straight line transects of minimum desirable lengths everywhere in the sanctuary. Therefore, we used existing animal trails and recorded both the animal bearing and observer bearing at every animal sighting. Uses of such trails are scientifically validated in many other conservation areas with steep terrain for ungulate abundance estimation (Bhattacharya and Sathyakumar 2011). The Girnar forest is divided into 10 forest rounds for administrative purposes (Parmar 2005). Trails were systematically distributed throughout the entire Girnar by demarcating 1-2 trails in each forest round. Each 1.2 - 3.2 km trail was sampled 1-3 times by two



experienced observers during early morning hours (6:30 AM – 8:30 AM) when ungulate activity was the highest.

### **Lion prey base estimation in Eastern Landscape**

Considering the vastness and good road network of the human-dominated corridor landscape, we resorted to distance sampling using vehicle transect (VT) approach ( $n = 33$  spatial and 70 temporal replicates; 940.8 km four-wheel drive effort) spaced throughout the landscape (**Figure 10.2**). Open-width transects were run using an open jeep with a constant speed of  $< 20$  km/hour during morning (6:00 AM - 9:00 AM) and evening (4:00 PM – 7:00 PM) by a team of 4 experienced observers (one driver, one data recorder, two observers at the back of the vehicle).

Information was recorded on prey species, group size, perpendicular sighting distance at the center of the group (for VTs); animal bearing, walk bearing and angular sighting distance at the center of the group (for TTs) on datasheet for each animal sighting. Data collection was aided by a handheld GPS unit (Garmin 12 and 72 units), LASER range finder (Bushnell) and magnetic compass (SUUNTO see through compass). Program DISTANCE (Thomas et al. 2010) was used to compute densities of individual prey species. We differentiated between cattle and feral cattle on the basis of presence of herder, ornamentation, tethered rope, behavior and body condition of the individual cattle.

We first carried out exploratory analyses as prescribed by Buckland et al. (2001). The fit of possible alternative models to each dataset was judged using Akaike's information criteria values (Burnham and Anderson 2002) that presented a compromise between the quality of fit and increased number of model parameters and the goodness-of-fit tests generated by program DISTANCE (for details, see Buckland et al. 2001). We report estimates with standard error of the following parameters: encounter rate ( $n/L$ ); group/cluster density; estimated cluster size; effective strip width and individual animal density. To improve model fit and subsequent inference from DISTANCE, we pooled data from across similar habitat types to deduce detection probability and effective strip width estimates to obtain more precise and robust density estimates. Individual prey densities were used to estimate the prey biomass by multiplying with the average body weights of individual wild and domestic prey species taken from literature (Schaller 1967; Berwick and Jordan 1971; Prater 1971; Dave 1977; Acharya 1982; Ali and Ripley 1983; Karanth and Sunquist 1995; Singh et al. 2002; Bhatt et al. 2005; Mehta et al. 2007; Pandey and Singh 2010).



### **Lion predation events**

Lion kills were recorded opportunistically in Girnar (n = 88) and the eastern landscape (n = 87). The activity of crows, other scavengers, presence of drag marks on ground, odor of the decomposing flesh and information from forest department staff and local people acted as important cues in locating kills. Lions kills were distinguished from leopard kills by a combination of factors like associated pug marks, mode of feeding, state of the rumen sac (leopard removed the rumen sac intact from the carcass) and presence of predators' hair (leopard hairs were bi-colored white/yellow and black while lion hairs were either white or brownish yellow). For each carcass GPS fix was recorded and data on prey species' identity, age and gender was collected.

### **Lion scat collection and analysis**

Lions' diet was determined by analysis of 185 (107 in Girnar and 78 in the eastern landscape) scats (Korschgen 1980). The scats were collected in paper bags and the date, locality and GPS fixes were noted. Scats were collected opportunistically from all the potential lion habitats (based on chapter 8 and 9) across the Gir landscape (**Figure 10.3**). Lion scats were distinguished from those of other predators, particularly leopard scats, based on associated signs, tracks and size (Joslin 1973). We did not include ambiguous scats (n = 5) in the analysis.



Figure 10.1: Distribution of the trail transects (n = 21) for prey base enumeration in Girnar forests.

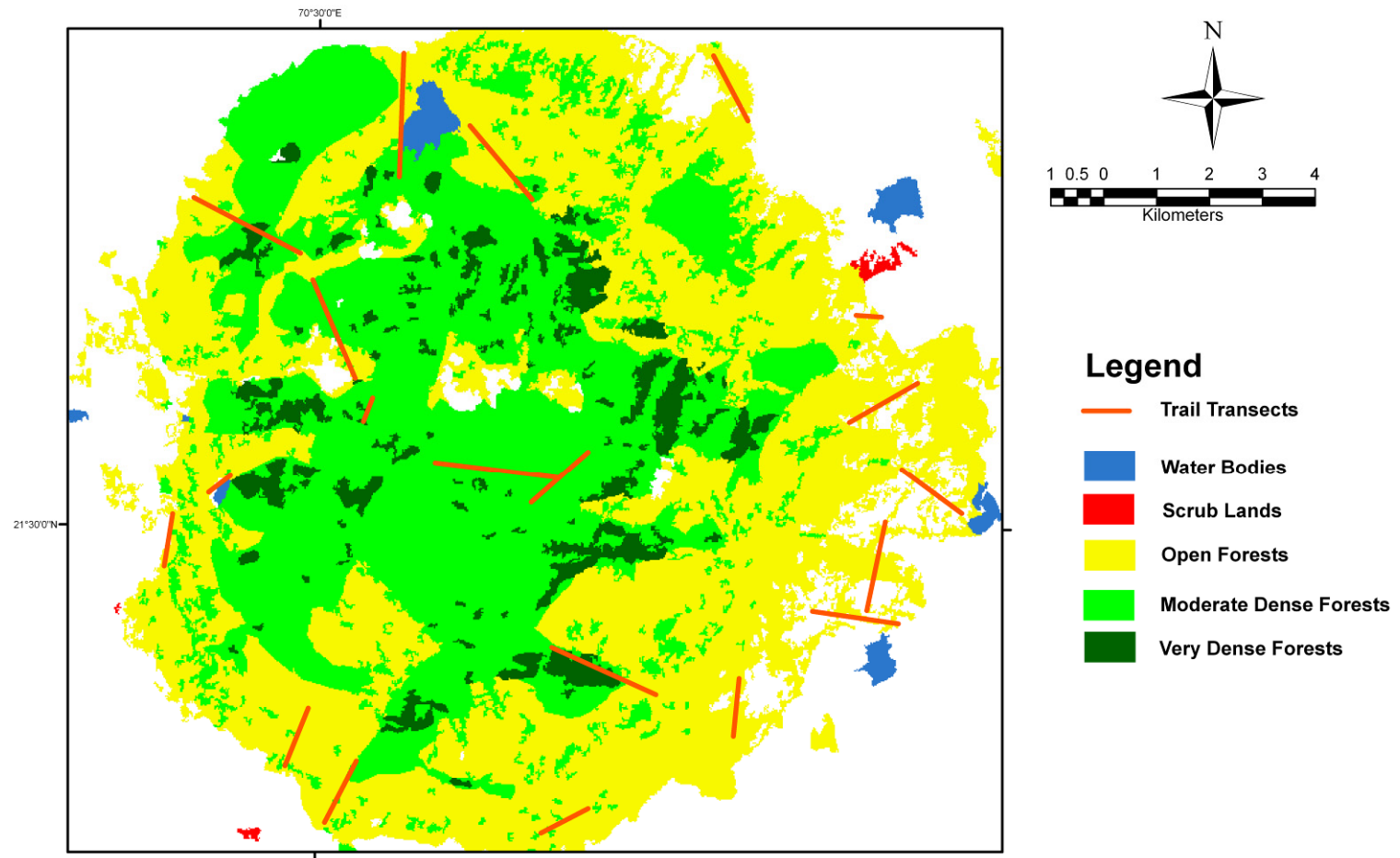




Figure 10.2: Distribution of the vehicle transects (n = 33) for prey base enumeration in the agro-pastoral eastern landscape.

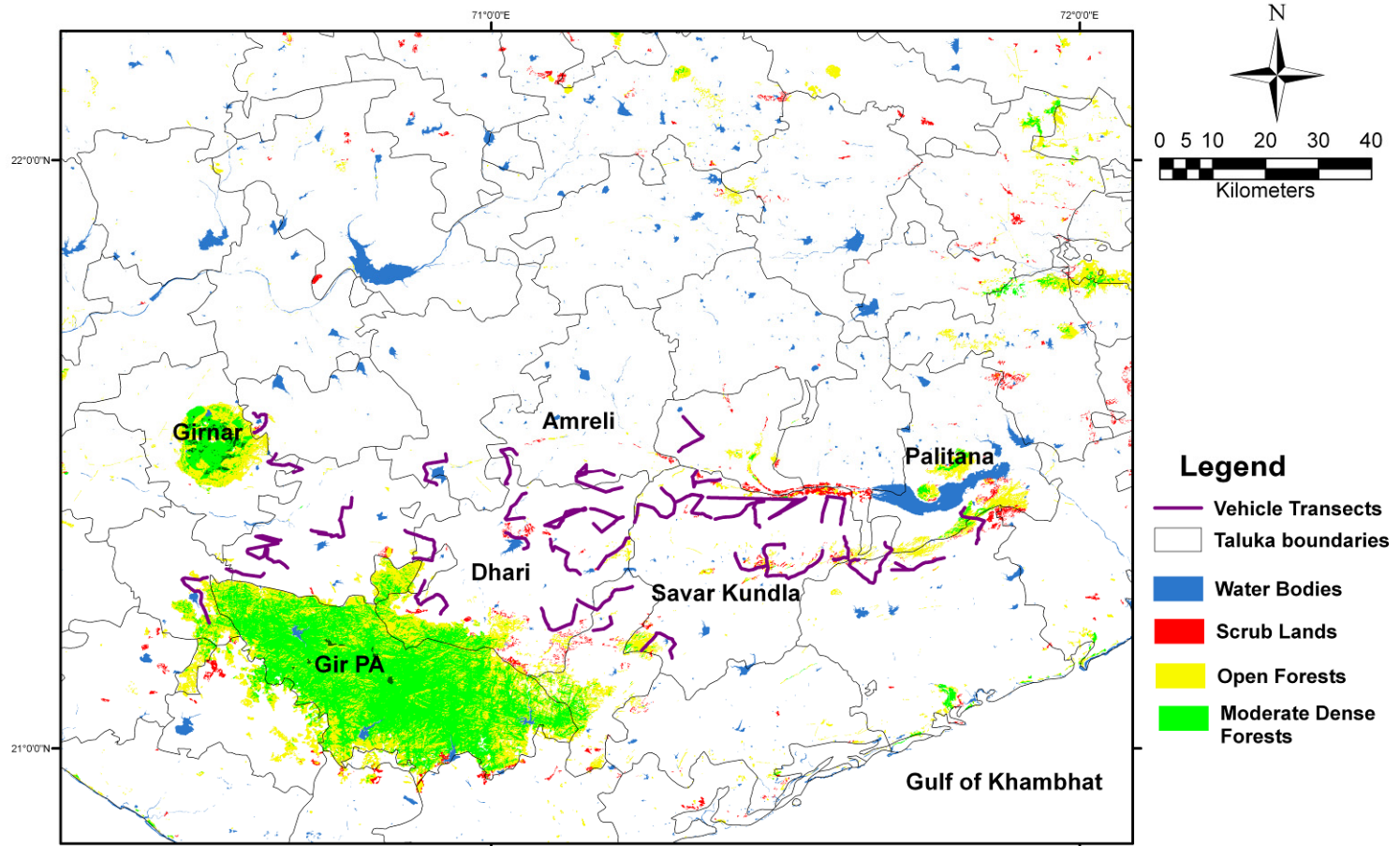
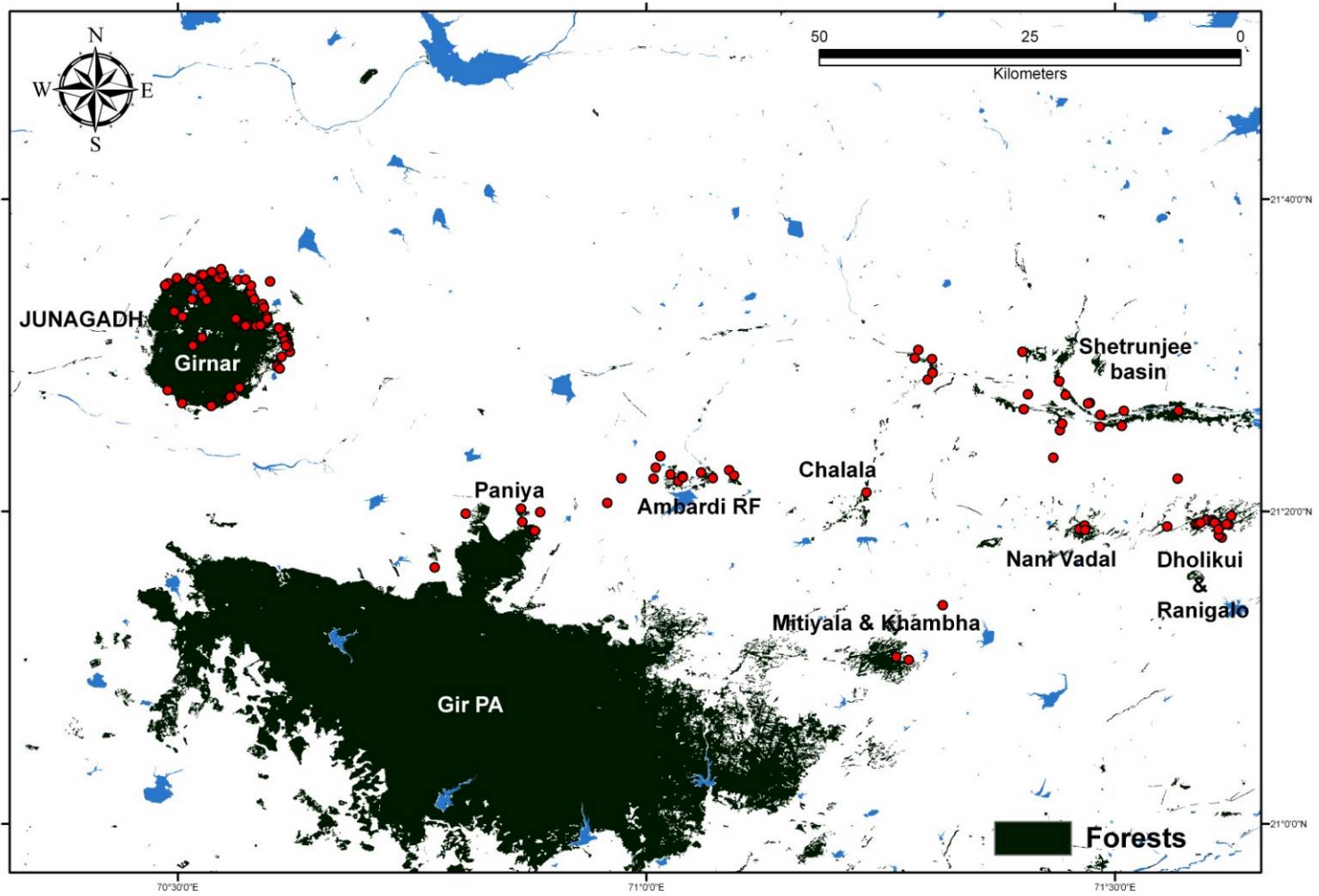




Figure 10.3: Lion scat collection fixes spreading in all potential lion habitats across the Gir landscape.





Each scat was then broken down and washed under running water by using a sieve. The scat contents were then teased apart with forceps and undigested prey remains such as hair, bones, skin, claws, hooves, mandible, quills and vegetable material were separated. Undigested prey hair which remained in the scat after washing was used for the identification of prey species as described by Mukherjee et al. (1994a, b). At least 20 hairs were picked up randomly from each scat for the preparation of slides. A combination of hair characteristics like color, length, width, medullary structure, ratio of medulla width to hair width, cuticular pattern of the prey hairs of each scat collected were observed under a microscope and compared with the reference slides available in the laboratory of Wildlife Institute of India, Dehradun. Prey remains such as hair, bones, hooves, quills and teeth of the prey consumed were identified to species using reference samples (Mukherjee et al. 1994a, b).

Data were analyzed as frequency of occurrence and percent occurrence. We assessed adequacy of sample size by plotting the proportional frequency of occurrence of cumulative 10 scat sample of each prey item (Jethva and Jhala 2003). We used 1000 bootstrap iterations (Krebs 1989) using SIMSTAT (Péladeau 1995) to generate 95% confidence intervals on frequency of occurrence of different prey items in the lions' diet. Due to a differential surface area to volume ratio of small versus large prey, the frequency of occurrence data was corrected to arrive at biomass consumption per collectible scat (Lockie 1959; Floyd et al. 1978; Ackerman et al. 1984). We used the conventional Ackerman's equation [developed for cougar (*Felis concolor*)] to convert frequency of occurrence into biomass assuming lions to have a similar digestive physiology as cougars. The equation was  $y = 1.980 + 0.035 x$ , where  $y$  is the biomass of prey consumed (kg) to produce a single field collectable scat and  $x$  is the average body weight of the prey species (kg). The body weights of the potential prey species were taken from literature mentioned earlier. Prey densities estimated by line transects were used as availability.

Selectivity can be defined as taking a prey at frequencies different from that expected given its availability (Chesson 1978). If there is no selection one would expect a prey item to be taken at relative frequencies similar to the relative frequency of its availability. Any statistically significant deviation, whether positive or negative, would indicate preference or avoidance of that prey type. We compared observed number of scats associated with each prey item with the estimated prey availability using 1,000 bootstrap iterations in program SCATMAN (Hines and Link 1994) to assess selectivity in utilization. Observed and expected proportions of prey species



in the scats were then compared using a G test (Zar 2010) with  $\alpha = 0.05$  level. If there was a pattern of overall selective prey utilization, lions' use of each prey species as calculated by the program SCATMAN was inspected. Food preference of lions in the study area was computed by Jacob's Index (Jacob 1974) due to its lower bias, smaller confidence intervals with low heterogeneity and freedom from non-linearity compared with other electivity indices (Hayward and Kerley 2005; Banerjee et al.2013).

**Lion feeding events through continuous monitoring of radio-collared lions** (n = 5,880 hours of observation on 20 radio-collared lions) to determine the amount of food consumed through predation and scavenging (**Figure 10.4**) as well as interval between feeding events.

## **Results**

### **Lion prey abundance**

In Girnar, density of lion prey (chital, sambar, nilgai, buffalo and cattle) was 8.7 (SE 1.2)/km<sup>2</sup> (**Table 10.1**). Sambar with a density of 3.8 (SE 0.7)/km<sup>2</sup> was the most abundant lion prey species in Girnar (**Figure 10.5**). I did not record any wild pig sighting on transects in Girnar. Total biomass of lion prey was estimated to be 171,516 kg with the maximum contribution from sambar (48.1%, **Figure 10.5**). In human-dominated eastern landscape, cattle contributed maximum in lion prey density and biomass (**Figure 10.5**) while wild prey constituted 3% of lion prey biomass (**Table 10.2**).



**Figure 10.4: Monitoring radio-collared lions to distinguish between i) lion predation and ii) lion scavenging events.**

**i)**



**ii)**





**Table 10.1: Estimates of density, ESW (effective strip width), average group size, encounter rate and biomass with their standard errors of lion prey species in Girnar forest. Lion prey encompasses chital, sambar, nilgai, buffalo and cattle while wild prey constitutes of chital, sambar and nilgai. Percentage figures along total biomass represent contribution of different prey species/category in the total lion prey biomass.**

Prey species	Unit weight (kg)	Density/km <sup>2</sup>	ESW (meter)	Average group size	Encounter rate/km	Biomass density (kg/km <sup>2</sup> )	Total biomass (kg)
Chital	42	2.7 (± 0.9)	27.9 (± 6.2)	4.9 (± 0.7)	0.14 (± 0.05)	112.9 (± 56.1)	20,320 (± 10,093, 11.8%)
Sambar	119	3.8 (± 0.7)	38.5 (± 5.0)	2.3 (± 0.2)	0.29 (± 0.05)	458.1(± 110.7)	82,460 (± 19,940, 48.1%)
Nilgai	136	1.5 (± 0.4)	41.3 (± 5.5)	3.1 (± 0.5)	0.12 (± 0.03)	200.5(± 75.9)	36,091 (± 13,654, 21%)
Common langur	8	2.1 (± 0.5)	32.8 (± 2.3)	8.9 (± 1.5)	0.13 (± 0.04)	16.7(± 5.7)	3,053 (± 1,021)
Peafowl	4	9.2 (± 1.7)	36.8 (± 3.5)	1.9 (± 0.2)	0.67 (± 0.12)	38.7(± 8.6)	6,963 (± 1,547)
Buffalo	204	0.5 (± 0.2)	120.6 (± 24.4)	23.7 (± 4.7)	0.13 (± 0.05)	110.4(± 62.6)	19,877 (± 11,268, 11.6%)
Cattle	136	0.5 (± 0.2)	41.7 (± 6.1)	10.4 (± 2.1)	0.04 (± 0.02)	70.9(± 56.4)	12,767 (± 10,146, 7.5%)
<b>Lion prey</b>	--	<b>8.7 (± 1.2)</b>	<b>44.1 (± 4.5)</b>	<b>7.1 (± 1.1)</b>	<b>0.77 (± 0.08)</b>	--	<b>171,516</b>
<b>Wild prey</b>	--	<b>6.2 (± 0.8)</b>	<b>45.3 (± 2.9)</b>	<b>3.2 (± 0.3)</b>	<b>0.57 (± 0.05)</b>	--	<b>138,871 (80%)</b>



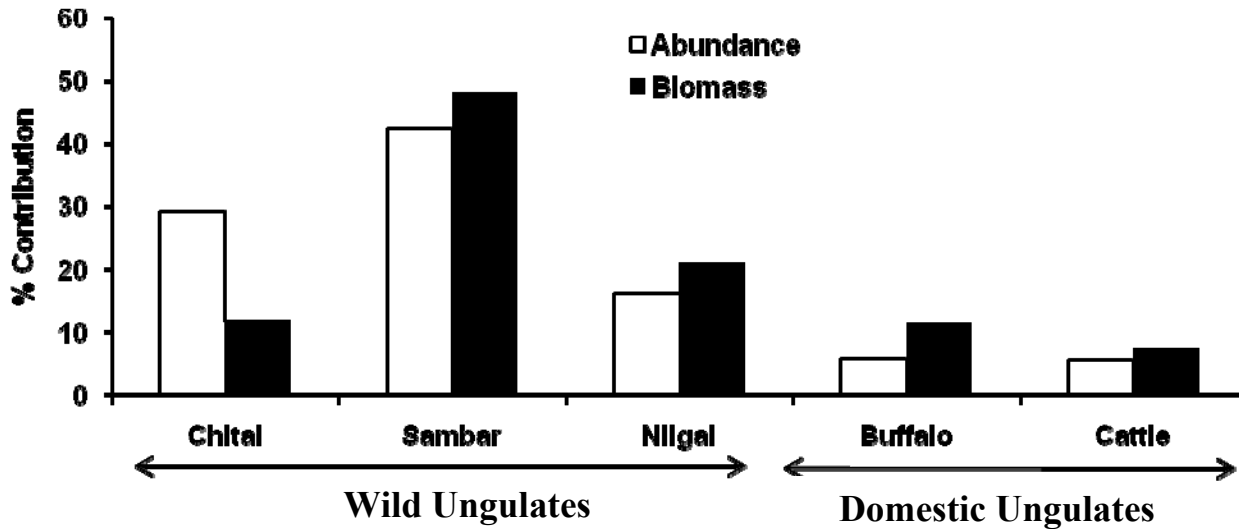
**Table 10.2: Estimates of density, ESW (effective strip width), average group size, encounter rate and biomass with their standard errors of lion prey species in human-dominated eastern landscape. Lion prey encompasses nilgai, wild pig, chital, buffalo, cattle, feral cattle, feral pig, donkey, horse, goat and sheep while wild prey constitutes of chital, wild pig and nilgai. Percentage figures along total biomass represent contribution of different prey species/category in the total lion prey biomass.**

Prey species	Unit weight (kg)	Density/km <sup>2</sup>	ESW (meter)	Average group size	Encounter rate/km	Biomass density (kg/km <sup>2</sup> )	Total biomass (kg)
Nilgai	136	0.55 (± 0.1)	104.8 (± 8.7)	3.3 (± 0.3)	0.11 (± 0.02)	74.8 (± 12.2)	105,169 (± 17,209; 2.6%)
Peafowl	4	1.9 (± 0.3)	76.7 (± 4.8)	2.5 (± 0.2)	0.28 (± 0.05)	7.6 (± 1.2)	10,686 (± 1,687)
Wild pig	28	0.05 (± 0.02)	139.1 (± 28.9)	11.5 (± 2.1)	0.01 (± 0.008)	1.4 (± 0.6)	1,968 (± 787; 0.1%)
Chital	42	0.2 (± 0.07)	62.1 (± 7.4)	4.6 (± 0.7)	0.02 (± 0.01)	8.4 (± 2.9)	11,810 (± 4,134; 0.3%)
Chinkara	23	0.24 (± 0.08)	127.9 (± 16.3)	2.9 (± 0.4)	0.06 (± 0.03)	5.5 (± 1.8)	7,761 (± 2,587)
Blackbuck	40	0.01 (± 0.002)	**	18.4 (± 7.1)	0.01 (± 0.004)	0.2 (± 0.1)	281 (± 113)
Buffalo	204	6.1 (± 0.4)	84.4 (± 2.4)	6.9 (± 0.5)	1.03 (± 0.07)	1244.4 (± 81.6)	1,749,626 (± 114,730; 43.6%)
Cattle	136	9.6 (± 0.8)	107.3 (± 3.3)	6.3 (± 1.02)	2.10 (± 0.16)	1305.6 (± 108.8)	1,835,674 (± 152,973; 45.9%)
Feral cattle	136	0.5 (± 0.1)	56.6 (± 6.7)	8.5 (± 1.3)	0.06 (± 0.01)	68.0 (± 13.6)	95,608 (± 19,122; 2.4%)
Feral pig	30	0.24 (± 0.1)	17.6 (± 6.5)	5.5 (± 1.3)	0.01 (± 0.004)	7.2 (± 3.0)	10,123 (± 4,218; 0.3%)
Donkey	130	0.11 (± 0.04)	48.04 (± 12.1)	4.8 (± 1.1)	0.01 (± 0.004)	14.3 (± 5.2)	20,106 (± 7,311; 0.5%)
Horse	302	0.13 (± 0.02)	112.3 (± 14.1)	1.3 (± 0.1)	0.03 (± 0.01)	39.3 (± 6.0)	55,200 (± 8,492; 1.4%)
Goat	37	1.2 (± 0.2)	88.1 (± 11.2)	29.8 (± 2.5)	0.22 (± 0.02)	44.4 (± 7.4)	62,426 (± 10,404; 1.6%)
Sheep	27	0.4 (± 0.9)	117.3 (± 10.9)	47.4 (± 4.3)	0.10 (± 0.02)	10.8 (± 1.9)	15,185 (± 2,657; 0.4%)
Camel	520	0.053 (± 0.026)	**	**	0.004 (± 0.003)	27.6 (± 13.5)	38,749 (± 19,010; 1.0%)
<b>Lion prey</b>	--	<b>18.9 (± 1.4)</b>	<b>97.6 (± 3.9)</b>	--	<b>3.68 (± 0.3)</b>	--	<b>4,001,645</b>
<b>Wild prey</b>	--	<b>0.8 (± 0.1)</b>	<b>95.3 (± 7.9)</b>	--	<b>0.2 (± 0.02)</b>	--	<b>118,948 (3%)</b>

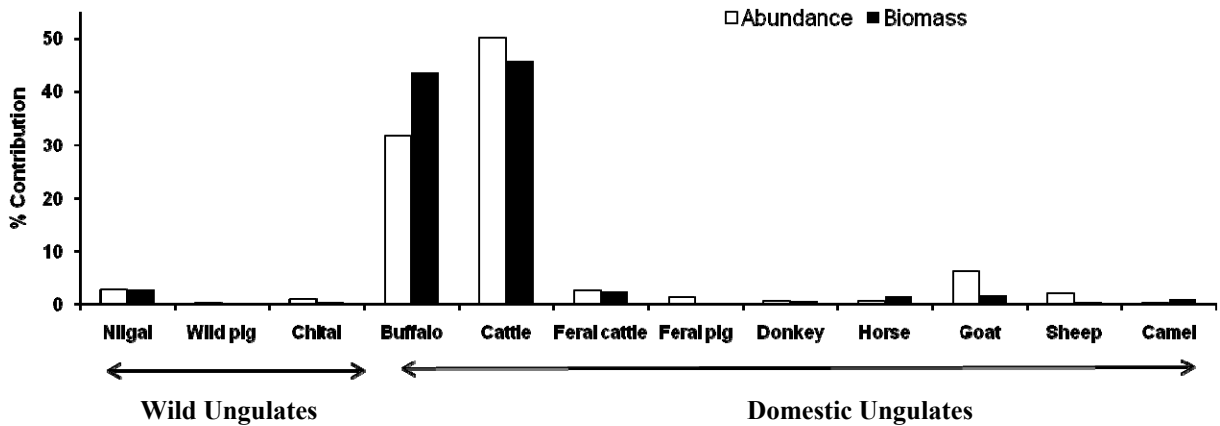


Figure 10.5: Percent contribution of different lion prey species in total prey abundance and biomass in A) Girnar forest and B) eastern landscape.

A.



B.



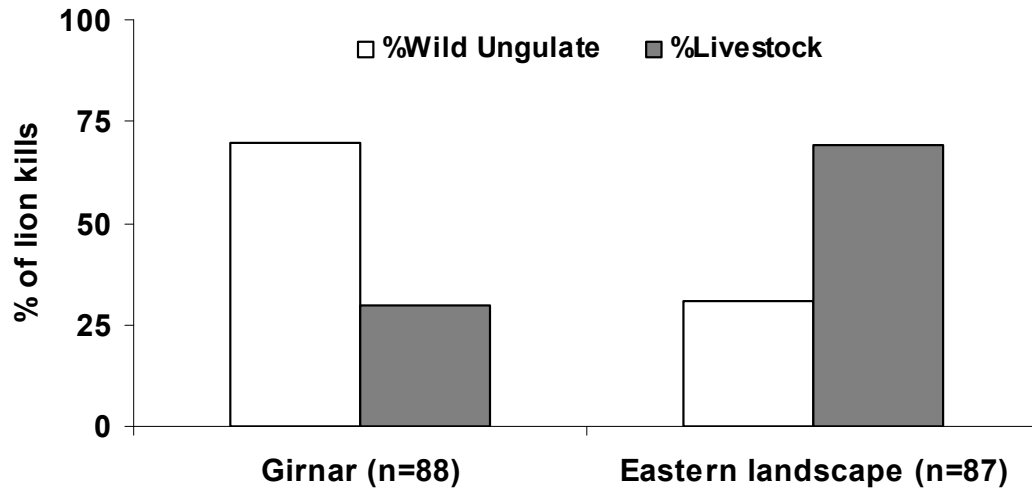
### Lion predation events

A total of 88 lion kills in Girnar and 87 lion kills in the eastern landscape were recorded. Majority (70%) of kills in Girnar was composed of wild ungulates while livestock dominated (69%) the lion kills in the eastern landscape (Figure 10.6). We did not observe any sambar kill

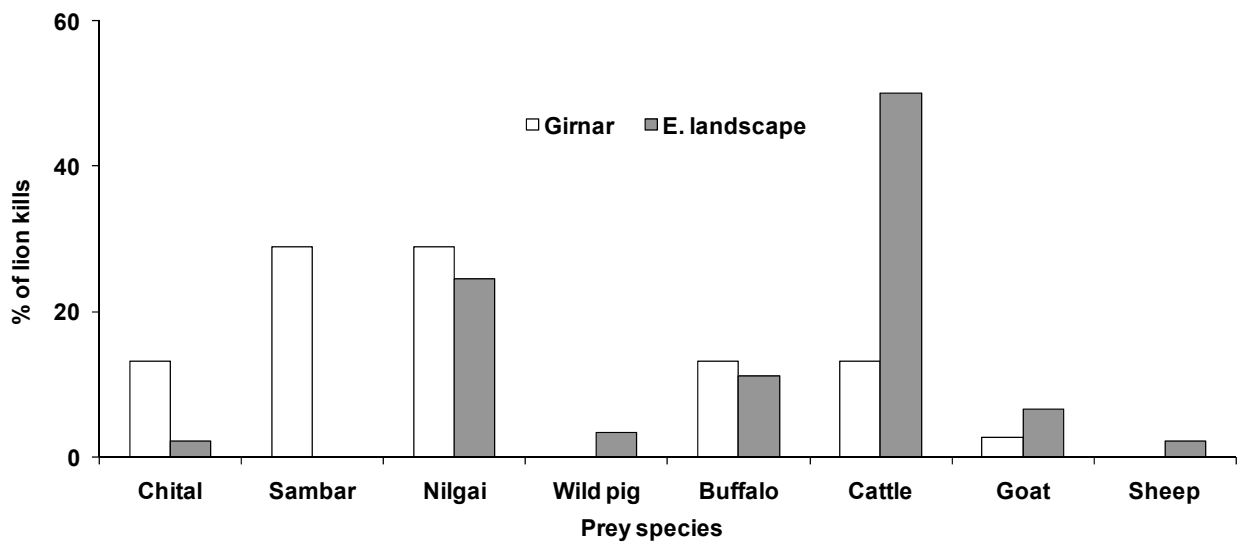


in the eastern landscape and wild pig kill in Girnar. Sambar (29%) and nilgai (29%) predominated lion kills in Girnar while cattle (50%) constituted majority of eastern landscape lion kills (Figure 10.7).

**Figure 10.6: Composition of lion kills in Girnar Wildlife Sanctuary and the eastern landscape.**



**Figure 10.7: Percent contribution of different prey species among lion kills in Girnar and the eastern landscape.**



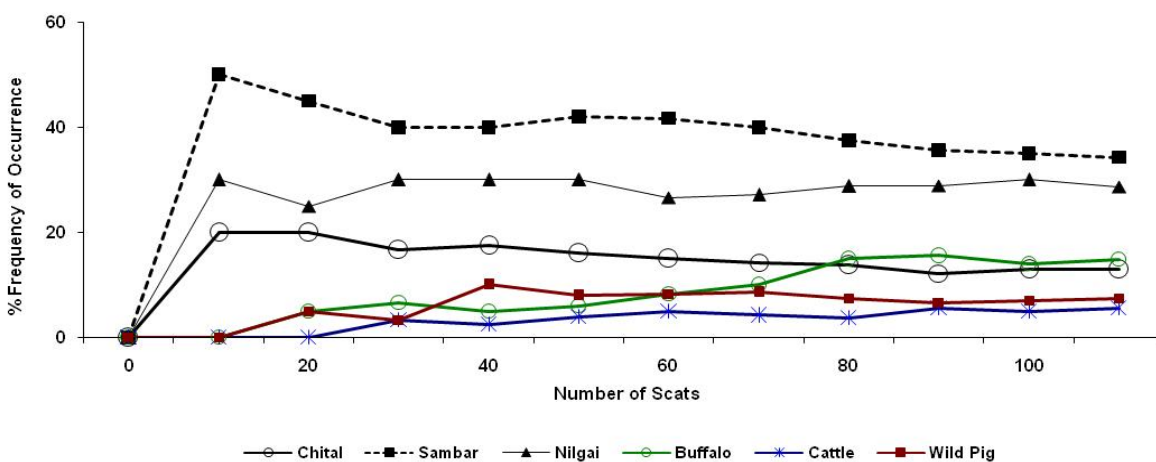


## Lion diet

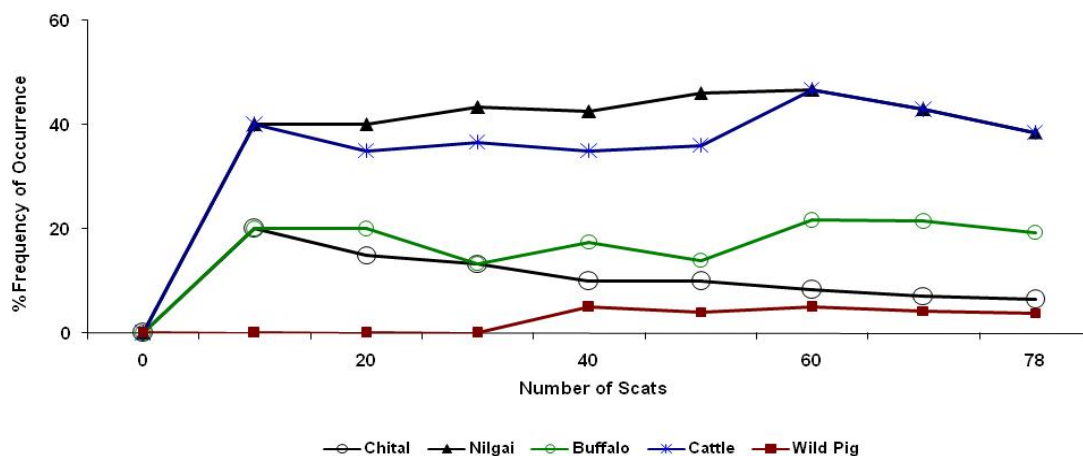
Frequency of occurrence of all prey items in scats reached an asymptote after sampling about 40 – 60 scats both in Girnar and the eastern landscape (**Figure 10.8**); so the sample sizes of 107 and 78 scats were deemed sufficient. A total of six prey items (chital, sambar, nilgai, wild pig, cattle and buffalo) were identified in lion scats of which most (94.5%) scat contained a single prey type, remaining 5.5% of the scats had two prey items.

**Figure 10.8: Estimation of minimum number of scats that need to be analyzed for studying lion food habits in the Gir landscape.**

### i) Girnar



### ii) Eastern Landscape





In Girnar, wild ungulates comprising chital, sambar, nilgai and wild pig together accounted for 80% of all prey occurrences, while domestic livestock (buffalo and cattle) contributed the rest (**Table 10.3**). In the eastern landscape, wild ungulates (chital, nilgai and wild pig) accounted for 45% of all prey occurrences while livestock contributed the remaining 55% (**Table 10.4**).

In Girnar, percentage biomass contribution of different prey species to the lions' diet was most for nilgai (35%) followed by sambar (31%) and domestic buffaloes (20%). There was evidence of selective utilization in the overall pattern of lion prey use ( $G= 11.4$ ,  $p = 0.04$ ,  $df = 5$ ). Nilgai ( $\chi^2 = 3.77$ ,  $p < 0.05$ ) and buffaloes ( $\chi^2 = 5.43$ ,  $p = 0.02$ ) were used more than their availability. Chital ( $\chi^2 = 0.59$ ,  $p = 0.44$ ), sambar ( $\chi^2 = 1.31$ ,  $p = 0.25$ ), wild pigs ( $\chi^2 = 3.06$ ,  $p = 0.08$ ) and cattle ( $\chi^2 = 0.03$ ,  $p = 0.9$ ) were utilized in proportion to their availability. Lions' preferred prey in Girnar as estimated by Jacob's Index was buffaloes, nilgai and cattle (**Figure 10.9**).

In the eastern landscape, percentage biomass contribution of different prey species to the lions' diet was most for nilgai (41%) followed by cattle (33%) and domestic buffaloes (22%). There was evidence of selective utilization in the overall pattern of lion prey use ( $G= 153.6$ ,  $p < 0.001$ ,  $df = 4$ ). Chital ( $\chi^2 = 67.40$ ,  $p < 0.001$ ), nilgai ( $\chi^2 = 185.28$ ,  $p < 0.001$ ) and wild pigs ( $\chi^2 = 155.84$ ,  $p < 0.001$ ) were used more than their availability while buffalo ( $\chi^2 = 291.29$ ,  $p < 0.001$ ) were utilized in lower than their availability. Cattle ( $\chi^2 = 0.93$ ,  $p = 0.33$ ) were utilized according to their availabilities. Lions' preferred prey in this landscape as estimated by Jacob's Index was wild pig, nilgai and chital (**Figure 10.10**).



**Table 10.3: Prey species composition in Asiatic lion scats and their relative biomass contribution to lion diet in Girnar Wildlife Sanctuary, India.**

Prey Items	Body Weight (kg), (x)	Total Number of Scats	Observed Frequency of Occurrence [F] (95% CI)*	Relative Occurrence (as %)	Collectable scats/kill (y)	% Biomass Consumed (95% CI)
Chital	42	13.5	13.1 (6.5 – 18.7)	12.5	3.5	6.5 (3.2 – 9.8)
Sambar	119	36	34.6 (25.9 – 43.9)	33	6.2	30.6 (22.9 – 38.9)
Nilgai	136	30.5	29 (20.6 – 37.4)	28	8.3	34.6 (24.6 – 44.7)
Wild pig	28	7.5	7.5 (1.9 – 11.2)	7.1	2.9	3.2 (0.8 – 4.8)
Buffalo	204	15	15 (8.4 – 20.6)	14.3	9.1	19.6 (11 – 27)
Cattle	136	6	5.6 (1.9 – 10.3)	5.1	6.7	5.5 (1.8 – 9.9)

x and y are related through the equation  $y = 1.98 + 0.035 x$  (Ackerman et al. 1984). \* 95% CIs obtained by 1,000 bootstrapped replicates



**Table 10.4: Prey species composition in Asiatic lion scats and their relative biomass contribution to lion diet in human dominated eastern landscape.**

Prey Items	Body Weight (kg), (x)	Total Number of Scats	Observed Frequency of Occurrence [F] (95% CI)*	Relative Occurrence (as %)	Collectable scats/kill (y)	% Biomass Consumed (95% CI)
Chital	42	3.5	6.4 (1.3 – 10.3)	6.1	3.5	2.8 (0.6 – 4.5)
Nilgai	136	28	38.5 (29.5 – 51.3)	36.1	8.3	40.5 (31.1 – 54.1)
Wild pig	28	3	3.8 (0 – 7.7)	3.6	2.9	1.4 (0 – 2.9)
Buffalo	204	14	19.2 (11.5 – 29.5)	18.1	9.1	22.3 (13.3 – 34.2)
Cattle	136	28	38.5 (28.2 – 50.0)	36.1	6.7	32.9 (24.1 – 42.8)

x and y are related through the equation  $y = 1.98 + 0.035 x$  (Ackerman et al. 1984). \*95% CIs obtained by 1,000 bootstrapped replicates.



Figure 10.9. Food preference of lions in Girnar based on Jacob's index (Jacob 1974). At 10% CV (Hines and Link 1994), \* Nilgai ( $p < 0.05$ ) and \*buffaloes ( $p = 0.02$ ) were used more than their availability while chital ( $p = 0.44$ ), sambar ( $p = 0.25$ ), wild pigs ( $p = 0.08$ ) and cattle ( $p = 0.9$ ) were utilized in proportion to their availability.

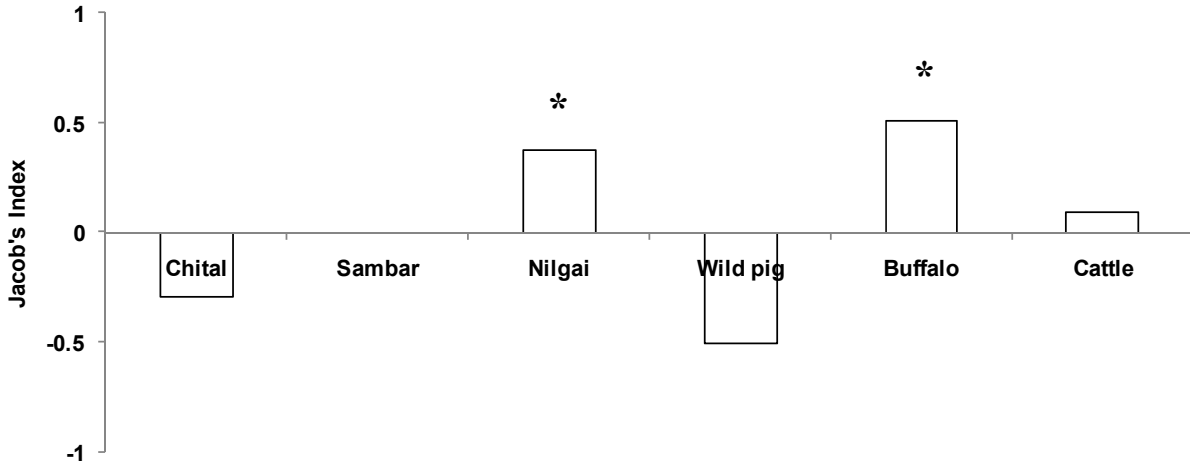
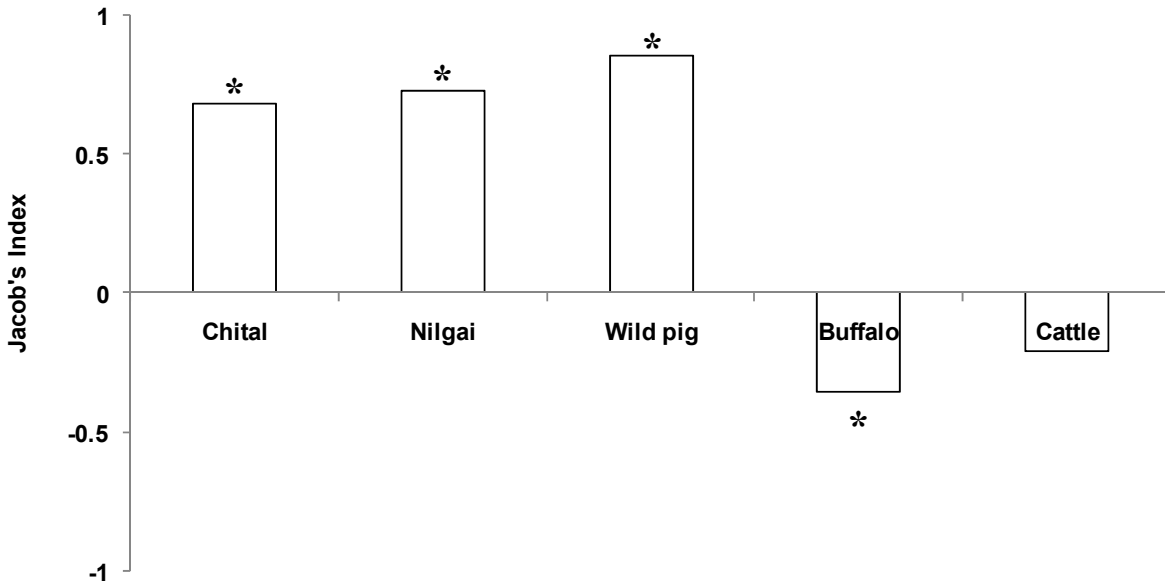


Figure 10.10. Food preference of lions in the eastern landscape based on Jacob's index (Jacob 1974). At 10% CV (Hines and Link 1994), \* Chital ( $p < 0.001$ ), \*nilgai ( $p < 0.001$ ) and \*wild pigs ( $p < 0.001$ ) were used more than their availability while \*buffalo ( $p < 0.001$ ) were underused. Cattle ( $p = 0.33$ ) were used according to their availability.





### **Lion predation and scavenging through telemetry**

Inter-feeding interval of lion was 3.7 (SE 0.7) days. Lions were found to feed on an average group of 2 (SE 0.22; median: 1; range 1 – 6) individuals. Telemetry data showed that livestock constituted 25% (12.5% from predation and 12.5% from scavenging) of the feeding events in Girnar while wild ungulates comprised the rest 75% (**Figure 10.11**). In the eastern landscape, livestock composed 71% (20% from predation and 51% from scavenging) of lions' feeding events. We did not record any lion scavenging event on wild ungulates during the continuous monitoring sessions in this landscape (**Figure 10.12**).

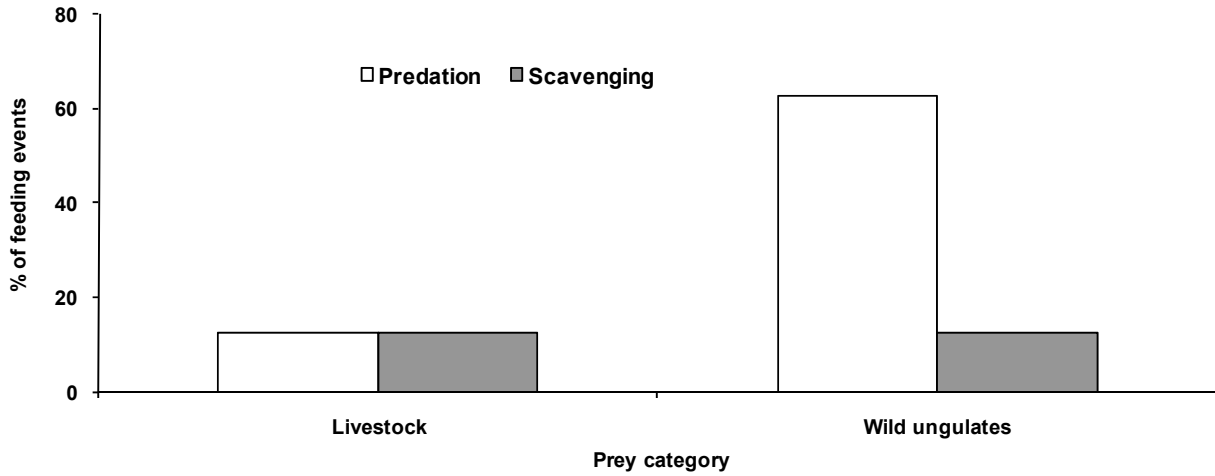
### **Discussions**

Poorly designed diet studies like predicting a carnivore's diet for an entire landscape of thousands of square kilometer based on localized sampling in a few square kilometers may be erroneous. The current study addresses this issue by adequately sampling (scat collection and kill information) throughout the potential lion habitats of the eastern landscape. Radio-collared lions were also spread across the eastern landscape (chapter 8 and 9). Even if their core areas were restricted to certain parts of the landscape, they moved a larger area in the landscape during the continuous monitoring sessions and this provided with fairly uniform chance of collecting data on lion feeding events. This was possible because of the monitoring schedule of each lion spread over successive two-three 'feast-famine' cycles which allowed them to explore their ranges in search of food.

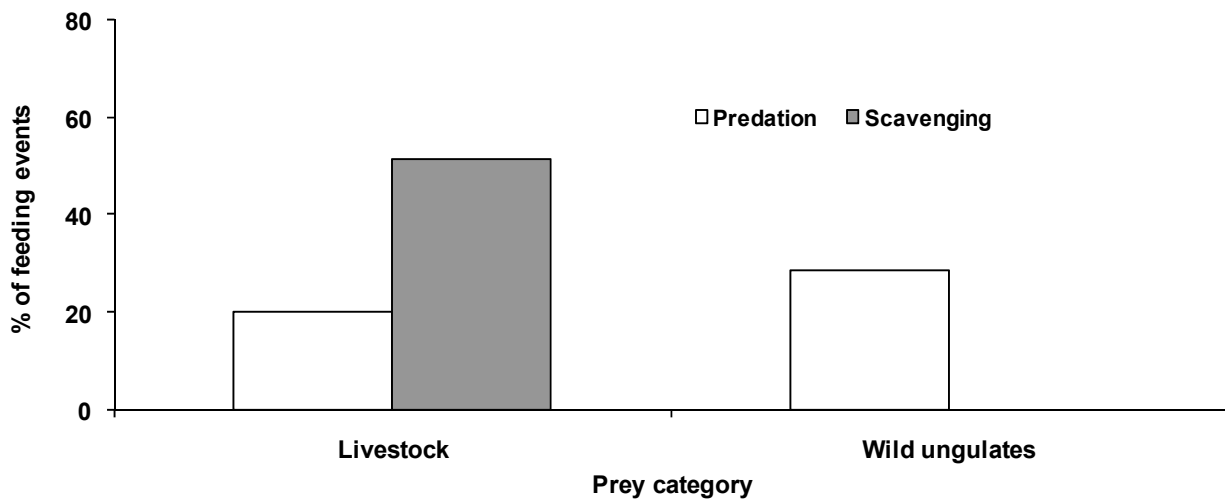
Livestock density in Girnar during the present study was found to be much lower than that reported by a total count (34,313) method by Dharaiya (2001). Although Girnar forests are being managed as reserve forests since 1946, the Gujarat Forest Department did not extinguish the grazing rights of surrounding villages and used to maintain grazing fee system (*masvadi* pass; Parmar 2005). After declaration of a wildlife sanctuary in 2008, grazing has been totally banned in Girnar (Government of Gujarat 2008). This caused partial to full abandonment of Girnar forests by many resident pastoral families resulting into lower livestock abundance during my study compared to 2001. This may have a positive role in increasing the natural prey population in Girnar. Sambar density in Girnar has increased compared to 0.69/km<sup>2</sup> estimated in an earlier



**Figure 10.11: Lion feeding events quantified through continuous monitoring on radio-collared lions (n = 720 hours observation on 3 radio-collared lions) in Girnar.**



**Figure 10.12: Lion feeding events quantified through continuous monitoring on radio-collared lions (n = 3,384 hours of observation on 4 radio-collared lions) in the eastern landscape.**





study (Dharaiya 2001). Similar patterns have also been reported for the Gir PA by Khan (1993), Sharma (1995) and Dave (2008); where partial or full removal of grazing pressures by domestic livestock has led to population recovery of wild ungulates.

Opportunistic study of predation pattern is generally biased with higher chance of detecting livestock kills while wild ungulate carcasses may go unnoticed. In the larger landscape, however, nilgai carcasses in farmlands had fairly good chance of detection with local farmers often reporting them instantaneously. Scats provide an unbiased estimate of lion's diet but cannot reflect some important aspects of feeding ecology (like proportion of predation *vs* scavenging, inter-feeding interval etc.) crucial for conflict study which can be procured only through telemetry. To address the inherent limitations of each method, we studied lion feeding ecology in Girnar and the eastern landscape by a combination of three methods *viz.*, predation, scats and telemetry. In Girnar, wild ungulates comprised 70% of lion kills, 76% of biomass consumed by lions and 75% of lions' feeding events. In the eastern landscape, livestock contributed 69% of lion kills, 56% of lions' biomass consumption and 71% of lions' feeding intervals. The close estimates of lions' dependence on wild ungulates and livestock both in Girnar and the larger landscape among three methods further strengthen our choice of combination of methods and quantify lion food habits in a robust way. The difference between livestock's contribution in lions' diet in the human-dominated eastern landscape assessed through scats and predation is likely to reflect higher detection probability livestock kills in this landscape (as discussed earlier).

Prey selectivity being an index of prey uses *vs.* availability precludes relevant information which may be crucial for understanding lion feeding ecology. For instance, although sambar and chital composed a major component of lions' kills and biomass consumption, they are not being preferred by Girnar lions. Even lion feeding events showed that Girnar lions substantially depend on wild ungulates as a source of their food. This has significance on management of Girnar lion populations. Currently, wild ungulates have low densities in Girnar. Based on lion prey base, the predicted carrying capacity for Girnar lions was 9/100 km<sup>2</sup> (chapter 3) while the current estimates of adult lion population is 6/100 km<sup>2</sup> (Banerjee et al. 2010). With an 2.2% annual growth rate for the Asiatic lions, considering a major proportion of Girnar lion population in a recruitment stage and high leopard population in Girnar (18/100 km<sup>2</sup>; Basu



2012), such prey base may not be sustainable (Coe et al. 1976; Caughley 1977) for Girnar lions for long-term. Moreover, high predation rates will not allow the wild prey population to increase by regulating at lower densities. This would in turn increase conflicts with local people as lions would go for stock raiding in the peripheral villages and become more vulnerable to various anthropogenic threats. Thus this component of the study re-emphasizes (chapter 9 for more details) the possibilities of restocking Girnar with wild ungulates (especially chital and sambar) after necessary ecological considerations.

Prey body size, density and the prey capture efficiency were found to be the major ecological determinants of group sizes in social carnivores (Krukk 1972; Schaller 1972; Van Orsdol et al. 1985). In areas where small to medium sized prey are consumed, such as in the Kalahari, lions exist in small group sizes or are solitary (Eloff 1973). In Etosha, lion group sizes fluctuate seasonally with respect to changes in prey availability (Stander 1991). The current study clearly demonstrates this. Smaller group sizes of lions were observed in the Gir PA where lions primarily depend on small to medium sized wild prey (Meena et al. 2011) in comparison to larger lion groups observed in the Girnar Sanctuary and the agro-pastoral eastern landscape where large-sized livestock constitutes comparatively a greater extent of lions' diet. A similar pattern was also reported from the Gir PA where lion group sizes got reduced over the years after removal of *Maldhari* livestock (Jhala et al. 2009; Banerjee et al. 2013).

The current study contributes immensely in understanding the actual conflict with local communities in terms of livestock depredation by distinguishing between lion predation and scavenging. Within our study area of the eastern landscape, livestock comprised about 69% of lion kills; an indicative of conflict with human communities. But scat analysis suggests that livestock contributes 56% in lions' biomass consumption. Besides, analysis of feeding events showed that although livestock constitutes 71% of lion feeding events, only 20% are predated and the rest (51%) are scavenged. Under the influence of Jainism and Hinduism, this part of the landscape holds several charitable cattle camps (locally known as *Gaushalas* and *Panjrampoles*) for old, unproductive, ill, distressed and abandoned cattle. Everyday substantial numbers of cattle die naturally and carcasses are dumped at specific dumping yards (locally known as *Bham*). Being mostly old, these cattle are often more vulnerable toward lion predation as well while grazing. A similar pattern has also been observed for cattle of Gir *Maldharis* (chapter 11). Moreover, most of these cattle camps take annual or biennial lease of parts of government owned



grasslands (*vidis*) which happen to be one of the most preferred lion habitats and crucial refuge patches (chapter 9) and thereby have higher lion densities than other parts of the landscape. Lions in this landscape take cue into this ‘free’ resource of livestock carcasses (by scavenging them) to optimize their energy economics by maximizing the net food intake per unit time available for foraging. This gets further support from our predation data which suggests that a significant part (30%) of the livestock predation events were recorded on *Gaushala* cattle (unproductive), 3% on feral cattle of the villages and rest (36%) on domestic livestock of economic value. Often, demands have been made by local forest officials about removal of such cattle camps from the landscape. Such steps may have detrimental impact on lion biology and more importantly on the extent of lion-human conflicts. Rather the current practice of grass plantations and soil-moisture-conservation works by the forest department in these *vidis* may be beneficial for lion conservation in future. However, monitoring of illegal grazing, cutting, lopping and grass cutting should be done regularly. Some crucial *vidis* in terms of lion conservation (Nani Vadal, Ranigalo, Dholikui, Gebar, Rajasthali) currently have lower number of frontline staff. More recruitment can be made here for ensuring better protection. Besides, most of these *vidis* currently lack adequate drinking water facilities for wildlife. Construction of more water points (managing them by indigenously designed wind mills) can be thought of. Monitoring vaccination of livestock in these cattle camps should be prioritized so as to avoid spread of any disease to wild ungulates.

The study clearly demonstrates that despite lions’ use of a human-dominated landscape, their dependence on productive livestock was minimal. A similar pattern has been observed inside the Gir PA where livestock contributed between 25 to 42% of lions’ biomass consumptions, of which only 16% was predated; rest scavenged (chapter 11; Banerjee et al. 2013). The pattern within the Gir PA was found to be substantially contributing in shaping *Maldhari*-lion coexistence and we expect the same mechanism to be operating in the larger landscape too. Furthermore, lions’ dependence on nilgai in the larger landscape for their diet would be able to foster greater tolerance of the local farmers toward lions. Nilgai, wild pigs and other wild ungulates cause financial loss of varying extents to the local farmers. In the absence of any compensation scheme for crop damage, farmers consider lions as a mechanism of crop damage control. This gets additional support from my questionnaire survey and socio-economic data which indicates that most of the farmers wanted to have lions in future in the landscape



chiefly because of economic reasons (Banerjee 2012). However, it should be kept in mind that lions' hunting peaks are early mornings and evenings (chapter 8) which also coincides with the human activity peaks in an agro-pastoral landscape. Nilgai and wild pigs are mostly forest 'edge' species spending the whole days in forested patches and gregariously attacking croplands at nights and often attracting lions. This enhances the probability of lion attacks on humans as most of the farmers spend their nights at farmlands guarding crops (Banerjee 2012).

The importance of an unbiased understanding of biological (target species' ecological needs) and social (communities' economic damage tolerance) carrying capacity cannot be overemphasized in shaping future of carnivore conservation outside Protected Areas (Hayward et al. 2007b). The current estimates of prey density could be useful in predicting the carrying capacity of Girnar Wildlife Sanctuary and the corridor landscape for lions. Crop raiding by wild ungulates has been an intensifying problem for the Gir region. Currently, Gujarat Forest Department does not have any compensation scheme redressing the economic damage faced by the farmers. Anti-crop raiding measures adopted by farmers outside Gir contribute significantly towards lion mortality (by electrocution, trapping in snares etc.; Singh 2007; Banerjee and Jhala 2012). Assessment and regular monitoring of ungulate abundance in the human-dominated landscape therefore becomes crucial for the managers to quantify the actual economic damage incurred by the locals. The current study provides a baseline for that by evaluating ungulate density in the entire eastern landscape.

The study elucidates the biological basis of human-lion coexistence in the agro-pastoral Gir landscape. Within the Gir PA, lion-*Maldhari* coexistence is delicately balanced on a fulcrum of protection, livelihood economics and traditional value systems (chapter 11). *Maldharis'* free access to forest resources and the government compensation scheme for livestock depredation were found to be the most important ingredients behind such legendary 'Gir model' of tolerance. In the agro-pastoral landscapes, there are no free economic benefits for the communities. Economics of livelihood was found to be more instrumental in shaping local people's positive attitudes toward lions in the Gir landscape in comparison to experience of staying with lions (chapter 11). Incorporation of lost opportunity cost, prompt and systematic payments and timely revision of the Government Compensation Scheme therefore become extremely crucial for maintaining the goodwill of the communities towards lion conservation (Banerjee et al. 2013) and maintaining viable populations of other carnivores elsewhere on the Globe.



## CHAPTER XI

### *ECONOMICS OF LION-MALDHARI CO-EXISTENCE IN THE GIR FOREST*

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#### **Introduction**

Protected Areas (PA) have been the mainstay of international conservation commitments since past two centuries (Adams 2004). With over 100,000 PAs covering 11.7% of the earth's land surface (Phillips 2004), conservation is rapidly becoming one of humanity's major land-use objectives often competing with other type of land-uses. In a country like India which is home to approximately 1.2 billion people (UN 2009), majority (70%) being rural; forest resources have been part of traditional livelihoods for generations (Rai 2007). India's pre-independence (1947) colonial exploitative forest policies and subsequently post-independence exclusionary forest management often gave rise to polarized conservation debates about the rights of forest-dwelling communities (Saberwal and Rangarajan 2003). Politics of ecology becomes more contentious with pro-people group often arguing about the merit of conservation governances that alienates traditional forest-dwellers' access to forests and its resources, while their livelihood economics were marginalized due to wildlife damages and poor access to markets (Adams and Hutton 2007). Rarely do forest-dwelling pastoral communities coexist in harmony with large predators. Either the communities suffer substantial economic loss due to predation on their stock and/or large carnivores suffer heavy losses and even extirpation due to retaliation (Ogada et al. 2003; Inskip and Zimmerman 2009). Understanding the people-carnivore relationship, therefore, becomes more crucial especially in the conservation management of large carnivores (Treves and Karanth 2003; Karanth and Chellam 2009).

Although large carnivores often kill humans (Saberwal et al. 1994; Packer et al. 2005), the major form of conflict arises due to their habit of predating livestock and the resulting threat on economic security of the pastorals (Karanth and Chellam 2009). Human communities react differently to this conflict depending on their religious beliefs, customs, cultures, actual and perceived magnitudes of economic losses (Goldman et al. 2010). Reactions range from total extermination of large carnivores (Mech 1991), occasional removal of problem animals (Athreya et al. 2011) to tolerance and coexistence (Raval 1991).



With the exception of the cheetah (*Acinonyx jubatus*), India boasts of an intact large carnivore community despite high human population density and conflict with large carnivores (Divyabhanusinh 2006). Two-thirds of India's wildlife reserves are grazed by livestock (Kothari et al. 1995) where they are often predated upon by large carnivores (Sawarkar 1986). Cultural, ethical and religious reverence towards life forms including large carnivores is undoubtedly important in contributing to the continued survival of large carnivores in India (Gadgil and Thapar 1990). However, in modern times, western utilitarian values are fast replacing the custodial role of human society in maintaining natural systems. We believe that in this world of changing values, economics will be the driving force that will determine the fate of large carnivores in a landscape of conflict.

At the onset of the nineteenth century, Asiatic lions (*Panthera leo persica*) became restricted to the Gir forests of western India and their numbers declined to around 50 individuals due to hunting and habitat loss (Kinnear 1920; Fenton 1924). However, owing to the timely and stringent protection by the Rulers of Junagadh and subsequently during the post-independence by the State-run forest department; Gir lions have increased to about 400 and dispersed into a large tract of agro-pastoral landscape adjoining the Gir forests embodying a global conservation success story (Singh and Gibson 2011; Banerjee and Jhala *in press*).

Gir Forests are inhabited by trans-nomadic, multiethnic pastoral communities, called *Maldharis* for past one and a half century (Casimir 2001). Their main religion is Hinduism and they have strong religious ethics and sentiments towards nature and natural resources. They are primarily vegetarian and keep livestock for sale of dairy products. Due to their long history of apparent co-existence with lions that often predate on their livestock, it would be important to understand the underlying economics that permit such tolerance. In this chapter we quantify predation losses of livestock, estimate lion densities and diet and evaluate the economics of rearing livestock in lion habitats. We examined the notion that the legendary tolerance of the *Maldharis* towards lions (Raval 1991; Singh and Kamboj 1996) is not solely due to their beliefs and cultural sentiments but also because it is economically more profitable to live with lions.



## Methodology

### *Maldharis* and the study area

Gir PA is subjected to biotic pressure from 50 *Maldhari* settlements (*Nesses*) and 14 forest settlement villages (human population of 4,500; nearly 23,440 livestock) inside the PA boundary. There are 97 peripheral villages with a human population of approximately 150,000 and a livestock population of 94,600 within one km of the PA. The villagers use the PA for livestock grazing and other minor forest produces (Singh and Kamboj 1996; Singh and Gibson 2011). Each *Maldhari* family rears about 20-100 regionally famous indigenous breed of livestock, primarily Jafrabadi breed of buffalo (*Bubalus bubalis*) and Gir breed of cattle (*Bos indicus*). Often one or two camels (*Camelus dromidarius*) are kept for carrying fuel wood and fodder. The sale of dairy products has always been the mainstay of *Maldharis*' traditional economy (Varma 2009). Our study concentrated in the eastern part of Gir PA that is dotted with *ness* sites and has good lion density. The study area covered the livestock grazing areas of a cluster of six *nesses* namely Asundrali, Dodhi, Gudjinjva, Khajuri, Leriya and Mindha (**Figure 11.1**).

