

**RANGING PATTERNS, HABITAT USE AND FOOD
HABITS OF THE SATELLITE LION POPULATIONS
(*Panthera leo persica*) IN GUJARAT, INDIA**

THESIS
SUBMITTED TO THE
FOREST RESEARCH INSTITUTE UNIVERSITY
DEHRADUN, UTTARAKHAND
For
THE AWARD OF THE DEGREE OF
DOCTOR OF PHILOSOPHY IN FORESTRY
(WILDLIFE SCIENCES)



By

KAUSIK BANERJEE

WILDLIFE INSTITUTE OF INDIA
DEHRA DUN, UTTARAKHAND
2012

DECLARATION

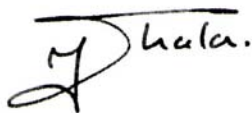
I hereby declare that the dissertation “Ranging patterns, habitat use and food habits of the satellite lion populations (*Panthera leo persica*) in Gujarat, India” is original research conducted by me under the supervision of Dr. Yadvendradev V. Jhala and Shri Qamar Qureshi of the Wildlife Institute of India. The thesis has been submitted to the Forest Research Institute University for the award of the degree of Doctor of Philosophy in Forestry (Wildlife Science), and has not formed the basis for the award of any other degree. It embodies my own work and observations, and in that respect the investigation appears to advance knowledge on the subject.

Date: 31.8.2012
Place: Dehra Dun



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August 31, 2012

CERTIFICATE

This is to certify that the dissertation "Ranging Patterns, Habitat Use and Food Habits of the Satellite Lion Populations (*Panthera leo persica*) in Gujarat, India", submitted to the Forest Research Institute University, embodies original research conducted by Mr. Kausik Banerjee under our supervision. This work has not been submitted, in part or full, for any other degree. The dissertation fulfills the partial requirements for the award of a Ph.D. degree in Forestry (Wildlife Science) as specified in the ordinance of FRI University.

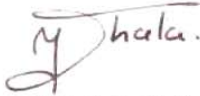
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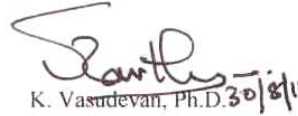
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Copy to:

1. ✓ Dr. Y.V. Jhala, Professor, Wildlife Institute of India, Chandrabani, Dehradun – 248 001 for information.
3. Dr. Qamar Qureshi, Reader, Wildlife Institute of India, Chandrabani, Dehradun – 248 001 for information.
3. Dr. K. Sankar, Nodal Officer, Wildlife Institute of India, Chandrabani, Dehradun – 248 001 for information (D.D. of Rs. 6,000/- No. 473297 dated 1.6.2007 is enclosed)
4. The Guard File.

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Table of Contents

Title	Page
Acknowledgement	i
Executive Summary	xii
List of Figures	xxiv
List of Tables	xxxiii
Chapter 1: Introduction & Literature Review	1
Chapter 2: Study Area	26
Chapter 3: Lion Abundance & Population Structure	44
Chapter 4: Lion Demography	77
Chapter 5: Lion Spatial Organization	96
Chapter 6: Lion Habitat Use & Resource Selection	186
Chapter 7: Lion's Diet	212
Chapter 8: ASPECTS OF HUMAN-LION CONFLICTS IN THE GIR LANDSCAPE	
Sub Chapter 8.1: Economics of Lion- <i>Maldhari</i> Coexistence in the Gir Forest	241
Sub Chapter 8.2: Spatio-temporal Pattern of Lion Attacks on Humans in the Gir Landscape	267
Sub Chapter 8.3: Assessment of People's Perception toward Lion Conservation in the Gir Landscape	291
Literature Cited	337

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“....**M**en are easily inspired by human ideas, but they forget them just as quickly. Only Nature is eternal, unless we senselessly destroy it. In fifty years’ time nobody will be interested in the results of the conferences which fill to-day’s headlines. **B**ut when fifty years from now a lion walks into the red dawn and roars resoundingly, it will mean something to people and quicken their hearts whether they are bolsheviks or democrats, or whether they speak English, German, Russian or Swahili.”

(Professor Bernhard Grzimek: *Serengeti Shall not Die*, 1959)

I honestly confess that wildlife was never a childhood dream for me! Born and brought up in a cosmopolitan city of Kolkata, eastern India, neither me nor my family had any orientation for forests. As a kid, like many Indian middle class children of our time, I dreamt rather to be a bus conductor or a railway driver which subsequently got replaced by a secondary school teacher, an undergraduate history lecturer and a doctor during the school and college days!! Joining Forest Research Institute for my masters and later Wildlife Institute of India (WII) in that way were more of circumstance-driven than however, I never lamented later on. More I got involved in this field and more the inextricable bonds between man, life-forms and nature got unfolded in front of me; I started to adore it---a true admiration for the Indian forests and the people engrossed for the cause of conservation! Almost a decade after my reincarnation in the arena of wildlife, today, I know the pains and gains in this field; the former mostly outnumbering the latter. As a matter of fact, I do not see myself as a wildlife biologist nor a conservationist; rather a crusader fighting to allow many distant generations to behold “a lion walking into the red dawn and roaring resoundingly”....a gift bestowed upon us by our forefathers. How can we deprive our children and many future ‘lionologists’ of such magnificent spectacle?

A crusade is not a lone man’s task. Nor was mine! During the past seven years’ work on the last lions of Asia, I was greatly indebted by direct and indirect helps provided by Many.....I emphasize *Many*.....acknowledging all of whom is perhaps beyond this dais. Nonetheless, I crave some space at the beginning to express my words of gratitude to as many of them as I can. Some are directly linked with my work; while others remotely and most often unknowingly influenced my philosophy of life.

In a more formal way to begin with, I acknowledge Training, Research and Academic Council (TRAC-WII) and Grant-in-Aid for financially sustaining India’s

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Personal thanksgiving list is however longer but hopefully exciting with some hitherto non-shared confessions of my life!

I lose all my expressions when my turn comes to thank Dr. Yadvendradev Jhala, my PhD supervisor. The fragrance of memory is still fresh in mind when way back in 2003 I first hesitantly approached him for my master's dissertation project. His instantaneous offers were: tigers, wolves, hyenas, foxes and vultures. I was firm on

lions! Things settled (rather started) in Kuno and subsequently in Gir and the rest is history! I always cherished the moments we spent together in Gir by roaming at nights, camping out, catching lions, putting radio-transmitters, designing my questionnaire sitting beneath a *Ficus* tree, enjoying food either in field or farmhouse and sometimes even getting scolded for one of my 'bad habits' that he utterly dislikes! The greatest charm was off course writing something with him; be it a report, a manuscript, a grant proposal or thesis chapters. His lucid way of explaining even the most difficult theory, being fatherly supportive and cheerful whenever I felt a bit low and his vision have always amazed me beyond expression. Thanks a lot sir for keeping faith on me; even at times when I lost faith on myself! Sir, truly speaking that in my life influence of Bapu's wordings and blessings is as much, if not more, as of yours! Even today I enjoy following many of his advices in my daily life. Thank you Bapu for your blessings! I would also like to thank Rajeshwari madam, Harshini, Dhananjay and Preeti Ba for some lovely memories of Karshangadh! Lalubha and Digpalsinh were always good companies. Surely I shall miss Hemu Bhai!

I am indebted a lot to Shri Qamar Qureshi, my PhD co-supervisor. In fact, I began my maiden fieldwork in Kuno with him. During my research period although it was not always possible for me to be in close touch with him, but I always liked the brief interactions with him; be it on whatever. I shall always cherish my lovely memories of roaming around in Gir and Girnar with him. Thanks are due for Dr. Nita Shah, chatting with whom was always refreshing.

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One person has always been instrumental not only in the smooth conduct of my research; but also by substantially building my ideas about ethics and principles in life. Shri Bharat Pathak (IFS), the Director GEER Foundation (Gandhinagar) was the co-investigator in the research project as his capacity of the Gir Park Director. But for me he was more than that! Interactions with him, whether in field or his office or at his residence were always energizing. Any troubleshoot call to his mobile, even at

the odd hours of night; the problem is solved at once. Today, I have no hesitation to confess that he was one of the very few people I met during my field days with a 'genuine' commitment toward lion conservation. Thanks a lot sir and hope to be of your assistance in the battle for conservation!

I always enjoyed the brief companies of Shri Mayank Sharma (IFS), former CCF (WL-Junagadh) and amazed at his promptness in decision making and lovely sense of humors. Interactions with his successors Shri S.K. Chaturvedi (IFS) and Shri R.L. Meena (IFS) were briefer but enjoyable.

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time I promise you that we will complete our unfinished agenda of visiting *Bruhad* Gir together! Rohit Vyas, Chaitanya Joshi, Gaurang Joshi, Raghu Bapu and Abhhist were some outstanding companies at Sasan and Ahmadabad. On my onward and return journeys from Gir I bothered Abhhist many a times by dumping my heavy luggage at his home in Ahmadabad even at odd hours but always amazed to feel the warm acceptance from his family! Even today I seriously enjoy teasing Abhhist and love to see his reactions! Thanks a lot to everyone for being so supportive!

Girnar was always amusing! Charm of bonfiring till late nights with cups of 'rogi' (black lemon tea) amidst Bheda, Kathi, Poonja, Dangar, Gambhirsinh, Yusuf, Dhumalia, Khavdu, Raju, Ramesh, Nandania, Mokaria is what I miss a lot today. Full day of hectic field and a simple but tasty dinner cooked by Gobar bhai or Walli bhai used to be like an elixir!

I confess that given a chance to spend a single night in Gir even after a decade, I would choose Dholikui-Ranigalo; an exquisite chunk of savanna grassland amidst vast sea of human dominated areas situated in Bhavnagar (provided it does not succumb to human greed by then!). This is more because of some excellent memories shared with Bharat Solanki and Gauridas Gondalia (for me, Mahatma)! Mahatma's house at Kantrodi eventually became my second field base. For me, Bharat was more a close friend than a forester. From Mahatma I learned one of the important yet fundamental lessons in my life---lesson of simplicity and it always reminded me of our ancient tradition.

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Saurashtra! And I reverberate what the poet rightly says *Unchi medi te mara sant ni re, dhanya dhanya mara sorath ni bhum*i (Praise Sorath, a land of saints). When people ask me about my study area I tell them that I work in Saurashtra and not in Gir! Being a non-Gujarati, I was always apprehensive about my local acceptance when I joined the research project seven years back! And today, I sometime feel that I am imbibed

into the local culture even more than my native traditions! How can I forget the hospitality and warmth of an unknown passerby (I do not even remember his name!) missing his lunch in a scorching summer afternoon and riding his pillion for 50 kilometer just to bring a mechanic; when my vehicle once broke down? I am heartily indebted to Sorath for thousands of such instances of cordiality and in a broader sense for leaving some permanent footprints on my own character!

Working on a long ranging carnivore in a vast human-dominated landscape never happens without direct and indirect supports rendered by many. Since access to many private owned grasslands need permits from their owners therefore, many times such helps became crucial in shaping the success of my fieldworks. Some people are really worthy of special mentions. Lakhabapa, Motbhai and Manshukhbhai at Bhalchhel always made me feel homely thousand miles away from home! Late night chatting and joking with Motbhai at his farmhouse had always prepared me for the next day's tedious schedule. At Sasan, I am thankful to Dosu and his family, Manohar, Nika, Khim, Narshi, Ramzan, Kamlesh, Dinesh, Naresh, Prateek, Anil, Bharat, Sarang, Yash. Thanks Kanti, Sailesh, Raju, Jayesh and Bhavesh for urgently repairing my vehicles even at midnights! Haresh and Bhupat were always great companies. My work outside the Gir PA could not have been materialized without active support from Gabru Khuman and Babla Khuman at Savarkundla, Amru bhai at Akolda, Mahendra Khuman at Krakanch, Navghan bhai and Dewat bhai at Karjala, Shakti bhai at Kantrodi and Suresh Maitra at Vanda. Taju dada at Kedaria always made a special place in my heart. I cannot express my gratitude for them in words.

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I already mentioned that I was too much anticipative about my local acceptance, chiefly owing to the language barrier. I was therefore desperate to start work in

Sasan where at least I could communicate as people can understand Hindi. On the contrary, I started at a remote place, Tulsishyam where I was totally dumb for the first fortnight! But today, I feel Tulsishyam closer to my heart and this was possible only by cordial welcome and cheerful support by the local people and *Maldharis*. Many of them even worked as my informants in instantaneous reporting livestock depredation events. Special thanks to Mannu, Lalu, late Lakhman bhai, Ada bhai, Megha bhai, Khoru bhai, late Aapa bhai, Selar bhai, Bhagwan bhai, Samat bhai, Pata bhai, Devshi bhai, Vanraj, Ashok and Mohan bhai.

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Dehra Dun
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Kausik Banerjee

Executive Summary

1. 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 world today is probably witnessing the highest concern society has ever shown towards the conservation of large carnivores and their ecosystems. Nevertheless, recent assessments of the conservation status of carnivores present an alarming global picture of ongoing declines and range contractions. Certain *k*-selected traits inherent to large carnivores body size, complex social behaviour, low population density, specialized niche requirements, high trophic level and large home range size like make them more vulnerable to habitat loss and environmental stochastic events. The situation became more worrying in a country like India chiefly with an agrarian economy. Intensive trophy hunting of large mammals before independence (1947) and tremendous socio-political pressures to improve lives of millions after independence have decimated ranges of many carnivores in the country. Today, most of India's protected areas are either embedded in a heterogeneous matrix of land-uses or have human-modified landscapes within their boundaries.

Asiatic lions (*Panthera leo persica*) is a global conservation icon, elucidates India's conservation commitments and typifies all of the above scenarios. Owing to rapid habitat loss and hunting, lions lost most of their ranges and were found only in the Gir forests of Gujarat, west India by 1880s. Timely and stringent protection by the erstwhile rulers of Junagadh and post-independence management interventions by the State-run forest department have caused lion population numbers and extent to increase from below 50 individuals occupying a few hundred km² to over 400 covering over 9,000 km² of agro-pastoral Gir landscape. With lions

living in close proximity with humans, conflicts are inevitable. Moreover, long-term persistence of the Gir lions is enhanced by the metapopulation structure wherein individual lions from different breeding populations can potentially disperse among these populations. However, traditional land-use pattern in the Gir landscape is changing at an unprecedented rate under the pressures of urbanizations and agro-industrial infrastructural developments. Understanding these and planning conservation strategies based on lion ecology will thus 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.

2. My study area of the Gir landscape consisted of 9,000 km² of the agro-pastoral landscape within south west part of Saurashtra region in the state of Gujarat, western India. Gir landscape is a multiple land-use area composed of the 1,880 km² Gir Protected Area (Gir PA), the 180 km² Girnar Wildlife Sanctuary (Girnar), and approximately 7,000 km² of human-dominated agro-pastoral landscape of Amreli, Bhavnagar, and Junagadh districts (eastern landscape) and coastal forests. It is a typical biogeographic representative of the semi-arid Gujarat-Rajputana Zone. There are three 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). 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 like fodder, fuel wood, and minor forest products from within Gir PA. The agro-pastoral landscape consists of private farmlands, 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.

3. Current lion total counts (census) methods of the Gujarat Forest Department are error prone as they lack measures of detection probabilities; require trained field staff and intensive field efforts. The prevailing lion census method could only be used to formulate a

good index for lion numbers, given it is calibrated against contemporaneous mark-recapture population estimation in double sampling framework. Lion (> 1.5 years) populations in the Gir landscape were estimated in a mark-recapture framework based on individual lion identification. Lion density was estimated in half the mean maximum distance moved ($\frac{1}{2}$ MMDM) method. Townships and large permanent water reservoirs were excluded while calculating sampled area. *Ad libitum* lion sightings were analyzed to deduce population structure and group sizes. A population viability analysis (PVA) model (500 iterations for 100 years) 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. Density of adult lions (> 1.5 years) was estimated to be 5.6 (SE 0.7) lions/100 km² in Girnar and 2 (SE 0.1) lions/100 km² in the eastern landscape. 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. Lion group sizes in the Gir PA were small in comparison to earlier reports and 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. 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. To ensure long-term viability of Girnar lion population the corridor area between the Gir PA and Girnar should be delineated and needs to be declared as 'ECOSENSITIVE' so as to curtail possible negative impacts of further developments

4. Demographic parameters of Gir lions were deduced by intensively monitoring 68 adult lions and 91 cubs from 38 litters using telemetry and individual lion ID profiles. Record of opportunistic mortality events (n = 88) was used to understand the mortality causes. 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%. 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) 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.

5. Gir lion populations are characterized by source–sink dynamics with the Gir PA serving as a source to populate and maintain lion occupancy of sink habitats (Girnar Wildlife Sanctuary, eastern landscape and the coastal forests). Understanding the impact of habitat fragmentations and other anthropogenic influences on lions in the Gir landscape requires quantitative assessment of habitat selection. Data from 13 radio-collared and 15 individually identified lions was analyzed to deduce lion ranging, movement, land tenure, territoriality, habitat use and activity patterns. A total of 3,414 hours of continuous monitoring (all occurrences) data was analyzed to understand lion activity pattern and foraging behaviors.

A mean of 398 (SE 124) locations 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 (GLC 2000 of Joint European Commission) 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. Day time lion locations were plotted on a GIS map and program Fragstats was used to estimate the mean day refuge patch sizes for male lions and breeding lionesses as well as to understand the characteristics of the patches intensively used by lions.

In the Gir PA, territorial males had 2.5 times larger range (average 103 km²) than breeding females (average 40 km²; one tailed $t = 3.66$, $df = 12$, $p = 0.006$) while dispersing males had 10 times larger range (average 401 km²) than breeding females (one tailed $t = 5.71$, $df = 11$, $p < 0.001$). In the eastern landscape the minimum home range size (95% FK) of territorial males was 333 (SE 40) km² and breeding females had range sizes (average 132 km²) about 8 times smaller than territorial males (one tailed $t = 8.05$, $df = 5$, $p = 0.005$). 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 core area of Gir lions was estimated to be 166 (SE 40) km². Average male core area [214 (SE 43)] was higher than average breeding female core area [85 (SE 17)] (one tailed $t = 2.62$, $df = 26$, $p = 0.01$). Territorial males within the PAs have smaller cores than eastern landscape males (one tailed $t = 2.49$, $df = 7$, $p = 0.04$). Average land tenure duration for territorial 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. Lower land tenure duration of male lions in Gir in comparison to Serengeti lions was due likely to dense habitats in Gir offering females safer den sites to avoid infanticidal males. Sub-adult males showed no or very little overlap with their natal territories so as 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 males have been found to successful tenures as territorial males and father cubs even after spending some time as nomads. Although ranges of the adjacent female prides showed overlap [35 (SE 16) %], Gir lionesses were more exclusive in defending their core area [overlap 3 (SE 0.1) %], a pattern also observed in the Serengeti lions. Territorial overlaps between males and females in Gir seem to be beneficial by reducing infanticides (confused paternity) and maximizing genetic variability of cub litters. 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 peaks coincided with the activity peaks of lions' preferred 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.

Lions in the Gir landscape mostly used agriculture followed by closed deciduous forests within their cores. Lions seemed to exhibit preference for certain habitats for their inner cores ($\chi^2 = 23.63$, $df = 5$, $p < 0.001$) as well as for the outer cores ($\chi^2 = 41.92$, $df = 5$, $p < 0.0001$). The order of habitat preference for both the inner and outer cores was scrublands > grasslands > deciduous closed forests > agriculture > deciduous open forests > barren lands. Lion core areas were observed to lie further from villages ($F_{2, 1026} = 3.87$, $p = 0.02$) and townships ($F_{2, 1026} = 3.38$, $p = 0.03$), but were closer to roads ($F_{2, 1026} = 4.87$, $p = 0.007$), 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 ($F_{2, 1026} = 7.91$, $p < 0.001$) but with less rugged terrains ($F_{2, 1026} = 5.15$, $p = 0.005$). Scrublands and agricultural areas were found to have higher lion cores in comparison to other land use classes ($F_{6, 1022} = 3.63$, $p = 0.001$). Average day time refuge patch size of lions in the eastern landscape was estimated to be 7.5 km² (SE 0.74; range: 0.07 km² – 21.5 km²). Breeding lionesses had similar sized day refuge patches (3.8 km², SE 1.7; range: 0.4 km² – 5.5 km²) like adult males (7.6 km², SE 0.77;

range: 0.07 km² – 21.5 km²) [$t = 0.95$, $p = 0.34$]. Minimum patch size in which a lioness reared her cubs successfully was 4.3 km².

The findings highlight the impact of even small vegetation patches as lion refuges. Patches greater than 4 km² were likely to be breeding refuges. 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 developments as majority of these patches are under private ownerships and not under the jurisdiction of the forest department.

6. Role of unbiased knowledge on food habit cannot be overemphasized in understanding carnivore ecology and managing conflicts. 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 (1,800 hours of monitoring on seven radio-collared lions) in order to address the inherent limitations of each method. Lions' food preference was computed by Jacob's Index.

Sambar was the most abundant lion prey species in Girnar. In human-dominated eastern landscape, cattle contributed maximum in lion prey density and biomass while wild prey constituted 3% of lion prey biomass. 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 wild ungulate (especially chital and sambar) restocking program in Girnar so as to assist the low density wild prey population to build up and provide enough food for high density lions and leopards (*Panthera pardus*). 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 cattle carcasses of 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. Most of the cattle camps are 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.

8. 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. I examine the mechanisms permitting the coexistence of Asiatic lions and pastoral communities (*Maldharis*) in the eastern part of the Gir PA. I monitored six *Maldhari* settlements during my 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. I see no end to compensation programs worldwide 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.

9. Gir lions are occupying landscapes where people have no recent memorable experience of living with them. These escalate hitherto less known incidents of lion attacks on humans in the Gir landscape in recent years and are likely to increase as lion number increases and lion range expands further. This was investigated by collecting data on lion attacks (n = 76) from the Gir landscape. Primarily, the victim, family members of the victim and the local people were informally interviewed to obtain the details about the demographic profile of the victim, human activity patterns during the lion attacks and a brief description about the attack event (location, time, nature, body parts attacked etc.). Information on body parts attacked and extent of injury was used to develop an index of severity of injury (mild-medium, severe and fatal). To understand the human context involved in attack events, I classified them into three major categories as 1) deliberate, 2) accidental and 3) provocative. The attack data was analyzed to arrive at the spatio-temporal pattern of such attacks and used chi-square analysis [$\alpha = 0.05$] to compare attack events between districts, seasons, months of the year, time of the day and different human demography classes. Distance of each attack point to the nearest river, road and human habitation was calculated to understand the spatial context of the attack events.

A total 76 (13.6 attacks/year) lion attack events on humans have been recorded during my study period. Despite increase in lions' use of human dominated landscape during the past two decades, the attack rates on humans remained about the same. Annual rate of lethal lion attacks in Gir also decreased from 2.2 to 0.7 during last two decades. Mean daily lion-human encounter in my study area was estimated to be 15 (SE 5) which translates into about 5,475 such encounters by a lion in a year. Only negligible part (0.002%) of this was found to be translating into attacks on humans. Most lion attacks (67%) resulted in mild to medium mauling of victims; 28% of the attacks resulted into severe injuries while only four attacks (5%; 0.7/year) were fatal ($\chi^2 = 22.1$, df = 3, $p < 0.001$). Lion attacks were biased toward

males (96%) compared to women ($\chi^2 = 57.4$, $df = 1$, $p < 0.001$). Most of the victims were middle aged, with the average age of the victims being 39.3 years (SD 14, median: 40 years, range 8 -72; $\chi^2 = 52.6$, $df = 4$, $p < 0.001$). Lion attacks on humans in the Gir landscape peaked in evenings, nights and early mornings ($\chi^2 = 92.3$, $df = 4$, $p < 0.001$). Mostly, single lion was involved in attacking humans in the Gir landscape [average group size of attacking lion: 1.4 (SE 0.11)]. Over half (53%) the attack events were recorded from Junagadh district compared to 38% from Amreli district and 9% from Bhavnagar district ($\chi^2 = 28.8$, $df = 2$, $p < 0.001$). Majority of attacks occurred in the outskirts of villages when the victims were either outside home in the agricultural fields or in other open areas ($\chi^2 = 101.7$, $df = 6$, $p < 0.001$). Lion attacks on humans were nearer to villages and forest patches.

Lion attacks on humans, although less may be perceived by local communities as a serious threat for human safety. A crop damage compensation scheme and subsidized damage control measures may substantially lessen the financial burden of the local farmers and subsequently incidents of lion attacks on humans. Education awareness programs should be run wherein local people especially the younger generation should be taught about lion ecology (activity peaks, the refuge patches that need to be avoided and so on). Employments of the family members of critically injured or deceased victims with the forest department will ensure livelihood supports and greater tolerance toward lions.

10. 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 adopts the current policies to suit the challenges.

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 ($\chi^2 = 6.5$, $df = 2$, $p = 0.03$), well offs ($\chi^2 = 16.8$, $df = 2$, $p < 0.001$), 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 out poaching as a probable threat to lion survival and I 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 cannot be overruled and respondents' opinions probably reflect this.