### Lion density estimation

Lion population was estimated using closed-population mark-recapture (Pollock et al. 1990). We used cues, including tracks, roars and alert behavior of prey to locate lions. The entire study area of eastern Gir PA was systematically searched by vehicle and on foot within a period of 3-4 days which represented a single occasion. A total effort of 53 days representing 17 occasions was expended. Lions were approached within 10-30 meters to determine their whisker spot patterns with binoculars, and by a 15 to 60 X spotting scope. We individually identified lions (> 1.5 year) from their unique whisker spot patterns and other permanent unique marks (Pennycuick and Rudnai 1970). Close-up color photographs using an 80 - 400 mm zoom lens were taken of both sides of the face and a full-face view to supplement field drawings (Jhala et al. 1999, 2004). Capture histories of individual lions were used to make an X matrix (Pollock et al. 1990) formally tested for population closure (Stanley and Burnham 1999) and analyzed using program CAPTURE (Rexstad and Burnham 1991) to deduce population size ( $\hat{N}$ ). The effectively sampled area was estimated by creating a polygon joining the outermost lion locations buffered by a



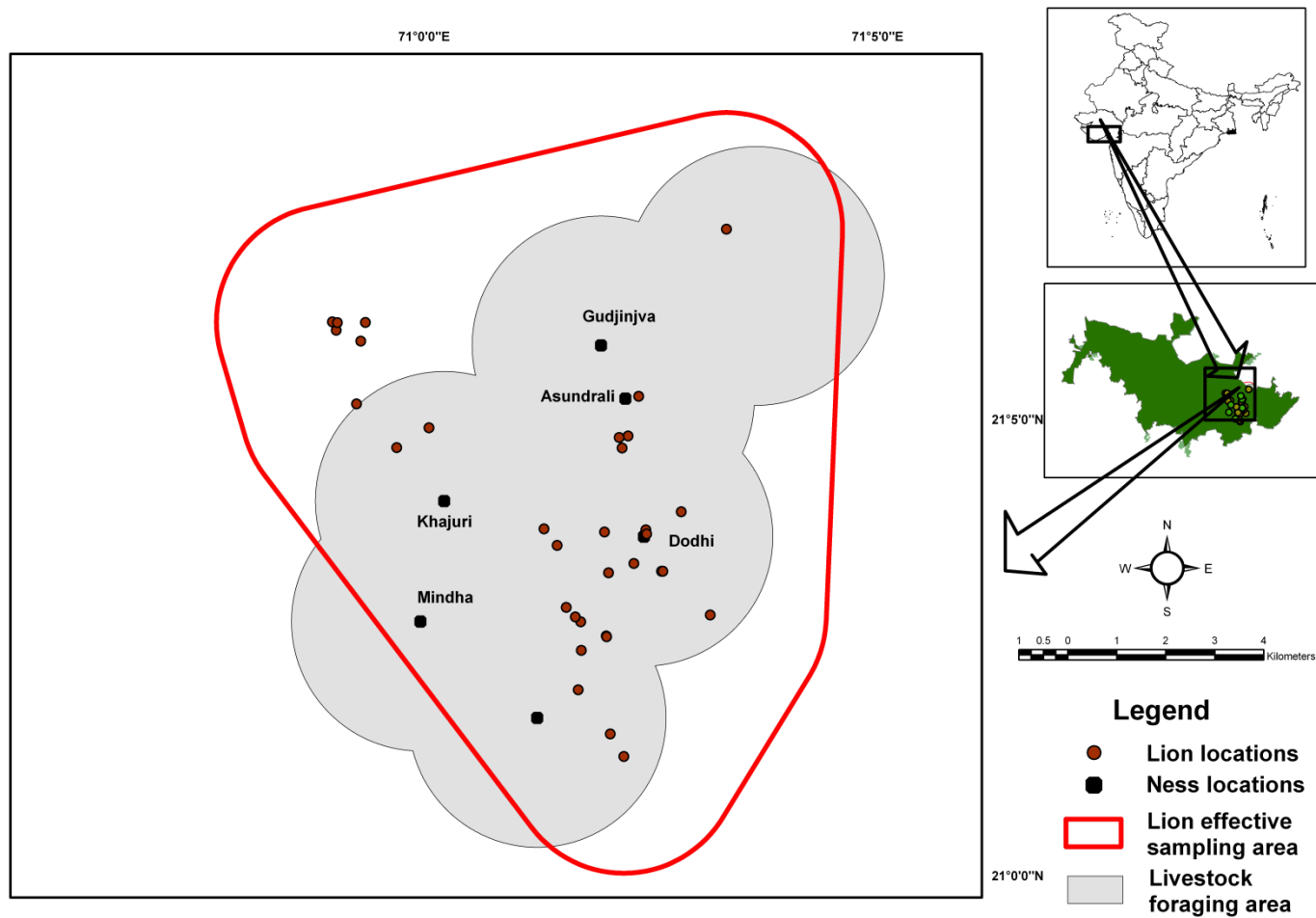
width estimated by half of the mean maximum distance moved ( $\frac{1}{2}$  MMDM) by recaptured lions (Karanth and Nichols 1998; Banerjee et al. 2010; **Figure 11.1**).

### **Livestock population and density**

A total head count of livestock in each *ness* was carried out. Livestock were counted during evening hours when all livestock were corralled for the night. Data was recorded on number and demographic structure of the livestock belonging to each family in a *ness*. We classified livestock as calf, juvenile, sub-adult and adult of both sexes. Adult female livestock were further classified into a) milk yielding, b) temporary dry but breeding age and c) non-productive. Seasonal livestock grazing circuits were estimated and mapped by accompanying three livestock herds from each *ness* in each season from early morning, when they leave to forage in the forest, till they return to the *ness* and were corralled for the night. Data was recorded on distance moved and linear displacement of livestock herds from the *ness* sites from 50 grazing circuits in the form of GPS (Garmin International, Kansas, USA) track logs (Dave 2008; Dave and Jhala 2011). Age-gender-productivity class composition of grazing herds as well as their spatial arrangement in a herd was also recorded at every 500 meter interval. Each *ness* site was buffered with its average seasonal foraging radius to compute the foraging area in a GIS map using program Arc GIS (ESRI, Redlands, CA). Seasonal livestock density was calculated as the total number of livestock divided by the total foraging area (Dave and Jhala 2011).



Figure 11.1: Study site within the Gir forests showing locations of different study *Nesses* buffered by average livestock foraging area, lion capture points and effective lion trapping area. The maps inset show the location of the Gir PA in India and the study site within the eastern part of the Gir forests.





## Lion diet

Lions' diet was determined by analysis of 165 lion scats (Korschgen 1980) and by monitoring of 4 radio-collared lions continuously for 5-12 day sessions (detailed below) within the study area. Lion scats were distinguished from those of other predators, particularly leopard scats, based on associated signs, tracks and size (Joslin 1973). We did not include ambiguous scats in the analysis. Prey remains such as hair, bones, hooves, quills and teeth of the prey consumed were identified to species using reference samples (Mukherjee et al. 1994a, b). Data were analyzed as frequency of occurrence and percent occurrence. We assessed adequacy of sample size by plotting the cumulative proportional frequency of occurrence against number of analyzed scat samples of each prey item (Jethva and Jhala 2003). One thousand bootstrap iterations (Krebs 1989) using SIMSTAT (Péladeau 1995) were used to generate 95% confidence intervals on frequency of occurrence of different prey items in the lions' diet.

Due to a differential surface area to volume ratio of small versus large prey, the frequency of occurrence data was corrected to arrive at biomass consumption per collectible scat (Floyd et al. 1978; Ackerman et al. 1984). We used Ackerman's equation [developed for cougar (*Felis concolor*)] to convert frequency of occurrence into biomass assuming lions to have a similar digestive physiology as cougars. The equation was  $y = 1.980 + 0.035 x$ , where  $y$  is the biomass of prey consumed (kg) to produce a single field collectable scat and  $x$  is the average body weight of the prey species (kg). The body weights of the potential prey species were taken from literature (Schaller 1967; Prater 1971) and corrected by field estimates. Prey densities (Dave and Jhala 2011) were used as availability. We compared counts of each prey item in the scats with the estimated prey availability using 1000 bootstrap iterations in program SCATMAN (Hines and Link 1994) to assess selectivity in utilization. Observed and expected proportions of prey species in the scats were then compared using a G test (Zar 2010) with  $\alpha = 0.05$  level. If there was a pattern of overall selective prey utilization, lions' use of each prey species as calculated by the program SCATMAN was further inspected. Food preference of lions in the study area was also computed by Jacob's Index (Jacob 1974) due to its lower bias, smaller confidence intervals with low heterogeneity and freedom from non-linearity compared with other electivity indices (Hayward and Kerley 2005).

Though frequency of occurrence in scats is a reliable technique for understanding the range of diet items, the method usually cannot distinguish between prey that are killed or



scavenged (Jethva and Jhala 2004). Consequently derived predation rates may be unreliable and an invalid basis to predict lion-*Maldhari* conflict levels. Therefore, we additionally followed four radio-collared lions on foot and/or four-wheel drive for seven sessions ranging from continuous 192 hours to 360 hours per session to understand the starve-feed cycle of lion foraging behaviour and distinguish between predation and scavenging events (Schaller 1972). A total of 1,798 hours of monitoring data was recorded during the study period. During this duration, lions were kept in view or within 100 meter from the observers day and night. Lions were initially habituated for 1-3 days prior to data collection and care was taken not to disturb the 'normal' behavior of the lions. During dark nights, a flashlight was used at intervals of 30-60 minutes to ascertain lion location apart from the radio signals. All predation and the scavenging events by the lions were recorded during continuous monitoring. Feeding interval was defined as the time lapse between two subsequent feeding events.

On an average 75% of the biomass of each carcass/kill was observed to be utilized by the predators (Chellam 1993). We estimated livestock's contribution to lion's diet from lion numbers in the study area obtained from lion density multiplied by daily intake requirement (7.3 kg/day, Joslin 1973) per lion, scat analysis and continuous monitoring of radio-collared lions in the study area.

### **Livestock depredation pattern**

Data on livestock depredation was obtained by forming a network of informants with appropriate incentives in all six *nesses* where all events of livestock predation and death were reported within a few hours by mobile-phone to our research team. Each predation site was visited within 24 hours to collect information on the time of day of each attack, the number, species and age-sex-productivity class of livestock killed, approximate weight of the predated individual, name of the owner and the identity of the predator.

Livestock that died due to natural causes were generally dumped at specific sites outside the *nesses*. We recorded scavenging events by large carnivores which were identified based on direct sightings, vocalization and signs. Owners of dead/predated livestock were interviewed to evaluate the market price of the livestock and whether they had filed a claim for the Government Compensation Scheme for livestock depredation or not. The compensation claims were cross validated from the Forest Department's records.



The monetary value of livestock was assigned in accordance with average prevalent market rate (**Table 11.1**). We compared this with the present compensation scheme provided by the Gujarat State Forest Department (**Table 11.1**) and the proportion of predation events claimed for compensation from the Government to estimate the offset of the capital loss incurred by the *Maldharis* due to livestock predation.

### **Lion carrying capacity**

In order to understand the relative significance of wild ungulates and *Maldhari* livestock in maintaining lion density in the study area, we used a regression model (Hayward et al. 2007a) that related prey biomass and lion density to estimate the ecological carrying capacity of the eastern Gir for lions. There are several approaches to indirectly predict carnivore density at a site; but studies have shown that it can be obtained more reliably by regressing against prey biomass (Carbone and Gittleman 2002). The carnivore density derived from this relationship only works as long as no other mechanisms besides prey availability limit a carnivore population. We used prey biomass for predicting lion carrying capacity in the study area as other major top-down limiting factors like trophy hunting and incidence of epizootics (Kissui and Packer 2004; Whitman et al. 2007) were not prevalent in Gir (Pathak et al. 2002). The model (Hayward et al. 2007a) based on lions' preferred prey species was more suited when lions occur sympatric with other carnivores like leopards. The equation was  $y = -2.158 + 0.377x$  ( $r^2 = 0.71$ ,  $n = 23$ ) where  $y$  is the  $\log_{10}$  of lion density and  $x$  is the  $\log_{10}$  of preferred prey biomass (Hayward et al. 2007a). We deduced prey biomass of different species by multiplying their densities (Dave 2008, Dave and Jhala 2011) with their respective unit weights. Since all the livestock units were not available for lion predation, we therefore assessed the lion carrying capacity for three different scenarios; i) no livestock biomass (depicting a situation where there were no *Maldhari* livestock inside the Gir forest), ii) 100% livestock biomass available and iii) 24% (based on the information on feeding events and predation we considered all carcasses of dead livestock and a proportion of dry females, sub- adults and calves that foraged within the forest to be available to lions; this proportion was about 24% of the total livestock population). This enabled us to examine the relative importance of different levels of livestock biomass in sustaining lion population in the study site of eastern Gir sanctuary.



**Table 11.1: Average monetary values (Indian Rupees ₹.; 1 US\$ ~ ₹. 50 ) for various age-sex-productivity categories of livestock (buffalo and cattle) used for analysis. The values in parentheses show the compensations amounts paid by the state forest department for the respective livestock classes to offset economic loss due to predation by carnivores in and around the Gir Protected Area (after Singh 2007).**

	Male calf	Female calf	Juvenile male	Juvenile female	Sub-adult male	Sub-adult female	Milk yielding adult female	Dry productive adult female	Non-productive adult female	Adult male	Non-productive adult male
Buffalo	800 (1,100)	1,000 (1,500)	1,200 (1,100)	2,500 (1,500)	3,500 (3,500)	4,000 (2,100)	15,000 (8,000)	10,000 (2,100)	4,000 (1,100)	5,000 (3,500)	3,000 (1,100)
Cattle	500 (1,100)	800 (1,100)	500 (1,100)	1,200 (1,100)	2,000 (3,500)	3,500 (2,100)	8,000 (6,000)	5,000 (1,100)	1000 (1,100)	8,000 (6,000)	500 (1,100)



## Cost of lion predation on *Maldharis*' livestock husbandry

We compared the livestock rearing costs by a *Maldhari* herder living within Gir with a livestock herder living outside the forest. *Maldhari* livestock within Gir obtain most of their forage requirements from the forest free of cost, while a major proportion of the fodder for livestock outside the PA needed to be purchased. Occasional predation by lions is the cost of rearing livestock in the Gir forests. We developed a deterministic economic model (**Table 11.4**) where we hypothesized that all other costs and profits being equal between the forest dwelling *Maldharis* and pastoralists living outside, it would be economically profitable for the *Maldharis* to stay in the forest with lions, if cost of obtaining livestock forage was greater than the economic loss due to lion predation.

The cost of lion predation was estimated in two parts:

- a) Capital loss- the market price of the predated livestock and
- b) Lost opportunity cost (Buchanan 2003) i.e. the opportunity to earn from the predated livestock in the years to come had it not been killed (**Table 11.4**).

Hypothetically this component of cost (b) would occur if there was a deficit between market rates and government compensation paid for different livestock classes predated by lions. We calculated the lost opportunity cost as the amount of income that a *Maldhari* would have made from the predated livestock based on its life expectancy and productivity (**Table 11.4**). We modeled two scenarios of *Maldhari*-lion economics; i) with the current state-run predation compensation scheme and ii) without any such compensation scheme to understand the efficacy of the predation compensation scheme in permitting lion-*Maldhari* co-existence inside the Gir forests and its implications for the larger lion-occupied agro-pastoral landscape as well.

## Results

### Lion density

We obtained 36 sightings of 20 individual lions (three adult males, 10 adult females and seven sub-adults). Plot of cumulative number of unique lions against lion sightings reached an asymptote suggesting adequacy of sampling. The model selection procedure of program CAPTURE selected the model incorporating time variation and individual heterogeneity ( $M_{th}$ , scored at 1). Program CloseTest supported population closure ( $\chi^2 = 30.2$ ,  $df = 12$ ,  $p = 0.19$ ). Capture probability of lions was 0.24 and the population estimate under  $M_{th}$  was 20 (SE 1) lions.



Using the  $\frac{1}{2}$  MMDM approach, we estimated a buffer width of 2.4 (SE 0.2) km and an effectively sampled area of 131 (SE 17) km<sup>2</sup>. Lion density was estimated at 15.2 (SE 0.1) lions/100 km<sup>2</sup>.

### **Livestock density, demography and holding**

The average foraging radius of livestock herds of six *ness* sites was 1.9 (SE 0.1) km. Some foraging areas of two or more *nesses* overlapped i.e. these areas were used by livestock from more than one *nesses*. Therefore, a common buffer of 1.9 km was created on the cluster of *ness* locations to compute livestock density. Livestock foraging area was maximum (95.2 km<sup>2</sup>) in pre-monsoon followed by 76.3 km<sup>2</sup> during summer and minimum foraging area during winter (65.9 km<sup>2</sup>). All *ness* sites showed seasonal fluctuation in livestock population. Maximum livestock number was observed during monsoon while during winter and summer livestock numbers decreased due to emigration of the herders outside the Gir PA. The livestock density was 31.4/km<sup>2</sup> in winter, 30.1/ km<sup>2</sup> in monsoon and 24.7/ km<sup>2</sup> during summer.

The total livestock holding of the study *nesses* was 2,140 (SE 296). Buffaloes were dominant contributing at 78.1%, while cattle (21.1%) and camels (0.8%) constituted the remainder livestock numbers. Overall population structure of buffaloes and cattle was largely composed of adult and sub-adult females (**Figure 11.2**). Few adult males were kept for breeding purpose. The average livestock holding of a *Maldhari* family varied from 29 (SE 3) in summer to 31 (SE 3) in winter and 39 (SE 4) in the monsoon.

Average grazing herd size was 22 (SE 2) and was always of mixed composition of cattle and buffaloes. High priced, milk yielding livestock were rarely taken out of the corrals to graze. These were stall fed by forage collected from the forest and by concentrates purchased from the market. Average number of herdsman accompanying herds was 2 (SE 0.04). Spatial lay out of the herds were with cattle (low monetary value) leading, buffaloes (high monetary value) in the middle and juvenile/sub-adult animals (low monetary value) trailing. The herdsman were usually mobile sometimes leading and at times pushing the herd from the rear.

### **Lion diet**

Frequency of occurrence of all prey items in scats reached an asymptote after sampling over 130 scats; so the sample size of 165 scats was deemed sufficient. Most (97.6%) lion scat contained a single prey type, while 2.4% of the scats had two prey items. Wild ungulates comprising chital,



sambar, nilgai and wild pig together accounted for 76.4% of all prey occurrences, while domestic livestock (buffalo 13.7% and cattle 7.8%) contributed the rest (**Table 11.2**). Percentage biomass contribution of different prey species to the lions' diet was most for livestock (33.7%) followed by chital (28.9 %) and sambar (28.3%). There was evidence of selective utilization of prey by lions ( $G = 76.9$ ,  $p < 0.001$ ,  $df = 5$ ). Chital ( $\chi^2 = 12.3$ ,  $p < 0.001$ ), sambar ( $\chi^2 = 103.4$ ,  $p < 0.001$ ), nilgai ( $\chi^2 = 2.4$ ,  $p < 0.05$ ) and wild pig ( $\chi^2 = 34.1$ ,  $p < 0.001$ ) were found to be utilized more than their availability while buffaloes ( $\chi^2 = 60.3$ ,  $p < 0.001$ ) were used less than their availability. Cattle ( $\chi^2 = 0.9$ ,  $p = 0.33$ ) were utilized in proportion to their availability. The order of prey preference by lions as estimated by Jacob's Index was sambar, wild pig, nilgai, chital and cattle (**Figure 11.3**).

### Livestock depredation pattern

We recorded a total 308 livestock mortality from the six *nesses* during my study period, of which 58.4% was due to lion predation, 3.2% was due to predation by leopards and 38.4% was due to other natural causes. Lion predation was mostly on cattle (69.4%) followed by buffaloes (29.4%) and camels (1.2%). Non-productive cattle dominated lion kills (**Figure 11.4**). Average age of livestock predated by lions was estimated at 4 (SE 0.2) years. Of the 118 events of natural death of livestock, 46.6% were scavenged by lions, mostly adult female buffalo carcasses (27.2%) reflecting a higher availability of this livestock category in the study area.

**Figure 11.2: Average seasonal livestock holding of *Maldhari* family within the Gir forest (error bars are standard errors).**

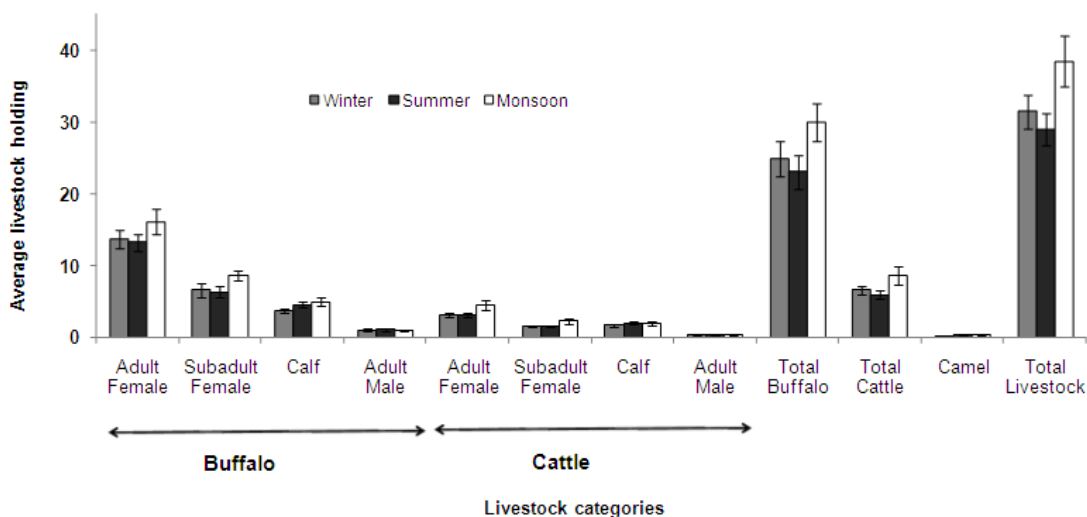




Figure 11.3: Food preference of lions in the Gir forests, India based on Jacob's index (Jacob 1974). Program SCATMAN (Hines and Link 1994) suggests that at 10% CV \* Chital ( $p < 0.001$ ), sambar ( $p < 0.001$ ), nilgai ( $p < 0.05$ ) and wild pig ( $p < 0.001$ ) were found to be positively selected while \*\*buffaloes ( $p < 0.001$ ) were underused in proportion to their availabilities. Cattle ( $p = 0.33$ ) were utilized in proportion to their availabilities.

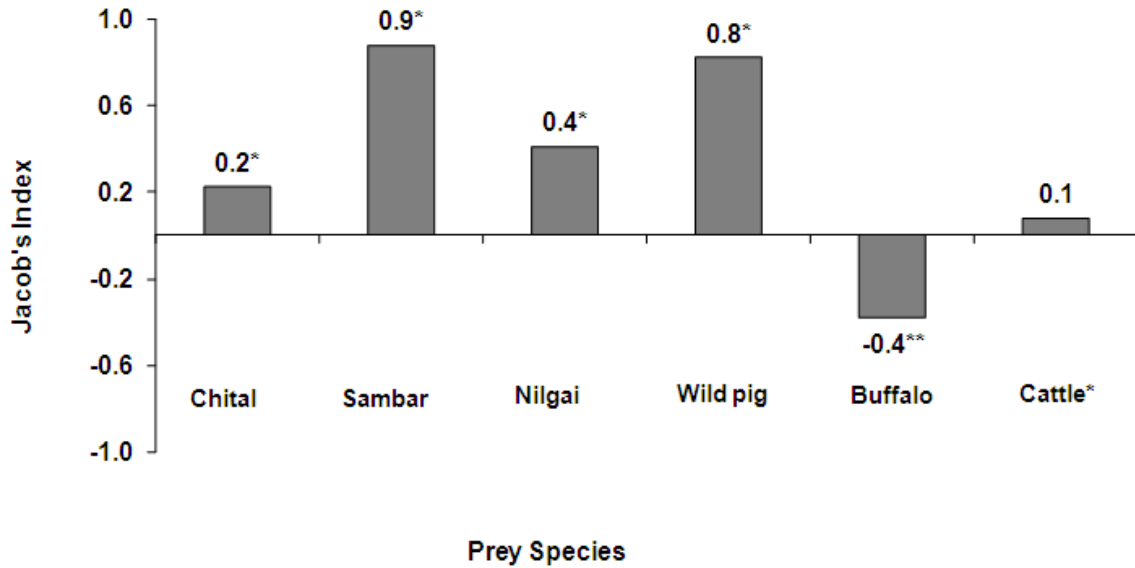
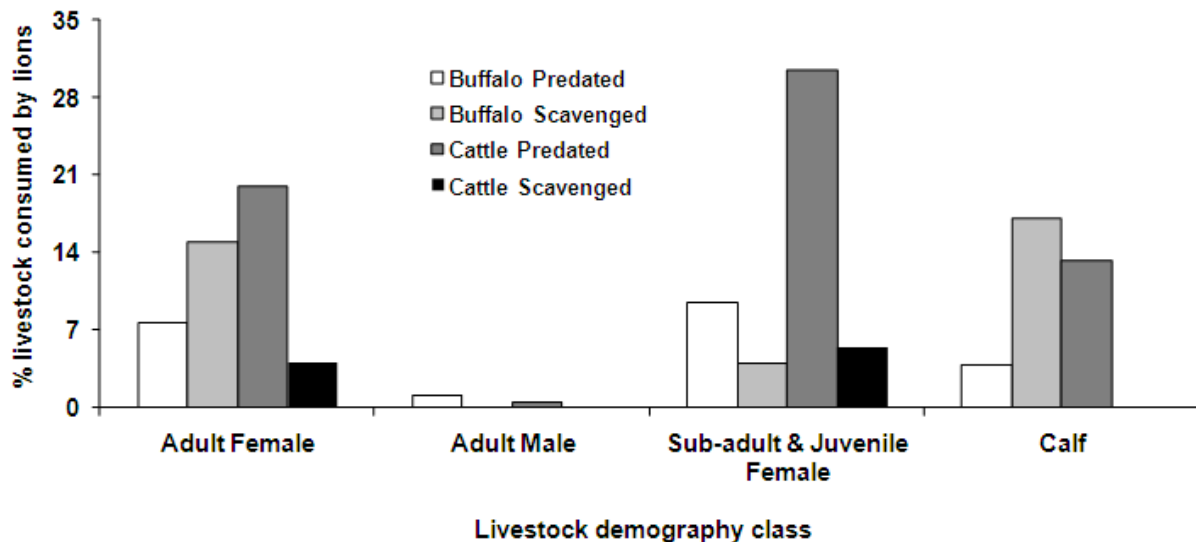


Figure 11.4: Livestock utilization by lions in the Gir East Sanctuary, India showing percent contribution of different livestock classes in livestock feeding events documented by continuous monitoring on radio-collared lions.





**Table 11.2: Prey species composition in Asiatic lion *Panthera leo persica* scats (n = 165) and their relative biomass contribution to lion diet in eastern part of the Gir forests, India. Where x and y are related through the equation  $y = 1.98 + 0.035 x$  (Ackerman et al. 1984).**

Prey Items	Body Weight (kg), (x)	Total Number of Scats	Observed Frequency of Occurrence [F] (95% CI)*	Relative Occurrence (as %)	Collectable scats/kill (y)	% Biomass Consumed (95% CI)
Chital	42	72.5	44 (37 - 51.8)	45	3.5	28.9 (24.3 – 34.1)
Sambar	119	40	24.4 (17.9 – 30.6)	24.9	6.2	28.3 (20.9 – 35.7)
Nilgai	136	7.5	4.6 (1.8 - 8.5)	4.7	8.3	7.2 (2.8 – 13.4)
Wild pig	28	5.5	3.4 (1.6 - 6.8)	3.4	2.9	1.9 (0.8 – 3.8)
Buffalo	204	22.5	13.7 (8.6 - 19.1)	13.9	9.1	23.6 (14.8 – 33)
Cattle	136	13	7.8 (3.7 - 11.7)	8.1	6.7	10.1 (4.7 – 14.9)

\* 95% CIs obtained by 1,000 bootstrapped replicates



The 180 lion kills recorded involved 151 successful hunt events [average killed/hunt 1.2 (SD 0.5)]. The number of livestock killed per successful hunt was weakly correlated with the number of lions reported by the herders (Spearman rank correlation  $r_s = 0.15$ ,  $p = 0.03$ ). Of the successful lion attack events on livestock, only 13% occurred within the *ness* when lions jumped into the fenced *ness* and killed livestock while 87% occurred in forests when livestock were out grazing. We did not record any leopard attack on grazing herds. In 68 events of lion attacks on grazing herds the herders could affirm the gender of the lions making the kills. Female lions with dependent cubs were responsible for 54.4% of the attacks; single male or male coalitions were responsible for 19.1% of the attacks and mixed groups of lions made 26.4% of the kills. Lionesses in the study area were found to raid livestock in proportion to the prevailing adult sex ratio in the population ( $\chi^2 = 0.19$ ,  $df = 1$ ,  $p = 0.66$ ). Thus all lions were equally likely to predate livestock.

Most (49%) of the lion predation events on livestock were recorded during early morning (7AM – 11 AM), followed by 39% in late afternoon (3 PM – 7 PM) [ $\chi^2 = 29.5$ ,  $df = 2$ ,  $p < 0.0001$ ]. But during monsoon, most predation events (44%) occurred during late afternoon or evening ( $\chi^2 = 14.2$ ,  $df = 2$ ,  $p < 0.001$ ) due to cooler ambient temperature, poor visibility owing to bad light, rain and thick vegetation undergrowth. Livestock losses to lions were different between seasons ( $\chi^2 = 6.5$ ,  $df = 2$ ,  $p = 0.04$ ), with 45% occurring in summer, followed by 30% in monsoon and 25% in winter.

A crude estimate of total intake requirement of the lion population in the study area was about 124,733 kg for the study period of 28 months. Livestock were found to be contributing about 31,582 kg (25.3 %) of biomass to the lion's diet. Inter-feeding interval of lions estimated by the continuous monitoring was 3.5 (SE 0.7) days with an average associated lion group size during feeding being 3.5 (SE 0.8). Telemetry data showed that livestock composed 42% of lions' feeding events (16% from predation and 26% was from scavenging on livestock carcasses). Wild ungulates were found to compose the remainder 58% of lions' feeding events (47% predated and 11% appropriated from leopard kills or other lion kills).

### **Lion carrying capacity**

Under the assumption of 100% availability of livestock biomass to lion predation, the lion carrying capacity was estimated to be 22 (95% CI 20-25) lions/100 km<sup>2</sup> while with no availability of livestock, the carrying capacity was 12 (95% CI 9-15) lions/100km<sup>2</sup>. Lion



carrying capacity with 24% of livestock population available for lions were 16 (95% CI 13-18) lions/100km<sup>2</sup> (Table 11.3).

### **Economics of lion predation**

Annual fodder cost for maintaining 100 livestock was estimated to be ₹. 1,460,000 [1US\$ ~ ₹. 50]. For forest-dwelling *Maldhari* this resource is available free of cost. Average cost of livestock units predated by lion was ₹. 4,018 ± 278 SE. *Maldharis* incurred an annual capital loss of ₹. 33,751 ± 2,335 SE/100 livestock by lion predation. Sixty four percent of this cost was offset by the government compensation (i.e. capital loss with Government compensation was ₹. 12,150 ± 840 SE/100 livestock). The annual lost opportunity costs incurred by *Maldharis* was ₹. 136,156 ± 3,430 SE/100 livestock with Government compensation. The same cost without Government compensation was ₹. 378,212 ± 9,529 SE/100 livestock. By living in the Gir forests, 58 ± 0.2 SE% of livestock rearing cost of *Maldharis* was accounted for by free forest resources in comparison to a non-forest dwelling pastoralist. With government predation compensation scheme this profit margin was further augmented to 76 ± 0.05 SE% (Table 11.4). Cost saving (additional profit) by *Maldharis* living in Gir was therefore, ₹. 1,104,373 /100 livestock/year (or 214 man-day wages/*Maldhari* family/month) and ₹. 840,717/100 livestock/year (or 163 man-day wages/*Maldhari* family/month) with and without a lion predation compensation scheme respectively in comparison with non-forest dwelling pastoralists (Table 11.4).

### **Discussions**

We found that presently *Maldhari* and lions co-exist in a win-win state where lions get a considerable part of their food from *Maldhari* livestock and *Maldharis* profit substantially by free access to forest resources. Average annual financial loss/*Maldhari* household due to livestock predation by lions after offsetting by the compensation was minimal (₹. 2,038) and was only 5% of the average *per capita* income for Gujarat province and 7% of the national average during the fiscal year 2005-06 (Ministry of Finance, Government of India 2009). With free grazing rights and at current rate of compensation, additional profits of a *Maldhari* family residing inside Gir approximately amount to a person's annual minimal wage (231 man-day wages). Current government compensation scheme, though small in comparison to the value of free resources, was important as it provided a *Maldhari* family an additional monthly monetary



**Table 11.3: Predicted carrying capacity of lions in the eastern part of the Gir forests at different availability of livestock biomass. Lion carrying capacity was predicted using the equation  $y = -2.158 + 0.377x$  ( $r^2 = 0.71$ ,  $n = 23$ ) where  $y$  is the  $\log_{10}$  of lion density and  $x$  is the  $\log_{10}$  of preferred prey biomass (Hayward et al. 2007a). Figures within parentheses are 95% CIs. Densities of wild ungulates (chital, sambar, nilgai and wild pig) were taken from Dave and Jhala 2011.**

Prey species	Density/km <sup>2</sup>	Body weight (kg)	100% livestock biomass available			No livestock biomass available			24% livestock biomass available		
			Biomass density/km <sup>2</sup>	Log (prey biomass)	Predicted lion carrying capacity (lions/100 km <sup>2</sup> )	Biomass density/km <sup>2</sup>	Log (prey biomass)	Predicted lion carrying capacity (lions/100 km <sup>2</sup> )	Biomass density/km <sup>2</sup>	Log (prey biomass)	Predicted lion carrying capacity (lions/100 km <sup>2</sup> )
Chital	35.1 (16.0 - 54.5)	42	1473.4 (673.7 - 2,289)	3.2 (2.8 - 3.4)	<b>22</b> (20 - 25)	1473.4 (673.7 - 2,289)	3.2 (2.8 - 3.4)	<b>12</b> (9 - 15)	1473.4 (673.7 - 2,289)	3.2 (2.8 - 3.4)	<b>16</b> (13 - 18)
Sambar	2.9 (1.3 - 4.4)	119	340.3 (153.5 - 527.2)	2.5 (2.2 - 2.7)		340.3 (153.5 - 527.2)	2.5 (2.2 - 2.7)		340.3 (153.5 - 527.2)	2.5 (2.2 - 2.7)	
Nilgai	1.2 (0 - 3.4)	136	159.1 (0 - 455.7)	2.2 (0 - 2.7)		159.1 (0 - 455.7)	2.2 (0 - 2.7)		159.1 (0 - 455.7)	2.2 (0 - 2.7)	
Wild pig	0.4 (0 - 1)	28	11.2 (0 - 27.7)	1.0 (0 - 1.4)		11.2 (0 - 27.7)	1.0 (0 - 1.4)		11.2 (0 - 27.7)	1.0 (0 - 1.4)	
Buffalo	32.8 (26.6 - 39.1)	204	6,699.4 (5,420.3 - 7,978.4)	3.8 (3.7 - 3.9)		--	--		1,599.8 (1,294.4 - 1,905.3)	3.2 (3.1 - 3.3)	
Cattle	9.2 (7.5 - 11)	136	1,256.4 (1,017.3 - 1,496)	3.1 (3.0 - 3.2)		--	--		300.1 (242.9 - 357.2)	2.5 (2.4 - 2.6)	



**Table 11.4: Description and estimation of cost parameters used for economic analysis. Final estimates are in Indian Rupees ₹. (1 US\$ ~ ₹. 50). Values within parentheses are 95% CIs.**

Equation Number	Parameters	Parameter Description	Final Estimates (95% CI)
A	Fodder cost for 100 livestock (LS)/year	8 kg fodder/LS/day @ ₹. 5/kg for 365 days for 100 livestock	1,460,000
B	Loss of capital due to lion predation <b>(with Govt. compensation)</b> per 100 LS/year	(Average cost of livestock predated – Government compensation received) X (% of LS killed by lions)	12,150 (10,502 – 13,799)
C	Loss of capital due to lion predation <b>(without Govt. compensation)</b> per 100 LS/year	(Average cost of livestock predated) X (% of LS killed by lions)	33,751 (29,173 - 38,329)
D	Lost opportunity cost due to lion predation <b>with Govt. compensation</b>	Computed by considering the proportion of productive LS (0.28) in the population and the average potential life of a predated livestock and its productivity within that span. The total average life expectancy i.e. 12 yr – average age of predation i.e. 3.9 yrs) was used to compute life remaining. Predation rate of lions on 100 livestock was used to compute numbers killed. These were corrected for by percent of natural mortality (i.e. lion predation of 8.4%, while natural mortality of 5.5% of 8.4% was 0.4%). Annual profit/LS from milk was computed as 200 days of milk yield annually of an average yield of 5 liters/LS and a cost of ₹. 20/liter. A livestock was considered to calve once each year with an equal sex ratio amongst calves. An average calf was computed to cost ₹. 845 (considering the proportion of cattle and buffaloes in the LS population) and this was added to the milk production i.e. $(5 \times 20 \times 200) + 845$ . With government compensation scheme for livestock predation 64% of this cost gets compensated and remaining 36% was uncompensated. Therefore the final equation becomes $(12 - 3.9) \times (8.4 - 0.4) \times [(5 \times 20 \times 200) + 845] \times 0.28 \times 0.36$	136,156 (129,432 – 142,880)
E	Lost Opportunity cost <b>without compensation</b>	Same as equation D but with 100% of the cost being uncompensated. Therefore the final equation becomes $(12 - 3.9) \times (8.4 - 0.4) \times [(5 \times 20 \times 200) + 845] \times 0.28$	378,212 (359,535 – 396,889)
F	Guarding cost for <i>Maldhari</i> (Assuming that outside herder will need half the herders than a <i>Maldhari</i> in lion habitat)	1 person extra for a herd of 25 therefore for 100 LS the cost is of 4 persons @ ₹. 142 <sup>s</sup> /day for a year	207,320
G	Total revenue loss to <i>Maldhari</i> by lion	B+D+F	355,626 (353,979 – 357,275)



	predation & extra guard cost when <b>Govt. compensation is availed</b> for lion predation		
H	Total revenue loss to <i>Maldhari</i> by lion predation & extra guard cost when <b>Govt. compensation is not availed</b> for lion predation	C+E+F	619,283 (614,705 – 623,861)
I	Profit of living in lion habitat <b>with Govt. compensation</b> for lion predation	A-G	1,104,373 (1,102,725 – 1,106,021 )
J	Profit of living in lion habitat <b>without Govt. compensation</b> for lion predation	A-H	840,717 (836,139 – 845,295)
K	% of cost offset by living in Gir forest <b>with Govt. compensation</b>	100*(I/A)	75.6 (75.5 – 75.7)
L	% of cost offset <b>without compensation</b>	100*(J/A)	57.5 (57.2 – 57.9)
<b>Average livestock holding in a <i>Maldhari</i> family</b>			<b>33</b>
M	Total monthly cost for rearing 33 LS units outside Gir would be	[(A/100)*33]/12	40,150
N*	By living in the Gir forest this is reduced by 58%, therefore the monthly monetary gain	M-(1-L)*M	162.8 (161.9 – 163.7)
O*	By lion predation Govt. compensation the monthly rearing cost is reduced by 82%, therefore monthly actual monetary advantage	M-(1-K)*M	213.8 (213.5 – 214.2)
	Additional monetary advantage due to compensation*	N-O	51

§ Daily labor's wage rate of the Gujarat State Government Labor Department during the study period.

\*Final estimates are in man-day units which were calculated by dividing the monthly monetary gains in ₹. by labor rate i.e. ₹. 142.



advantage of 21 man-day wages to a no-compensation scenario (**Table 11.4**). We did not, however, consider the additional benefits *Maldharis* enjoy by dwelling inside Gir i.e. from other ecological services and amenities (collection of fuel wood and minor forest products, use of forest topsoil mixed with dung sold as manure, free access to water, job opportunities with the forest department and maintaining their social customs). These, when incorporated into our analysis, further augment the benefits *Maldharis* make by living inside Gir.

The *Maldhari*-lion co-existence in Gir forests is long debated with one school of thought attributing ecological deterioration of the Gir to the traditional way of resource usage by *Maldharis* (Pati 2000) and therefore advocates their relocation outside the PA (Pathak et al. 2002). The other school, on the contrary, attributed exclusionary forest policy and insufficient compensation scheme by the Forest Department as causes of economic marginalization of Gir *Maldharis* (Mukherjee and Borad 2004). Livestock has always been an important part of lion's diet in Gir ranging between 83 to 25% (Joslin 1973; Sinha 1987; Chellam 1993; Meena et al. 2011). We studied livestock depredation pattern by lions with a combination of methods *viz.*, scat analysis, predation pattern and feeding events of the radio-collared lions in order to address inherent limitations of each method and estimated biomass contribution by domestic livestock in lions' diet to range between 25 to 42% within eastern Gir PA. Past long-term research from Africa have shown that prey availability and density govern lion demography like cub survival and dispersal rates (Schaller 1972; Van Orsdol et al. 1985). The current study suggested that the carrying capacity of lions modeled with available biomass of dead livestock and livestock classes vulnerable to lion predation (24%) was almost similar with the current lion density estimated in the study area (15 lions/100 km<sup>2</sup>). However, when we considered a hypothetical situation where there were no *Maldhari* settlements in the study area and therefore no availability of livestock biomass for lions, the predicted lion carrying capacity went down (12 lions/100 km<sup>2</sup>), albeit not statistically significant. Moreover, lions in Gir obtained a major part of their diet from scavenging livestock. Being a free resource for lions, this optimized the Gir lions' energy economics by maximizing the net food intake per unit time available for foraging (Stephens and Krebs 1986). Abrupt removal of livestock as a food source is thus likely to have a detrimental effect on lion density and demography in Gir (Jhala et al. 2004, 2011a). Therefore the current study recommends that if removal of livestock is to be considered, it should be in a phased manner so as to allow natural wild prey population to build up and replace livestock (Singh



2007). With a lion focused conservation objective of Gir, maintaining livestock at the current or lower stocking densities could also be considered as an alternative management practice. However, to avoid negative impacts of livestock trampling, livestock numbers should be regulated at the *nesses* with their locations rotated every four-five years (Dave and Jhala 2011).

Human attitudes towards large carnivores have been shaped by psychology of fear and personal experience (Røskoft et al. 2003), and also depend on their attachment to livestock (Vittersø et al. 1998). Gir *Maldharis* did not view lions as a threat to their lives (Raval 1991) and there was no lion attack on humans within our study area during past two decades. Moreover, unproductive cattle (such as males and poor condition calves, aged, and dying cattle) were mostly targeted by lion predation. The average cost of such unproductive cattle was ₹. 3,425 and at times, it was not profitable to maintain them by stall-feeding. We believe that retaliatory killing of lions is not prevalent in Gir due to low economic losses, *Maldharis*' cultural ethics, combined with strict legal enforcement by the Gir Park management. But traditional value systems of the *Maldharis* are rapidly changing under the influence of globalization and free markets (Sinha et al. 2004). Younger generations are less tolerant to even small monetary losses which older generations considered as *fait-accomplis*. We anticipate that such changes in attitudes and values are likely to result in a change of *Maldharis*' harmonious coexistence with lions. A similar transition has happened with the pastoral Masai community in the eastern Africa within the past two decades (Homewood et al. 2009; McCabe et al. 2010). With this change in values, comes complacency towards professional lion poachers by local communities. This was probably the case when 8- 10 lions were poached for their body parts in the recent past in Gir (Singh 2007; Fair 2009) and elsewhere in India in the case of tigers, *Panthera tigris* (Check 2006; Gopal et al. 2010). Reparative measures such as compensation programs become important herein, mitigating conflicts by offsetting monetary costs to local communities (Agarwala et al. 2010). The success of Asiatic lion conservation is partly attributable to the early policies (1930s) of the erstwhile Junagadh Nawabs (Gee 1964) and later to the state run Gujarat Forest Department in implementing compensation schemes for livestock predation (Singh 2007). In order to reflect the current market value of the livestock, the compensation rate is usually revised at an interval of every 6-8 years (Singh 2007). We found that the current compensation scheme substantially minimized lion-*Maldhari* conflicts by lowering the latter's capital loss by 64% and allowing them to make an additional monthly monetary profit of 51 man-day wages/family in comparison



to a non-compensation scenario. We believe that this had a positive role in shaping *Maldharis*' perceptions about their personal losses and thus acts as an important factor promoting their coexistence with lions. A similar pattern has been observed among the Masai community residing around the Mbirkani Ranch, Kenya where individuals receiving compensation from a local NGO showed a lower propensity to kill lions and were found to bear more positive attitude towards conservation (Hazzah et al. 2009; MacLennan et al. 2009). The current compensation scheme in Gir addresses *Maldharis*' capital loss to a significant extent. Increasing this to current market value of the predated livestock by timely revision (every 2 years) would ensure that there is no lost opportunity cost to the local communities. However, recognizing the role of compensation policies in providing instant financial relief, the procedural framework of the current system in Gir could be more streamlined and provisions of onsite payments with active involvement of local non-governmental organizations like that prevailing in Corbett and Dudwa Tiger Reserves, India (WWF-India 2007) could also be adopted.

*Maldharis* and Masai seemed to have mastered husbandry practices over generations to minimize predation losses to lions and permit co-existence. Both communities corral their livestock at night in their 'bomas' and graze the livestock during daytime, avoiding peak lion activity period and having expert herdsman (Ikanda and Packer 2008). In Gir, cattle were the preferred prey of lions as they are easy to kill due to their behavior of flight when attacked while buffaloes have a defense strategy and often attack lions as a cohesive group. Cattle are relatively less priced in comparison to buffaloes and therefore *Maldhari* grazing herds were always observed to have a few non-productive cattle. Thus, when lions attack, they are more likely to kill these vulnerable cattle. Moreover, *Maldhari* herdsman orient their herds with cattle leading, buffaloes in the middle and juvenile animals trailing. We speculate that the current traditional mechanism of warding off lion predation by corralling livestock at night and having a mixed grazing herd composition being always accompanied by expert herdsman minimized the risks and economic losses to lion predation. In Gir since livestock are reared only for dairy products and are not consumed by *Maldharis* (Raval 1991) there is a large cohort of old and weak cattle in which natural mortality is high and these carcasses are available to lions for scavenging.

We conclude that the underlying economics of *Maldhari* livelihood securities, their religious sentiments, ecological benefits enjoyed by pastoralists living in lion habitats and strict legal protection regime for lions in the Gir forests (Raval 1991; Singh and Kamboj 1996; Pathak



et al. 2002) are all needed as recipe for lion-*Maldhari* co-existence. Indefinite increase in human and livestock population within the Gir forests would upset this balance by altering the forest composition or even population dynamics of wild prey (Owen-Smith 2002) and would thus be detrimental for the conservation objective of the Protected Area. Presently lions are dispersing out of the Gir PA and have already occupied about 9,000 km<sup>2</sup> of agro-pastoral landscape (Banerjee et al. 2010; Singh and Gibson 2011). The current study suggests that lions outside the PA depend substantially on livestock (see chapter 10 for more details), thereby increasing the chances of human-lion conflict in the region. In the agro-pastoral landscapes, there are no free economic benefits for the communities. Government compensation scheme therefore becomes extremely crucial for maintaining the goodwill of the communities towards lion conservation. Compensation cannot ‘buy’ an individual’s tolerance of carnivores (Naughton-Treves et al. 2003) but does ameliorate hostility.

Due to high human densities and demand for land most human free inviolate protected areas in India and elsewhere are too small to hold viable populations of large carnivores for the long-term (Narain et al. 2005). Coexistence with humans therefore becomes essential if large carnivores were to be conserved for the long-term. Considering the case of Asiatic lions, only about 7% of the adult lion population resides in the human-free Gir National Park, 49% of adult lion population resides in the Gir sanctuary (with *Maldhari* settlements) while 44% of the adult lion population resides in the human-dominated agro-pastoral landscape of Saurashtra (Gujarat Forest Department 2010; Jhala et al. 2011a). A similar situation exists with most tiger populations in India as well (Jhala et al. 2011b). Such scenarios are common to several developing countries and activities like paying compensation should be considered as ecosystem maintenance costs that need to be paid to the local communities by Global societies or Governments for the continued survival of large carnivores within landscapes of conflict to promote coexistence. This would foster greater tolerance by local communities towards lion conservation in the Gir landscape and for other large carnivores elsewhere. We see no end to this or similar programs worldwide and believe that they form an integral component of coexistence and an important component of conserving viable populations of large carnivores.



## *CHAPTER XII*

### *ASSESSMENT OF LOCAL PEOPLE'S PERCEPTION TOWARD LION CONSERVATION IN THE GIR LANDSCAPE*

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#### **Introduction**

Caughley and Sinclair (1994) suggested that the first step of conflict management should be the identification of the real damage and actual level of conflict. Although in some cases losses might not be economically significant at a regional scale, for the affected household, they could be damaging (Mishra 1997) or at least perceived to be so. Therefore understanding the economic strain of conflict on local peoples' livelihoods and their attitudes towards conservation are central to the successful conflict mitigation. People who endure conflict and feel they are ineffective in ameliorating the problem are likely to be more inclined to retaliate (Mills and Hofer 1998). Public attitudes are generally believed to be most positive in areas where carnivores are absent (Zimmermann et al. 2001) or in areas with an unbroken carnivore-human coexistence (Boitani 1995). But while attitudes might be favorable in a large portion of today's urban population, locally the old conflicts still might exist with marginalized communities like farmers and pastorals strongly opposed to carnivore recovery. They are the groups most directly affected, and they are afraid of damage to livestock and game, increased costs and working efforts, foreign involvement and new restrictions (Kaczensky 2003). In the absence of large carnivores, locals have often abandoned traditional herding methods and may have lost the knowledge about the predators themselves. The re-appearance of large carnivores, therefore, may result in locally high damage levels (Kaczensky 1999) and/or a high level of fear among local residents (Zimmermann et al. 2001). In addition, with the perceived social pressure to act in a certain way, this may result in a highly negative attitude across a whole region. Even though the actual financial losses might be small, the recoveries of large carnivores are seen as threats to the traditional lifestyle and often highlight a gap between urban and rural people in modern society (Breitenmoser 1998).

Zimmermann et al. (2001) found that the proportion of people with negative attitudes continues to increase to its maximum with the arrival of large carnivores, and then decreases with experience of living with large carnivores over time. Similarly, they found that the proportion of people afraid of large carnivores was relatively high during initial phase of



carnivore arrival but also decreased with experience. It appears that people can learn to coexist with large carnivores and change their views. This could have been attributed to the human fear psychology (bio-phobic or bio-philic) and peoples' concern about their own safety and health (Røskaft et al. 2003). However; ethical, cultural and traditional values and beliefs of the communities towards wildlife and particular species as well as political representation of the species could be the most important socio-ecological factors governing such perceptions and thereby could be a significant driver in shaping human-wildlife conflicts (Mishra 1997, Naughton-Treves et al. 2003).

Gir PA has a legacy of harmonious co-existence of lions and other wildlife species along with its traditional pastoral communities (*Maldharis*) in spite of livestock depredation by lions and leopards (Singh and Kamboj 1996; Divyabhanusinh 2005). There is a state run compensation scheme for livestock depredation which is being revised periodically in reflectance with market values (Singh 2007). Additionally, these communities being at the centre of the forests enjoy free access to many forest resources and are economically benefited at the prevailing Compensation Scheme. These act as the economic driver behind *Maldhari*-lion co-existence (Banerjee et al. 2013). But this equation of coexistence may not hold true in the vast unprotected agro-pastoral landscape outside the Gir PA where lion conservation is not a prime land-use objective and communities get compensation but do not have any access to other free forest resources. A farmer outside the Gir might have economic gains in having lions as a control to crop damage by killing agricultural pests (wild ungulates) but a pastoral with hardly any access to the forest resources and often ignorant about the government compensation schemes might hold hostility towards lions. Livestock constitutes majority of lions' diet in the larger landscape (Chapter 10). Although lions mostly scavenged on carcasses and mostly predated on unproductive cattle but local communities might perceive otherwise. Local tolerance towards lion populations is determined by several factors but we hypothesize that these would primarily be economics of damage and perception of threat. The prediction that follows this hypothesis is that lion populations that obtain most of their food by scavenging, predation on unproductive livestock, and wild prey, would be tolerated or even encouraged by local communities while others persecuted.

The future of survival and conservation of lions in the Gir landscape will depend significantly on how local communities outside the Gir PA perceive lions and react accordingly



(tolerance *versus* hostility; see Conover 2002). Currently park management and conservation communities may be elated by the success story of the Gir lions (Lenin 2011; Singh and Gibson 2011) but we feel that this should not preclude the foresightedness in planning based on realistic future projections of conservation risks and management challenges. It is therefore imperative to have an unbiased understanding of the local communities' perception towards lion conservation in the human-dominated landscape and timely adopt the current policies to suit the challenges. This effectively checks public repercussions even before they sprout. In this chapter we assess the local communities' perception towards lion conservation and government compensation scheme in the agro-pastoral Gir landscape. This component of the study would highlight the conservation perception at different socio-economic level and would be useful to identify the social carrying capacity for lions in the landscape. This understanding would be the necessary ingredient in the recipe for future persistence of lion population in the larger landscape.

## **Methodology**

**Field method:** A closed and open ended structured questionnaire (Bath 1987; Bernard 1995) was administered to 680 respondents (272 from Junagadh district, 238 from Amreli district and 170 from Bhavnagar district) from 254 villages of the Gir landscape (84 villages of Junagadh, 138 villages of Amreli and 32 villages of Bhavnagar; **Figure 12.1**) to get an overview of the socio-economic conditions of the local people, occupational patterns in the area and the attitudes and support of local communities towards lion conservation. All respondents were above 18 years and were questioned only if they agreed to answer the questions and participate in the survey. Interviews were conducted in vernacular language (Gujarati and *Kathiawari* accent) and in an informal way of conversation by memorizing the questions leading the discussion to acquire the desired information. The questionnaire survey was primarily carried out by the same research team members so as to maintain the uniformity and reduce the individual biasness in the scoring of the answers. A family was treated as the basic unit for the purpose of this study, with only one respondent from a family being interviewed. The respondent was treated as a representative of the family unit.

The structured questionnaire used was divided into three main sections (**Table 12.1**). The first section primarily dealt with the demographic details (age, gender, caste, education level, etc.), awareness of the interviewee regarding animal species present in and around the villages and a visual assessment of the economic condition of the interviewee. The second part dealt with



socio-economic questions pertaining land holding, livestock owned and occupation. The final section comprised of questions pertaining attitudes and perception of the respondents towards lions and government compensation scheme paid for livestock predation. The initial questions were related to simple demographic information. This helped to ease the respondents into the interview session. If the respondent did not understand any given question, it was repeated and elaborated till it became clear that the respondent had understood it, and only then was the response noted down.

Although the questionnaire had a provision for gender but we could not interview women sufficiently (n = 4) and excluded them from our dataset.

**Analytical method:** Responses from the questionnaire survey were analyzed to arrive at economic well being index, primary source of livelihood in the area and the attitudes and perceptions of people towards lion.

*Economic well-being index:* To make it possible to compare data among different respondents, it was important to get all the answer categories into a uniform system. Therefore, the responses were at first put into categories explained in details in **Table 12.1**. Each question was then assigned a score. Total score for all the questions was calculated and then an average score was calculated to indicate the economic well being of the people. The combined weighted scores were then graphically represented for a better visual interpretation.

*Source of livelihood:* The livelihood sources of the people were categorized into major four groups- agriculture, pastoralism, agro-pastoralism (we assumed the person holding land along with at least eight livestock unit as an agro-pastoralist) and others (service, business and daily wage labor). Service includes all private and government jobs where the respondent is getting paid by his/her employer while business includes a variety of self-entrepreneur employments like shop-keeping, motor garage, priest, blacksmith, potter etc.

*Attitudes and perceptions of people towards lion conservation:* Attitudes and perceptions of people towards lions were examined by considering both—effect of lions on people’s lives and the effect of the people’s lifestyles on lions. Answers to different questions were once again scored generally with the more ‘negative attitudes’ getting lower scores while more ‘positive attitudes’ getting the higher scores.

All data analysis was done with SPSS version 19.0 (SPSS Inc., Chicago, USA). A test was considered significant at  $P < 0.05$  level and were two tailed. Responses were either on



continuous scale (e.g. land holding, herd size etc.), or categorical form (e.g. major future threats to lions, like to have lions in the neighborhood etc.) later converted into proportion of positive response in different categories. To characterize the socio-economy and demography of the landscape, we reported mean and 95% confidence intervals of these variables. The differences in attitudes towards lions among various demographic groups were analyzed using chi-square analysis (Zar 2010).

We divided our dataset into two categories; i) attitude and perception towards lion conservation (like to have lions or not; section C of **Table 12.1**) and ii) perception about the government compensation provided for livestock depredation (section D of **Table 12.1**). To explore the interrelatedness of socioeconomic variables for both the data sets (i and ii), we used Spearman's rank correlation coefficients (Zar 2010) to check for redundancy in the socioeconomic variables and selected only one for further statistical analysis when two or more variables significantly correlated with each other. We performed generalized linear models (GLM; McCullagh and Nelder 1989) with a linear scale response to investigate local people's liking for having lions in neighborhood in future and efficacy of government compensation scheme for livestock predation (is the compensation appropriate in monetary term). We constructed *a priori* candidate models representing factors behind local people's attitudes toward lions and the Government compensation scheme for livestock predation. Given the available data and knowledge of the study landscape, we constructed each candidate model based on the plausibility of *a priori* hypothesis (Burnham and Anderson 2002). We used information-theoretic approach to select between candidate models (Kullback and Leibler 1951); either selecting the one with the smallest  $\Delta AIC$  value (Akaike 1974) or conducting multi-model averaging (Burnham and Anderson 2002), if competing non-nested models had similar  $\Delta AIC$  values ( $< 5$ ). Model averaging was performed in R environment using lme4 (Bates et al. 2011) package.



**Table 12.1: Questions asked to sampled households in the 254 villages of the Gir landscape to assess socio-economic status and community perception towards lion conservation.**

<b>Section A. Personal/Demographic</b>	
Gender	Male = 1, Female = 2
Age Group	Young (18-30 yrs), Middle (30-60 yrs), Old (> 60 yrs)
Education	0-6 scale where 0 = no education, 1 = primary, 2 = secondary, 3 = higher secondary, 4 = below graduate, 5 = graduate and 6 = above graduate
Visual assessment of the footwear of the respondent	1-5 scale where 1 = no footwear, 5 = costly footwear
Visual assessment of the cloth of the respondent	1-5 scale where 1 = torn cloth, 5 = excellent cloth
Visual assessment of the ornaments (bangles, ear rings, wrist watches etc.) of the respondent	1-5 scale where 1 = no ornament, 5 = costly ornaments
Visual assessment of the housing of the respondent	1-5 scale where 1 = thatch, 2 = <i>kutchal</i> /semi- <i>pucca</i> tinned/cement sheet roof, 3 = <i>kutchal</i> /semi- <i>pucca</i> mud baked tiles roof, 4 = <i>pucca</i> mud baked tiles roof, 5 = concrete
Economic status	Rated in a 1-3 scale where 1 = very poor, 2 = well off and 3 = affluent
<b>Section B: Occupation</b>	
Pastoralist	If yes, holding pattern of buffaloes, cattle, shoat (sheep + goat) and others (camel, pig, horse, donkey etc.)
Farmer	If yes, land holding (in <i>bighas</i> ) 1 <i>bigha</i> = approx 2,327 m <sup>2</sup> Is the land irrigated/non-irrigated/ <i>vidi</i> ( <i>gauchar</i> ) in a 1-3 scale
Agro-pastoralist (land + livestock > 8 units)	Both land holding and livestock holding pattern in the same pattern mentioned above
Others (business, service, daily wage labor)	Approximate monthly salary (Indian Rupees ₹.)
<b>Section C: Attitude &amp; perception about wildlife &amp; lion conservation</b>	
Awareness of presence of large animals surrounding his/her villages	Rated in a 1-5 scale where 1 = most seen animal and 5 = least seen animal, verified with a pictorial guide of mammal (Prater 1971; Menon and Daniel 2003)
Awareness of risk in having lions in the neighborhood	Kills people on sight = -2, tremendous havoc to livestock = -1, rarely a risk to human life but does



<i>Table 8.3.1 Contd.</i>	occasionally kill livestock = 0 and does not kill humans or livestock = 1
Since when lions started living in the vicinity?	0-3 scale where 0 = no idea, 1 = < 5 yrs, 2 = 5-10 yrs and 3 = > 10 yrs
How did lions reach in your area?	0-2 scale where 0 = no idea, 1 = natural dispersal and 2 = left over by the forest department
Would you like lions to continue to live in your neighborhood?	0 = no/dislike; 1 = yes/like
Reason for like/dislike	Personal grievance (loss of livestock, family member) = -4, perceived hatred & danger = -3, economic loss = -2, perceived control of land and resources by the forest department = -1, indifferent = 0, values lion for beauty, nobility & charisma = 1, views lions as pride of the native land = 2, understands the ecological role of lions = 3, understands the conservation significance of lions = 4 & economic reasons (wildlife damage control, tourism etc.) = 5
Recommendation for conserving lions in the landscape	No idea = 0, do nothing = 1, capture lion back to Gir = 2, develop eco-restoration = 3, create more PAs = 4, people's participation = 5, economic incentives (tourism, payment, compensation) = 6
What can be done to gain more public support for lion conservation?	Remove lions = -1, no idea = 0, better compensation = 1, subsidize wildlife damage control = 2, educational awareness campaign = 3 & more employment generation with the forest department = 4
<b>Section D: Livestock predation compensation scheme</b>	
Is the person aware of the scheme?	0 = no, 1 = yes
Is the scheme appropriate in terms of monetary value?	-1 = no, 0 = no idea, 1 = yes
Is the scheme prompt & systematic in payment?	-1 = no, 0 = no idea, 1 = yes
Are false claims major problem?	-1 = no, 0 = no idea, 1 = yes
Is irregularity in payment a major problem?	-1 = no, 0 = no idea, 1 = yes
Suggestion to improve the scheme	Do nothing/no idea = 0, monetary increment = 1, more prompt & systematic = 2, prompt & monetary increment both = 3
Perceived major threat to lion survival in future?	None, indifferent, poaching, poisoning, electrocution, open well, loss of habitat, loss of wild prey



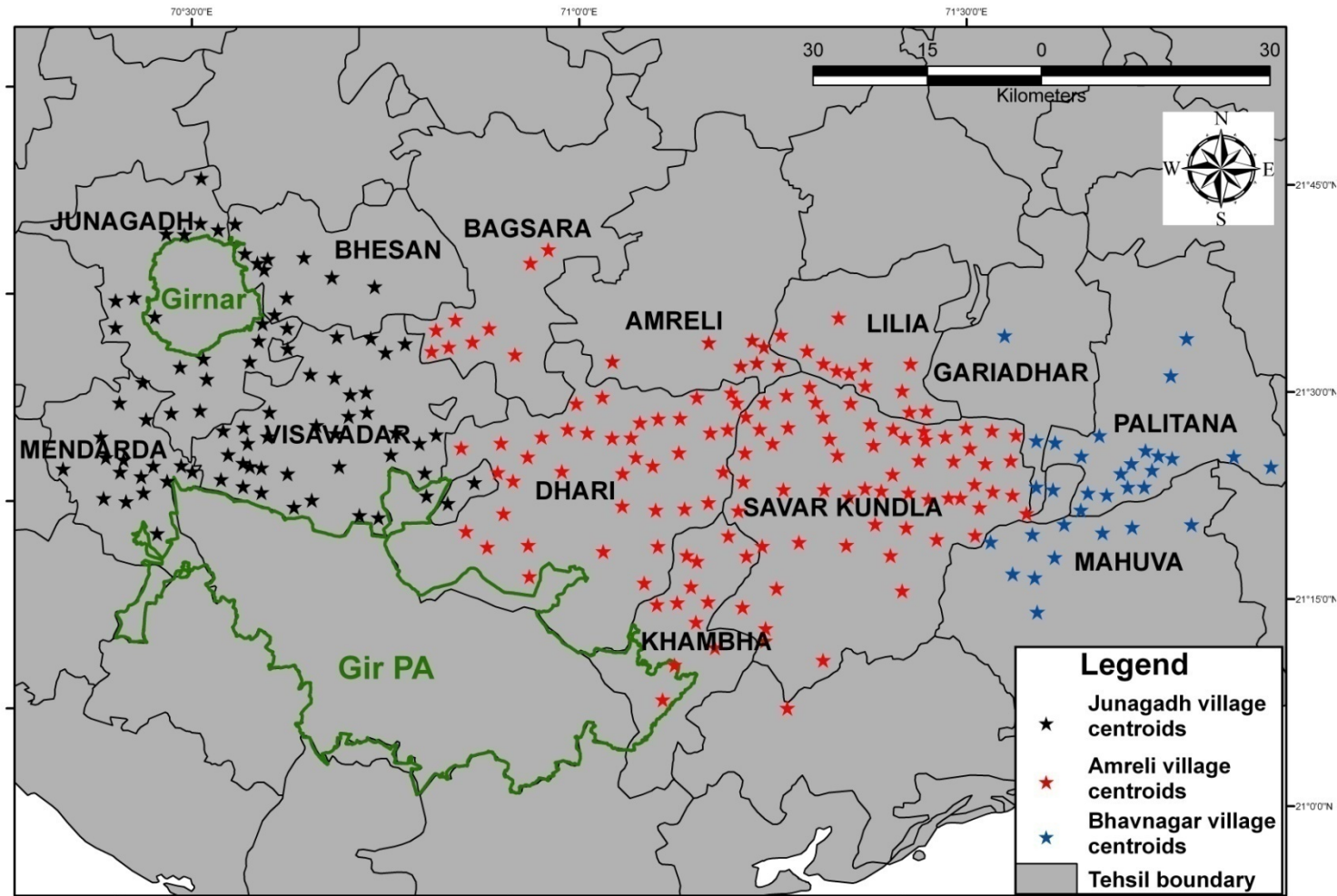
## Results

A total of 680 respondents from 254 villages were interviewed during the study. Majority of the respondents were middle-aged, with the medium economic status and lower education status (**Table 12.2**). Majority of the respondents were farmers (41%) followed by people engaged in other occupations (27%), agro-pastoralists (19%), and pastoralists (13%). Average landholding was 38 (SE 4) *bighas*. Average livestock holding of the respondents was 33 (SE 6) livestock units. All respondents were aware of large animals present in the surrounding of their villages and lion, leopard and nilgai were reported to be the most seen animals by them out of the total 18 species reported (**Table 12.3**). Three respondents (0.4%) confirmed presence of wolves in the surroundings of their villages.

Majority (67%) of the overall respondents opined that lions were rarely a risk to human beings but occasionally killed livestock and there was no significant difference in this opinion among different age groups ( $\chi^2 = 7.8$ ,  $df = 6$ ,  $p = 0.25$ ) or economic status ( $\chi^2 = 10.2$ ,  $df = 6$ ,  $p = 0.11$ ). Respondents from Bhavnagar district mostly opined (75%) that ‘lions caused tremendous havoc to livestock’ while respondents from Junagadh district were mostly (73%) of the view that lion was ‘rarely a risk to human life but occasionally kills livestock’ ( $\chi^2 = 87.5$ ,  $df = 6$ ,  $p < 0.001$ ). Twenty nine percent pastoralists and 15% of the farmers felt that ‘lions caused tremendous havoc to livestock’ while 67% of the pastoralists and 80% of the farmers opined that lion was ‘rarely a risk to human life but occasionally kills livestock’ ( $\chi^2 = 50.1$ ,  $df = 9$ ,  $p < 0.001$ ). Respondents’ awareness of risk in having lions differed among different education levels ( $\chi^2 = 164.6$ ,  $df = 18$ ,  $p < 0.001$ ) (**Figure 12.2**).



Figure 12.1: Gir landscape showing centroids of villages (n = 254) sampled for studying local people's attitudes toward lion conservation. *Tehsil* names and boundaries of the Gir PA and Girnar are shown. Village centroids of three districts are marked separately.





Majority (56%) of the respondents were of view that lions living in their surroundings for more than 10 years (**Figure 12.3**) with more elderly people saying this compared to the younger groups ( $\chi^2 = 8.7$ ,  $df = 4$ ,  $p = 0.06$ ). We found no difference of this view among different economic status ( $\chi^2 = 4.1$ ,  $df = 4$ ,  $p = 0.39$ ) or among different occupation ( $\chi^2 = 6.4$ ,  $df = 6$ ,  $p = 0.37$ ). However, respondents from Amreli district mostly (45%) opined that lions reached their neighborhood in  $< 5$  years while those from Junagadh and Bhavnagar mostly (62.5% in both) opined that lions reached in their locality more than 10 years ago ( $\chi^2 = 71.8$ ,  $df = 4$ ,  $p < 0.001$ ). No respondent from Bhavnagar opined that lions reached in their locality in less than 5 years ago. Majority (63%) of the lower educated respondents opined that lions reached in their locality more than 10 years back while all postgraduate respondents felt that lions reached in their vicinity in less than last 5 years ( $\chi^2 = 252.4$ ,  $df = 12$ ,  $p < 0.001$ ; **Figure 12.3**).

Overall 86% of the respondents felt that lions reached in the agro-pastoral landscape by natural migration while 8% of them felt that ‘problem’ lions from the Gir PA were left over by the forest department (**Figure 12.4**). Twenty six percent of the respondents in Amreli district viewed lions to be left over by the forest department whilst none from Bhavnagar district and 5% respondents from Junagadh district viewed likewise ( $\chi^2 = 43.1$ ,  $df = 4$ ,  $p < 0.001$ ; **Figure 12.4**). We found no significant differences in the respondents’ view about how lions reached in their locality among different age-groups ( $\chi^2 = 5.5$ ,  $df = 4$ ,  $p = 0.24$ ), among different economic status ( $\chi^2 = 2.7$ ,  $df = 4$ ,  $p = 0.60$ ) or among people of different occupations ( $\chi^2 = 5.7$ ,  $df = 6$ ,  $p = 0.44$ ). Less educated people viewed lions to be left over by the forest department ( $\chi^2 = 106.1$ ,  $df = 12$ ,  $p < 0.001$ ).



**Table 12.2: Summary of average scores of demography, economic well-being index and livelihood assessment of the respondents in the Gir landscape. Numbers within parentheses are standard errors.**

	Average score- age group	Average score- footwear**	Average score- clothing**	Average score- ornaments**	Average score- housing type**	Average score- economic status	Average score- education	Average landholding (bighas*)	Average livestock holding	Average monthly salary/income (₹.)
Amreli	1.71 (0.10)	2.61 (0.14)	2.68 (0.16)	2.28 (0.22)	3.47 (0.19)	2.16 (0.11)	1.78 (0.23)	60.62 (13.38)	45 (27)	4,789 (999)
Bhavnagar	1.87 (0.12)	2.68 (0.23)	2.81 (0.20)	2.56 (0.28)	3.81 (0.29)	2.25 (0.17)	1.18 (0.36)	59.62 (13.34)	32 (10)	3,857 (419)
Junagadh	2.08 (0.05)	2.22 (0.05)	2.45 (0.06)	1.96 (0.07)	3.37 (0.09)	2.16 (0.05)	1.47 (0.10)	30.88 (2.66)	31 (5)	5,693 (504)
Overall	2.03 (0.04)	2.31 (0.05)	2.51 (0.06)	2.03 (0.06)	3.41 (0.07)	2.18 (0.04)	1.53 (0.09)	37.93 (3.38)	33 (6)	5,343 (406)

\*1 bigha = approximately 2,327 square meter. \*\*measured in a 1-5 scale where 1 = lower value, 5 = higher value

**Table 12.3: Summary of large animals most frequently reported by the respondents surrounding their villages. 1-5 scale where 1 = most seen and 5 = least seen. Numbers within parentheses are 95% confidence intervals.**

Lion	Leopard	Nilgai	Wild pig	Chinkara	Hyena	Chital	Sambar	Blackbuck	Jackal	Wolf	Hare	Mongoose	Porcupine	Peafowl
1.80 (0.16)	2.36 (0.14)	2.74 (0.13)	3.30 (0.14)	3.96 (0.14)	3.85 (0.11)	3.71 (0.16)	3.66 (0.08)	3.75 (0.19)	4.18 (0.18)	4.33 (0.15)	4.72 (0.07)	4.52 (0.11)	4.42 (0.14)	4.82 (0.05)

\*each of honey badger (*Mellivora capensis*), hedgehog (*Paraechinus micropus*) and jungle cat (*Felis chaus*) were mentioned by single respondent.

\*\* Lion = *Panthera leo persica*, Leopard = *Panthera pardus*, Nilgai = *Boselaphus tragocamelus*, Wild pig = *Sus scrofa*, Chinkara = *Gazella bennettii*, Hyena = *Hyaena hyeana*, Chital = *Axis axis*, Sambar = *Rusa unicolor*, Blackbuck = *Antelope cervicapra*, Jackal = *Canis aureus*, Wolf = *Canis lupus pallipes*, Hare = *Lepus nigricollis*, Mongoose = *Herpestes edwardsii*, Porcupine = *Hystrix indica*, Peafowl = *Pavo cristatus*.



Figure 12.2: Awareness of risks of 680 respondents from 254 villages in the eastern landscape to question on having lions in the vicinity of their villages.

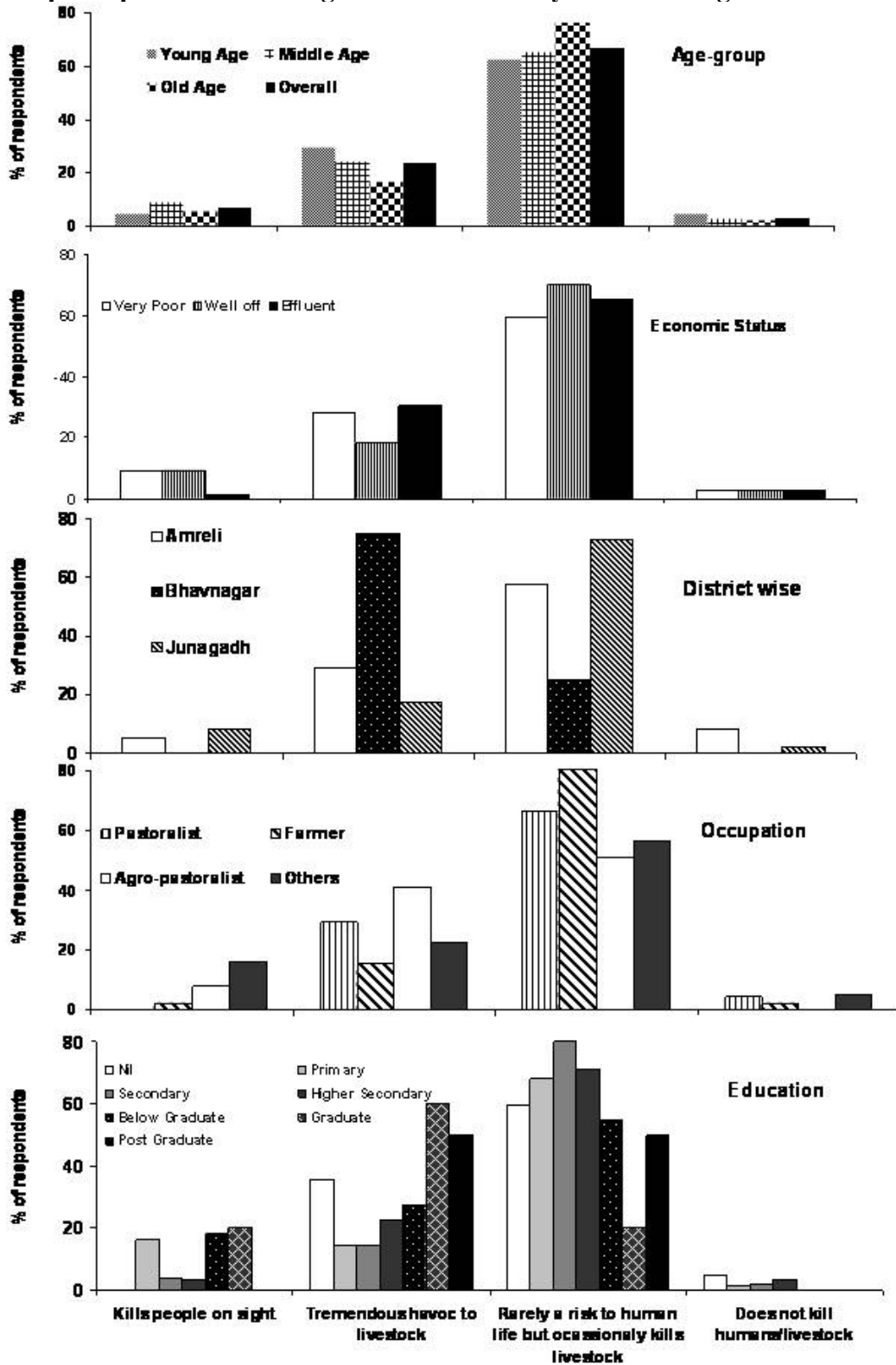




Figure 12.3: Views of 680 respondents from 254 villages in the eastern landscape to question on when lions started to live in their vicinity.

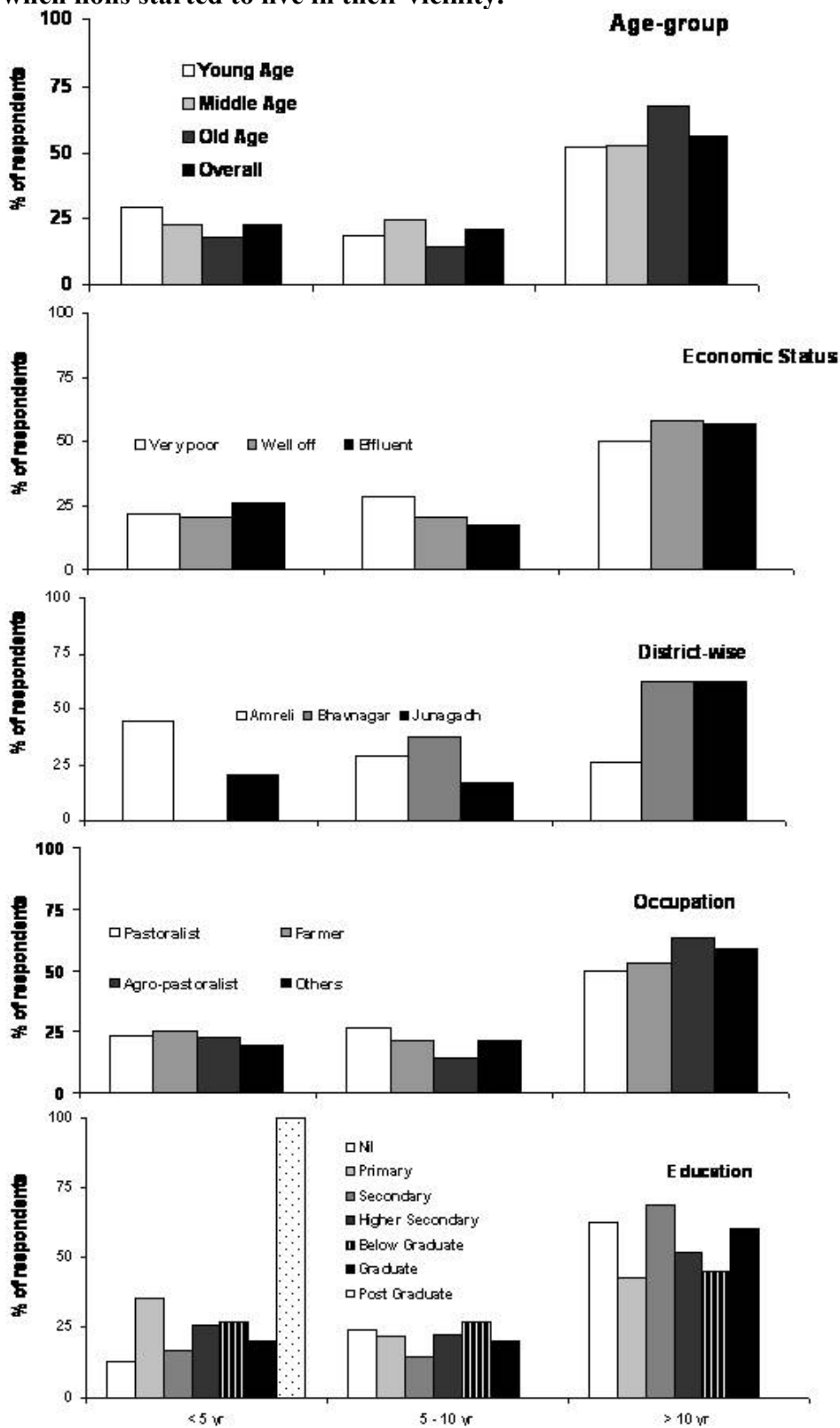
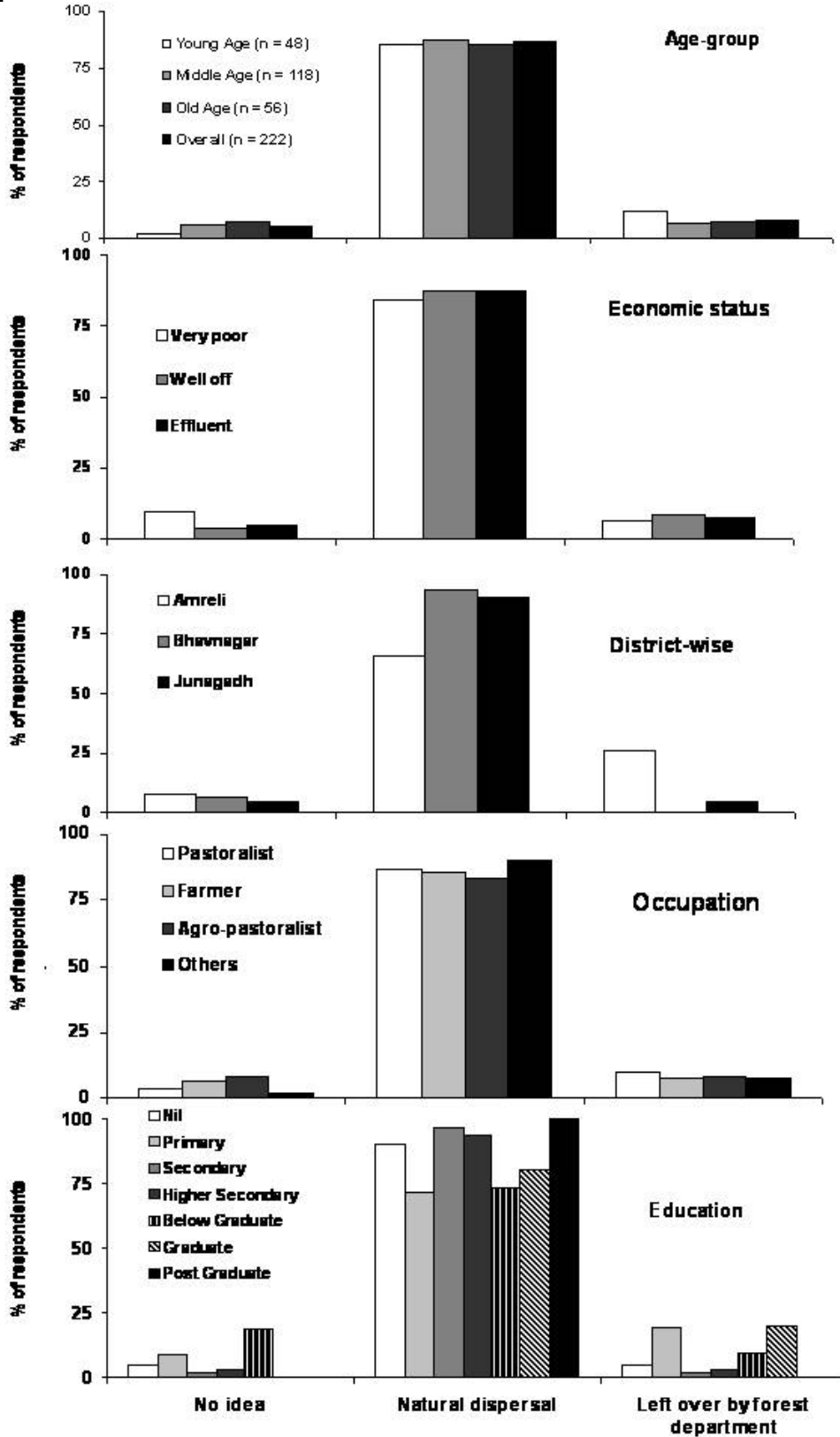




Figure 12.4: Views of 680 respondents from 254 villages in the eastern landscape to question on how did lions reach in their localities.





Majority (72%) of the respondents liked lions to continue to live in their surroundings with the young age respondents liking lions more than the middle and old aged groups ( $\chi^2 = 6.5$ ,  $df = 2$ ,  $p = 0.03$ ; **Figure 12.5**). Respondents from Junagadh district were more unwilling to have lions in future (33%) compared to those from Bhavnagar (6%) and Amreli (18%) districts ( $\chi^2 = 23.7$ ,  $df = 2$ ,  $p < 0.001$ ; **Figure 12.5**). Respondents of lower economic status were more unwilling (47%) to have lions in future than well offs (28%) and effluents (21%) [ $\chi^2 = 16.8$ ,  $df = 2$ ,  $p < 0.001$ ]. Occupation-wise order of unwillingness to have lions in the neighborhood in future was agro-pastoralists (41%) > pastoralists (30%) > farmers (27%) > others (18%) [ $\chi^2 = 13.1$ ,  $df = 3$ ,  $p = 0.004$ ]. More educated respondents were more willing to 'like to have lions in future' ( $\chi^2 = 86.7$ ,  $df = 6$ ,  $p < 0.001$ ).

The major reason (46%) behind the respondents who liked lions to live in their surroundings was economic profit (wildlife damage control in the farmlands, tourism etc.) while majority of the respondents who did not like lions to live in their surroundings were either indifferent (10%) or due to personal loss (7%) [**Figure 12.6**].

Majority (20%) of the respondents opined that no intervention was needed for lion conservation while 18% respondents were of the view that lions should be captured and sent back to the Gir PA (**Figure 12.7**). Old aged respondents mostly (23%) wanted lions to be captured and sent back to the Gir PA while the young aged respondents mostly (25%) opined that people's participation was needed for lion conservation ( $\chi^2 = 23.9$ ,  $df = 12$ ,  $p = 0.02$ ). Majority (44%) of the respondents from Bhavnagar district wanted creation of more Protected Areas for lion conservation while majority of the respondents from Junagadh (22%) wanted lions to be captured and released back inside the Gir PA ( $\chi^2 = 80.8$ ,  $df = 12$ ,  $p < 0.001$ ; **Figure 12.7**). Pastoralists (17%) and agro-pastoralists (31%) wanted lions to be released back to the Gir PA while majority of the farmers (21%) opined that no intervention was needed for lion conservation ( $\chi^2 = 43.8$ ,  $df = 18$ ,  $p < 0.001$ ). Respondents with poor economic status mostly (28%) had no opinion about this while well off and effluent respondents opined that the no intervention was needed for lion conservation or either sought more people's participation in conservation activities ( $\chi^2 = 43.8$ ,  $df = 12$ ,  $p < 0.001$ ). Recommendation for saving lions in future also significantly differed among different education groups with more literate groups asking for more economic incentives for lion conservation ( $\chi^2 = 538.1$ ,  $df = 36$ ,  $p < 0.001$ ; **Figure 12.7**).



Thirty percent of the overall respondents (38% of young-aged, 26% of the middle aged and 32% of the old aged) felt that creation of more employment with the forest department for the local people would be helpful to gain more public participation in lion conservation ( $\chi^2 = 25.6$ ,  $df = 10$ ,  $p = 0.004$ ; **Figure 12.8**). Twenty percent respondents from Junagadh district, 11% respondents from Amreli district and none from Bhavnagar district felt that removal of lions could be way to gain more public support ( $\chi^2 = 57.8$   $df = 10$ ,  $p < 0.001$ ). Pastoralists mostly wanted better compensation (37.5%) and removal of lions (25%) for gaining more public support (**Figure 12.8**) while agro-pastoralists wanted more employment with the forest department (43.5%) and subsidized wildlife damage control measures (20.5%) for ensuring more public support ( $\chi^2 = 95.7$ ,  $df = 15$ ,  $p < 0.001$ ). Farmers mostly (30%) wanted more employment with the department. Poor respondents mostly wanted better compensation (28%) and employment with the department (22%) for gaining more public support while majority of well off and affluent respondents (32% each) wanted more employment generation with the forest department ( $\chi^2 = 64.6$ ,  $df = 10$ ,  $p < 0.001$ ; **Figure 12.8**). The views varied significantly with the education level too with 100% of the postgraduate respondents felt educational awareness could secure more public support while others mostly emphasized more employment with the department, better compensation or subsidized wildlife damage control measures for gaining public support ( $\chi^2 = 487$ ,  $df = 20$ ,  $p < 0.001$ ; **Figure 12.8**).



Figure 12.5: Views of 680 respondents from 254 villages in the eastern landscape to question on their opinions to let lions to continue to live in their surroundings.

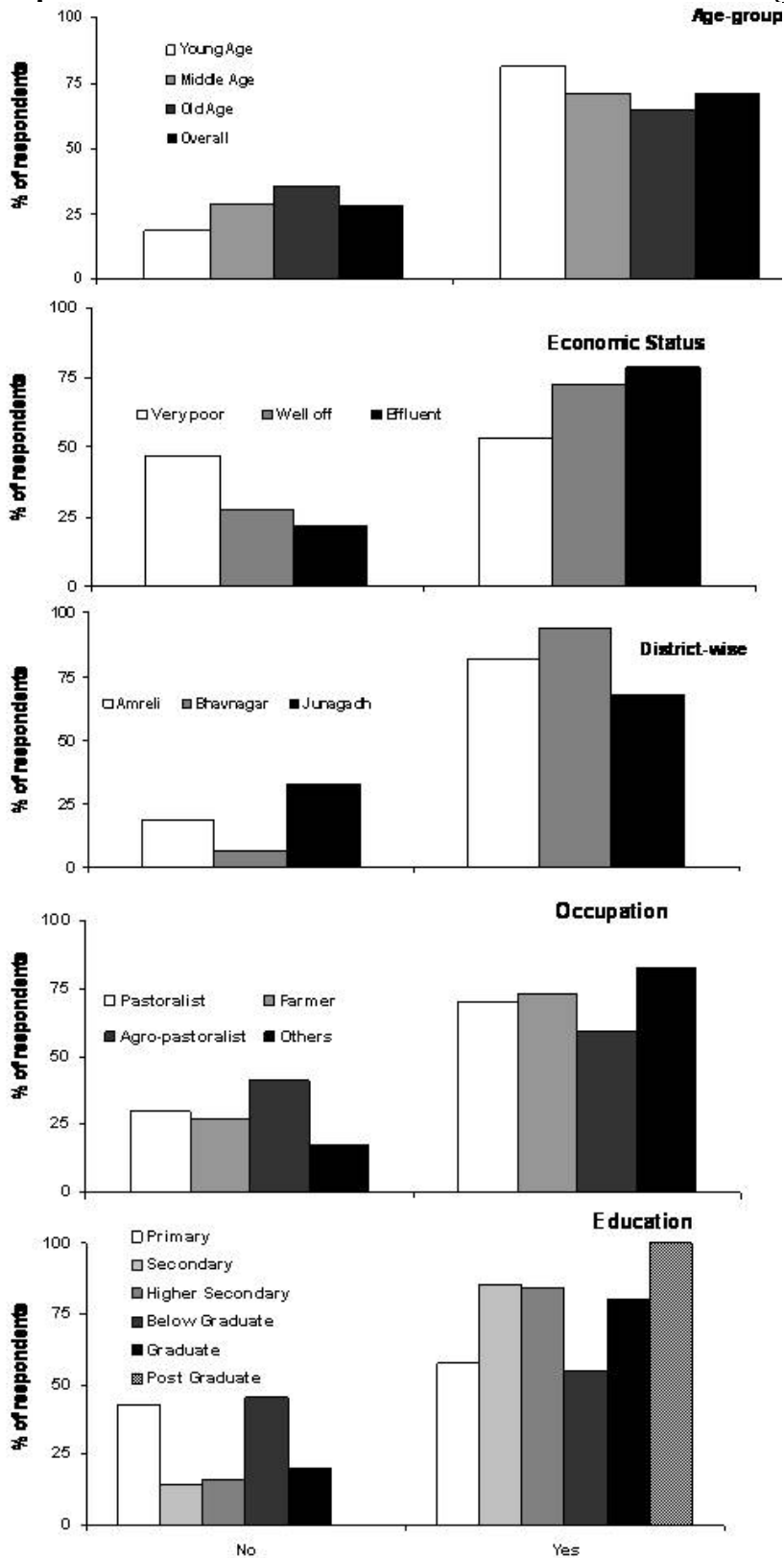




Figure 12.6: Views of 680 respondents from 254 villages in the eastern landscape to question on the reasons behind their liking/disliking lions to continue to live in their neighborhoods.

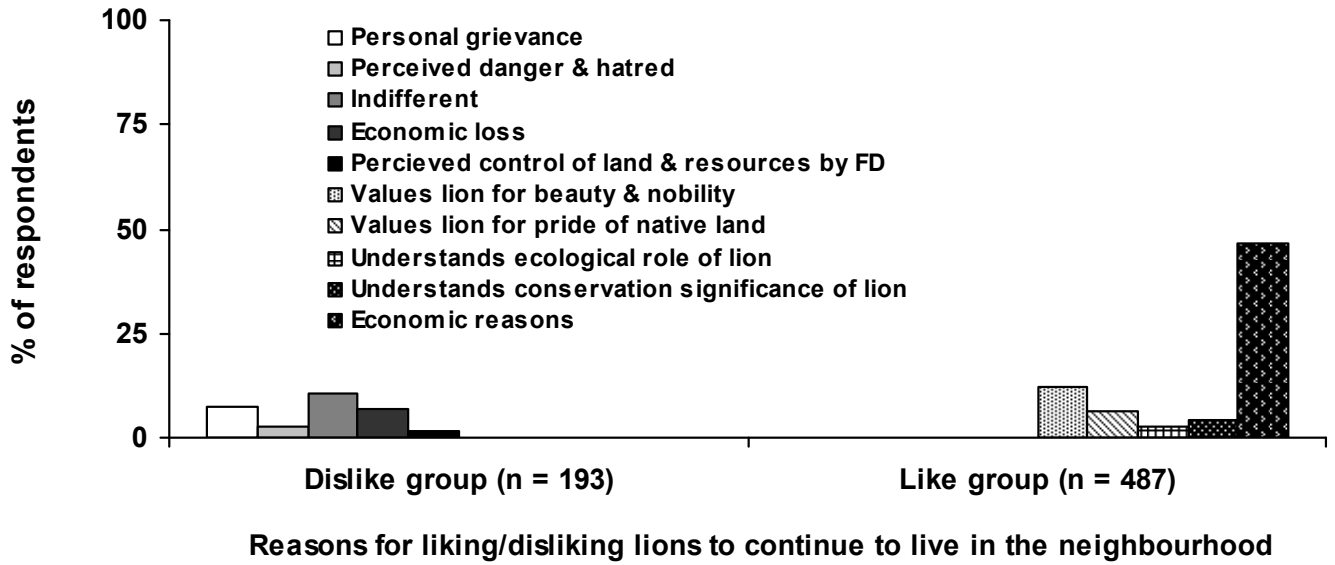




Figure 12.7: Views of 680 respondents from 254 villages in the eastern landscape to question on their recommendations for future lion conservation.

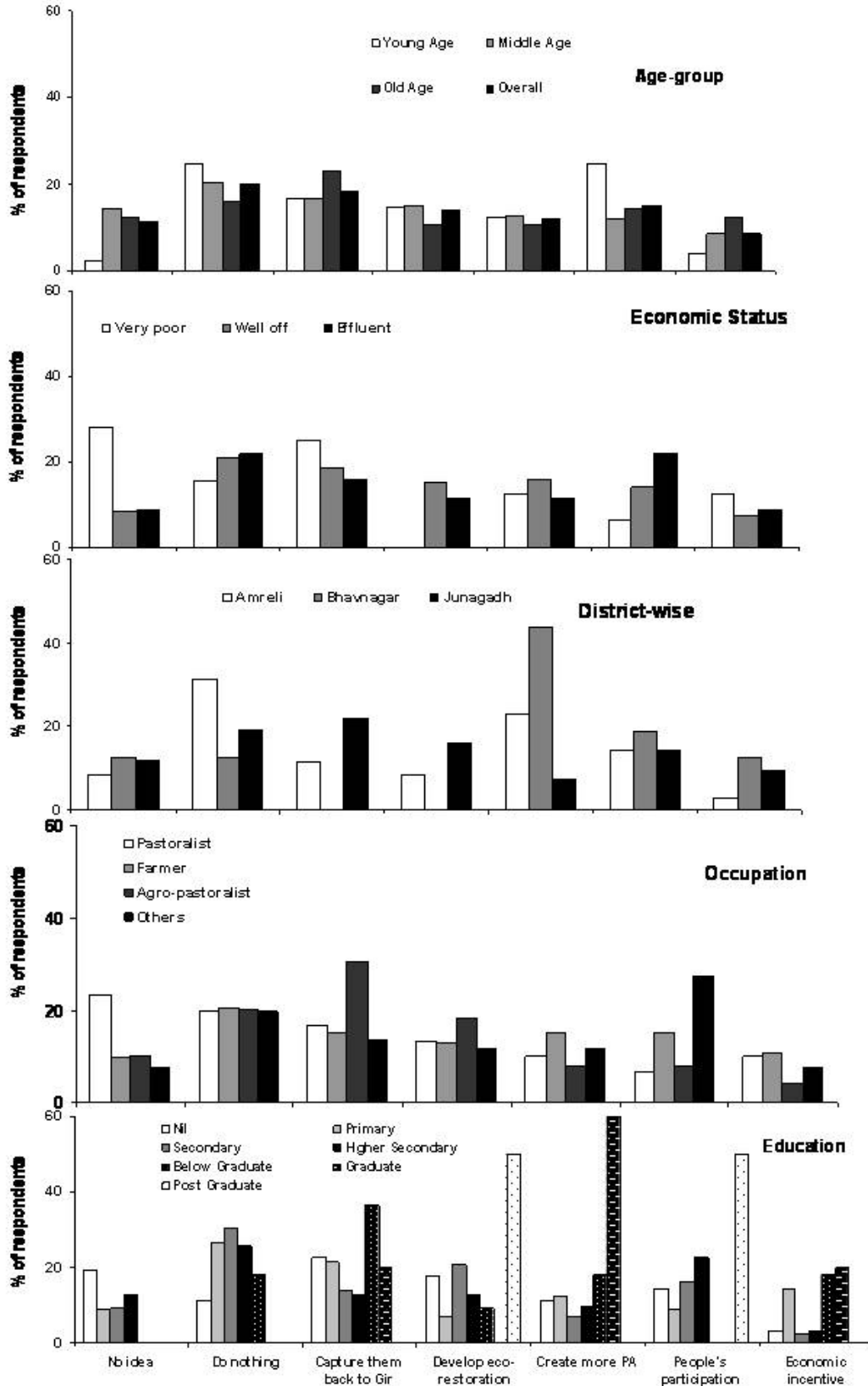
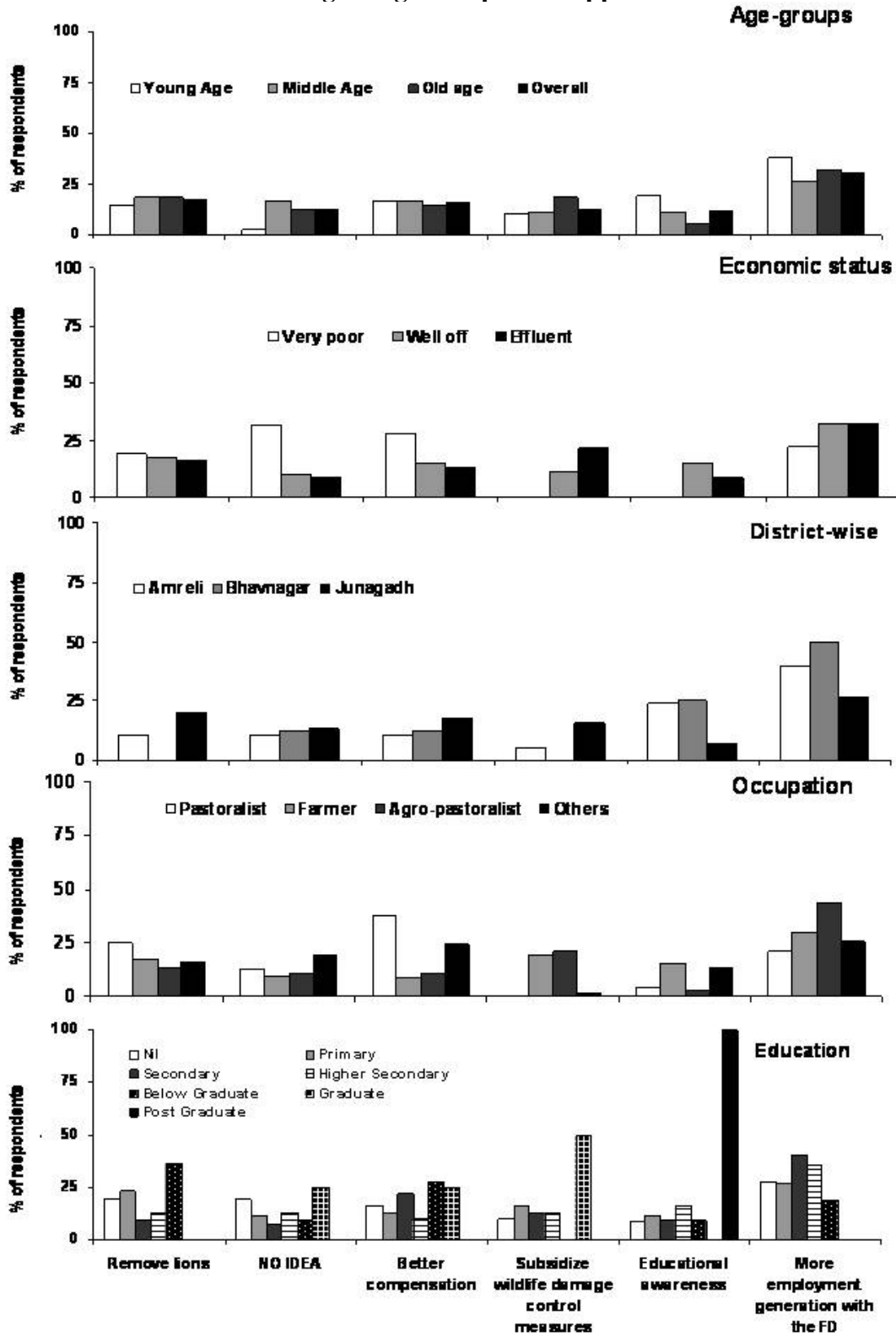




Figure 12.8: Views of 680 respondents from 254 villages in the eastern landscape to question on their recommendations gaining more public support for lion conservation.





One hundred and thirty six respondents (20%) were totally unaware about the compensation scheme paid by the Gujarat Forest Department for mitigating livestock depredation by lions and other carnivores (**Figure 12.9**). Respondents from Amreli district were more unaware (31.5%) of the scheme in comparison to those from Bhavnagar (12.5%) and Junagadh (17.8%) districts ( $\chi^2 = 11.6$ ,  $df = 2$ ,  $p = 0.002$ ; **Figure 12.9**). Young aged respondents were more unaware (31%) of the scheme compared to middle aged (18%) and old aged (14%) respondents ( $\chi^2 = 10.6$ ,  $df = 2$ ,  $p = 0.004$ ). Respondents from poor economic status were less aware (69%) compared to those from well off (83%) and affluent (81%) economic status ( $\chi^2 = 6.8$ ,  $df = 20$ ,  $p = 0.03$ ). All of the pastoralists interviewed were aware of the compensation scheme for livestock depredation (**Figure 12.9**) while agro-pastoralists were more aware (92%) of the scheme compared to farmers (81%) and people engaged in other professions (63%;  $\chi^2 = 57.2$ ,  $df = 3$ ,  $p < 0.001$ ). More educated respondents were less aware of the compensation scheme ( $\chi^2 = 61.1$ ,  $df = 6$ ,  $p < 0.001$ ; **Figure 12.9**).

Overall 67% of the respondents felt that the government compensation scheme for livestock predation by carnivores was not appropriate in monetary terms and old aged respondents felt this more (76%) compared to middle aged (69%) and young aged (51%) [ $\chi^2 = 15.1$ ,  $df = 4$ ,  $p = 0.004$ ; **Figure 12.10**]. Seventy four percent respondents from Junagadh district informed that the scheme was not financially appropriate compared to 40% respondents from Bhavnagar and 47% respondents from Amreli districts ( $\chi^2 = 68.9$ ,  $df = 4$ ,  $p < 0.001$ ). Large proportions of pastoralists (83%) and agro-pastoralists (82%) did not consider the compensation scheme to be financially appropriate compared to the farmers (68%) and people in other occupations (50%) [ $\chi^2 = 55.1$ ,  $df = 6$ ,  $p < 0.001$ ; **Figure 12.10**]. We found no difference among respondents with various economic status regarding their views on the appropriateness of the compensation scheme in terms of money ( $\chi^2 = 4.6$ ,  $df = 4$ ,  $p = 0.32$ ). However, respondents from various education levels opined differently on their views on compensation scheme ( $\chi^2 = 209.3$ ,  $df = 12$ ,  $p < 0.001$ ).



Figure 12.9: Views of 680 respondents from 254 villages in the eastern landscape to question on if the were aware of the forest department’s compensation scheme paid for livestock depredation.

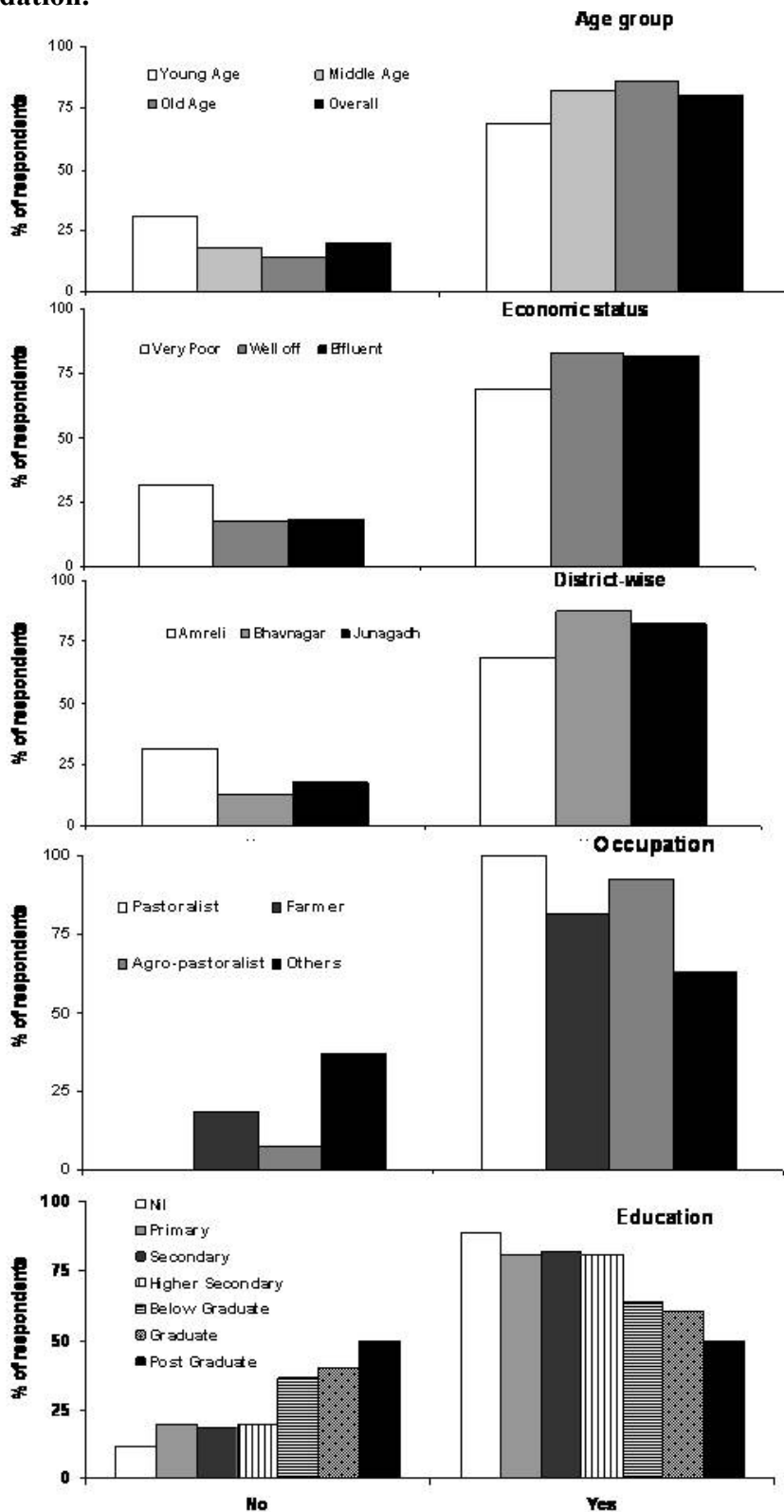
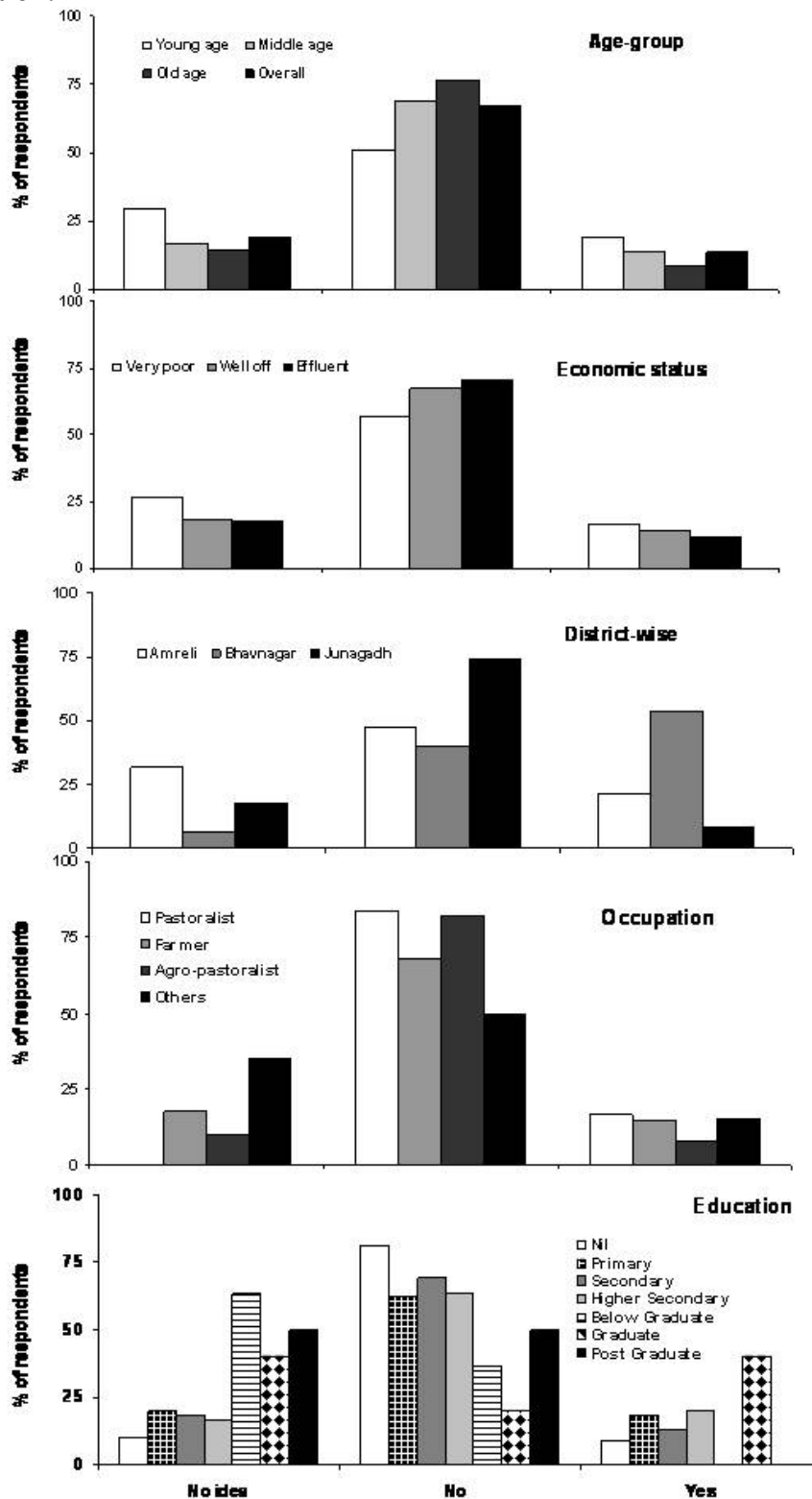




Figure 12.10: Views of 680 respondents from 254 villages in the eastern landscape to question on financial appropriateness of the Government compensation scheme for livestock predation.





Majority (56%) of the respondents opined that the compensation scheme was not prompt and systematic. Old aged respondents opined this more (75%) compared to young aged (45%) and middle aged respondents (52%;  $\chi^2 = 26.8$ ,  $df = 4$ ,  $p < 0.001$ ; **Figure 12.11**). Respondents from Junagadh district (67%) informed that the scheme was not prompt and systematic more in comparison to those from Amreli (21%) and Bhavnagar (27%) districts ( $\chi^2 = 81.6$ ,  $df = 4$ ,  $p < 0.001$ ). Pastoralists (79%) considered the scheme less prompt and systematic compared to the agro-pastoralists (56%) and farmers (63%;  $\chi^2 = 61.5$ ,  $df = 6$ ,  $p < 0.001$ ; **Figure 12.11**). We did not find any significant difference in the respondents' view about the promptness of the scheme among various economic status ( $\chi^2 = 7.8$ ,  $df = 4$ ,  $p = 0.09$ ). Respondents of different education levels informed in a mixed way with more ill-literate people considering the scheme 'not prompt and systematic' in comparison to the higher educated respondents ( $\chi^2 = 238.9$ ,  $df = 12$ ,  $p < 0.001$ ).

False claim (claiming compensation from the Government against the kills of feral cattle) was not a major problem (74% of the overall respondents opined). However, middle aged (9%) respondents considered this as a problem more than those of young age (2%) and old age (4%;  $\chi^2 = 16.4$ ,  $df = 4$ ,  $p = 0.002$ ; **Figure 12.12**). Many respondents (37%) from Amreli district were unaware of such claims. No respondents from Bhavnagar district informed about false claims compared to the respondents from Amreli (8%) and Junagadh (6%) districts ( $\chi^2 = 38.8$ ,  $df = 4$ ,  $p < 0.001$ ). Pastoralists (17%) and agro-pastoralists (8%) considered false claims as problems more compared to the farmers (3%) or respondents engaged in other occupations (5%;  $\chi^2 = 49.6$ ,  $df = 6$ ,  $p < 0.001$ ; **Figure 12.12**). Respondents from different economic status did not significantly differ regarding their attitudes on false claims ( $\chi^2 = 3.2$ ,  $df = 4$ ,  $p = 0.50$ ; **Figure 12.12**). However, respondents from various education levels opined differently on false claims and the difference was significant ( $\chi^2 = 121.6$ ,  $df = 12$ ,  $p < 0.001$ ).



Figure 12.11: Views of 680 respondents from 254 villages in the eastern landscape to question on promptness and systematic payment of the Government compensation scheme for livestock predation.

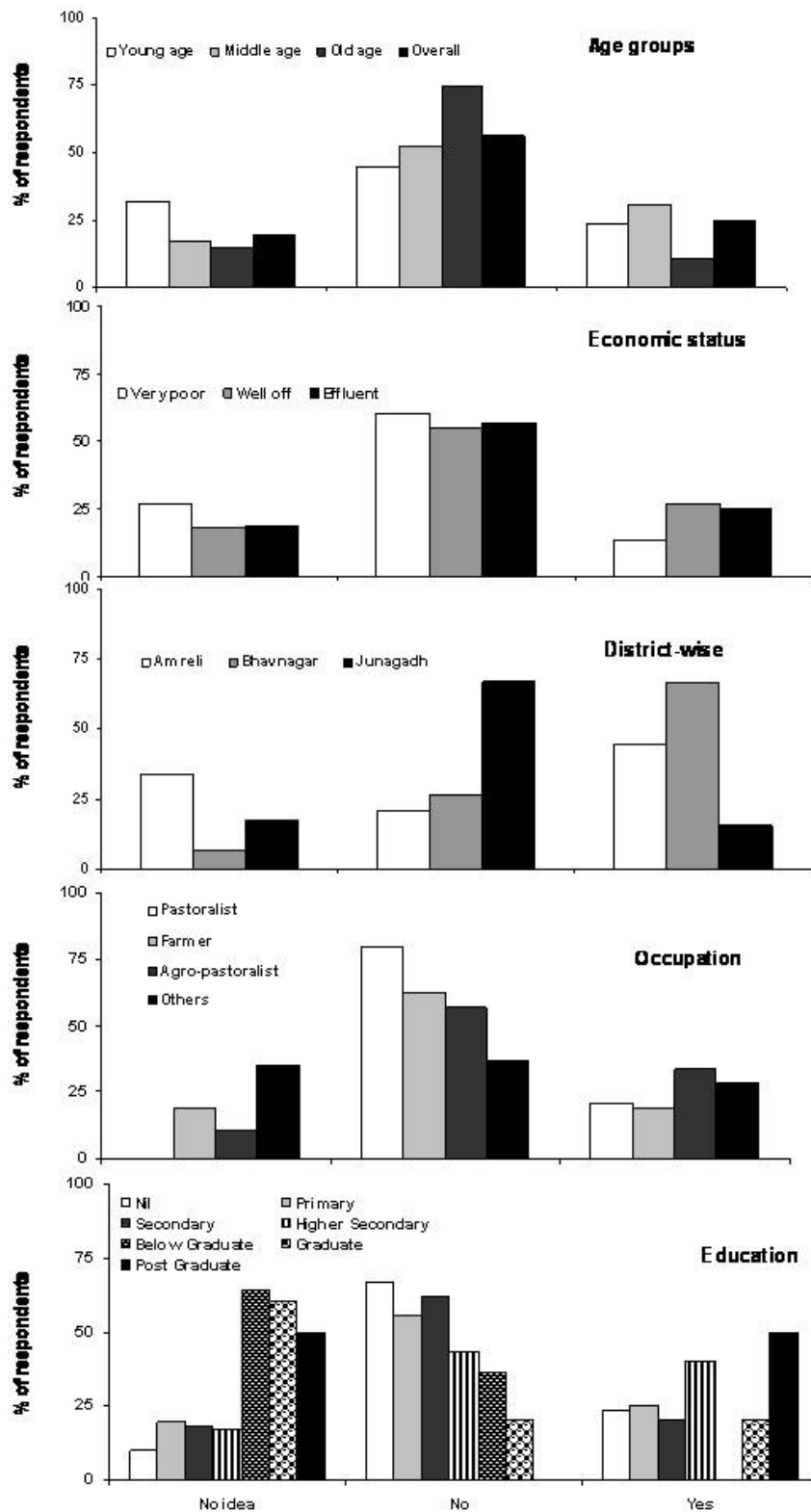
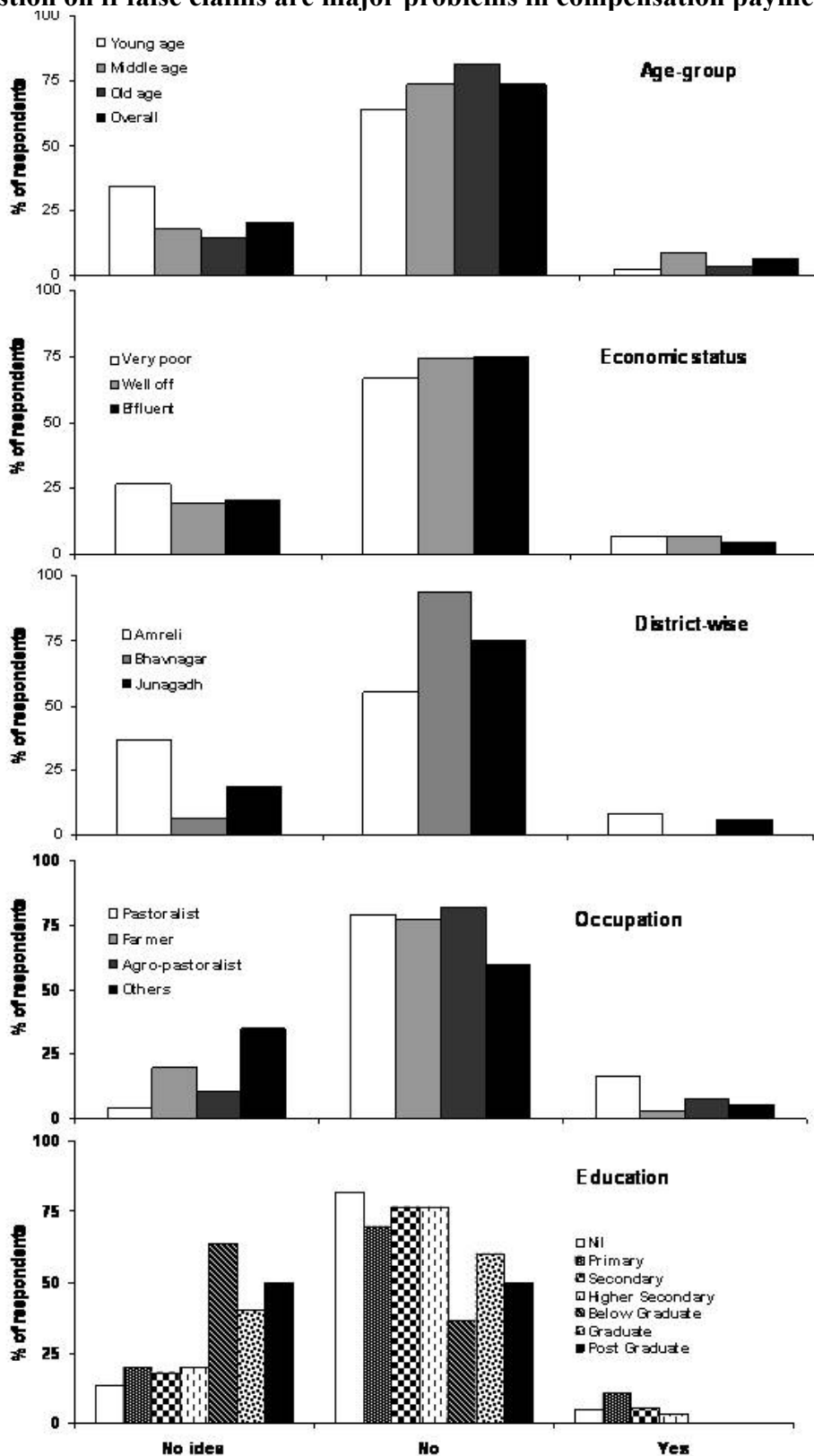




Figure 12.12: Views of 680 respondents from 254 villages in the eastern landscape to question on if false claims are major problems in compensation payments.





Although majority (60%) of the respondents informed that irregularity in payment was not a problem in the Government compensation payment; a considerable proportion (19%) of the respondents however felt that irregularity in payment was a problem in the compensation scheme. Old aged respondents felt this more (27%) compared to young aged (14%) and middle aged (17%) respondents ( $\chi^2 = 14.2$ ,  $df = 4$ ,  $p = 0.006$ ; **Figure 12.13**). Respondents from Junagadh district (23%) informed irregularity in payment in the compensation scheme more than those from Amreli (8%) or Bhavnagar (0%) districts ( $\chi^2 = 56.4$ ,  $df = 4$ ,  $p < 0.001$ ). Economically affluent respondents felt irregularity in payment as a problem in the compensation scheme more than those from lower economic status ( $\chi^2 = 19.2$ ,  $df = 4$ ,  $p < 0.001$ ) while pastoralists and agro-pastoralists considered irregularity in payment as problem more in comparison to the farmers and respondents having other occupations ( $\chi^2 = 34.1$ ,  $df = 6$ ,  $p < 0.001$ ; **Figure 12.13**). Sixty seven percent of the ill-literate respondents felt that there was no irregularity in payment in the compensation while 50% of the postgraduate respondents informed no irregularities in compensation payment ( $\chi^2 = 121.6$ ,  $df = 12$ ,  $p < 0.001$ ).

Monetary increment in the Government compensation to better it was the suggested measure by majority (59%) of the respondents. Old aged respondents wanted this more (67%) than young aged (45%) and middle aged (61%) respondents ( $\chi^2 = 21.5$ ,  $df = 12$ ,  $p = 0.001$ ; **Figure 12.14**). Majority (47%) of the respondents from Bhavnagar district wanted no improvement in the current scheme while 66% of the respondents from Junagadh district wanted a monetary increment in the scheme ( $\chi^2 = 58.0$ ,  $df = 6$ ,  $p < 0.001$ ). Poor respondents wanted the scheme to be 'more prompt and systematic' compared to well offs and effluents ( $\chi^2 = 18.2$ ,  $df = 6$ ,  $p = 0.001$ ; **Figure 12.14**). Agro-pastoralists (72%) wanted monetary increment in the scheme more than respondents from any other occupation ( $\chi^2 = 59.8$ ,  $df = 9$ ,  $p < 0.0001$ ). We found a significant difference in respondents' suggestion in improving the compensation scheme among different education levels with ill-literate respondents wanting the monetary increment more than higher educated groups ( $\chi^2 = 147.2$ ,  $df = 15$ ,  $p < 0.0001$ ; **Figure 12.14**).



Figure 12.13: Views of 680 respondents from 254 villages in the eastern landscape to question on if irregularities in payment are major problems in the compensation scheme.

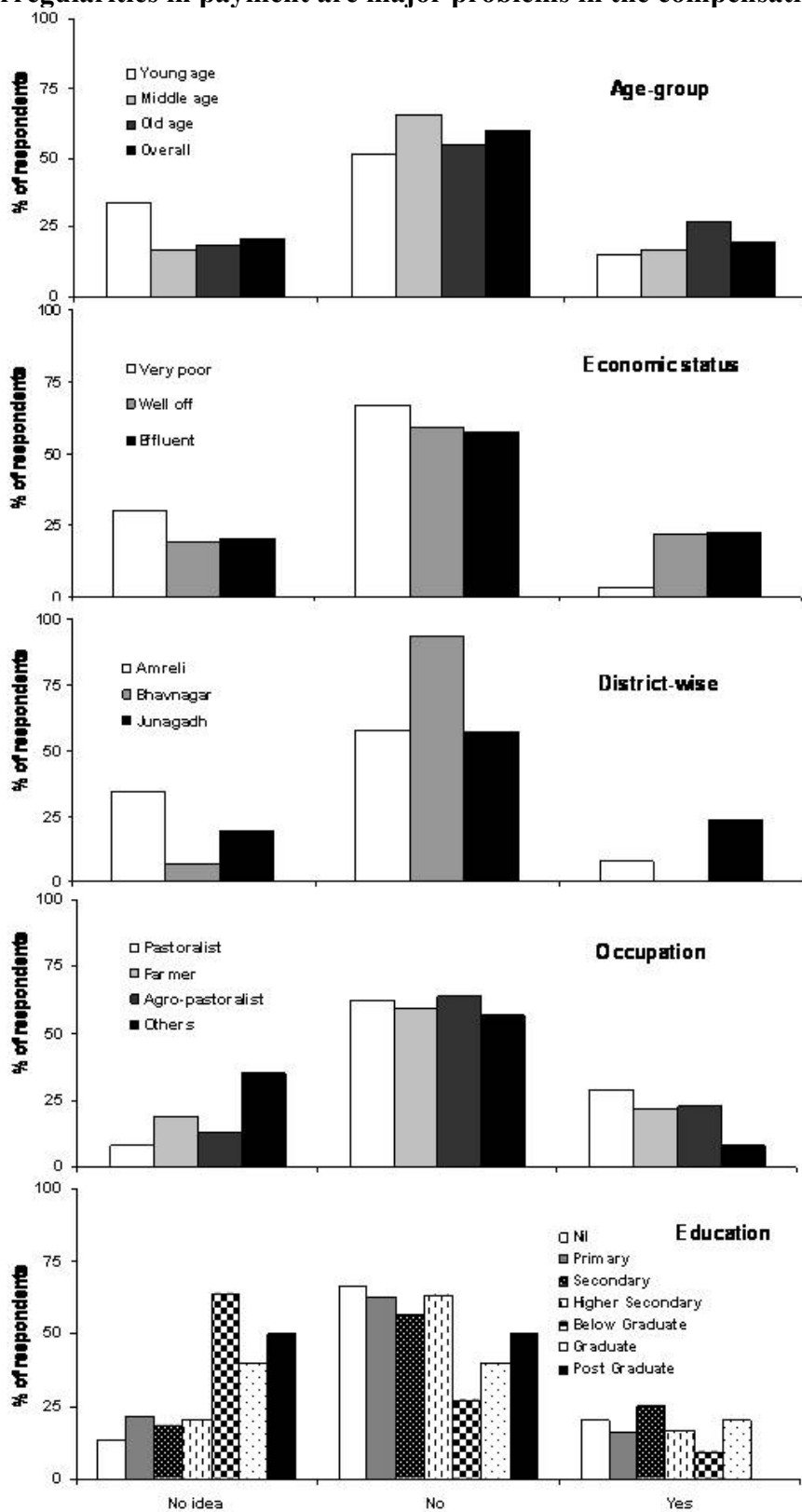
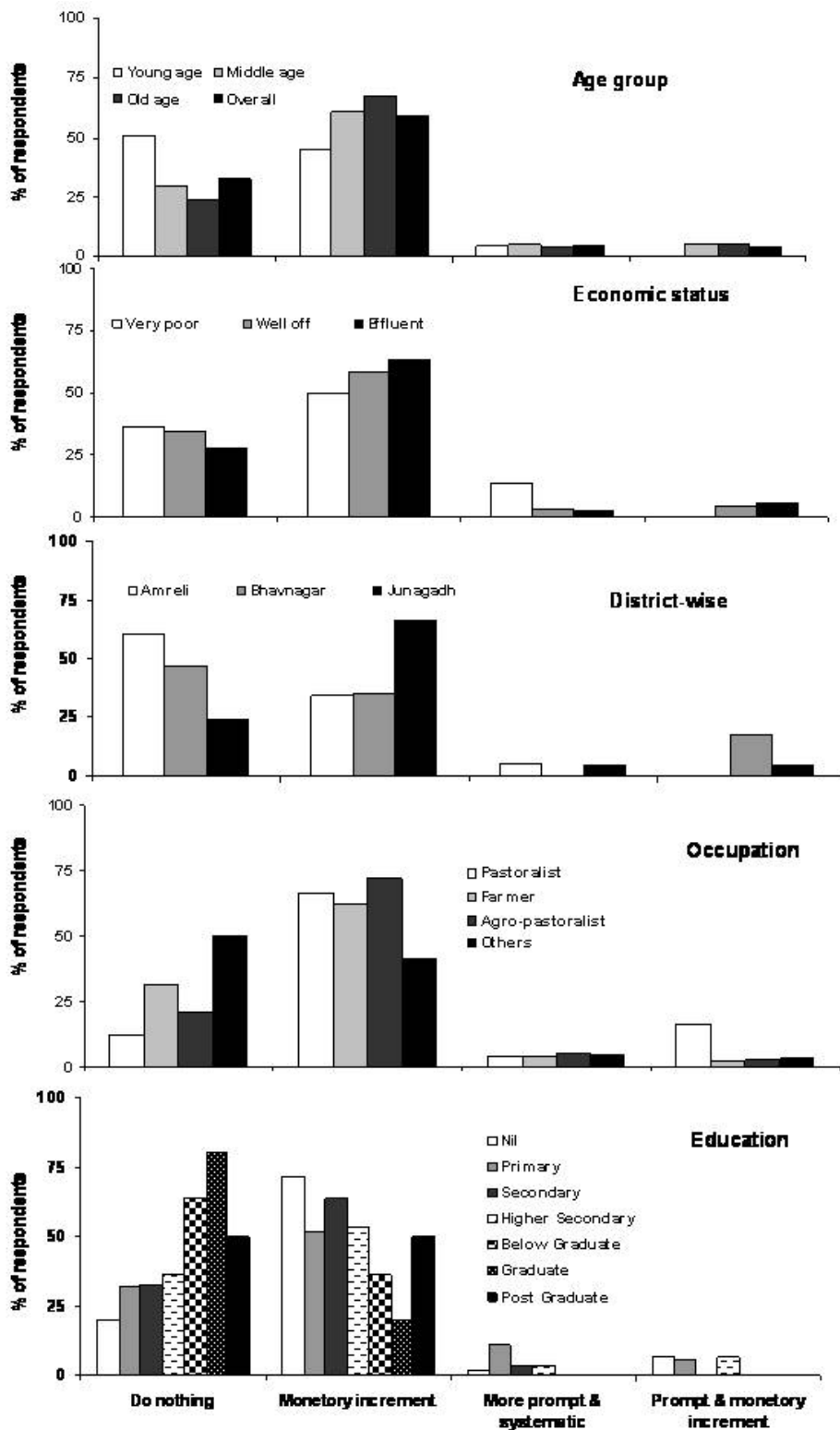




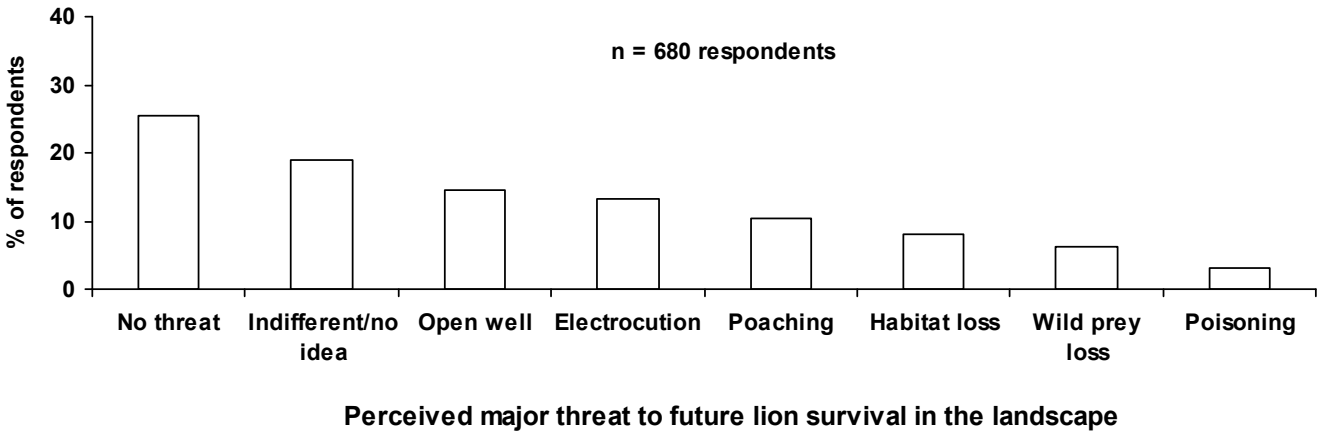
Figure 12.14: Views of 680 respondents from 254 villages in the eastern landscape to question on suggestion to improve the Government compensation scheme for livestock predation.





Majority (25%) of the respondents opined that lions do not have any future threat in this landscape while 14% interviewees felt that open well posed a serious threat for future lion survival (**Figure 12.15**). Ten percent respondents opined that poaching could be a serious threat for lions' future while 3% felt that poisoning might be a serious threat for conserving lions ( $\chi^2 = 29.4, df = 7, p < 0.001$ ).

**Figure 12.15: Respondents' perceptions about future threat for lion survival in the eastern landscape.**



Respondents' age, occupation, education and economic status and many of the attitudes towards lion conservation were correlated (**Table 12.4**). This left six variables describing socioeconomic and perception related factors (education, occupation, awareness of risks in having lions, how did lions reach in the vicinity, reasons to have lions in the neighborhood and perceived major threat for lions in future) to predict local people's attitudes towards lions and three variables (age, occupation and ideas about irregularities in compensation payment) in understanding the efficacy of the current scheme.