My 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, 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.

11. Lion conservation in the Gir landscape is a success story and it showcases India's conservation commitments without succumbing to the mounting pressures of human population growths, agricultural intensifications and urban sprawls. 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, too. However, in order to ensure long-term survival of lions in this landscape the study recommends:

- i. Conservation of all vegetation patches larger than 4 km² 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.

- ii. 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.
- iii. Girnar population of lions exists as a metapopulation sink in connection with the Gir PA and the corridor habitat delineated should be made 'eco-sensitive'.
- iv. Girnar carrying capacity needs to be enhanced by restorative management and wild prey enhancement by supplementation.
- v. *Gaushalas* and *Panjrapoles* are major food sources for lions outside the Gir PA and have significant roles in minimizing conflicts with local people. They need to be continued and mechanism of zoning should be utilized so that grazing lands are available to these charities.
- vi. 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.
- vii. 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 promptness and transparent implementation.
- viii. 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) while maintaining density of about 2-4 lions/100km².

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 bound to create conflict situations. Good management is to address these conflicts in a timely meaningful way so that society continues to be tolerant to large

carnivore persistence in their neighborhood. This thesis provides some insights based on science to make this happen.

List of Figures

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 (from Antunes et al. 2008); B: Historical range of *Panthera leo persica* (from Nowell and Jackson 1996).

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

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.

Figure 2.1: Map of the 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.

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).

Figure 3.1: 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 3.1: 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).

Figure 3.2: 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 3.3: Minimum convex polygon defining lion search within the potential lion habitats of the Eastern landscape, buffered with $\frac{1}{2}$ MMDM.

Figure 3.4: Saturation curves for lion captures during mark recapture session in i) Girnar Wildlife Sanctuary and ii) the eastern landscape.

Figure 3.5: Age and sex composition of Asiatic lions in i) Gir PA, ii) Girnar forests and iii) the eastern landscape.

Figure 3.6: 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.

Figure 3.7: 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 3.1. N = population size. I. Mean survival probability of Girnar lions under different modelled scenarios.

Figure 3.8: Mean stochastic growth rate (r) of the Girnar lion population under different modeled scenarios. Details of the scenarios are explained in Table 3.1.

Figure 3.9: Location of Gir PA, Girnar forest and the connecting habitat corridor across the agro-pastoral landscape proposed as an eco-sensitive area.

Figure 4.1: 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.

Figure 4.2: Reproductive success of Asiatic lioness (*Panthera leo persica*, 91 cubs from 38 lionesses) measured as percentage of cubs that survived to adulthood.

Figure 4.3: 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 4.4: Cause specific mortality in Asiatic lions (*Panthera leo persica*; n = 88) in the Gir Landscape between 2006-2010.

Figure 5.1: A. Lion radio collaring, B. A radio-collared male lion after revival from the anesthesia, C. Radio-tracking lions from a vehicle.

Figure 5.2: 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.

Figure 5.3: 95% MCP home ranges (km²) of Asiatic lions (n = 28) across the agro-pastoral Gir landscape, Gujarat, India.

Figure 5.4: 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.

Figure 5.5: Core areas (km²) 85% fixed kernels of Asiatic lions in the Gir landscape, Gujarat, India.

Figure 5.6: Distribution of observed tenure shift in territorial male Asiatic lions (n = 7) during the study period (January 2006 – January 2012).

Figure 5.7: Ranging pattern of radio-collared male M1. Extent of major human habitations demarcated by using night light satellite data.

Figure 5.8: Tenure shift of prime adult male M2 in the Gir PA, India. Tenure centroids shown by flags.

Figure 5.9: 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.

Figure 5.10: Ranging of coalition males M4, M12 and M14 across the human-dominated eastern landscape. Human habitations demarcated by using night light satellite data.

Figure 5.11: Tenure shift of prime adult male M12 in the eastern landscape. Tenure centroids shown by flags.

Figure 5.12: Tenure shift of young adult male M5 in Girnar. Tenure centroids shown by flags.

Figure 5.13: Range use and dispersal of M6 within the Gir PA, India.

Figure 5.14: Dispersal of sub-adult male M6 in Gir PA. Tenure centroids shown by flags.

Figure 5.15: Tenure shift of prime adult male M7 in Gir PA. Tenure centroids shown by flags.

Figure 5.16: Tenure shift of prime adult male M8 in Gir PA. Tenure centroids shown by flags.

Figure 5.17: Dispersal of sub-adult male M10 in Gir PA. Tenure centroids shown by flags.

Figure 5.18: Ranging pattern of young-adult male M11 between Gir and Girnar.

Figure 5.19: 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.

Figure 5.20: Ranging patterns of lionesses F2 and F11 in Girnar Wildlife Sanctuary.

Figure 5.21: Ranging pattern and dispersal of prime adult female F5. Human habitations demarcated by night light satellite data.

Figure 5.22: Male range and female core area (85% FK) overlap in i) Gir PA and ii) eastern landscape.

Figure 5.23: Movement of M11 between Gir PA and Girnar Wildlife Sanctuary.

Figure 5.24: Movement of M6 from western Gir to eastern Gir.

Figure 5.25: 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.

Figure 5.26: 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.

Figure 5.27: 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.

Figure 5.28: Time invested by territorial males and dispersing males in different activities. Error bars = 95% CI.

Figure 5.29: 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 5.30: 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 5.31: 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 5.32: 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 5.33: 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 5.34: 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 5.35: 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 5.36: 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 5.37: 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 5.38: 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 5.39: Proportional time spent by dispersing males in different activities during different times of the day and the related activity peaks deduced by program Oriana.

Figure 6.1: Various land-use classes in the Gir landscape showing distribution of lion core areas (85%FK and 50% FK).

Figure 6.2: Use and availability of different land-use types for lions' core areas in the Gir landscape. Error bars are standard errors.

Figure 6.3: Influence of villages explaining lions' core selection in the Gir landscape.

Figure 6.4: Influence of roads explaining lions' core selection in the Gir landscape.

Figure 6.5: Influence of rivers explaining lions' core selection in the Gir landscape.

Figure 6.6: Influence of human habitations (delineated by night lights) explaining lions' core selection in the Gir landscape.

Figure 6.7: Influence of Protected Areas explaining lions' core selection in the Gir landscape.

Figure 6.8: Influence of pre-monsoon NDVI explaining lions' core selection in the Gir landscape.

Figure 6.9: Influence of elevations explaining lions' core selection in the Gir landscape.

Figure 6.10: Influence of terrain ruggedness explaining lions' core selection in the Gir landscape.

Figure 6.11: Minimum day time habitat refuge patch (0.07 km²) for lions in the Gir landscape embedded within human habitations, road network and rivers.

Figure 6.12: Largest day time refuge patch (21.5 km²) of lions in the Gir landscape represented by Mitiyala Sanctuary.

Figure 6.13: 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.

Figure 7.1: Distribution of the trail transects (n = 21) for prey base enumeration in Girnar forests.

Figure 7.2: Distribution of the vehicle transects (n = 33) for prey base enumeration in the agro-pastoral eastern landscape.

Figure 7.3: Lion scat collection fixes spreading in all potential lion habitats across the Gir landscape.

Figure 7.4: Monitoring radio-collared lions to distinguish between i) lion predation (photo courtesy: Y.V. Jhala) and ii) lion scavenging events.

Figure 7.5: Percent contribution of different lion prey species in total prey abundance and biomass in A) Girnar forest and B) eastern landscape.

Figure 7.6: Composition of lion kills in Girnar Wildlife Sanctuary and the eastern landscape.

Figure 7.7: Percent contribution of different prey species among lion kills in Girnar and the eastern landscape.

Figure 7.8: Estimation of minimum number of scats that need to be analyzed for studying lion food habits in the Gir landscape.

Figure 7.9. 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 7.10. 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.

Figure 7.11: Lion feeding events quantified through continuous monitoring on radio-collared lions ($n = 720$ hours observation on 3 radio-collared lions) in Girnar.

Figure 7.12: 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.

Figure 8.1.1: 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.

Figure 8.1.2: Average seasonal livestock holding of *Maldhari* family within the Gir forest (error bars are standard errors).

Figure 8.1.3: 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 8.1.4: 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.

Figure 8.2.1: Gir landscape, showing lion attack points (n = 76) on humans between 2007 and 2012. Fatal attack points (n = 4) are marked in red. Human habitations delineated on the basis of night light data.

Figure 8.2.2: Extent of the victims' injuries due to lion attacks in the Gir landscape during the study period of 2007 and 2012.

Figure 8.2.3: Year-wise variation of lion attacks on humans during the study period (2007-2012) in the Gir landscape.

Figure 8.2.4: Seasonal pattern of lion attacks on humans in the Gir landscape between 2007 and 2012.

Figure 8.2.5: Temporal variation of lion attacks on humans in different times of the day in the Gir landscape between 2007 and 2012. Time is in Indian Standard Time (IST: + 5:30 hrs GMT).

Figure 8.2.6: Group size of lions attacking humans in the Gir landscape between 2007 and 2012.

Figure 8.2.7: Group composition of the lions attacking human in the Gir landscape in between 2007 and 2012.

Figure 8.2.8: District-wise lion attack events on humans in the Gir landscape between 2007 and 2012.

Figure 8.2.9: Locations of the victims during lion attacks in the Gir landscape between 2007 and 2012.

Figure 8.2.10: Activity of the victims during lion attacks in the Gir landscape between 2007 and 2012.

Figure 8.2.11: Nature of lion attacks in the Gir landscape between 2007 and 2012.

Figure 8.3.1: 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.

Figure 8.3.2: 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 8.3.3: Views of 680 respondents from 254 villages in the eastern landscape to question on when lions started to live in their vicinity.

Figure 8.3.4: Views of 680 respondents from 254 villages in the eastern landscape to question on how did lions reach in their localities.

Figure 8.3.5: 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 8.3.6: 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 8.3.7: Views of 680 respondents from 254 villages in the eastern landscape to question on their recommendations for future lion conservation.

Figure 8.3.8: Views of 680 respondents from 254 villages in the eastern landscape to question on their recommendations gaining more public support for lion conservation.

Figure 8.3.9: 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 8.3.10: Views of 680 respondents from 254 villages in the eastern landscape to question on financial appropriateness of the Government compensation scheme for livestock predation.

Figure 8.3.11: 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 8.3.12: Views of 680 respondents from 254 villages in the eastern landscape to question on if false claims are major problems in compensation payments.

Figure 8.3.13: 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 8.3.14: Views of 680 respondents from 254 villages in the eastern landscape to question on suggestion to improve the Government compensation scheme for livestock predation.

Figure 8.3.15: Respondents' perceptions about future threat for lion survival in the eastern landscape.

List of Tables

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

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

Table 3.1: Rationale behind Population Viability Analysis (PVA) models used in Program VORTEX for the Girnar lion population.

Table 3.2: Summary of lion density estimation in Girnar forests and the human-dominated eastern landscape.

Table 3.3: Lion population estimates in i) the Girnar Wildlife Sanctuary and ii) the human-dominated eastern landscape using various estimators in Program CAPTURE.

Table 3.4: Population viability model predictions for Girnar lions under various combinations of stochastic events for the next 100 years.

Table 3.5: Lion density and prey biomass density from different Protected Areas of Africa and Gir PA.

Table 4.1: Survival rates and cause specific mortality of Asiatic lions between 2005 and 2010 in the Gir Landscape, India.

Table 4.2: Comparison of demographic parameters of free ranging Asiatic lions with those of African lion populations obtained from published studies.

Table 5.1: Definition of different key activities (ethogram) used in the study for calculating time budget pattern in Gir lions (modified after Schaller 1972; Bertram 1978).

Table 5.2: Estimated annual home ranges (km^2) of Asiatic lions in Gir landscape, India. MCP = minimum convex polygon, FK = fixed kernel.

Table 5.3: 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.

Table 5.4: Seasonal home range sizes (km²) of Asiatic lions in Gir landscape, Gujarat, India. Lion IDs are same as in Table 5.2. Figures within parentheses are standard errors.

Table 5.5: Land tenure duration and distances between successive territories of adult male Asiatic lions.

Table 5.6: Dispersal age and dispersal distance of sub-adult male Asiatic lions in the Gir landscape, India.

Table 5.7: 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.

Table 5.8: Average movement parameters of Asiatic lion in the Gir landscape. Figures within parentheses are standard errors.

Table 5.9: 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).

Table 5.10: Lion home ranges (100% MCP unless otherwise mentioned) and prey biomass density from different Protected Areas of Africa and previous studies in Gir PA.

Table 7.1: 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. Figures within parentheses are SEs.

Table 7.2: 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. Figures within parentheses are SEs.

Table 7.3: Prey species composition in Asiatic lion scats and their relative biomass contribution to lion diet in Girnar Wildlife Sanctuary, India.

Table 7.4: Prey species composition in Asiatic lion scats and their relative biomass contribution to lion diet in eastern landscape.

Table 8.1.1: 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).

Table 8.1.2: 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).

Table 8.1.3: 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.

Table 8.1.4: 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.

Table 8.3.1: Questions asked to sampled households in the 254 villages of the Gir landscape to assess socio-economic status and community perception towards lion conservation.

Table 8.3.2: 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.

Table 8.3.3: 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.

Table 8.3.4: Spearman rank correlation plot showing correlation coefficients between respondents' attitudes towards lion conservation in the Gir landscape and different socio-economic variables.

Table 8.3.5: A priori candidate models for data predicting the effect of socio-economic factors on respondents' attitudes towards lions in the Gir landscape.

Table 8.3.6: Parameter estimates and the 95% confidence intervals (CI) for the best model explaining respondents' attitudes towards lions in the Gir landscape.

Table 8.3.7: 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.

Table 8.3.8: 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.

Introduction & Literature Review

INTRODUCTION & LITERATURE REVIEW

Carnivore Conservation

Global carnivores comprise of 283 extant species in 123 genera belonging to 15 families (Macdonald 2010). The study of carnivores has contributed substantially to our understanding of natural history, ecological processes and human impacts on ecosystems. Ecology of large carnivores presents difficult problem for conservation as their management requires vast tracts of habitat due to their large ranges; this often competes and conflicts with other types of 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 genetic, species diversity and the diversity of ecosystem structure and function (Redford and Richter 1999). A momentum towards this direction was achieved during the last two decades with the societal commitments towards sustainable development of the natural resources was declared at the 1992 Convention on Biological Diversity (CBD) held at Rio-de-Janeiro, Brazil. Simultaneous with this increasing emphasis on biodiversity in all its components has been an increase in the scale of planning for conservation work (Sanderson et al. 2002), typically through mechanisms that emphasize entities other than the population or species as a target for conservation effort (Noss 1991; Salwasser 1991). In spite of this approach of maintaining biodiversity in all of its myriad forms and interrelationships, 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).

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. Carnivores in wildlands have always had a deep capture on human psyche and historically, they were feared as predators, domesticated as pets, and intensively managed as pests or harvested species (Minta et al. 1999). Our imagination has been played out in folklores, art, literature, private and government programs, using images of carnivores to symbolize the strengths of

governments and chiefdoms, adorn our currencies, coats of arms and emblems of national sports teams and guard our sacred and ceremonial places (Clark et al. 1999). 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). The world today is witnessing the highest concern society has ever shown towards the conservation of large carnivores and their ecosystems (Mech 1996; Weber and Rabinowitz 1996). Large carnivores 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).

Carnivore decline: global and national scenarios

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 (Karanth and Chellam 2009; Karanth et al. 2010). Though carnivores owing to their position in the food chain and wide-ranging habitat uses are considered important arbiters of ecosystem responses to change, the same qualities have made them formidable competitors with and even enemies of humans (Casey and Clark 1996). The fact that we evolved with carnivores as predators and competitors has certainly shaped how we perceive them and how we manage them (Minta et al. 1999). The current unprecedented rate of global extinction of species is estimated to be 100 times higher than natural background rates (Gittleman et al. 2001). Species of large carnivores have faced dramatic contraction in their ranges and their populations have decimated worldwide due to human population explosions and ecosystem fragmentations (Fuller 1995). Some species of carnivores such as grizzly bear (*Ursus arctos horribilis*), American black bear (*Ursus americanus*), gray wolves (*Canis lupus*), red wolves (*Canis aureus*), mountain lions (*Puma concolor*), wolverines (*Gulo gulo*) and Florida panthers (*P.c. cory*) were in the verge of extirpation before the concerted government conservation efforts were launched (Goodall et al. 2010). The wolf populations in Europe declined drastically following the industrial revolution, now there are signs of recovery due to concerted conservation efforts (Merrigi and Lovari 1996). In central and southern America, jaguar (*Panthera onca*) and puma (*P. concolor*) population decline have been documented since 1960s (Polisar et al. 2003). Jaguar

has suffered a loss of historical range at an estimated rate of one latitudinal degree every 10 years in its southern range in the Atlantic Rain Forest of Brazil (Mazzolli et al. 2009). The African wild dog (*Lycaon pictus*), cheetah (*Acinonyx jubatus*) and African lion (*Panthera leo*) populations have all declined substantially over the past three decades (Ginsberg and Macdonald 1990; Nowell and Jackson 1996). Historically, lions occupied a range in Africa of over 22,211, 900 km² which has been currently reduced to less than 3,802,873 km²—a reduction of 83% (Ray et al. 2005). Simultaneously, lion numbers declined from little less than 100,000 in 1990 (Nowell and Jackson 1996) to a current estimates of continent-wide numbers ranging from 23,000 (Bauer and Van Der Merwe 2004) to 39,000 (Chardonnet 2002).

The situation becomes even 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 British colonial policy prior to 1947 encouraged intensive trophy and overhunting of large mammals during the 1850s to 1920s in India (Shakespear 1862; Simson 1886; Wardrop 1923). Carnivore trophy and bounty targets included tigers, leopards, lions, wolves, hyenas, wild dogs, and bears (Sterndale 1887; Sanderson 1896; Russell 1900; Fenton 1921). Herbivore targets included rhino, wild buffalo, gaur, and several deer species (Baker 1891; Burton 1933). 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). Despite high economic growth of about eight percent over last two decades, India ranks 88th out of 135 countries under the Human Poverty Index (United Nations 2009). Recent rapid economic and technological changes have improved the lives of millions but there is now tremendous political pressure to improve lives of all people (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 resulting in unplanned land use change and exploitation of natural resources and

likely to escalate human-carnivore conflicts under different landscapes. During post-colonial era, with progressive intensification of land use, sedenterization, diversification of livelihoods and land fragmentation through privatization of land tenure driven by dynamic socio-political, demographic and economic pressures; the Protected Areas in India are becoming more and more analogous to small islands in a vast sea of ecologically unsustainable land-uses of varying degrees (Scindia et al. 1983). In the past 50 years, Indian forests have been exploited largely to meet growing demands for food, fresh water, timber, fiber, fodder and fuel (Millennium Ecosystem Assessment 2005) more rapidly and extensively than in any comparable period of time in human history. All these escalated human-wildlife conflicts often resulting into local extirpations or significant range shrinkage of many large mammals while undermining the future survivals of many more. Despite a long history of concern for wild tigers (*Panthera tigris*), both their range and total number have collapsed: fewer than 3,500 wild tigers now live in the world, occupying less than 7% of their historical range with a 41% historical range loss during last decade (Dinerstein et al. 2007). An estimated population of around 40,000 wild tigers (*P. t. tigris*) 100 years back (Pocock 1929; Mondol et al. 2009) has presently declined to less than 2,000 (Jhala et al. 2008). Indian gray wolf (*Canis lupus pallipes*) population, a top carnivore species of the open plains (semi-arid grasslands, scrublands, grazing land, etc.), has drastically declined to 2000-3000 individuals in the entire Indian peninsula (Jhala 2000). Many species have become rare localized endemics (Nilgiri tahr- *Hemitragus hylocrius*, swamp deer- *Cervus duvaucelii*) while many are widely distributed but at low densities (mouse deer- *Moschiola meminna*, four-horned antelope- *Tetracerus quadricornis*) (Karanth 2008).

Despite the immense and ever mounting demographic pressure, India has lost only one large mammalian species since the country's independence in 1947. If the Javan (*Rhinoceros sondaicus inermis*) and the Sumatran (*Dicerorhinus sumatrensis lasiotis*) rhinoceroses, which in any case had peripheral existence in the eastern extremity of the country, be excluded, India has not lost a large mammalian species in historical times, barring one—the cheetah (*Acinonyx jubatus venaticus*) (Divyabhanusinh 2006; Ranjitsinh and Jhala 2010). Rather, there are conservation success stories where species recovered from the brink of extinction, survived and expanded their ranges by concerted government efforts coupled with non-governmental interventions backed by social supports as illustrated by

crocodile (*Crocodylus* spp), gharial (*Gavialis gangeticus*), Indian rhinoceros (*Rhinoceros unicornis*), pygmy hog (*Porcula salvania*) and Asiatic lion (*Panthera leo persica*) (Martin et al. 1987; Singh 1999; USFWS 2000; Divyabhanushinh 2005; Deuti 2006; Jackson 2006; Narayan et al. 2008).

Asiatic lion (*Panthera leo persica*): a conservation success story

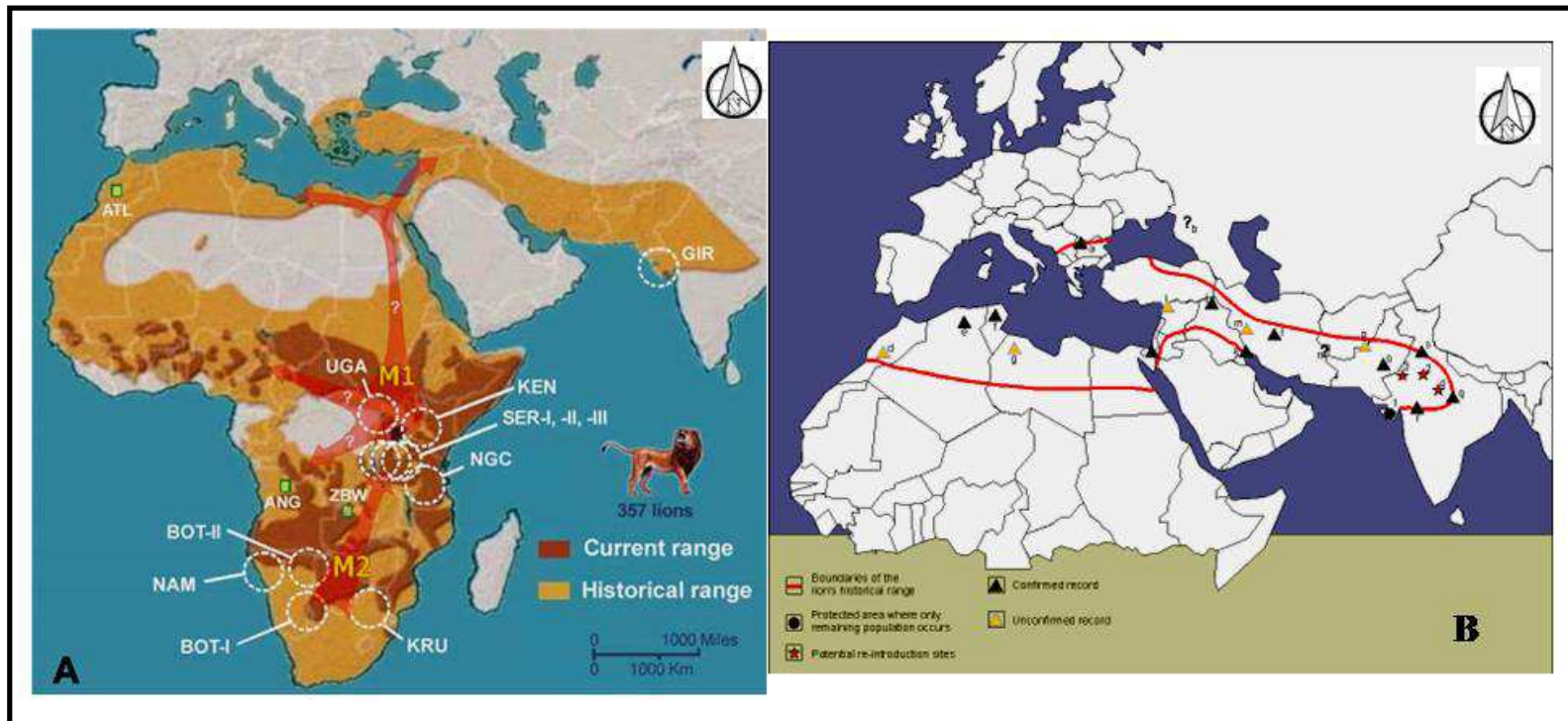
Evolution

Two models have been proposed to explain the diversification of lions – multiregional origin model and single origin replacement model (Barnett et al. 2006). While the former supports long term evolution and diversification of present-day lion, the latter proposes that a single population of lions replaced the older populations in Africa and southwestern Eurasia (Yamaguchi et al. 2004), following a population bottleneck (Barnett et al. 2006). Recent investigations on phylogeographic history of modern lions, based on analysis of mtDNA sequences, indicates a single African origin model of modern lion evolution (Barnett et al. 2006).