**Table 12.4: Spearman rank correlation plot showing correlation coefficients between respondents' attitudes towards lion conservation in the Gir landscape and different socio-economic variables.**

	LVL	AG	OC	ES	ED	ARL	LLV	HLR	RHL	RSL	PS	CS	CAM	CPS	CFC	IP	SIC	PMT
LVL	1																	
AG	-0.13	1																
OC	0.12	-0.10	1															
ES	0.13		-0.19	1														
ED	0.13	-0.30	0.19	0.25	1													
ARL	0.30		-0.21			1												
LLV		0.11					1											
HLR							-0.16	1										
RHL	0.82		0.12	0.16		0.21			1									
RSL	0.23			0.14	0.1			0.19	0.16	1								
PS	0.65	-0.09		0.12	0.10	0.19			0.55	0.45	1							
CS	0.15	0.14	-0.24	0.08	-0.20	0.20	0.33		0.16	0.13	0.13	1						
CAM		-0.19	0.15	-0.09	0.19	-0.12	-0.17	0.15	-0.07			-0.54	1					
CPS	0.09	-0.19	0.23		0.12	-0.13	-0.28	0.13	0.07	-0.13		-0.27	0.33	1				
CFC	-0.13	-0.10	0.13		0.09	-0.22	-0.26		-0.18		-0.13	-0.70	0.35	0.22	1			
IP	-0.17			.076	0.11	-0.14			-0.16		-0.10	-0.38		-0.14	0.37	1		
SIC		0.19	-0.20		-0.21	0.13	0.18					0.65	-0.68	-0.42	-0.44	-0.20	1	
PMT	0.22		-0.09	0.09		0.22		0.18	0.18			0.10	-0.14		-0.11			1

**Only significant correlation coefficients ( $p < 0.05$ ) have been reported. Variable abbreviations:** LVL= Like to have lions, AG = Age group, OC = Occupation, ES = Economics status, ED = Education, ARL = Awareness of risks in having lions in neighborhood, LLV = Since when lions started living in vicinity, HLR = How did lions reach, RHL = Reasons to have lions to continue to live in neighborhood, RSL = Recommendations in saving lions in the landscape, PS = What can be done to gain more public support, CS = Aware about the Government compensation scheme for livestock depredation, CAM = Is the compensation scheme appropriate in monetary terms? CPS = Is the compensation scheme prompt and systematic? CFC = Are false claims major problems in compensation, IP = Is irregularity a major problem in compensation payment? SIC = Suggestions to improve compensation scheme, PMT = Perceived major future threat for lions in the landscape.



### Respondents' attitudes towards lions in the Gir landscape

We selected the best model among a set of six *a priori* candidate models constructed to predict people's attitudes towards lions in the landscape (**Table 12.5**). Model with the lowest AIC value was considered to be the best approximating model in the set of candidate models considered.

**Table 12.5: A priori candidate models for data predicting the effect of socio-economic factors on respondents' attitudes towards lions in the Gir landscape.**

Model no	Predictor set	Parameters	Wald chi-square	df	P	AIC	ΔAIC
<b>1</b>	<b>OC+ARL</b>	<b>2</b>	<b>41.51</b>	<b>7</b>	<b>&lt; 0.01</b>	<b>1,363</b>	<b>0</b>
2	OC+ ED+ARL+HLR	4	47.26	15	< 0.01	1,373	10
3	OC+ ED+ARL	3	45.85	13	< 0.01	1,371	8
4	OC+ ED	2	18.74	10	0.04	1,392	29
5	ED+ARL	2	34.55	10	< 0.01	1,376	13
6	OC+PMT	2	34.55	10	< 0.01	1,376	13

*Variable abbreviations:* OC = Occupation, ED = Education, ARL = Awareness of risks in having lions in neighborhood, HLR = How did lions reach, PMT = Perceived major future threat for lions in the landscape.

Multinomial logistic regression analysis suggested that model containing respondents' occupation and awareness of having lions in the neighborhood to be the best for predicting local people's attitudes towards lions (**Table 12.5**). **Table 12.6** shows the parameter estimates for the best model (Model number 1, **Table 12.5**). Although respondents' education level influenced their attitudes towards lions but the effect was not significant. Pastoralism was the most important factor shaping people's attitudes towards lions in the landscape (**Table 12.6**). For instance, a pastoral was 35% more unwilling to have lions in the Gir landscape in comparison with a person involved in other services.



**Table 12.6: Parameter estimates and the 95% confidence intervals (CI) for the best model explaining respondents' attitudes towards lions in the Gir landscape.**

Parameter	Estimates	SE	95% Confidence Interval		Wald Chi-Square	P	Odd ratios
			Lower	Upper			
<b>Occupation</b>							
<b>Pastoralist</b>	<b>-0.43</b>	<b>0.14</b>	<b>-0.70</b>	<b>-0.17</b>	<b>10.01</b>	<b>0.002*</b>	<b>0.65</b>
Farmer	-0.09	0.09	-0.28	0.10	0.79	0.373	0.91
Agro-pastoralist	0.14	0.12	-0.13	0.33	0.76	0.382	1.15
Others	Used as a reference category						
<b>Awareness of risks in having lions in the vicinity</b>							
Kills people on sight	-1.09	0.73	-2.52	0.33	2.283	0.131	0.33
Tremendous havoc to livestock	-0.34	0.71	-1.74	1.06	0.228	0.633	0.71
Rarely a risk to human life but does occasionally kill livestock	-0.22	0.71	-1.61	1.18	0.093	0.760	0.80
Does not kill humans or livestock	Used as a reference category						

### **Respondents' attitudes towards the Government compensation for livestock depredation**

$\Delta$ AIC values of the top ranked models (model 1 & 2; Table 12.7) were similar ( $<5$ ) and therefore a model averaging was performed to obtain the best explained estimate. The model-averaged importance value for each parameter is given in Table 12.8.

**Table 12.7: A priori candidate models for data predicting the effect of socio-economic factors on respondents' attitudes towards appropriateness of the Government compensation scheme in monetary terms.**

Model no	Predictor set	Parameters	Wald chi-square	df	P	AIC	$\Delta$ AIC
1	IP	1	62.20	2	$< 0.01$	1,293	0
2	AG+OC+IP	3	70.59	7	$< 0.01$	1,295	2
3	OC	1	17.74	3	$< 0.01$	1,302	9
4	AG	1	13.00	2	0.02	1,303	10
5	AG+OC	2	26.14	5	$< 0.01$	1,304	11

**Variable abbreviations:** AG = Age group, OC = Occupation, CC = Is irregularity a major problem in compensation payment?

Respondents' opinion about the irregularities in the compensation payment influenced their views about the financial appropriateness of the compensation scheme for livestock predation the most (Table 12.8). For instance, respondents opining that irregularities in the



compensation payment was a problem viewed the scheme financially less appropriate by a factor of 12 in comparison with a respondent with no idea about such payment irregularities ( $P = 0.001$ ).

**Table 12.8: Most influential model-averaged parameter estimates from the top models explaining respondents’ opinion about the financial appropriateness of the government compensation scheme for livestock depredation.**

Parameters	$\beta$ Estimates	SE	Odd ratios	Z	P
Age	0.018	0.05	1.01	0.374	0.71
<b>Idea about irregularities in compensation payment</b>	<b>-0.117</b>	<b>0.03</b>	<b>0.88</b>	<b>3.272</b>	<b>0.001*</b>
Occupation	-0.038	0.03	0.96	1.139	0.25

## Discussions

Human ecology is concerned with how humans adapt to a changing environment (Catton 1987). Environmental change is often manifested as conflicts over the meaning and use of natural resources. One central issue in resource management is how the various interest groups perceive the environment, which values and beliefs do they attach to the environment, and how do diverse environmental beliefs affect the position different actors take in conflict situations? Successful resource management is becoming increasingly dependent upon knowledge about how conflicts are constructed, and this entails identifying attitudes and beliefs held by various interest groups.

An “attitude is the product of a person’s perception of how good or bad the outcome associated with a certain behaviour is” (Beedell and Rehman 1999). An optimal output can arise when all known costs and benefits are evaluated. Of course, different individuals can perceive the costs and benefits differently, and this is influenced by various factors. This perception then produces the 'best' attitude for the person and directs the appropriate response towards a subject or an object. An advantage of an already formed attitude is that it allows one to make a rapid decision about which behaviour to adopt. The decision is rapid because only the outcome of the evaluation and not all the steps that led to it has to be remembered.

People’s attitudes toward large carnivores across the world are polarized with different demographic and socio-economic groups (Kellert 1996). Pastoralists, the elderly, people with less education, communities less involved in recreational activities (tourism), and rural inhabitants often express negative attitudes toward large carnivores, while younger,



better educated, and urban people express more positive attitudes toward this species (Kellert 1985, 1991; Dahle 1987; Bjerke et al. 1998). Attitudes towards large carnivores seem to be related to what experience respondents have had with them. Acceptance is high as long as the carnivores are far away from where people live, or if the chance of re-establishment is very low (e.g. in towns). When carnivores come closer, acceptance decreases, and negative attitudes come to a peak when the carnivores actually first arrive. As experience with carnivores increases over time, negative attitudes decrease. After carnivores have become established, fewer people have negative attitudes than at the starting point (Zimmermann et al. 2001).

The current study has revealed a mixed pattern in local attitudes towards lion conservation in the Gir landscape. Respondents hold a diversity of attitudes toward lions that are both positive and negative. Majority of the respondents were aware of the presence of large mammals surrounding their villages (**Table 12.3**). Younger generation was found to be overall more positive towards lions. More elderly people than younger folks did not want lions in the vicinity of their houses and recommended to capture lions and release them back in the Gir PA (**Figures 12.5 and 12.7**); although both having same awareness of risks in having lions in the neighborhood. Older aged people also expressed more hostility towards the Government compensation scheme for livestock predation. This might be because of older generations' newer exposures to lions and lack of plasticity in their behavior to adapt with lions. Younger generations in the Gir landscape, on the other hand are familiar with lions since their childhood and expressed more positive views about lions. Moreover, old age groups are likely to hold more bad memories about government policies than the younger groups. For example, with the regular revision of the government compensation scheme for livestock predation over time, it is likely that a substantial proportion of new generations do not experience the same bad memories as older age groups. Being less educated than the younger generations, older age groups' awareness about their rights in the conservation system, various government schemes and facilities is also lower in comparison to young generations. Correlation analysis suggests that younger people in the landscape are getting inclined to other occupations than traditional pastoralism or farming (**Table 12.4**) and thus do not have a direct impact of lions on their livelihoods. All these probably shape younger generations' perceptions toward lions more positive than the older generations in the Gir landscape. A similar pattern was also observed among the Maasai communities in Tarangire-Manyara ecosystem in Tanzania and Greater Amboseli ecosystem in Kenya where elderly people expressed their dislikes for lions more in comparison to the young warriors and



perception of the formers on livelihood securities has been attributed to such age polarized attitudes toward lions (Goldman et al. 2010).

Human-carnivore conflict is believed to be shaped by the economic condition of the local communities. Lion occupied landscape is one of the most backward regions of the Saurashtra and the financial loss burdened by the local communities (even if little in amount) might be disastrous for an affected family depending upon its socio-economic stature (Mishra et al. 2003). As expected, respondents of lower income group in the study are more unwilling to have lions in future than more affluent people (**Figure 12.5**). Poor people being less educated are unaware of their rights and various ongoing government schemes (**Table 12.4 and Figure 12.9**) compared to the affluents and this is one of the reasons behind their hostility toward lions. Moreover, loss of even a single livestock unit may affect livelihood income of the poor people more in comparison to economically affluent people. Interestingly poor respondents wanted the compensation scheme to be 'more prompt and systematic' while affluents wanted monetary increment (**Figure 12.14**). This could be attributed to the formers' viewing compensation as an 'instant relief' of their financial losses due to livestock predation.

Respondents' education level was not found to be a significantly explaining factor behind their attitudes toward lion conservation. However **Table 12.4** suggests that respondents' education level was negatively correlated with age and positively correlated with economic status and views about like to have lions in the neighborhood. As reported by Bath (1987) in a survey about perceptions towards wolves, there was a relationship between knowledge of the species and perceptions. The low educational levels of the older generation and lower income groups in the Gir landscape is likely to have influenced their attitudes about lions by lowering their awareness about their conservation rights and various government run schemes (like the compensation program for livestock depredation) to elicit more public support in lion conservation.

People have always been concerned about their own health and safety, and they have evolved both positive and negative responses to large carnivores. Self reported fear has played an important role in the conservation many large carnivores, especially in the Scandinavian countries (Røskaft et al. 2003). The current study also identifies such risk perceptions as one of the main factors shaping people's attitudes toward lions in the Gir landscape. For example, a respondent considering lions as threats to humans was 77% more unwilling to have lions ( $P = 0.13$ ) in comparison with a respondent thinking that lions 'neither kill humans nor livestock'. Similarly, a respondent with the view that lions killed



livestock was 29% less willing ( $P = 0.63$ ) to continue to live with lions in future. Many wildlife managers, until recently, underestimate significance of these fears and psychology shaping them. It is more important to gain a better understanding of attitudes to carnivores and explore the behavioral and cultural factors influencing them. This is especially relevant in the Gir landscape where lions are being conserved in multiple land-use landscapes with high human density.

Studies on different continents under diverse social and economic circumstances have concluded that depredation on livestock is an important cause of human intolerance for large carnivores, frequently leading to their extirpation (Karanth and Chellam 2009). Studies in East Africa provide similar evidence that African lion populations are declining due to rapid habitat loss and inter-specific conflicts over resources in areas where pastoralism persists (Frank 1998; Ikanda and Packer 2008; MacLennan et al. 2009). A majority of India's protected areas have livestock-related conflicts (Kothari et al. 1989). For example, tigers are also in conflict with pastoralists as 10–12% of their diet consists of domestic livestock in many parts of India (Biswas and Sankar 2002; Bagchi et al. 2003). The problem is more severe in the Himalayas where local pastorals experience livestock depredation problems by snow leopards (Bagchi and Mishra 2006). Pastoral communities react differently to this conflict depending on their religious beliefs, customs, cultures, perceptions of economic losses (Goldman et al. 2010). In India although people resent having large carnivores in their pastures, they do not actively persecute them as in other parts of Central Asia (Mishra and Fitzherbert 2004). The current study highlights this wherein we found a pattern of people's attitudes strongly polarized with occupation. Economic reasons were found to be one of significant factors shaping people's attitudes about future lion conservation ( $r_s = 0.82$ ; **Table 12.4**). Communities making direct and indirect economic gains from lion conservation extended more support for future lion conservation. Farmers in the Gir landscape considered lion to be an 'economic boon' as a natural regulation of agricultural damage control by killing the pests like nilgai and wild pigs. For people with other occupations the incentive comes from prospects of eco-tourism and hence they are more willing to have lions in future. On the other hand pastoralists in the Gir landscape experience loss of their livestock from lions and therefore considered lions to be a risk more than farmers and people involved in other occupations (**Figure 12.2**) and more unwilling to continue to live with lions in future than the latter (**Figure 12.5**).

From the Mongolian steppe to the ranches of Montana, the link between stock losses and carnivore persecution has prompted reparatory measures such as livestock compensation



schemes with the general intention of mitigating this conflict (Montag and Patterson 2001). Conserving large carnivores in close juxtaposition with humans often involves costs to local people. It is increasingly clear that to promote coexistence in wildlife habitats where local people live, there is a need not only to evaluate and offset the costs but to make wildlife conservation more beneficial for local people (Prins et al. 2000). Unless there are tangible economic returns, local communities are unwilling and often unable to adopt conservation-friendly practices. Incentive programs like compensation cannot ‘buy’ an individual’s tolerance of carnivores (Naughton-Treves et al. 2003) but does ameliorate hostility. Gir has a long history of compensation program for livestock depredation since the time of erstwhile local rulers (Nawabs) in pre-independence era (Gee 1964) which has been continued by the Gujarat Forest Department during the post-independence period (Singh 2007). Banerjee et al. 2013 clearly showed that the Government compensation scheme has a significant role in shaping legendary lion-*Maldhari* coexistence within the Gir PA by ensuring livelihood securities for the latter. The fulcrum of coexistence however is delicately balanced by the free grazing rights of *Maldharis* within the Gir PA. In the larger landscape pastorals hardly had any access to forest resources and expectedly expressed their antagonism toward the compensation scheme. Majority of the respondents in the Gir landscape expressed their discontent over the monetary values and promptness of payment of the compensation scheme and called for enhancing the payment amount and making it more systematic and timely. Incorporation of lost opportunity cost by the communities in the compensation scheme has been highlighted in the Banerjee et al. 2013. We, however, did not include the travel cost by the local communities in getting compensations (like time invested and travel to forest office for lodging the complaints, pursuing the case and getting the payment cheque). These when considered further diminish the financial impact of the compensation amount in offsetting the pastorals’ loss due to livestock predation. Gujarat government regularly revises this scheme in accordance with the market prices. The scheme seems to have improved over the years as the people’s awareness about the prevailing compensation scheme has increased in compared to a previous study (Saberwal et al. 1994). Moreover, the younger generation who were more recently exposed to lions has a better opinion of it. Also communities who were less directly impacted by compensation like the farmers and people engaged in other services had a better opinion than pastoralists and agro-pastoralists. Respondents of Amreli district were more unaware of the compensation scheme in comparison with those from Junagadh and Bhavnagar. This is likely due to the higher education level among the respondents in Amreli district. More educated people in the landscape were found to engage themselves in other



services than traditional pastoralism and farming. Job in diamond industry is one of the commonest sources of income for respondents in Amreli district and being a non-impacted group they showed less awareness about the compensation scheme. In the agro-pastoral landscapes, in the absence of any free economic benefits for the communities, the Government compensation scheme becomes extremely crucial for maintaining the goodwill of the communities towards lion conservation. Recognizing the role of compensation policies in providing instant financial relief, the procedural framework of the current system in Gir could be more streamlined and provisions of onsite payments with active involvement of local non-governmental organizations like that prevailing in Corbett Tiger Reserve, India (WWF-India 2007) could also be adopted. Incorporating lost opportunity cost in the compensation and revising compensation amounts every three years would offset economic losses incurred by the local people in the process of livestock predation by lions and other predators and foster their greater tolerance towards conservation (Banerjee et al. 2013).

Lion density (2/100 km<sup>2</sup>) in the larger landscape was seemingly under the threshold of social tolerance as greater part of the respondents wanted to have lions in their vicinity. Farmers in the region viewed lions as agricultural pest control measures. But lion density should not be allowed to increase indefinitely considering their negative impacts on other communities' (pastoralists and agro-pastoralists) livelihoods. At present there is no government compensation in the Gir landscape for crop damage by wild ungulates despite substantial crop damage incidents (*personal observation*) and this provokes many farmers to install illegal like electric surrounding their farmlands causing deaths of wildlife as well as lions which were non-target species (see chapter 4 for more details). Moreover, lack of such compensation also compel local farmers to guard their crops even at nights and this increases the likelihood of lion attacks on humans in the landscape (Banerjee 2012). We, therefore, advocate that introduction of a compensation scheme for crop damage in the landscape would significantly diminish local farmers' antagonism toward wild ungulates and assist in promoting greater tolerance for lions and other carnivores in the landscape. Alternatively, wildlife damage control measures (like pulsating electric fences; Chauhan 2006) could be subsidized to ensure better tolerance of agricultural communities.

The study also evidently highlights a spatial pattern in the local people's attitudes. Bhavnagar district was found to be more lion friendly while Junagadh the least. People in Junagadh district has an uninterrupted history of staying with lions while it is only in recent time that lions dispersed in the agro-pastoral landscape of Bhavnagar and Amreli districts (Pathak et al. 2002; Divyabhanusinh 2005; Singh 2007). Residents of Junagadh district were



more aware of lions and the compensation scheme than those of Amreli and Bhavnagar owing to their experiences. However, Junagadh houses major part of the Gir PA and has a higher lion density often resulting into more lion attacks on humans than Amreli and Bhavnagar districts (Banerjee 2012). Longer history of tolerating conflicts with lions and other carnivores might have made respondents of Junagadh comparatively more hostile than people from Amreli or Bhavnagar districts. Moreover, most part of our study area within Junagadh district (Mendarda, Talala, Visavadar, Junagadh and Bhesan talukas) was densely populated and had intensive farming thereby escalating conflicts with lions and other carnivores. On the contrary, our study area within Bhavnagar and Amreli districts (upper and lower Shetrunjee basins, vast agro-pastoral tracts of Chalala, Khambha, Savarkundla, Dhari, Amreli, Palitana, Talaja, Sihor, Mahuva and Gariadhar talukas) was typically pastoral, comparatively less populated and predominantly characterized by broken terrain with sparse agricultural cover, private and government owned grasslands (*vidis*), *Prosopis juliflora* thickets and drainage networks. Most of the cattle camps (*gaushalas* and *panjrapoles*) of Kathiawar region are also concentrated in this part of the landscape due to impact of Jainism. Therefore, despite lions' use of human-dominated landscape they chiefly depend on low priced unproductive and feral cattle (see chapter 9 for more details). We anticipate that all these together make Bhavnagar and Amreli more 'lion friendly' than Junagadh. Thus the study contradicts notion that longer exposure to carnivores enhances local people's tolerances. It rather emphasizes the importance of livelihood securities and economics of coexistence as major ingredient in shaping human tolerance in the Gir landscape.

Although majority of the respondents believe that lions do not have any major future threat in the landscape, a substantial proportion, however, opine human-causes as the main future threat for lions. This might be driven by their old experiences. Currently Gujarat forest department has an ongoing project of constructing parapet around the open farm wells and with the covering of about 17,000 wells in past three years (B.J. Pathak, Director Geer Foundation-Gandhinagar, Gujarat, *personal communication*) such threat is likely to get diminished in future. About 10% of the respondents pointed out poaching as a probable threat to lion survival and we attribute this to their remembrance of three incidents of poaching that happened in Gir landscape in March-April 2007 (Fair 2009). Due to high price of lion body parts in international markets especially in China (Check 2006), the possibilities of such incident cannot be overruled and respondents' opinions probably reflect this. With the rapid change of the land-use pattern, livelihood diversification and local communities' traditional custodian roles of nature getting fast eroded by western utilitarian values, such perceived



animosity, although small, might even lead to complacency with the professional poaching gangs that happened in Gir in 2007 (Fair 2009) and elsewhere in India (Narain et al. 2005; Gopal et al. 2010). Gir PA is likely to be lion unabated stronghold in future owing to the strong protection regime of the forest department. However, we believe that law enforcement alone cannot secure lion survival in the Gir landscape. A broader rural support base has to be generated. In the human-dominated landscape where conservation is not a major land-use objective, understanding the nature and costs of human-lion conflicts through combined assessment of both actual and perceived dimensions of the problem therefore becomes imperative. The findings of the present study have the significant implications herein as it highlights the perceived conflict which could be used to project the threshold of social tolerances for lions in future. The increasing investments in conventional 'solutions' to human-wildlife conflicts such as culling problem animal cannot be adopted in Indian scenario because of legal prohibitions (Karanth and Gopal 2005). Instead, mitigation of lion-human conflict in the Gir landscape bags pragmatic approaches based on ecology based policy framework with a harmonious amalgamation of state's land, tourism and rural development policies. This could be done by targeting appropriate stakeholders through awareness campaigns. Currently the Gujarat Forest Department has an 'Education Camp' program aiming younger generation only. But this should be made available even to the poorer and backward sectors of the society so as to disseminate the ideas about the conservation benefits even to the lowest stratum of the society. Compensation amount paid to the pastoralists should be enhanced by incorporating lost opportunity cost, streamlined and revised regularly. A compensation for crop damage should be thought upon. Gujarat forest department often argues the complexities in identifying the extent of crop damage as a deterrent of introducing such scheme (S.M. Raja, ex-DCF, Gir, *personal communication*). But this can be handled by training local officials and staff by adopting expertise of the Junagadh Agriculture University, other forest departments (like Karnataka Forest Department) and national NGOs already working on related issues. Once the frontline staff gets trained in this they will be able to do this on their own in future. Alternatively, agricultural damage control measures can be subsidized. Since expanding the prospects of eco-tourism may not be a viable option at the landscape level owing to low lion density and lack of a PA; other income generating options (employment of the local people with the forest department, hiring labors from local communities, contract of local businessmen and farms for departmental engineering and maintenance works etc.) could be thought upon. All these will enhance local people's attitudes for lions and likely to foster their tolerance to a greater extent.



## LITERATURE CITED

- Ables, E.D. 1974. The Axis deer in Texas. The Caeser Kleberg Research Programme. The Texas Agricultural Experiment Station. A & M University System. Texas, 86 pp.
- Acharya, R.M. 1982. Sheep and goat breeds of India. FAO Animal production and Health paper 30, Food and Agriculture Organisation of the United Nation, Rome, Italy.
- Ackerman, B.B., Lindzey, F.G. and Hemker, T.P. 1984. Cougar food habits in Southern Utah. *The Journal of Wildlife Management*, 48: 147-155.
- Adams, E.S. 2001. Approaches to the study of territory size and shape. *Annual Review of Ecology and Systematics*, 32: 277-303.
- Adams, W.M. 2004. *Against extinction: the story of conservation*. EarthScan, London, UK, xvi + 311 pp.
- Adams, W.M., and Hutton, J. 2007. People, parks and poverty: political ecology and biodiversity conservation. *Conservation and Society*, 5: 147-183.
- Aebischer, N.J., Robertson, P.A. and Kenward, R.E. 1993. Compositional analysis of habitat use from animal radiotracking data. *Ecology*, 74: 1313-1325.
- Agarwala, M., Kumar, S., Treves, A. and Naughton-Treves, L. 2010. Paying for wolves in Solapur, India and Wisconsin, USA: comparing compensation rules and practice to understand the goals and politics of wolf conservation. *Biological Conservation*, 143: 2945–2955.
- Akaike, H., 1974. A new look at the statistical model identification. *IEEE Transactions on Automatic Control*, 19: 716-723.
- Akçakaya H.R. and Sjögren-Gulve, P. 2000. Population viability analysis in conservation planning: an overview. *Ecological Bulletins*, 48: 9-21.
- Ali, S. and Ripley, S.D. 1983. *Handbook of the birds of India and Pakistan*, Oxford University Press, New Delhi, India.
- Allen, T.F.H. and Starr, T.B. 1982. *Hierarchy perspective for ecological complexity*. University of Chicago Press, Chicago, USA, 310 pp.
- Altizer, S., Harvell, D. and Friedle, E. 2003. Rapid evolutionary dynamics and disease threats to biodiversity. *Trends in Ecology and Evolution*, 18: 589–596.
- Altmann, J. 1974. Observational study of behaviour: sampling methods. *Behaviour*, 49: 227-267.
- Amstrup, S.C., McDonald, T.L. and Manly, B.F.J. 2005. *Handbook of capture*. Oxford: Princeton University Press, 312 pp.
- Andersen, D.C., Wilson, K.R., Miller, M.S. and Falck, M. 2000. Movement patterns of riparian small mammals during predictable floodplain inundation. *Journal of Mammalogy*, 81: 1087-1099.
- Anderson, D.J. 1982. The home range: a new nonparametric estimation technique. *Ecology*, 63: 103–112.



- Anderson, D.R. 1997. Corridor use, feeding ecology, and habitat relationships of black bears in a fragmented landscape in Louisiana. M.Sc. Thesis, University of Tennessee, Knoxville, Tennessee, USA, 124 pp.
- Andersone, Ž. and Ozoliņš, J. 2004. Public perception of large carnivores in Latvia. *Ursus*, 15: 181–187.
- Andheria, A.P., Karanth, K.U. and Kumar, N.S. 2007. Diet and prey profiles of three sympatric large carnivores in Bandipur Tiger Reserve, India. *Journal of Zoology*, 273: 169–175.
- Antunes, A., Troyer, J.L., Roelke, M.E., Pecon-Slattery, J., Packer, C., Winterbach, C., Winterbach, H., Hemson, G., Frank, L., Stander, P., Siefert, L., Driciru, M., Funston, P.J., Alexander, K.A., Prager, K.C., Mills, G., Wildt, D., Bush, M., O'Brien, S.J. and Johnson, W.E. 2008. The evolutionary dynamics of the lion *Panthera leo* revealed by host and viral population genomics. *PLoS Genetics*, 4(11): e1000251.
- Ashraf, N.V.K., Chellam, R., Molur, S., Sharma, D. and Walker, S. 1995. Population and habitat viability assessment workshops for Asiatic lion, *Panthera leo persica*, report July 1995. Conservation Breeding Specialist Group, Apple Valley, Minnesota, USA, 113 pp.
- Athreya, V., Odden, M., Linnell, J.D.C. and Karanth, K.U. 2011. Translocation as a tool for mitigating conflict with leopards in human-dominated landscapes of India. *Conservation Biology*, 25: 133-141.
- Badoni, V., Jhala, Y.V. and Qureshi, Q. 2005. Lion monitoring system-version 1.0: software for long term monitoring of lions. Wildlife Institute of India, Dehra Dun, India.
- Bagchi, S. and Mishra, C. 2006. Living with large carnivores: predation on livestock by the snow leopard (*Uncia uncia*). *Journal of Zoology*, 268: 217–224.
- Bagchi, S.P., Goyal, P. and Sankar, K. 2003. Prey abundance and prey selection by tigers (*Panthera tigris*) in a semi-arid, dry deciduous forest in western India. *Journal of Zoology*, 260: 285–290.
- Bailey, T.N. 1993. The African leopard. Ecology and behavior of a solitary felid. Columbia University Press, New York, USA, 429 pp.
- Banerjee, K. 2012. Ranging patterns, habitat use and food habits of the satellite lion populations (*Panthera leo persica*) in Gujarat, India. Ph.D. thesis, Forest Research Institute Deemed University, Dehradun, India, 435 pp.
- Banerjee, K. and Jhala, Y.V. 2012. Demographic parameters of endangered Asiatic lions (*Panthera leo persica*) in Gir forests, India. *Journal of Mammalogy*, 93: 1420 – 1430.
- Banerjee, K., Jhala, Y.V. and Pathak, B. 2010. Demographic structure and abundance of Asiatic lions (*Panthera leo persica*) in Girnar Wildlife Sanctuary, Gujarat, India. *Oryx*, 44: 248-251.
- Banerjee, K., Jhala, Y.V., Chauhan, K.S. and Dave, C.V. 2013. Living with lions: economics of coexistence in the Gir forests, India. *PLoS ONE*, 8(1):e49457. DOI:10.1371/journal.pone.0049457.
- Barnett, R., Yamaguchi, N., Shapiro, B., Ho, S.Y.W., Barnes, I., Sabin, R., Werdelin, L., Cuisin, J. and Larson, G. 2014. Revealing the maternal demographic history of *Panthera leo* using ancient DNA and a spatially explicit genealogical analysis. *BMC Evolutionary Biology*, 14: 70.



- Basu, A. 2012. Abundance estimation of leopards (*Panthera pardus*) in Girnar wildlife sanctuary, Gujarat. Master thesis, Forest Research Institute Deemed University, Dehra Dun, India, 49 pp.
- Basu, P. 2013. Assessment of landscape pattern for modelling habitat suitability for Lions and Prey species in Gir protected area, Gujarat. Ph.D. thesis, Forest Research Institute Deemed University, Dehradun. India, 288 pp.
- Bates, D., Maechler, M. and Bolker, B. 2011. lme4: Linear mixed-effects models using S4 classes. Version: 0.999375-42. <http://cran.r-project.org/web/packages/lme4/index.html>.
- Bath, A.J. 1987. Attitudes of various interest groups in Wyoming toward wolf reintroduction in Yellowstone National Park. MA Thesis, University of Wyoming, Laramie, 124 pp.
- Bauer, H. and De Iongh, H.H. 2005. Lion (*Panthera leo*) home ranges and livestock conflicts in Waza National Park, Cameroon. *African Journal of Ecology*, 43: 208-214.
- Bauer, H. and Van Der Merwe, S. 2004. Inventory of free-ranging lion *Panthera leo* in Africa. *Oryx*, 38:26-31.
- Beedell, J. and Rehman, T. 1999: Using social-psychology models to understand farmers' conservation behavior. *Journal of Environmental Management*, 57: 169-176.
- Belovsky, G. E. 1987. Extinction models and mammalian persistence, 35-57: In *Viable populations for conservation*, Soule, M.E. (ed). Cambridge University Press, Cambridge, UK.
- Bennett, A., Radford, J. and Haslem, A. 2006. Properties of land mosaics: Implications for nature conservation in agricultural environments. *Biological Conservation*, 133: 250-264.
- Bennett, E.L. and Robinson, J.G., 2000. *Hunting for sustainability in tropical forests*, Columbia University Press, 582 pp.
- Berger, K.M. and Gese, E.M. 2007. Does interference competition with wolves limit the distribution and abundance of coyotes? *Journal of Animal Ecology*, 76: 1075–1085.
- Bernard, H.R. 1995. *Social research methods: quantitative and qualitative approaches*. Sage, Thousand Oaks, 784 pp.
- Berry, H., Bush, M., Davidson, B., Forge, O., Fox, B., Grisham, J., Howe, M., Hurlbut, S., Marker-Kraus, L., Martenson, J., Munson, L., Nowell, K., Schumann, M., Shille, T., Stander, F., Venzke, K., Wagener, T., Wildt, D., Ellis, S. and Seal, U. 1997. Population and habitat viability assessment for the Namibian cheetah (*Acinonyx jubatus*) and lion (*Panthera leo*). Workshop Report. IUCN/SSC Conservation Breeding Specialist Group: Apple Valley, MN 1997.
- Bertram, B.C.R. 1975. Social factors influencing reproduction in wild lions. *Journal of Zoology* 177: 463-482.
- Bertram, B.C.R. 1978. *Pride of lions*. J.M. Dent and Sons Ltd., London, UK, 253 pp.
- Bertrand, M.R., DeNicola, A.J., Beissinger, S.R. and Swihart, R.K. 1996. Effects of parturition on home ranges and social affiliations of female white-tailed deer. *The Journal of Wildlife Management*, 60: 899–909.
- Berwick, M. 1990. The ecology of the Maldhari graziers in the Gir forest, 81-94: In *Conservation in developing countries: problems and prospects*. Proceedings of the centenary seminar of the



- Bombay Natural History Society 1983, Daniel, J.C. and Serrao, J.S. (eds), Oxford University Press, Bombay, India.
- Berwick, S. 1974. The community of wild ruminants in Gir ecosystem. Ph.D. thesis, Yale University, USA, 225 pp.
- Berwick, S.H. and Jordan, P.A. 1971. First report of the Yale-Bombay Natural History Society studies of wild ungulates at the Gir forest, Gujarat, India. *Journal of the Bombay Natural History Society*, 68: 412-423.
- Bhagwat, S.A., Willis, K.J., Birks, H.J. and Whittaker, R.J. 2008. Agroforestry: a refuge for tropical biodiversity? *Trends in Ecology and Evolution*, 23: 261-267.
- Bhatt, Y.C., Verma, R.N., Sharma, A.K. and Tiwari, G. 2005. Draughtability assessment of Indian donkey through fatigue analysis. *Indian Journal of Animal Research*, 39: 1-7.
- Bingham, B.B. and Noon, B.R. 1997. Mitigation of habitat 'take': application to habitat conservation planning. *Conservation Biology*, 11: 127-139.
- Biswas, S. and Sankar, K. 2002. Prey abundance and food habit of tigers (*Panthera tigris tigris*) in Pench National Park, Madhya Pradesh, India. *Journal of Zoology*, 256: 411-420.
- Bjerke, T., Reitan, O. and Kellert, S. R. 1998. Attitudes toward wolves in southeastern Norway. *Society and Natural Resources*, 11: 169-178.
- Björklund, M. 2003. The risk of inbreeding due to habitat loss in the lion (*Panthera leo*). *Conservation Genetics*, 4: 515-523.
- Blake, S. and Hedges, S. 2004. Sinking the flagship: the case of forest elephants in Asia and Africa. *Conservation Biology*, 18: 1191-1202.
- Boitani, L. 1995. Ecological and cultural diversities in the evolution of wolf-human relationships, 3-12: In *Ecology and conservation of wolves in a changing world*, Carbyn, L.N., Fritt, S.H. and Seip, D.R. (eds.), Canadian Circumpolar Institute, University of Alberta, Edmonton, Alberta, Canada.
- Borchers, D.L. and Efford, M.G. 2008. Spatially explicit maximum likelihood methods for capture-recapture studies. *Biometrics*, 64: 377-385.
- Börger, L., Franconi, N., De Michele, G., Gantz, A., Mesch, F., Manica, A., Lovari, S. and Coulson, T. 2006. Effects of sampling regime on the mean and variance of home range size estimates. *Journal of Animal Ecology*, 75: 1393-1405.
- Boulanger, J.G. and White, G.C. 1990. A comparison of home-range estimators using Monte Carlo simulation. *The Journal of Wildlife Management*, 54: 310-315.
- Bowne, D.R. and Bowers, M.A. 2004. Interpatch movements in spatially structured populations: a literature review. *Landscape Ecology*, 19: 1-20.
- Breitenmoser U. 1998. Large predators in the Alps: the fall and rise of man's competitors. *Biological Conservation*, 83: 279-289.
- Breitenmoser, U., Mallon, D.P., Khan, J.A. and Driscoll, C. 2008. *Panthera leo ssp. persica*. In: IUCN 2011. IUCN Red List of Threatened Species. Version 2011.2, available at [www.iucn.org](http://www.iucn.org). (Accessed June 20, 2014).



- Brook, B.W., Tonkyn, D.W., O'Grady, J.J. and Frankham, R. 2002. Contribution of inbreeding to extinction risk in threatened species. *Conservation Ecology*, 6: 16.
- Brotons, L., Thuiller, W., Araújo, M.B. and Hirzel, A.H. 2004. Presence-absence versus presence-only modelling methods for predicting bird habitat suitability. *Ecography*, 27: 437-448.
- Brown, W.H. and Curtis, J.T. 1952. The upland conifer hardwood forests of northern Wisconsin, *Ecological Monograph*, 22: 217-234.
- Bruner, A.G., Gullison, R.E., Rice, R.E., da Fonseca, G.A.B., 2001. Effectiveness of parks in protecting tropical biodiversity. *Science* 291, 125–127.
- Buchanan, J.M. 2003. Cost and choice. 454-456: In *The encyclopedia of public choice*, Rowley, C.K. and Schneider, F. (eds.), Kluwer Academic Publishers, London, UK.
- Buckland, S.T., Anderson, D.R. Burnham, K.P., Laake, J.L., Borchers, D.L. and Thomas, L. 2001. An introduction to distance sampling: estimating abundance of biological populations. Oxford University Press, Oxford, UK, 432 pp.
- Burdett, C.L., Moen, R.A., Niemi, G.J. and Mech, L.D. 2007. Defining space use and movement of Canada lynx with global positioning system telemetry. *Journal of Mammalogy*, 88: 457-467.
- Burgman, M. A., Ferson, S. and Akçakaya, H. R. 1993. Risk assessment in conservation biology. Chapman and Hall, London, UK, 314 pp.
- Burnham, K., and Anderson, D. 2002. Model selection and multimodel inference. Springer, New York, USA, 488 pp.
- Burrows, R. 1992. Rabies in wild dogs. *Nature*, 359: 277.
- Burrows, R., Hofer, H. and East, M.L. 1994. Demography, extinction and intervention in a small population: the case study of Serengeti wild dogs. *Proceedings of Royal Society London B*, 256: 281-292.
- Callicott, J.B. 1990. Whither conservation ethics? *Conservation Biology*, 4: 15-20.
- Camenzind, F.J. 1978. Behavioral ecology of coyotes on the National Elk Refuge, Jackson, Wyoming. 267-294: In *Coyotes: biology, behavior and management*, Bekoff, M. (ed.), Academic Press, New York, USA.
- Caraco, T. and Wolf, L.L. 1975. Ecological determinants of group sizes of foraging lions. *The American Naturalist*, 109: 343-352.
- Carbone, C. and Gittleman, J. L. 2002. A common rule for the scaling of carnivore density. *Science*, 295: 2273 – 2276.
- Cardillo, M., Purvis, A., Sechrest, W., Gittleman, J.L., Bielby, J. and Mace, G.M. 2004. Human population density and extinction risk in the world's carnivores. *PLoS Biology*, 2: 909-913.
- Caro, T.M. 1994. Cheetahs of the Serengeti plains: group living in an asocial species. University Of Chicago Press, Chicago, USA, 500 pp.
- Caro, T.M. and Collins, D. A. 1987. Ecological characteristics of territories of male cheetahs (*Acinonyx jubatus*). *Journal of Zoology*, 211: 89-105.



- Caro, T.M. and Laurenson, M.K. 1994. Ecological and genetic factors in conservation: a cautionary tale. *Science*, 263: 485-486.
- Caro, T.M., Pelkey, N., Borner, M., Severre, E.L.M., Campbell, K.L.I., Huish, S.A., Ole Kuwai, J., Farm, B.P. and Woodworth, B.L. 1998. The impact of tourist hunting on large mammals in Tanzania: an initial assessment. *African Journal of Ecology*, 36: 321-346.
- Casimir, M. J. 2001. Of lions, herders and conservationists: brief notes on the Gir Forest National Park in Gujarat (Western India). *Nomadic Peoples*, 5: 154-161.
- Catton, W.R. 1987. The world's most polymorphic species. *Bioscience*, 37: 413-419.
- Caughley, G. 1977. *Analysis of vertebrate populations*. Wiley, London, UK, 234 pp.
- Caughley, G. 1994. Directions in conservation biology. *Journal of Animal Ecology*, 63: 215-244.
- Caughley, G. and Sinclair, A.R.E. 1994. *Wildlife ecology and management*. Blackwell, Oxford, UK, 334 pp.
- Champion, F.W. 1934. *With a camera in tiger land*. Chatto and Windus, London, UK, 228 pp.
- Champion, H. and Seth, S. 1968. *A revised study of the forest types of India*. Government of India Press, New Delhi, India, 404 pp.
- Chao, A. and Huggins, R.M. 2005. Modern closed population capture-recapture models, 58-87: In *Handbook of capture recapture analysis*, Amstrup, S.C., McDonald, T.L. and Manly, B.F.J. (eds.), Princeton University Press, Princeton and Oxford.
- Chardonnet, P. 2002. Conservation of the African lion: contribution to a status survey. International Foundation for the Conservation of Wildlife, Paris, France and Conservation Force, USA, 171 pp.
- Chauhan, N.P.S. 2006. *Manual on power fencing for wild animals*. Wildlife Institute of India, Dehradun, India, [http://www2.wii.gov.in/publications/researchreports/2006/manual\\_power\\_fencing\\_content.pdf](http://www2.wii.gov.in/publications/researchreports/2006/manual_power_fencing_content.pdf). Accessed August 17, 2012.
- Chauvenet, A. 2009. Canine distemper virus impact on lion-cheetah interactions in the Serengeti National Park. Master's thesis submitted to the Imperial College, London, UK, 50 pp.
- Chavan, S.A. 1993. *Vegetational and wildlife studies in Gir forest*. Ph.D. Thesis, M.S. University, Vadodara, India.
- Chazdon, R.L., Harvey, C.A., Komar, O., Griffith, D.M., Ferguson, B.G., Martínez-Ramos, M., Morales, H., Nigh, R., Soto-Pinto, L., van Breugel, M. and Philpott, S.M. 2009. Beyond reserves: a research agenda for conserving biodiversity in human-modified tropical landscapes. *Biotropica*, 41: 142-153.
- Check, E. 2006. The tiger's retreat. *Nature* 441: 927-930.
- Chefaoui, R. M., Hortal, J. and Lobo, J. M. 2005. Potential distribution modelling, niche characterization and conservation status assessment using GIS tools: A case study of Iberian *Capris* species. *Biological Conservation*, 122: 327-338.
- Chellam, R. 1993. *Ecology of the Asiatic lion (Panthera leo persica)*. Ph.D. thesis, Saurashtra University, Rajkot, India, 170 pp.



- Chellam, R. and Johnsingh, A.J.T. 1993. The management of Asiatic lions in the Gir forest, India. *Symposia of the Zoological Society*, 65: 409-424.
- Chesson, J. 1978. Measuring preference in selective predation. *Ecology*, 59: 211-215.
- Choudhury, S.R. 1970. Let us count our tigers. *Cheetal*, 14: 41-51.
- Ciucci, P., Boitani, L., Francisci, F. and Andreoli, G. 1997. Home range, activity and movements of a wolf pack in central Italy. *Journal of Zoology*, 243: 803-819.
- Clark, T.W., Minta, S.C., Curlee, A.P. and Kareiva, P.M. 1999. A model ecosystem for carnivores in Greater Yellowstone, 1-9: In *Carnivores in ecosystems: the Yellowstone experience*, Clark, T.W., Curlee, A.P., Minta, S.C. and Kareiva, P.M. (eds.), Yale University Press, New Haven, Connecticut, USA.
- Coe, M.J., Cummings, D.H. and Phillipson, J. 1976. Biomass and production of large African herbivores in relation to rainfall and primary production. *Oecologia*, 22: 341-354.
- Cohen, W.B. and Goward, S.N. 2004. Landsat's role in ecological applications of remote sensing. *Bioscience*, 54: 535-545.
- Collinge, S.K. 1996. Ecological consequences of habitat fragmentation: implications for landscape architecture and planning. *Landscape and Urban Planning*, 36: 59-77.
- Collinge, S.K. 2009. *Ecology of fragmented landscapes*. The Johns Hopkins University Press. Maryland, USA, xiii + 340pp.
- Congalton, R.G. 1991. A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing of the Environment*, 37: 35-46.
- Conover, M. 2002. *Resolving human-wildlife conflicts: the science of wildlife damage management*. CRC Press, Boca Raton, Florida, USA, 418 pp.
- Cooch, W. and White, G. 2009. *Program MARK: a gentle introduction*. 9th edition, <http://www.phidot.org/software/mark/docs/book/markbook.exe> (accessed December 2013)
- Cooper, J. 1942. An exploratory study on African lions. *Comparative Psychological Monographs*, 17: 1-48.
- Cooper, S.M. 1991. Optimal hunting group size: the need for lions to defend their kills against loss to spotted hyenas. *African Journal of Ecology*, 29: 130 -136.
- Coppin, P.R. and Bauer, M.E. 1994. Processing of multitemporal Landsat TM imagery to optimize extraction of forest cover change features. *IEEE Transactions on Geoscience and Remote Sensing*, 32: 918-927.
- Cresswell, W.J. and Smith, G.C. 1992 The effects of temporally autocorrelated data on methods of home range analysis, 272-284: In *Wildlife telemetry remote monitoring and tracking of animals*, Priede, I.G. and Swift, S.M. (eds.), Ellis Horwood Ltd., New York, USA.
- Curtis, J.H. and McIntosh, R.P. 1950. The interrelations of analytic and synthetic phytosociological characters. *Ecology*, 31:434-435.
- Curtis, J.T. and Cotton, G. 1956. *Plant ecology workbook: laboratory field reference manual*. Burgess Publishing Co., Minnesota, USA, 193 pp.



- Dahle, L. 1987. Haldningar til bjørn, jerv og ulv i Norge (Attitudes toward bears, wolverines and wolves in Norway). M.Sc. Thesis, Agricultural University of Norway.
- Dalerum, F., Somers, M.J., Kunkel, K.E. and Cameron, E.Z. 2008. The potential for large carnivores to act as biodiversity surrogates in southern Africa. *Biodiversity and Conservation*, 17: 2939-2949.
- Daniel, J.C. 1984. A survey of Gir National Park and Sanctuary: a report to the Government of India about the extraction of trees fallen during cyclone in 1982.
- Dave, C. 2008. Ecology of chital (*Axis axis*) in Gir. Ph.D. thesis, Saurashtra University, Rajkot, India, 262 pp.
- Dave, C. and Jhala, Y. 2011. Is competition with livestock detrimental for native wild ungulates? - A case study of chital (*Axis axis*) in Gir forest, India. *Journal of Tropical Ecology*, 27: 239-247.
- Dave, P.O. 1977. Monograph on Patanwadi sheep of Gujarat. Technical bulletin, Directorate of Animal Husbandry, Gujarat State, Ahmedabad.
- de Solla, S.R., Bonduriansky, R. and Brooks, R.J. 1999. Eliminating autocorrelation reduces biological relevance of home range estimates. *Journal of Animal Ecology*, 68: 221-234.
- DeFries, R., Hansen, A., Newton, A.C. and Hansen, M.C. 2005. Increasing isolation of protected areas in tropical forests over the past twenty years. *Ecological Applications*, 15: 19–26.
- DeFries, R.S., Bounoua, L. and Collatz, G.J. 2002. Human modification of the landscape and surface climate in the next fifty years. *Global Change Biology*, 8: 438-458.
- Department of Finance, Gujarat state 2008. Socio-economic review Gujarat state 2007-08. Government of Gujarat, Gandhinagar, India. [www.gujaratindia.com/pdf/ser0708.pdf](http://www.gujaratindia.com/pdf/ser0708.pdf). (Accessed July 14, 2012).
- Dettki, H., Lofstrand, R. and Edenius, L. 2003. Modeling habitat suitability for moose in coastal northern Sweden: empirical vs. process-oriented approaches. *Ambio*, 32: 549–556.
- Dharaiya, N. 2001. A study on the ecology of the satellitic lion metapopulation outside Gir PA and its conservation. Ph.D. thesis, Saurashtra University, Rajkot, India, 119 pp.
- Diamond, J.M. 1984. Historic extinctions: a Rosetta stone for understanding prehistoric extinctions, 821-862: In *Quaternary extinctions: a prehistoric revolution*, Martin, P.S. and Klein, R.G. (eds.), University of Arizona Press, Tucson, Arizona.
- Divyabhanusinh, C. 2005. The story of Asia's lions. Marg Publication, Mumbai, India, 259 pp.
- Divyabhanusinh, C. 2006. The end of a trail: cheetah in India. Third edition, Oxford Publishers, New Delhi, India. 268 pp.
- Dixon, K.R. and Chapman, J.A. 1980. Harmonic mean measure of animal activity areas. *Ecology*, 61: 1040–1044.
- Driscoll, C.A., Menotti-Raymond, M., Nelson, G., Goldstein D. and O'Brien, S.J. 2002. Genomic microsatellites as evolutionary chronometers: A test in wild cats. *Genome Research*, 12: 414-423.
- Druce, D., Genis, H., Braak, J., Greatwood, S., Delsink, A., Kettles, R., Hunter, L. and Slotow, R. 2004. Population demography and spatial ecology of a reintroduced lion population in the Greater Makalali Conservancy, South Africa. *Koedoe*, 47: 103–118.



- Dunbar-Brander, A.A. 1923. Wild animals in central India. E. Arnold and Co., London, UK, 296 pp.
- Dunning J.B. Jr, Borgella R., Clements C. and Meffe G.K. 1995. Patch isolation, corridor effects, and colonization by a resident sparrow in a managed pine woodland. *Conservation Biology*, 9: 542–550.
- East, R. 1984. Rainfall, soil nutrient status and biomass of large African savanna mammals. *African Journal of Ecology*, 22: 245-270.
- Eastman, R. 2000. IDRISI 32 guide to GIS and image processing; Clark University, Worcester, MA, USA. Volume 1, 109-142 pp.
- Edgaonkar, A. 2008. Ecology of the leopard (*Panthera pardus*) in Bori Wildlife Sanctuary and Satpura National Park, India. Ph.D. thesis, University of Florida, USA. 135 pp.
- Edwards, S. M. and Fraser, L.G. 1907. The Gir forests and its lions. In *The Ruling Princes of India, Junagadh; Being a Historical, Archeological, Political and Statistical Account of the Premier State of Kathiawar, Bombay*. Times of India Press.
- Ehleringer, J.R. and Field, C.B. (eds.) 1993. *Scaling physiological processes: leaf to globe*. Academic Press, New York, USA, 388 pp.
- Eidenshink, J.C. 1992. The 1990 conterminous US AVHRR data set. *Photogrammetric Engineering and Remote Sensing*, 58: 809-813.
- Elliott, J. P. and Cowan, I.M. 1978. Territoriality, density and prey of the lion in Ngorongoro Crater, Tanzania. *Canadian Journal of Zoology*, 56: 1726-1743.
- Eloff, F.C. 1973. Lion predation in the Kalahari Gemsbok National Park. *Journal of South African Wildlife Management Association*, 3: 59-63.
- Eloff, F.C. 1980. Cub mortality in the Kalahari lion *Panthera leo vernayi* (Roberts, 1948). *Koedoe*, 23: 163-170.
- Eloff, F.C. 1984. Food ecology of the Kalahari lion *Panthera leo*. *Koedoe*, 27 (supplementary): 249 - 258.
- Elvidge, C.D., K.E. Baugh, E.A. Kihn, H.W. Kroehl and Davis, E.R. 1997. Mapping city lights with nighttime data from the DMSP operational linescan system. *Photogrammetric Engineering and Remote Sensing*, 63: 727–734.
- Ewers, R.M. and Didham, R.K. 2006. Confounding factors in the detection of species responses to habitat fragmentation. *Biological Reviews*, 81:117-142.
- Fahrig, L. 2003. Effects of habitat fragmentation on diversity. *Annual Review of Ecological Systems*, 34: 487–515.
- Fahrig, L. and Merriam, G. 1985. Habitat patch connectivity and population survival. *Ecology*, 66: 1762–1768.
- Fair, J. 2009. Crime-busting to save rare lions. *News of the earth section*. BBC Wildlife, March 2009: 39.
- Fenton, L.L. 1924. *The Rifle in India: Being the sporting experiences of an Indian officer*. W. Thacker and Co., London, UK, 329 pp.



- Ferreras, P., Aldama, J.J., Beltrán, J.F. and Delibes, M. 1992. Rates and causes of mortality in a fragmented population of Iberian lynx *Felis pardina* Temminck, 1824. *Biological Conservation*, 61: 197-202.
- Floyd, T.J., Mech, L.D. and Jordan, P.A. 1978. Relating wolf scat content to prey consumed. *The Journal of Wildlife Management*, 42: 528-532.
- Foose, T. 1977. Demographic models for management of captive populations. *International Zoo Yearbook*, 17: 70-76.
- Forest (Conservation) Act, 1988. Forest (Conservation) Act 1980 with Amendments made in 1988. Ministry of Environment and Forests, Government of India, New Delhi. [www.moef.nic.in/legis/forest/forest2.html](http://www.moef.nic.in/legis/forest/forest2.html). (Accessed on 21 January, 2014).
- Forest Survey of India (FSI) 2009. State of Forest Report 2009. Forest Survey of India, Dehra Dun, India.
- Forman, R.T.T. and Alexander, L.E. 1998. Roads and their major ecological effects. *Annual Review of Ecology Evolution and Systematic*, 29: 207–231.
- Frank, L.G. 1998. Living with lions: carnivore conservation and livestock in Laikipia district, Kenya. Report prepared for the U.S. Agency for International Development as part of the Conservation of Biodiverse Resource Areas Project, contract number 623-0247-C-00-3002-00. Mpala Research Centre, Nanyuki, Kenya, 63 pp.
- Frankham, R. 1995. Inbreeding and extinction: a threshold effect. *Conservation Biology*, 9: 792-799.
- Frankham, R., Briscoe, D.A. and Ballou, J.D. 2002. Introduction to conservation genetics. Cambridge University Press, UK, 617 pp.
- Fuller, T.K. 1989. Population dynamics of wolves in north-central Minnesota. *Wildlife Monographs*, 105: 3-41.
- Fuller, T.K. 1995. An international review of large carnivore conservation status, 410-412: In *Integrating people and wildlife for a sustainable future*, Bissonette, J.A. and Krausman, P.R. (eds.), The Wildlife Society, Bethesda, MD, USA.
- Funston, P. 2002. Game Reserves and National Parks: Factors relevant to lion conflict, 21-22: In *Lion conservation research, workshop 2: modelling conflict*, Loveridge, A.J., Lynam, T. and Macdonald, D.W. (eds.), Wildlife Conservation Research Unit (WildCRU), Oxford, UK.
- Funston, P. J., Mills, M.G.L., Biggs, H.C. and Richardson P.R.K. 1998. Hunting by male lions: ecological influences and socioecological implications. *Animal Behaviour*, 56: 1333–1345.
- Funston, P., Frank, L., Stephens, T., Davidson, Z., Loveridge, A., Macdonald, D.M., Durant, S., Packer, C., Mosser, A. and Ferreira, S.M. 2010. Substrate and species constraints on the use of track incidences to estimate African large carnivore abundance. *Journal of Zoology*, 281: 56-65.
- Funston, P.J., Mills, M.G.L., Richardson, P.R.K. and van Jaarsveld, A.S. 2003. Reduced dispersal and opportunistic territory acquisition in male lions (*Panthera leo*). *Journal of Zoology*, 259: 131 – 142.
- Gadgil, M. and Thapar, R. 1990. Human ecology in India: some historical perspectives. *Interdisciplinary Science Reviews*, 15: 209-223.



- Gardner, R.H. 1998. Pattern, process, and the analysis of spatial scales. 17-34 In: Ecological scale, Peterson D.L. and Parker V.T. (eds), Columbia University Press, New York, USA.
- Gardner, T.A., Barlow, J., Chazdon, R., Ewers, R.M., Harvey, C.A., Peres, C.A. and Sodhi, N.S. 2009. Prospects for tropical forest biodiversity in a human-modified world. *Ecology Letters*, 12: 561-582.
- Garshelis, D.L. 1992. Mark-recapture density estimation for animals with large home ranges, 1098–1111: In *Wildlife 2001: populations*, McCullough, D.R. and Barrett, R.H. (eds.), Elsevier Applied Science, New York, USA.
- Garshelis, D.L., Joshi, A.R. and Smith, J.L.D. 1999. Estimating density and relative abundance of sloth bears. *Ursus*, 11: 87-98.
- Gausson H., Legris, P., Viart, M. and Meher-Homji, V.M. 1968. Sheet Kathiawar; in *International map of vegetation and environmental conditions* (Indian Council of Agricultural Research, New Delhi and French Institute of Pondicherry, Puducherry), Series No 9.
- Gee, E.P. 1964. *The wildlife of India*. Collins, London, UK. 94 pp.
- Gehrt, S.D., Riley, S.P.D. and Cypher, B.L. (eds.) 2010. *Urban carnivores: ecology, conflict, and conservation*. JHU Press, Maryland, USA. 304 pp.
- Gibbs, J.P., Snell, H.L. and Causton, C.E. 1999. Effective monitoring for adaptive wildlife management: lessons from the Galapagos Islands. *The Journal of Wildlife Management*, 63: 1055–1065.
- Gilpin, M.E. and Soulé, M.E. 1986. Minimum viable populations: processes of species extinction, 19–34: In *Conservation Biology: the science of scarcity and diversity*, Soulé, M.E. (ed.), Sinauer, Sunderland, MA, USA.
- Ginsberg, J.R. 2001. Setting priorities for carnivore conservation: what makes carnivores different? 498-523: In *Carnivore Conservation*, Gittleman, J. L., Funk, S.M., Macdonald, D. and Wayne, R.K. (eds.), Cambridge University Press, Cambridge, UK.
- Ginsberg, J.R., and MacDonald, D.W. (eds.) 1990. *Foxes, wolves, jackals, and dogs: an action plan for the conservation of canids*. IUCN/SSC Canid Specialist Group, Gland, Switzerland.
- Gittleman, J.L. (ed) 1996. *Carnivore behaviour, ecology and evolution: Vol 2*. Ithaca: Cornell University Press.
- Gittleman, J.L. and Harvey, P.H. 1982. Carnivore home range size, metabolic needs and ecology. *Behavioral Ecology and Sociobiology*, 10: 57-63.
- Gittleman, J.L., Funk, S.M., Macdonald, D.W. and Wayne, R.K. 2001. Why 'carnivore conservation'? 1-8: In *Carnivore conservation*, Gittleman, J. L., Funk, S.M., Macdonald, D. and Wayne, R.K. (eds.), Cambridge University Press, Cambridge, UK.
- Goldman, M.J., De Pinho, J.R. and Perry, J. 2010. Maintaining complex relations with large cats: Maasai and lions in Kenya and Tanzania, *Human Dimensions of Wildlife*, 15: 332-346.
- Goodrich, J.M., Kerley, L.L., Smirnov, E.N., Miquelle, D.G., McDonald, L., Quigley, H.B., Hornocker, M.G. and McDonald, T. 2008. Survival rates and causes of mortality of Amur tigers on and near the Sikhote-Alin Biosphere Zapovednik. *Journal of Zoology*, 276: 323-329.



- Goodrich, J.M., Miquelle, D.G., Smirnov, E.N., Kerley, L.L., Quigley, H.B. and Hornocker, M.G. 2010. Spatial structure of Amur (Siberian) tigers (*Panthera tigris altaica*) on Sikhote-Alin Biosphere Zapovednik, Russia. *Journal of Mammalogy*, 91:737–748.
- Gopal, R., Qureshi, Q., Bharadwaj, M., Singh, R.K.J. and Jhala, Y.V. 2010. Evaluating the status of the endangered tiger *Panthera tigris* and its prey in Panna Tiger Reserve, Madhya Pradesh, India. *Oryx*, 44: 383–398.
- Gore, A.P., Paranjape, S.A., Rajgopalan G. Kharshikar, A.V., Joshi, N.V., Watve, M. and Gogate, M. 1993. Tiger census: role of quantification. *Current Science*, 64: 711–714.
- Gore, M.L., Nelson, M. P., Vucetich, J. A., Smith, A. M. and Clark, M. 2011. Exploring the ethical basis for conservation policy: the case of inbred wolves of Isle Royale. *Conservation Letters*, 4: 394-401.
- Government of Gujarat 1975. Junagadh District. Gazetteers of Gujarat. In Rajyagor, S.B. (ed.) Government of Gujarat, India, 848 pp.
- Government of Gujarat 2008. Forest and Environment Department, Sachivalaya, Gandhinagar, Notification Number GVN-2008(28) VPS-102007-2069-W (5071).
- Government of India 2011. Census of India 2011. Available at <http://censusindia.gov.in/> (Accessed in June 2012).
- Gratwicke, B., Mills, J., Dutton, A., Gabriel, G., Long, B., Seidensticker, J., Wright, B., You, W. and Zhang, L. 2008. Attitudes towards consumption and conservation of tigers in China. *PLoS ONE*, 3(7): e2544 doi:10.1371/journal.pone.0002544.
- Griffiths, D. 1980. Foraging costs and relative prey size. *The American Naturalist*, 116: 743-752.
- Grogan, R. G. and Lindzey, F.G. 1999. Estimating population size of a low-density black bear population using capture-resight. *Ursus*, 11: 117–122.
- Groom, M.J., Meffe, G.K. and Carroll, C.R. (eds.) 2005. *Principles of conservation biology*. 3<sup>rd</sup> edition, Sunderland, MA: Sinauer Associates, 699 pp.
- Gros, P.M., Kelly, M.J. and Caro, T.M. 1996. Estimating carnivore densities for conservation purposes: indirect methods compared to baseline demographic data. *Oikos*, 77: 197–206.
- Guggisberg, C.A.W. 1961. *Simba, the life of the lion*. Howard Timmins, Capetown, South Africa, 304 pp.
- Guindon, B., Zhang, Y. and Dillabaugh, C. 2004. Landsat urban mapping based on a combined spectral-spatial methodology. *Remote Sensing of Environment*, 92: 218-232.
- Guisan, A. and Zimmermann, N. E. 2000. Predictive habitat distribution models in ecology. *Ecological Modelling*, 135: 147-186.
- Gujarat Forest Department 2010. Distribution of Asiatic lions in Gir National Park, sanctuary and other areas in 13<sup>th</sup> Asiatic lion population estimate - 2010. <http://gujaratforest.gov.in/downloads/lion-censues-20-5-2010.pdf>. (Accessed 18 September, 2010).
- Gupta, S.K. 1972. Chronology of the raised beaches and inland coral reefs of the Saurashtra Coast. *Journal of Geology*, 80: 357–361.



- Gustafson, E.J. and Parker, G.R. 1992. Relationships between landcover proportion and indices of landscape spatial pattern. *Landscape Ecology*, 7: 101–110.
- Haddad, N.M. and Baum, K.A. 1999. An experimental test of corridor effects on butterfly densities. *Ecological Applications*, 9: 623-633.
- Halfpenny, J.C., Sanders, M.A. and McGrath, K.A. 1991. Human-lion interactions in Boulder County, Colorado: past, present and future, 10-16: In *Mountain lion-human interaction symposium and workshop*, Braun, C.E. (ed.), Colorado Divisions of Wildlife, Denver, USA.
- Hanby J.P., Bygott J.D. and Packer, C. 1995. Ecology, demography and behaviour of lions in two contrasting habitats: Ngorongoro Crater and the Serengeti plains and their social systems, 315-331: In *Serengeti II: dynamics, management and conservation of an ecosystem*, Sinclair, A.R.E. and Arcese, P. (eds.), University of Chicago Press, Chicago, USA.
- Hanby, J.P. and Bygott, J.D. 1987. Emigration of sub-adult lions. *Animal Behavior*, 35: 161-169.
- Hanski, I. 1994. A practical model of metapopulation dynamics. *Journal of Animal Ecology*, 63: 151-162.
- Hanski, I.A. and Gilpin, M.E. 1997. *Metapopulation biology: ecology, genetics and evolution*. Academic Press, San Diego, CA, USA, 512 pp.
- Hansteen, T.L., Andreassen, H.P. and Ims, R.A. 1997. Effects of spatiotemporal scale on autocorrelation and home range parameters. *The Journal of Wildlife Management*, 61: 280-290.
- Harmsen, B.J., Foster, R.J. and Doncaster, C.P. 2010. Heterogeneous capture rates in low density populations and consequences for capture recapture analysis of camera-trap data. *Population Ecology*, 53: 253–259.
- Harris, S., Cresswell, W.J., Forde, P.G., Trehwella, W.J., Wollard, T. and Wray, S. 1990. Home-range analysis using radio-telemetry data: A review of problems and techniques particularly as applied to the study of mammals. *Mammal Review*, 20: 97–123.
- Harrison, S., Murphy, D.D. and Ehrlich, P.R. 1988. Distribution of the bay checkerspot butterfly, *Euphydryas editha bayensis*: evidence or a metapopulation model. *The American Naturalist*, 132: 360–382.
- Harvey, C.A., Gonzalez, J. and Somarriba, E. 2006. Dung beetle and terrestrial mammal diversity in forests, indigenous agroforestry systems and plantain monocultures in Talamanca, Costa Rica. *Biodiversity and Conservation*, 15: 555-585.
- Hayward, M.W. and Hayward, G.J. 2007. Activity patterns of reintroduced lion *Panthera leo* and spotted hyena *Crocuta crocuta* in the Addo Elephant National Park, South Africa. *African Journal of Ecology*, 45: 135-141.
- Hayward, M.W. and Kerley, G.I.H. 2005. Prey preferences of the lion (*Panthera leo*). *Journal of Zoology*, 267: 309–322.
- Hayward, M.W., Adendorff, J., O'Brien, J., Sholto-Douglas, A., Bissett, C., Moolman, L.C., Bean, P., Fogarty, A., Howarth, D., Slater, R. and Kerley, G.I.H. 2007b. Practical considerations for the reintroduction of large, terrestrial, mammalian predators based on reintroductions to South Africa's Eastern Cape Province. *The Open Conservation Biology Journal*, 1: 1-11.



- Hayward, M.W., de Tores, P.J., Augee, M.L. and Banks, P.B. 2005. Mortality and survivorship of the quokka (*Setonix brachyurus*) (Macropodidae: Marsupialia) in the northern Jarrah forest of Western Australia. *Wildlife Research*, 32: 715-722.
- Hayward, M.W., O'Brien, J. and Kerley, G.I.H. 2007a. Carrying capacity of large African predators: predictions and tests. *Biological Conservation*, 139: 219–229.
- Hazzah, L., Mulder, M.B. and Frank, L. 2009. Lions and warriors: social factors underlying declining African lion populations and the effect of incentive-based management in Kenya. *Biological Conservation*, 142: 2428-2437.
- Heisey, D.M. and Fuller, T.K. 1985. Evaluation of survival and cause specific mortality rates using telemetry data. *The Journal of Wildlife Management*, 49: 668 – 674.
- Hemson, G. 2003. The ecology and conservation of lions: human-wildlife conflict in semi-arid Botswana. Ph.D. Thesis, University of Oxford, UK, 213 pp.
- Hemson, G., Johnson, P., South, A., Kenward, R., Ripley, R. and Macdonald, D. 2005. Are kernels the mustard? Data from global positioning systems (GPS) collars suggests problems for kernel home-range analyses with least-squares cross-validation. *Journal of Animal Ecology*, 74: 455–463.
- Henschel, P., Coad, L., Burton, C., Chataigner, B., Dunn, A., MacDonald, D., Saidu, Y. and Hunter, L.T.B. 2014. The lion in West Africa is critically endangered. *PLoS ONE*, 9(1): e83500.
- Hill, M.O. 1979. TWINSpan- a Fortran programme for arranging multivariate data in an ordered two-way table by classification of the individuals and the attributes. Cornell University, Ithaca, New York, 48 pp.
- Hines, J.E. and Link, W.A. 1994. SCATMAN, USGS-Patuxant Wildlife Research Center, Patuxant, Maryland, USA. Available at <http://www.mbr-pwrc.usgs.gov/software.html/>. (Accessed November 10 2012).
- Hirzel, A.H., Hausser, J. and Perrin, N. 2006. Biomapper 3.2. Lab for Conservation Biology. University of Lausanne, Lausanne, Switzerland. <http://www.unil.ch/biomapper/> (accessed March 2014).
- Hirzel, A.H., Hausser, J., Chessel, D. and Perrin, N. 2002. Ecological-niche factor analysis: How to compute habitat suitability maps without absence data? *Ecology*, 83: 2027 - 2036.
- Hirzel, A.H., Helfer, V. and Metral, F. 2001. Assessing habitat-suitability models with a virtual species. *Ecological Modelling*, 145: 111-121.
- Hobbs, R.J. 1990. Remote sensing of spatial and temporal dynamics of vegetation, 203-219: In *Remote sensing of biosphere functioning (ecological studies vol. 79)*, Hobbs, R.J. and Mooney, H.A., (eds.), Springer-Verlag, New York, USA.
- Hodd, K.T.B. 1970. The ecological impact of domestic stocks on the Gir forest, 259-265: In eleventh technical meeting. IUCN publications new series No. 17, Elliot, H.F.I. (ed.), IUCN, Morges, Switzerland.
- Homewood, K., Patti, K. Pippa, T. (eds.) 2009. *Staying Maasai: livelihoods, conservation and development in East African rangelands*. Springer; New York. 418 pp.



- Hornocker, M. 1970. An analysis of mountain lion predation upon mule deer and elk in Idaho primitive area. *Wildlife Monographs*, 21: 3-39.
- Houser, A.M., Somers, M.J. and Boast, L.K. 2009. Spoor density as a measure of true density of a known population of free-ranging wild cheetah in Botswana. *Journal of Zoology*, 278: 108–115.
- Hunter, L.T.B. 1998. The behavioural ecology of reintroduced lions and cheetahs in the Phinda Resource Reserve, Kwazulu-Natal, South Africa. Ph.D. thesis, University of Pretoria, South Africa, 222 pp.
- IGBP 1993. Relating land use and global land cover change. IGBP Report 24, IHDP Report 5 (Stockholm: International Geosphere-Biosphere Programme).
- IGBP/IHDP 1995. Land use and land cover change science research plan. IGBP Report 35, IHDP Report 7 (Stockholm: International Geosphere-Biosphere Programme), 132 pp.
- IIASA, 1998. Modeling land-use and land cover changes in Europe and Northern Asia, 1999 Research Plan (Laxenburg: IIASA).
- Ikanda, D. and Packer, C. 2008. Ritual vs. retaliatory killing of African lions in the Ngorongoro Conservation Area, Tanzania. *Endangered Species Research*, 6: 67-74.
- Inskip, C. and Zimmerman, A. 2009. Human-felid conflict: a review of patterns and priorities worldwide. *Oryx*, 43: 18–34.
- Jacob, J. 1974. Quantitative measurement of food selection. *Oecologia* 14: 413–417.
- Jacques, C.N., Jenks, J.A. and Klaver, R.W. 2009 Seasonal movements and home-range use by female pronghorns in sagebrush-steppe communities of western South Dakota. *Journal of Mammalogy*, 90: 433–441.
- Jarman, P.J. 1974. The social organization of antelope in relation to their ecology. *Behaviour*, 48: 215-267.
- Jepson, S. 1937. Big game encounters. Critical moments in the lives of well-known shikaris. H.F. and G. Witherby Ltd. London, UK, 196 pp.
- Jethva, B. and Jhala, Y.V. 2003. Sample size considerations for food habit studies of wolves from scats. *Mammalia*, 68: 589-591.
- Jethva, B.D. and Jhala, Y.V. 2004. Foraging ecology, economics and conservation of Indian wolves in the Bhal region of Gujarat, western India. *Biological Conservation*, 116: 351-357.
- Jhala, Y.V., Chellam, R., Pathak, B., Qureshi, Q., Meena, V., Chauhan, K., Dave, C., Banerjee, K. and Basu, P. 2012b. Ecology of lion in the agro-pastoral greater Gir landscape—phase I. Technical Report, Wildlife Institute of India, Dehra Dun, India, TR-2012/004, xiv + 382 pp.
- Jhala, Y.V. (ed.) 2004. Monitoring of Gir. A technical consultancy report submitted to the Gujarat Forest Department under the GEF – India eco development Program, Wildlife Institute of India, Dehra Dun, India, RR-04/002, 157 pp.
- Jhala, Y.V. and Sharma, D.K. 1997. Child lifting by wolves in eastern Uttar Pradesh, India. *Journal of Wildlife Research*, 2: 94-101.



- Jhala, Y.V., Chellam, R., Pathak, B., Qureshi, Q., Meena, V., Chauhan, K., Dave, C., Banerjee, K. and Basu, P. 2011a. Ecology of lions in Greater Gir landscape. A technical report (TR-2011/001), Wildlife Institute of India, Dehra Dun, 439 pp.
- Jhala, Y.V., Chellam, R., Qureshi, Q., Pathak, B., Meena, V., Dave, C., Chauhan, K.S. and Banerjee, K. 2006. Social organization and dispersal of Asiatic lions and ecological monitoring of Gir. Technical Report. Wildlife Institute of India, Dehradun, India, pp 100.
- Jhala, Y.V., Gopal, R. and Qureshi, Q. 2008. Status of tigers, co-predators and prey in India. National Tiger Conservation Authority and Wildlife Institute of India, Dehradun, India, TR 08/001, 164 pp. Available: [http://www.wii.gov.in/publications/statusof\\_tigers2008.pdf](http://www.wii.gov.in/publications/statusof_tigers2008.pdf) .
- Jhala, Y.V., Mukherjee, S., Shah, N., Chauhan, K.S., Dave, C and Zala, Y.P. 2004. Monitoring lions, 55-71: In Monitoring of Gir, Jhala, Y.V. (ed.), Technical Report, Wildlife Institute of India, Dehra Dun, India, RR -04/002.
- Jhala, Y.V., Mukherjee, S., Shah, N., Chauhan, K.S., Dave, C.V., Meena, V. and Banerjee, K. 2009. Home range and habitat preference of female lions (*Panthera leo persica*) in Gir forests, India. *Biodiversity and Conservation*, 18: 3383–3394.
- Jhala, Y.V., Qureshi, Q. and Basu, A. 2012c. A report population and density estimation of leopards in Girnar Wildlife Sanctuary, Gujarat, 2012. A technical report of Wildlife Institute of India submitted to Gujarat Forest Department, 25 pp.
- Jhala, Y.V., Qureshi, Q. and Gopal, R. 2011b. Can the abundance of tigers be assessed from their signs? *Journal of Applied Ecology*, 48: 14-24.
- Jhala, Y.V., Qureshi, Q., Basu, P. and Banerjee, K. 2012a. Assessment of the landscape between the Gir Protected Area and the Girnar Wildlife Sanctuary, Gujarat, for a potential lion habitat corridor. A Technical Publication of the Wildlife Institute of India, Dehra Dun submitted to the Gujarat Forest Department, TR – 2012/002, xiii + 88 pp.
- Jhala, Y.V., Qureshi, Q., Bhuvra, V. and Sharma, L.N. 1999. Population estimation of Asiatic lions. *Journal of the Bombay Natural History Society*, 96: 3-15.
- Jhala, Y.V., Qureshi, Q., Gopal, R. and Sinha, P.R. (Eds.). 2011c. Status of the tigers, co-predators, and prey in India. National Tiger Conservation Authority, Govt. of India, New Delhi, and Wildlife Institute of India, Dehradun. TR 2011/003 pp-302.
- Johnsingh, A.J.T. 1983. Large mammalian prey-predators in Bandipur. *Journal of the Bombay Natural History Society*, 80: 1-57.
- Johnsingh, A.J.T., Chellam, R. and Sharma, D. 1998. Prospects for conservation of Asiatic lions in India. *Biosphere Conservation*, 1: 81-89.
- Johnson, D. H. 1980. The comparison of usage and availability measurements for evaluating resource preference *Ecology*, 61: 65 -71.
- Johnson, D.D.P., Kays, R., Blackwell, P.G. and Macdonald, D.W. 2002. Does the resource dispersion hypothesis explain group living? *Trends in Ecology and Evolution*, 17: 563-570.
- Johnston, R.F. 2001. Synanthropic birds of North America, 49–67: In *Avian ecology and conservation in an urbanizing world*, Marzluff, J.M., Bowman, R. and Donnelly, R. (eds.), Kluwer, Boston, Massachusetts, USA.



- Jolliffe, I.T. 2002. Principal component analysis. Second edition. Springer, New York, USA, pp 487.
- Joshi, R.R. and Karamchandani, K.P. 1976. Working plan for Gir forests, Volume I and II. Gujarat Forest Department, India, xvii+153 pp.
- Joslin, P. 1973. The Asiatic lion: a study of ecology and behavior. PhD thesis, Department of Forestry and Natural Resources, University of Edinburgh, UK, 249 pp.
- Jung, M., Churkina, G. and Henkel, K. 2006. Exploiting synergies of global land cover products for carbon cycle modeling. *Remote Sensing of Environment*, 101: 534-553.
- Kaczensky, P. 1999. Large carnivore predation on livestock in Europe. *Ursus*, 11: 59–72.
- Kaczensky, P. 2003. Is coexistence possible? Public opinion of large carnivores in the Alps and Dinaric Mountains, 59-89: In *Living with bears: a large carnivore in a shrinking world*, Krystufek, B., Flajsman, B. and Griffiths, H.I. (eds.), Ecological Forum of the Liberal Democracy of Slovenia, Ljubljana, Slovenia.
- Karant, K.K. and DeFries, R. 2010. Conservation and management in human-dominated landscapes: case studies from India. *Biological Conservation*, 143: 2865-2869.
- Karant, K.U. 1995. Estimating tiger *Panthera tigris* populations from camera-trap data using capture recapture models. *Biological Conservation*, 71: 333-338.
- Karant, K.U. 2003. Tiger ecology and conservation in the Indian subcontinent. *Journal of the Bombay Natural History Society*, 100: 169-189.
- Karant, K.U. and Chellam, R. 2009. Carnivore conservation at the crossroads. *Oryx*, 43: 1-2.
- Karant, K.U. and Gopal, R. 2005. An ecology-based policy framework for human-tiger coexistence in India, 373-387: In *People and wildlife: conflict or coexistence?* Woodroffe, R., Thirgood, S. and Rabinowitz, A. (eds.), Cambridge University Press, UK.
- Karant, K.U. and Nichols, J.D. 1998. Estimating tiger densities in India from camera trap data using photographic captures and recaptures. *Ecology*, 79: 2852–2862.
- Karant, K.U. and Sunquist, M.E. 1995. Prey selection by tiger, leopard and dhole in tropical forests. *Journal of Animal Ecology*, 64: 439-450.
- Karant, K.U., Kumar, N.S. and Nichols, J.D. 2002. Field surveys: estimating absolute densities of tigers using capture-recapture sampling, 139-152: In *Monitoring tigers and their prey: a manual for researchers, managers and conservationists in tropical Asia*, Karant, K.U and Nichols, J.D. (eds.), Centre for Wildlife Studies, Bangalore, India.
- Karant, K.U., Nichols, J.D., Kumar, N.S., Link, W.A. and Hines, J.E. 2004. Tigers and their prey: predicting carnivore densities from prey abundance. *Proceedings of the National Academy of Sciences*, 101: 4854-4858.
- Karant, K.U., Nichols, J.D., Seidensticker, J., Dinerstein, E., Smith, J.L.D., McDougal, C., Johnsingh, A.J.T., Chundawat, R.S. and Thapar, V. 2003. Science deficiency in conservation practice: The monitoring of tiger populations in India. *Animal Conservation*, 6: 141-146.
- Karesh, W. B. 1995. Wildlife rehabilitation: additional considerations for developing countries. *Journal of Zoo and Wildlife Medicine*, 26: 2-9.



- Keane, B., Creel, S.R. and Waser, P.M. 1996. No evidence of inbreeding avoidance or inbreeding depression in a social carnivore. *Behavioral Ecology*, 7: 480-489.
- Kearney, M. 2006. Habitat, environment and niche: what are we modelling? *Oikos*, 115: 186-191.
- Keiter, R.B. and Boyce, M.S. (eds.) 1991. *The Greater Yellowstone Ecosystem: redefining America's wilderness heritage*. Yale University Press, New Haven, USA, xix + 428 pp.
- Keith, L.B. 1974. Some features of population dynamics in mammals. *Proceedings of International Game Congress*, 11: 17-58.
- Keller, L.K. and Waller, D.M. 2002. Inbreeding effects in wild populations. *Trends in Ecology and Evolution*, 17: 230-241.
- Kellert, S.R. 1985. The public and the timber wolf in Minnesota. *Transactions of the North American Wildlife and Natural Resources Conference*, 51: 193-200.
- Kellert, S.R. 1996. *The value of life. Biological diversity and human society*. Washington, D.C.: Island Press, 280 pp.
- Kellert, S.R., Black, M., Rush, C.R. and Bath, A.J. 1996. Human culture and large carnivore conservation in North America. *Conservation Biology*, 10: 977-990.
- Kelly, M.J., Laurenson, M.K., FitzGibbon, C.D., Collins, D.A., Durant, S.M., Frame, G.W., Bertram, B.C.R. and Caro, T.M. 1998. Demography of the Serengeti cheetah (*Acinonyx jubatus*) population: the first 25 years. *Journal of Zoology*, 244: 473-488.
- Kelly, M.J., Noss, A.J. Di Bitetti, M.S., Maffei, L., Arispe, R.L., Paviolo, A., De Angelo, C.D. and Di Blanco, Y.E. 2008. Estimating puma densities from camera trapping across three study sites: Bolivia, Argentina, and Belize. *Journal of Mammalogy*, 89: 408-418.
- Kendall, W.L. 1999. Robustness of closed capture-recapture methods to violations of closure assumption. *Ecology*, 80: 2517-2525.
- Kenward, R.E. 1992. Quantity versus quality: programmed collection and analysis of radio-tracking data, 231-246: In *Wildlife telemetry remote monitoring and tracking of animals*, Priede, I.G. and Swift, S.M. (eds.), Ellis Horwood Ltd., New York, USA.
- Kenward, R.E., Clarke, R.T., Hodder, K.T. and Walls, S.S. 2001. Density and linkage estimators of home range: nearest-neighbor clustering defines multinuclear cores. *Ecology*, 82: 1905-1920.
- Kernohan, B.J., Gitzen, R.A. and Millspaugh, J.J. 2001. Analysis of animal space use and movements, 125-166: In *Radio tracking and animal populations*, Millspaugh, J.J. and Marzluff, J.M. (eds.), Academic Press, London, UK.
- Kernohan, B.J., Millspaugh, J.J., Jenks, J.A. and Naugle, D.E. 1998. Use of an adaptive kernel home-range estimator in a GIS environment to calculate habitat use. *Journal of Environmental Management*, 53: 83-89.
- Khan, J.A. 1993. Ungulate-habitat relationships in Gir forest ecosystem and its management implications. Ph.D. thesis, Aligarh Muslim University, India, 277 pp.
- Khan, J.A., Chellam, R., Rodgers, W.A. and Johnsingh, A.J.T. 1996. Ungulate density and biomass in the tropical dry deciduous forests of Gir, Gujarat, India. *Journal of Tropical Ecology*, 12: 149-162.



- Khan, J.A., Rodgers, W.A., Johnsingh, A.J.T. and Mathur, P.K. 1990. Gir lion project: ungulate habitat ecology in Gir. Unpublished project completion report of the Wildlife Institute of India, Dehradun.
- Kie, J.G., Matthiopoulos J., Fieberg J., Powell R.A., Cagnacci F., Mitchell M.S., Gaillard J.M. and Moorcroft P.R. 2010. The home-range concept: are traditional estimators still relevant with modern telemetry technology? *Philosophical Transactions of the Royal Society B*, 365: 2221-2231.
- Kie, J.G. and Boroski, B.B. 1996. Cattle distribution, habitats, and diets in the Sierra Nevada of California. *Journal of Range Management*, 49: 482-488.
- Kie, J.G., Bowyer, R.T., Boroski, B.B., Nicholson, M.C. and Loft, E.R. 2002. Landscape heterogeneity at differing scales: effects on spatial distribution of mule deer. *Ecology*, 83: 530-544.
- Kienast, F. 1993. Analysis of historic landscape patterns with a Geographic Information System – a methodological outline. *Landscape Ecology*, 8: 103-118.
- Kingdon, J. 1997. *The Kingdon field guide to African mammals*, Academic Press, London, 450 pp.
- Kinnear, N.B. 1920. The past and present distribution of the lion in south eastern Asia. *Journal of the Bombay Natural History Society*, 27: 34-39.
- Kiss, A. 1990. *Living with wildlife: wildlife resource management with local participation in Africa*. World Bank Technical Paper 130, World Bank, Washington DC, USA.
- Kissui, B.M. 2008. Livestock predation by lions, leopards, spotted hyenas, and their vulnerability to retaliatory killing in the Maasai steppe, Tanzania. *Animal Conservation*, 11: 422-432.
- Kissui, B.M. and Packer, C. 2004. Top-down population regulation of a top predator: lions in the Ngorongoro crater. *Proceedings of the Royal Society London – B*, 207: 1867-1874.
- Knowlton, F.F. and Tzilkowski, W.M. 1979. Trends on bobcat visitations to scent-station survey lines in western United States, 8-12: In *Proceedings of bobcat research conference: current research on biology and management of Lynx rufus*.
- Kohlmann, S.G., Schmidt, G.A. and Garcelon, D.K. 2005. A population viability analysis for the Island Fox on Santa Catalina Island, California. *Ecological Modelling* 183: 77-94.
- Koppen, J.M. 1931. *Grundriss der Klimakunde*. Walter de Grayter, Berlin, Germany, 388 pp.
- Korschgen, L.K. 1980. Procedures for food habit analysis, 113-128: In *Wildlife management techniques manual*, Schemnitz, S.D. (ed.), The Wildlife Society, Washington DC, USA.
- Kothari, A., Pande, P., Singh, S. and Variava, D. 1989. *Management of national parks and sanctuaries in India: a status report*. Indian Institute of Public Administration, New Delhi, India, 298 pp.
- Kothari, A., Suri, S. and Singh, N. 1995. People and Protected Areas: rethinking conservation in India. *Ecologist*, 25: 188-194.
- Kozakiewicz, M. 1993. Habitat isolation and ecological barriers – the effect on small mammal populations and communities. *Acta Theriologica*, 38: 1-30.
- Krebs, C.J. 1989. *Ecological Methodology*. Harper and Row, New York, USA. 654 p.



- Krebs, C.J. 1994. Ecology: The experimental analysis of distribution and abundance. Addison-Wesley Publishers, 620 pp.
- Kreeger, T.K. 1996. Handbook of chemical immobilisation. International wildlife veterinary services Inc. Post Box 37, Laramie, WY, USA, 356 pp.
- Kruuk, H. 1972. The spotted hyena: a study of predation and social behaviour. The University of Chicago Press, Chicago, 335 pp.
- Kruuk, H. 2002. Hunter and hunted: relationships between carnivores and people. Cambridge University Press, Cambridge, UK, xii + 246 pp.
- Kumar, A., Pethiyagoda, R. and Mudappa, D. 2004. Western Ghats and Sri Lanka, 152-157: In Hotspots revisited – earth's biologically richest and most endangered ecoregions, Mittermeier, R. A. et al. (eds.), CEMEX, Mexico.
- Kuninori, O. 1999. Land use for global environmental conservation (LU/GEC). Final report of the LU-GEC first phase (1995-1997) (Environmental Agency of Japan: National Institute for Environmental Studies).
- Lack, D. 1933. Habitat selection in birds. With special reference to the effects of afforestation on the Breckland avifauna. The Journal of Animal Ecology, 2: 239-262.
- Lacy, R.C. 1993. Vortex: a computer simulation model for population viability analysis. Wildlife Research, 20: 45-65.
- Lacy, R.C., Borbat, M. and Pollak, J.P. 2009. Vortex: A stochastic simulation of the extinction process. Version 9.99. Chicago Zoological Society, Brookfield, Illinois, USA.
- Lair, H. 1987. Estimating the location of the focal center in red squirrel home ranges. Ecology, 68: 1092-1101.
- Lal, B. 2000. Greater Gir ecosystem – eco-restoration of Girnar forest & recapture of lost territory by *Panthera leo persica* (Asiatic lion). 297-316: In Forest restoration for wildlife conservation, Elliot, S., Kerby, J., Blakesley, D., Hardwick, K., Woods, K. and Anusarnsunthorn, V. (eds.), International Tropical Timber Organization and The Forest Restoration Research Unit, Chiang Mai University, Thailand.
- Lancia, R.A. Nichols, J.D. and Pollock, K.H. 1996. Estimating the number of animals in wildlife population, 215-253: In Research and management techniques for wildlife and habitats, Bookhout, T.A. (ed.), 5<sup>th</sup> edition. The Wildlife Society, Bethesda, MD.
- Landis, J.R. and Koch, G.G. 1977. The measurement of observer agreement for categorical data. Biometrics, 33: 159-174.
- Laurance, W.F. and Bierregaard, R.O.J. (eds.) 1997. Tropical forest remnants: ecology, management and conservation of fragmented communities. University of Chicago Press, Chicago, Illinois, 632 pp.
- Lauver, C.L. and Whistler, J.L. 1993. A hierarchical classification of Landsat TM Imagery to identify natural grassland areas and rare species habitat. Photogrammetric Engineering and Remote Sensing, 59: 627-634.
- Laver, P.N. and Kelly, M.J. 2008. A critical review of home range studies. The Journal of Wildlife Management, 72: 290-298.



- Leban, F. 1999. Resource selection software for Windows. Available at [http://members.xoom.com/fred\\_leban/reselect.html](http://members.xoom.com/fred_leban/reselect.html). Accessed in February 2012.
- Ledoux, L., Crooks, S., Jordan, A. and Turner, K. 2000. Implementing EU biodiversity policy UK experiences. *Land Use Policy*, 17: 257-268.
- Lehmann, M.B., Funston, P.J., Owen, C.R. and Slotow, R. 2008. Home range utilization and territorial behavior of lions (*Panthera leo*) on Karongwe Game Reserve, South Africa. *PLoS ONE*, 3(12): e3998.
- Lenin, J. 2011. Gir lion project: a rare conservation success story. Firstpost, December 2011. Available at [www.firstpost.com/india/gir-lion-project-a-rare-glimpse-into-a-conservation-success-story-153147.html](http://www.firstpost.com/india/gir-lion-project-a-rare-glimpse-into-a-conservation-success-story-153147.html). Accessed 20 July, 2012.
- Leroy, E.M., Rouquet, P., Formenty, P., Souquie`re, S., Kilbourne, A., Froment, J-M., Bermejo, M., Smit, S., Karesh, W., Swanepoel, R., Zaki, S.R. and Rollin, P.E. 2004. Multiple Ebola virus transmission events and rapid decline of Central African wildlife. *Science*, 303: 387-390.
- Levin, S.A. 1992. The problem of pattern and scale in ecology. *Ecology*, 73: 1943-1967.
- Levins, S.A. 1976. Spatial patterning and the structure of ecological communities. *Lecture on Mathematics in the Life Science*, 81: 1-35.
- Linkie, M., Chapron, G., Martyr, D.J., Holden, J. and Leader-Williams, N. 2006. Assessing the viability of tiger populations in a fragmented landscape. *Journal of Applied Ecology*, 43: 576–586.
- Linkie, M., Dinata, Y., Nofrianto, A. and Leader-Williams, N. 2007. Patterns and perceptions of wildlife crop raiding in and around Kerinci Seblat National Park, Sumatra. *Animal Conservation*, 10: 127–135.
- Linklater, W.L. 2003. Science and management in a conservation crisis: a case study with rhinoceros. *Conservation Biology*, 17: 968–975.
- Linnell, J.D.C., Swenson, J.E. and Andersen, R. 2001. Predators and people: conservation of large carnivores is possible at high human densities if management policy is favourable. *Animal Conservation*, 4: 345-349.
- Lockie, J.D. 1959. The estimation of the food of foxes. *The Journal of Wildlife Management*, 23: 224-227.
- Lockwood, M., Worboys, G.L. and Kothari, A. 2006. *Managing protected areas: a global guide*. Earthscan Publications Ltd., Oxford, UK, 802 pp.
- Loveridge, A.J. 2002. Dimension of the problem. 3. Synthesis, 24-29: In *Lion conservation research, workshop 2: modelling conflict*, Loveridge, A.J., Lynam, T. and Macdonald, D.W. (eds.), Wildlife Conservation Research Unit (WildCRU), Oxford, UK.
- Loveridge, A.J. and Macdonald, D.W. 2002. Habitat ecology of two sympatric species of jackals in Zimbabwe. *Journal of Mammalogy*, 83: 599-607.
- Loveridge, A.J., Hemson, G., Davidson, Z. and Macdonald, M. 2010. African lions on the edge: reserve boundaries as 'attractive sinks', 283-304: In *Biology and conservation of wild felids*, Macdonald, D. and Loveridge, A.J. (eds.), Oxford University Press, London, UK.



- Loveridge, A.J., Lynam, T. and Macdonald, D.W. 2001. Lion conservation research - workshop 1: survey techniques. Wildlife Conservation Research Unit, Oxford, UK.
- Loveridge, A.J., Searle, A.W., Murindagomo, F. and Macdonald, D.W. 2007. The impact of sport-hunting on the population dynamics of an African lion population in a protected area. *Biological Conservation*, 134: 548 – 558.
- Lusambo, L.P., Monela, G.C., Katani, J. and Mombo, F. 2007. Socio-economic analysis of land use factors causing degradation and deforestation Of Miombo woodlands in Kilosa district, Tanzania. *Tanzanian Journal of Forestry and Nature Conservation*, 76: 28-39.
- Lydekker, R. 1916. *Wildlife of the world*. Vol.II. Rowland Ward Ltd., London, U.K, 439 pp.
- Lyons, A.L., Gaines, W.L. and Servheen, C. 2003. Black bear resource selection in the northeast Cascades, Washington. *Biological Conservation*, 113: 55–62.
- Macdonald, D.W. 1983. The ecology of carnivore social behavior. *Nature*, 301: 379-384.
- Macdonald, D.W. 2010. *The encyclopedia of mammals*. Oxford University Press, UK, 936 pp.
- Macdonald, D.W. and Sillero-Zubiri, C. 2002. Large carnivores and conflict: lion conservation in context, 1-8: In *Lion conservation research. Workshop 2: modelling conflict*, Loveridge, A.J., Lynam, T. and Macdonald, D.W. (eds.), Wildlife Conservation Research Unit, Oxford, UK.
- MacLennan, S.M., Groom, R.J., Macdonald, D.W. and Frank, L.G. 2009. Evaluation of a compensation scheme to bring about pastoralist tolerance of lions. *Biological Conservation*, 142: 2419-2427.
- Madhusudan, M.D. and Mishra, C. 2003. Why big, fierce animals are threatened: conserving large mammals in densely populated landscapes, 31-55: In *Battles over nature: science and politics of conservation*, Saberwal, V. and Rangarajan, M. (eds.), Permanent Black, New Delhi, India.
- Malila, W.A. 1980. Change vector analysis: An approach for detecting forest changes with Landsat. 326-336: In *Proceedings of the IARS machine processing of remotely sensed data symposium*, West Lafayette, Indiana.
- Manly, B.F.J., McDonald, L.L., Thomas, D.L., McDonald, T.L. and Erickson, W.P. 2002. *Resource selection by animals: Statistical design and analysis for field studies*, 2nd edition, Kluwer Academic Publishers, Dordrecht, xiii + 221 pp.
- Mann, H.S. and Shankarnarayan, K.A. 1980. The role of *Prosopis cineraria* in an agropastoral system in Western Rajasthan, 437-442: In *Browse in Africa*, LeHouerou, H.N. (ed.), International Livestock Centre for Africa, Addis Ababa, Ethiopia.
- Marcelli, M. and Fusillo, R. 2009. Assessing range re-expansion and recolonization of human-impacted landscapes by threatened species: a case study of the otter (*Lutra lutra*) in Italy. *Biodiversity and Conservation*, 18: 2941–2959.
- Mardia, K.V. and Jupp, P. 2000. *Directional statistics*. 2nd edition, Wiley, Michigan, USA, 350 pp.
- Marker, L.L., Dickman, A.J., Mills, M.G.L., Jeo, R.M. and Macdonald, D.W. 2008. Spatial ecology of cheetahs (*Acinonyx jubatus*) on north central Namibian farmlands. *Journal of Zoology*, 274: 226-238.
- Matson, P.A., Parton, W.J., Power, A.G. and Swift, M.J. 1997. Agricultural intensification and ecosystem properties. *Science*, 277: 504-509.



- McCabe, J.T., Leslie, P.W. and DeLuca, L. 2010. Adopting cultivation to remain pastoralists: the diversification of Maasai livelihoods in northern Tanzania. *Human Ecology*, 38: 321-334.
- McClennen, N., Wigglesworth, R.R. and Anderson, S.H. 2001. The effect of suburban and agricultural development on the activity patterns of coyotes (*Canis latrans*). *American Midland Naturalist*, 146: 27-36.
- McCullagh, P. and Nelder, J.A. 1989. *Generalized linear models*, 2<sup>nd</sup> edition. Chapman and Hall, London, UK, 511 pp.
- McCune, B. and Grace, J.B. 2002. *Analysis of ecological communities*. MjM Software, Gleneden Beach, Oregon, USA ([www.pcord.com](http://www.pcord.com)), 304 pp.
- McGarigal, K. and Marks, B.J. 1995. FRAGSTATS: spatial pattern analysis program for quantifying landscape structure. General Technical Report PNW-GTR-351, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, 122 pp.
- McKinney, M.L. 1997. Extinction vulnerability and selectivity: combining ecological and paleontological views. *Annual Review of Ecology and Systematics*, 28: 495-516.
- McNeely, J.A., Miller, K.R., Ried, W.V., Mittermeier, R.A. and Werner, T.B. 1990. *Conserving the world's biological diversity*. Gland and Washington DC, IUCN - The World Conservation Union, World Resources Institute, Conservation International, World Wildlife Fund-US and World Bank.
- Mech, L.D. 1970. *The wolf: the ecology and behavior of an endangered species*. University of Minnesota Press, Minneapolis, MN, USA, 389 pp.
- Mech, D.L. 1991. Returning the wolf to Yellowstone, 309-322: In *The Greater Yellowstone ecosystem: redefining America's wilderness heritage*, Keiter, R.B. and Boyce, M.S. (eds.), Yale University Press, New Haven, Connecticut, USA.
- Meena, R.L. and Kumar, S. 2012. *Management plan for Gir Protected Areas, volume 1*. Gujarat Forest Department, Gujarat, India, 290 pp.
- Meena, V. 2008. *Reproductive strategy and behaviour of male Asiatic lions*. Ph.D. thesis, Forest Research Institute University, Dehra Dun, India, 179 pp.
- Meena, V., Jhala, Y.V., Chellam, R. and Pathak, B. 2011. Implications of diet composition of Asiatic lions for their conservation. *Journal of Zoology*, 284: 60-67.
- Meentemeyer, V. and Box, E.O. 1987. Scale effects in landscape studies, 15-34: In *Landscape heterogeneity and disturbance*, Turner M.G. (ed.), Springer-Verlag, New York, USA.
- Mehta, S.C., Bhardwaj, B. and Sahani, M.S. 2007. Status and conservation of Mewari and Jaisalmeri camels in India. *Animal Genetic Resources Information*, 40:87-101.
- Menon, V. and Daniel, J.C. 2003. *A field guide to Indian mammals*. Penguin Book, New Delhi, India, 200 pp.
- Michel, A.L., Bengis, R.G., Keet, D.F., Hofmeyr, M., Klerk, L.M.D., Cross, P.C., Jolles, A.E., Cooper, D., Whyte, I.J., Buss, P. and Godfroid, J. 2006. Wildlife tuberculosis in South African conservation areas: implications and challenges. *Veterinary Microbiology*, 112: 91-100.
- Millennium Ecosystem Assessment 2005. *Ecosystems and human well-being, synthesis*. Island Press, Washington DC, 155 pp.



- Mills, M.G.L. and Biggs, H.C. 1993. Prey apportionment and related ecological relationships between large carnivores in Kruger National Park. *Symposia of the Zoological Society of London*, 65: 253-268.
- Mills, M.G.L. and Hofer, H. 1998. Hyenas: status survey and conservation action plan. World Conservation Union, Gland, Switzerland, vi + 154 pp.
- Mills, M.G.L., Juritz, J.M. and Zucchini, W. 2001. Estimating the size of spotted hyena (*Crocuta crocuta*) through playback recordings allowing for non-response. *Animal Conservation*, 4: 335–343.
- Millspaugh, J.J. and Marzluff, J.M. (eds.) 2001. Radio tracking and animal populations. Academic Press, San Diego, CA, xvii + 474 pp.
- Millspaugh, J.J., Nielson, R.M., McDonald, L., Marzluff, J.M., Gitzen, R.A., Rittenhouse, C.D., Hubbard, M.W. and Sheriff, S.L. 2006. Analysis of resource selection using utilization distributions. *The Journal of Wildlife Management*, 70: 384–395.
- Ministry of Environment and Forests, Government of India 1986. The Environmental Protection Act 1986, number 29 of 1986. May 1986, New Delhi, India. Available at [http://moef.nic.in/downloads/rules-and-regulations/eprotect\\_act\\_1986.pdf](http://moef.nic.in/downloads/rules-and-regulations/eprotect_act_1986.pdf).
- Ministry of Finance, Government of India, 2009. Public private partnerships in India- state economy. Available <http://www.pppinindia.com/state-economy-gujarat.asp>. Accessed 23 November 2010.
- Miquelle, D., Nikolaev, I., Goodrich, J., Litvinov, B., Smirnov, E. and Suvorov, E. 2005. Searching for the co-existence recipe: a case study of conflicts between people and tigers in the Russian Far East, 305-322: In *People and wildlife: conflict or co-existence?* Woodroffe, R. and Thirgood, S. (eds.), Cambridge University Press, Cambridge, UK.
- Miquelle, D.G., Smirnov, E.N., Hornocker H.G. Nikolaev I.G. and Matyushkin E.N. 1996. Food habits of Amur tigers in Skhote-Alin Zapovednik and the Russian Far East and implications for conservation. *Journal of Wildlife Research*, 1: 138-147.
- Mishra, C. 1997. Livestock depredation by large carnivores in the Indian trans-Himalaya: conflict perceptions and conservation prospects. *Environmental Conservation*, 24: 338-343.
- Mishra, C. and Fitzherbert, A. 2004. War and wildlife: a post conflict assessment of Afghanistan's Wakhan corridor. *Oryx*, 38: 102–105.
- Mishra, C., Allen, P., McCarthy, T., Madhusudan, M.D., Bayarjargal, A. and Prins, H.H.T. 2003. The role of incentive programs in conserving the snow leopard. *Conservation Biology*, 17: 1512-1520.
- Mizutani, F. and Jewell, P.A. 1998. Home-range and movements of leopards (*Panthera pardus*) on a livestock ranch in Kenya. *Journal of Zoology*, 244: 269-286.
- Mohr, C.O. 1947. Table of equivalent populations of North American small mammals. *American Midland Naturalist*, 37: 223-249.
- Mondal, K. 2011. Ecology of leopard (*Panthera pardus fusca*) in Sariska Tiger Reserve, Rajasthan, India. Ph.D. thesis, Saurashtra University, Rajkot. India. 235 pp.
- Mondal, K., Gupta, S., Qureshi, Q. and Sankar, K. 2011. Prey selection and food habits of leopard (*Panthera pardus fusca*) in Sariska Tiger Reserve, Rajasthan, India. *Mammalia*, 75: 201–205.



- Mondol, S., Karanth, K.U., Kumar, N.S., Gopaldaswamy, A.M., Andheria, A. and Ramakrishnan, U. 2009. Evaluation of non-invasive genetic sampling methods for estimating tiger population size. *Biological Conservation*, 142: 2350-2360.
- Montag, J. and Patterson, M. 2001. Predator compensation programs: a state of knowledge report. School of Forestry, University of Montana, Billings.
- Morrison, M. L., Marcot, B. G. and Mannan, R. W. (eds.) 2006. *Wildlife-habitat relationships: concepts and applications*, 3<sup>rd</sup> edition, Island Press, Washington, USA, xxv + 434 pp.
- Mukherjee, A. and Borad, C.K. 2004. Integrated approach towards conservation of Gir National Park: the last refuge of the Asiatic lions, India. *Biodiversity and Conservation*, 13: 2165-2182.
- Mukherjee, S. and Mishra, C. 2001. Predation by leopard *Panthera pardus* in Majhatal Harsang Wildlife Sanctuary, W. Himalayas. *Journal of the Bombay Natural History Society*, 98: 267–268.
- Mukherjee, S., Goyal, S.P. and Chellam, R. 1994a. Refined techniques for the analysis of Asiatic lion *Panthera leo persica* scats. *Acta Theriologica*, 39: 425-430.
- Mukherjee, S., Goyal, S.P. and Chellam, R. 1994b. Standardization of scat analysis techniques for leopard (*Panthera pardus*) in Gir National Park, western India. *Mammalia*, 58: 139-143.
- Muller-Dombois, D. and Ellenberg, H. 1974. *Aims and methods of vegetation ecology*. John Wiley and Sons, New York, New York, 547 pp.
- Narain, S., Panwar, H.S., Gadgil, M., Thapar, V. and Singh, S. 2005. *Joining the dots: the report of the Tiger Task Force*. Project Tiger, Ministry of Environment and Forests, Government of India, New Delhi. Available at [http://projecttiger.nic.in/TTF2005/pdf/full\\_report.pdf](http://projecttiger.nic.in/TTF2005/pdf/full_report.pdf). Accessed in 13 January 2008.
- Naughton-Treves, L., Grossberg, R. and Treves, A. 2003. Paying for tolerance: rural citizens' attitudes toward wolf depredation and compensation. *Conservation Biology*, 17: 1500–1511.
- Nee, S. and May, R.M. 1992. Dynamics of metapopulations: habitat destruction and competitive coexistence. *Journal of Animal Ecology*, 61: 37-40.
- Nellemann, C., Redmond, I. and Refisch, J. 2010. *The last stand of the gorilla: the environmental crime and conflict in the Congo basin. A rapid response assessment*. United Nations Environment Programme, GRID-Arendal, Norway.
- Nicholson, K.L., Krausman, P.R., Munguia-Vega, A. and Culver, M. 2011. Spatial and temporal interactions of sympatric mountain lions in Arizona. *European Journal of Wildlife Research*, 57: 1151-1163.
- Noble, I.R. and Dirzo, R. 1997. Forests as human dominated ecosystems. *Science*, 277: 522-525.
- Noss, R.F. 1996. Protected areas: How much is enough? 91-120: In *National Parks and Protected Areas*, Wright, R.G. (ed.), Blackwell, Cambridge, MA, USA.
- Nowell, K., and Jackson, P. 1996. *Wild cats: status survey and conservation action plan*. World Conservation Union, Gland, Switzerland.
- O'Brien, S.J. 2003. Prides and prejudice, 35-55: In *Tears of the cheetah and other tales from the genetic frontier: the genetic secrets of our animal ancestors*. O'Brien, S.J. Thomas Dunne Books, NY, USA.



- O'Brien, S.J., Joslin, P., Smith III, G.L. Wolfe, R., Schaffer, N., Heath, E., Ott-Joslin, J., Wildt, D.E. and Bush, M. 1987. Evidence for African origins of founders of the Asiatic lion species survival plan. *Zoo Biology*, 6: 99-116.
- O'Brien, S.J., Wildt, D.E. and Bush, M. 1986. The African cheetah in genetic peril. *Scientific American*, 254: 84-92.
- Ogada, M.O., Woodroffe, R., Oguge, N.O. and Frank, L.G. 2003. Limiting depredation by African carnivores: the role of livestock husbandry. *Conservation Biology*, 17: 1-10.
- Ogutu, J.O., Bhola, N. and Reidi, R. 2005. The effects of pastoralism and protection on the density and distribution of carnivores and their prey in the Mara ecosystem of Kenya. *Journal of Zoology*, 265: 281–293.
- Ogutu, J.O., Piepho, H.P., Dublin, H.T., Reid, R.S. and Bhola, N. 2006. Application of mark-recapture methods to lions: satisfying assumptions by using covariates to explain heterogeneity. *Journal of Zoology*, 269: 161–174.
- Ogutu, J.O. and Dublin, H.T. 1998. The response of lions and spotted hyenas to sound playbacks as a technique for estimating population size. *African Journal of Ecology*, 36: 83–95.
- Ogutu, J.O. and Dublin, H.T. 2002. Demography of lions in relation to prey and habitat in the Maasai Mara National Reserve, Kenya. *African Journal of Ecology*, 40: 120-129.
- Ogutu, J.O. and Dublin, H.T. 2004. Spatial dynamics of lions and their prey along an environmental gradient. *African Journal of Ecology*, 42: 8-22.
- Ojima, D.S., Galvin, K.L. and Turner, B.L. 1994. The global impact of land use change. *BioScience*, 44: 300-304.
- Osborne, P.E. and Sua' rez-Seoane, S. 2002. Should data be partitioned spatially before building large-scale distribution models? *Ecological Modeling*, 157: 249–259.
- Otis, D.L. and White, G.C. 1999. Autocorrelation of location estimates and the analysis of radiotracking data. *The Journal of Wildlife Management*, 63: 1039-1044.
- Otis, D.L., Burnham, K.P., White, G.C. and Anderson, D.R. 1978. Statistical inference from capture data of closed populations. *Wildlife Monographs*, 62: 1-135.
- Owen-Smith, N. 2002. Adaptive herbivore ecology: from resources to populations in variable environments. Cambridge University Press, Cambridge, UK, 374 pp.
- Packer, C. 2006. Best practices for trophy hunting of African lions, 7-15: In Proceedings of the 1st Tanzania Lion and Leopard Conservation Action Plan Workshop. 20–22 February 2006, Tanzania Carnivore Unit, TAWIRI, Arusha, Tanzania.
- Packer, C. and Pusey, A.E. 1983a. Male takeovers and female reproductive parameters: a simulation of oestrus synchrony in lions (*Panthera leo*). *Animal Behaviour*, 31: 334-340.
- Packer, C. and Pusey, A.E. 1983b. Adaptations of female lions to infanticide by incoming males. *The American Naturalist*, 121: 716-728.
- Packer, C. and Pusey, A.E. 1995. The Lack clutch in a communal breeder: lion litter size is a mixed evolutionarily stable strategy. *The American Naturalist*, 145: 833-841.



- Packer, C. and Rutman, L.M. 1988. The evolution of cooperative hunting. *The American Naturalist*, 132: 159-198.
- Packer, C., Brink, H., Kissui, B.M., Maliti, H., Kushnir, H. and Caro, T. 2010. Effects of trophy hunting on lion and leopard populations in Tanzania. *Conservation Biology*, 25: 142-153.
- Packer, C., Herbst, L. Pusey, A.E., Bygott, J.D., Hanby, J.P., Cairns, S.J. and Borgerhoff- Mulder 1988. Reproductive success of lions, 363-383: In *Reproductive success*, Clutton-Brock, T.H. (ed.), University of Chicago Press, Chicago.
- Packer, C., Ikanda, D., Kissui, B. and Kushnir, H. 2005. Lion attacks on humans in Tanzania. *Nature*, 436: 927-928.
- Packer, C., Pusey, A.E., Rowley, H., Gilbert, D.A., Martenson, J. and O'Brien, S.J. 1991. Case study of a population bottleneck: lions of the Ngorongoro Crater. *Conservation Biology*, 5: 219-230.
- Palomares, F., Ferreras, P., Fedrinal, J.M. and Delibes, M. 1996. Spatial relationships between Iberian lynx and other carnivores in an area of south-western Spain. *Journal of Applied Ecology*, 33: 5-13.
- Pandey, A. and Singh, S.K. 2010. Factors affecting body weight in landrace, desi and their half bred pigs. *International Journal of Molecular Biology*, 1: 21-24.
- Panwar, H.S. 1980. A note on tiger census technique based on pugmark tracings. *Cheetal*, 22: 40-46.
- Parmar, M.V. 2005. Working plan for Junagadh forest division and Porbandar forest sub division, Volume I, Junagadh Circle, Gujarat state. Gujarat Forest Department, Gandhinagar, Gujarat, India, 210 pp.
- Pathak, B., Pati, B.P., Kumar, R., Kumar, A., Raval, P.P., Patel, V.S. and Rana, V.J. 2002. Biodiversity conservation plan for Gir (a supplementary management plan, 2002-03 to 2006-07). Wildlife Circle, Junagadh. Gujarat Forest Department, India, 407 pp.
- Pati, B.P. 2000. Impact of livelihood practices of Maldhari tribe on wildlife habitat of Gir Protected Area. *Indian Forester*, 126: 1120-1127.
- Patterson, B.D., Kasiki, S.M., Selempo, E. and Kays, R.W. 2004. Livestock predation by lions (*Panthera leo*) and other carnivores on ranches neighbouring Tsavo National Parks, Kenya. *Biological Conservation*, 119: 507-516.
- Pax Lenney, M., Woodcock, C. E., Collins, J. B., and Hamdi, H. 1996. The status of agricultural lands in Egypt: the use of multitemporal NDVI features derived from Landsat TM. *Remote Sensing of Environment*, 56: 8-20.
- Péladeau, N. 1995. SIMSTAT 3.5. Provails Research, USA. Available [www.provalisresearch.com/Documents/simstat.pdf](http://www.provalisresearch.com/Documents/simstat.pdf) Accessed November 1, 2011.
- Pennycuik, C.J. and Rudnai, J. 1970. A method of identifying individual lions *Panthera leo* with an analysis of the reliability of identification. *Journal of Zoology*, 160: 497-508.
- Peterson, J.T. and Dunham, J.A. 2003. Combining inferences from models of capture efficiency, detectability, and suitable habitat to classify landscapes for conservation of threatened bull trout. *Conservation Biology*, 17: 1070-1077.



- Petit, L.J. and Petit, D.R. 2003. Evaluating the importance of human-modified lands for Neotropical bird conservation. *Conservation Biology*, 17: 687-694.
- Phillips, A. 2004. History of the international system of Protected Area management categories. *Parks*, 14: 4-14.
- Pielou, E.C. 1966. The measurement of diversity in different types of biological collections. *Journal of Theoretical Biology*, 13: 131-144.
- Pocock, R.I. 1930. Lions of Asia. *Journal of the Bombay Natural History Society*, 34: 638-665.
- Pollock, K.H., Nichols, J.D., Brownie, C. and Hines, J.E. 1990. Statistical inference for capture-recapture experiments. *Wildlife Monographs*, 107: 1-97.
- Pollock, K.H., Winterstein, S.R., Bunck, C.M. and Curtis, P.D. 1989. Survival analysis in telemetry studies: the staggered entry design. *The Journal of Wildlife Management*, 53: 7-15.
- Poole, K.G., Mowat, G. and Fear, D.A. 2001. DNA based population estimate for grizzly bears *Ursus arctos* in northeastern British Columbia, Canada. *Wildlife Biology*, 7: 105-115.
- Poudevigne, I., Alard, D., Leuven, R.S.E.W. and Nienhuis, P.H. 2002. A systems approach to river restoration: a case study in the lower Seine valley, France. *River Research and Applications*, 18: 239-247.
- Powell, R.A. 1987. Black bear home range overlap in North Carolina and the concept of home range applied to black bears. *International Conference on Bear Research and Management*, 7: 235-242.
- Powell, R.A. 2000. Animal home ranges and territories and home range estimators, 65-110: In *Research techniques in animal ecology: controversies and consequences*, Boitani, L. and Fuller, T.K. (eds.), Columbia University, New York.
- Prater, S.H. 1971. *The book of Indian animals*. The Bombay Natural History Society, Bombay, India. 324 pp.
- Prins, H.H.T., Grootenhuys, J.G. and Dolan, T.T. (eds.) 2000. *Wildlife conservation by sustainable use*. Kluwer Academic Publishers, Boston, USA, 496 pp.
- Pulliam, H.R. 1988. Source, sinks, and population regulation. *The American Naturalist*, 132: 652-661.
- Puri, G.S., Meher-Homji, V.M., Gupta, R.K. and Puri, S. 1983. *Forest ecology: phytogeography and forest conservation*. Oxford and IBH Publ. Co. Pvt. Ltd., New Delhi, India, 349 pp.
- Purvis, A., Mace, G.M. and Gittleman, J.L. 2001. Past and future carnivore extinctions: a phylogenetic perspective, 11-34: In *Carnivore Conservation*, Gittleman, J.L., Funk, S.M., Macdonald, D. and Wayne, R.K. (eds.), Cambridge University Press, Cambridge, UK.
- Pusey, A.E. and Packer, C. 1987. The evolution of sex-biased dispersal in lions. *Behaviour*, 101: 275-310.
- Qureshi, Q. and Shah, N. 2004. Vegetation and habitat monitoring, 8-14: In *Monitoring of Gir, Jhala*, Y.V. (ed.), Technical Report, Wildlife Institute of India, Dehra Dun, India, RR -04/002.



- Rai, N.D. 2007. The ecology of income. Can we have both fruit and forest? 147-162: In Making conservation work, Sahabuddin, G. and Rangarajan, M. (eds.), Permanent Black, New Delhi, India.
- Raman, T.R. 2006. Effects of habitat structure and adjacent habitats on birds in tropical rainforest fragments and shaded plantations in the Western Ghats, India. *Biodiversity and Conservation*, 15: 1577-1607.
- Raval, S.R. 1991. The Gir National Park and the Maldharis: “setting aside”, 68-86: In Resident peoples and national parks—social dilemmas and strategies in international conservation, West, P.C. and Brechin, S.R. (eds.), University of Arizona Press, USA.
- Ravenel, R.M. and Redford, K.H. 2005. Understanding IUCN Protected Area categories. *Natural Areas Journal*, 25: 381-389.
- Ray N. 2005. PATHMATRIX: a GIS tool to compute effective distances among samples, *Molecular Ecology Notes*, 5: 177-180.
- Ray, J., Hunter, L. and Zigouris, J. 2005. Setting conservation and research priorities for larger African carnivores, 216: In Working Paper No. 24. Wildlife Conservation Society (WCS), New York, USA.
- Redford, K.H. and Richter, B.D. 1999. Conservation of biodiversity in a world of use. *Conservation Biology*, 13: 1246-1256.
- Reutter, B.A., Helfer, V., Hirzel, A.H. and Vogel, P. 2003. Modelling habitat suitability using museum collections: an example with three sympatric *Apodemus* species from the Alps. *Journal of Biogeography*, 30: 581–590.
- Rexstad, E.A. and Burnham, K.P. 1991. User’s guide for interactive program CAPTURE. Colorado Cooperative Wildlife Research Unit, Colorado State University, Fort Collins Co. 29 pp.
- Reynolds, T.D. and Laundre, J.W. 1990. Time intervals for estimating pronghorn and coyote home ranges and daily movements. *The Journal of Wildlife Management*, 54: 316-322.
- Rice, W. 1884. Lion shooting. Indian game (from quail to tiger), W.H. Allen and Co., London, 221 pp.
- Ricketts, T.H. 2001. The matrix matters: effective isolation in fragmented landscapes. *The American Naturalist*, 158: 87–99.
- Riggio, J., Jacobson, A., Dollar, L., Bauer, H., Becker, M., Dickman, A., Funston, P., Groom, R., Henschel, P., Iongh, H., Lichtenfeld, L. and Pimm, S. 2013. The size of savannah Africa: a lion’s (*Panthera leo*) view. *Biodiversity and Conservation*, 22: 17-35.
- Ripple, W.J., Estes, J.A., Beschta, R.L., Wilmers, C.C., Ritchie, E.G., Hebblewhite, M., Berger, J., Elmhagen, B., Letnic, M., Nelson, M.P., Schmitz, O.J., Smith, D.W., Wallach, A.D. and Wirsing, A.J. 2014. Status and ecological effects of the world’s largest carnivores. *Science*, 343: 1241484 [DOI:10.1126/science.1241484].
- Rishi, V. 1997. Monitoring tiger populations by pad-impression pad method. *Indian Forester*, 123: 583-600.



- Robinson, H.S., Wielgus, R.B., Cooley, H.S. and Cooley, S.W. 2008. Sink populations in carnivore management: cougar demography and immigration in a hunted population. *Ecological Applications* 18: 1028-1037.
- Rodgers, A.R. and Kie, J.G. 2010. HRT: Home Range Tools for ArcGIS®, version 1.1, 24.4.2011. <http://flash.lakeheadu.ca/~arodgers/hre/Draft%20HRT%20Users%20Manual%20Sep%2028%202010.pdf> (accessed in November, 2012).
- Rodgers, W.A. and Panwar, H.S. 1988. Planning a wildlife protected area network in India. 2 vols. Project FO: IND/82/003. FAO, Dehra Dun. 339, 267 pp.
- Rodriguez, E., Morris, C.S., Belz, J.E., Chapin, E.C., Martin, J.M., Daffer, W. and Hensley, S. 2005. An assessment of the SRTM topographic products. JPL Publications, D31639, 143 pp.
- Roelke-Parker, M.E., Munson, L., Packer, C., Kock, R., Cleveland S., Carpenter, M., O'Brian, S.J., Pospischil, A., Hoffman-Lehmann, R., Lutz, H., Mwamengele, G.L.M., Mgas, M.N., Machange, G.A., Summers, B.A. and Appel, M.G J. 1996. A canine distemper virus epidemic in Serengeti lions. *Nature*, 379: 411-445.
- Rolston, H. 1992. Ethical responsibilities toward wildlife. *Journal of American Veterinary Medical Association* ,200: 618-622.
- Røskaft, E., Bjerke, T., Kaltenborn, B.P., Linnell, J.D.C. and Andersen, R. 2003. Patterns of self-reported fear towards large carnivores among the Norwegian public. *Evolution and Human Behavior*, 24: 184-198.
- Rudnai, J.A. 1973. The social life of the lion. Lancaster: MTP Co. Ltd, 122 pp.
- Russell, C.E.M. 1900. *Bullet and shot in Indian Forest, plain and hill*. Thacker and Co. Ltd. Bombay, India, 572 pp.
- Ryen, M. and Soresina, A. 2003. Tarangire lion project (TLP) report. Available at [http://www.alessandrasoresina.com/allegati/progetti/report2002\\_03\\_171105\\_051443.pdf](http://www.alessandrasoresina.com/allegati/progetti/report2002_03_171105_051443.pdf).
- Saberwal, V. and Rangarajan, M. (Eds.) 2003. *Battles over nature: science and politics of conservation*. Permanent Black, New Delhi, India, viii + 412 pp.
- Saberwal, V., Gibbs, J.P., Chellam, R. and Johnsingh, A.J.T. 1994. Lion-human conflict in the Gir forest, India. *Conservation Biology*, 8: 501-507.
- Sabins, F.F. 1997. *Remote sensing: principles and interpretation*. W.H. Freeman and Co., New York, USA, 494 pp.
- Samuel, M.D., Pierce, D.J. and Garton, E.O. 1985. Identifying areas of concentrated use within the home range. *Journal of Animal Ecology*, 54: 711-719.
- Sánchez-Azofeifa, G.A., Kalacska, M., Quesada, M., Calvo, J., Nassar, J. and Rodriguez, J.P. 2005. Need for integrated research for a sustainable future in tropical dry forests. *Conservation Biology*, 19: 1-2.
- Sanderson, E.W., Jaiteh, M., Levy, M.A., Redford, K.H., Wannebo, A.V. and Woolmer, G. 2002. The human footprint and the last of the wild. *Bioscience*, 52: 891-904.



- Sankar, K. 1994. The ecology of three large sympatric herbivores with special reference to reserve management in Sariska Tiger Reserve, Rajasthan. Ph.D. Thesis, University of Rajasthan, Jaipur, India, 190 pp.
- Santapau, H. and Raizada, M. B. 1956. Contribution to the flora of Gir in Saurashtra. *Indian Forester*, 40: 105-170.
- Saunders, D.A., Hobbs, R.J. and Margules, C.R. 1991. Biological consequences of ecosystem fragmentation: A review. *Conservation Biology*, 5: 18-32.
- Sawarkar, V.B. 1986. Animal damage: predation on domestic livestock by large carnivores. *Indian Forester*, 112: 858-866.
- Schaller, G. 1967. *The deer and the tiger*. University of Chicago Press, Chicago, USA. 370 pp.
- Schaller, G. 1972. *The Serengeti lion*. University Of Chicago Press, Chicago, USA, 480 pp.
- Schaller, G. 1996. Carnivores and conservation biology, 1-10: In *Carnivore behavior, ecology and evolution*, Volume 2, Gittleman, J.L. (ed.), Cornell University Press, Ithaca, New York, USA.
- Scheel, D. and Packer, C. 1995. Variation in predation by lions: tracking a movable feast, 299-314: In *Serengeti II: dynamics, management and conservation of an ecosystem*, Sinclair, A.R.E. and Arcese, P. (eds.), Chicago: University of Chicago Press, Chicago, USA..
- Schmitt, C.B., Belokurov, A., Besançon, C., Boisrobert, L., Burgess, N.D., Campbell, A., Coad, L., Fish, L., Gliddon, D., Humphries, K., Kapos, V., Loucks, C., Lysenko, I., Miles, L., Mills, C., Minnemeyer, S., Pistorius, T., Ravilious, C., Steininger, M. and Winkel G. 2008. Global ecological forest classification and forest protected area gap analysis. Analyses and recommendations in view of the 10% target for forest protection under the Convention on Biological Diversity (CBD). Freiburg University Press, Freiburg, Germany.
- Schnitzler, A.E. 2011. Past and present distribution of the north African-Asian lion subgroup: a review. *Mammal Review*, 41: 220-243.
- Seaman, D.E. 1993. Home range and male reproductive optimization in black bears. Ph.D. thesis, North Carolina State University, USA, 107 pp.
- Seaman, D.E. and Powell, R.A. 1990. Identifying patterns and intensity of home range use. *International Conference on Bear Research and Management*, 8: 243-249.
- Seaman, D.E. and Powell, R.A. 1996. Accuracy of kernel estimators for animal home range analysis. *Ecology*, 77: 2075-2085.
- Seaman, D.E., Millspaugh, J.J., Kernohan, B.J., Brundige, G.C., Raedeke, K.J. and Gitzen, R.A. 1999. Effects of sample size on kernel home range estimates. *The Journal of Wildlife Management*, 63: 739-747.
- Seber, G.A.F. 1982. *The estimation of animal abundance*. London: Edward Arnold, xvii + 654 pp.
- Senft, R.L., Coughenour, M.B., Bailey, D.W., Rittenhouse, L.R., Sala, O.E. and Swift, D.M. 1987. Large herbivore foraging and ecological hierarchies. *Bioscience*, 37: 789-799.
- Shaffer, M.L. 1981. Minimum population sizes for species conservation. *BioScience*, 31: 131-134.



- Shah, R. 2006. Charcoal mafia threat to Banni grassland. Times of India report available at [http://articles.timesofindia.indiatimes.com/2006-01-21/ahmedabad/27816153\\_1\\_banni-grassland-gando-baval-charcoal](http://articles.timesofindia.indiatimes.com/2006-01-21/ahmedabad/27816153_1_banni-grassland-gando-baval-charcoal). Accessed on August 12, 2012.
- Shakespeare, H. 1862. The wild sports of India. Smith, Elder and Co. London, UK, 365 pp.
- Shankaranarayanan, P., Banerjee, M., Kacker, R.K., Aggarwal, R.K. and Singh, L. 1997. Genetic variation in Asiatic lions and Indian tigers. *Electrophoresis*, 18: 1693-1700.
- Shannon, C.E. and Weaver, W. 1949. The mathematical theory of communication. Urbana, IL: University of Illinois Press, 117 pp.
- Sharma, D. 1995. Ecology and management of lion and ungulate habitats in Gir. Ph.D. thesis, Saurashtra University, Rajkot, India, 178 pp.
- Sharma, R.K., Jhala, Y., Qureshi, Q., Vattakaven, J., Gopal, R. and Nayak, K. 2010. Evaluating capture-recapture population and density estimation of tigers in a population with known parameters. *Animal Conservation*, 13: 94–103.
- Sharma, S., Jhala, Y. and Sawarkar, V.B. 2005. Identification of individual tigers (*Panthera tigris*) from their pugmarks. *Journal of Zoology (London)*, 267: 9-18.
- Silverman, B.W. 1986. Density estimation for statistics and data analysis. London: Chapman and Hall, 175 pp.
- Singh, A. 1987. Spectral separability of tropical forest cover classes. *International Journal of Remote Sensing*, 8: 971-979.
- Singh, A., Reddy, V.S. and Singh, J.S. 1995. Analysis of woody vegetation of Corbett National Park, India. *Vegetation*, 120: 69-79.
- Singh, H.S. 1997. Population dynamics, group structure and natural dispersal of the Asiatic Lion *Panthera leo persica*. *Journal of the Bombay Natural History Society*, 94: 65-70.
- Singh, H.S. 2007. The Gir lion *Panthera leo persica*- a natural history, conservation status and future prospect. Pugmark Qumulus Consortium, Ahmedabad, India, 320 pp.
- Singh, H.S. and Gibson, L.A. 2011. A conservation success story in the otherwise dire megafauna extinction crisis: the Asiatic lion (*Panthera leo persica*) of Gir forest. *Biological Conservation*, 144: 1753-1757.
- Singh, H.S. and Kamboj, R.D. 1996. Biodiversity conservation plan for Gir (a management plan for Gir Sanctuary and National Park), Volume I. Sasan Gir Wildlife Division, Gujarat Forest Department, Sasan Gir, Junagadh, India, 242 pp.
- Singh, M.K., Yadav, M.P. and Mehta, N.T. 2002. Breed characteristics of Marwari and Kathiawari horses. *Indian Journal of Animal Sciences*, 72: 319-323.
- Sinha, S.P. 1987. Ecology of wildlife with special reference to the lion (*Panthera leo persica*) in Gir wildlife sanctuary, Saurashtra, Gujarat. Ph.D. thesis, Saurashtra University, Rajkot, India, 291 pp.
- Sinha, S.P., Pathak, B.J. and Rawal, P.P. 2004. Man-animal conflicts in and around protected areas – a case study on Gir national park/wildlife sanctuary, Junagadh, Gujarat, India. *Tigerpaper* 31: 27-32.



- Skalski, J.R., Ryding, K.E. and Millspaugh, J.J. 2005. Wildlife demography: analysis of sex, age, and count Data. Elsevier Academic Press, Burlington, MA, USA, 636 pp.
- Smallwood, K.S. and Fitzhugh, E.L. 1993. A rigorous technique for identifying individual mountain lions *Felis concolor* by their tracks. *Biological Conservation*, 65: 51–59.
- Smith, D.W. and Almborg, E. 2007. Wolf diseases in Yellowstone National Park. *Yellowstone Science*, 15: 17-19.
- Smuts, G.L. 1976. Population characteristics and recent history of lions in two parts of the Kruger National Park. *Koedoe*, 19: 153-164.
- Smuts, G.L. 1978. Interrelations between predators, prey and their environment. *Bioscience*, 28: 316–324.
- Soisalo, M.K. and Cavalcanti, S.M.C. 2006. Estimating the density of a jaguar population in the Brazilian Pantanal using camera-traps and capture–recapture sampling in combination with GPS radio-telemetry. *Biological Conservation*, 129: 487–496.
- Songer, M., Aung, M., Senior, B., DeFries, R. and Leimgruber, P. 2009. Spatial and temporal deforestation dynamics in protected and unprotected dry forests: a case study from Myanmar (Burma). *Biodiversity and Conservation*, 18: 1001-1018.
- Soulé, M.E. (ed.) 1987. Viable populations for conservation. Cambridge University Press, UK, 189 pp.
- Soulé, M.E. and Simberloff, D. 1986. What do genetics and ecology tell us about the design of nature reserves? *Biological Conservation*, 35: 19-40.
- Spong, G. 2002. Space use in lions, *Panthera leo*, in the Selous Game Reserve: social and ecological factors. *Behavioral Ecology and Sociobiology*, 52: 303-307.
- Srivastav, A. 1997. Livestock predation by Gir lions and ecodevelopment. *Tigerpaper*, 24: 1-5.
- Stander, P.E. 1991. Demography of lions in Etosha National Park, Namibia. *Madoqua*, 18: 1-9.
- Stander, P.E. 1998. Spoor counts as indices of large carnivore populations: the relationship between spoor frequency, sampling effort and true density. *Journal of Applied Ecology*, 35: 378–385.
- Stander, P.E. 2006. Population ecology and demography of Kunene lions. Predator Conservation Trust research paper 2006/1, Namibia. Available at [http://www.desertlion.info/reports/klp\\_2006-sml.pdf](http://www.desertlion.info/reports/klp_2006-sml.pdf). (accessed May 2012).
- Stanley, T.R. and Burnham, K.P. 1999. A closure test for time-specific capture-recapture data. *Ecological Statistics*, 6: 197-209.
- Stephens, D.W. and Krebs, J.R. 1986. Foraging theory. Princeton, New Jersey: Princeton University Press. 262 pp.
- Stuart, C. and Stuart, T. 1997. Field guide to the larger mammals of Africa, Struik Publishers, Cape Town, 261 pp.
- Sunquist, M.E. 1981. The social organization of tigers (*Panthera tigris*) in Royal Chitawan National Park, Nepal. *Smithsonian Contribution to Zoology*, 336: 1-92.



- Sunquist, M.E. and Sunquist, F.C. 2001. Changing landscapes: consequences for carnivores, 399-418: In *Carnivore Conservation*, Gittleman, J.L., Funk, S.M., Macdonald, D. and Wayne, R.K. (eds.), Cambridge University Press, Cambridge, UK.
- Swihart, R.K. and Slade, N.A. 1985a. Testing for independence of observations in animal movements. *Ecology*, 66: 1176–1184.
- Swihart, R.K. and Slade, N.A. 1985b. Influence of sampling interval on estimates of home range size. *The Journal of Wildlife Management*, 49: 1019–1025.
- Tanaka, Y. 1998. Theoretical aspects of extinction by inbreeding depression. *Researches on Population Ecology*, 40: 279-286.
- Taylor, B.L. and Gerrodette, T. 1993. The uses of statistical power in conservation biology: the vaquita and the northern spotted owl. *Conservation Biology*, 7: 489–500.
- Taylor, P.D., Fahrig L., Henein K. and Merriam G. 1993. Connectivity is a vital element of landscape structure. *Oikos*, 68: 571–573.
- Tende, T., Ottosson, U., Hansson, B., Åkesson, M. and Bensch, S. 2010. Population size of lions in Yankari Game Reserve as revealed by faecal DNA sampling. *African Journal of Ecology*, 48: 949–952.
- Terborgh, J. 1974. Preservation of natural diversity: the problem of extinction prone species. *Bioscience*, 24: 715–722.
- Terborgh, J. and Winter, B. 1980. Some causes of extinction, 119-133: In *Conservation biology: an evolutionary-ecological perspective*, 7th edition, Soule, M.E. and Wilcox, B.A. (eds.), Sinauer Associates, Inc. Sunderland.
- Thomas, L., Buckland, S.T., Rexstad, E.A., Laake, J.L., Strindberg, S., Hedley, S.L., Bishop, J.R., Marques, T.A. and Burnham, K.P., 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. *Journal of Applied Ecology*, 47: 5–14.
- Tischendorf, L. and Fahrig, L. 2000. On the usage and measurement of landscape connectivity. *Oikos*, 90: 7–19.
- Todd, N.B. 1965. Metrical and non-metrical variation in the skulls of Gir lions. *Journal of the Bombay Natural History Society*, 62: 507-520.
- Townsend, J.R.G., Justice, C.O., Skole, D., Malingrean, J.P., Chilar, J., Teillet, P.M., Sadowrhi, F. and Rutienburg, S. 1994. The 1 km resolution global data set: needs of the international geographic-biosphere programme. *International Journal of Remote Sensing*, 1517: 3417-3441.
- Trent, T.T. and Rongstad, O.J. 1974. Home range and survival of cottontail rabbits in southwestern Wisconsin. *The Journal of Wildlife Management*, 38: 459-472.
- Treves, A. and Karanth, K.U. 2003. Human-carnivore conflict and perspectives on carnivore management worldwide. *Conservation Biology*, 17: 1491–1499.
- Treves, A., Wallace, R., Naughton-Treves, L. and Morales, A. 2006. Co-managing human-wildlife conflict. *Human Dimensions of Wildlife*, 11: 1-14.