Extant lions (*Panthera leo*), originated from several Pleistocene *refugia* in East and South Africa (Antunes et al. 2008) , became widely distributed throughout most of the Africa, Asia, Europe, America and northern part of South America (Werdelin and Lewis 2005; Schnitzler 2011) [**Figure 1.1**]. Lions were the most widespread large terrestrial mammal during the late Pleistocene and had established in the entire Holarctic region (Barnett et al. 2006; Mazák 2010; Schnitzler 2011) including Africa, most of Eurasia and North America. Traditionally twelve and later eight sub-species of *Panthera leo* have been classified based on location, mane appearance, size and distribution (Burger et al. 2004, Barnett et al. 2006). Two distinct lineages are recognized to have existed at the end of Pleistocene, namely, the Holarctic cave lion (*Panthera leo spelaea*) and the modern lion (*Panthera leo* spp.) (Burger et al. 2004). Recent studies have shown that mitochondrial variation is limited and does not merit taxonomic distinctions among extant African lions (Dubach et al. 2005). Hence, all sub-Saharan lions are classified into a single subspecies (Dubach et al. 2005; O’ Brien et al. 1987). However, they may be divided into two main clades: to the west and east of the Great Rift Valley indicated by the fact that lions from Tsavo in Eastern Kenya are much closer genetically to lions in Transvaal (South Africa), than to those in the Aberdare Range in Western Kenya (Barnett et al. 2006). Recent

evolutionary history of lions has resulted in three geographic populations on the basis of their recent evolutionary history, namely, North-African-Asian, southern African and middle African populations (Barnett et al. 2006). The oldest true lions (*Panthera leo spelaea*) evolved about 600,000 years ago and were probably found in the first millennium BCE and eventually became extinct around 100 to 300 BCE (Neff 1983). The range of the lions north of the African Sahara extended from the African Mediterranean coast into Northern Arabia, Persia, Eastern Europe and into India (Mazák 2010). Within the past two centuries, however, the range of this lineage has steadily declined due to habitat loss and overhunting. Two distinct subspecies of extant lions, namely the African and Asiatic have been recognized that have diverged in recent times, about 55,000 and 200,000 years ago (O'Brien et al. 1987). History of lions in India was not entirely known but one theory suggests that Asiatic lions (*Panthera leo persica*) entered the Indian continent any time between the latter part of the 3rd millennium BCE to the end of the 2nd millennium BCE and moved to the north and west India between 1,500 to 600 BCE (Singh 2007). Divyabhanusinh (2005) attributed entry of lions in the western and north-western parts of India to the loss of tropical forests by environmental changes caused due to prolonged drought as well as the impact of human settlements.

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 (from Antunes et al. 2008); B: Historical range of *Panthera leo persica* (from Nowell and Jackson 1996)



Distribution and status

Asiatic lion historically had a wide distribution (**Figure 1.1**). The erstwhile range of the Asiatic lion, reconstructed mainly based on paleontological evidence, literature, art-culture-sculpture and old *shikar* (game hunting) documents suggest an extensive area from Syria across the Middle East to Eastern India (Kinnear 1920; Joslin 1973). In India, lions inhabited the entire northern Indo-Gangetic Basin in North and Central India and were abundant in the states of Punjab, Haryana, Rajasthan, Uttar Pradesh, Madhya Pradesh, Gujarat, western Bihar and Orissa (Fenton 1908; Pocock 1930; Dalvi 1969) till mid 1800s when they were exterminated from most of its range due to hunting and development-induced natural habitat loss and modifications (Divyabhanusinh 2005). By 1880s they were restricted as a single free-ranging population in and around the Barda hills, Alech hills, Mitiyala, Girnar and Gir forests in the Saurashtra peninsula of Gujarat, western India (Dalvi 1969). Further fragmentation of forested patches and irreversible loss of habitat connectivity due to agricultural expansion and grazing needs in the region finally restricted lions to the 1,883km² of the Gir forests (Divyabhanusinh 2005).

With the consistent shrinkage in the lions' distribution, there has also been a wide fluctuation in population numbers over the years and lion number was believed to be as low as 50 individuals in the early 1900s and very close to extinction (Wynter-Blyth and Dharmakumarsinhji 1950; Divyabhanusinh 2005). Owing to the timely protection measures taken by the erstwhile local rulers (*Nawabs* of Junagadh), the lion population survived (Divyabhanusinh 2005) and reached 287 in 1936 census (Dalvi 1969). From mid 1900s, lions started to move out occasionally in the adjoining forests of Gir and started appearing in Mitiyala hills in the dominion of the erstwhile princely state of Bhavnagar from 1917 and they were last reported in 1968 census from this area. Lions were frequently seen in small numbers in Girnar hills adjoining Junagadh till 1963 (Singh 2007). After the enforcement of complete ban on lion shooting in 1955 by the Government of India, declaration of Gir forests as Gir Wildlife Sanctuary in 1965 and subsequent protection and habitat manipulations by the state run Gujarat Forest Department (GFD); the lion population has shown a steady increase (Singh and Kamboj 1996) and reached a figure of 411 in 2010 lion census conducted by the GFD (Gujarat Forest Department 2010; **Figure 1.2**). Within the past two decades, lions have dispersed from the Gir Protected Area into agro-pastoral landscape of the

surrounding districts of Junagadh, Amreli and Bhavnagar covering about 10,000 km² of human-dominated landscapes (Srivastava et al. 1998; Pathak et al. 2002; Singh 1997, 2007; Banerjee et al. 2010; Singh and Gibson 2011; Banerjee and Jhala 2012; **Figure 1.3**).

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

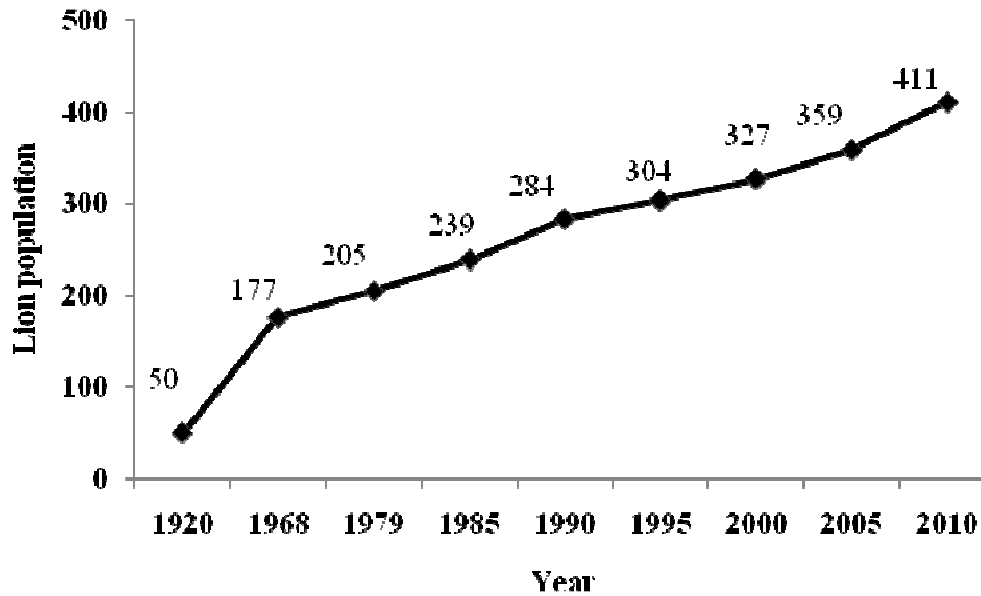
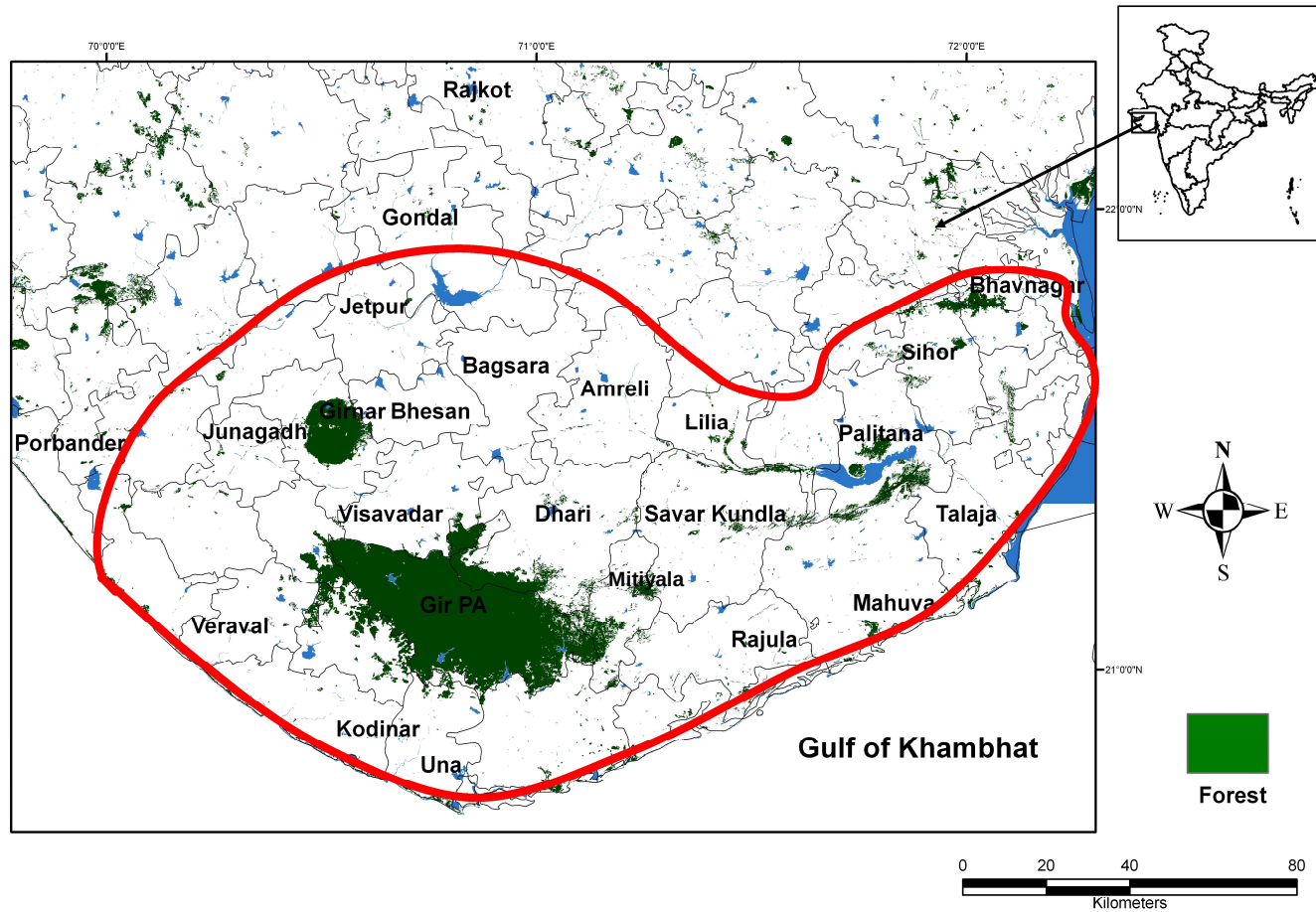


Figure 1.3: Current *tehsil* level distributions of Asiatic lion in Gujarat state, India. The map inset shows outline map of India with location of the Gir landscape. The red boundary indicates areas most frequented by lions.



Drastic reduction in the numbers of isolated 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). Wildt et al. (1987) based on their studies of the captive Asiatic lions have established deleterious effects of inbreeding caused by small founder base and demographic contraction on the physiological traits that govern the reproductive performance of Gir lions. Apart from the negative impacts due to the loss of genetic diversity, 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; Johnsingh et al. 1998). Any free ranging naturally established population of a highly endangered species like the Asiatic lion which interacts as a metapopulation has a high conservation value as it enhances the long term survival prospects of the species (Hanski and Gilpin 1997). Assessment of the risks of extinction or quasi-extinction (Gilpin and Soulé 1986; Boyce 1992; Morris and Doak 2002) of such species helps in conceptualizing reserve network design (Pressey 1999; Cabeza et al. 2004). In this context, I tried to investigate the metapopulation dynamics of lions in the Greater Gir Landscape in this thesis as such understanding is central to innovative approaches of land use planning that maintain connectivity between source lion populations.

Lion ecology and behavior: a brief overview

Lions are the only social felids that live together in fission-fusion groups called pride (Schaller 1972; Bertram 1978; Packer et al. 1990). The species is polygynous and highly dimorphic (Clutton-Brock 1989). A pride comprises an average of 2-9 related females (range 1-18), their dependent cubs, sub-adults and a resident coalition of 2-6 males (Schaller 1972; Bygott et al. 1979; Packer et al. 1990; Packer and Pusey 1993). In Gir, males did not associate with females and tended to move and feed independently and average female group size (excluding cubs) was $1.3 \pm \text{SD } 0.51$ (Jhala et al. 2009). Mean pride sizes vary between study sites: 7.1 in the Serengeti (Schaller 1972), Masai Mara 9.2 (Ogutu and Dublin 2002), 4.2 in Etosha woodland (Stander 1990), 4.2 in Kruger (Smuts 1976), 3.5 in Luangwa Valley (Yamazaki 1996), 4.2 in Kalahari Transfrontier Park (KTP) (Funston and Hermann 2002), and appear to be positively correlated with prey abundance, size of the typical prey during the period of least abundance (lean season) (Hanby and Bygott 1979; Van Orsdol et al. 1985) and habitat structure (Funston et al. 2003). The interesting feature of lion sociality is that they

do not form dominance hierarchies within prides (Schaller 1972; Bertram 1975; Bygott et al. 1979; Packer and Pusey 1982). Female companions of a pride are always closely related, male companions are either closely related or unrelated and mating partners are usually unrelated (Packer et al. 1991). Female lions reproduce all-year round, litters are commonly born synchronously within a pride following a pride takeover by adult males (Bertram 1975; Packer and Pusey 1983a). Cubs born less than one year apart constitute a cohort (Packer and Pusey 1993). Gestation averages 110 days with an inter-birth interval of 0.8 to 3.3 years (Schaller 1972; Joslin 1973; Funston et al. 2003; Stander 2006). Average litter size ranges between one to four cubs (Schaller 1972; Joslin 1973; Chellam 1993; Hanby et al. 1995; Jhala et al. 2009; Banerjee et al. 2010) with 70% females producing 2-3 cubs (Packer and Pusey 1987). However, lion productivity is limited by food availability (Packer and Pusey 1995). Cub mortality is highest in the first year; it drops dramatically from year 3 and stays at lower levels until the 11th year when it picks up again (Packer et al. 1998). Adult survival rate is high; 90% in the Serengeti and the Gir forests (Schaller 1972; Joslin 1973).

Prides are territorial; they defend exclusive territories against other prides and often occupy the same range over several generations (Schaller 1972; Packer and Pusey 1993), although individual responses to interlopers are varied (Heinsohn and Packer 1995). Pride size appears to be density dependent and is maintained by emigration of females in the Serengeti (Bertram 1973; Hanby and Bygott 1987). Lions show a higher *per-capita* food intake rate and high cub recruitment at low population density (Kissui and Packer 2004). Lionesses are able to identify both numbers and identities of other lions by their roars and this may facilitate both spacing and avoidance of potentially infanticidal males (McComb et al. 1993; McComb et al. 1994).

Male lions are transient in the life of the pride and generally form stable single sex groups during sub-adulthood and adulthood (Schaller 1972) these groups or coalitions are typically 2-3 males (range 1-7) and while they may be siblings or close relatives they are not exclusively so (Bygott et al. 1979; Packer and Pusey 1982). In plains habitats it has been suggested that these coalitions disperse considerable distances and become nomadic for their sub-adult life however, data from Kruger national park in South Africa, a wooded environment, suggests that males may settle closer to their natal range (Funston et al. 2003). At approximately 4-6 years old, a male coalition may begin challenging for pride tenure.

Relatively little is known about sub-adult male dispersal distances and mortality, as most research has concentrated on the behavioural ecology of the females, but dispersal may be local or as far as 120 km in Africa (Pusey and Packer 1987; Funston et al. 2003) or 23 km as recorded for a single instance in Gir (Meena 2008). Males generally remain in the same pride for 2–3 years and typically father only one cohort per pride (Pusey and Packer 1993). The association of adult male coalitions and female prides may be occasional or throughout the tenure of territorial males and may vary in different areas. In open areas, males associate with the prides throughout their tenure and thus show direct parental investment by providing protection to dependent cubs from infanticidal nomadic males (Kleiman and Malcolm 1981). Males engage in territorial patrols and defense of their cubs. Therefore, male presence is crucial for cub survival and successful recruitment of offspring. A coalition should retain residence for at least two years to successfully raise their young; frequent replacement of resident males severely depresses cub recruitment, and could have cascading effects leading to the overall population decline (Starfield et al. 1981; Whitman and Packer 1997; Whitman et al. 2004; Loveridge et al. 2007).). Larger male coalitions have high *per-capita* reproductive success (Bygott et al. 1979; Grinnell et al. 1995).

The diet of the lion constitutes a broad range of prey species that vary between habitats depending on the most common and locally available prey species. Medium (100-300kg) to large (average 400+kg) prey is the most preferred range of species (Hayward and Kerley 2005). In Gir, livestock formed 75% of the lion's diet (Joslin 1973). However, during the subsequent period 52% (in early 1980s) and 75% (in the late 1980s) of prey consumed were wild prey (Sinha 1987; Chellam 1993). Meena et al. (2011) found that lions in Gir made one kill in every 4 days and based on scat analysis found that the diet primarily consisted of chital (*Axis axis*) representing 80% of the lion's diet, though lions were yet responsible for majority of livestock loss to the resident nomadic pastorals (*Maldharis*). In the newly declared Girnar Wildlife Sanctuary near the Gir, Asiatic lions primarily feed on domestic livestock, sambar and wild pigs whereas lions in the coastal forests largely depend on domestic livestock (Dharaiya 2001). In a review paper, Sunquist and Sunquist (1997) have shown that abundance of prey species, size of the prey, temporal and spatial distribution of prey and defense and anti-predatory tactics of the prey may affect prey preferences for lions. In addition, environmental factors such as vegetation height, time of the day, terrain, may all

affect the hunting success and therefore prey preference of a predator (Mills et al. 1995; Funston et al. 2001; Hopcraft et al. 2005). Predator related behavioral traits such as grouping pattern and hunting strategy may also influence prey preference and hunting success (Packer et al. 1990).

Individual lions in a pride sometimes hunt cooperatively, and cooperative hunting was originally proposed as an evolutionary force for social living in lions (Schaller 1972). Macdonald (1983), suggested dispersion of prey and abundance of resources to have been the evolutionary catalyst for group living, and might have produced constraints leading to the evolution of sociality in mammalian species. However, Packer et al. 1990 showed that foraging requirement was not sufficient to explain the observed grouping pattern seen in lions. Instead, they suggested that lions grouped to protect their young against infanticide. The need to maintain territory and females' reproductive success patterns all strongly influenced lion grouping. The most recent analysis of group living and territoriality in lions by Mosser and Packer (2009) suggested that habitat heterogeneity could have enhanced the evolution of territoriality in lions because, as despots, large prides out-compete small ones over high quality resource patches.

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 merely linear (Carbone and Gittleman 2002) but 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). Lion home range sizes, however, were found to be varied between 45 km² in Ngorongoro Carter (Hanby et al. 1995) to 1,000 km² in Chobe National Park, Botswana (Cooper 1991). In Gir, male home range was 85 km² (Meena 2008) while female home range was 48 km² (Jhala et al. 2009). Lions are found in a considerable diversity of habitats including dense forest, desert and swamp but are most often associated with plains, scrub, deciduous woodland and savannah (Boitani 1998). In plains habitat females do most of the hunting and males scavenge meals from these hunts (Schaller 1972) in contrast males hunted frequently and successfully in the thicker habitats in Kruger

(Funston et al. 1998). Contrary to the popular belief of being ‘savanna specialist’, the Asiatic lion in Gir shows a habitat preference for dense vegetation (Jhala et al. 2009).

Lion and Indian culture

“No other wild mammal on the Indian subcontinent.....has had such a man-caused impact upon its daily life, food habits and behavior as the lion. Few animals have hovered so long between survival and extinction”—M. K. Ranjitsinh (in Lion, from Beyond the tiger: portrait of Asia’s wildlife. Brijbasi, New Delhi, 1997)

The roots of environmental conservation go back to religion which emphasizes harmonious living with nature’s creation (*Atharvaveda* 11.2.24; *Bhagvad Gita*: 5.19; Raychaudhuri 1958; Kansara 1995). Carnivore conservation depends on sociopolitical landscapes as much as biological landscapes (Treves and Karanth 2003). Studies have shown that successful mammalian conservation is strongly related with social systems embedded within people’s values, norms, beliefs, perceptions and attitudes. As different cultures and communities hold different values and beliefs, it is imperative to recognize how specific values are interspersed within a society and in turn, how they influence human attitudes and ultimately behavior (Roque de Pinho 2002). In this section studies on successful conservation of species having cultural and religious values are discussed and compared with historical positions of lions in Indian culture.

Social reverence toward life forms resulting into tolerance has always been an important factor ensuring future survival potential of many species. Kaltenborn et al. 1998 illustrates that attitudes towards large carnivores are highly correlated with environmental beliefs and traditional behavior. Recently, Karanth (2008) found that human cultural tolerance have a major role in promoting persistence of species in human-dominated landscapes. She found that Nilgai (*Boselaphus tragocamelus*), blackbuck (*Antelope cervicapra*), and chinkara (*Gazella bennetti*) in parts of Northern and Western India, to some extent gaur (*Bos gaurus*) in central and southern India, and elephants (*Elephas maximus*) across their entire range, except the northeastern hills, exemplify this phenomenon. Although hyena (*Crocuta crocuta*) kills represent a very small percentage of livestock loss compared to other predators in Kenya (Frank 1998); nevertheless hyenas are loathed in Maasai society

and are associated with negative connotations like greed, ignorance, ugliness and malevolence (Goldman et al. 2010). On the contrary, though Maasai do come into conflict with lions, their relationship with lions is far more complex and includes positive mixed dimensions like that of feelings of awe, fascination and admiration as well as fear and resentment (Goldman et al. 2010; Kushnir et al. 2010). Mishra (1997) found that though the Buddhist communities in Indian trans-Himalaya resent living with carnivores, but they do not actively persecute all of them because of their religious prohibitions and cultural beliefs. For example, wolves (*Canis lupus*) are highly persecuted by the Buddhist communities because of negative cultural beliefs, but snow leopards (*Uncia uncia*), responsible for majority of the livestock depredations, are rarely persecuted.

Despite legal protection over most of its range, prohibition of international trade, anti-poaching efforts, and millions spent by NGOs and governments, demand for tiger parts showed no sign of abating until the recent unveiling of a tent at the Litang Horse Festival in Tibet made from the skins of 108 tigers underscoring the sense of emergency (Banks et al. 2006). Tibetans believe in wearing a tiger skin as a sign of promoting an image of economically prospering Tibet. This practice was, however, brought in control at Kalachakra Buddhist Festival held in south India in 2006 when the highest religious leader of the community, Dalai Lama pledged to Tibetans “neither use, sell, or buy wild animals, their products or derivatives” (Banks et al. 2006). This had a positive effect across the Tibetan plateau and amongst Tibetan communities in India and Nepal where large groups of people voluntarily burnt their skin-decorated costumes on huge bonfires (Banks et al. 2006).

In addition, there are many examples that illustrate how existing cultural norms impede locals from destroying their environment (Gadgil 2001). Communities in northern India worship many species of animals and plants and although they lose ample livestock to carnivores, they still retain a positive outlook towards wildlife and conservation (Sekar 1998). Animals are worshipped in many parts of India as deities, as, for instance, the elephant-god *Ganesha* and the monkey-god *Hanuman*, or as the fish, tortoise and boar—incarnations of Lord *Vishnu* (a Hindu God) (Krishna 2010). Some species, such as the swan, bull, lion and tiger, regarded as *Vahanas* (vehicles of deities) developed sanctity by association. Others, such as the snake are worshipped out of fear or birds like crow are associated with abode of the dead (Krishna 2010). Besides, political representation of

carnivores also shapes peoples' tolerance levels towards carnivores and subsequently towards conservation (Naughton-Treves and Treves 2005). An example is the ubiquitous lion symbol in Kenya where lions are found on currencies and are the emblem of many tour companies and NGOs in Africa.