- Trinkel, M., Funston, P., Hofmeyr, M., Hofmeyr, D., Dell, S., Packer, C. and Slotow, R. 2010. Inbreeding and density-dependent population growth in a small, isolated lion population. *Animal Conservation*, 13: 374-382.
- Tumenta, P.N., Kok, J.S., van Rijssel, J.C., Buij, R., Croes, B.M., Funston, P.J., de Iongh, H.H. and Udo de Haes, H.A. 2009. Threat of rapid extermination of the lion (*Panthera leo leo*) in Waza National Park, Northern Cameroon. *African Journal of Ecology*, 48: 888-894.
- Tuomisto, H., Linna, A. and Kalliola, R. 1994. Use of digitally processed satellite images in studies of tropical rain forest vegetation. *International Journal of Remote Sensing*, 15: 1595-1610.
- Turner, I.M. 1996. Species loss in fragments of tropical rain forest: a review of the evidence. *Journal of Applied Ecology*, 33: 200-209.
- Turner, M.G. 1989. Landscape ecology: the effect of pattern on process. *Annual Review of Ecological Systematics*, 20: 171-197.
- Turner, M.G. and Gardner, R.H. (eds.) 1991. *Quantitative methods in landscape ecology: the analysis and interpretation of landscape heterogeneity*. Springer Verlag, New York, USA, 556 pp.
- Turner, M.G., Romme, W.H., Gardner, R.H., O'Neill, R.V., and Kratz, T.K. 1993. A revised concept of landscape equilibrium: disturbance and stability on scaled landscapes. *Landscape Ecology*, 8: 213-227.
- United Nations 2006. *Human development report. Beyond scarcity: power, poverty, and the global water crisis*. United Nations Development Programme. Palgrave Macmillan, New York, USA.
- United Nations. 2009. *Human development report. Overcoming barriers: human mobility and development*. United Nations Development Programme. Palgrave Macmillan, New York, USA. 217 p.
- Van Orsdol, K.G. 1981. *Lion predation in Rwenzori National Park, Uganda*. Ph.D. thesis, University of Cambridge, UK.
- Van Orsdol, K.G., Hanby, J.P. and Bygott, J.D. 1985. Ecological correlates of lion social organization (*Panthera leo*). *Journal of Zoology*, 206: 97-112.
- Van Rijssel, J., Kok, J.S., Fobuzie, P.T., Buij, R. and de Iongh, H.H. 2008. *Lion (*Panthera leo*) ecology and livestock conflicts in Waza National Park, Cameroon*. Environment and Development Student Report no. 233. Department Environment and Development, Institute of Environmental Sciences (CML), Leiden University, the Netherlands.
- van Winkle, W. 1975. Comparison of several probabilistic home-range models. *The Journal of Wildlife Management*, 39: 118-123.
- Vanak, A.T. and Gompper, M.E. 2010. Multi-scale resource selection and spatial ecology of the Indian fox in a human-dominated dry grassland ecosystem. *Journal of Zoology (London)*, 281: 140-148.
- Vandermeer, J. and Perfecto, I. 2007. The agricultural matrix and a future paradigm for conservation. *Conservation Biology*, 21: 274-277.
- Varma, K. 2009. The Asiatic lion and the Maldharis of Gir forest: an assessment of Indian Eco-development. *The Journal of Environment and Development*, 18: 154-176.



- Viljoen, P.C. 1993. The effects of changes in prey availability on lion predation in a large natural ecosystem in northern Botswana. *Symposia of the Zoological Society of London*, 65: 193–213.
- Visser, H.D., Müller, L., Tumenta, P.N., Buij, R. and de Iongh, H.H. 2009. Factors affecting lion (*Panthera leo*) home range, movement and diet in Waza National Park, Cameroon. *Journal of Zoology*, 300: 131-142.
- Vitousek, P.M., Mooney, H.A., Lubchenco, J. and Melillo, J.M. 1997. Human domination of earth's ecosystems. *Science*, 277: 494-499.
- Vittersø, J., Kaltenborn, B.P. and Bjerke, T. 1998. Attachment to livestock and attitudes toward large carnivores. *Anthrozoös*, 11: 210-217.
- Vos C.C., Baveco H. and Grashof-Bokdam C.J. 2002. Corridors and species dispersal, 84-104 In: *Applying Landscape Ecology in Biological Conservation*, Gutzwiller K.J. (ed.), Springer, New York, USA.
- Vos, C.C., Ter Braak, C.J.F. and Nieuwenhuizen, W. 2000. Empirical evidence of metapopulation dynamics; the case of the tree frog (*Hyla arborea*). *Ecological Bulletins*, 48: 165 –180.
- Weatherhead, P.J. and Robertson, I.C. 1990. Homing to food by black rat snakes (*Elaphe obsoleta*). *Copeia*, 1990: 1164- 1165.
- White, G.C. and Burnham, K.P. 1999. Program MARK: survival estimation from populations of marked animals. *Bird Study*, 46: 120–138.
- White, G.C. and Garrott, R.A. 1990. *Analysis of radio tracking data*. New York, Academic Press, New York, 383 pp.
- White, G.C., Anderson, D.R., Burnham, K.P. and Otis, D.L. 1982. *Capture-recapture and removal methods for sampling closed populations*. Los Alamos National Laboratory, LA-8787-NERP, Los Alamos, New Mexico.
- White, G.C., Burnham, K.P., Otis, D.L. and Anderson, D.R. 1978. *Users' manual for program CAPTURE*. Logan: Utah State University, USA.
- Whitfield, D.P., McLeod, D.R.A., Fielding, A.H., Broad, R.A., Evans, R.J. and Haworth, P.F. 2002. The effects of forestry on golden eagles on the island of Mull, western Scotland. *Journal of Applied Ecology*, 38: 1208-1220.
- Whitman, K., Starfield, A.M., Quadling, H. and Packer, C. 2004. Sustainable trophy hunting of African lions. *Nature*, 428: 175-178.
- Whitman, K., Starfield, A.M., Quadling, H. and Packer, C. 2007. Modeling the effects of trophy selection and environmental disturbance on a simulated population of African lions. *Conservation Biology*, 21: 591–601.
- Wiens, J.A. 1989. Spatial scaling in ecology. *Functional Ecology*, 3: 385-397.
- Wiens J.A. 1997. Metapopulation dynamics and landscape ecology. 43-62: In *Metapopulation biology*, Hanski I.A. and Gilpin M.E. (eds.), Academic Press, London, UK.
- Wiens, J.A., Crawford, C.S. and Gosz, J.R. 1985. Boundary dynamics: a conceptual framework for studying landscape ecosystems. *Oikos*, 45: 421–427.



- Wilcove, D.S., Rothstein, D., Dubow, J., Phillips, A. and Losos, E. 1998. Quantifying threats to imperiled species in the United States. *Bioscience*, 48: 607-615.
- Wildlife Protection Act (WPA). 1972. Wildlife Protection Act, Act number 53 of 1972, 9th September, 1972, Ministry of Law, Justice and Company, New Delhi, India. Available at <http://moef.nic.in/downloads/public-information/Annexure-IV-NBA.pdf>. (Accessed 26 September, 2009).
- Wildt, D.E., Bush, M., Goodrowe, K.L., Packer, C., Pusey, A.E., Brown, J.L., Joslin, P. and O'Brien, S.J. 1987. Reproductive and genetic consequences of founding isolated lion populations. *Nature*, 329: 328-331.
- Wilkie, D.S. and Finn, J.T. 1996. Remote Sensing imagery for natural resources monitoring: a guide for first time users. Columbia University Press, New York, USA, 295 pp.
- Williams, B.K., Nichols, J.D. and Conroy, M.J. 2002. Analysis and management of animal populations. Academic Press, London, UK, 817 pp.
- Wood, T.F. and Foody, G.M. 1989. Analysis and representation of vegetation continua from Landsat thematic mapper data for lowland heaths. *International Journal of Remote Sensing*, 10: 181-191.
- Woodcock, C.E., Macomber, S.A., Pax-Lenney, M. and Cohen, W.B. 2001. Monitoring large areas for forest change using Landsat: generalization across space, time and Landsat sensors. *Remote Sensing of Environment*, 78: 194-203.
- Woodroffe, R. 2000. Predators and people: using human densities to interpret declines of large carnivores. *Animal Conservation*, 3: 165-173.
- Woodroffe, R. and Ginsberg, J.R. 1998. Edge effects and the extinction of populations inside protected areas. *Science*, 280: 2126-2128.
- Woodroffe, R., and Frank, L.G. 2005. Lethal control of African lions (*Panthera leo*): local and regional population impacts. *Animal Conservation*, 8: 91-98.
- Worton, B.J. 1987. A review of models of home range for animal movement. *Ecological Modelling*, 38: 277-298.
- Worton, B.J. 1989. Kernel methods for estimating the utility distribution in home-range studies. *Ecology*, 70: 164-168.
- Worton, B.J. 1995. Using Monte Carlo simulation to evaluate kernel-based home range estimators. *The Journal of Wildlife Management*, 59: 794-800.
- Wright, S.J. 2005. Tropical forests in a changing environment. *Trends in Ecology and Evolution*, 20: 553-60.
- Wu, J. and Levin, S.A. 1994. A spatial patch dynamic modeling approach to pattern and process in an annual grassland. *Ecological Monographs*, 64: 447-464.
- WWF-India. 2007. Landscapes of hope: conservation of the tiger, rhino and the Asian elephant. Species Conservation Programme, WWF-India secretariat, New Delhi, India. 78 p. Available at <http://wwf.se/source.php?id=1168636>. Accessed April 23 2012.
- Wynter-Blyth, M.A. 1949. The Gir forest and its lions. *Journal of the Bombay Natural History Society*, 48: 493-513.



Yamazaki, K. 1996. Social variation of lions in a male-depopulated area in Zambia. *Journal of the Wildlife Management*, 60: 490 – 497.

Zar, J.H. 2010. *Biostatistical analysis*. Fifth edition, Prentice Hall, New Jersey, USA, 960 pp.

Zimen, E. 1976. On the regulation of pack size in wolves. *Zeitschrift fuer Tierpsychologie*, 40: 300-341.

Zimmermann, B., Wabakken, P. and Dötterer, M. 2001. Human-carnivore interactions in Norway: how does the re-appearance of large carnivores affect people's attitudes and levels of fear? *Forest Snow and Landscape Research*, 76: 137–153.



## ACADEMIC ACHIEVEMENTS



### Peer-reviewed publications:

- Jhala, Y. V., Mukherjee, S., Shah, N., Chauhan, K.S., Dave, C.V., Meena, V. and Banerjee, K. 2009. Home range and habitat preference of female lions (*Panthera leo persica*) in Gir forests, India. *Biodiversity and Conservation* 18: 3383–3394.
- Banerjee, K., Jhala, Y.V. and Pathak, B. 2010. Demographic structure and abundance of Asiatic lions (*Panthera leo persica*) in Girnar Wildlife Sanctuary, Gujarat, India. *Oryx* 44: 248-251.
- Dave, C. and Jhala, Y.V. 2011. Is competition with livestock detrimental for native wild ungulates? - A case study of chital (*Axis axis*) in Gir forest, India. *Journal of Tropical Ecology* 27: 239-247.
- Meena, V., Jhala, Y.V., Chellam, R. and Pathak, B. 2011. Implications of diet composition of Asiatic lions for their conservation. *Journal of Zoology*, 284: 60-67.
- Banerjee, K. and Jhala, Y.V. 2012. Demographic parameters of endangered Asiatic lions (*Panthera leo persica*) in Gir forests, India. *Journal of Mammalogy* 93 (6): 1420-1430.
- Banerjee, K., Jhala, Y.V., Chauhan, K.S. and Dave, C.V 2013. Living with lions: economics of coexistence in the Gir forests, India. *PLoS ONE* 8(1):e49457. DOI:10.1371/journal.pone.0049457.

### Three publications in communication

### International Conference Proceedings:

- Basu, P., Jhala, Y.V., Qureshi, Q. 2012. Habitat fragmentation displeasing metapopulation dynamics of the Asiatic lions: importance of maintaining functionality of corridors in a highly fragmented landscape. Conference Proceeding of Geomatrix 12, 2012.
- Basu, P., Jhala, Y.V., Qureshi, Q. 2012. Assessment of the future of potential dispersal corridors of Asiatic Lions (*Panthera leo persica*) across the agro-pastoral landscape between Gir and Girnar Wildlife Sanctuary. Conference Proceeding of India Geospatial Forum, 2012.



### **Doctoral and Masters Thesis:** Two doctoral Theses and two Masters Theses

- Banerjee, K. 2012. Ranging patterns, habitat use and food habits of the satellite lion populations (*Panthera leo persica*) in Gujarat, India. PhD thesis submitted to the Forest Research Institute University, Dehradun, India, xxxv + 400 pp.
- Basu, A. 2012. Abundance estimation of leopards (*Panthera pardus*) in Girnar wildlife sanctuary, Gujarat. Masters thesis submitted to the Forest Research Institute Deemed University, Dehradun, India, 49 pp.
- Basu, P. 2013. Assessment of landscape pattern for modelling habitat suitability for Lions and Prey species in Gir protected area, Gujarat. PhD thesis submitted to the Forest Research Institute University, Dehradun, India, pp xxi + 267.
- Chakrabarti, S. 2013. Computing biomass consumption from prey occurrences in scats of tropical felids. Masters thesis submitted to Saurashtra University, Rajkot, India, iv + 57 pp.

### **Technical Reports:**

- Jhala, Y.V., Ravi Chellam, B. Pathak, V.Meena, K. Banerjee and Basu, P. 2011. Social Organization and Dispersal of Asiatic Lions. Technical Report, Vol. I submitted to the Gujarat Forest Department. Wildlife Institute of India, Dehra Dun, India. TR-2011/001.
- Jhala, Y.V., Q. Qureshi, C. Dave and Chauhan, K.S. 2011. Ecological Monitoring of Gir. Technical Report Vol. II submitted to the Gujarat Forest Department. Wildlife Institute of India, Dehra Dun, India. TR- 2011/001.
- Jhala, Y., Chellam, R., Pathak, B., Qureshi, Q., Meena, V., Chauhan, K., Dave, C., Banerjee, K. and Basu, P. 2012. Ecology of Lion in the Agro-pastoral Greater Gir Landscape—Phase I. Technical Report, Wildlife Institute of India, Dehra Dun, India, pp xiv + 382. TR-2012/004.
- Jhala, Y.V., Qureshi, Q., Basu, P. and Banerjee, K. 2012. Assessment of the landscape between the Gir Protected Area and the Girnar Wildlife Sanctuary, Gujarat, for a potential lion habitat corridor. A Technical Publication of the Wildlife Institute of India, Dehra Dun submitted to the Gujarat Forest Department, TR – 2012/002, pp xiii + 88.
- Jhala, Y.V., Qureshi, Q. and Basu, A. 2012. A report on population and density estimation of leopards in Girnar Wildlife Sanctuary, Gujarat, 2012. A technical report submitted to the Gujarat Forest Department, pp 24.

Besides, there have been six International and fifteen National Conference and symposia presentations and four popular articles published based on the research findings of this project. The project has received good press coverage, nationally and internationally.



## **APPENDIX**

### **PEER-REVIEWED PUBLICATIONS**

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## Short Communication

# Demographic structure and abundance of Asiatic lions *Panthera leo persica* in Girnar Wildlife Sanctuary, Gujarat, India

KAUSIK BANERJEE, YADVENDRADEV V. JHALA and BHARAT PATHAK

**Abstract** Asiatic lions *Panthera leo persica*, once confined to the 1,883 km<sup>2</sup> Gir Protected Area in Gujarat, India, have in the past 2 decades colonized the adjacent Girnar forest, coastal scrub and agro-pastoral areas covering c. 10,000 km<sup>2</sup>. In May 2008 the Government of Gujarat declared 180 km<sup>2</sup> of the sacred Girnar forests a Wildlife Sanctuary. We obtained data on location, age, gender and group composition of lions in Girnar Wildlife Sanctuary from opportunistic sightings during March–May 2008 and from systematic surveys in April 2008 (six surveys of 3–4 days each), totalling 81 lions on 40 occasions. Of the 81 sightings 43% were in the recruitment age group. Adult sex ratio was 0.87 males : 1 female. In the systematic survey we made 26 sightings of nine individuals, identified from their vibrissae patterns and permanent body markings, and used these for population estimation using a capture–recapture analysis. The population estimate using the best fit null model  $M_0$  was  $10 \pm SE 1.2$  giving an adult lion density of  $5.6 \pm SE 0.7$  per 100 km<sup>2</sup>. Population viability analysis emphasized the importance of immigrants for the persistence of this small population. One immigrant in 2 years reduced the probability of extinction by 16%. Conservation of the habitat matrix to the south-east of the Sanctuary, used as a corridor for movement between Girnar and Gir, by declaring it an eco-sensitive zone would facilitate the long-term survival of the Girnar lion population.

**Keywords** Age structure, capture–recapture, corridor, density, Girnar Wildlife Sanctuary, India, lion, *Panthera leo persica*

Large carnivores have traditionally served as charismatic flagship and umbrella species for the conservation of biodiversity worldwide (Dalerum et al., 2008). However, their conservation is fraught with difficulties as most live at low densities, require large areas, and often conflict with

human interests through predation on livestock and sometimes on people (Saberwal et al., 1994; Karanth & Chellam, 2009). Lions have been driven almost to extinction in Asia (Kinnear, 1920; Pocock, 1930; Divyabhanusinh, 2005). The only surviving free-ranging Asiatic lion *Panthera leo persica* population is in and around the Gir forests of Gujarat, India (Divyabhanusinh, 2005). This population has increased from c. 20 in 1920 to a current population of c. 360 (Singh, 2007).

The population was formerly restricted to the c. 1,883 km<sup>2</sup> Gir Protected Area (Johnsingh et al., 2007) but during the last 2 decades lions have dispersed to establish small breeding units in the districts of Junagadh, Amreli and Bhavnagar, covering c. 10,000 km<sup>2</sup> of agro-pastoral and scrub landscapes (Divyabhanusinh, 2005; Singh, 2007). One such population became established in Girnar forest, c. 35 km north-west of the Gir Protected Area, in the mid 1980s (Singh, 2007) and lions occasionally move between the two areas. This movement enhances the long-term survival prospects of the subspecies (Hanski & Gilpin, 1997). The 180 km<sup>2</sup> Girnar forest is bounded on three sides by the townships of Junagadh, Bilkha and Bhesan (Fig. 1). The forest is considered sacred; Hindu and Jain temples on the peaks of Mount Girnar are frequented by hundreds of thousands of pilgrims each year. The area was notified as a Wildlife Sanctuary in May 2008 (Government of Gujarat, 2008). Here we assess the population size and demographic structure of the lion population of Girnar Wildlife Sanctuary and discuss its medium- to long-term conservation prospects using a population viability analysis.

We obtained data on location, age, gender and group composition of lions in Girnar Wildlife Sanctuary from opportunistic sightings during March–May 2008 and from systematic surveys in April 2008 (see below), totalling 81 lions on 40 occasions. Lions were classified into six age groups based on size, body colouration and teeth wear (Schaller, 1972; Jhala et al., 2004). The lions of Girnar are relatively well-habituated and thus their teeth can be observed with binoculars or a spotting scope when they yawn or snarl.

We collected data for a capture–recapture analysis (Ogutu et al., 2006) by systematically searching for lions on foot and by vehicle over the entire lion habitat of Girnar in six surveys of 3–4 days each, for a total of 19 days, in April 2008. Lions

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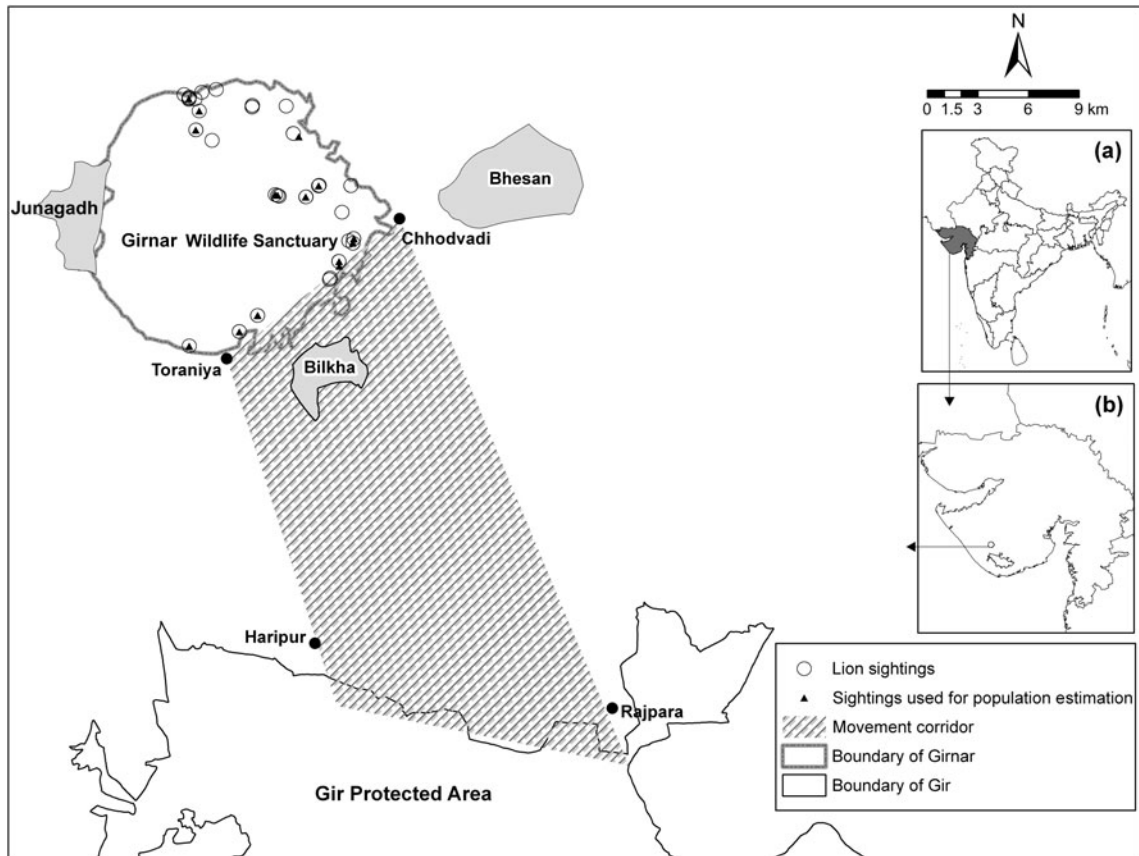


FIG. 1 The location of Girnar Wildlife Sanctuary with respect to Gir Protected Area, showing the locations where we observed lions in Girnar and the potential movement corridor between the two areas. The insets show the location of Girnar (b) within the state of Gujarat (a) in India.

were individually identified based on their vibrissae patterns and permanent body marks (Pennycuik & Rudnai, 1970; Jhala et al., 1999). From the capture histories of individual lions an X matrix was constructed, which was then used for mark-recapture population estimation (Pollock et al., 1990). Considering the long lifespan of lions relative to the short sampling duration and our coverage of the entire lion habitat, we assumed demographic and geographical closure (Chao & Huggins, 2005) and tested for this using software *CloseTest* (Stanley & Burnham, 1999).

Although we surveyed the entire Sanctuary we did not record lions in the western part, a much-disturbed area with pilgrim shrines and proximal to human habitation (Junagadh city; Fig. 1). Cubs (< 1 year old) comprised 14% of the population, reproductive lionesses 20%, and sub-adults (1–3 years old) 43% (Fig. 2). The ratio of cubs to breeding females was 0.68:1 and was higher than that reported for Gir Protected Area (0.47:1; Jhala et al., 2004) but within the range reported by Schaller (1972) for Serengeti (0.40–0.66). The adult sex ratio of 0.87:1 (males: females) was higher than that reported for Africa (Schaller, 1972; Packer et al., 1988; Creel & Creel, 1997). The number of cubs accompanying mothers was 2–3 ( $n = 3$ ).

For the capture–recapture analysis we obtained 26 sightings of nine individual lions. A plot of the number of unique lions against lion sightings reached an asymptote, suggesting adequacy of sampling. The model selection procedure of software *CAPTURE-2* (Otis et al., 1978; Rexstad & Burnham, 1991) selected the null model ( $M_0$ , scored at 1), followed by a model incorporating individual heterogeneity in capture probabilities ( $M_{th}$ , scored at 0.77). *CloseTest* supported population closure ( $\chi^2 = 6.16$ ,  $P = 0.18$ ). Capture probability of lions in Girnar was 0.31 and the population estimate using model  $M_0$  was  $10 \pm SE 1.2$  lions. Girnar Wildlife Sanctuary is bounded by human habitations and agriculture but, although we observed lions venturing into agricultural areas at night to predate on cattle, they seldom spent the daylight hours beyond Girnar forest. For estimating lion density we therefore considered the forested Sanctuary boundary to be a ‘hard boundary’. Density of lions (> 1.5 years old) was estimated to be  $5.6 \pm SE 0.7$  per 100 km<sup>2</sup>. The lion density in Girnar is therefore lower than that of Gir Protected Area (14.3–15.5 lions per 100 km<sup>2</sup>; Jhala et al., 2004) but the high proportion of lions in recruitment age groups in Girnar and ample availability of prey (wild ungulates as well as domestic livestock; Dharaia, 2001) suggest an increasing lion population.

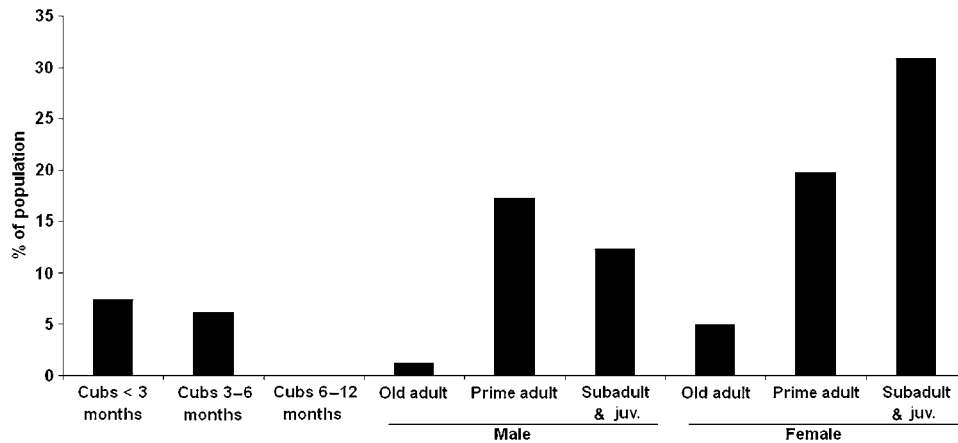


FIG. 2 Age and sex composition of the lion population of Girnar Wildlife Sanctuary (Fig. 1) based on 81 lion sightings on 40 occasions.

We conducted a population viability analysis (PVA; Akçakaya & Sjögren-Gulve, 2000), using published lion demographic data (Schaller, 1972; Joslin, 1973; Jhala et al., 2004), with the software *VORTEX v. 9.1* (Lacy, 1993). We set the carrying capacity of Girnar forest at 25 lions (a conservative estimate based on lion densities in Gir Protected Area; Jhala et al., 1999, 2004) to assess the potential for long-term persistence of this small lion population with and without immigration. We included inbreeding depression and a catastrophe frequency of 1 in 10 years in which reproduction is reduced by 50% and survival by 25% (Ashraf et al., 1995). Rigorous estimates of viability are contingent upon knowledge of the status of a population at a fixed point in time and its dynamics over a certain time frame (White et al., 2002). Our analysis meets both these requirements as we conducted a mark-recapture analysis and used published population parameters. The frequency and rates of catastrophes that we used represent a reasonably severe scenario and the PVA outcomes are therefore conservative (Kohlmann et al., 2005). The PVA suggests that the Girnar lion population could potentially survive for the short- to medium-term (25–50 years, probability of extinction 5–10%) without immigrants. However, for long-term (100 years) persistence connectivity with the Gir Protected Area is crucial. Even if 1–2 lions immigrate to Girnar once in 2 years extinction probabilities are reduced from 36% (without immigrants) to 20% (with immigrants).

We are currently conducting a telemetry study of lions in Girnar Wildlife Sanctuary, Gir Protected Area and the surrounding landscape along with high resolution mapping of land-use in the region. The habitat matrix in south-east Girnar consists of broken topography and small drainage systems, and is predominantly agricultural with seasonal crops and fruit orchards. It is therefore conducive for lion movement between Girnar and Gir. Telemetry data on lions (Jhala et al., 2009; K. Banerjee & Y. Jhala, unpubl. data) show that these land uses are not barriers to lion movement, and lions have been frequently observed in this

habitat (B. Pathak, pers. obs.). Traditional land uses are fast changing in this region, with development of limestone mines and infrastructure such as highways altering the habitat matrix and making it hostile for movement of lions. Results from our ongoing telemetry and mapping studies will provide further details of the habitat corridors between Gir Protected Area and Girnar. Meanwhile, declaring the region between the village lands of Toraniya, Chhodavadi, Haripur and Rajpara (Fig. 1), where lions have been frequently sighted, as an eco-sensitive area (under The Environment (Protection) Act 1986, Government of India) would curtail adverse change of land uses and prevent further deterioration of this habitat for movement of lions.

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### References

- AKÇAKAYA, H.R. & SJÖGREN-GULVE, P. (2000) Population viability analysis in conservation planning: an overview. *Ecological Bulletin*, 48, 9–21.
- ASHRAF, N.V.K., CHELLAM, R., MOLUR, S., SHARMA, D. & WALKER, S. (1995) *Population and Habitat Viability Assessment P.H.V.A. Workshops for Asiatic Lion, Panthera leo persica, Report, July 1995*. Conservation Breeding Specialist Group, Apple Valley, USA.
- CHAO, A. & HUGGINS, R.M. (2005) Modern closed-population capture-recapture models. In *Handbook of Capture-Recapture Analysis* (eds S.C. Amstrup, T.L. McDonald & B.F.J. Manley), pp. 58–87. Princeton University Press, Oxford, UK.

- CREEL, S. & CREEL, N.M. (1997) lion density and population structure in the Selous Game Reserve: evaluation of hunting quotas and offtake. *African Journal of Ecology*, 35, 83–93.
- DALERUM, F., SOMERS, M.J., KUNKEL, K.E. & CAMERON, E.Z. (2008) The potential for large carnivores to act as biodiversity surrogates in southern Africa. *Biodiversity and Conservation*, 17, 2939–2949.
- DHARAIYA, N. (2001) *A Study on the Ecology of the Satellic Lion Metapopulation outside Gir PA and its Conservation*. PhD thesis, Saurashtra University, Rajkot, India.
- DIVYABHANUSINH, C. (2005) *The Story of Asia's Lions*. Marg Publication, Mumbai, India.
- GOVERNMENT OF GUJARAT (2008) Forest and Environment Department, Sachivalaya, Gandhinagar, Notification Number GVN-2008(28) VPS-102007-2069-W (5071).
- HANSKI, I.A. & GILPIN, M.E. (1997) *Metapopulation Biology: Ecology, Genetics and Evolution*. Academic Press, San Diego, USA.
- JHALA, Y.V., MUKHERJEE, S., SHAH, N., CHAUHAN, K.S., DAVE, C. & JHALA, Y.S. (2004) Monitoring lions. In *Monitoring of Gir* (ed. Y.V. Jhala), pp. 55–71. Technical Report. Wildlife Institute of India, Dehra Dun, India.
- JHALA, Y.V., MUKHERJEE, S., SHAH, N., CHAUHAN, K.S., DAVE, C.V., MEENA, V. & BANERJEE, K. (2009) Home range and habitat preference of female lions (*Panthera leo persica*) in Gir forests, India. *Biodiversity & Conservation*, 18, 3383–3394.
- JHALA, Y.V., QURESHI, Q., BHUVA, V. & SHARMA, L.N. (1999) Population estimation of Asiatic lions. *Journal of Bombay Natural History Society*, 96, 3–15.
- JOHNSINGH, A.J.T., GOYAL, S.P. & QURESHI, Q. (2007) Preparations for the reintroduction of Asiatic lion *Panthera leo persica* into Kuno Wildlife Sanctuary, Madhya Pradesh, India. *Oryx*, 41, 93–96.
- JOSLIN, P. (1973) *The Asiatic lion: a study of ecology and behaviour*. PhD thesis, Department of Forestry and Natural Resources, University of Edinburgh, Edinburgh, UK.
- KARANTH, K.U. & CHELLAM, R. (2009) Carnivore conservation at the crossroads. *Oryx*, 43, 1–2.
- KINNEAR, N.B. (1920) The past and the present distribution of the lion in South-eastern Asia. *Journal of Bombay Natural History Society*, 27, 33–39.
- KOHLMANN, S.G., SCHMIDT, G.A. & GARCELON, D.K. (2005) A population viability analysis for the island fox on Santa Catalina Island, California. *Ecological Modelling*, 183, 77–94.
- LACY, R.C. (1993) VORTEX: a computer simulation model for population viability analysis. *Wildlife Research*, 20, 45–65.
- OGUTU, J.O., PIEPHO, H.P., DUBLIN, H.T., REID, R.S. & BHOLA, N. (2006) Application of mark–recapture methods to lions: satisfying assumptions by using covariates to explain heterogeneity. *Journal of Zoology*, 269, 161–174.
- OTIS, D.L., BURNHAM, K.P., WHITE, G.C. & ANDERSON, D.R. (1978) Statistical inference from capture data of closed populations. *Wildlife Monographs*, 62.
- PACKER, C., HEBST, L., PUSEY, A.E., BYGOTT, J.D., HANBY, J.P., CAIRNS, S. & BORGERHOFF-MULDER, M. (1988) Reproductive success of lions. In *Reproductive Success* (ed. T.H. Clutton-Brock), pp. 363–383. University of Chicago Press, Chicago, USA.
- PENNYCUIK, C.J. & RUDNAL, J. (1970) A method of identifying individual lions *Panthera leo* with an analysis of the reliability of identification. *Journal of Zoology*, 160, 497–508.
- POCOCK, R.I. (1930) Lions of Asia. *Journal of Bombay Natural History Society*, 34, 638–665.
- POLLOCK, K.H., NICHOLS, J.D., BROWNIE, C. & HINES, J.E. (1990) Statistical inference for capture–recapture experiments. *Wildlife Monographs*, 107, 1–97.
- REXSTAD, E.A. & BURNHAM, K.P. (1991) *User's Guide for Interactive Program CAPTURE*. Colorado Cooperative Wildlife Research Unit, Colorado State University, Fort Collins, USA.
- SABERWAL, V., GIBBS, J.P., CHELLAM, R. & JOHNSINGH, A.J.T. (1994) Lion–human conflict in the Gir Forest, India. *Conservation Biology*, 8, 501–507.
- SCHALLER, G. (1972) *The Serengeti Lion: A Study of Predator–Prey Relations*. University of Chicago Press, Chicago, USA.
- SINGH, H.S. (2007) *The Gir Lion Panthera leo persica—A Natural History, Conservation Status and Future Prospect*. Pugmark Qumulus Consortium, Ahmedabad, India.
- STANLEY, T.R. & BURNHAM, K.P. (1999) A closure test for time-specific capture–recapture data. *Ecological Statistics*, 6, 197–209.
- WHITE, G.C., FRANKLIN, A.B. & SHENK, T.M. (2002) Estimating parameters of PVA models from data on marked animals. In *Population Viability* (eds S.R. Beissinger & D.M. McCullough), pp. 169–190. University of Chicago Press, Chicago, USA.

### Biographical sketches

KAUSIK BANERJEE is studying lion populations residing outside protected areas, and also has research interests in carnivore ecology and behaviour, with an emphasis on predation, ranging patterns, habitat use, population dynamics and human–carnivore conflicts. YADVENDRADEV JHALA's research interests are in carnivore conservation, with an emphasis on ecology, population estimation, monitoring and human–carnivore conflicts. BHARAT PATHAK is a wildlife manager. He has been managing the wildlife and protected areas of Gujarat, including the Gir Protected Area, for the past 22 years. His research interests are human–wildlife conflict resolution, wildlife law and policy.

# Is competition with livestock detrimental for native wild ungulates? A case study of chital (*Axis axis*) in Gir Forest, India

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**Abstract:** Livestock graze Indian forests to varying extents but their impact on wild native ungulates is rarely understood. Negative impacts of sympatric livestock on chital (*Axis axis*) demography and food availability were assessed and compared in the Gir Forest, India, at different spatio-temporal scales. No difference in average group size (mean  $\pm$  SE) ( $7.11 \pm 0.8$  indiv.) (short-term response), fawn to doe ratio ( $0.43 \pm 0.03$ ) (short- to medium-term response), chital density ( $44.8 \pm 7.1$  indiv.  $\text{km}^{-2}$ ) (medium- to long-term response), and rate of population increase ( $r = 0.07 \pm 0.014$ ) (long-term response) was found between areas sympatric and livestock-free at the larger spatial scale of Gir Forest. Instead, chital density was correlated with rainfall ( $r = 0.92$ ). After controlling for confounding factors of rainfall, vegetation community, terrain and lion density, chital density was 62% higher for livestock-free compared with sympatric areas but other demographic parameters showed no statistical difference. Peak above-ground biomass was greater in livestock-free ( $3255 \pm 209$   $\text{kg ha}^{-1}$ ) compared to sympatric areas ( $1438 \pm 152$   $\text{kg ha}^{-1}$ ), but chital food was more abundant in moderately grazed areas compared to livestock-free areas. Overall, long-term livestock grazing has depressive effects on chital but in the short term habitat productivity and suitability overrides the depressive effects of sympatric livestock.

**Key Words:** above-ground biomass production, body condition, deer, density, distance sampling, group size, realized growth rate

## INTRODUCTION

Livestock are sympatric with wild ungulates in most forest areas of India (Kothari *et al.* 1989) where they potentially compete for important resources. The interactions with livestock could be detrimental (Madhusudan 2004, Mishra *et al.* 2004), facilitative (Rannestad *et al.* 2006) or have no effect on wild ungulates (Berwick 1974, Khan 1995). Competition between domestic and wild ungulates has long been the focus of scientific investigation (Pickford & Reid 1948), yet recent reviews show a remarkable scarcity of information on the subject (Prins 2000, Putman 1996). One of the important reasons for the indecisive outcomes of such studies is due to the difficulty in demonstrating livestock as the only factor responsible for poor population performance of wild herbivores through depletion of shared resources. Ecological heterogeneity resulting from environmental stochasticity has a fundamental effect on herbivore

population dynamics especially in semi-arid landscapes (Owen-Smith 2002) and could potentially mask the competitive effects of livestock. Due to difficulties in designing and implementing perturbation experiments (Prins & Olf 1998, Schoener 1983, Young *et al.* 2005), rarely are data collected on a spatio-temporal scale to understand and control for the effects of the environmental stochasticity in studies involving competition. An alternative approach is to assess the population performance of a species of interest over ecologically comparable sites differing in terms of sympatric livestock. Such opportunities abound in protected areas of India where human settlements along with their livestock have been relocated in recent times (Kothari *et al.* 1989).

We use chital (*Axis axis*, Exelbern), an important forest ungulate in the subcontinent, as a model to study the effects of livestock on native ungulates in the Gir Forest of Gujarat, India. If sympatric livestock had a detrimental effect on chital then the following predictions that cover various time-scale responses should hold. In areas of sympatry with livestock we would expect chital

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to have: (1) Smaller group sizes – a population parameter that balances anti-predatory strategy (Beauchamp 2003, Bednekoff & Lima 2004) with immediate food-resource availability (Jarman 1974). (2) Poorer body condition – this is a short-term (seasonal) response to poor forage quality and quantity (Brochu *et al.* 1988, Clutton-Brock *et al.* 1997, Sinclair & Norton-Griffiths 1982). (3) Lower fawn to doe ratio – an annual response to reduced forage quantity and quality (Robbins 1993). (4) Lower density – chital density is a medium- to long-term response to range conditions incorporating processes of fecundity, mortality, immigration and emigration (Sinclair *et al.* 2006). (5) Poor population growth – the realized rate of increase  $r$  of a population is a long-term collective response of all individuals in a population to environmental influences (Caughley 1977). (6) Depleted food resources – above-ground herbaceous biomass, especially chital food resources, should be depleted in sympatric areas compared with livestock-free areas (Madhusudan 2004, Mishra *et al.* 2004). (7) Also, we would expect a negative correlation between chital and livestock abundance. Livestock density has reduced over the past 30 y following relocations of human settlements from the Gir Forest (Singh & Kamboj 1996). In this paper we test these hypotheses with field data collected between 2004 and 2006.

## STUDY AREA

The Gir Forest is home to the last surviving population of the Asiatic lion (*Panthera leo persica*). It spreads over 1883 km<sup>2</sup> including 259 km<sup>2</sup> as a National Park which was created in 1978 by relocating all human settlements and livestock from within it (Singh & Kamboj 1996). The remaining part of the Gir Forest is a wildlife sanctuary, which is a multiple-use area with resident human and livestock populations but with wildlife especially lion conservation as the primary objective.

The Gir Forest experiences three distinct seasons, cold season (November–February), hot season (March–June) and rainy season (July–October). Average minimum and maximum temperature was 9 °C and 42 °C respectively (Singh & Kamboj 1996). The average annual precipitation for the past 20 y showed a gradient decreasing eastward. The precipitation in the western part of Gir sanctuary was 89 ± 2 cm y<sup>-1</sup>; Central, National Park and adjacent areas was 80 ± 5 cm y<sup>-1</sup> and the eastern part of Gir sanctuary was 56 ± 2 cm y<sup>-1</sup> (Singh & Kamboj 1996). The rainfall gradient is well reflected in the vegetation communities (Qureshi & Shah 2004). The western part of the sanctuary supports relatively more diverse, productive and riparian plant communities dominated by teak (*Tectona grandis* L.) compared with the National Park and eastern part of the Gir sanctuary where

*Anogeissus latifolia* (Roxb. ex DC.) Wall. ex Guill. & Perr. and thorn forest dominate (Qureshi & Shah 2004).

The Gir Forest is largely composed of dry deciduous vegetation, which is classified as 5A/C1b biogeographic subtype (Champion & Seth 1968). Wild ungulate species of Gir are chital, sambar (*Cervus unicolor*, Kerr), nilgai (*Boselaphus tragocamelus*, Pallas), four-horned antelope (*Tetracerus quadricornis*, Blainville), chinkara (*Gazella bennettii*, Sykes) and wild pig (*Sus scrofa*, Linnaeus). In Gir, chital constitute 91% in terms of density and 78% of the wild ungulate community biomass (Dave 2008). Chital contributes 44–50% to the lion's diet (Jhala *et al.* 2006). The other major food source for lions in Gir was livestock, contributing between 26–70% to the lion's diet (Chellam 1993, Jhala *et al.* 2006, Joslin 1973).

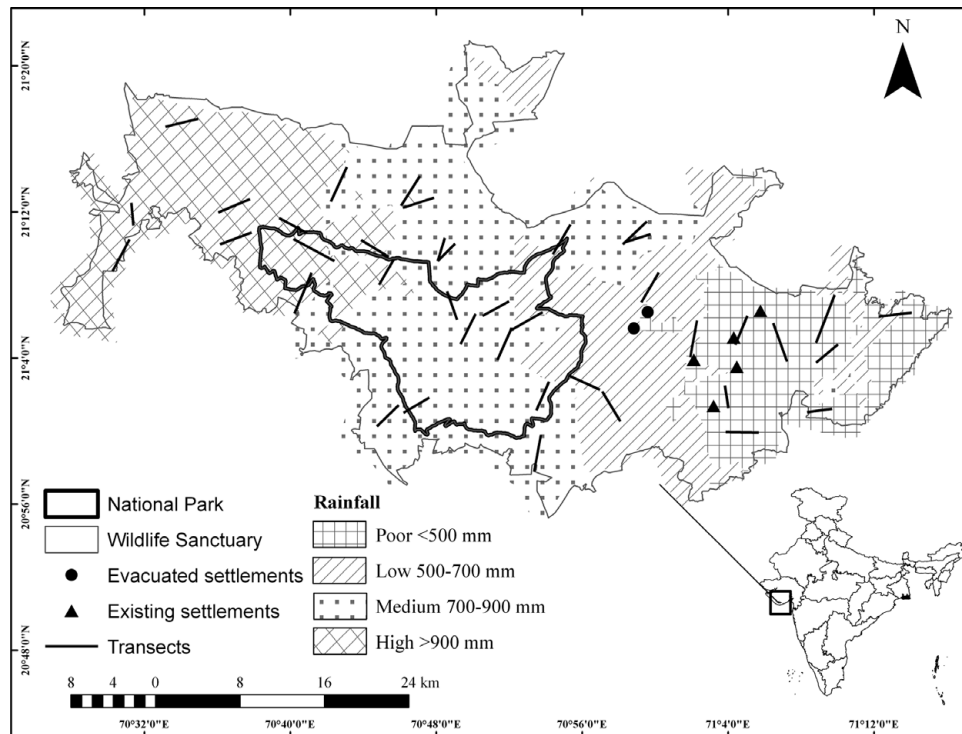
The study was conducted at two spatial scales; at the landscape scale we sampled the entire Gir Forest. At a local scale, we sampled two similar sites in the eastern part of the Gir Forest constituting two evacuated settlement sites (livestock free) and the grazing areas of five settlements (area sympatric with livestock). By estimating and comparing chital demographic parameters from these two sites we controlled for the confounding factors of topography, pastoral settlement site selection (as they tend to be located near perennial water), lion density and plant productivity resulting from the rainfall gradient (Allcock & Hik 2003, Coe *et al.* 1976, Harrington *et al.* 1995).

## METHODS

### Chital demographic characteristics at the landscape scale

We used distance sampling (Buckland *et al.* 1993, Burnham *et al.* 1980) on systematic line transects ( $n = 44$  spatial and 82 temporal replicates; with 231 km of effort) spaced throughout the Gir Forest for estimating chital densities and group sizes between December 2006 and January 2006. The Gir Forest is divided into 37 forest blocks for administrative purposes. We systematically distributed line transects throughout the entire Gir Forest by demarcating one or two line transects in each forest block (Figure 1). Each 2–3-km transect was sampled two or three times during early morning hours (6h30–8h30) when ungulate activity was highest. Chital density was estimated using the program DISTANCE 5.0 (Thomas *et al.* 2010). Mean (MGS) and typical group sizes (TGS) of chital (Jarman 1974) were computed. Data on TGS were bootstrapped (Krebs 1989) 100 times to generate standard errors and we compared MGS and TGS between livestock-free and sympatric areas by means of a  $t$ -test (Zar 2005).

The nutritional pinch period in Gir is just prior to the onset of the rainy season. During this period (last week



**Figure 1.** Location of foot transects and intensive study area around the evacuated and existing pastoral settlements on a precipitation gradient map of the Gir Forest. Map inset shows the location of Gir within the State of Gujarat, India.

of May and first week of June 2006) we systematically sampled throughout the Gir Forest and scored a minimum of three chital in each group encountered ( $n = 730$  chital) for body condition. The index consisted of scoring different regions of the chital's body, i.e. the rump, thigh, pelvic girdle, pectoral girdle and ribs (Riney 1960). We used multi-response permutation procedure (MRPP, Berry & Mielke 1983) in BLOSSOM software (Cade & Richards 2005) to simultaneously compare the five body-condition scores of chital obtained from livestock-free areas and areas sympatric with livestock. We computed the fawn to doe ratios (Caughley 1977, Skalski *et al.* 2005) of chital considering sampling with replacement scheme and compared them between livestock-free and sympatric areas using Fisher's Exact test (Zar 2005). Chital density, mean group size and typical group size were compared between areas that were sympatric and livestock-free by independent-sample *t*-tests (Zar 2005).

#### Growth rate and abundance of chital in relation to livestock abundance at the landscape scale

Several researchers have reported ungulate densities of Gir (Berwick 1974, Goyal *et al.* 2004, Joslin 1973, Khan *et al.* 1996). Simultaneously, a good record has been kept by the protected-area management on the number of human families and livestock resettled in the past 30 y (Singh & Kamboj 1996). We used this

information to compute the realized rate of increase for chital by regressing natural logarithm-transformed density estimates against time (Caughley 1977) for the entire Gir Forest and separately for the livestock-free (National Park) and sympatric (Sanctuary) areas of the Gir Forest. We computed the Pearson's correlation coefficient (Zar 2005) between chital abundance and livestock (cattle and buffalo) abundance over a temporal scale of 30 y ( $n = 5$  population estimates).

#### Chital demography at the local scale

At these two ecologically similar sites in the eastern part of Gir Forest, we collected data on chital group sizes, fawn to doe ratio ( $n = 45$  and 52 for livestock-free and sympatric area, respectively), body condition ( $n = 124$  and 160 for livestock-free and sympatric area, respectively), and density ( $n = 32$  and 36 for livestock-free and sympatric area, respectively) by line transects ( $n = 68$  spatial replicates, Buckland *et al.* 1993). The data were analysed to compare chital demographic parameters between livestock-free and sympatric areas of the Gir Forest.

#### Livestock density

The livestock in the Gir Forest are herded into thorn corrals at each settlement every night as an anti-predatory

strategy against lions and leopards. Livestock numbers were estimated for each settlement in the intensive study area by total counts when they were confined in the corrals.

Pastoralists take their stock out into the forest every morning to graze and return to the settlement before sundown. We accompanied livestock on their grazing circuits ( $n = 50$ ) with a hand-held GPS unit (Garmin™ 72) to determine the route and distance they travel. We buffered each settlement with the average linear distance moved by the livestock to determine the area of impact by livestock (Riginos & Hoffman 2003). Density of livestock was computed as the total number divided by their foraging area.

### Herbaceous biomass at a local scale

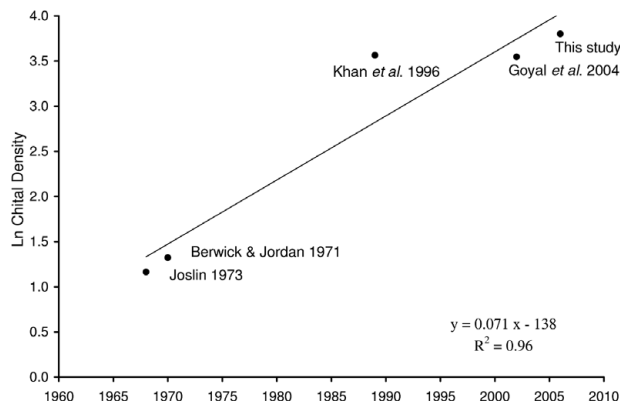
We set up  $10 \times 10$ -m ungulate-proof exclosures with chain-link fencing close to settlement sites (high-intensity livestock grazing  $n = 3$  within 500 m of settlement), far from settlement sites (low-intensity livestock grazing  $n = 3$ , 500–1500 m from settlements), and in livestock-free areas ( $n = 4$ ). We sampled peak above-ground biomass (AGB) just prior to the next growing season (May 2006) by clipping five paired quadrats of  $1 \text{ m}^2$  inside and outside each exclosure (Beebe *et al.* 2002). Clipped herbaceous biomass was sorted to species and was classified as palatable and unpalatable based on chital and livestock food habits (Dave 2008) and oven dried at  $60^\circ\text{C}$  to constant dry weight. We analysed the herbaceous biomass data with two-way ANOVA (Zar 2005) with main effects as: (1) Livestock grazing intensity category having three treatments (close to settlement, far from settlements, and livestock-free areas) and (2) Exclosures having two treatments i.e. inside (ungrazed) and outside (grazed).

## RESULTS

### Effect of sympatric livestock on chital demography: comparisons at the landscape scale

Mean group size (MGS  $\pm$  SE) of chital ( $n = 296$  groups) was  $7.11 \pm 0.8$  while typical group size (TGS  $\pm$  SE) was  $18.5 \pm 1.7$  for the entire Gir Forest. Mean group sizes were similar between livestock-free ( $6.73 \pm 0.96$ ) and sympatric areas ( $7.30 \pm 1.0$ ;  $t$ -test:  $t = 0.99$ ,  $P = 0.34$ ). Typical group size of chital in livestock-free areas was smaller ( $10.0 \pm 2.0$ ) compared with typical groups observed in areas sympatric with livestock ( $21.4 \pm 3.78$ ,  $t$ -test,  $t = 18.9$ ,  $P < 0.001$ ).

Body condition of chital in livestock-free areas was significantly better (MRPP, test statistic =  $-14.0$ ,  $P < 0.001$ ). Chital density  $\hat{D}$  ( $\pm$ SE) in the Gir Forest was estimated at  $44.8 \pm 7.1$  individuals  $\text{km}^{-2}$ . Chital density



**Figure 2.** The natural logarithm of chital density plotted against years (1969 and 2006) for computing the realized rate of increase for chital (Axis axis) in the Gir Forest.

in areas sympatric with livestock was  $47.0 \pm 9.3$  indiv.  $\text{km}^{-2}$  and was similar to livestock-free areas ( $33.2 \pm 6.6$  chital  $\text{km}^{-2}$ ,  $t$ -test,  $t = 1.39$ ,  $P = 0.17$ ). Chital densities were correlated with average rainfall with marginal statistical significance due to small sample size of four rainfall zones (Pearson's correlation coefficient,  $r = 0.923$ ,  $P = 0.077$ ). The fawn to doe ratio for chital in Gir was  $0.43 \pm 0.03$ . The fawn to doe ratio did not differ between areas sympatric with livestock ( $0.42 \pm 0.043$ ) and livestock-free areas ( $0.44 \pm 0.036$ , Fisher's exact test,  $P = 0.554$ ).

### Growth rate and abundance of chital in relation to livestock abundance at landscape scale

The realized rate of increase ( $r \pm$  SE) for chital was  $0.071 \pm 0.014$  ( $P \leq 0.001$ ,  $R^2 = 0.9$ ) in the Gir Forest, with initial population density of  $3.2$  indiv.  $\text{km}^{-2}$  (1968–1971, Joslin 1973) that increased to  $44.8$  indiv.  $\text{km}^{-2}$  in 2006 (present study) (Figure 2). The realized rate of increase for chital population did not differ between areas sympatric with livestock ( $0.069 \pm 0.008$ ,  $P = 0.003$ ,  $R^2 = 0.97$ ) and livestock-free areas ( $0.055 \pm 0.008$ ,  $P = 0.02$ ,  $R^2 = 0.95$ ;  $t$ -test,  $t = 1.33$ ,  $P = 0.22$ ). On a temporal scale chital densities were found to increase as livestock densities decreased (Pearson's correlation coefficient  $r = -0.93$ ,  $P = 0.022$ ).

### Livestock density, composition and grazing impact zone at local scale

Official livestock population for the Gir Forest was reported to be 11 000 (Pathak *et al.* 2002). Our seasonal total counts of eight pastoral settlements yielded an estimate of  $533 \pm 86.9$  cattle and  $1747 \pm 234$  buffalo. On average livestock travelled a total distance (mean  $\pm$  SE) of  $5.8 \pm$

**Table 1.** Comparison of density (mean  $\pm$  SE), mean group size (MGS) and typical group size (TGS) of chital (*Axis axis*) in two ecologically similar sites differing in presence of sympatric livestock in the eastern part of Gir Sanctuary.

Chital ( <i>Axis axis</i> )	Livestock present	Livestock absent	Statistical test	Test statistic	P value
Density ( $\text{km}^{-2}$ )	55.8 $\pm$ 9.6	89.5 $\pm$ 12.9	<i>t</i> test	2.61	0.037
Fawn to doe ratio	0.44 $\pm$ 0.036	0.49 $\pm$ 0.058	Fisher's exact test		0.54
Mean group size	5.92 $\pm$ 0.87	5.95 $\pm$ 0.82	<i>t</i> test	0.03	0.98
Typical group size	11.9 $\pm$ 0.36	10.6 $\pm$ 0.28	<i>t</i> test	2.84	0.006

0.22 km during their daily grazing circuit in the cold season and were observed to have an average ( $\pm$  SE) daily linear displacement of  $1.9 \pm 0.12$  km from settlements. Some impact zones of two or more pastoral sites overlapped i.e. these areas were used by livestock from more than one settlements. Therefore, a common buffer of 1.9 km was created on the cluster of settlement locations to generate a polygon ( $9.8 \pm 1.1 \text{ km}^2$ ) to compute livestock density and their overall impact zone. The average livestock density for our study area was  $31.4 \text{ livestock km}^{-2}$  for the cold season of 2005–2006.

#### Response of chital demography and herbaceous biomass to livestock at the local scale

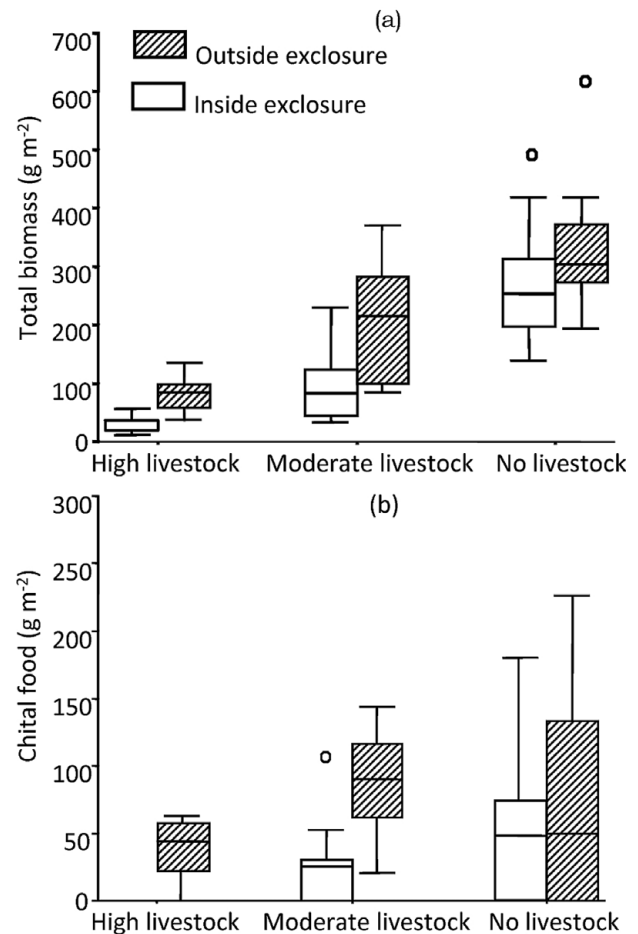
When we controlled for the effect of rainfall and pastoral site location, typical group size and density were significantly higher in the livestock-free area compared with the area sympatric with livestock (Table 1). However, fawn to doe ratio, mean group size and body condition did not differ between areas sympatric and free from livestock (Table 1).

Peak above-ground biomass of herbaceous vegetation increased as livestock grazing intensity decreased ( $1438 \pm 152 \text{ kg ha}^{-1}$  in areas sympatric with livestock to  $3260 \pm 209 \text{ kg ha}^{-1}$  in areas devoid of livestock) (Figure 3). However, chital food production in moderately grazed areas ( $877 \pm 92 \text{ kg ha}^{-1}$ ) was more than in areas devoid of livestock ( $539 \pm 167 \text{ kg ha}^{-1}$ ) after short-term (1 y) grazing exclusion (Figure 3).

## DISCUSSION

#### Effect of livestock on chital at the landscape scale

Most of our predictions in support of the hypothesis that livestock detrimentally affect chital did not hold at the landscape scale. We believe that two factors were primarily responsible for non-conformity to our predictions at the landscape scale. These factors were: (1) response of chital to a precipitation gradient, as chital density was found to be correlated with rainfall and increased from east to west by a factor of 0.6; and (2) the livestock-free habitat comprising the National Park is more hilly and not the prime habitat for chital (Khan 1995), good chital habitat is found in the eastern and



**Figure 3.** Above-ground herbaceous biomass (AGB) sampled during the month of May 2005 and 2006 at different livestock grazing intensity in the Gir Forest. The box-and-whisker plots represent the interquartile range of total herbaceous above-ground biomass (a) and herbaceous chital food biomass (b); boxes are limited by the 25th and 75th percentile, the midlines in boxes are the median values, the whiskers are mild outliers, while the severe outlier values are shown as circles.

western parts of the Sanctuary which were also used by livestock.

Many studies have explained the regulatory role of food resources in maintaining equilibrium density of ungulates (Dublin *et al.* 1990, Sinclair 1977, Skogland 1980). Productivity of semi-arid regions is primarily dictated by annual rainfall (Allcock & Hik 2003, Harrington *et al.* 1995). Ungulate populations in such regions are mainly regulated through food resource availability dictated by

rainfall patterns (Illius & O'Connor 2000, Mandujano & Naranjo 2010). Chital in the semi-arid landscape of Gir likely conform to this pattern. Due to these overriding effects of habitat productivity and habitat suitability on chital, negative competitive effects of livestock on chital were likely masked (Bugmann & Weisberg 2003).

#### Effect of livestock on chital at the local scale

When we controlled for this masking effect of confounding factors by selecting two sites with similar rainfall and pastoral site selection factors, differing only in the presence of sympatric livestock, evidence was found in support of our competition hypothesis (Table 1). Chital density was significantly higher in livestock-free areas compared with areas with livestock. Short- to medium-term responses of average group size, body condition, and fawn to doe ratio were similar between the two sites (Table 1). The annual rainfall during 2005–2006 was exceptionally good, and we believe that these short-term response parameters were influenced by this higher food availability which reduced average competitive interactions between chital and livestock. The long-term response of depressed chital density had a substantial size effect with chital density being 60% higher in livestock free-area.

#### Long-term effect of livestock removal on chital at the landscape scale

Chital population of the Gir Forest was found to increase at the realized rate of  $0.07 \pm 0.014$ . Most ungulate populations have a potential  $r_{max}$  between 0.16 and 0.22 (Owen-Smith 2006). The realized rate of increase ( $r$ ) for chital for the past 34 y was much lower than the potential  $r_{max}$ . This could be either due to intra- and inter-specific competition for limited resources or high rate of predation. Gir has a high density of large carnivores, with about 18 lions and 15 leopards per 100 km<sup>2</sup> (Singh & Kamboj 1996). We failed to detect differences in the realized growth rate of chital between livestock-free areas and areas sympatric with livestock. When the central part of the Gir Forest was gazetted as a National Park, all the resident livestock herders from the National Park area were relocated outside or on the periphery of the Gir Forest. However, during the past 34 y livestock densities have also been reduced in the sanctuary part of the Gir Forest by voluntarily relocating pastoral families and their livestock outside of Gir Forest as a management practice (Pathak *et al.* 2002). Therefore, even though livestock were sympatric with chital in the sanctuary area their densities have been declining over the past 34 y. This, combined with better

chital habitat found in the sanctuary area could be the probable reason that chital continued to increase at a similar rate between sympatric and livestock-free areas. The continued increase in the chital population in the Gir Forest for the past 34 y cannot be solely attributed to removal and reduction of livestock from the Gir Forest. As a result of a cyclone in 1983, many trees in the Gir Forest were uprooted; several of these still survive lying prostrate with their foliage within browsing reach of ungulates. This opening up of the canopy and increase in browse availability has likely increased the ungulate-carrying capacity of Gir. Besides, illegal hunting of wild ungulates has been almost eliminated in the Gir Forest by better management, protection measures, stringent law and increased awareness (Pathak *et al.* 2002). With a lack of past detailed information on competition with livestock, increase in forage availability, or illegal harvest rates, it is not possible to attribute the continued increase of chital to any one of these factors. It is also possible that all of the three factors may be contributing to the observed rate of increase in chital density.

A better insight is provided into the long-term effect of livestock removal by the high negative correlation ( $r = -0.93$ ,  $P = 0.022$ ) obtained between livestock and chital numbers in the Gir Forest. Although correlation analysis cannot be ascribed as cause and effect (Draper & Smith 1981), this result lends additional support to the competition hypothesis.

#### Effect of livestock removal and different grazing intensity on herbaceous vegetation

The impact of livestock on the herbaceous community is through biomass removal (Fleischner 1994) and trampling (Cumming & Cumming 2003, Hobbs & Searle 2005). Exclosure studies showed that grazing by ungulates (wild and domestic) reduced above-ground biomass substantially. Wild ungulates accounted for removal of  $14.4\% \pm 6.9\%$  of the standing above-ground biomass, whereas both livestock and wild ungulates removed  $54.4\% \pm 5.0\%$  of the standing above-ground biomass. Considering utilization by wild ungulates to be similar between livestock-free areas and areas sympatric with livestock, removal by livestock was estimated at 40.0% of the standing AGB. Livestock grazing was bound to reduce AGB and our result shows the obvious; however, does this reduction in AGB translate to reduced forage availability for chital? We find that chital food biomass is significantly reduced in the proximity of settlement sites – an area of high livestock impact. But moderately grazed areas by livestock still had good quantities of chital food available at the worst time of the year, i.e. the hot season prior to rainy season (Figure 3). When this moderately used area by livestock was protected

from grazing, chital food biomass equalled or exceeded that produced in livestock-free areas – a response that is suggestive of a highly resilient system even with short-term protection from grazing. Considering the absence of any large native coarse feeder in Gir cattle and buffalo are likely fulfilling an important ecological role by grazing on coarse perennial grasses and facilitating forage availability to chital (Gwyne & Bell 1968, McNaughton 1979). Wild ungulate grazing did not compensate for the removal of livestock as AGB was substantially higher in livestock-free areas. This suggests that wild ungulates did not negatively impact livestock food resources (Young *et al.* 2005). Over 80% of the AGB in livestock-free areas was composed of perennial coarse grasses, which are not the preferred food of chital (Dave 2008), while in moderately grazed areas by livestock 43% of AGB was composed of chital food plants, which is indicative of facilitation by livestock. Typical group size of chital was observed to be larger in areas sympatric with livestock both at the larger landscape scale and local scale of the Gir Forest, suggestive of higher food availability for chital caused as a result of possible facilitation by livestock. Overall, our data suggest that habitat productivity and suitability were more important for chital demographic response in comparison to competition with livestock.

Livestock form a substantial part of the lion's diet (Chellam 1993, Jhala *et al.* 2006, Joslin 1973). Lion densities and pride sizes were observed to be larger in areas sympatric with livestock (Jhala *et al.* 2006). Considering these ecological roles of livestock in the Gir Forest, it may be relevant to consider management strategies that maintain low livestock densities instead of strategies that aim at total removal. However, we caution that though our data and experimental design of vegetation exclosures targeted the pinch period of the year, our work was done in years of relatively good rainfall. It is likely that in years of poor rainfall, competition between chital and livestock can become severe and could deplete chital food with serious consequences. Also, our study targeted chital, an intermediate feeder (Hofmann 1985) with the ability to be extremely selective due to morphological adaptation of mouth parts in comparison to other wild ungulates. It is possible that competition with livestock may be an important limiting factor for other wild ungulates that have similar diets to livestock (Madhusudan 2004, Mishra *et al.* 2004).

In conclusion, our data support the competition hypothesis with livestock depressing chital densities – a long-term response to competition. In the short term, we either found no effect of sympatric livestock or an indication of grazing facilitation. Our study highlights that interactions between native wild ungulates and livestock are complex and varied under different ecological conditions. Interactions between chital and livestock are likely driven through a dynamic mechanism

of forage production and their density wherein, when forage production is low and density of livestock is high, competition is likely to be a much stronger force than facilitation (Hobbs *et al.* 1996). To mimic the livestock density of moderately grazed areas wherein our results suggest minimal negative impacts on chital food plants we recommend that livestock densities in Gir be reduced by half of the current stocking densities. Large ungulates (livestock) have significantly greater trampling impacts (Hobbs & Searle 2005) therefore we recommend that pastoral sites be rotated at an interval of a 3–4 y period so as to have minimal long-term trampling effects on the vegetation as observed by our exclosure studies in close proximity to pastoral settlements (where chital food plants were greatly reduced but were extremely resilient). Such management strategies would minimize the detrimental effect of livestock on wild ungulates and still be able to harness the positive role that livestock are likely to play.