Rangarajan (2001) and Divyabhanusinh (2005) gave a vivid description of how lions became a symbol of power and strength early in human history. Lion was not as common as tiger five millennia years ago in the Harappan culture, but there are also records of two-headed lion figures during the mature phase of the civilization (Thapar 2002). After about 1,500 BC the tiger seems to have lost his supremacy in India and lion took over and made its position in the Indian art-culture-sculpture-literature (Iyer 1977; Sankhala 1978). Soon, lions caught human psyche as insignia of “a mood of isolation and majesty”, *chakravartin* or the supreme ruler, power, strength and royalty, a heraldic crest of over-lordship and made permanent place in art, religion, sculpture, culture and literature including national emblems of India and Iran (Divyabhanusinh 2005). Maiden glimpse of lions in Indian history dated back to the Indus Valley civilization (~ circa 3,000 BCE) with the discovery of artifacts and subsequently from the *Rigveda* as *Simha* to the royal symbol on gold coins during the reign of Chandra Gupta II (375-415 AD) (Thapar 2002). The lion symbolism reached its climax with the animal's close association with Buddhism and during the era of Ashoka when Buddhism got the recognition of the state religion. Lion, majestic with back-to-back in a Persepolitan style appeared on the capitals of Ashokan pillars (at Sarnath, Uttar Pradesh) proclaiming the ruler's universal all-encompassing vision of *dharma* which subsequently became the national emblem for contemporary India. Lion's association with Hinduism was depicted in the lion headed *Narasimha* incarnation of the Lord *Vishnu* which is more an iconography than being popularly worshipped (Pattanaik 2006; Krishna 2010). Till date experts argue if the state of West Bengal has ever had lions (as only one Pleistocene deposit of lion fossil has been unearthed from Bankura, western part of the state), nevertheless, the main goddess of the state (Goddess *Durga*) is worshipped with her chosen mount—a lion; a fact strongly elucidating the tremendous societal influence lions have on human *élan vital* (Rangarajan 2001; Divyabhanusinh 2005).

It took only 3,000 years of human domination on the environment to destroy much of the Asiatic lions' range (Divyabhanusinh 2005). Reconstruction of geological history

suggested that about twenty five hundred years back, the Kathiawar peninsula was separated from the mainland India by rising water causing the first genetic bottleneck that isolated the ancestral founders of the present Asiatic lion population compelling them to inbreed for several generations (O'Brien 2003). By the time the peninsular water receded, much of the mainland populations were extirpated due to habitat loss and hunting (Divyabhanusinh 2005). The second bottleneck, less severe but better known, happened at the onset of the nineteenth century when lions got restricted only to the Gir forests and their number declined to around 50 individuals due to hunting and habitat loss (Divyabhanusinh 2005). The Kathiawar peninsula was an agrarian-pastoral region even during the Sultanates and Mughals. The exploitation of lions by changing land use pattern must have come to equilibrium by the early Christian era after the first great phase of colonization was over, but saw unprecedented climax especially during the Second World War (Divyabhanusinh 2005). Irreversible loss of potential habitats and principal prey species caused by agricultural and industrial expansion and indiscriminant game hunting exterminated lions across most of its former range. By late nineteenth century they were restricted only in the Gir forests and its surroundings in the Saurashtra peninsula of India.

Carnivore conservation outside Protected Area: factors affecting conflict and local response

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. 2007a). During this stage, space and conflict mitigation become the principal conservation concerns (Macdonald and Sillero-Zubiri 2002; Inskip and Zimmermann 2009). Among these issues, livestock predation is the most challenging (Saberwal et al. 1994; Macdonald and Sillero-Zubiri 2002; Hemson 2003; Bagchi and Mishra 2006; Holmern et al. 2007; Kissui 2008; Sangay and Vernes 2008). In this final section, I will discuss underlying socio-ecological and economic intricacies behind such conflicts and try to correlate with the conservation scenario of Asiatic lion in agro-pastoral landscapes outside the Gir PA.

Conservation is rapidly becoming one of the humanity's major land-use objectives (Ogra and Badola 2008) resulting in establishment of sanctum sanctorum or formal Protected Areas (PA) supported by national and international agencies (Sekhar 2003). Successful conservation policies have resulted in recovery of several previously endangered species globally (Schwerdtner and Gruber 2007; Marcelli and Fusillo 2009) often leading to population spill over of many species outside the formal PAs (Karanth and DeFries 2010). Large carnivores owing to their slow life histories, complex social structures, long ranging patterns, large body sizes and lower population densities (Cardillo et al. 2004) often compete with varying human interests for the use of biological resources and thus their occurrence can cause significant damages (Macdonald and Sillero-Zubiri 2002) and raises human-wildlife conflicts (Wang and Macdonald 2006) under diverse socio-economic and bio-political landscapes. Such conflicts can be particularly contentious when the resources concerned have economic value and the predators involved are legally protected (Sawarkar 1986; Thirgood et al. 2000). The economic significance of these conflicts is generally minor relative to losses to disease, rodents or invertebrate pests (Knight 2000). However, the underlying conservation implications are significant as livestock-predator conflict and resulting human retaliations have been noted as one of the primary sources of population decline of carnivores (Karanth and Chellam 2009; Dickman 2010). Majority of such conflicts occur outside protected areas and pose great challenge for many conservationists; often forcing a decision between focusing conservation efforts in human dominated landscapes or inside protected areas (Woodroffe et al. 2005b). The situation becomes even more complex when there is occasional loss of human lives due to attack by large predators (Saberwal et al. 1994; Goyal 2001; Sillero-Zubiri and Laurenson 2001; Packer et al. 2005) resulting in retaliatory extermination of the latter. Despite the growing relevance of such conflicts, a theoretical framework to integrate understandings of dynamics of economics, alteration of land use and landscaping patterns and competitive interactions between prey and predators in conflict management is still limited (Conover 2002). Such approaches become imperative for policy making and legislations for the successful management of the last free-ranging population of the Asiatic lions in the semi-arid landscapes of the Greater Gir landscape. There is an assemblage of underlying factors that predispose some communities to higher rates of conflict (Woodroffe et al. 2005a) and therefore an in-depth understanding of these specific factors will

prove instrumental in conservation planning and management. In the context of human-lion conflict in the agro-pastoral Gir landscape, the current thesis aims to quantify the socio-economic drivers behind such conflict to develop appropriate mitigation strategies.

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 (Røskoft et al. 2003; Athreya 2006; Rahalkar 2008; Dickman 2010; Athreya et al. 2011).

Tolerance towards carnivores and their conservation are thus likely formed by a combination of both perceptions and past experiences. 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 factor governing such perceptions and thereby could be a significant driver in shaping such human-wildlife conflicts (Mishra 1997; Ikanda and Packer 2008; Hazzah et al. 2009). Gir forest has a legacy of harmonious co-existence of lions and other wildlife species along with its traditional trans-nomadic pastoral communities (*Maldharis*) (Berwick 1990) in spite of livestock depredation by lions and leopards (Divyabhanusinh 2005). There is a state run compensation scheme for livestock depredation which is being revised in reflectance with market values (Singh 2007). Additionally, these communities being at the centre of the forests enjoy many more facilities (Varma 2009) and are overall economically benefited at the prevailing Compensation Scheme (Banerjee et al. 2013). This might be the economic driver behind such long, harmonious co-existence of them with lions. But the situation might not be the same for marginally protected areas outside the Gir. A farmer outside the Gir might have economic gains in having lions as a control to agricultural damage but a pastoral with hardly any access to the forest resources and ignorant about the government schemes like Compensation run to redress conflicts (Personal Observation.) might hold hostility towards lions. Moreover, lions outside of the PA are likely to obtain much of their food from livestock but do also predate wild prey. Local tolerance towards lions in Gir may be determined by several factors. I hypothesize that economics of damage and perception of threat would predominate. I anticipate that the lions obtaining majority of food by scavenging/predating unproductive livestock and wild prey, will be tolerated by some communities while persecuted by others. Such tolerance will primarily depend on relative impacts on local communities' livelihoods and secondarily on their socio-cultural status and beliefs and customs.

In India, development efforts such as large scale expansion of infrastructure, basic services such as electricity and water, urbanization, mining, dams, tourism are resulting in

unplanned land use change and exploitation of natural resources and likely to escalate human-carnivore conflicts under different landscapes. Impacts of such developments would be more intense in economically well-off states like Gujarat. I try to highlight the conservation perception at different socio-economic level that could be projected to infer on development induced impact on lion-human co-existence, if any. Moreover, I use data generated by telemetry on how often lions venture into or in close proximity of settlements, are there specific patterns temporally or seasonally for such behavior, what are the food habits of peripheral lion populations, how often do lions predate on livestock, what factors reduce the risk of lion attacks on livestock and people, prevention of crop damage by the wild ungulates —answers to these questions would help to understand the economics of lion conservation, management strategies for maintaining lion densities at socially desired and ecologically viable levels in this agro-pastoral landscape and educational awareness campaigns in sensitizing local people to conservation needs and avoiding conflict. These will in turn address the issues of human-lion interface thereby ensuring long term survival potential of lions to coexist with humans in the human dominated landscape of the Greater Gir ecosystem.

Study objectives

Broadly, an important component of my research includes quantification of the lion-human conflict, perception of the conflict by the local communities, and their attitudes towards having lions in their neighborhood in the Greater Gir landscape. I intended to address the critical issues concerning the lion population dynamics and demography in the Greater Gir landscape, lion ranging and movement pattern, habitat use and diet, habitat requirements of breeding nuclei outside Gir PA and assessment of the magnitude of actual conflict inferred through telemetry in comparison to that perceived by the local population, through questionnaire surveys. I hypothesized that survival of lion in the agro-pastoral landscape outside the Gir PA could be safeguarded by evaluating the mechanisms that may permit human-lion coexistence in a human dominated landscape through a) economics of damage and perception of threat, b) appropriate compensation schemes, c) education and sensitization campaigns, d) maintaining lion density in an ecological viable and socially acceptable level outside the Gir PA, e) economics of lion conservation i.e. predation on agricultural pests and potential for ecotourism, f) assist the forest department by identifying and maintaining critical habitat patches for ensuring breeding nuclei and g) maintain lion-friendly habitat matrices and connectivity in the landscape. Specifically, I will try to elucidate the following:

1. To estimate lion demography and population structure.
2. To estimate ranging, dispersal, movement and habitat use by lions in the Gir landscape.
3. To estimate lions' diet, and
4. To examine aspects of human-lion conflict in the Gir landscape.

Organization of the thesis

The thesis is organized into eight chapters.

Chapter 1- INTRODUCTION: discusses the ecological and social facets of the carnivore conservation at the global scale and particularly of the conservation history and current scenario of the Gir lion. Additionally, it elucidates the background of the current study and highlights the research questions and 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- LION ABUNDANCE & POPULATION STRUCTURE: deals with estimation of lion abundance and population structure and discusses their importance in the conservation-management of the Gir lions.

Chapter 4- LION DEMOGRAPHY: deals with lion demography and discusses the underlying conservation significance.

Chapter 5- LION SPATIAL ORGANIZATION: deals with lion ranging and movement and discusses their significance in the context of mitigating conflicts.

Chapter 6- LION HABITAT USE & 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 7- LION'S DIET IN THE GIR LANDSCAPE: assesses lion diet in the landscape through a combination of methods and uses this information to evaluate human-lion conflict.

Chapter 8 ASPECTS OF HUMAN-LION CONFLICTS IN THE GIR LANDSCAPE: is further subdivided into i) economics lion-*Maldhari* (local pastoral community) coexistence in the Gir forest, ii) spatio-temporal patterns of lion attacks on humans in the Gir landscape and iii) people's perceptions toward future lion conservation in the Gir landscape.

Study Area

STUDY AREA

The study was carried out in about 9,000 km² Greater Gir Landscape (**Figure 1.3**) spreading over 18 *talukas* of three districts (counties) of Saurashtra peninsula of Gujarat, western India.

The entire landscape is divided into:

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

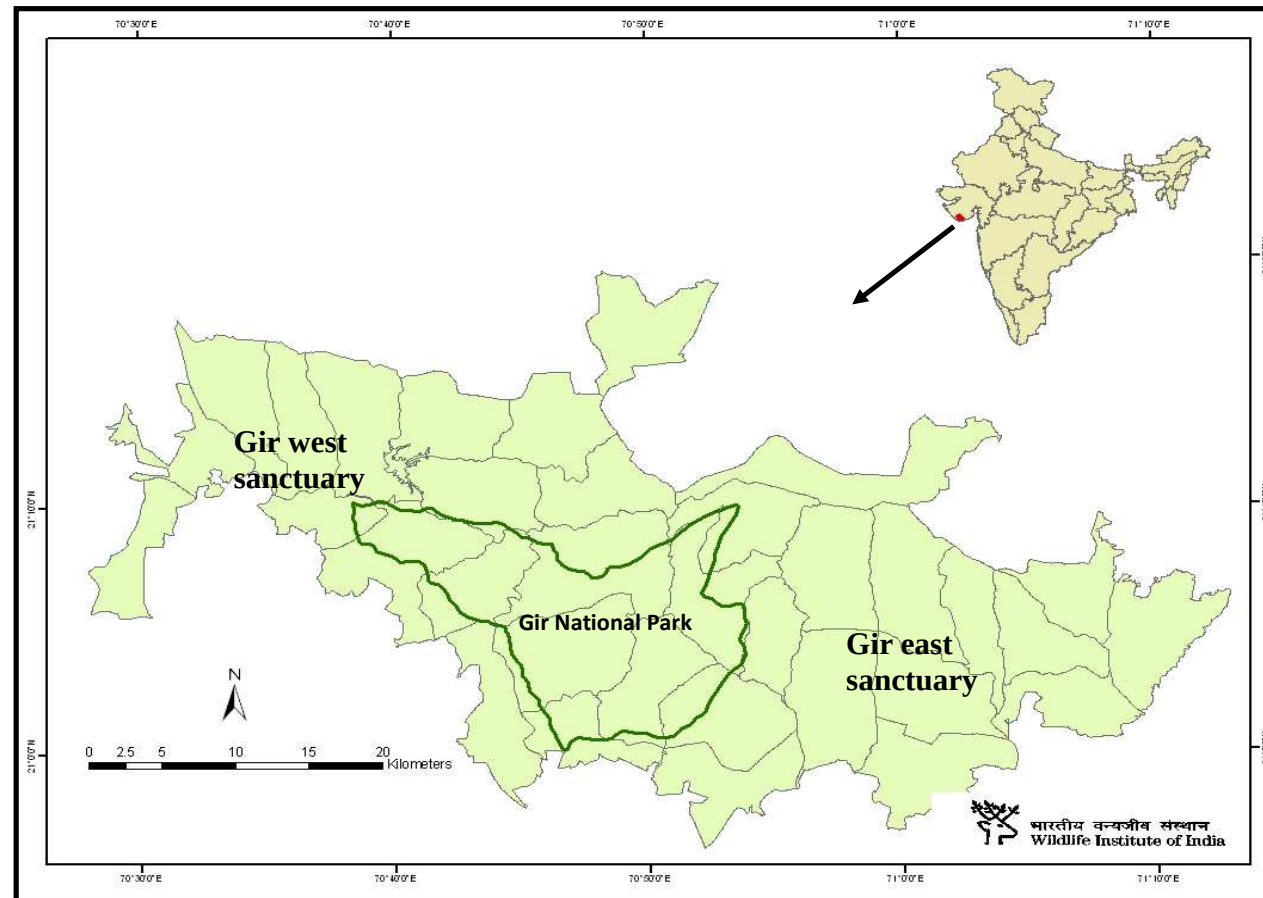
1. Gir Protected Area (GPA)

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 km²) and National Park (258.71 km²) is 1412.13 km² (**Figure- 2.2**). Recently the Chachai-Pania wildlife sanctuary (39.64 km²) 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 km²), Protected forest (107.51 km²) and Unclassed forest (77.19 km²) comprising of grasslands and forests (Pathak et al. 2002). The Gir PA 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. Gir is located about 50 km from Junagadh in south west and 75 km from Amreli in south east, head quarters of the 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 km² 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 owing to cultivation. Uncontrolled commercial exploitation of forest resources and increasing demand for cultivation land by the expansion of human settlement led to a continuous decline in the area under 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) was 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 the present size of the PA. Subsequently, a tract of land nearly 150 km² was declared as a National Park in 1975 and was enlarged to its present size in 1978.

Figure 2.1: Map of the 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.



Topography

The terrain of Gir includes 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. 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). 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 (Puri et al. 1983).

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 the 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 other parts 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.

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: The Percent Contribution Land use within Gir Protected Area (Qureshi and Shah 2004)

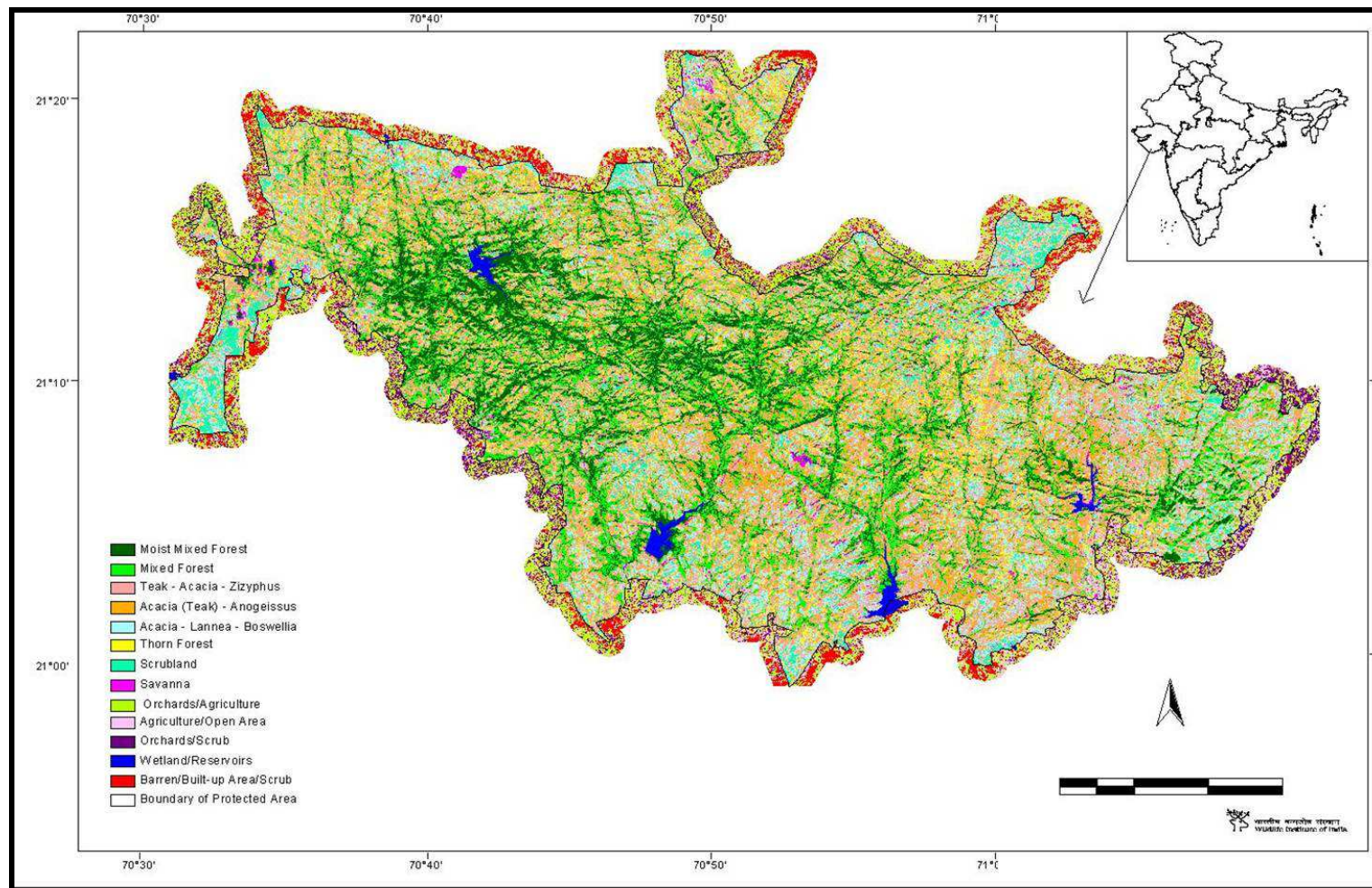
Vegetation Type	Percent Area
Wetland	0.69
Moist Mixed Forest	12.76
Mixed Forest	16.95
Teak-Acacia-Zizyphus	29.71
Acacia (Teak)-Anogeissus	13.38
Acacia-Lannea-Boswelina	12.54
Thorn Forest	7.73
Scrublands	4.48
Savanna	1.38
Agriculture/Open Area	0.29

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*, *Syzygium* 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 contortus*, *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).

Figure 2.2: Vegetation Types in Gir Protected Area and its 1 km Surrounds (Source: 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*), rusty spotted cat (*Prionailurus rubiginosus*), striped hyena (*Hyaena hyaena*), jackal (*Canis aureus*), Indian fox (*Vulpes benghalensis*), ratel (*Mellivora capensis*), mongoose (*Herpestes edwardsi*) and small Indian civet (*Viverricula indica*). Major herbivores include chital (*Axis axis*), sambar (*Rus 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 of mud and locally available timber. Usually, *Ness* is 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 developments in transportation and increase in their access to peripheral towns, they have started selling milk to nearby towns (Berwick 1990; Varma 2009).

2. Girnar Wildlife Sanctuary (GWS)

History, Location and Size

This newly formed Protected Area (c.a. 180 km²) (Government of Gujarat 2008) of Gujarat is a famous and historical site of pilgrimage for both Hindus and Jains 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' North and longitude of 70.30' and 70.40' East. 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 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 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 2.3: 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. Mount Girnar 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 support little tree growth. It is encircled by almost a broken series of smaller hills lying within a radius of 4 km from its central peak Gorakhnath.

The surrounding 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 Dunger (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 to supply drinking water to Junagadh town.

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 the soil is fairly deep, supporting good forests. Red lateritic and clayey soils are found in smaller proportions. Clayey loam is also found although in low 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 41⁰ C and minimum 7⁰ 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 lebbeck*.

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*, *Embllica 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 funiculata*, *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 km² 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, Jains 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. Pattanaik, ex-Deputy Conservator of Forests (Junagadh), *personal communication*).

3. Eastern Landscape (EL)

This eastern revenue belt of Savarkundla-Palitana (including Ambardi Reserve Forests and 18 km² 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 6,900 km² (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 230 km² of the landscape (chiefly *vidis*) with the potential lion habitats have already been delineated and proposed to be managed as a 'Conservation Reserve' (Wildlife Protection Act 1972; Ravenel and Redford 2005) by the Gujarat Forest Department (Singh 2007).

Land-use in the EL is private farm, 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 the EL (**Table 2.2**).

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

	Areas	Total lion number
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
	Total	411

Lion Abundance & Population Structure

LION ABUNDANCE & POPULATION STRUCTURE

Part of the chapter published as a peer-reviewed publication: **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.**

3.1. 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. 2010, 2011a). 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 (*Panthera leo persica*) in the Gir forests in the province 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. 2007). 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 (Divyabhanush 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 km² 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 predating 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). 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), 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. 2007) 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. 2011a). 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. I deduced the demographic parameters of Asiatic lions (through telemetry and reported as a separate chapter — Chapter 4 in this thesis) 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.

3.2. Methodology:

3.2.1. 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. I 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 3.1**). Spots were

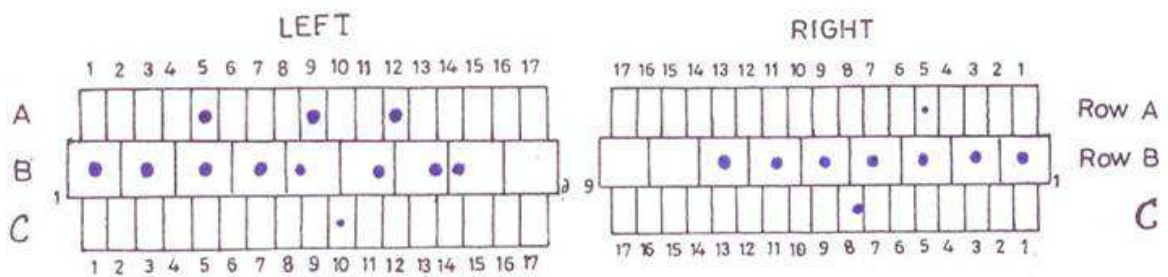
counted from nose to eye direction in both left and right sides. Row B can have anywhere between 5 to 9 spots. Rows A and C are not complete rows but consist of sporadic occurrence of spots. Row A consists of spots above row B. The spots in the above row A are defined in relation to their position to spots in row B (**Figure 3.1**). 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 3.1 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 3.1 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).

3.2.2. 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). I 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 3.1: 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).