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## LITERATURE CITED

- ALLCOCK, K. G. & HIK, D. S. 2003. What determines disturbance-productivity-diversity relationships? The effect of scale, species and environment on richness patterns in an Australian woodland. *Oikos* 102:173–185.
- BEAUCHAMP, G. 2003. Group size effects on vigilance: a search for mechanisms. *Behavioural Processes* 63:111–121.
- BEDNEKOFF, P. A. & LIMA, S. L. 2004. Risk allocation and competition in foraging groups: reversed effects of competition if group size varies under risk of predation. *Proceedings of the Royal Society, Biology Letters* 271:1491–1496.
- BEEBE, J., EVERETTE, R., SCHERER, G. & DAVIS, C. 2002. *Effect of fertilizer applications and grazing exclusion on species composition and biomass in wet meadow restoration in eastern Washington*. Research Paper PNW-RP-542, Pacific Northwest Research Station, Forest Service, United States Department of Agriculture, Washington, DC. 15 pp.
- BERRY, K. J. & MIELKE, P. W. 1983. Computation of finite population parameters and approximate probability values for multi-response permutation processes (MRPP). *Communication in Statistics – Simulation and Computation* 12:83–107.
- BERWICK, S. 1974. *The community of wild ruminants in Gir ecosystem*. PhD thesis, Yale University, Connecticut. 225 pp.

- BERWICK, S. H. & JORDAN, P. A. 1971. First report of Yale–Bombay Natural History Society studies of wild ungulates at the Gir Forest, Gujarat, India. *Journal of Bombay Natural History Society* 68:412–423.
- BROCHU, L., CARON, L. & BERGERON, J. M. 1988. Diet quality and body condition of dispersing and resident voles (*Microtus pennsylvanicus*). *Journal of Mammalogy* 69:704–710.
- BUCKLAND, S. T., ANDERSON, A. R., BURNHAM, K. P. & LAAKE, J. L. 1993. *Distance sampling: estimating abundance of biological populations*. Chapman and Hall, London. 446 pp.
- BUGMANN, H. & WEISBERG, P. 2003. Forest ungulate interactions: monitoring, modeling and management. *Journal of Nature Conservation* 10:193–201.
- BURNHAM, K. P., ANDERSON, D. R. & LAAKE, J. L. 1980. Estimation of density from line transect sampling of biological populations. *Wildlife Monograph* 72:1–202.
- CADE, B. S. & RICHARDS, J. D. 2005. *User manual for BLOSSOM statistical software*. USGS, Fort Collins Science Center, Reston. 124 pp.
- CAUGHLEY, G. 1977. *Analysis of vertebrate populations*. (First edition). John Wiley & Sons, Chichester. 234 pp.
- CHAMPION, H. & SETH, S. 1968. *A revised study of the forest types of India*. Government of India Press, New Delhi. 404 pp.
- CHELLAM, R. 1993. *Ecology of Asiatic lion (Panthera leo persica)*. PhD thesis, Saurashtra University, Rajkot, India. 170 pp.
- CLUTTON-BROCK, T. H., ILLIUS, A. W., WILSON, K., GRENFELL, B. T., MACCOLL, A. D. C. & ALBON, S. D. 1997. Stability and instability in ungulate populations: an empirical analysis. *American Naturalist* 149:195–219.
- COE, N. J., CUMMING, D. H. & PHILLIPSON, J. 1976. Biomass and production of large African herbivores in relation to rainfall and primary production. *Oecologia (Berlin)* 22:341–354.
- CUMMING, D. H. M. & CUMMING, G. S. 2003. Ungulate community structure and ecological processes: body size, hoof area and trampling in African savannas. *Oecologia* 134:560–568.
- DAVE, C. V. 2008. *Ecology of chital (Axis axis) in Gir*. PhD thesis, Saurashtra University, Rajkot, India. 263 pp.
- DRAPER, N. & SMITH, H. 1981. *Applied regression analysis*. (Second edition). John Wiley & Sons, New York. 407 pp.
- DUBLIN, H. T., SINCLAIR, A. R. E., BOUTIN, S., ANDERSON, M. & ARCESE, P. 1990. Does competition regulate ungulate populations? Further evidence from Serengeti, Tanzania. *Oecologia (Berlin)* 82:283–288.
- FLEISCHNER, T. L. 1994. Ecological costs of livestock grazing in western North America. *Conservation Biology* 8:629–644.
- GOYAL, S. P., MUKHERJEE, S., QURESHI, Q., SANKAR, K., SHAH, N., DAVE, C. & ZALA, Y. P. 2004. Monitoring ungulates (relative abundance and density estimation). Pp. 15–35 in Jhala, Y. V. (ed.). *Monitoring of Gir*. Wildlife Institute of India, Dehradun.
- GWYNE, M. & BELL, R. H. V. 1968. Selection of grazing components by grazing ungulates in the Serengeti National Park. *Nature* 220:390–393.
- HARRINGTON, R. A., FOWNES, J. H., MEINZER, F. C. & SCOWCROFT, P. G. 1995. Forest growth along a rainfall gradient in Hawaii: *Acacia koa* stand structure, productivity, foliar nutrients, and water and nutrient use efficiencies. *Oecologia (Berlin)* 102:277–284.
- HOBBS, N. T. & SEARLE, K. R. 2005. A reanalysis of the body mass scaling of trampling by large herbivores. *Oecologia* 145:462–464.
- HOBBS, N. T., BAKER, D. L., BEAR, G. D. & BOWDEN, D. C. 1996. Ungulate grazing in sagebrush grassland: mechanisms of resource competition. *Ecological Applications* 6:200–217.
- HOFMANN, R. R. 1985. Digestive physiology of the deer – their morphophysiological specialisation and adaptation. Pp. 393–407 in Fennessy, P. F. & Drew, K. R. (eds.). *Biology of deer production*. The Royal Society New Zealand Bulletin 22, Wellington.
- ILLIUS, A. W. & O'CONNOR, T. G. 2000. Resource heterogeneity and ungulate population dynamics. *Oikos* 89:283–294.
- JARMAN, P. J. 1974. The social organization of antelope in relation to their ecology. *Behaviour* 48:215–267.
- JHALA, Y. V., CHELLAM, R., QURESHI, Q., PATHAK, B., MEENA, V., DAVE, C., CHAUHAN, K. & BANNERJEE, K. 2006. *Social organization and dispersal of Asiatic lions and ecological monitoring of Gir*. Technical Report. Wildlife Institute of India, Dehradun. 100 pp.
- JOSLIN, P. 1973. *Asiatic lion: a study of ecology and behaviour*. PhD thesis. University of Edinburgh. 249 pp.
- KHAN, J. A. 1995. Conservation and management of Gir Lion Sanctuary and National Park, Gujarat, India. *Biological Conservation* 73:183–188.
- KHAN, J. A., CHELLAM, R., RODGERS, W. A. & JOHNSINGH, A. J. T. 1996. Ungulate density and biomass in the tropical dry deciduous forests of Gir, Gujarat, India. *Journal of Tropical Ecology* 12:149–162.
- KOTHARI, A., PANDE, P., SINGH, S. & VARIAVA, D. 1989. *Management of National Parks and Wildlife Sanctuaries in India. A status report*. Indian Institutes of Public Administration, New Delhi. 298 pp.
- KREBS, C. J. 1989. *Ecological methodology*. (First edition). Harper and Row, Publishers, New York. 654 pp.
- MADHUSUDAN, M. D. 2004. Recovery of wild large herbivores following livestock decline in a tropical Indian wildlife reserve. *Journal of Applied Ecology* 41:858–869.
- MANDUJANO, S. & NARANJO, E. 2010. Ungulate biomass across a rainfall gradient: a comparison of data from neotropical and palaeotropical forests and local analyses in Mexico. *Journal of Tropical Ecology* 26:13–23.
- MCNAUGHTON, S. J. 1979. Grazing as an optimization process: grass–ungulate relationships in the Serengeti. *American Naturalist* 113:691–703.
- MISHRA, C., VAN WIEREN, S., KENTER, P., HEITKÖNIG, I. & PRINS, H. H. T. 2004. Competition between domestic livestock and wild bharal *Pseudois nayaur* in the Indian Trans-Himalaya. *Journal of Applied Ecology* 41:344–354.
- OWEN-SMITH, N. 2002. *Adaptive herbivore ecology: from resources to populations in variable environments*. Cambridge University Press, Cambridge. 398 pp.
- OWEN-SMITH, N. 2006. Demographic determination of the shape of density dependence for three African ungulate populations. *Ecological Monographs* 76:93–109.
- PATHAK, B., PATI, B. P., KUMAR, R., KUMAR, A., RAVAL, P. P., PATEL, V. S. & RANA, V. J. 2002. *Biodiversity Conservation Plan for Gir (A supplementary Management Plan, 2002–03 to 2006–07)*. Wildlife Circle, Junagadh, Gujarat Forest Department.

- PICKFORD, G. D. & REID, E. H. 1948. *Forage utilization on summer cattle ranges in eastern Oregon*. Circular 796. United States Department of Agriculture, Washington, DC. 27 pp.
- PRINS, H. H. T. 2000. Competition between wildlife and livestock in Africa. Pp. 51–80 in Prins, H. H. T., Grootenhuis, J. G. & Dolan, T. T. (eds.). *Wildlife conservation by sustainable use*. Kluwer Academic Publishers, Boston.
- PRINS, H. H. T. & OLFF, H. 1998. Species-richness of African grazer assemblages: towards a functional explanation. Pp. 449–490 in Newbery, D. M., Prins, H. H. T. & Brown, N. (eds.). *Dynamics of tropical communities*. Blackwell Science, Oxford.
- PUTMAN, R. J. 1996. Introduction. Pp.1–10 in Putman, R. J. (ed.). *Competition and resource partitioning in temperate ungulate assemblies*. Wildlife Ecology and Behaviour Series. Chapman and Hall, London.
- QURESHI, Q. & SHAH, N. 2004. Vegetation and habitat monitoring. Pp. 8–14 in Jhala, Y. V. (ed.). *Monitoring of Gir*. Wildlife Institute of India, Dehradun.
- RANNESTAD, O. H., DANIELSEN, T., MOE, S. R. & STOKKE, S. 2006. Adjacent pastoral areas support higher densities of wild ungulates during the wet season. *Journal of Tropical Ecology* 22:675–683.
- RIGINOS, C. & HOFFMAN, T. M. 2003. Changes in population biology of two succulent shrubs along a grazing gradient. *Journal of Applied Ecology* 40:615–625.
- RINEY, T. 1960. A field technique for assessing physical condition of some ungulates. *Journal of Wildlife Management* 24:92–94.
- ROBBINS, C. T. 1993. *Wildlife feeding and nutrition*. New York Academic Press, New York. 343 pp.
- SCHOENER, T. W. 1983. Field experiments on interspecific competition. *American Naturalist* 122:240–285.
- SINCLAIR, A. R. E. 1977. *The African buffalo: a study of resource limitations of population*. University of Chicago Press, Chicago. 354 pp.
- SINCLAIR, A. R. E. & NORTON-GRIFFITHS, M. 1982. Does competition or facilitation regulate migrant ungulate populations in the Serengeti? *Oecologia (Berlin)* 53:361–369.
- SINCLAIR, A. R. E., FRYXELL, J. M. & CAUGHLEY, G. 2006. *Wildlife ecology, conservation, and management*. (Second edition). Blackwell Publishing, Oxford. 488 pp.
- SINGH, H. S. & KAMBOJ, R. D. 1996. *Biodiversity conservation plan for Gir (A management plan for Gir Sanctuary and National Park, Part-I & II)*. Gujarat Forest Department, India. 247 & 157 pp.
- SKALSKI, J. R., RYDING, K. E. & MILLSPAUGH, J. J. 2005. *Wildlife demography: analysis of sex, age, and count data*. Elsevier Academic Press, Burlington. 636 pp.
- SKOGLAND, T. 1980. Comparative summer feeding strategies of arctic and alpine *Rangifer*. *Journal of Animal Ecology* 49:81–98.
- THOMAS, L., BUCKLAND, S.T., REXSTAD, E. A., LAAKE, J. L., STRINDBERG, S., HEDLEY, S. L., BISHOP, J. R. B., MARQUES, T. A. & BURNHAM, K. P. 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. *Journal of Applied Ecology* 47:5–14.
- YOUNG, T. P., PALMER, T. M. & GADD, M. E. 2005. Competition and compensation among cattle, zebras, and elephant in a semi-arid savanna in Laikipia, Kenya. *Biological Conservation* 121:351–359.
- ZAR, J. H. 2005. *Biostatistical analysis*. (Second edition: third Indian reprint). Pearson Education (Singapore) Pte. Ltd., New Delhi. 718 pp.

## **Demographic parameters of endangered Asiatic lions (*Panthera leo persica*) in Gir Forests, India**

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## Demographic parameters of endangered Asiatic lions (*Panthera leo persica*) in Gir Forests, India

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Historical bottlenecks, habitat fragmentation, and small populations resulting in decreased heterozygosity typify conservation concerns of globally threatened carnivore populations. We monitored the endangered Asiatic lion (*Panthera leo persica*) by radiotelemetry ( $n = 20$ ), individual profiles ( $n = 55$  adults and 91 cubs from 38 litters), and observed mortalities ( $n = 88$ ) to estimate survival, mortality causes, interlitter interval, and litter size in the Gir Forest region of Gujarat, western India, between 2000 and 2010. Lions increased from about 177 in 1968 to about 411 by 2010 with  $r = 0.022 \pm 0.001$  SE. The male:female ratio was  $0.63 \pm 0.04$  SE, whereas the cub:adult lioness ratio was  $0.37 \pm 0.02$  SE. Mating peaked in winter and birth peaked in late summer. Average litter size was  $2.39 \pm 0.12$  SE. Interbirth interval was 1.37 years  $\pm 0.25$  SE ( $n = 7$  lionesses) and was higher ( $2.25 \pm 0.41$  years) when cubs of the previous litter survived to independence. Cub survival was  $0.57 \pm 0.04$  SE, whereas survival from cub to recruitment age (3 years) was  $51\% \pm 4\%$  SE, with mortalities due to infanticides being  $30\% \pm 7\%$ . Juvenile (1–2 years) and subadult (2–3 years) survival rates were  $0.87 \pm 0.04$  SE and  $0.90 \pm 0.04$ , respectively. Average annual survival rate of adult lions (>3 years) was  $0.9 \pm 0.12$  SE. Adult lions died primarily due to natural causes (54.5%); however, human-caused mortality was substantial (43.2%) and was likely additive to natural causes. Demographic parameters of genetically less-diverse Asiatic lions did not differ from those of African lions.

Key words: inbreeding, litter size, mortality, rate of increase, sex ratio, survival

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Most large carnivores have low genetic diversity (Caro and Laurenson 1994; O'Brien 2003). Low genetic diversity coupled with their low density, small population size, and fragmented habitats are considered major impediments to their conservation (Brook et al. 2002). The last free-ranging population of Asiatic lions (*Panthera leo persica*) in the Gir Forests of western India exemplifies these problems (Driscoll et al. 2002; Johnsingh et al. 1998; O'Brien 2003).

With their origin in East and South Africa (Antunes et al. 2008), Asiatic lions extended from the African Mediterranean coast into Eastern Europe, the Middle East, and into India sometime between 3,000 and 2,000 years ago (Divyabhanusinh 2005). Driscoll et al. (2002) suggest that about 2,680 (range 1,081–4,279) years ago, the Kathiawar Peninsula where the Gir forest is located was separated from mainland India by rising sea level (Gupta 1972), causing the 1st genetic bottleneck that isolated the founders of the present Asiatic lion population, compelling them to inbreed for several generations (O'Brien 2003). A 2nd, less-severe bottleneck occurred at the onset of the 19th century when lions became restricted to the Gir Forests and their number declined to around 50 individuals,

due to hunting and habitat loss (Edwards and Fraser 1907; Kinnear 1920; Pocock 1930).

Allozyme and microsatellite studies indicate that the Asiatic lion population is genetically monomorphic due to an isolated, inbred population with a small founder base (O'Brien 2003; Shankaranarayanan et al. 1997; Wildt et al. 1987), although random amplified polymorphic DNA analysis showed some level of polymorphism in Asiatic lions (Shankaranarayanan et al. 1997). Although the extent of inbreeding and homozygosity in the Gir lion population is debatable, there is little doubt that these lions have decreased heterozygosity in comparison to African lions. Decreased heterozygosity likely diminishes reproductive vigor and survival and is believed to impair a population's long-term viability (Björklund 2003; Foose 1977; O'Brien et al. 1986; Packer et al. 1991).

Because of the timely and stringent protection by the rulers of Junagadh and, subsequently, during postindependence by



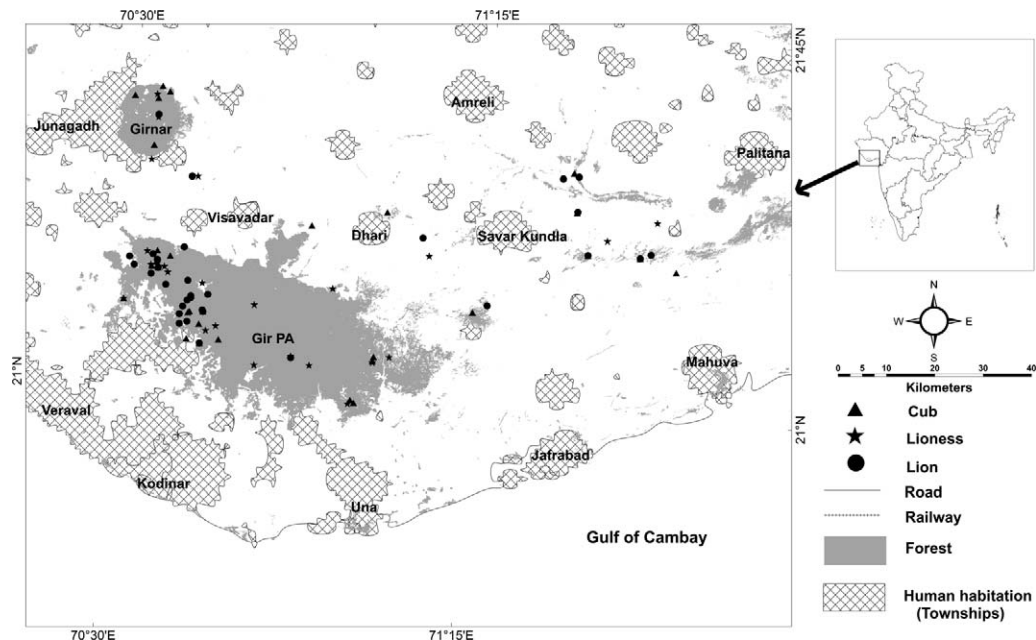
the state-run forest department, Asiatic lions have increased to about 400 (Gujarat Forest Department 2010) and dispersed into a large tract of agropastoral landscape adjoining the Gir Forests (Banerjee et al. 2010; Singh and Gibson 2011). Vital rates of an animal population determine its size and composition and represent the aggregate life-history performances of its constituents (Robinson et al. 2008). It is widely believed that the effects of inbreeding and subsequent low genetic diversity should manifest in poor population vital rates (Frankham et al. 2002). Yet declines in large carnivore populations are most often attributed to causes other than lack of measured genetic diversity and subsequent depression of population vital rates (Altizer et al. 2003; Caughley 1994). We collected long-term data from free-ranging Asiatic lions on survival, litter size, interlitter interval, and rate of population increase by radiotelemetry of 20 lions and individual monitoring of 55 lions, and compared these with genetically more diverse African lion (*Panthera leo leo*) populations to determine if the demography of the Gir lions was compromised due to inbreeding depression.

## MATERIALS AND METHODS

**Study area.**—The study was conducted between 2000 and 2010 across about 9,000 km<sup>2</sup> of the Gir Landscape within the southwestern part of the Saurashtra region in the state of Gujarat, western India. The Gir Landscape is a multiple land-use area composed of the 1,880-km<sup>2</sup> Gir Protected Area (Gir PA); the 180-km<sup>2</sup> Girnar Wildlife Sanctuary (Girnar); and approximately 7,000 km<sup>2</sup> of human-dominated agropastoral landscape of Amreli, Bhavnagar, and Junagadh districts (Eastern region; Fig. 1). The Gir Landscape, described elsewhere (Singh and

Gibson 2011), is a typical biogeographic representative of the semiarid Gujarat–Rajputana Zone (Rodgers and Panwar 1988), located between the coordinates 21°35'N, 70°28'E; 21°07'N, 70°28'E; 21°47'N, 72°02'E; and 21°08'N, 71°59'E. There are 3 distinct seasons: dry, hot summer (March–June, mean maximum temperature 38°C), monsoon (July–October, mean maximum temperature 33°C, average rainfall 980 mm), and mostly dry winter (November–February, minimum average temperature 5°C). Adult lion densities (lion numbers/100 km<sup>2</sup>) of Gir PA, Girnar, and Eastern region were 15, 6, and 2, respectively (Banerjee et al. 2010; Jhala et al. 2004, 2011). Gir PA has 50 Maldhari (local pastoralist) settlements and 14 forest settlement villages (human population 4,500, with approximately 23,440 livestock) inside the protected area boundary, along with 97 peripheral villages (human population approximately 150,000, with 94,600 livestock) that use resources such as fodder, fuel wood, and minor forest products from within Gir PA (Singh and Gibson 2011; Singh and Kamboj 1996). The 7,000-km<sup>2</sup> Eastern region consists of private farmlands and industrial and pastoral lands of private and government ownership. Livestock rearing for dairy products, seasonal crop agriculture, and horticulture are the main economies of the region. The landscape outside Gir PA is traversed by national and state highways, district- and village-level roads, and railway lines.

**Radiotelemetry.**—Twenty lions (10 males and 10 females) ranging between approximately 2.5 and 12 years, from different prides spaced throughout the Gir Landscape, were radiocollared (11 lions in Gir PA, 4 lions in Girnar, and 5 lions in Eastern region; Fig. 1). Lions were anesthetized using a combination of ketamine hydrochloride (2.5–3 mg/kg body weight) and medetomidine (0.04–0.06 mg/kg body weight—Kreeger 1996) injected intramuscularly using a gas-powered



**FIG. 1.**—Location centroids of study lions and location of litters used in the analysis of survivorship. Map inset shows the location of the Gir Landscape in Gujarat State, India. We used night-light satellite data for mapping human habitations (Elvidge et al. 1997) in the region. LISS-III sensor data of IRS-1C satellite was used to map extent of forest cover (Forest Survey of India 2009).

projectile (Telinject Inc., Agua Dulce, California) dart delivery system. We used the reversal agent atipamezole (0.05–0.1 mg/kg body weight) resulting in the total recovery of anesthetized lions within 3–10 min. Each sedated lion was sexed, aged, measured, and weighed, ectoparasites were collected, and the lion was photographed. Lions were equipped with combination of very-high-frequency ( $n = 10$ , Telonics Inc., Mesa, Arizona; and  $n = 4$ , Wildlife Materials Inc., Murphysboro, Illinois), global positioning system ( $n = 3$ , HABIT Research Ltd., Victoria, British Columbia, Canada; and  $n = 2$ , Vectronics Aerospace GmbH, Berlin, Germany), and global positioning system plus satellite ( $n = 1$ , Vectronics Aerospace GmbH) radiocollars. The collar weights were <1% of the body weight of the lions.

*Monitoring lions.*—Collared lions were monitored from the ground by a 4-wheel-drive vehicle or on foot, using a 3-element yagi antenna (AF Antronics Inc., Urbana, Illinois) and a handheld receiver (HABIT receiver model HR 2600; HABIT Research Ltd.; and Vectronics GPS Plus Handheld Terminal Unit; Vectronics Aerospace GmbH). Considering the vastness of the landscape, we attempted to visually locate every collared lion at least biweekly. Once activated, global positioning system and global positioning system–satellite collars provided 6–8 daily locations either via the Iridium 2-way satellite network using low-earth-orbit satellites (Iridium Communications Inc., McLean, Virginia) or the ultra-high-frequency–based ground download facility.

We additionally individually identified and monitored 55 lions (37 males and 18 females aged approximately 1.513 years) between 2004 and 2010 across the entire landscape, based on their unique vibrissae patterns and additional body marks (Jhala et al. 1999; Pennycuick and Rudnai 1970); we maintained their individual profiles based on repeated sightings in the database program LION version 1.0 (Badoni et al. 2005). We monitored these noncollared, known lions ( $n = 55$ ) by locating them visually at least once every 2 months.

We classified the 20 collared and 55 individually identified noncollared lions into 7 age categories (Jhala et al. 2004) based on body size, coloration, secondary sexual characteristics, and tooth eruption and wear (Schaller 1972). Age categories were: small cubs (<6 months), large cubs (6 months–1 year), juveniles (1–2 years), subadults (2–3 years), young adults (3–5 years), prime adults (5–10 years), and old adults (>10 years). We, and our field assistants, 1st practiced and compared our age-category classification skills on known-age captive and free-ranging lions to ensure consistency and accuracy. We could accurately and consistently age lions up to the age of 5 years. Variability between observers ranged between 1 and 3 years for age estimation of lions greater than 5 years. We therefore used a consensus age (year) estimate for lions older than 5 years between 2 or more observers. Because of small sample sizes in each age group and to avoid errors of estimating exact age from biasing our survival estimates, we report stage-specific rates (averaged across all ages within that stage) and not age-specific rates. We used the 20 radiocollared and 55 noncollared individuals to estimate stage-specific adult

lion mortality (see “Adult survivorship and annual mortality rate” below).

*Sex ratio.*—We used 412 opportunistic lion sightings (281 in Gir PA, 41 in Gimar, and 90 in Eastern region) across the Gir Landscape to deduce sex ratios, reported as ratio of adult males to adult females. There was a possibility of sampling individuals more than once because not all lions observed were able to be individually identified. Therefore, a single-sample survey with replacement model was used to compute the adult sex ratio (Skalski et al. 2005).

*Reproduction and cub survival.*—Seasonality of mating was deduced from direct sightings ( $n = 29$  mating events). We accounted for varying search effort in different seasons by dividing the number of mating events recorded by the number of field days spent searching for lions in that season. The young : adult lioness ratio was calculated as ratio of cubs and juveniles to breeding lionesses ( $n = 215$ ) in the population using the single survey without replacement model (Skalski et al. 2005) because all mothers were individually identified and their young were counted a single time in our analyses. We monitored 91 cubs from 38 litters of 31 females across the Gir Landscape between 2002 and 2010 (55 cubs in 23 litters from 18 females in Gir PA, 11 cubs in 5 litters from 5 females in Gimar, and 25 cubs in 10 litters from 8 females in the Eastern region) to estimate litter size and cub survival rate. Litter size and cub mortality until about 1 month could not be ascertained because of observational difficulties, therefore, survival rates have been calculated from 1 month of age when cubs start movement with lionesses. We calculated cub recruitment as the proportion of cubs reaching young adult stage (3 years). Most of the cub mortalities were recorded when found dead; however, not all carcasses could be detected. Therefore, a cub was considered dead if it was not observed with the pride on 2 or 3 subsequent observations and not seen thereafter (Goodrich et al. 2008). Whenever possible, causes of cub mortality were classified into 4 categories: infanticide by adult males; other natural causes such as rejection by mother, diseases, and injury; anthropogenic (e.g., falling into parapetless irrigation wells, road kills, electrocution by live wires illegally set around agriculture fields to deter crop damage by wild herbivores, and poaching); and unknown. We used program MICROMORT (Heisey and Fuller 1985) to compute cause-specific cub mortality.

Interlitter interval was calculated as the time interval between successive litters of a lioness (Packer et al. 1988). We measured reproductive success of lionesses as percent of cubs that survived to adulthood by a female (Kelly et al. 1998) during the study period.

*Adult survivorship and annual mortality rate.*—We primarily detected mortality of radiocollared lions when radiocollars went into mortality mode and investigated the site to determine cause of death. For noncollared animals, all births and mortality events were recorded as far as possible, from scheduled fieldwork combined with exchange of information with park authorities, local tourist guides, and villagers. The causes of lion mortalities were rarely ambiguous

because we collected the information in a combination of ways: direct inspection of the site within 24–36 h, information gathered from the park authorities with verification from the veterinary officer, inspection of postmortem reports, and by interviewing local witnesses. Adult lion mortality ( $n = 88$ ) events were categorized into natural mortality (intraspecific strife, disease, old age, snake bites, and flash flood), human-caused mortality (falling in farmland irrigation wells, road accidents, poaching, and electrocution), and unknown causes.

We estimated stage-specific annual and span survival probabilities of adult lions using a known-fate model (Skalski et al. 2005) in program MARK (White and Burnham 1999), using the staggered-entry design (Hayward et al. 2005; Pollock et al. 1989). This technique can be used where fate of an identifiable individual is known with certainty and independently. Mortality dates of all study lions were known within 5 days of occurrence. We grouped encounter histories of lions into time intervals of 6 months each and created a live–dead matrix where 10 meant the individual lived through the interval, 11 meant the individual died during the interval, and 00 meant censoring the individual (when unaware about the fate—Cooch and White 2009). For our survivorship analysis, we right-censored surviving lions in our sample at the end of December 2010. Lions monitored before adulthood, and that lived long enough to enter the next stage class, were included in all appropriate stage classes with the assumption that survival rates in different age classes of an animal were independent. We estimated adult lion survival by monitoring 75 lions (20 radiocollared and 55 noncollared) where stage-specific sample sizes were juvenile,  $n = 56$ ; subadult,  $n = 42$ ; young adult male,  $n = 28$ ; young adult female,  $n = 15$ ; prime adult male,  $n = 28$ ; prime adult female,  $n = 24$ ; old adult male,  $n = 15$ ; and old adult female,  $n = 15$ . We also estimated cause-specific mortality using program MICROMORT (Heisey and Fuller 1985), according to the total number of monitoring days and deaths of monitored lions occurring in the interval covered (Trent and Rongstad 1974). We generated 95% confidence

intervals on survival rates (Zar 1984); nonoverlapping confidence intervals on survival estimates were considered significantly different.

*Realized rate of increase of Asiatic lion population.*—We computed the realized rate of increase for lion population by regressing natural logarithm–transformed population estimates against time (Caughley 1977). We used historical lion census data published in literature and reports (Divyabhanusinh 2005; Singh 2007). Since 1963, the Gujarat Forest Department has estimated lion numbers about every 5 years by a labor-intensive, 3-day census of lions using a live-bait method (Jhala et al. 1999; Singh 2007). Most lions in Gir regularly kill livestock, so readily approached buffalo bait. A daily record was kept of all lions that visited the baits. Lions feeding on the bait remained stationary in the vicinity of the bait for 3–4 days. If, however, lions moved away to another bait site a record of this movement was kept and accounted for while computing total number of lions so as to minimize double counts. The maximum number of lions recorded on any single day was considered to be the total population. Although total counts are known to be error prone in population estimation (Williams et al. 2002), in the case of Gir lions they provided a reasonably reliable index of population trends as the same method and effort has been used since 1968.

*Comparing demographic parameters of African and Asiatic lions.*—We surveyed published literature and obtained information from 19 studies on various demographic parameters of African lions. We constructed 95% confidence intervals on demographic parameters of Asiatic and African lions and considered them to be similar if the confidence intervals overlapped.

## RESULTS

The adult sex ratio (male : female) was female-biased in Gir PA and Girnar ( $0.52 \pm 0.04$  SE and  $0.70 \pm 0.13$ , respectively), whereas it was male-biased in the Eastern region ( $1.21 \pm$

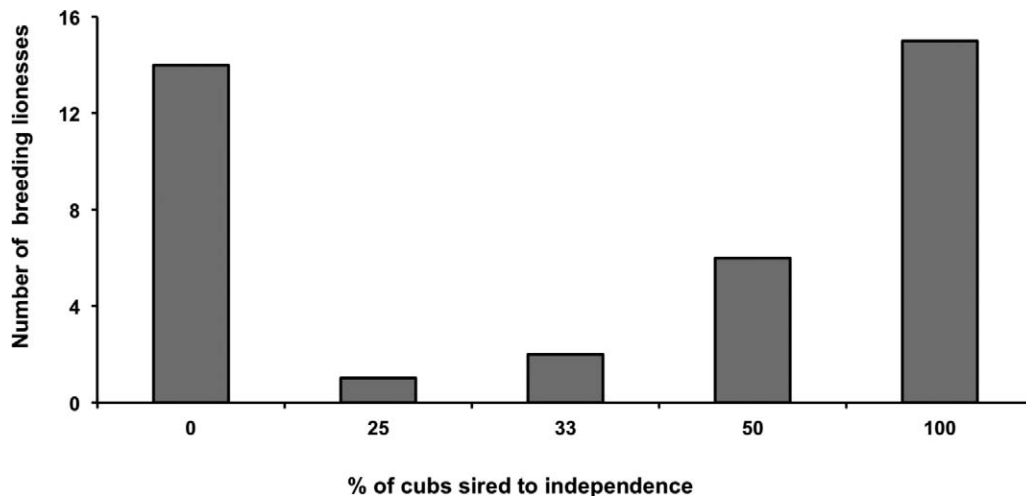
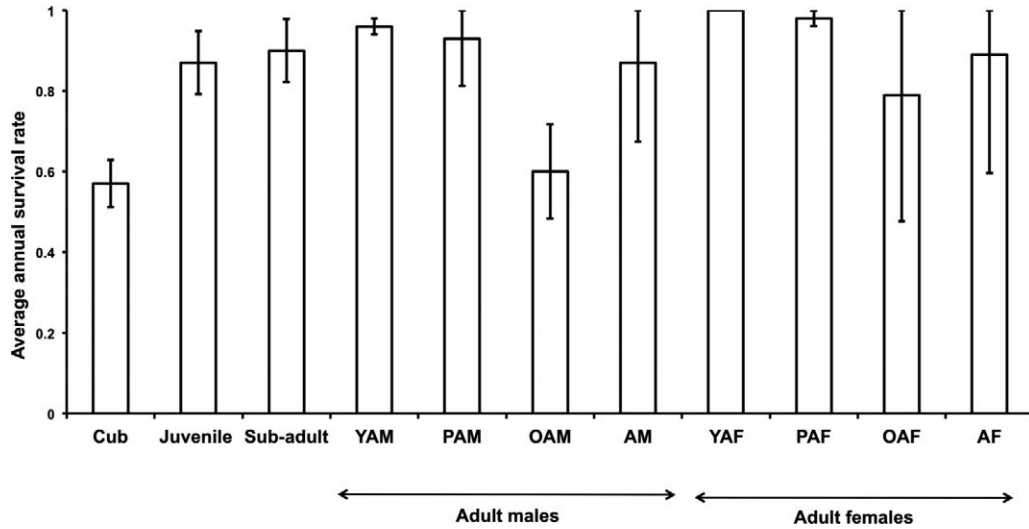


FIG. 2.—Reproductive success of Asiatic lionesses (*Panthera leo persica*, 91 cubs from 38 lionesses) measured as percentage of cubs that survived to adulthood.



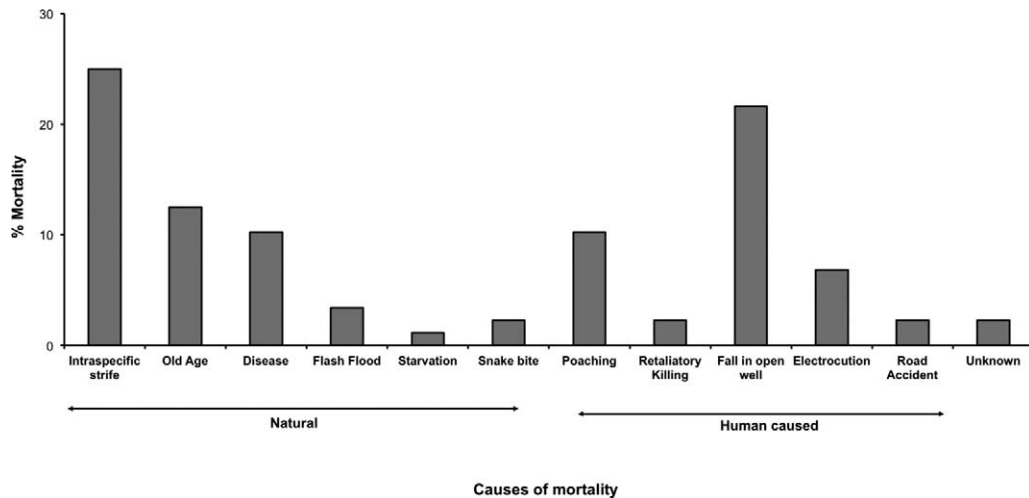


**FIG. 3.**—Comparison of stage-specific average annual survival rates of Gir lions. YAM = young adult male, PAM = prime adult male, OAM = old adult male, AM = adult male (>3 years, inclusive of YAM, PAM, and OAM), YAF = young adult female, PAF = prime adult female, OAF = old adult female, and AF = adult female (>3 years, inclusive of YAF, PAF, and OAF). Error bars are 95% confidence intervals.

demographic parameters were depressed in comparison to other lion populations. O’Brien et al. (1987) and Wildt et al. (1987) found that Asiatic lions and cheetahs (*Acinonyx jubatus*) showed a high incidence of morphologically abnormal spermatozoa (79% and 71%, respectively) when compared to free-ranging African lions (25–61%) and other species such as bulls and dogs (20–30%). The serum testosterone (a critical hormone for spermatogenesis) was low and Asiatic lions had lower variability in the major histocompatibility complex gene responsible for body immunity in comparison with those of populations of African lions (O’Brien 2003; Wildt et al. 1987). These traits were believed to impair their reproductive vigor and population vital rates and were attributed to low genetic variation. Todd (1965) attributed dentition abnormalities in Asiatic lions to inbreeding depression. Brook et al. (2002) estimated that with the prevailing inbreeding depression and subsequently compromised demography, the mean time to

extinction of Gir lions with an initial population size of 250 individuals was likely to be 39.3 years. It is possible that harmful effects of inbreeding on Asiatic lions may diminish as deleterious recessive genes are purged from the population by selection (Frankham et al. 2002; Keane et al. 1996; Tanaka 1998), resulting in comparable population growth rate and vital rates to genetically diverse lion populations.

Adult sex ratios in free-ranging lion populations are generally female-biased (Banerjee et al. 2010; Chellam and Johnsingh 1993; Joslin 1973; Packer et al. 1988; Schaller 1972). In populations with selective harvest and trophy hunting of adult male lions, adult sex ratios are highly skewed in favor of females (Cooper 1991; Loveridge et al. 2007; Yamazaki 1996). Our finding of male-skewed sex ratio in the Eastern region suggests a male-biased dispersal (Schaller 1972) from the “source” Gir PA into the “sink” Eastern region (Hanski and Gilpin 1997), which is supported by our ongoing telemetry



**FIG. 4.**—Cause-specific mortality in Asiatic lions (*Panthera leo persica*,  $n = 88$ ) in the Gir Landscape between 2006 and 2010.

TABLE 2.—Comparison of demographic parameters of free-ranging Asiatic lions with those of African lion populations obtained from published studies. 95% CI = 95% confidence interval.

Location	Population growth			Adult survival	Interbirth interval (year)	Adult sex ratio (male: female)	Cub: female ratio	Reference
	Litter size	Cub survival	Population rate ( $\lambda$ )					
Serengeti, Tanzania	2.1	0.3	0.9	0.9	0.8	0.5	0.4	Schaller (1972)
Nairobi National Park, Nairobi		0.8				0.4		Rudnai (1973)
Serengeti National Park, Tanzania	2.5	0.1			1.6			Bertram (1975)
Ngorongoro Crater, Tanzania		0.6				1.1		Elliott and Cowan (1978)
Kalahari Gemsbok National Park, South Africa		0.1				0.5		Eloff (1980)
Ishasha, Queen Elizabeth National Park, Uganda	2.6	0.8				0.2		Van Orsdol et al. (1985)
Mweya, Queen Elizabeth National Park, Uganda	2.3	0.4				0.5		Van Orsdol et al. (1985)
Ngorongoro Crater, Tanzania	2.8	0.7						Hanby et al. (1995)
Serengeti plains, Tanzania	2.7	0.2						Hanby et al. (1995)
Etosha National Park, Namibia			0.97					Berry et al. (1997)
Maasai Mara National Park, Kenya	1.9	0.7				1	0.4	Ogutu and Dublin (2002)
Tarangire National Park, Tanzania		0.7				0.3	0.7	Ryen and Soresina (2003)
Kruger National Park, South Africa		0.8			3.3	0.4	0.6	Funston et al. (2003)
Laikipia district, Kenya	2.2	0.7	0.95	0.8				Woodroffe and Frank (2005)
Kunene region, Namibia		0.8	1.16	0.7	2.1	1		Stander (2006)
Serengeti, Tanzania			1.08					Chauvenet (2009)
Madikwe Game Reserve, South Africa	3.0		1.38		2.0			Trinkel et al. (2010)
$\bar{X}$ (95% CI)	2.45 (2.33–2.57)	0.55 (0.47–0.62)	1.06 (0.98–2.05)	0.8 (0.7–0.9)	1.9 (1.2–2.6)	0.59 (0.48–0.69)	0.5 (0.3–0.7)	
Gir, India	2.1	0.4		0.9	1.2	0.9		Joslin (1973)
Gir, India	2.3		1.02			0.4		Chellam and Johnsingh (1993)
Gir, India						0.4		Jhala et al. (1999)
Gir, India						0.4	0.6	Jhala et al. (2004)
Gir Landscape, India (95% CI)	2.39 (2.2–2.6)	0.57 (0.49–0.64)	1.022 (1.02–1.024)	0.90 (0.66–1.00)	1.37 (0.88–1.86)	0.63 (0.55–0.70)	0.37 (0.33–0.40)	Present study

study (Jhala et al. 2011). Fewer females were recorded compared to males in the eastern landscape and this also could be attributed to lower availability of suitable habitat patches for breeding lionesses in this human-dominated landscape. The ratio of cubs to adult lionesses was indicative of births every other year and high infant mortality, as expected in lion populations at carrying capacity (Kissui and Packer 2009; Schaller 1972).

Most mating occurred during late winter (January) and, with an average gestation period of 110 days (Cooper 1942), cub birth showed a peak during summer (April–May). Lion reproduction coincides either with the fawning peak of chital (*Axis axis*) in December–January or with the rutting season of chital and fawning peak of sambar (*Rusa unicolor*) during May–June (Ables 1974; Dunbar-Brander 1923; Lydekker 1916; Prater 1971; Schaller 1967). Chital and sambar form the major prey for lions in the Gir Forests (Chellam and Johnsingh 1993; Dave and Jhala 2011; Meena et al. 2011), with fawns and rutting males most vulnerable to predation (Hornocker 1970; Johnsingh 1983). Moreover, during summer most of the domestic livestock are in poor body condition, making them more vulnerable to natural death and lion predation (Jhala et al. 2006). Thus, food availability increases during late winter to summer and breeding lionesses likely cue into this increased resource to time births for maximizing survival of their young.

Joslin (1973) estimated an annual adult mortality rate of approximately 2% in Gir PA ( $n = 16$  lions). Our estimates of Gir lion survival rates were similar to those observed for African lions (Table 2). For the past decade lion populations within the Gir Landscape have been intensively managed. Wildlife managers intervene by treating sick and injured lions either in situ or by temporary translocation to a health-care facility within the protected area (Pathak et al. 2002). We truncated 9 lions in our survival analysis at dates when these lions were captured for treatment, because they were unlikely to have survived in the wild if left untreated. Our estimates of survival are still somewhat confounded with the management intervention of minor treatments to some of our intensively monitored lions. Other demographic parameters such as litter size, cub survival, interlitter interval, and age at 1st litter were not likely to be affected by this management intervention. Such management interventions, although well intentioned, interfere with the natural processes of selection and social dynamics (Packer et al. 2010; Whitman et al. 2004). Deleterious genes that would normally be selected against in an inbred population may continue to be propagated through ensured survival of unfit lions by health-care interventions (Keller and Waller 2002). In the case of endangered species that are highly visible, it is often difficult to refrain from treating sick and injured individuals due to public perception (Karesh 1995; Rolston 1992). Such interventions may be essential when population numbers are extremely small and survival of each individual is crucial to ensure population persistence (Leroy et al. 2004; Nellemann et al. 2010; Smith and Almborg 2007), but these interventions need to be carefully evaluated for their need and

effectiveness and should be scientifically implemented (Burrows 1992; Burrows et al. 1994). However, in the case of Asiatic lions, the population is reasonably large and increasing. We therefore recommend that diseased lions, even if treated, should not be released back into the wild, as a precaution, in case susceptibility to infection has a genetic basis (Keller and Waller 2002; Michel et al. 2006). Such interventions also are at odds with the guiding philosophy of managing protected areas (Lockwood et al. 2006; Nelson and Vucetich, in press) and should therefore be kept to a minimum. Examination of our data shows infanticide as a major cause of mortality for cubs, which could be due to a disruption of social dominance and territoriality of male coalitions (Whitman et al. 2004) by managerial interventions such as removing coalition partners temporarily for treatment of minor ailments and injuries.

Our ongoing telemetry study shows that male lion coalitions in the Gir Landscape have large ranges, approximately 8–10 times larger than those of females (Jhala et al. 2006, 2009). This makes males more vulnerable to anthropogenic threats. Juveniles and subadult lions had high survival rates in comparison to cubs; this was likely due to their mobility and ability to avoid contact with infanticidal males because of the dense habitats of Gir (Jhala et al. 2009). Juveniles and subadults also adopted a strategy of staying with the natal pride for a prolonged duration. These patterns were similar to those observed in Kruger National Park (South Africa), where lions live in habitats comparable to those in Gir (Funston et al. 2003).

Infanticide by adult males, synchronous with pride takeovers (Packer and Pusey 1983b), was found to be most significant cause of cub mortality. By infanticide, incoming males accelerate females' return to estrus (Packer and Pusey 1983a) by an average of approximately 5 months  $\pm$  0.66 SE in Gir lions. Other observed causes of cub mortality in Gir Landscape were starvation, disease, abandonment by mother, predation, and snakebite, as also observed in Africa (Eloff 1980; Guggisberg 1961; Joslin 1973; Schaller 1972).

Retaliatory killing of lions was not a major source of mortality in the Gir Landscape because of cultural reverence by local communities and strict legal enforcement by management authorities (Pathak et al. 2002). However, with fast-changing land-use patterns and commercialization of natural resources, such societal constraints are rapidly eroding. Local communities' apathy toward lion conservation resulting from livestock depredation by carnivores (lions and leopards [*Panthera pardus*]) often leads to complacency toward professional lion poachers (Fair 2009; Singh 2007). Outside of the protected area, lion conservation is not the prime objective for land management, and tolerance toward livestock depredation by communities is lower. To ensure the persistence of lions in this human-dominated landscape, it is essential to manage lion densities within social and economically acceptable levels (Treves et al. 2006).

Our study suggests that the genetically depauperate Asiatic lion population does not suffer from depressed demographic parameters. However, small populations that are isolated and genetically less diverse are more vulnerable to environmental

and demographic stochasticity, making them prone to local extinction events (Frankham 1995). Because Asiatic lions currently exist as a single population that is vulnerable to local extinction processes, establishing other free-ranging populations geographically distant from Gir (Johnsingh et al. 1998) should be considered a conservation priority. Human causes were a significant source of lion mortality in the Gir Landscape. Because human-caused mortality is not directed to old and young lions that have higher chances of dying from natural causes, this mortality is likely to be additive to natural causes. Although currently lions continue to expand their range and density, it seems that in the future human-caused mortality is likely to increase due to enhanced human–lion conflict and become a major concern for lion persistence in the Gir Landscape. It would, therefore, be prudent to plan mitigation measures to manage conflict so as to minimize human-caused lion mortality for ensuring the long-term survival of this endangered lion subspecies in the Gir Landscape.

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#### LITERATURE CITED

- ABLES, E. D. 1974. The *Axis* deer in Texas. Caesar Kleberg Research Programme, Texas Agricultural Experiment Station, Texas A&M University System.
- ALTIZER, S., D. HARVELL, AND E. FRIEDLE. 2003. Rapid evolutionary dynamics and disease threats to biodiversity. *Trends in Ecology & Evolution* 18:589–596.
- ANTUNES, A., ET AL. 2008. The evolutionary dynamics of the lion *Panthera leo* revealed by host and viral population genomics. *PLoS Genetics* 4:e1000251.
- BADONI, V., Y. V. JHALA, AND Q. QURESHI. 2005. Lion monitoring system—version 1.0: software for long term monitoring of lions. Wildlife Institute of India, Dehra Dun, India.
- BANERJEE, K., Y. V. JHALA, AND B. PATHAK. 2010. Demographic structure and abundance of Asiatic lions (*Panthera leo persica*) in Gir Wildlife Sanctuary, Gujarat, India. *Oryx* 44:248–251.
- BERRY, H., ET AL. 1997. Population and habitat viability assessment for the Namibian cheetah (*Acinonyx jubatus*) and lion (*Panthera leo*). Workshop Report. IUCN/SSC Conservation Breeding Specialist Group, Apple Valley, Minnesota.
- BERTRAM, B. C. R. 1975. Social factors influencing reproduction in wild lions. *Journal of Zoology (London)* 177:463–482.
- BJÖRKLUND, M. 2003. The risk of inbreeding due to habitat loss in the lion (*Panthera leo*). *Conservation Genetics* 4:515–523.
- BROOK, B. W., D. W. TONKYN, J. J. O'GRADY, AND R. FRANKHAM. 2002. Contribution of inbreeding to extinction risk in threatened species. *Conservation Ecology* 6:16.
- BURROWS, R. 1992. Rabies in wild dogs. *Nature* 359:277.
- BURROWS, R., H. HOFER, AND M. L. EAST. 1994. Demography, extinction and intervention in a small population: the case study of Serengeti wild dogs. *Proceedings of the Royal Society of London, B. Biological Sciences* 256:281–292.
- CARO, T. M., AND M. K. LAURENSEN. 1994. Ecological and genetic factors in conservation: a cautionary tale. *Science* 263:485–486.
- CAUGHLEY, G. 1977. Analysis of vertebrate populations. Wiley, London, United Kingdom.
- CAUGHLEY, G. 1994. Directions in conservation biology. *Journal of Animal Ecology* 63:215–244.
- CHAUVENET, A. 2009. Canine distemper virus impact on lion–cheetah interactions in the Serengeti National Park. M.S. thesis, Imperial College, London, United Kingdom.
- CHELLAM, R., AND A. J. T. JOHNSINGH. 1993. The management of Asiatic lions in the Gir forest, India. *Symposia of the Zoological Society* 65:409–424.
- COOCH, W., AND G. WHITE. 2009. Program MARK: a gentle introduction. 9th ed. <http://www.phidot.org/software/mark/docs/book/markbook.exe>. Accessed 12 April 2010.
- COOPER, J. 1942. An exploratory study on African lions. *Comparative Psychological Monographs* 17:1–48.
- COOPER, S. M. 1991. Optimal hunting group size: the need for lions to defend their kills against loss to spotted hyenas. *African Journal of Ecology* 29:130–136.
- DAVE, C., AND Y. JHALA. 2011. Is competition with livestock detrimental for native wild ungulates? A case study of chital (*Axis axis*) in Gir Forest, India. *Journal of Tropical Ecology* 27:239–247.
- DIVYABHANUSINH, C. 2005. The story of Asia's lions. Marg Publications, Mumbai, India.
- DRISCOLL, C. A., M. MENOTTI-RAYMOND, G. NELSON, D. GOLDSTEIN, AND S. J. O'BRIEN. 2002. Genomic microsatellites as evolutionary chronometers: a test in wild cats. *Genome Research* 12:414–423.
- DUNBAR-BRANDER, A. A. 1923. Wild animals in central India. E. Arnold and Co., London, United Kingdom.
- EDWARDS, S. M., AND L. G. FRASER. 1907. The Gir Forests and its lions. in *The ruling princes of India, Junagadh; being a historical, archeological, political and statistical account of the premier state of Kathiawar, Bombay*. Times of India Press, India.
- ELLIOTT, J. P., AND I. M. COWAN. 1978. Territoriality, density and prey of the lion in Ngorongoro Crater, Tanzania. *Canadian Journal of Zoology* 56:1726–1743.
- ELOFF, F. C. 1980. Cub mortality in the Kalahari lion *Panthera leo vernayi* (Roberts, 1948). *Koedoe* 23:163–170.
- ELVIDGE, C. D., K. E. BAUGH, E. A. KIHN, H. W. KROEHL, AND E. R. DAVIS. 1997. Mapping city lights with nighttime data from the DMSP operational linescan system. *Photogrammetric Engineering and Remote Sensing* 63:727–734.
- FAIR, J. 2009. Crime-busting to save rare lions. *News of the earth section. BBC Wildlife March 2009*:39.

- FOOSE, T. 1977. Demographic models for management of captive populations. *International Zoo Yearbook* 17:70–76.
- FOREST SURVEY OF INDIA, 2009. India State Forest Report 2009. Forest Survey of India Ministry of Environment and Forests, Government of India, Dehra Dun.
- FRANKHAM, R. 1995. Inbreeding and extinction: a threshold effect. *Conservation Biology* 9:792–799.
- FRANKHAM, R., D. A. BRISCOE, AND J. D. BALLOU. 2002. Introduction to conservation genetics. Cambridge University Press, Cambridge, United Kingdom.
- FUNSTON, P. J., M. G. L. MILLS, P. R. K. RICHARDSON, AND A. S. VAN JAARVELD. 2003. Reduced dispersal and opportunistic territory acquisition in male lions (*Panthera leo*). *Journal of Zoology (London)* 259:131–142.
- GOODRICH, J. M., ET AL. 2008. Survival rates and causes of mortality of Amur tigers on and near the Sikhote-Alin Biosphere Zapovednik. *Journal of Zoology (London)* 276:323–329.
- GUGGISBERG, C. 1961. Simba. Howard Timmins, Cape Town, South Africa.
- GUJARAT FOREST DEPARTMENT. 2010. Distribution of Asiatic lions in Gir National Park, sanctuary and other areas in 13th Asiatic Lion Population Estimate—2010. <http://gujaratforest.gov.in/downloads/lion-censues-20-5-2010.pdf>. Accessed 18 November 2010.
- GUPTA, S. K. 1972. Chronology of the raised beaches and inland coral reefs of the Saurashtra Coast. *Journal of Geology* 80:357–361.
- HANBY, J. P., J. D. BYGOTT, AND C. PACKER. 1995. Ecology, demography and behaviour of lions in two contrasting habitats: Ngorongoro Crater and the Serengeti plains. Pp. 315–331 in *Serengeti II: dynamics, management and conservation of an ecosystem* (A. R. E. Sinclair and P. Arcese, eds.). University of Chicago Press, Chicago, Illinois.
- HANSKI, I. A., AND M. E. GILPIN. 1997. *Metapopulation biology: ecology, genetics and evolution*. Academic Press, San Diego, California.
- HAYWARD, M. W., P. J. DE TORES, M. L. AUGEE, AND P. B. BANKS. 2005. Mortality and survivorship of the quokka (*Setonix brachyurus*) (Macropodidae: Marsupialia) in the northern Jarrah forest of Western Australia. *Wildlife Research* 32:715–722.
- HEISEY, D. M., AND T. K. FULLER. 1985. Evaluation of survival and cause specific mortality rates using telemetry data. *Journal of Wildlife Management* 49:668–674.
- HORNOCKER, M. 1970. An analysis of mountain lion predation upon mule deer and elk in Idaho primitive area. *Wildlife Monographs* 21:3–39.
- JHALA, Y. V., ET AL. 2006. Social organization and dispersal in Asiatic lions and ecological monitoring of Gir. Wildlife Institute of India, Dehra Dun, India, Technical Report 100 pp.
- JHALA, Y. V., ET AL. 2009. Home range and habitat preference of female lions (*Panthera leo persica*) in Gir Forests, India. *Biodiversity and Conservation* 18:3383–3394.
- JHALA, Y. V., R. CHELLAM, B. PATHAK, V. MEENA, K. BANERJEE, AND P. BASU. 2011. Social organization and dispersal of Asiatic lions. Vol. I. submitted to the Gujarat Forest Department, Wildlife Institute of India, Dehra Dun, India, Technical Report TR-2011/001:163 pp.
- JHALA, Y. V., S. MUKHERJEE, N. SHAH, K. S. CHAUHAN, C. DAVE, AND Y. S. JHALA. 2004. Monitoring lions. Pp. 55–71 in *Monitoring of Gir* (Y. V. Jhala, ed.). Wildlife Institute of India, Dehra Dun, India, Technical Report RR-04/002:157 pp.
- JHALA, Y. V., Q. QURESHI, V. BHUVA, AND L. N. SHARMA. 1999. Population estimation of Asiatic lions. *Journal of Bombay Natural History Society* 96:3–15.
- JOHNSINGH, A. J. T. 1983. Large mammalian prey–predators in Bandipur. *Journal of Bombay Natural History Society* 80:1–57.
- JOHNSINGH, A. J. T., R. CHELLAM, AND D. SHARMA. 1998. Prospects for conservation of Asiatic lions in India. *Biosphere Conservation* 1:81–89.
- JOSLIN, P. 1973. The Asiatic lion: a study of ecology and behaviour. Ph.D. dissertation, Department of Forestry and Natural Resources, University of Edinburgh, Edinburgh, United Kingdom.
- KARESH, W. B. 1995. Wildlife rehabilitation: additional considerations for developing countries. *Journal of Zoo and Wildlife Medicine* 26:2–9.
- KEANE, B., S. R. CREEL, AND P. M. WASER. 1996. No evidence of inbreeding avoidance or inbreeding depression in a social carnivore. *Behavioral Ecology* 7:480–489.
- KELLER, L. K., AND D. M. WALLER. 2002. Inbreeding effects in wild populations. *Trends in Ecology & Evolution* 17:230–241.
- KELLY, M. J., ET AL. 1998. Demography of the Serengeti cheetah (*Acinonyx jubatus*) population: the first 25 years. *Journal of Zoology (London)* 244:473–488.
- KINNEAR, N. B. 1920. The past and present distribution of the lion in south eastern Asia. *Journal of Bombay Natural History Society* 27:34–39.
- KISSUI, B. M., AND C. PACKER. 2009. Top-down population regulation of a top predator: lions in the Ngorongoro Crater. *Proceedings of the Royal Society, B. Biological Sciences* 207:1867–1874.
- KREEGER, T. J. 1996. *Handbook of wildlife chemical immobilization*. 1st ed. International Wildlife Veterinary Services Inc., Laramie, Wyoming.
- LEROY, E. M., ET AL. 2004. Multiple Ebola virus transmission events and rapid decline of Central African wildlife. *Science* 303:387–390.
- LOCKWOOD, M., G. L. WORBOYS, AND A. KOTHARI. 2006. *Managing protected areas: a global guide*. Earthscan Publications Ltd., Oxford, United Kingdom.
- LOVERIDGE, A. J., A. W. SEARLE, F. MURINDAGOMO, AND D. W. MACDONALD. 2007. The impact of sport-hunting on the population dynamics of an African lion population in a protected area. *Biological Conservation* 134:548–558.
- LYDEKKER, R. 1916. *Wildlife of the world*. Rowland Ward Ltd., London, United Kingdom. Vol. II.
- MEENA, V., Y. V. JHALA, R. CHELLAM, AND B. PATHAK. 2011. Implications of diet composition of Asiatic lions for their conservation. *Journal of Zoology (London)* 284:60–67.
- MICHEL, A. L., ET AL. 2006. Wildlife tuberculosis in South African conservation areas: implications and challenges. *Veterinary Microbiology* 112:91–100.
- NELLEMANN, C., I. REDMOND, AND J. REFISCH. 2010. The last stand of the gorilla: the environmental crime and conflict in the Congo basin. A rapid response assessment. United Nations Environment Programme, GRID-Arendal, Arebdal, Norway.
- NELSON, M. P., AND J. A. VUCETICH. In press. Environmental ethics and wildlife management. In *Human dimensions of wildlife management* (D. J. Decker, S. J. Riley, and W. F. Siemer, eds.). 2nd ed. Johns Hopkins University Press, Baltimore, Maryland. [www.conservationethics.org/CEG/wrkgrp\\_files/Ethical\\_Discourse.doc](http://www.conservationethics.org/CEG/wrkgrp_files/Ethical_Discourse.doc). Accessed 2 June 2011.
- O'BRIEN, S. J. 2003. *Tears of the cheetah and other tales from the genetic frontier: the genetic secrets of our animal ancestors*. Thomas Dunne Books, New York.
- O'BRIEN, S. J., ET AL. 1987. Evidence for African origins of founders of the Asiatic lion species survival plan. *Zoo Biology* 6:99–116.

- O'BRIEN, S. J., D. E. WILDT, AND M. BUSH. 1986. The African cheetah in genetic peril. *Scientific American* 254:84–92.
- OGUTU, J. O., AND H. T. DUBLIN. 2002. Demography of lions in relation to prey and habitat in the Maasai Mara National Reserve, Kenya. *African Journal of Ecology* 40:120–129.
- PACKER, C., H. BRINK, B. M. KISSUI, H. MALITI, H. KUSHNIR, AND T. CARO. 2010. Effects of trophy hunting on lion and leopard populations in Tanzania. *Conservation Biology* 25:142–153.
- PACKER, C., ET AL. 1988. Reproductive success of lions. Pp. 363–383 in *Reproductive success: studies of individual variation in contrasting breeding systems* (T. H. Clutton-Brock, ed.). University of Chicago Press, Chicago, Illinois.
- PACKER, C., AND A. E. PUSEY. 1983a. Adaptations of female lions to infanticide by incoming males. *American Naturalist* 121:716–728.
- PACKER, C., AND A. E. PUSEY. 1983b. Male takeovers and female reproductive parameters: a simulation of oestrus synchrony in lions (*Panthera leo*). *Animal Behaviour* 31:334–340.
- PACKER, C., A. E. PUSEY, H. ROWLEY, D. A. GILBERT, J. MARTENSON, AND S. J. O'BRIEN. 1991. Case study of a population bottleneck: lions of the Ngorongoro Crater. *Conservation Biology* 5:219–230.
- PATHAK, B. J., ET AL. 2002. Biodiversity conservation plan for Gir. Supplementary management plan. Gujarat Forest Department, Gandhinagar, India.
- PENNYCUICK, C. J., AND J. RUDNAI. 1970. A method of identifying individual lions *Panthera leo* with an analysis of reliability of the reliability of identification. *Journal of Zoology (London)* 160:497–508.
- POCOCK, R. I. 1930. Lions of Asia. *Journal of Bombay Natural History Society* 34:638–665.
- POLLOCK, K. H., S. R. WINTERSTEIN, C. M. BUNCK, AND P. D. CURTIS. 1989. Survival analysis in telemetry studies: the staggered entry design. *Journal of Wildlife Management* 53:7–15.
- PRATER, S. H. 1971. *The book of Indian animals*. Bombay Natural History Society, Bombay, India.
- ROBINSON, H. S., R. B. WIELGUS, H. S. COOLEY, AND S. W. COOLEY. 2008. Sink populations in carnivore management: cougar demography and immigration in a hunted population. *Ecological Applications* 18:1028–1037.
- RODGERS, W. A., AND H. S. PANWAR. 1988. Planning a wildlife protected area network in India. *Wildlife Institute of India, Dehra Dun, India*. Vols. I and II.
- ROLSTON, H. 1992. Ethical responsibilities toward wildlife. *Journal of American Veterinary Medical Association* 200:618–622.
- RUDNAI, J. A. 1973. *The social life of the lion: a study of the behaviour of wild lions (Panthera leo massaica [Newmann]) in the Nairobi National Park, Kenya*. MTP Co., Ltd., Lancaster, United Kingdom.
- RYEN, M., AND A. SORESINA. 2003. Tarangire lion project (TLP) report. [http://www.alessandrasoresina.com/allegati/progetti/report2002\\_03\\_171105\\_051443.pdf](http://www.alessandrasoresina.com/allegati/progetti/report2002_03_171105_051443.pdf). Accessed 11 January 2011.
- SCHALLER, G. 1967. *The deer and the tiger*. University of Chicago Press, Chicago, Illinois.
- SCHALLER, G. 1972. *The Serengeti lion: a study of predator-prey relations*. University of Chicago Press, Chicago, Illinois.
- SHANKARANARAYANAN, P., M. BANERJEE, R. K. KACKER, R. K. AGGARWAL, AND L. SINGH. 1997. Genetic variation in Asiatic lions and Indian tigers. *Electrophoresis* 18:1693–1700.
- SINGH, H. S. 2007. The Gir lion *Panthera leo persica*—a natural history, conservation status and future prospect. Pugmark Qumulus Consortium, Ahmedabad, India.
- SINGH, H. S., AND L. A. GIBSON. 2011. A conservation success story in the otherwise dire megafauna extinction crisis: the Asiatic lion (*Panthera leo persica*) of Gir forest. *Biological Conservation* 144:1753–1757.
- SINGH, H. S., AND R. D. KAMBOJ. 1996. Biodiversity conservation plan for Gir (a management plan for Gir Sanctuary and National Park). Gujarat Forest Department, Gandhinagar, India. Vols. I and II.
- SKALSKI, J. R., K. E. RYDING, AND J. J. MILLSPAUGH. 2005. *Wildlife demography: analysis of sex, age, and count data*. Elsevier Academic Press, Burlington, Massachusetts.
- SMITH, D. W., AND E. ALMBERG. 2007. Wolf diseases in Yellowstone National Park. *Yellowstone Science* 15:17–19.
- STANDER, P. 2006. Population ecology and demography of Kunene lions. Predator Conservation Trust research paper 2006/1, Namibia. [http://www.desertlion.info/reports/klp\\_2006-sml.pdf](http://www.desertlion.info/reports/klp_2006-sml.pdf). Accessed 11 January 2011.
- TANAKA, Y. 1998. Theoretical aspects of extinction by inbreeding depression. *Researches on Population Ecology* 40:279–286.
- TODD, N. B. 1965. Metrical and non-metrical variation in the skulls of Gir lions. *Journal of Bombay Natural History Society* 62:507–520.
- TRENT, T. T., AND O. J. RONGSTAD. 1974. Home range and survival of cottontail rabbits in southwestern Wisconsin. *Journal of Wildlife Management* 38:459–472.
- TREVES, A., R. B. WALLACE, L. NAUGHTON-TREVES, AND A. MORALES. 2006. Co-managing human-wildlife conflicts: a review. *Human Dimensions of Wildlife* 11:383–396.
- TRINKEL, M., ET AL. 2010. Inbreeding and density-dependent population growth in a small, isolated lion population. *Animal Conservation* 13:374–382.
- VAN ORSDOL, K. G., J. P. HANBY, AND J. D. BYGOTT. 1985. Ecological correlates of lion social organization (*Panthera leo*). *Journal of Zoology (London)* 206:97–112.
- WHITE, G. C., AND K. P. BURNHAM. 1999. Program MARK: survival estimation from populations of marked animals. *Bird Study* 46:120–138.
- WHITMAN, K., A. M. STARFIELD, H. S. QUADLING, AND C. PACKER. 2004. Sustainable trophy hunting of African lions. *Nature* 428:175–178.
- WILDT, D. E., ET AL. 1987. Reproductive and genetic consequences of founding isolated lion population. *Nature* 329:328–331.
- WILLIAMS, B. K., J. D. NICHOLS, AND M. J. CONROY. 2002. *Analysis and management of animal populations*. Academic Press, London, United Kingdom.
- WOODROFFE, R., AND L. G. FRANK. 2005. Lethal control of African lions (*Panthera leo*): local and regional population impacts. *Animal Conservation* 8:91–98.
- YAMAZAKI, K. 1996. Social variation of lions in a male-depopulated area in Zambia. *Journal of Wildlife Management* 60:490–497.
- ZAR, J. H. 1984. *Biostatistical analysis*. 2nd ed. Prentice Hall, Englewood Cliffs, New Jersey.