Ear notch at 11 o' clock

Ear notch at 9 o' clock

Black spot below right eye

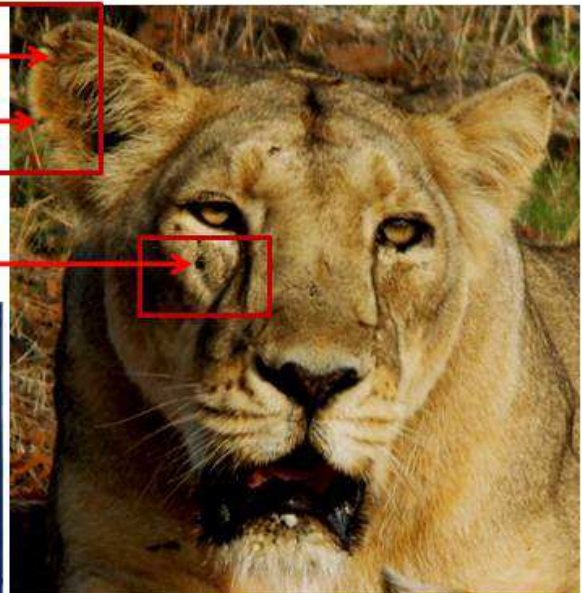


Figure 3.1: ii. Performa of the data sheet used in the field for individual lion identification. Vibrissae patterns are calibrated on a graph paper and position of additional body marks are recorded. (Source: Jhala et al. 2004).



Lion Identification Data Sheets

11.6.2010 Phawale Galt, Patrun, Girnar GPS: 21°33'48.5" / 76°34'42.2"

8:00 hrs Prime Adult ♀



LEFT

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•



RIGHT

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•

Left Row:

A = 3, 5, 6 1/2

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

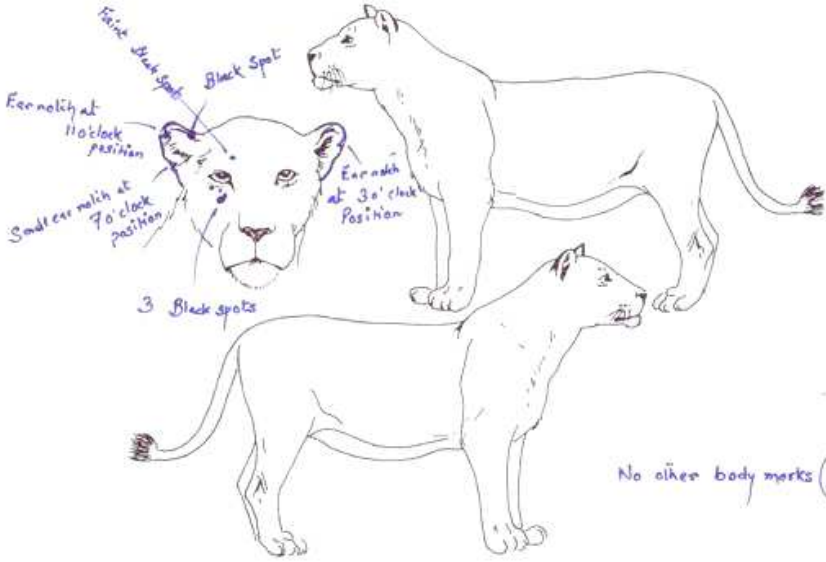
C = 5 1/2 (very faint spot)

Right Row:

A = 3 (faint spot)

B = 7

C = 4 1/2



No other body marks (permanent)

NOTES

Habitat: Tank 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.

3.2.3. 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. I therefore considered the forested boundary (180 km^2) as a “hard edged boundary” while calculating lion density for Girnar (Banerjee et al. 2010) [Figure 3.2 and 3.3].

3.2.4. 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.

3.2.5. 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 3.1** 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). I 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. 2007). 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. (2007) 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 7 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 3.1: Rationale behind Population Viability Analysis (PVA) models used in Program VORTEX for the Girnar lion population.

Modeled Scenario	Rationale
Scenario 1: No harvest (poaching and accidents), no catastrophe, habitat linkage between Gir PA and Girnar	
Scenario 2: 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).
Scenario 3: 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.
Scenario 4: 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.
Scenario 5: 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.
Scenario 6: 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.
Scenario 7: 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.
Scenario 8: Every alternative year harvest, both catastrophes, no habitat linkage between Gir PA and Girnar	

Figure 3.2: Lion sighting points in Girnar Wildlife Sanctuary. Potential habitat corridor linking Girnar to Gir Protected Area proposed as an Eco-sensitive Zone is shown.

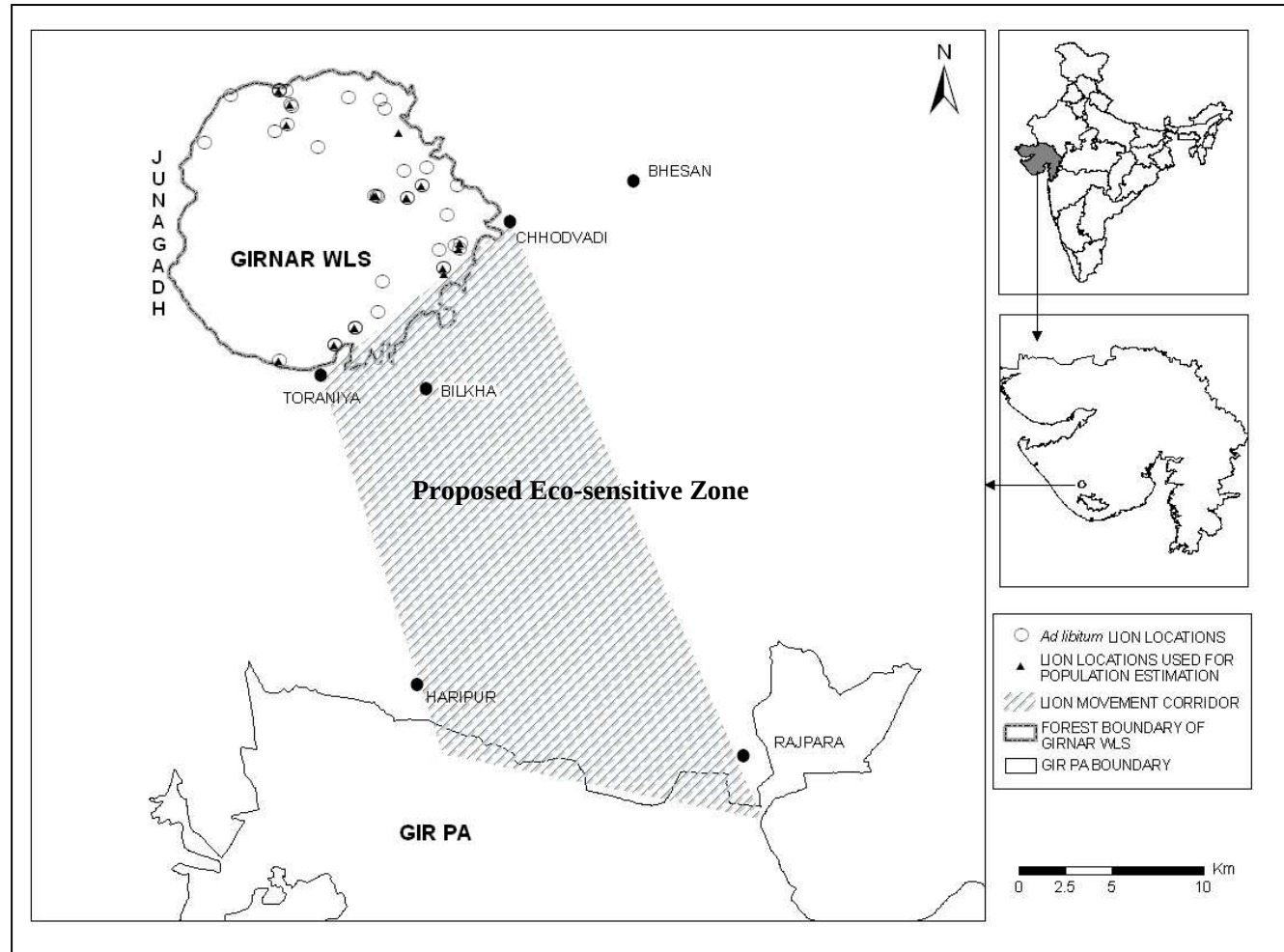
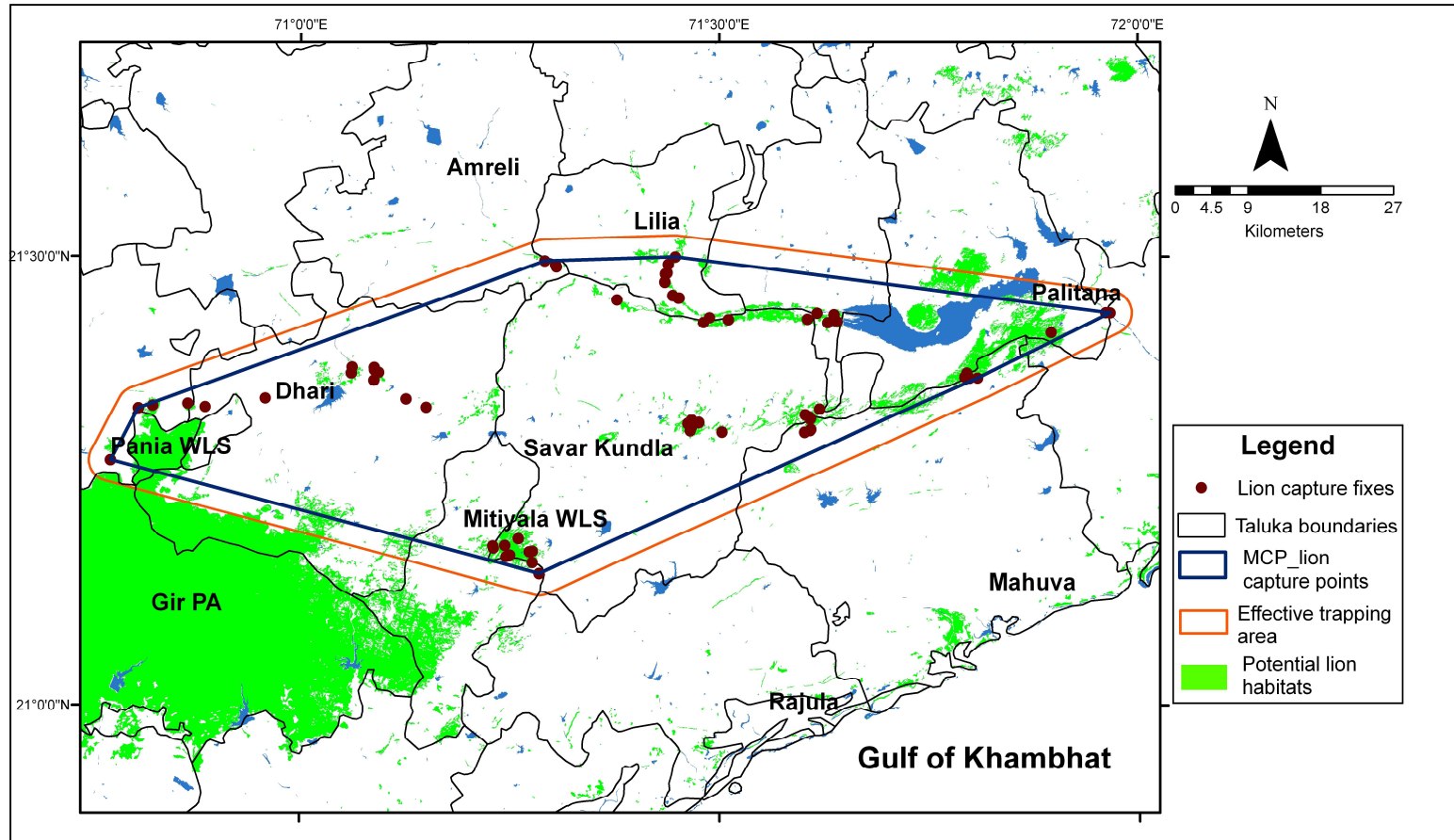


Figure 3.3: Minimum convex polygon defining lion search within the potential lion habitats of the Eastern landscape, buffered with half MMDM.



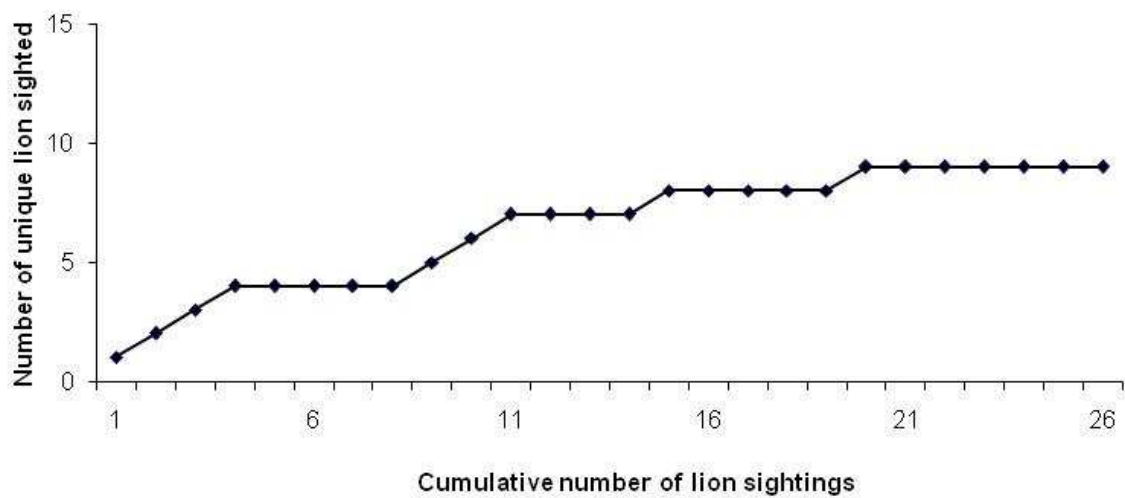
3.3. Results:

3.3.1. Lion population and density estimation

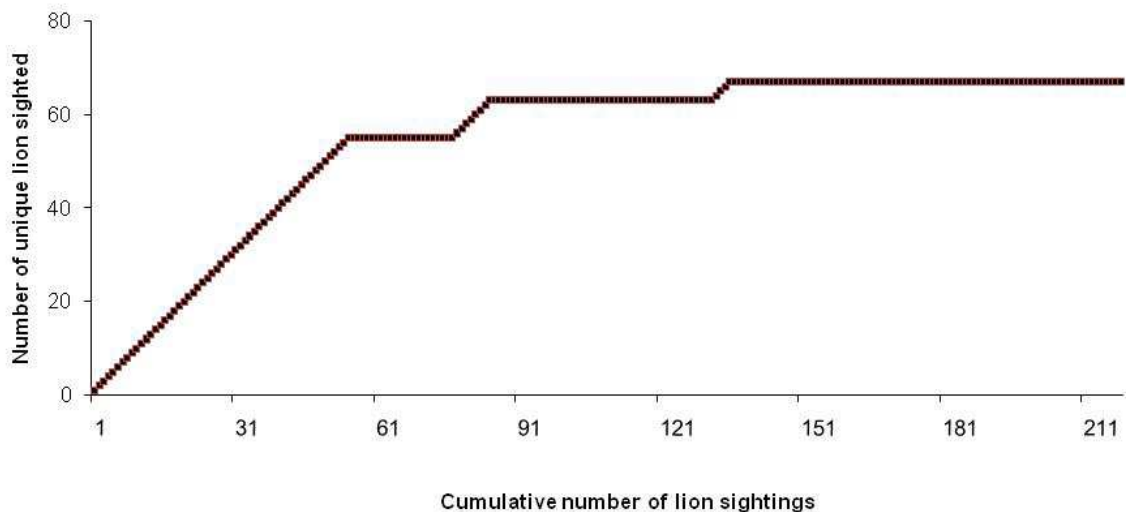
Number of unique lions sighted when plotted against cumulative lion sightings, reached an asymptote suggesting adequacy of sampling and population closure (**Figure 3.4**).

Figure 3.4: 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 3.2**). 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 3.3**). 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 3.3**).

Density of lions (> 1.5 years) was estimated to be 5.6 or about 6 (SE 0.7) lions/100 km² in Girnar Wildlife Sanctuary (**Table 3.2**). In the eastern landscape, the polygon formed by the outermost lion locations measured 2,599 km². 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) km² were estimated. The area masked was 408 km² making a final effectively sampled area of 3,292 (SE 34) km². 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 km² (**Table 3.2**).

Table 3.2: Summary of lion density 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 ²)	Density [lion/100 km ²] (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 3.3: 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 ₀	10	1.2	9 – 14	1.00
M _h	9	0.3	9 - 11	0.77
M _t	9	0.6	9 - 13	0.00
M _b	9	0.9	9 - 17	0.28
M _{th}	8	0.0	9 - 9	0.51
M _{bh}	9	0.5	9 - 11	0.65
M _{tb}	9	0.4	9 - 11	0.25

ii) Eastern Landscape

Model	Population estimate	SE	95% CI	Model selection criteria score
M ₀	67	0.6	67 - 68	0.37
M _h	68	5.2	68 - 103	0.47
M _t	67	0	67 - 67	0.48
M _b	67	0.6	67 - 68	0.10
M _{th}	67	1.1	67 - 74	1.00
M _{bh}	67	0.4	67 - 68	0.50
M _{tb}	67	0.4	67 - 68	0.00

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

3.3.2. 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 3.5**).

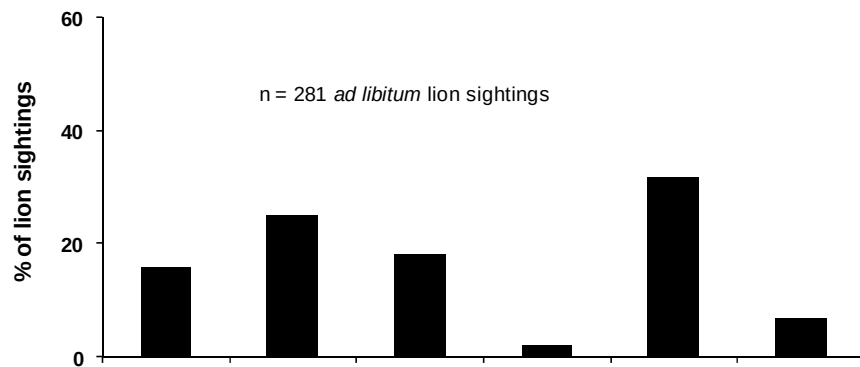
In Gir PA, average group size (including cubs) was 1.98 (SE 0.11), while adult (excluding cubs) group size was 1.71 (SE 0.1), group size of females (> 2 years) was 1.52 (SE 0.07) and males (> 2 years) was 1.42 (SE 0.05). Typical group size, the size of a group in which a lion is typically found was 3.67 (including cubs), for adult lions it was 3.1, for lionesses it was 2, and for males it was 2.28 (**Figure 3.6**).

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 3.6**).

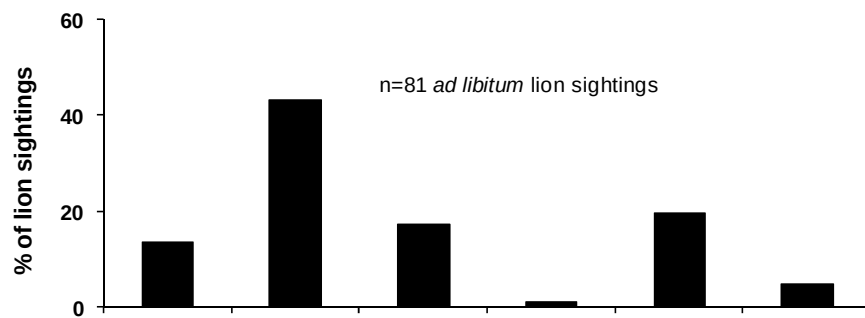
In the eastern landscape, average group size (including cubs) was 2.85 (SE 0.23), while adult (excluding cubs) group size was 2.10 (SE 0.18), group size of females (> 2 years) was 1.62 (SE 0.12) and males (>2 years) was 1.64 (SE 0.08). Typical group size was 4.5 (including cubs), for adult lions it was 3.4, for lionesses it was 2.37, and for males it was 2.05 (**Figure 3.6**).

Figure 3.5: Age and sex composition of Asiatic lions in i) Gir PA, ii) Girnar forests and iii) the eastern landscape.

i)



ii)



iii)

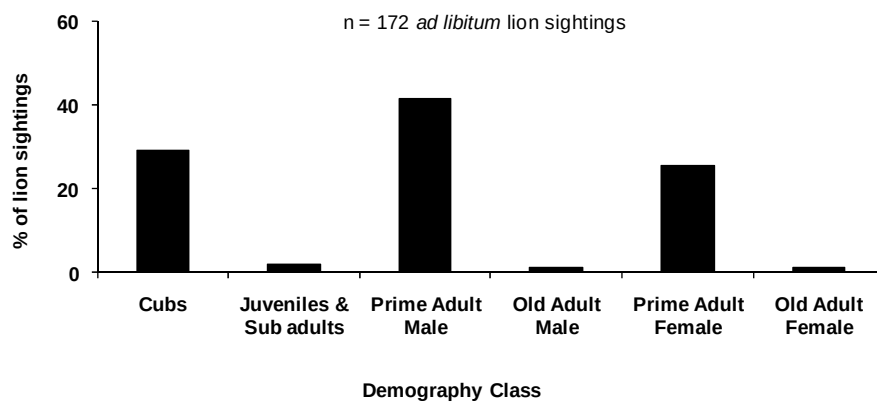
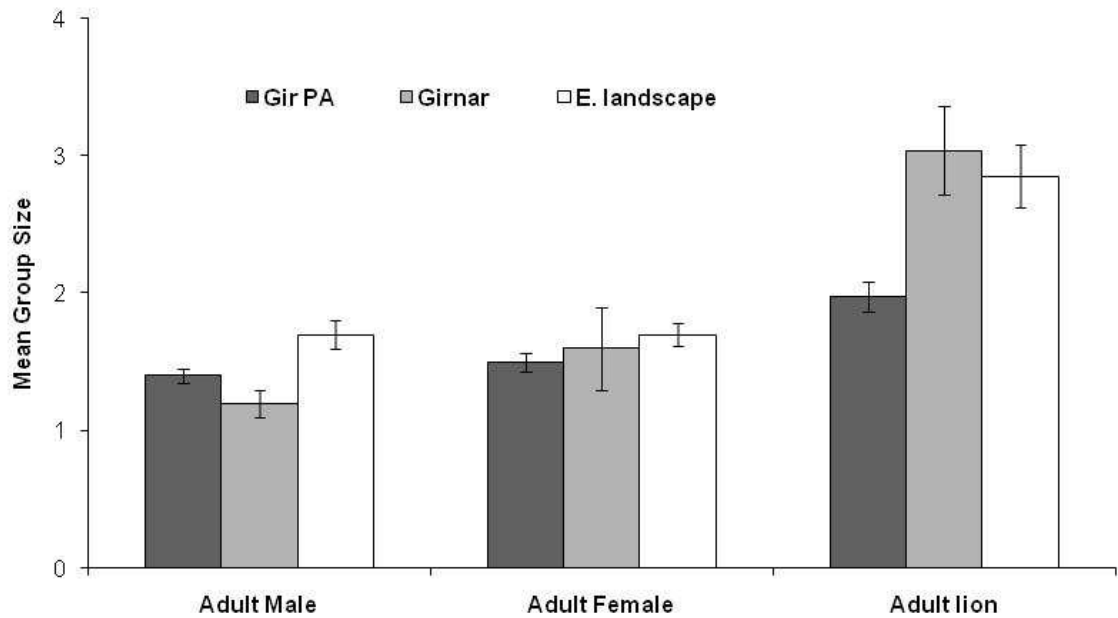
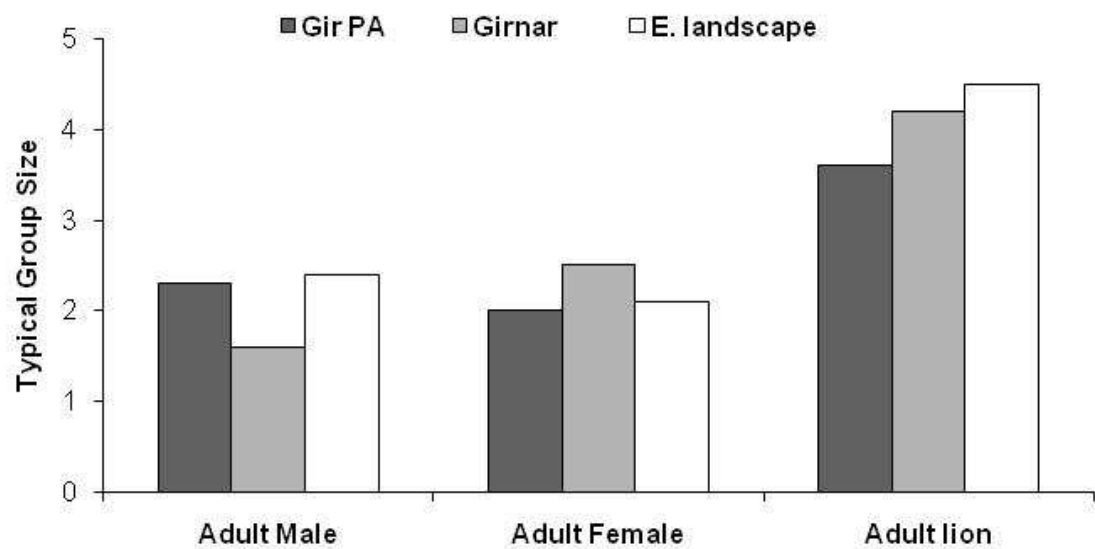


Figure 3.6: i) Mean group size (including cubs) and ii) Typical group size (including cubs) of Asiatic lions in the Gir PA, Girnar forests and the eastern landscape

i)



ii)



3.3.3. Population Viability Analysis of Girnar lions

The carrying capacity of Girnar for lions was estimated to be 9 lions/100 km² 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 3.4, Figure 3.7**). 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 in comparison to the median time to extinction of 3 years in the absence of such habitat linkage (**Table 3.4**).