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# Living with Lions: The Economics of Coexistence in the Gir Forests, India

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## Abstract

Rarely human communities coexist in harmony with large predators. Most often communities suffer due to predation on their stock while large carnivores suffer losses and at times extirpation due to retaliation. We examine the mechanisms permitting the coexistence of Asiatic lions (*Panthera leo persica*) and pastoral communities (*Maldharis*) in the Gir forests, India. We monitored six *Maldhari* settlements between 2005 and 2007 to quantify seasonal livestock holding, density and losses due to predation and other causes. Lion density, estimated by mark recapture, was  $15 \pm 0.1$  SE/100 km<sup>2</sup>. Livestock density, estimated by total counts, ranged between 25/km<sup>2</sup>–31/km<sup>2</sup> with buffaloes being most abundant. Average livestock holding of *Maldhari* families was  $33 \pm 3$  SE. Lions preyed mostly on unproductive cattle (30%). Scat analysis (n = 165), predation events (n = 180) and seven continuous monitoring sessions of 1,798 hours on four radio-collared lions estimated livestock to contribute between 25 to 42% of lions' biomass consumptions, of which only 16% was preyed; rest scavenged. With free grazing rights within Gir forests, *Maldharis* offset  $58 \pm 0.2$  SE% of annual livestock rearing cost in comparison to non-forest dwelling pastoralists. With government compensation scheme for livestock predation, this profit margin augmented to  $76 \pm 0.05$  SE%. Lion density was higher in areas with *Maldhari* livestock in comparison to areas without livestock. Thus, the current lifestyles and livestock holdings of *Maldharis* seem to be beneficial to both lions and local pastoralists. We conclude that a combination of strict protection regime for lions, *Maldharis*' traditional reverence towards lions and the livelihood economics permit the delicate balance of lion-*Maldhari* coexistence. Indefinite increase in human and livestock population within Gir might upset this equilibrium undermining the conservation objectives. We see no end to compensation programs worldwide as they constitute a crucial element needed for human-carnivore coexistence.

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## Introduction

Rarely do forest-dwelling pastoral communities coexist in harmony with large predators. Either the communities suffer substantial economic loss due to predation on their stock and/or large carnivores suffer heavy losses and even extirpation due to retaliation [1,2]. Understanding people-carnivore relationship, therefore, becomes crucial especially for the conservation of large carnivores [3,4]. Although large carnivores sometimes kill humans [5,6], the major form of conflict arises due to their habit of preying livestock and the resulting threat on economic security of the pastorals [4]. Human communities react differently to this conflict depending on their religious beliefs, customs, cultures, actual and perceived magnitudes of economic losses and the legal status of carnivores [7]. Reactions range from total extermination of large carnivores [8], occasional removal of problem animals [9,10] to tolerance and coexistence [11].

In a country like India which is home to approximately 1.2 billion people [12], the majority (70%) being rural; forest resources have been part of traditional livelihoods for generations [13]. India's pre-independence (1947) colonial exploitative forest

policies and subsequently post-independence exclusionary forest management often gave rise to polarized conservation debates about the rights of forest-dwelling communities [14,15]. Politics of ecology becomes more contentious with the pro-people groups often arguing about the merit of conservation governances that alienates traditional forest-dwellers' access to forests and their resources, while the livelihood economics of forest dwellers are marginalized due to wildlife damage and poor access to markets [16]. The contrary view by preservationists is that consumptive use by an increasing population of forest dwelling communities is unsustainable and detrimental to biodiversity conservation [17,18].

Two-thirds of India's wildlife reserves are grazed by livestock [19] where they are often preyed upon by large carnivores [20]. Traditional cultural, ethical and religious reverence towards life forms combined with recent legal protection is important in contributing to the continued survival of large carnivores in India [21,22,23,24]. Due to the changing values of a global economic world it is likely that even in rural areas these values will ultimately determine the fate of large carnivores [25]. To date pastoralist communities have shown tolerance to the presence of lions in the

Gir forests. Our objective was to assess whether this tolerance was supported by economics.

At the onset of the nineteenth century, Asiatic lions (*Panthera leo persica*) became restricted to the Gir forests of western India and their numbers declined to around 50 individuals due to hunting and habitat loss [26,27]. Owing to the timely and stringent protection by the Rulers of Junagadh and subsequently during the post-independence by the State-run forest department; Gir lions have increased to about 400 and dispersed into a large tract of agro-pastoral landscape adjoining the Gir forests [28,29].

The Gir Forests have been inhabited by semi-nomadic pastoral communities called *Maldharis* for the past one and a half century [30]. Their religion is Hinduism and they have strong ethics and sentiments towards nature and natural resources [11]. They are primarily vegetarian and keep livestock for sale of dairy products. Due to their long history of living with lions that often predate on their livestock, it would be important to understand the underlying mechanisms that permit coexistence. In this article we quantify predation losses of livestock, estimate lion densities and diet and evaluate the economics of rearing livestock in lion habitats. We examined the notion that the tolerance of the *Maldharis* towards lions [11,31] is not solely due to their beliefs and cultural sentiments but also because it is economically more profitable to live with lions.

## Methods

### Ethics Statement

All permissions to carry out the field research were obtained from the Office of the Chief Wildlife Warden, Gujarat State and Ministry of Environment and Forests, Government of India under the provisions of the Wildlife (Protection) Act, 1972, Government of India. Livestock counts were conducted with permission from their owners without any coercion.

### Study Area

Gir Protected Area (PA) [1,883 km<sup>2</sup>, 20°57' to 21°20' N latitude and 70°27' to 71°13' E longitude] is a dry deciduous forest [32] situated in Gujarat province, western India (Fig. 1) and is made up of a Sanctuary (with human settlements and regulated grazing and other rights; [24]) covering 1,153 km<sup>2</sup>, a 259 km<sup>2</sup> National Park (devoid of humans) and 471 km<sup>2</sup> of additional reserve, protected and unclassified forests. Gir PA has a semi-arid climate with an average minimum and maximum temperature ranging from 5° to 38°C and an average rainfall of 980 mm [31]. Rugged hilly terrains form the catchments of seven perennial rivers. Dominant vegetation included *Tectona grandis*, *Anogeissus* spp, *Acacia* spp and *Ziziphus* spp.

Gir has a diverse assemblage of wild fauna. Apart from the last free-ranging population of the Asiatic lion, some of the other carnivores are leopard (*Panthera pardus*), striped hyena (*Hyaena hyaena*), jackal (*Canis aureus*) and ratel (*Mellivora capensis*). Major wild prey species of lions were chital (*Axis axis*), sambar (*Rusa unicolor*), nilgai (*Boselaphus tragocamelus*) and wild pig (*Sus scrofa*) [31].

Gir Protected Area has 50 *Maldhari* settlements (*nesses*). A *ness* consists of a cluster of thatch and mud hutments of 3–20 *Maldhari* families. [11,31,33]. Each *Maldhari* family rears about 20–100 regionally famous indigenous breed of livestock, primarily Jafrabadi breed of buffalo (*Bubalus bubalis*) and Gir breed of cattle (*Bos indicus*). Often one or two camels (*Camelus dromedarius*) are kept for carrying fuel wood and fodder. The sale of dairy products has always been the mainstay of *Maldharis*' traditional economy [33]. Our study area covered the livestock grazing areas of a cluster of six *nesses* namely Asundrali, Dodhi, Gudjinjva, Khajuri, Leriya

and Mindha (Fig. 1) which represent a typical scenario across Gir PA.

### Lion Density Estimation

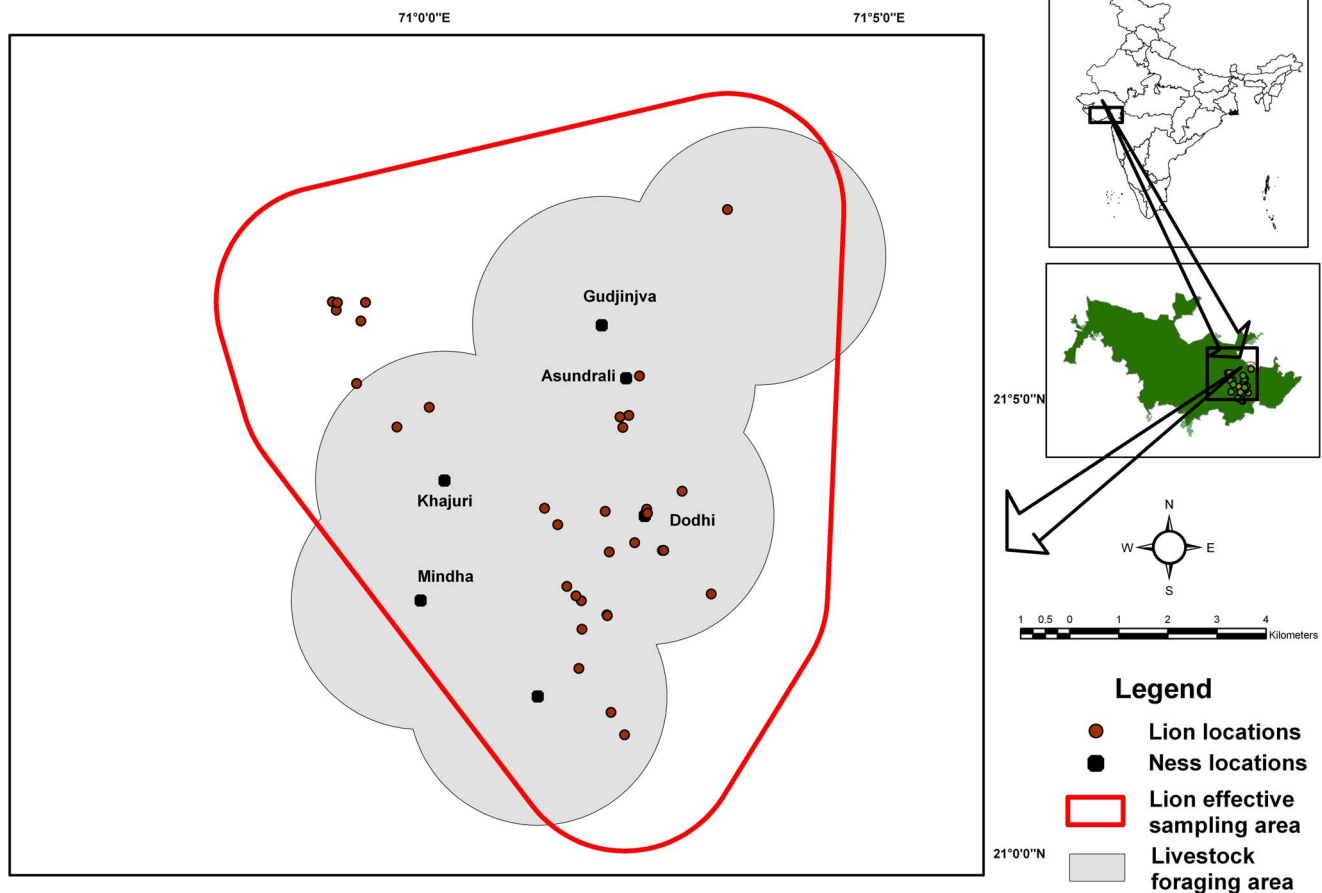
We estimated lion population using closed-population mark-recapture [34]. We used cues, including tracks, roars and alert behavior of prey to locate lions. The entire study area of eastern Gir PA was systematically searched by vehicle and on foot within a period of 3–4 days which represented a single occasion. A total effort of 53 days representing 17 occasions was expended. We approached lions within 10–30 meters to determine their whisker spot patterns with binoculars, and by a 15 to 60 X spotting scope. We individually identified lions (>1.5 year) from their unique whisker spot patterns and other permanent unique marks [35]. Close-up color photographs using an 80–400 mm zoom lens were taken of both sides of the face and a full-face view to supplement field drawings [36,37]. Capture histories of individual lions were used to make an X matrix [34], formally tested for population closure [38] and analyzed using program CAPTURE [39] to deduce population size. The effectively sampled area was estimated by creating a polygon joining the outermost lion locations buffered by a width estimated by half of the mean maximum distance moved (½ MMDM) by recaptured lions [40,41].

### Livestock Population and Density

A total head count of livestock in each *ness* was carried out. Livestock were counted during evening hours when all livestock were corralled for the night. We recorded data on number and demographic structure of the livestock belonging to each family in a *ness*. We classified livestock as calf, juvenile, sub-adult and adult of both sexes. Adult female livestock were further classified into a) milk yielding, b) temporary dry but breeding age and c) non-productive. Seasonal livestock grazing circuits were estimated and mapped by accompanying three livestock herds from each *ness* in each season from early morning, when they leave to forage in the forest, till they return to the *ness* and were corralled for the night. Data was recorded on distance moved and linear displacement of livestock herds from the *ness* sites from 50 grazing circuits in the form of GPS (Garmin International, Kansas, USA) track logs [42]. Age-gender-productivity class composition of grazing herds as well as their spatial arrangement in a herd was also recorded at every 500 meter interval. Each *ness* site was buffered with its average seasonal foraging radius to compute the foraging area in a GIS map using program Arc GIS (ESRI, Redlands, CA). We calculated seasonal livestock density as the total number of livestock divided by the total foraging area [42].

### Lion Food Habits

Lions' diet was determined by analysis of 165 lion scats [43,44] and by monitoring of four radio-collared lions continuously for 5–12 day sessions (detailed below) within the study area. Lion scats were distinguished from those of other predators, particularly leopard scats, based on associated signs, tracks and size [45]. We did not include ambiguous scats in the analysis. Prey remains such as hair, bones, hooves, quills and teeth of the prey consumed were identified to species using reference samples [46,47]. Data were analyzed as frequency of occurrence and percent occurrence. We assessed adequacy of sample size by plotting the cumulative proportional frequency of occurrence against number of analyzed scat samples of each prey item [48]. We used 1,000 bootstrap iterations [49] using SIMSTAT [50] to generate 95% confidence intervals on frequency of occurrence of different prey items in the lions' diet.



**Figure 1. Study site within the Gir forests showing locations of different study *Nesses* buffered by average livestock foraging area, lion capture points and effective lion trapping area.** The maps inset show the location of the Gir PA in India and the study site within the eastern part of the Gir forests.

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Due to a differential surface area to volume ratio of small versus large prey, the frequency of occurrence data was corrected to arrive at biomass consumption per collectible scat [51,52]. We used Ackerman's equation [developed for cougar (*Felis concolor*)] to convert frequency of occurrence into biomass assuming lions to have a similar digestive physiology as cougars. The equation was  $y = 1.980 + 0.035x$ , where  $y$  is the biomass of prey consumed (kg) to produce a single field collectible scat and  $x$  is the average body weight of the prey species (kg). The body weights of the potential prey species were taken from literature [53,54]. Prey densities [42] were used as availability. We compared counts of each prey item in the scats with the estimated prey availability using 1,000 bootstrap iterations in program SCATMAN [55,56] to assess selectivity [57] in utilization. Observed and expected proportions of prey species in the scats were then compared using a G test [58] with two tailed  $\alpha = 0.05$  level. If there was a pattern of overall selective prey utilization, lions' use of each prey species as calculated by the program SCATMAN was further inspected. Food preference of lions in the study area was also computed by Jacob's Index [59] due to its lower bias, smaller confidence intervals with low heterogeneity and freedom from non-linearity compared with other electivity indices [60].

Although frequency of occurrence in scats is a reliable technique for understanding the range of diet items, the method usually cannot distinguish between prey that are killed or scavenged

[61,62]. Consequently occurrence of livestock in the lions' diet is unreliable to assess lion-*Maldhari* conflict. Therefore, we additionally followed four radio-collared lions on foot and/or four-wheel drive for seven sessions ranging from continuous 192 hours to 360 hours per session to understand the starve-feed cycle of lion foraging behaviour and distinguish between predation and scavenging events [63,64]. A total of 1,798 hours of monitoring data was recorded during the study period. During this duration, lions were kept in view or within 100 meter from the observers day and night. Lions in Gir are regularly exposed to humans on foot; we further habituated each radio-collared lion for 1–3 days by following it on foot prior to data collection. Radio-collared lions were tolerant to our presence within 20 m without any obvious alteration in their behavior. During dark nights, a flashlight was used at intervals of 30–60 minutes to ascertain lion location apart from the radio signals. All predation and the scavenging events by the lions were recorded during continuous monitoring. Feeding interval was defined as the time lapse between two subsequent feeding events.

On average 75% of the biomass of each carcass/kill greater than 40 kg was observed to be utilized by the predators [65]. We estimated livestock's contribution to lions' diet from lion numbers in the study area obtained from lion density multiplied by daily intake requirement (7.3 kg/day/lion, [45]), scat analysis and continuous monitoring of radio-collared lions in the study area.

## Livestock Depredation Pattern

At each study *ness* a local *Maldhari* was employed to provide information to the authors in the event of a livestock death. KB and/or KSC visited the *ness* site of the mortality event within 24 hrs and recorded data on the time of day of each attack, the number, species and age-sex-productivity class of livestock killed, approximate weight of the predated individual, name of the owner and the identity of the predator. Livestock that died due to natural causes were generally dumped at specific sites outside the *nesses*. We recorded scavenging events by large carnivores which were identified based on direct sightings, vocalization and signs. Information from the owners of dead/predated livestock was obtained on the market price of the livestock and if they had claimed compensation from the Government under the current livestock depredation scheme. The compensation claims were cross validated from the Forest Department's records.

The monetary value of livestock was assigned in accordance with average prevalent market rate (Table S1). We compared this with the present compensation scheme provided by the Gujarat State Forest Department (Table S1) and the proportion of predation events claimed for compensation from the Government to estimate the offset of the capital loss incurred by the *Maldharis* due to livestock predation.

## Lion Carrying Capacity

In order to understand the relative significance of wild ungulates and *Maldhari* livestock in maintaining lion density in the study area, we used a regression model [66] that related prey biomass and lion density to estimate the ecological carrying capacity of the eastern Gir for lions. There are several approaches to indirectly predict carnivore density at a site; but studies have shown that it can be obtained more reliably by regressing against prey biomass [67]. The carnivore density derived from this relationship only works as long as no other mechanisms besides prey availability limit a carnivore population. We used prey biomass for predicting lion carrying capacity in our study area as other major top-down limiting factors like trophy hunting and incidence of epizootics [68,69] were not prevalent in Gir [70]. The model [66] based on lions' preferred prey species was used. The equation was  $y = -2.158 + 0.377x$  ( $r^2 = 0.71$ ,  $n = 23$ ) where  $y$  is the  $\log_{10}$  of lion density and  $x$  is the  $\log_{10}$  of preferred prey biomass [66]. We deduced prey biomass of different species by multiplying their densities [42,71] with their respective unit weights. Since all the livestock units were not available for lion predation, we therefore assessed the lion carrying capacity for three different scenarios; i) no livestock biomass (depicting a situation where there were no *Maldhari* livestock inside the Gir forest), ii) 100% livestock biomass available and iii) 24% (based on our data of feeding events and predation we considered all carcasses of dead livestock and a proportion of dry females, sub-adults and calves that foraged within the forest to be available to lions; this proportion was about 24% of the total livestock population). This enabled us to examine the relative importance of different levels of livestock biomass in sustaining lion population in our study site.

## Cost of Lion Predation on *Maldharis'* Livestock Husbandry

We compared the livestock rearing costs by a *Maldhari* herder living within Gir with a livestock herder living outside the forest. *Maldhari* livestock within Gir obtain most of their forage requirements from the forest free of cost, while a major proportion of the fodder for livestock outside the PA needed to be purchased. Occasional predation by lions is the cost of rearing livestock in the

Gir forests. We developed a deterministic economic model (Table S2) where we hypothesized that all other costs and profits being equal between the forest dwelling *Maldharis* and pastoralists living outside, it would be economically profitable for the *Maldharis* to stay in the forest with lions, if cost of obtaining livestock forage was greater than the economic loss due to lion predation.

The cost of lion predation was estimated in two parts:

- Capital loss- the market price of the predated livestock and
- Lost opportunity cost [72] i.e. the opportunity to earn from the predated livestock in the years to come had it not been killed (Table S2).

Hypothetically this component of cost (b) would occur if there was a deficit between market rates and government compensation paid for different livestock classes predated by lions. We calculated the lost opportunity cost as the amount of income that a *Maldhari* would have made from the predated livestock based on its life expectancy and productivity (Table S2). We modeled two scenarios of *Maldhari*-lion economics; i) with the current state-run predation compensation scheme and ii) without any such compensation scheme to understand the efficacy of the predation compensation scheme in permitting lion-*Maldhari* coexistence inside the Gir forests and its implications for the larger lion-occupied agro-pastoral landscape as well.

## Results

### Lion Density

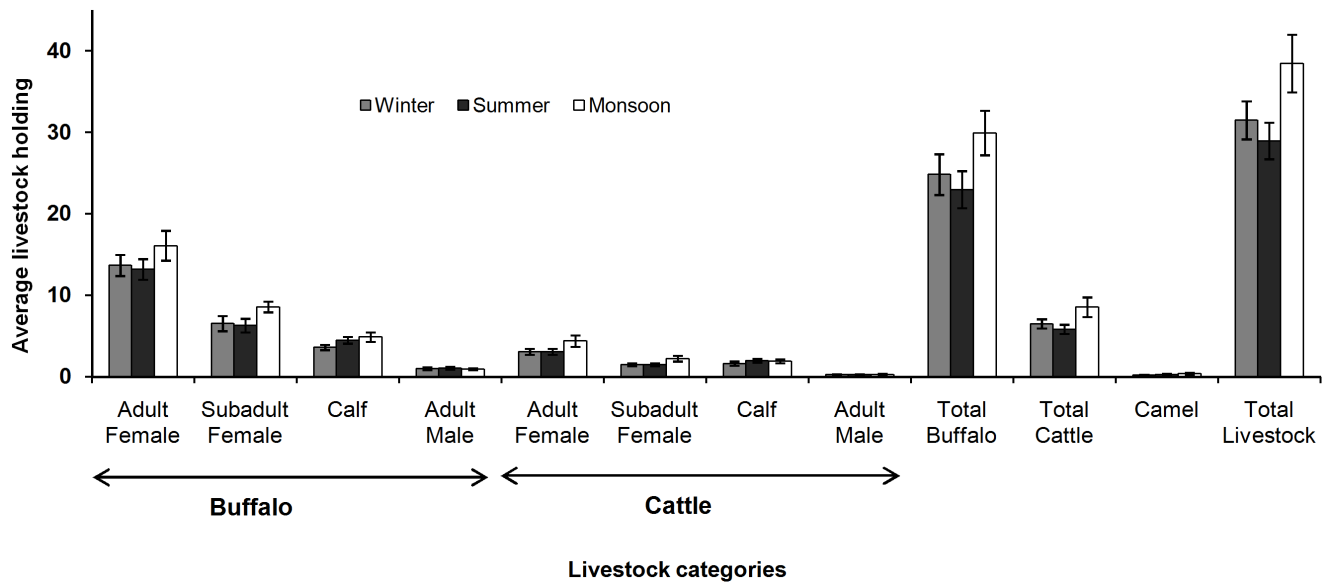
We obtained 36 sightings of 20 individual lions (3 adult males, 10 adult females and 7 sub-adults). Plot of cumulative number of unique lions against lion sightings reached an asymptote suggesting adequacy of sampling. The model selection procedure of program CAPTURE selected the model incorporating time variation and individual heterogeneity ( $M_{th}$ , scored at 1). Program CloseTest supported population closure ( $\chi^2_{12} = 30.2$ ,  $P = 0.19$ ). Capture probability of lions was 0.24 and the population estimate under  $M_{th}$  was  $20 \pm 1$  SE lions.

Using the  $\frac{1}{2}$  MMDM approach, we estimated a buffer width of  $2.4 \pm 0.2$  SE km and an effectively sampled area of  $131 \pm 17$  SE  $\text{km}^2$ . Lion density was estimated at  $15.2 \pm 0.1$  SE lions/100  $\text{km}^2$ .

### Livestock Density, Demography and Holding

The average foraging radius of livestock herds of six *ness* sites was  $1.9 \pm 0.1$  SE km. Some foraging areas of two or more *nesses* overlapped i.e. these areas were used by livestock from more than one *nesses*. Therefore, a common buffer of 1.9 km was created on the cluster of *ness* locations to compute livestock density. Livestock foraging area was maximum ( $95.2 \text{ km}^2$ ) in pre-monsoon followed by  $76.3 \text{ km}^2$  during summer and minimum foraging area during winter ( $65.9 \text{ km}^2$ ). All *ness* sites showed seasonal fluctuation in livestock population. Maximum livestock number was observed during monsoon while during winter and summer livestock numbers decreased due to emigration of the herders outside the Gir PA. The livestock density was  $31.4/\text{km}^2$  in winter,  $30.1/\text{km}^2$  in monsoon and  $24.7/\text{km}^2$  during summer.

The total livestock holding of the study *nesses* was  $2,140 \pm 296$  SE. Buffaloes were dominant contributing at 78.1%, while cattle (21.1%) and camels (0.8%) constituted the remainder livestock numbers. Overall population structure of buffaloes and cattle was largely composed of adult and sub-adult females (Fig. 2). Few adult males were kept for breeding purpose. The average livestock



**Figure 2. Average seasonal livestock holding of Maldhari family within the Gir forests.** (Error bars are standard errors). doi:10.1371/journal.pone.0049457.g002

holding of a *Maldhari* family varied from  $29 \pm 3$  SE in summer to  $31 \pm 3$  SE in winter and  $39 \pm 4$  SE in the monsoon.

Average grazing herd size was  $22 \pm 2$  SE and was always of mixed composition of cattle and buffaloes. High priced, milk yielding livestock were rarely taken out of the corrals to graze. These were stall fed by forage collected from the forest and by concentrates purchased from the market. Average number of herdsmen accompanying herds was  $2 \pm 0.04$  SE. Spatial lay out of the herds were with cattle (low monetary value) leading, buffaloes (high monetary value) in the middle and juvenile/sub-adult animals (low monetary value) trailing. The herdsmen were usually mobile sometimes leading and at times pushing the herd from the rear.

### Lion Food Habits

Frequency of occurrence of all prey items in scats reached an asymptote after sampling over 130 scats; so our sample size of 165 scats was deemed sufficient. Most (97.6%) lion scat contained a single prey type, while 2.4% of the scats had two prey items. Wild ungulates comprising chital, sambar, nilgai and wild pig together accounted for 76.4% of all prey occurrences, while domestic livestock (buffalo 13.7% and cattle 7.8%) contributed the rest (Table 1). Percentage biomass contribution of different prey species to the lions' diet was most for livestock (33.7%) followed by chital (28.9%) and sambar (28.3%). There was evidence of selective utilization of prey by lions ( $G = 76.9$ ,  $P < 0.001$ ,  $df = 5$ ). Chital ( $\chi^2 = 12.3$ ,  $P < 0.001$ ), sambar ( $\chi^2 = 103.4$ ,  $P < 0.001$ ), nilgai ( $\chi^2 = 2.4$ ,  $P < 0.05$ ) and wild pig ( $\chi^2 = 34.1$ ,  $P < 0.001$ ) were found to be utilized more than their availability while buffaloes ( $\chi^2 = 60.3$ ,  $P < 0.001$ ) were used less than their availability. Cattle ( $\chi^2 = 0.9$ ,  $P = 0.33$ ) were utilized in proportion to their availability. The order of prey preference by lions as estimated by Jacob's Index was sambar, wild pig, nilgai, chital and cattle (Fig. 3).

### Livestock Depredation Pattern

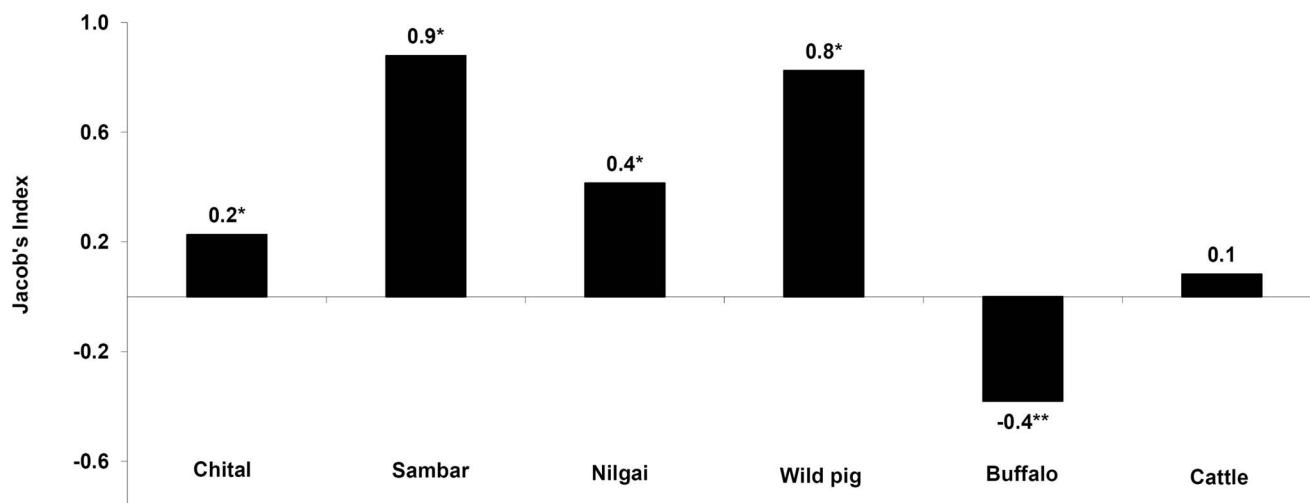
We recorded a total 308 livestock mortalities from the six *nesses* between April 2005 and August 2007, of which 58.4% was due to lion predation, 3.2% was due to predation by leopards and 38.4% was due to other natural causes. Lion predation was mostly on

cattle (69.4%) followed by buffaloes (29.4%) and camels (1.2%). Non-productive cattle dominated lion kills (Fig. 4). Average age of livestock predated by lions was estimated at  $4 \pm 0.2$  SE years. Of the 118 events of natural death of livestock, 46.6% were scavenged by lions, mostly adult female buffalo carcasses (27.2%) reflecting a higher availability of this livestock category in the study area.

The 180 lion kills recorded involved 151 successful hunt events [average killed/hunt  $1.2 \pm 0.5$  SE]. The number of livestock killed per successful hunt was weakly correlated with the number of lions reported by the herders (Spearman rank correlation  $r_s = 0.15$ ,  $P = 0.03$ ). Of the successful lion attack events on livestock, only 13% occurred within the *ness* when lions jumped into the fenced *ness* and killed livestock while 87% occurred in forests when livestock were out grazing. We did not record any leopard attack on grazing herds. In 68 events of lion attacks on grazing herds the herders could affirm the gender of the lions making the kills. Female lions with dependent cubs were responsible for 54.4% of the attacks; single male or male coalitions were responsible for 19.1% of the attacks and mixed groups of lions made 26.4% of the kills. Lionesses in the study area were found to raid livestock in proportion to the prevailing adult sex ratio in the population ( $\chi^2_1 = 0.19$ ,  $P = 0.66$ ). Thus all lions were equally likely to predate livestock.

Most (49%) of the lion predation events on livestock were recorded during early morning (7 AM – 11 AM), followed by 39% in late afternoon (3 PM – 7 PM) [ $\chi^2_2 = 29.5$ ,  $P < 0.0001$ ]. But during monsoon, most predation events (44%) occurred during late afternoon or evening ( $\chi^2_2 = 14.2$ ,  $P < 0.001$ ) due to cooler ambient temperature, poor visibility owing to bad light, rain and thick vegetation undergrowth. Livestock losses to lions were different between seasons ( $\chi^2_2 = 6.5$ ,  $P = 0.04$ ), with 45% occurring in summer, followed by 30% in monsoon and 25% in winter.

A crude estimate of total intake requirement of the lion population in the study area was about 124,733 kg for the study period of 28 months. Livestock were found to be contributing about 31,582 kg (25.3%) of biomass to the lion's diet. Inter-feeding interval of lions estimated by the continuous monitoring was  $3.5 \pm 0.7$  SE days with an average associated lion group size during feeding being  $4 \pm 1$  SE. Telemetry data showed that livestock



**Figure 3. Food preference of lions in the Gir forests, India based on Jacob's index [59].** Program SCATMAN [55] suggests that at 10% CV \* Chital ( $P < 0.001$ ), sambar ( $P < 0.001$ ), nilgai ( $P < 0.05$ ) and wild pig ( $P < 0.001$ ) were found to be positively selected while \*\*buffaloes ( $P < 0.001$ ) were underused in proportion to their availabilities. Cattle ( $P = 0.33$ ) were utilized in proportion to their availabilities. doi:10.1371/journal.pone.0049457.g003

composed 42% of lions' feeding events (16% from predation and 26% was from scavenging on livestock carcasses). Wild ungulates were found to compose the remainder 58% of lions' feeding events (47% preyed and 11% appropriated from leopard kills or other lion kills).

### Lion Carrying Capacity

Under the assumption of 100% availability of livestock biomass to lion predation, the lion carrying capacity was estimated to be 22 (95% CI 20–25) lions/100 km<sup>2</sup> while with no availability of livestock, the lion carrying capacity was 12 (95% CI 9–15) lions/100 km<sup>2</sup>. Lion carrying capacity with 24% of livestock population available for lions was 16 (95% CI 13–18) lions/100 km<sup>2</sup> (Table S3).

### Economics of Lion Predation

Annual fodder cost for maintaining 100 livestock was estimated to be ₹1,460,000 [1US\$ ~ ₹50]. For forest-dwelling *Maldhari* this resource is available free of cost. Average cost of livestock units preyed by lion was ₹4,018±278 SE. *Maldharis* incurred an annual capital loss of ₹33,751±2,335 SE/100 livestock by lion predation. Sixty four percent of this cost was offset by the

government compensation (i.e. capital loss with Government compensation was ₹12,150±840 SE/100 livestock). The annual lost opportunity costs incurred by *Maldharis* was ₹136,156±3,430 SE/100 livestock with Government compensation. The same cost without Government compensation was ₹378,212±9,529 SE/100 livestock. By living in the Gir forests, 58±0.2 SE% of livestock rearing cost of *Maldharis* was accounted for by free forest resources in comparison to a non-forest dwelling pastoralist. With government predation compensation scheme this profit margin was further augmented to 76±0.05 SE% (Table 2). Cost saving (additional profit) by *Maldharis* living in Gir was therefore, ₹1,104,373/100 livestock/year (or 214 man-day wages/*Maldhari* family/month) and ₹840,717/100 livestock/year (or 163 man-day wages/*Maldhari* family/month) with and without a lion predation compensation scheme respectively in comparison with non-forest dwelling pastoralists (Table S2).

### Discussion

We found that presently *Maldhari* and lions coexist in a win-win state where lions get a considerable part of their food from *Maldhari* livestock and *Maldharis* profit substantially by free access

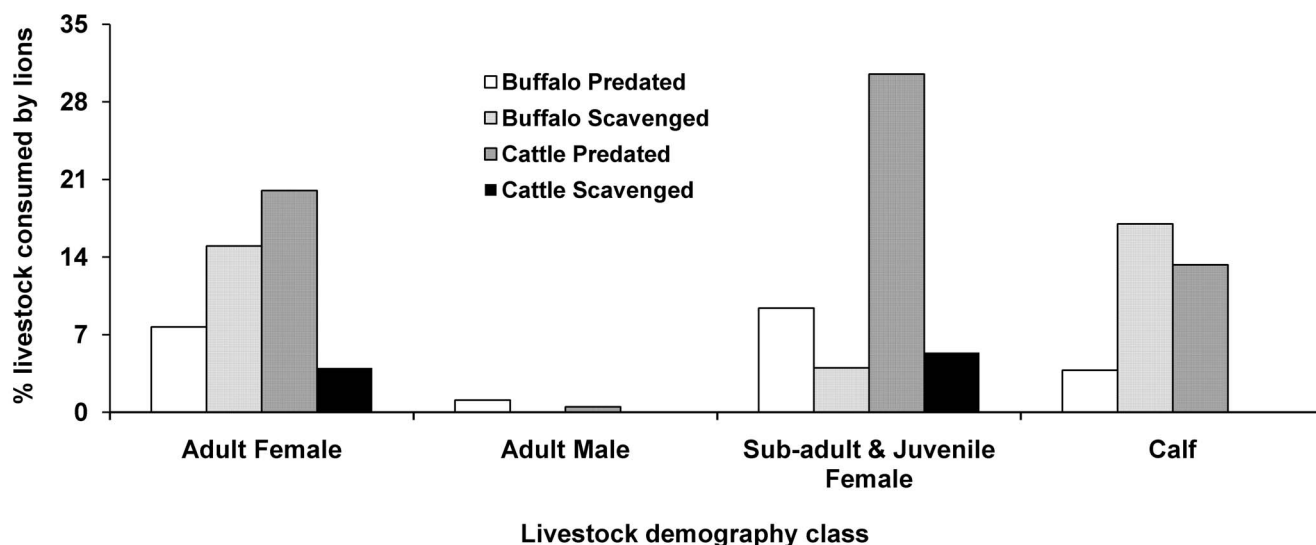
**Table 1. Prey species composition in Asiatic lion *Panthera leo persica* scats (n = 165) and their relative biomass contribution to lion diet in eastern part of the Gir forests, India.**

Prey Items	Body Weight (kg), (x)	Total Number of Scats	Observed Frequency of Occurrence [F] (95% CI)*	Relative Occurrence (as %)	Collectable scats/kill (y)	% Biomass Consumed (95% CI)
Chital	42	72.5	44 (37–51.8)	45	3.5	28.9 (24.3–34.1)
Sambar	119	40	24.4 (17.9–30.6)	24.9	6.2	28.3 (20.9–35.7)
Nilgai	136	7.5	4.6 (1.8–8.5)	4.7	8.3	7.2 (2.8–13.4)
Wild pig	28	5.5	3.4 (1.6–6.8)	3.4	2.9	1.9 (0.8–3.8)
Buffalo	204	22.5	13.7 (8.6–19.1)	13.9	9.1	23.6 (14.8–33)
Cattle	136	13	7.8 (3.7–11.7)	8.1	6.7	10.1 (4.7–14.9)

x and y are related through the equation  $y = 1.98 + 0.035 \times [x]$ .

\*95% CIs obtained by 1,000 bootstrapped replicates.

doi:10.1371/journal.pone.0049457.t001



**Figure 4. Livestock utilization by lions in the Gir East Sanctuary, India showing percent contribution of different livestock classes in livestock feeding events documented by continuous monitoring on radio-collared lions.**  
doi:10.1371/journal.pone.0049457.g004

to forest resources. Average annual financial loss/*Maldhari* household due to livestock predation by lions after offsetting by the compensation was minimal (₹2,038) and was only 5% of the average *per capita* income for Gujarat province and 7% of the national average during the fiscal year 2005–06 [73]. With free grazing rights and at current rate of compensation, additional profits of a *Maldhari* family residing inside Gir approximately amount to a person's annual minimal wage (213 man-day wages). Current government compensation scheme, though small in comparison to the value of free resources, was important as it provided a *Maldhari* family an additional monthly monetary advantage of 51 man-day wages to a no-compensation scenario (Table S2). We did not, however, consider the additional benefits *Maldharis* enjoy by dwelling inside Gir i.e. from other ecological services and amenities (collection of fuel wood and minor forest products, use of forest topsoil mixed with dung sold as manure, free access to water, job opportunities with the forest department and maintaining their social customs). These, when incorporated into our analysis, further augment the benefits *Maldharis* make by living inside Gir.

The *Maldhari*-lion coexistence in Gir forests is long debated with one school of thought attributing ecological deterioration of the

Gir to the traditional way of resource usage by *Maldharis* [74] and therefore advocates their relocation outside the PA. The other school, on the contrary, attributed exclusionary forest policy and insufficient compensation scheme by the Forest Department as causes of economic marginalization of Gir *Maldharis* [75]. Livestock has always been an important part of lion's diet in Gir ranging between 83 to 25% [45,65,76,77]. We studied livestock depredation pattern by lions with a combination of methods viz., scat analysis, predation pattern and feeding events of the radio-collared lions in order to address inherent limitations of each method and estimated biomass contribution by domestic livestock in lions' diet to range between 25 to 42% within eastern Gir PA. Past long-term research from Africa have shown that prey availability and density govern lion demography like cub survival and dispersal rates [63,78,79]. Our data suggested that the carrying capacity of lions modeled with available biomass of dead livestock and livestock classes vulnerable to lion predation (24%) was almost similar with the current lion density estimated in the study area (15 lions/100 km<sup>2</sup>). However, when we considered a hypothetical situation where there were no *Maldhari* settlements in the study area and therefore no availability of livestock biomass for lions, the predicted lion carrying capacity went down (12 lions/

**Table 2. Parameter values (95% CI) used for the deterministic model of *Maldhari* pastoral economics.**

Scenarios	Capital loss/100 livestock/year	Lost Opportunity cost/100 livestock/year	Total revenue loss by lion predation/100 livestock/year	Annual cost saving by living with lions/100 livestock	Percentage benefit as proportion of livestock rearing cost covered by living with lions after accounting for losses due to lion predation
With Government Compensation	12,150 (10,502–13,799)	136,156 (129,432–142,880)	355,626 (353,979–357,275)	1,104,373 (1,102,725–1,106,021)	75.6 (75.5–75.7)
Without Government Compensation	33,751 (29,173–38,329)	378,212 (359,535–396,889)	619,283 (614,705–623,861)	840,717 (836,139–845,295)	57.5 (57.2–57.9)

Final estimates are in Indian Rupees (1 US\$ ~ ₹50).  
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100 km<sup>2</sup>), albeit not statistically significantly. Moreover, lions in Gir obtained a major part of their diet from scavenging livestock. Being a free resource for lions, this optimized the Gir lions' energy economics by maximizing the net food intake per unit time available for foraging [80]. Abrupt removal of livestock as a food source is likely to have a detrimental effect on lion density and demography in Gir [37,81]. We recommend that if removal of livestock is to be considered, it should be in a phased manner so as to allow natural wild prey population to build up and replace livestock [82]. However, diet of wild ungulates in Gir differed substantially from those of livestock [71,83]; therefore, removal of livestock was unlikely to be fully compensated by increase in wild ungulate biomass. With a lion focused conservation objective of Gir, maintaining livestock at the current or lower stocking densities could also be considered as an alternative management practice. To avoid negative impacts of livestock trampling, livestock numbers should be regulated at the *nesses* with their locations rotated every 4–5 years [42].

Human attitudes towards large carnivores have been shaped by psychology of fear and personal experience [84], and also depend on their attachment to livestock [85]. Gir *Maldharis* did not view lions as a threat to their lives [11] and there was no lion attack on humans within our study area during past two decades. Moreover, unproductive cattle (such as males and poor condition calves, aged, and dying cattle) were mostly targeted by lion predation. The average cost of such unproductive cattle was ₹3,425 and at times, it was not profitable to maintain them by stall-feeding. We believe that retaliatory killing of lions is not currently prevalent in Gir due to low economic losses, *Maldharis*' cultural ethics, combined with strict legal enforcement by the Gir Park Management. But traditional value systems of the *Maldharis* are rapidly changing under the influence of globalization and free markets [25,86]. Younger generations are less tolerant to even small monetary losses which older generations considered as fait-accompli. We anticipate that such changes in attitudes and values are likely to result in a change of *Maldharis*' harmonious coexistence with lions. A similar transition has happened with the pastoral Masai community in the eastern Africa within the past two decades [87,88]. With this change in values, comes complacency towards professional lion poachers by local communities. This was probably the case when 8–10 lions were poached for their body parts in the recent past in Gir [82,89] and elsewhere in India in the case of tigers, *Panthera tigris* [90,91]. Reparative measures such as compensation programs become important herein, mitigating conflicts by offsetting monetary costs to local communities [92]. The success of Asiatic lion conservation is partly attributable to the early policies (1930s) of the erstwhile Junagadh Nawabs [93] and later to the state run Gujarat Forest Department in implementing compensation schemes for livestock predation [82]. In order to reflect the current market value of the livestock, the compensation rate is usually revised at an interval of every 6–8 years [82]. We found that the current compensation scheme substantially minimized lion-*Maldhari* conflicts by lowering the latter's capital loss by 64% and allowing them to make an additional monthly monetary profit of 51 man-day wages/family in comparison to a non-compensation scenario. We believe that this had a positive role in shaping *Maldharis*' perceptions about their personal losses and thus acts as an important factor promoting their coexistence with lions. A similar pattern has been observed among the Masai community residing around the Mbirkani Ranch, Kenya where individuals receiving compensation from a local NGO showed a lower propensity to kill lions and were found to bear more positive attitude towards conservation [94,95]. The current compensation scheme in Gir addresses

*Maldharis*' capital loss to a significant extent. Increasing this to current market value of the predated livestock by timely revision (every 2 years) would ensure that there is no lost opportunity cost to the local communities. However, recognizing the role of compensation policies in providing instant financial relief, the procedural framework of the current system in Gir could be more streamlined and provisions of onsite payments with active involvement of local non-governmental organizations like that prevailing in Corbett and Dudwa Tiger Reserves, India [96] could also be adopted.

*Maldharis* and Masai seemed to have mastered husbandry practices over generations to minimize predation losses to lions and permit coexistence. Both communities corral their livestock at night in their 'bomas' and graze the livestock during daytime, avoiding peak lion activity period and having expert herdsman [97]. In Gir, cattle were the preferred prey of lions as they are easy to kill due to their behavior of flight when attacked while buffaloes have a defense strategy and often attack lions as a cohesive group [98]. Cattle are relatively less priced in comparison to buffaloes and therefore *Maldhari* grazing herds were always observed to have a few non-productive cattle. Thus, when lions attack, they are more likely to kill these vulnerable cattle. Moreover, *Maldhari* herdsman orient their herds with cattle leading, buffaloes in the middle and juvenile animals trailing. We speculate that the current traditional mechanism of warding off lion predation by corralling livestock at night and having a mixed grazing herd composition being always accompanied by expert herdsman minimized the risks and economic losses to lion predation. In Gir since livestock are reared only for dairy products and are not consumed by *Maldharis* [11,33] there is a large cohort of old and weak cattle in which natural mortality is high and these carcasses are available to lions for scavenging.

We conclude that the underlying economics of *Maldhari* livelihood securities, their religious sentiments, ecological benefits enjoyed by pastoralists living in lion habitats and strict legal protection regime for lions in the Gir forests [11,31,70] are all needed as recipe for lion-*Maldhari* coexistence. Indefinite increase in human and livestock population within the Gir forests would upset this balance by altering the forest composition or even population dynamics of wild prey [99] and would thus be detrimental for the conservation objective of the Protected Area. Presently lions are dispersing out of the Gir PA and have already occupied about 9,000 km<sup>2</sup> of agro-pastoral landscape [28,29,41]. Our ongoing telemetry study suggests that lions outside the PA depend substantially on livestock, thereby increasing the chances of human-lion conflict in the region [81,100]. In the agro-pastoral landscapes, there are no free economic benefits for the communities. Government compensation scheme therefore becomes extremely crucial for maintaining the goodwill of the communities towards lion conservation.

Due to high human densities and demand for land most human free inviolate protected areas in India and elsewhere are too small to hold viable populations of large carnivores for the long-term [101,102]. Coexistence with humans therefore becomes essential if large carnivores were to be conserved for the long-term. Considering the case of Asiatic lions, only about 10% of the lion population resides in the human-free Gir National Park, 62% of lion population resides in the Gir Sanctuary (with *Maldhari* settlements) while 22% of the adult lion population resides in the human-dominated agro-pastoral landscape of Saurashtra [81,103]. A comparable situation exists with many tiger populations in India as well [104]. Such scenarios are common to several developing countries and activities like paying compensation should be considered as ecosystem maintenance costs that need to

be paid to the local communities by Global societies or Governments for the continued survival of large carnivores within landscapes of conflict to promote coexistence. This would foster greater tolerance by local communities towards lion conservation in the Gir landscape and for other large carnivores elsewhere. We see no end to this or similar programs worldwide and believe that they form an integral component of coexistence and an important component of conserving viable populations of large carnivores.

## Supporting Information

**Table S1 Average monetary values (Indian Rupees, 1 US\$ ~ ₹50 ) for various age-sex-productivity categories of livestock (buffalo and cattle) used for analysis.** The values in parentheses show the compensations amounts paid by the state forest department for the respective livestock classes to offset economic loss due to predation by carnivores in and around the Gir Protected Area (after [71]).  
(PDF)

**Table S2 Description and estimation of cost parameters used for economic analysis. Final estimates are in Indian Rupees (1 US\$ ~ ₹50).**  
(PDF)

**Table S3 Predicted carrying capacity of Asiatic lions in the eastern part of the Gir forests at different availabil-**

**ity of livestock biomass.** Lion carrying capacity was predicted using the equation  $y = -2.158 + 0.377 \times (x^2 = 0.71, n = 23)$  where  $y$  is the  $\log_{10}$  of lion density and  $x$  is the  $\log_{10}$  of prey biomass [57]. Figures within parentheses are 95% CIs. Densities of wild ungulates (chital, sambar, nilgai and wild pig) were taken from literature [38].

(DOC)

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## Author Contributions

Conceived and designed the experiments: YVJ. Performed the experiments: KB KSC CVD YVJ. Analyzed the data: KB YVJ. Wrote the paper: KB YVJ.

## References

- Ogada MO, Woodroffe R, Oguene ON, Frank GL (2003) Limiting depredation by African carnivores: the role of livestock husbandry. *Conserv Biol* 17: 1521–1530.
- Inskip C, Zimmerman A (2009) Human-felid conflict: a review of patterns and priorities worldwide. *Oryx* 43: 18–34.
- Treves A, Karanth KU (2003) Human–carnivore conflict and perspectives on carnivore management worldwide. *Conserv Biol* 17: 1491–1499.
- Karanth KU, Chellam R (2009) Carnivore conservation at the crossroads. *Oryx* 43: 1–2.
- Saberwal V, Gibbs JP, Chellam R, Johnsingh AJT (1994) Lion-human conflict in the Gir forest, India. *Conserv Biol* 8: 501–507.
- Packer C, Ikanda D, Kissui B, Kushnir H (2005) Lion attacks on humans in Tanzania. *Nature* 436: 927–928.
- Goldman MJ, De Pinho JR, Perry J (2010) Maintaining complex relations with large cats: Maasai and lions in Kenya and Tanzania. *Hum Dimens Wildl* 15: 332–346.
- Mech DL (1991) Returning the wolf to Yellowstone. In: Keiter RB, Boyce MS, editors. *The Greater Yellowstone ecosystem: redefining America's wilderness heritage*. Yale University Press, New Haven, Connecticut. 309–322.
- Athreya V, Odden M, Linnell JDC, Karanth KU (2011) Translocation as a tool for mitigating conflict with leopards in human-dominated landscapes of India. *Conserv Biol* 25: 133–141.
- Karanth KU, Gopal R (2005) An ecology-based policy framework for human-tiger coexistence in India. In: Woodroffe R, Thirgood S, Rabinowitz A, editors. *People and wildlife: conflict or coexistence?* Cambridge University Press, UK. 373–387.
- Raval SR (1991) The Gir National Park and the Maldharis: "Setting Aside". In: West PC, Brechin SR, editors. *Resident peoples and national parks—social dilemmas and strategies in international conservation*. University of Arizona Press, USA. 68–86.
- Census of India (2011) Provisional population totals. Paper 2, volume 1 of 2011. Rural-urban distribution India series 1. Office of the Registrar General and Census Commissioner, New Delhi, India. Data product 00-004-2011-Cen-Book (E).
- Rai ND (2007) The ecology of income. Can we have both fruit and forest? In: Sahabuddin G, Rangarajan M, editors. *Making conservation work*. Permanent Black, New Delhi, India. 147–162.
- Saberwal V, Rangarajan M (editors) (2003) *Battles over nature: Science and politics of conservation*. Permanent Black, New Delhi, India. 412 p.
- Rangarajan M (1996) Fencing the forest: conservation and ecological change in India's Central Provinces 1860–1914. Oxford University Press, New Delhi, India. 258 p.
- Adams WM, Hutton J (2007) People, parks and poverty: political ecology and biodiversity conservation. *Conservation and Society* 5: 147–183.
- Datta A, Anand MO, Naniwadekar R (2008) Empty forests: large carnivores and prey abundance in Namdhapa National Park, north-east India. *Biol Conserv* 141: 1429–1435.
- Guha R (2003) The authoritarian biologist and the arrogance of anti-humanism: wildlife conservation in the third world. In: Sabervall V, Rangarajan M, editors. *Battles over nature: Science and politics of conservation*. Permanent Black, New Delhi, India. 139–157.
- Kothari A, Suri S, Singh N (1995) *People and Protected Areas: rethinking conservation in India*. *Ecologist* 25: 188–194.
- Sawarkar VB (1986) Animal damage: predation on domestic livestock by large carnivores. *Indian Forester* 112: 858–866.
- Gadgil M, Thapar R (1990) Human ecology in India: some historical perspectives. *Interdiscip Sci Rev* 15: 209–223.
- Renugadevi R (2012) Environmental ethics in the Hindu Vedas and Puranas in India. *African Journal of History and Culture* 4: 1–3.
- Thapar R (1994) *Asoka and Buddhism as reflected in the Asokan edicts*. In: Seneviratna A, editor. *King Asoka and Buddhism: historical and literary studies*. Buddhist Publication Society, Kandy, Sri Lanka. 15–36.
- Wildlife Protection Act (1972) *Wildlife Protection Act, Act number 53 of 1972, 9th September, 1972, Ministry of Law, Justice and Company, New Delhi, India*. Available moef.nic.in/downloads/public-information/Annexure-IV-NBA.pdf. Accessed September 26 2011.
- Manfredi MJ, Teel TL, Bright AD (2003) Why are public values toward wildlife are changing? *Human Dimensions of Wildlife* 8: 287–306.
- Kinnear NB (1920) The past and present distribution of the lion in south eastern Asia. *Journal of the Bombay Natural History Society* 27: 34–39.
- Fenton LL (1924) *The rifle in India: being the sporting experiences of an Indian officer*. W. Thacker and Co., London, UK.
- Singh HS, Gibson LA (2011) A conservation success story in the otherwise dire megafauna extinction crisis: the Asiatic lion (*Panthera leo persica*) of Gir forest. *Biol Conserv* 144: 1753–1757.
- Banerjee K, Jhala YV (2012) Demographic parameters of endangered Asiatic lions (*Panthera leo persica*) in Gir forests, India. *J Mammal* 93: DOI: 10.1644/11-MAMM-A-231.1.
- Casimir MJ (2001) Of lions, herders and conservationists: brief notes on the Gir forest National Park in Gujarat (western India). *Nomadic Peoples* 5: 154–161.
- Singh HS, Kamboj RD (1996) *Biodiversity conservation plan for Gir (a management plan for Gir Sanctuary and National Park)*, Volume I. Sasan Gir Wildlife Division, Gujarat Forest Department, Sasan Gir, Junagadh, India. 242 p.
- Champion HG, Seth SK (1968) *A revised survey of the forest types of India*. Government of India, New Delhi, India. 404 p.
- Varma K (2009) The Asiatic lion and the *Maldharis* of Gir forest: an assessment of Indian Eco-development. *The Journal of Environment and Development* 18: 154–176.
- Pollock KH, Nichols JD, Brownie C, Hines JE (1990) Statistical inference for capture-recapture experiments. *Wildl Monogr* 107: 1–97.
- Pennycuik CJ, Rudnai J (1970) A method of identifying individual lions *Panthera leo* with an analysis of the reliability of identification. *J Zool* 160: 497–508.

36. Jhala YV, Qureshi Q, Bhuvra V, Sharma LN (1999) Population estimation of Asiatic lions. *Journal of the Bombay Natural History Society* 96: 3–15.
37. Jhala YV, Mukherjee S, Shah N, Chauhan KS, Dave C, et al. (2004) Monitoring lions. In: Jhala YV, editor. *Monitoring of Gir*, Technical Report, Wildlife Institute of India, Dehra Dun, India, RR -04/002. 55–71.
38. Stanley TR, Burnham KP (1999) A closure test for time-specific capture-recapture data. *Ecological Statistics* 6: 197–209.
39. Rexstad EA, Burnham KP (1991) User's guide for interactive program CAPTURE. Colorado Cooperative Wildlife Research Unit, Colorado State University, Fort Collins Co. 29 p.
40. Karanth KU, Nichols JD (1998) Estimation of tiger densities in India using photographic captures and recaptures. *Ecology* 79: 2852–2862.
41. Banerjee K, Jhala YV, Pathak B (2010) Demographic structure and abundance of Asiatic lions (*Panthera leo persica*) in Girnar Wildlife Sanctuary, Gujarat, India. *Oryx* 44: 248–251.
42. Dave C, Jhala Y (2011) Is competition with livestock detrimental for native wild ungulates? - A case study of chital (*Axis axis*) in Gir forest, India. *J. Trop. Ecol.* 27: 239–247.
43. Korschgen LK (1980) Procedures for food habit analysis. In: Schemnitz SD, editor. *Wildlife management techniques manual*. The Wildlife Society, Washington DC, USA. 113–128.
44. Klare U, Kamler JF, Macdonald DW (2011) A comparison and critique of different scat-analysis methods for determining carnivore diet. *Mammal Rev* 41: 294–312.
45. Joslin P (1973) The Asiatic lion: a study of ecology and behavior. Partial fulfillment of the requirements for the degree of Doctor of Science in the Department of Forestry and Natural Resources, University of Edinburgh, UK. 249 p.
46. Mukherjee S, Goyal SP, Chellam R (1994a) Refined techniques for the analysis of Asiatic lion *Panthera leo persica* scats. *Acta Theriol* 39: 425–430.
47. Mukherjee S, Goyal SP, Chellam R (1994b) Standardization of scat analysis techniques for leopard (*Panthera pardus*) in Gir National Park, western India. *Mammalia* 58: 139–143.
48. Jethva B, Jhala YV (2003) Sample size considerations for food habit studies of wolves from scats. *Mammalia* 68: 589–591.
49. Krebs CJ (1989) *Ecological Methodology*. Harper and Row, New York, USA. 654 p.
50. Péladeau N (1995) SIMSTAT 3.5. Provalis Research, USA. 268 p. Available: [www.provalisresearch.com/Documents/simstat.pdf](http://www.provalisresearch.com/Documents/simstat.pdf). Accessed 2011 Nov 1.
51. Floyd TJ, Mech LD, Jordan PA (1978) Relating wolf scat content to prey consumed. *J Wildl Manage* 42: 528–532.
52. Ackerman BB, Lindzey FG, Hemker TP (1984) Cougar food habits in southern Utah. *J Wildl Manage* 48: 147–155.
53. Schaller GB (1967) *The deer and the tiger*. University of Chicago Press, Chicago, USA. 370 p.
54. Prater SH (1971) *The book of Indian animals*. The Bombay Natural History Society, Bombay, India. 324 p.
55. Hines JE, Link WA (1994) SCATMAN, USGS-Patuxant Wildlife Research Center, Patuxant, Maryland, USA. Available: <http://www.mbr-pwrc.usgs.gov/software.html>. Accessed 2011 Nov 10.
56. Link WA, Karanth KU (1994) Correcting for overdispersion in tests of prey selectivity. *Ecology* 75: 2456–2459.
57. Manly BEJ, McDonald LL, Thomas DL (1992) *Resource selection by animals: statistical design and analysis for field studies*. Chapman and Hall, London, UK. 177 p.
58. Zar JH (2010) *Biostatistical analysis*. Fifth edition, Prentice Hall, New Jersey. 960 p.
59. Jacob J (1974) Quantitative measurement of food selection. *Oecologia* 14: 413–417.
60. Hayward MW, Kerley GIH (2005) Prey preferences of the lion (*Panthera leo*). *J Zool* 267: 309–322.
61. Mills MGL (1992) A comparison of methods used to study food habits of large African carnivores. In: McCulloch C, Barret RH, editors. *Wildlife 2001: Populations*. Elsevier, London, UK. 1112–1123.
62. Jethva BD, Jhala YV (2004) Foraging ecology, economics and conservation of Indian wolves in the Bhal region of Gujarat, western India. *Biol Conserv* 116: 351–357.
63. Schaller GB (1972) *The Serengeti lion: a study of predator-prey relations*. University of Chicago Press, USA. 480 p.
64. Beier P, Choate D, Barrett RH (1995) Movement patterns of mountain lions during different behaviors. *J Mammal* 76: 1056–1070.
65. Chellam R (1993) Ecology of the Asiatic lion (*Panthera leo persica*). Partial fulfillment of the requirements for the degree of Doctor of Science in the Department of Biosciences, Saurashtra University, Rajkot, India. 170 p.
66. Hayward MW, O'Brien J, Kerley GIH (2007) Carrying capacity of large African predators: predictions and tests. *Biol Conserv* 139: 219–229.
67. Carbone C, Gittleman JL (2002) A common rule for the scaling of carnivore density. *Science* 295: 2273–2276.
68. Kissui BM, Packer C (2004) Top-down population regulation of a top predator: lions in the Ngorongoro Crater. *Proc R Soc Lond B Biol Sci* 271: 1867–1874.
69. Whitman KL, Starfield AM, Quadling H, Packer C (2007) Modeling the effects of trophy selection and environmental disturbance on a simulated population of African lions. *Conserv Biol* 21: 591–601.
70. Pathak B, Pati BP, Kumar R, Kumar A, Raval PP, et al. (2002) Biodiversity conservation plan for Gir (a supplementary management plan, 2002–03 to 2006–07). Wildlife Circle, Junagadh. Gujarat Forest Department, India. 407 p.
71. Dave C (2008) Ecology of chital (*Axis axis*) in Gir. Partial fulfillment of the requirements for the degree of Doctor of Science in the Department of Biosciences, Saurashtra University, Rajkot, India. 262 p.
72. Buchanan JM (2003) Cost and choice. In: Rowley CK, Schneider F, editors. *The encyclopedia of public choice*. Kluwer Academic Publishers, London, UK. 454–456.
73. Ministry of Finance-Government of India (2009) Public private partnerships in India- state economy. Available: <http://www.pppinindia.com/state-economy-gujarat.asp>. Accessed 2010 Nov 15.
74. Pati BP (2000) Impact of livelihood practices of *Maldhari* tribe on wildlife habitat of Gir Protected Area. *Indian Forester* 126: 1120–1127.
75. Mukherjee A, Borad CK (2004) Integrated approach towards conservation of Gir National Park: the last refuge of the Asiatic lions, India. *Biodivers Conserv* 13: 2165–2182.
76. Meena V, Jhala YV, Chellam R, Pathak B (2011) Implications of diet composition of Asiatic lions for their conservation. *J Zool* 284: 60–67.
77. Sinha SP (1987) Ecology of wildlife with special reference to the lion (*Panthera leo persica*) in Gir wildlife sanctuary, Saurashtra, Gujarat. Ph.D. Partial fulfillment of the requirements for the degree of Doctor of Science in the Department of Biosciences, Saurashtra University, Rajkot, India. 291 p.
78. Van Orsdol KG, Hanby JP, Bygott JD (1985) Ecological correlates of lion social organization. *J Zool* 206: 97–112.
79. Hayward MW, Hayward GJ, Druce D, Kerley GIH (2009) Do fences constrain predator movements on an evolutionary scale? Home range, food intake and movement patterns of large predators reintroduced to Addo Elephant National Park, South Africa. *Biodivers Conserv* 18: 887–99.
80. Stephens DW, Krebs JR (1986) *Foraging theory*. Princeton, New Jersey: Princeton University Press. 262 p.
81. Jhala YV, Chellam R, Pathak B, Meena V, Banerjee K, et al. (2011a) Social organization and dispersal of Asiatic lions. Technical Report, Vol. I submitted to the Gujarat Forest Department. Wildlife Institute of India, Dehra Dun, India, TR-2011/001. 163 p.
82. Singh HS (2007) *The Gir lion Panthera leo persica- a natural history, conservation status and future prospect*. Pugmark Qumulus Consortium, Ahmedabad, India. 320 p.
83. Berwick S (1974) The community of wild ruminants in Gir ecosystem. Ph.D. Partial fulfillment of the requirements for the degree of Doctor of Science in the Yale University, USA. 225 p.
84. Roskaft E, Bjerke T, Kaltenborn BP, Linnell JDC, Andersen R (2003) Patterns of self-reported fear towards large carnivores among the Norwegian public. *Evol Hum Behav* 24: 184–198.
85. Vitterso J, Kaltenborn BP, Bjerke T (1998) Attachment to livestock and attitudes toward large carnivores. *Anthrozoos* 11: 210–217.
86. Sinha SP, Pathak BJ, Rawal PP (2004) Man-animal conflicts in and around protected areas—a case study on Gir national park/wildlife sanctuary, Junagadh, Gujarat, India. *Tigerpaper* 31: 27–32.
87. Homewood K, Patti K, Pippa T (editors) (2009) *Staying Maasai: Livelihoods, conservation and development in East African rangelands*. Springer; New York. 418 p.
88. McCabe JT, Leslie PW, DeLuca L (2010) Adopting cultivation to remain pastoralists: the diversification of Maasai livelihoods in northern Tanzania. *Hum Ecol* 38: 321–334.
89. Fair J (2009) Crime-busting to save rare lions. *News of the Earth Section. BBC Wildlife*, March 2009: 39.
90. Check E (2006) The tiger's retreat. *Nature* 441: 927–930.
91. Gopal R, Qureshi Q, Bhardwaj M, Singh RKJ, Jhala YV (2010) Evaluating the status of the endangered tiger *Panthera tigris* and its prey in Panna Tiger Reserve, Madhya Pradesh, India. *Oryx* 44: 383–398.
92. Agarwala M, Kumar S, Treves A, Naughton-Treves L (2010) Paying for wolves in Solapur, India and Wisconsin, USA: comparing compensation rules and practice to understand the goals and politics of wolf conservation. *Biol Conserv* 143: 2945–2955.
93. Gee EP (1964) *The wildlife of India*. Collins, London, UK. 94 pp.
94. Hazzah L, Mulder MB, Frank L (2009) Lions and warriors: social factors underlying declining African lion populations and the effect of incentive-based management in Kenya. *Biol Conserv* 142: 2428–2437.
95. MacLennan SM, Groom RJ, Macdonald DW, Frank LG (2009) Evaluation of a compensation scheme to bring about pastoralist tolerance of lions. *Biol Conserv* 142: 2419–2427.
96. WWF-India (2007) *Landscapes of hope: conservation of the tiger, rhino and the Asian elephant*. Species Conservation Programme, WWF-India secretariat, New Delhi, India. 78 p. Available: [www.wwf.se/source.php?id=1168636](http://www.wwf.se/source.php?id=1168636). Accessed 2012 Apr 23.
97. Ikanda D, Packer C (2008) Ritual vs. retaliatory killing of African lions in the Ngorongoro Conservation Area, Tanzania. *Endanger Species Res* 6: 67–74.
98. Tambling CJ, Druce D, Hayward MW, Castley JG, Adendorff J, et al. (2012) Spatial and temporal changes in group dynamics and range use enable anti-predator responses in African buffalo. *Ecology* 93: 1297–1304.
99. Owen-Smith N (2002) *Adaptive herbivore ecology: from resources to populations in variable environments*. Cambridge University Press, Cambridge. 374 p.

100. Banerjee K (2012) Ranging patterns, habitat use and food habits of the satellite lion populations (*Panthera leo persica*) in Gujarat, India. Ph.D. Partial fulfillment of the requirements for the degree of Doctor of Science in the Forest Research Institute University, India. 450 p.
101. Karanth KU (2003) Debating conservation as if reality matters. *Conservation and Society* 1: 65–68.
102. Narain S, Panwar HS, Gadgil M, Thapar V, Singh S (2005) Joining the dots: the report of the Tiger Task Force. Project Tiger, Ministry of Environment and Forests, Government of India, New Delhi. 206 p.
103. Gujarat Forest Department (2010) Distribution of Asiatic lions in Gir National Park, sanctuary and other areas in 13th Asiatic lion population estimate-2010. Available: <http://gujaratforest.gov.in/downloads/lion-censues-20-5-2010.pdf>. Accessed 2010 Sep 18.
104. Jhala YV, Qureshi Q, Gopal R, Sinha PR (editors) (2011b) Status of the tigers, co-predators, and prey in India. National Tiger Conservation Authority, Govt. of India, New Delhi, and Wildlife Institute of India, Dehradun, India. TR 2011/003. 302 p.



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