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 3.4**).

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 3.8**).

Table 3.4: 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	
Scenario1: 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 3.7: 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 3.1. N = population size. I. Mean survival probability of Girnar lions under different modelled scenarios.

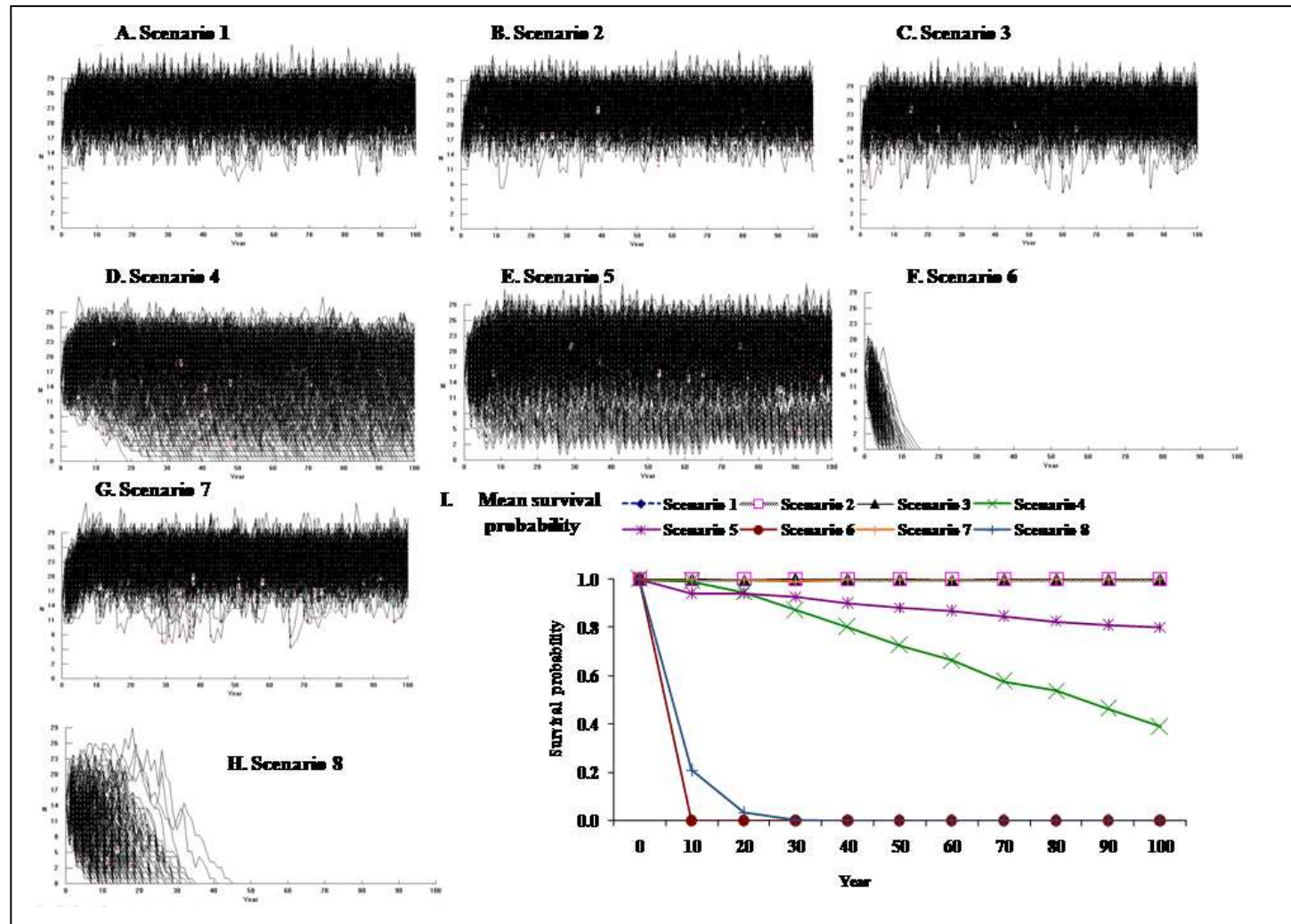
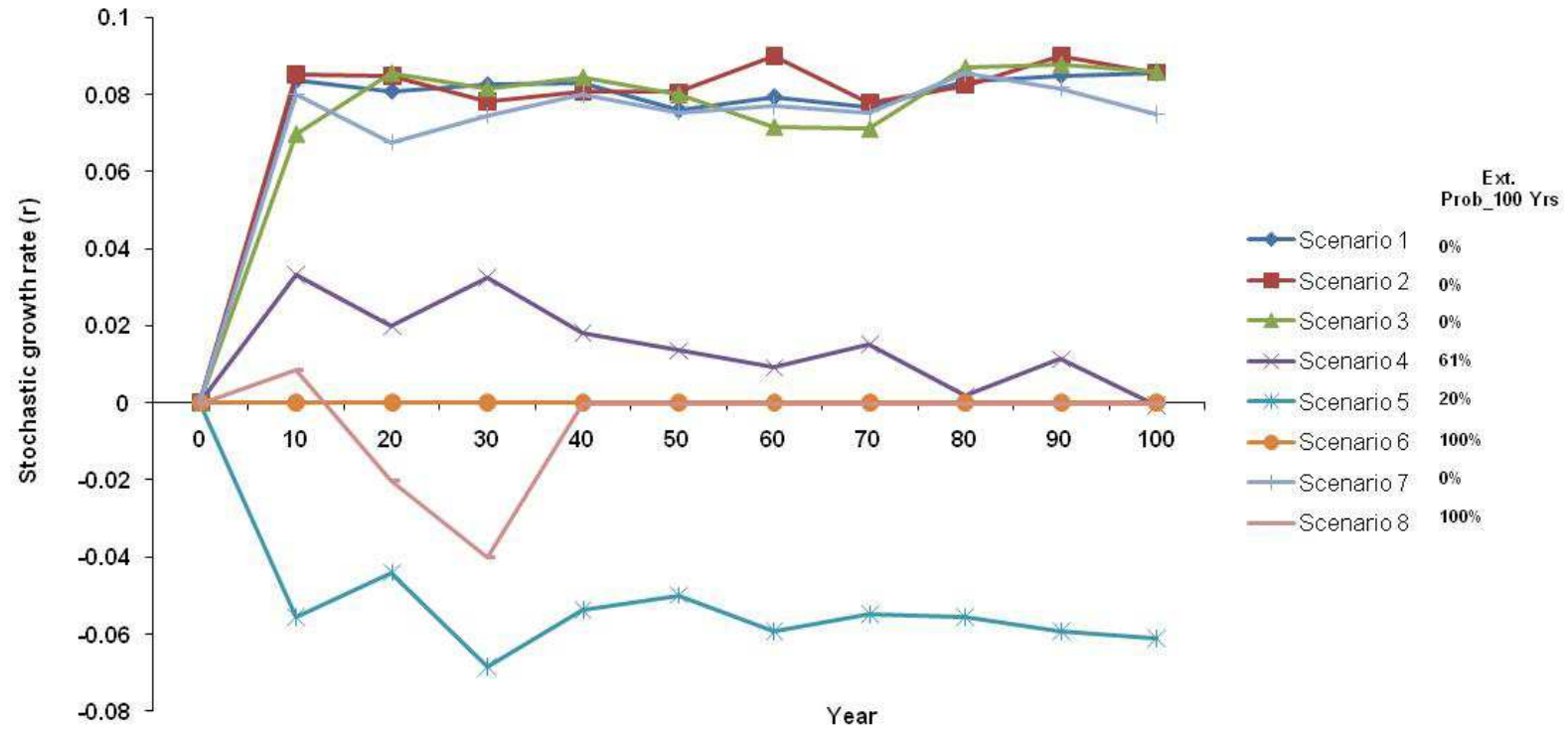


Figure 3.8: Mean stochastic growth rate (r) of the Girnar lion population under different modeled scenarios. Details of the scenarios are explained in Table 3.1.



3.4. Discussion

3.4.1. 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 3.5**). 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. 2007). 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 3.5: Lion density and prey biomass density from different Protected Areas across the Globe.

Lion Reserve	Country	Reserve area (km ²)	Lion density (lion/km ²)	Prey biomass density (kg/km ²)	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
Serenegeti	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
Girnar forest	India	180	0.06	953	1.4	1.9	Current study
Human dominated eastern landscape	India	3,292	0.02	98	1.6	1.6	Current study

3.4.2. 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 Rutten 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). 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 (*Panjrapoles* and *Gaushalas*) and temples spread across the landscape.

3.4.3. 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

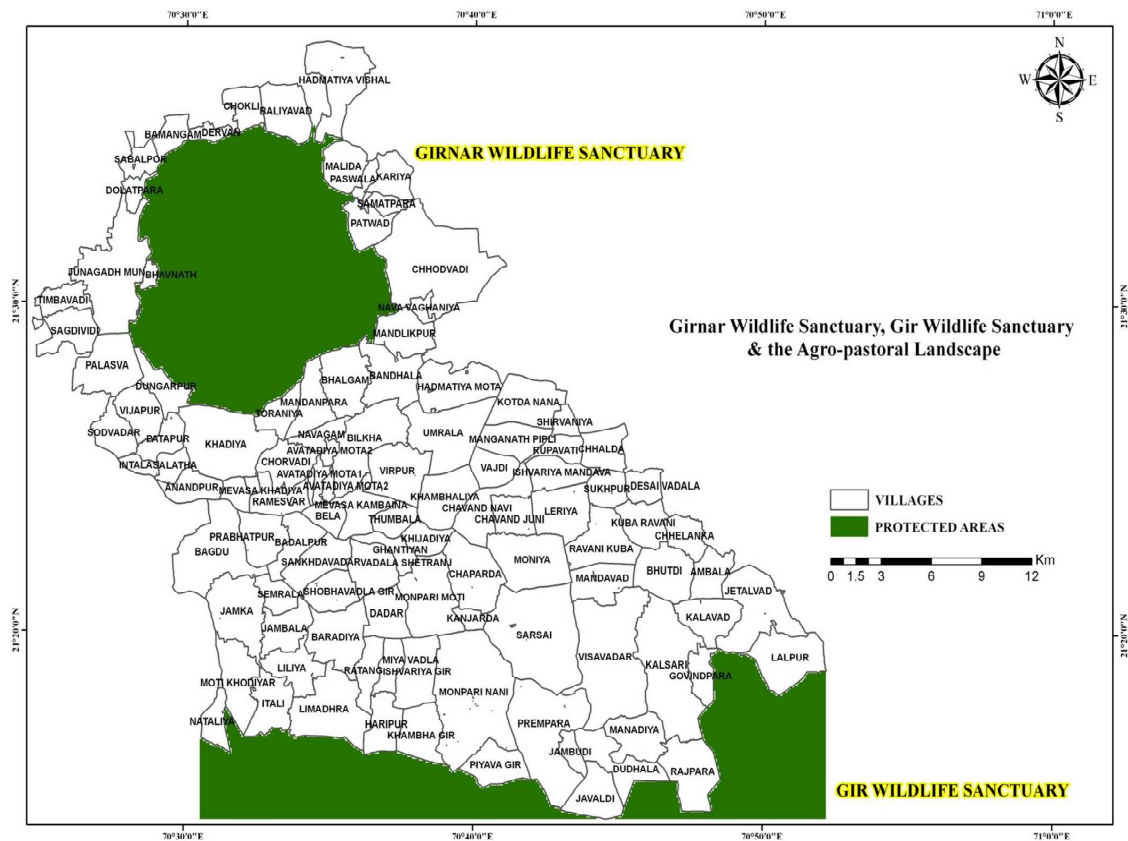
conservative than suggested by field data, Kissui and Packer 2004) and with the default setting of inbreeding depression available in VORTEX.

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 lions' 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). I, 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 km² 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 3.9**; Jhala et al. 2012) 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 3.9: 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.

Lion Demography

LION DEMOGRAPHY

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4.1. 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 (*Panthera leo persica*) 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). I collected six years' data from free ranging Asiatic lions on survival, litter size, inter litter interval, and rate of population increase by radio-telemetry on 13 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.

4.2. Methodology:

4.2.1. Data collection

Thirteen lions (10 males, 3 females) ranging between approximately 2.5 and 12 years, from different prides spaced throughout the Gir Landscape, were radio-collared (4 lions in the Gir PA, 4 lions in the Girnar Wildlife Sanctuary and 5 lions in the eastern landscape; **Figure 4.1**). 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 = 7; 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, I 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 (me and my field assistants) 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, I report stage specific rates (averaged across all ages within that stage) and not age specific rates.

I 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).

4.2.2. Sex ratio

I 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

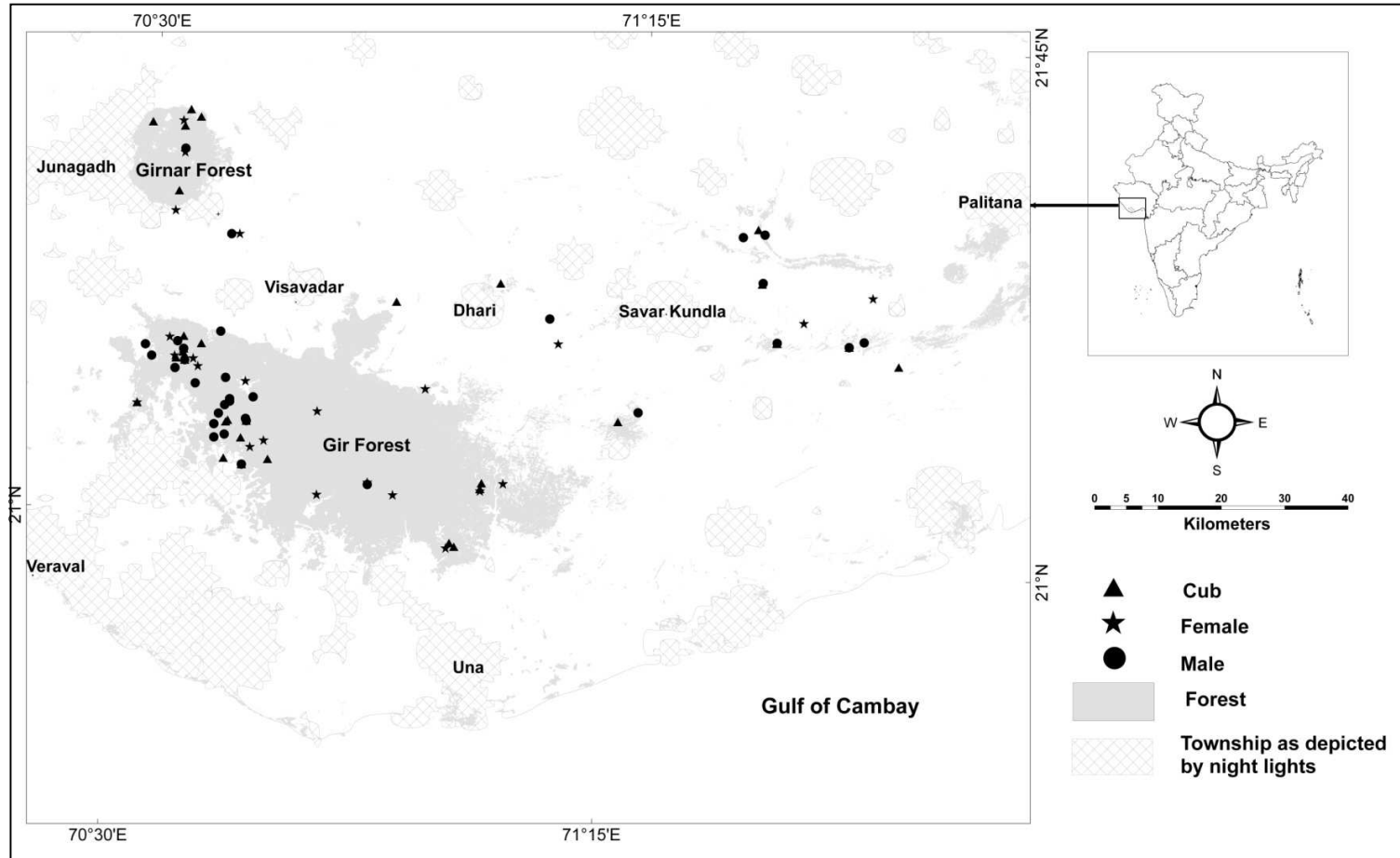
lions observed were able to be individually identified. Therefore, a single sample survey with replacement model was used to compute the adult sex ratio (Skalski et al. 2005).

4.2.3. Reproduction and cub survival

Seasonality of mating was deduced from direct sightings ($n = 29$ mating events). I 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). I 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 4.1: 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.



4.2.4. Adult survivorship and annual mortality rate

I 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 I 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. I 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, I 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. I 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 $n = 15$. I 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). I generated 95% confidence intervals on survival rates

(Zar 1984); non-overlapping confidence intervals on survival estimates were considered significantly different.

4.2.5. 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. I used this information to compute the realized rate of increase for lion population by regressing natural logarithm-transformed total counts against time (Caughley 1977).

4.2.6. Comparing demographic parameters of African and Asiatic lions

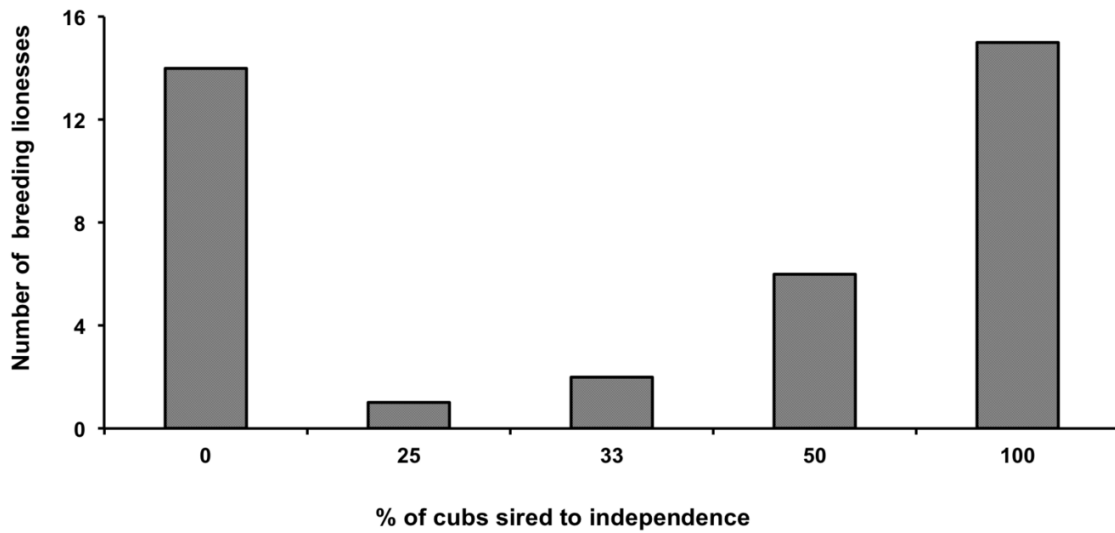
I surveyed published literature and obtained information from 19 studies on various demographic parameters of African lions. 95% confidence intervals on demographic parameters of Asiatic and African lions were constructed and considered them to be similar if the confidence intervals overlapped.

4.3. 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%; $\chi^2_{df\ 2} =$

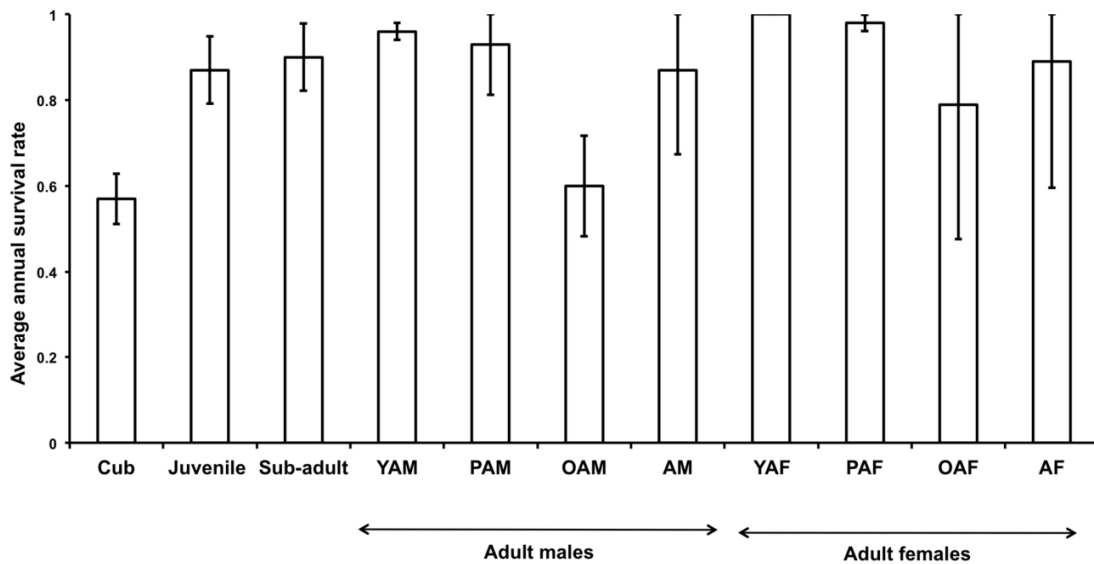
23.68, $P < 0.001$). Cub births peaked in summer (57%) followed by winter (37%) and monsoon (6%; $\chi^2_{df\ 2} = 39.66$, $P < 0.001$). I could confirm age of first litter in seven lionesses which ranged from 4 to 5 years with an average age of 4.39 (SE 0.17) years. Of the 38 litters for which litter 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 4.2**).

Figure 4.2: Reproductive success of Asiatic lioness (*Panthera leo persica*, 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 4.1**). 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 4.3**). 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 4.3**). The overall average annual survival rate of adult lions (> 3 years) was 0.90 (SE 0.12).

Figure 4.3: 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.



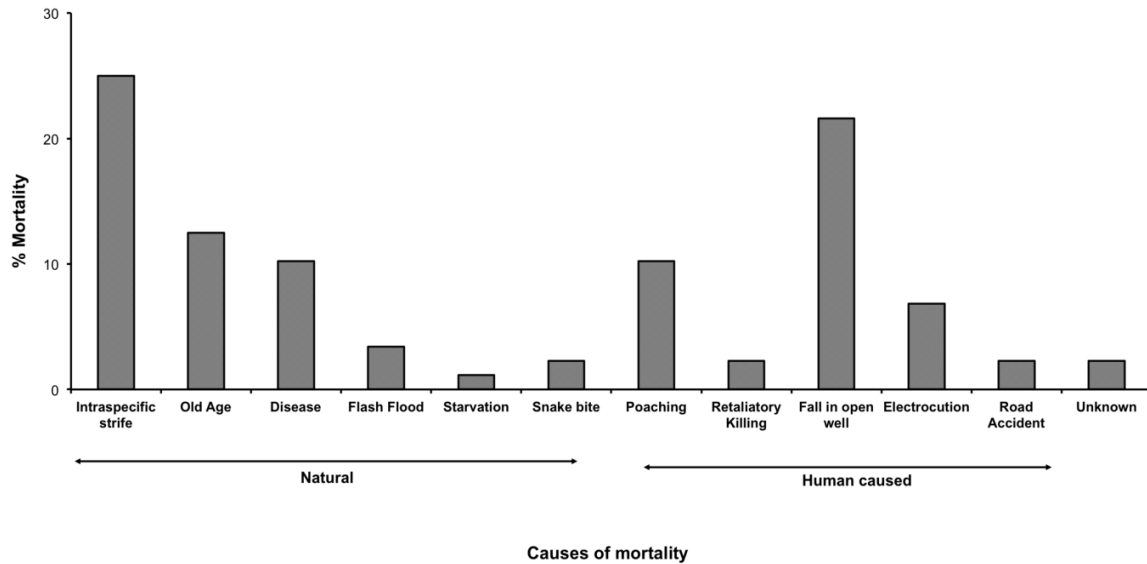
Mortality of radio-collared lions ($n = 8$) was primarily natural (87.5%), mostly due to old age (50%) or intraspecific strife (33.3%). One radio-collared lioness died due to human causes (12.5%). Out of the 88 observed mortalities across the Gir Landscape inclusive of collared and non-collared lions, 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 4. 4**).

Table 4.1: Survival rates and cause specific mortality of Asiatic lions between 2005 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 female (>10 y)	15	0.79 (0.16)	-	0.21 (0.009)	0	-	0.20 (0.03)	-	0.80 (0.03)	0	-
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)	-

Figure 4.4: Cause specific mortality in Asiatic lions (*Panthera leo persica*; n = 88) in the Gir Landscape between 2006-2010.



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 4.2**).

Table 4.2: Comparison of demographic parameters of free ranging Asiatic lions with those of African lion populations obtained from published studies.

Location	Population Growth Rate (λ)	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	Ogutu 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)
Mean (95% CI)	1.06 (0.98-2.05)	2.45 (2.33-2.57)	0.55 (0.47-0.62)	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				0.4		Chellam and Johnsingh (1993)
Gir, India	1.02							Jhala et al. (1999)
Gir, India						0.4	0.6	Jhala et al. (2004)
Gir Landscape, India (95% CI)	1.022 (1.02-1.024)	2.39 (2.2-2.6)	0.57 (0.49-0.64)	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

4.4. Discussion

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.

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 4.2**). 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). I 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; Nelson and Vucetich 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.

Lion Spatial Organization

LION SPATIAL ORGANIZATION

5.1. 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; Sunquist and Sunquist 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 19th and 20th 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 I investigate ranging, movement and activity pattern of Gir lions and discuss their underlying ecological implications for long-term lion conservation.

5.1.1. Lion space use and territoriality

The concept that individual animals restrict their movements to finite areas known as home ranges is perhaps as old as ecology itself (Darwin 1859). Seton (1909) observed that “no wild animal roams at random over the country; each has a home-region, even if it has not an actual home”. Home range is the fundamental measure of space use by an animal, defined most commonly as: “that area traversed by an individual in its normal activities of food gathering, mating and caring for young. Occasional sallies outside the area, perhaps exploratory in nature, should not be considered part of the home range” (Burt 1943). Burt's definition has persisted in the literature despite inquiries as to “what are the normal activities?” (White and Garrott 1990) and “how to quantify occasional sallies and identify the area from which the sallies are made?” (Powell 2000). The concept has been refined by several authors (Mohr 1947; Jewell 1966; Baker 1978): home-range is not the whole area that an animal traverses during its lifetime (Jewell 1966), but rather the area over which an animal normally travels in pursuit of its routine activities. More recently, Kernohan et al. 2001 defined home range “as

the extent of area with a defined probability of occurrence of an animal during a specified time period.”

Spatial organization of mammalian populations is influenced by environmental and ecological factors along with social behaviors (Emlen and Oring 1977). Spacing patterns of wild felids vary intra- and interspecifically, in terms of both home range sizes and overlap between individuals (Macdonald et al. 2010; Nicholson et al. 2011). The range of any animal is associated with the spatial distribution of limiting key resources (Mizutani and Jewell 1998; Mitchell and Powell 2004). Central to the concept, is ‘optimal foraging theory’ (OFT) (MacArthur and Pianka 1966). According to the theory, animals optimize energy according to the formula: $E/(s+h)$ (Begon et al. 2006) where E is the amount of energy of a prey item, s is the time invested in searching for the food and h is the handling time. In other words, this theory states that the optimal strategy for obtaining food is to capture and consume food containing the most energy while expending the least amount of energy possible in doing so.

Home range size is dependent on a broad scale of factors. A variety of power functions of the body mass has been derived to predict home range area (McNab 1963; Harestad and Bunnell 1979; Gittleman and Harvey 1982; Lindstedt et al. 1986; Swihart et al. 1988). Among carnivores, home range size increases with absolute metabolic needs (Gittleman and Harvey 1982). Short-tailed weasels (*Mustela erminea*) have an average home range of 0.14 km², leopards (*Panthera pardus*) 23.6 km², tigers (*Panthera tigris*) 71.4 km² and lions 240 km² (Gittleman and Harvey 1982). Carnivore home ranges are generally as large as is necessary and as small as possible to satisfy energetic needs (Gittleman and Harvey 1982; MacDonald 1983). Upper limits are determined by energy expenditure during territorial defense (Bertram 1973), while lower limits are governed by food and water availability (Van Orsdol et al. 1985; Viljoen 1993) which in turn is correlated with a combination of soil nutrient status and rainfall (East 1984). Other important factors influencing home range size include factors related to hunting success and opportunity (Bothma and Le Riche 1994), the presence of other predators and opportunities for reproduction (Caro 1994; Turner 2005), habitat qualities (Spong 2002) and reducing variation in their life processes (Ferguson et al. 1999). Social factors as group size and competition also influence home range size (Van Orsdol et al. 1985). Home ranges of different African lion populations were found to vary according to prey availability and,

environmental and landscape characteristics (Eloff 2002; Van Rijssel et al. 2008). Knowledge of carnivore home range size and spatial distribution are therefore fundamental to understand their distribution and abundance, population regulation (Wang and Grimm 2007), habitat selection (Rhodes et al. 2005), community structure (Fagan et al. 2007), and for management and conservation of the population (Woodroffe and Ginsberg 2000).

Animals are territorial only when they have a limiting resource, that is, a critical resource that is in short supply and limits population growth (Brown 1969). Optimality models view territory size as the outcome of economic decisions based on cost and benefits of foraging and defense, while in more crowded populations territory size is the outcome of competition between neighbors or between established residents and potential settlers (Adams 2002). Territory sizes are dynamic and change with regard to environmental conditions and resource availabilities (Hanby et al. 1985; Stander and Albon 1993). Territorial behavior is not a species characteristic. In some species, individuals defend territories in certain parts of the species' range but not in other parts (e.g. black bears *Ursus americanus* of the Great Smoky Mountains National Park, USA; Garshelis and Pelton 1981).

Social organization of felids can be highly variable due to distribution of key resources (McLoughlin et al. 2000). In most felids, solitary existence is maintained, with little overt aggression, mostly by mutual avoidance and scent marking (Hornocker et al. 1983; Sunquist and Sunquist 2002). Exceptions to this have been documented in few species including lions. Lions are the only social felids that live together in a fission-fusion social unit called pride (Schaller 1972). Lion prides live in territories, each one differing in size, scale and characteristic area of use (Schaller 1972). A territory is defined as an area exclusively defended by an animal for its own survival, protecting its own resources and offspring siring (Noble 1939; Pitelka 1959; Adams 2001). Burt (1943) defined that "every kind of mammal may be said to have a home range, stationary or shifting. Only those that protect some part of the home range, by fighting or aggressive gestures, from others of their kind, during some phase of their lives, may be said to have territories". A territory thus may be an animal's entire home range or it may be part of an animal's entire home range (core area for example) over which the animal has exclusive use, or perhaps priority use (Powell 2000). This is especially evident in lion sociality in which a territory is protected from conspecifics (Schaller 1972; Bertram 1973; Mosser and Packer 2009). Prides occupy

territories while nomadic lions wander into several ranges (Schaller 1972; Bertram 1978; Smuts 1982). Territories are delineated mostly by males by roaring, scent marking, head rubbing and continuous patrolling (Schaller 1972; Smuts 1982). This strategy is effective in discouraging rivals from entering the pride range so as to ensure greater reproductive success for the territorial males (Funston et al. 1998). Female prides can occupy the same 'natal' territory for a number of years and live in stable family groups with prides comprising of siblings and other related individuals (Guggisberg 1961; Schaller 1972; Pusey and Packer 1987; McComb et al. 1994). On the other hand, males are not related to females and only have tenure over a certain territory for 2 – 4 years and typically father one cohort per pride (Packer and Pusey 1987). Males are replaced by other males and as a consequence inbreeding is prevented. Males do form coalitions, which are small groups (2 – 4) of related or unrelated individuals, which allow them to occupy a territory for longer and improve their competing abilities with other males (Packer et al. 1990; Funston et al. 2003). Males protect their territories vigorously, and expend a considerable amount of energy in patrolling and maintaining territory boundaries (Schaller 1972).

General territory sizes are a function of resource abundance and availability, and the pride size occupying that specific territory (Schaller 1972; Macdonald 1983; Spong 2002; Hopcraft et al. 2005). Generally prides with a higher number of males occupy larger territories because they require more resources than smaller prides. In Gir, breeding lionesses defend resource based territories while male coalitions maximize coverage of female groups (Jhala et al. 2009). Therefore female range size is primarily dependent on prey density and distribution while the male range size is dependent on the availability of mating opportunities i.e. distribution of prides (Funston et al. 2003). Female prides occupy separate adjacent ranges (Pusey and Packer 1987; Mosser and Packer 2009; Kissui et al. 2010), while males are usually transient members of prides and they are replaced by new males who become residents for 2-4 years before being replaced by yet another coalition (Packer and Pusey 1987).

Males seem to have three distinct phases of range use (Turner 2005). Young males are evicted from their natal prides and disperse into neighboring territories (Hanby and Bygott 1987; Funston et al. 2003). In this first phase, they do not defend any resource. Males or male coalitions then attempt to take over a pride of females (Bertram 1975; Bygott et al.

1979). If successful at the takeover, the males spend most of their time courting and mating with the pride females (Schaller 1972). After the birth of cubs, males spend little time with females and more in patrolling their territory (Lehmann et al. 2008). Some males often become territorial again as adults, away from their natal area, only to become nomadic once more when replaced by other males. In addition, some nomads establish temporary territories in the plains. The land tenure system of males is thus in a continuous state of flux (Schaller 1972).

5.1.2. Lion movement

Most ecological and evolutionary processes involve individual movements, defined by Turchin (1998) as “the process by which individual organisms are displaced in space over time”. Animal movement is the result of the relation between characteristics of an individual, such as the internal state, motion, and navigation capacity, and a broad range of external factors (Nathan et al. 2008). Movement is fundamental to individual and population dynamics, as it is the mechanism allowing individuals to meet their basic requirements. General goals for movement include gaining energy, seeking safety, learning, and reproducing (Nathan et al. 2008). Indeed, movement is the process by which individuals respond to both short-term requirements (e.g. searching for food or for mates, escaping from predator) and long-term requirements (e.g. avoidance of intra-specific competition, inbreeding). Survival and reproduction are therefore linked intimately to movement strategies, which therefore should be driven by natural selection (Fahrig 2007). For lions territorial defense is an important addition to these factors. In mammals energy requirements explain a substantial variation in home range size and movements (Carfagno and Weatherhead 2008). Because movement is strongly related to obtaining food, the OFT is also applicable to movement. To gain the most energy per time unit (E), an animal should limit the movement invested in foraging (s) as much as possible. Travelling distances each day in search for food decreases the amount of energy invested in maintenance, repair and reproduction (Pontzer and Kamilar 2009).

Animal movement is the fundamental process that allows individuals to make choices concerning the exploitation of resources (Stephens and Krebs 1986; Bell 1991) at different spatial scales (e.g. dispersal, foraging) as it relates individuals to their environment. This is therefore a key process, because it influences the fitness of mobile individuals (Schooley and

Wiens 2003). Indeed, in heterogeneous and variable environments, movement enables animals to change environmental conditions according to their requirements. For example, in seasonal environments, when food availability and quality as well as climatic conditions may vary, mobile animals migrate to find better weather or resources. At a small spatial scale, when food resources are patchily distributed over the landscape, animals may move from low-quality patches (e.g. after depletion of the patch) to high-quality patches. Also, the quality of a same habitat (or habitat patch) might be perceived differentially according to animal requirements. Indeed, food resources and shelters (e.g. protection from heat or predators) are often spatially disconnected, which leads animals to make trade-offs between habitat types, moving from one habitat type to another according to their activity and requirements. Animal movement and habitat selection therefore are intimately linked, movement being the key mechanism underlying the habitat selection pattern.

In the Serengeti, on an average, lions spend about two hours a day walking, 40 to 50 minutes are spent eating, and they are inactive for 20 to 21 hours a day (Schaller 1972). Movement is not equally divided over the days; some days are spent without eating, while on others lions are eating for 4 to 5 hours (Schaller 1972). Although movement occurs all day, lion activity peaks are between 17:00 and 08:00 (Schaller 1972; Bertram 1978). Within these nightly hours, movement is mainly related to hunting (Schaller 1972; Eloff 1984). Male movements are mostly for patrolling their territories. Movement ends when the prey is killed, or, if the hunt is unsuccessful, when the temperature rises in the morning.

Because of differences in environmental factors between areas and through time, movement shows spatial and temporal differences. Optimal foraging theory suggests and experimental data confirm that in areas with high density of suitable prey and good hunting conditions, lions move less than in areas with a lower density of suitable prey and poor hunting conditions (Ogutu and Dublin 2002; Hemson 2003). As stated above, under sub-optimal conditions with a low density of suitable prey, lions are likely to switch their diet to livestock, which is easier to catch (Bauer and De Iongh 2005).

5.1.3. Lion activity pattern

In predators, activity is principally associated with the acquisition of food and to a lesser extent, territorial maintenance and reproduction and the key factor determining activity timing is the hunting success (Van Orsdol 2008). Patterns of activity develop in order to

allow an animal to most efficiently exploit its environment while minimizing risk. Activity cycles are thus influenced by a number of environmental and individual factors. These factors include prey abundance and distribution (Daan 1981), seasonal changes (Mech 1970), avoidance of interspecific predation or human related activities (Gese et al. 1989; Gehrt et al. 2009), the animal's physiological adaptations to activity during nocturnal and diurnal time periods (Kavanau and Ramos 1975; Daan 1981), and life-history strategies (e.g., hunting and social organization) (Gittleman 1986). Both the time and the intensity of activity can be temporally or geographically variable within species. For example, the documented activity patterns of wolves (*Canis lupus*) are highly variable between studies (e.g., Mech 1992; Vila et al. 1992). Wolves in Minnesota are exclusively nocturnal in summer but are active both diurnally and nocturnally in winter (Mech 1992). In contrast, wolves in Italy have been shown to be exclusively nocturnal (Ciucci et al. 1997).

Variation in activity patterns has often been attributed to differences in prey preferences and to prey abundance and distribution. The level of exploitation experienced by an animal may also influence activity patterns. Vila et al. (1992) noted an increase in nocturnal behavior of wolves in areas where human pressures were high, and suggested that this nocturnal behavior could be the result of wolves trying to reduce interactions with people. Activity patterns are flexible and vary in time and space, and important factors such as the presence of a superior predator or human activity may result in an adjustment to activity patterns. For example, it is suggested that cheetahs (*Acinonyx jubatus*) may hunt during the day (morning and evening) to avoid nocturnally active sympatric lions (Durant 1998; Sunquist and Sunquist 2002). In Israel, Blanford's fox (*Vulpes cana*) is strictly nocturnal and it is suggested that this is to avoid diurnally active birds of prey (Geffen and Macdonald 1993). Many studies indicate that different species including black bears (*Ursus americanus*), bobcats (*Felis rufus*), coyotes (*Canis latrans*) and leopard (*Panthera pardus*) have modified activity patterns in areas of increased human activity (Tigas et al. 2002; Beckman and Berger 2003; Ngoprasert et al. 2007) and many canids become more nocturnal in areas with high human persecution (Sillero-Zubiri et al. 2004). A coyote population in Colorado that had historically been exposed to human persecution shifted to higher levels of diurnal activity when exploitation ceased (Kitchen et al. 2000). Leopards tend to have different calling patterns in areas with high levels of human activity (Eisenberg and Lockhart

1972; Eisenberg 1981). In India, the leopard population in the Sariska Tiger Reserve showed a delayed activity peak in presence of tigers (Mondal et al. 2012).

5.1.4. 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, I 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, I 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?

5.2. Methodology

5.2.1. Field methods

5.2.1.1. 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 5.1**). 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. I monitored three additional radio-collared male lions (M2, M7 and M10; **Table 5.2**) from December 2005 onwards as a part of this research project but also used for a previous doctoral study on reproductive strategies of male Asiatic lions (Meena 2008) and included GPS fixes obtained from them for the current study. I 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 4 of the current thesis].

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 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.

5.2.1.2. 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, I 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 Vectronics GPS Plus Handheld Terminal Unit) (**Figure 5.1**). 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).

5.2.1.3. Monitoring individually known (non-collared) lions

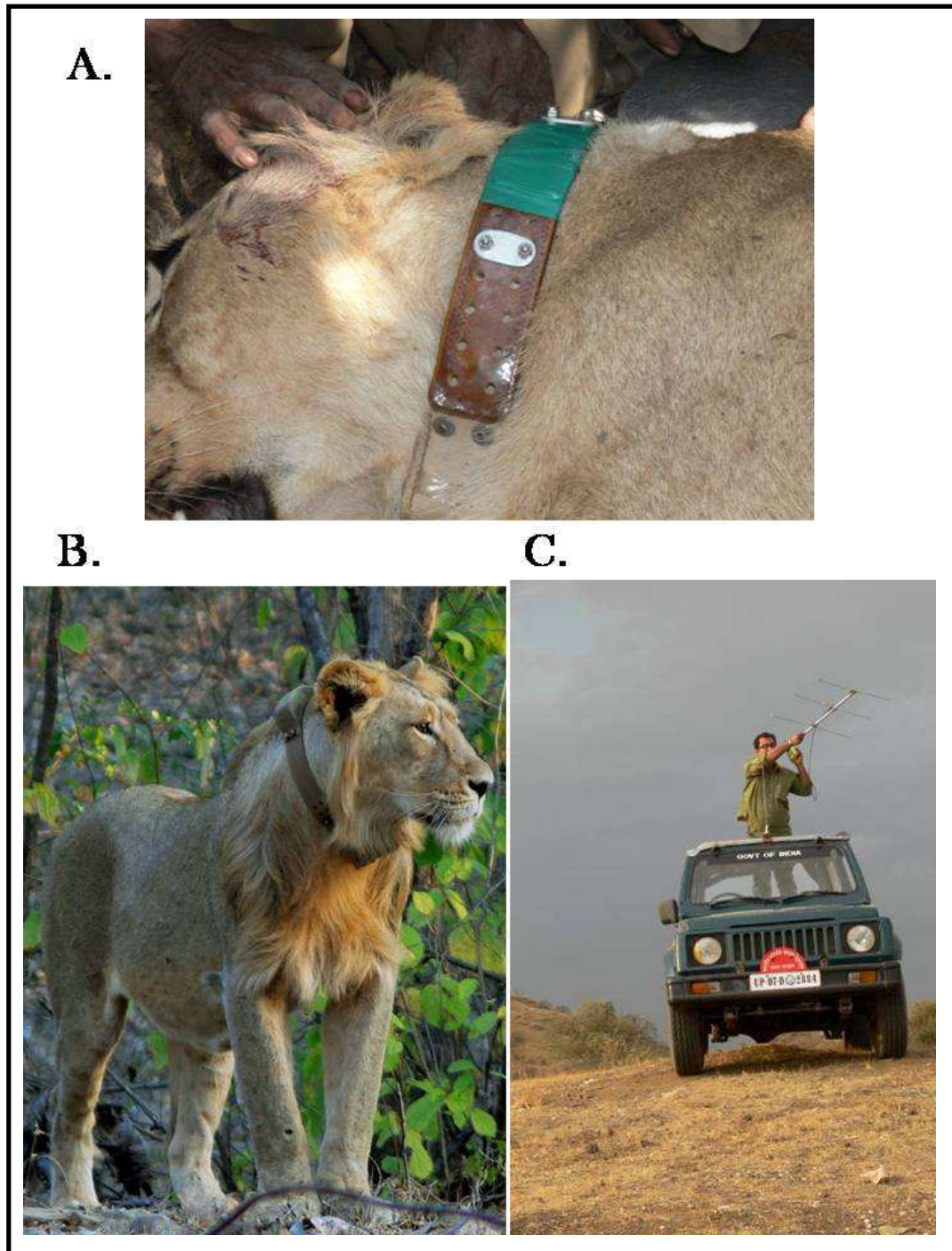
Additionally, I individually identified and monitored 15 lions (5 males and 10 females between approximate age of 2 to 13 years) between 2005 and 2011 across the Gir landscape based on their unique vibrissae patterns and additional body marks (Pennycuik and Rudnai 1970; Jhala et al. 1999) and by maintaining 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* sections 5.2.2.2 and 5.3.1 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 I 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.

5.2.1.4. Continuous monitoring

I 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 (Altman 1974) where specific animals were observed during 24- hour periods to record various ‘states’ and ‘events’. I defined a state (like moving, resting, sleeping, feeding, patrolling etc.) as any activity > 2 minute duration and measured them in time duration. I 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. I 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. I 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 5.1: A. Lion radio collaring, B. A radio-collared male lion after revival from the anesthesia, C. Radio-tracking lions from a vehicle.



5.2.2. Data analysis

5.2.2.1. Initial data screening and classification

I 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. I 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. I, 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].

5.2.2.2. 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 (Millsbaugh 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, I 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; Kernohan et al. 2001). For 100% MCP sample size estimation, I randomized the locations and added 10 locations at every increment (Harris et al. 1990). I 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. For this locations were taken whenever the study animals were encountered (maintaining time allotted between locations at 2-3 hours and 20 minutes during continuous monitoring).

5.2.2.3. Home range estimators

Quantifying an animal's home range is an act of using data about the animal's use of space to deduce the animal's cognitive map of its home (Peters 1978). Whilst advances in improving definitions of home range in recent years have been few (e.g. Kernohan et al. 2001), advances in the methods used to estimate this elusive concept have been considerable (reviews in Macdonald et al. 1980; Harris et al. 1990; Powell 2000; Kenward et al. 2001; Kernohan et al. 2001; Walter et al. 2011). Increases in available computing power have allowed ecologists to use increasingly sophisticated methods to estimate home-range use (for reviews see: Worton 1987; Harris et al. 1990; White and Garrot 1990; Powell 2000; Hemson

et al. 2005; Millspaugh et al. 2006; Laver and Kelly 2008; Horne et al. 2008) with no consensus for any single technique.

I 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, I 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, I 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) and was first adapted for animal home range analysis by Bruce Worton (Worton 1989) from a technique devised to estimate complex distributions from small samples (Silverman 1986). 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. On an x - y plane representing a study area, cover each location estimate for an animal with a three-dimensional “hill”, the kernel, whose volume is 1 and whose shape and width can be manipulated. The width of the kernel, called the band width (also called window width or h), and the kernel’s shape might hypothetically be chosen using location error, the radius of an animal’s perception, and other pertinent information. 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 I 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).

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). However, further investigation has provided only limited support for either of these methods. One study (Seaman and Powell 1996) found that LSCV smoothing provided the most accurate estimates, except with small sample sizes ($N < 50$ fixes) where it performed poorly. By contrast, Blundell et al. (2001) found that h_{ref} performed better than LSCV at estimating the 95% home ranges of river otters *Lontra Canadensis*. Least-squares cross-validation, however, tends to be especially sensitive to sample size. 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; I 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 (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.

I 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 I 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.

5.2.2.4. 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). Therefore, I used area/probability curves over specific core-area definitions because the method is objective and based on the spatial distribution of telemetry locations (Powell 2000). The null expectation was uniform use of all regions within a home range, represented as a linear relationship between the percentage of total home-range area and the probability isopleths. Area/probability curves are typically concave, indicating clustered use of space (Bingham and Noon 1997; Seaman and Powell 1990; Burdett et al. 2007). I used fixed kernel home ranges with isopleths at 5% increments from 5% to 100% (Powell 2000). I created area/probability curves by plotting the home range area within each isopleths as a

function of the isopleths. The point at which inflection of line (slope) changed was identified as the core area (Powell 2000).

5.2.2.5. Lion land tenure system

I monitored seven adult males and three sub-adult males (including non-collared lions) for studying territorial shift and dispersal. I defined a territorial shift when the male was never located in the previous (or natal for sub-adults) area. I 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.

5.2.2.6. 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, I 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).

5.2.2.7. 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. I 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.

5.2.2.8. Lion activity pattern

I used 5,880 hours of day and night continuous monitoring (30 sessions ranging from 120 hours to 360 hours) data on 13 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 5.1**) 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. I 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; explained earlier in section 5.2.2.1). I also 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.

Table 5.1: 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
States	
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;

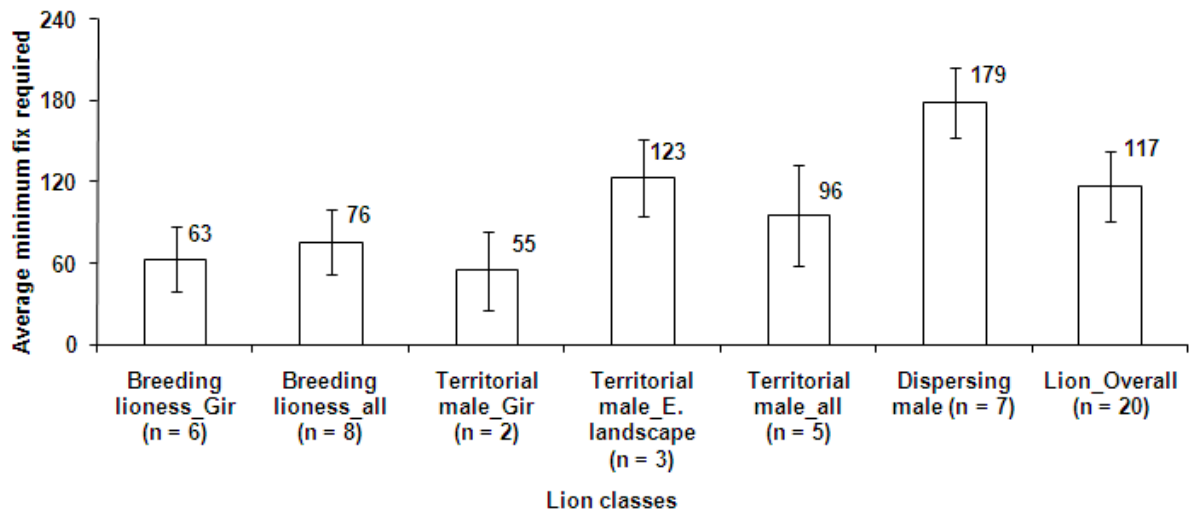
	either lying, sitting or moving.
Mating	Includes sniffing vulva, mounting, courtship and copulation.
Events	
Roaring	A vocalization with slightly raised muzzles and relaxed eyes and ears and includes woofing, grunting, soft and loud roaring.
Spraying	Stopping at intervals while walking by vegetation 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.

5.3. Results

5.3.1. 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 5.2**) 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 5.2: 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.



5.3.2. Effect of autocorrelations

I 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 km² (**Table 5.2**). 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. I 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 km² 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 my continuous monitoring dataset, I 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).

5.3.3. 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 5.2**). Since non-collared lion ranges were likely underestimated, I 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) km²] with that of radio-collared territorial male (n = 1; 95% FK home range: 95 km²) 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'. I 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 km²) than breeding females (average 40 km²; one tailed $t = 3.66$, $df = 12$, $p = 0.006$) while dispersing males had 10 times larger range (average 401 km²) than breeding females (one tailed $t = 5.71$, $df = 11$, $p < 0.001$; **Figure 5.3**). In the eastern landscape the minimum home range size (95% FK) of territorial males was 333 (SE 40) km² and breeding females had range sizes (average 132 km²) about 8 times smaller than territorial males (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) km²] was almost 3.5 times smaller than the average single night range sizes [36.2 (SE 12.4) km²] ($t = 2.36$, $df = 13$, $p = 0.03$; **Table 5.3**). Territorial males had larger night range sizes compared to day range sizes (**Table 5.3**) while breeding females and dispersing males had similar day and night ranges.

Gir lions had similar dry season [325.6 (SE 110.8) km²] and wet season [255.3 (SE 76.6) km²] home ranges ($t = 0.97$, $df = 12$, $p = 0.34$; **Table 5.4**). 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 5.4**). 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.

Table 5.2: Estimated annual home ranges (km²) 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	Non-collared, individually identified	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

The average single day home range (95% FK) size [10.4 (SE 3.2) km²] was almost 3.5 times smaller than the average single night range sizes [36.2 (SE 12.4) km²] ($t = 2.36$, $df = 13$, $p = 0.03$; **Table 5.3**). Territorial males had larger night range sizes compared to day range sizes (**Table 5.3**) while breeding females and dispersing males had similar day and night ranges.

Gir lions had similar dry season [325.6 (SE 110.8) km²] and wet season [255.3 (SE 76.6) km²] home ranges ($t = 0.97$, $df = 12$, $p = 0.34$; **Table 5.4**). 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 5.4**). 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.

Table 5.3: 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.

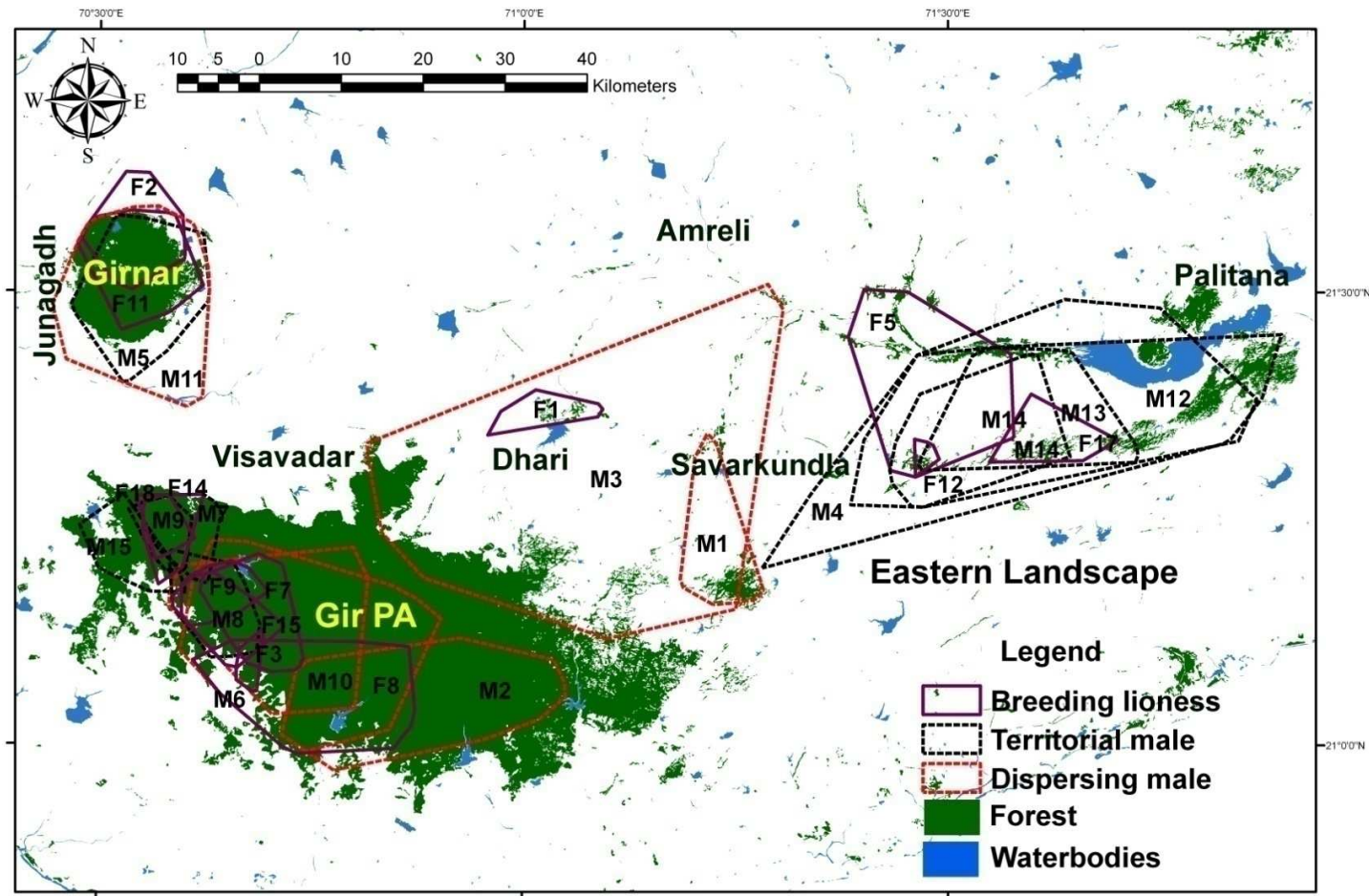
Lion demography class	Diurnal home range (km ²)		n (diurnal)	Nocturnal home range (km ²)		n (nocturnal)	Significance (* = significant)
	95 FK	85 FK		95 FK	85 FK		
Breeding lioness	9 (5)	6 (3)	8 lionesses, 79 days	22 (12)	17 (10)	8 lionesses, 70 nights	t = 1.93, df = 7, p = 0.09
Territorial males	17 (2)	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 5.4: Seasonal home range sizes (km²) of Asiatic lions in Gir landscape, Gujarat, India. Lion IDs are same as in Table 5.2. 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	--
Average	Overall	368 (135)	326 (111)	244 (80)	267 (107)	255 (78)	216 (70)	t = 0.97, df = 12, p = 0.34
Average	Gir PA	133 (94)	97 (58)	85 (52)	82 (47)	107 (62)	95 (55)	t = 0.82, df = 5, p = 0.45
Average	Girnar	192 (33)	194 (22)	128 (13)	61 (21)	111 (36)	74 (25)	t = 3.51, df = 2, p = 0.07
Average	Eastern landscape	852 (315)	767 (236)	568 (158)	700 (228)	586 (117)	504 (124)	t = 0.74, df = 3, p = 0.51
Average	Male lion	689 (234)	580 (194)	431 (137)	519 (187)	452 (118)	382 (114)	t = 0.81, df = 5, p = 0.45
Average	Breeding lioness	92 (29)	107 (39)	83 (32)	52 (20)	87 (41)	73 (39)	t = 0.79, df = 6, p = 0.45

*Based on 95% FK kernel seasonal range sizes

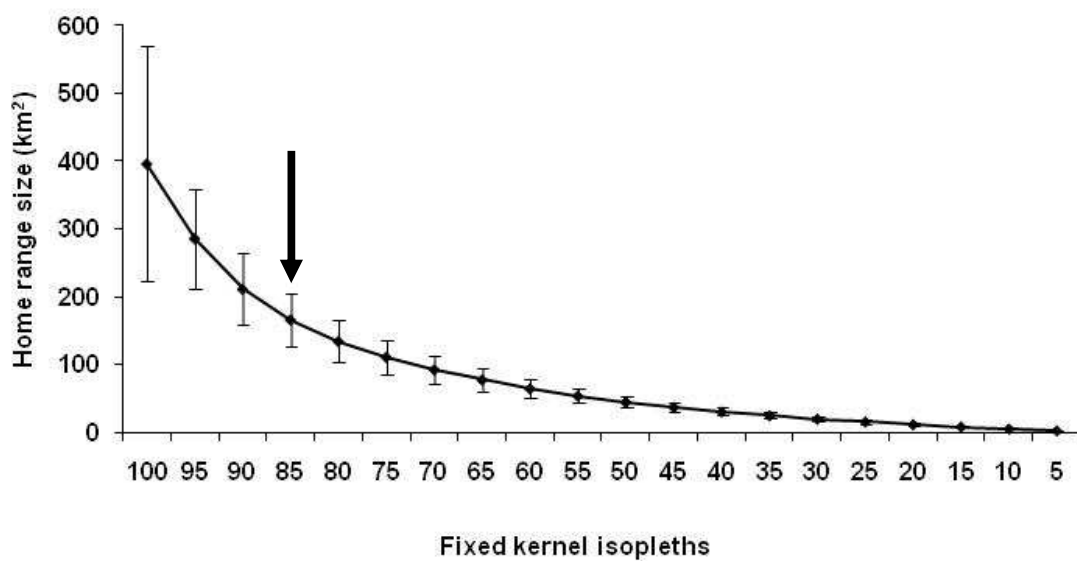
Figure 5.3: 95% MCP home ranges (km²) of Asiatic lions (n = 28) across the agro-pastoral Gir landscape, Gujarat, India.



5.3.4. Core area estimation

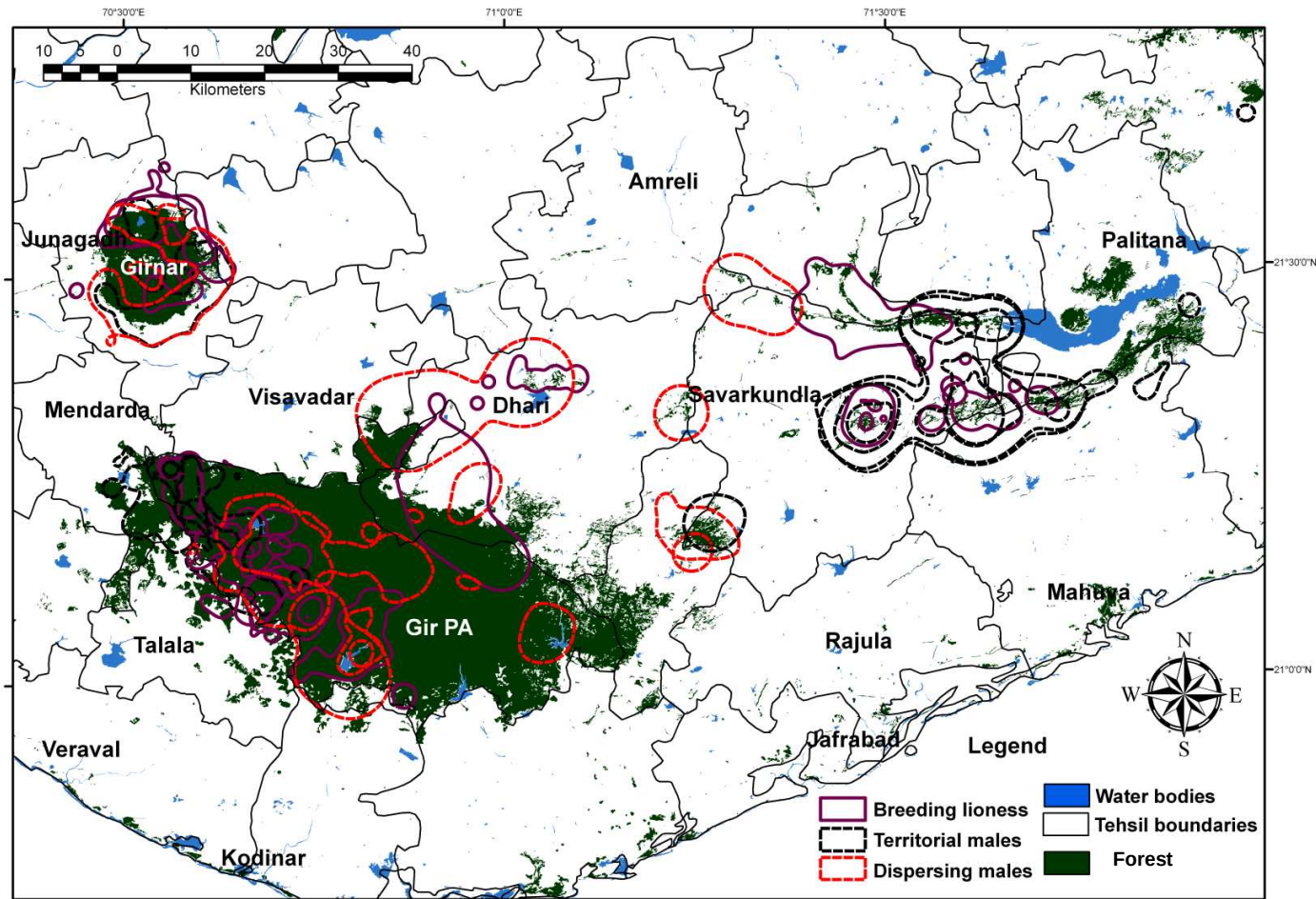
The point of inflexion in the home range size vs. Fixed Kernel isopleths graph suggests that at 85% FK the home range reduction was less in comparison to the changes in the isopleths and beyond it the increase was rapid (**Figure 5.4**). Hence 85% fixed kernel was chosen to estimate lion core areas.

Figure 5.4: 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) km² (**Figure 5.5, Table 5.2**). 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)] km² was smaller in comparison to that of the eastern landscape [334 (SE 110)] km² (one tailed $t = 2.49$, $df = 7$, $p = 0.04$). Average core area of breeding females in the eastern landscape [88 (SE 45)] km² was found to be larger than average core area of breeding females within the protected areas [60 (SE 28)] km² (one tailed $t = 0.79$, $df = 9$, $p = 0.44$).

Figure 5.5: Core areas (km²) 85% fixed kernels of Asiatic lions in the Gir landscape, Gujarat, India.



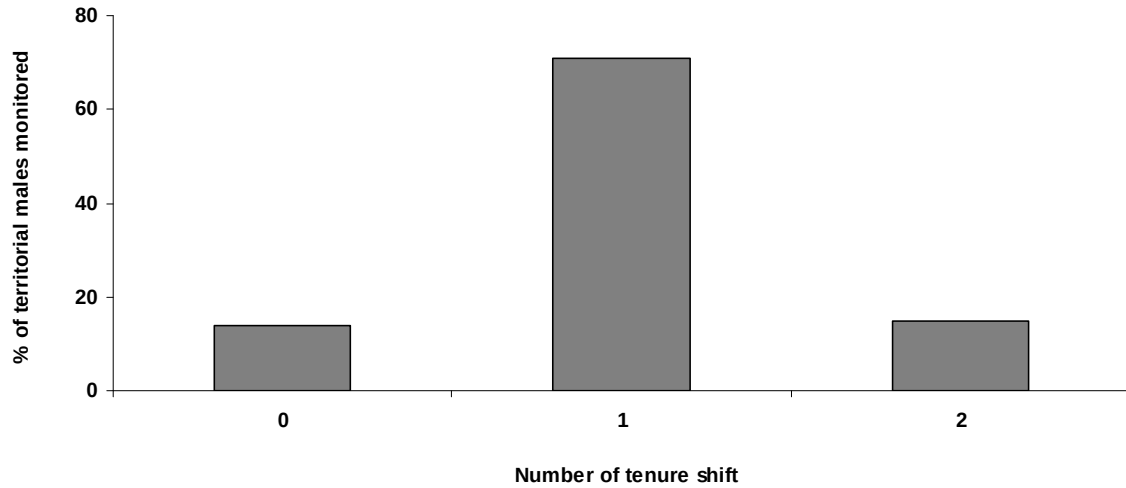
Average diurnal core area of lions [7 (SE 2) km²] was lower than average nocturnal core [26 (SE 9) km²] ($t = 2.4$, $df = 14$, $p = 0.03$) [**Table 5.3**]. There was no effect of time on core area size for breeding females, territorial males and dispersing males (diurnal core: $F = 0.60$, $df = 14$, $p = 0.56$; 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) km²] and nocturnal [6.9 (95% CI 3.1 – 10.7) km²] core areas than lionesses of the eastern landscape [$n = 1$, diurnal 30 km² and nocturnal 89 km²]. Dispersing males in the eastern landscape had smaller diurnal cores in comparison to nocturnal cores ($t = 23$, $df = 2$, $p = 0.02$; **Table 5.3**).

I did not find any seasonal difference in lions' average core area ($t = 0.50$, $df = 13$, $p = 0.60$; **Table 5.4**). 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.

5.3.5. 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 5.6**). 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 5.5**). 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 5.6: Distribution of observed tenure shift in territorial male Asiatic lions (n = 7) during the study period (January 2006 – January 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 5.6**). Average age of territory acquisition was estimated to be 4.3 (SE 0.16) years.

Table 5.5: 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 5.6: Dispersal age and dispersal distance of sub-adult male Asiatic lions in the Gir landscape, India.

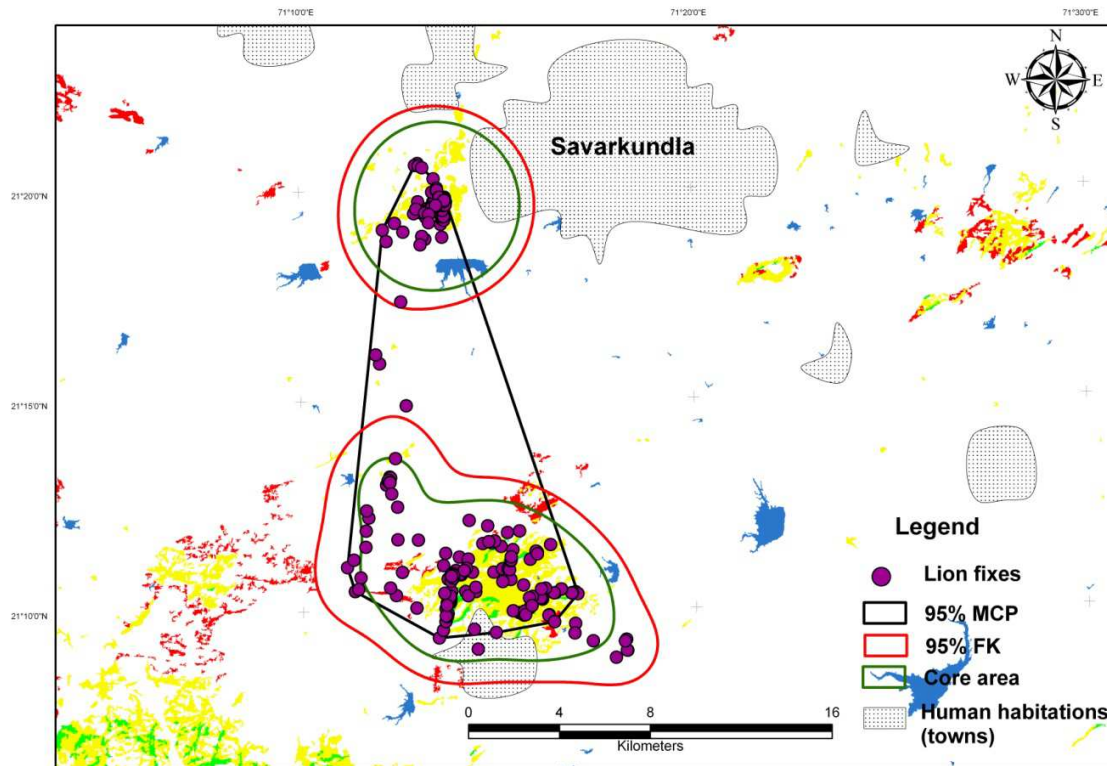
Male ID	Part of landscape	Age (year) at dispersal	Dispersal distance (km)	Age (year) of 1 st reproduction
M5	Girnar	3.7	9.9	4
M6	Gir PA	4	25.7	4.5
M10	Gir PA	4.2	12.3	4.5

Herein, I 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

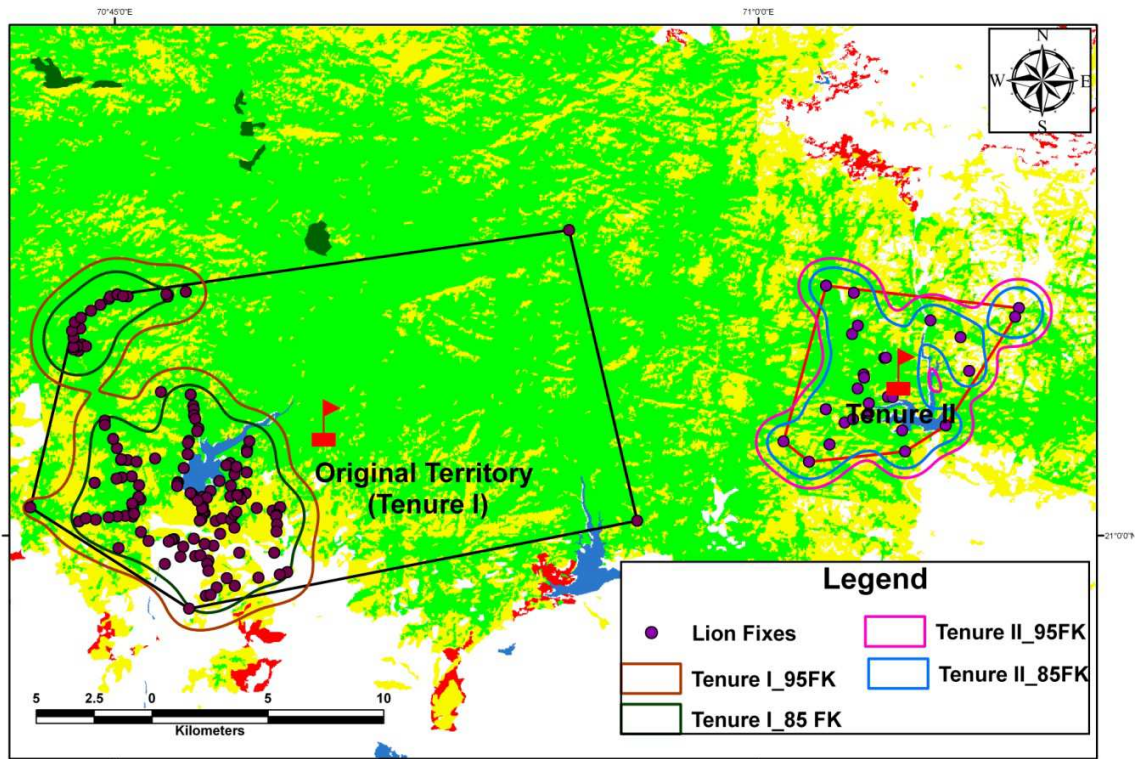
M1: This was a young adult male about 5 years old in the eastern landscape. The male was fitted with a satellite collar with IRIDIUM uplink on 7th January 2010 in the Ambardi Reserve forest, Dhari. The male mostly ranged in the Ambardi Reserve Forest, Mitiyala Wildlife Sanctuary and *Prosopis* dominated agro-pastoral areas and mango orchards of Dhari, Chalala, Khambha, and Savarkundla (**Figure 5.7**). The male was part of a three male coalition. The range size (95%FK) of the male was estimated to be 374 km² (**Table 5.2**) 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 23rd March, 2010.

Figure 5.7: Ranging pattern of radio-collared male M1. Extent of major human habitations demarcated by using night light satellite data.



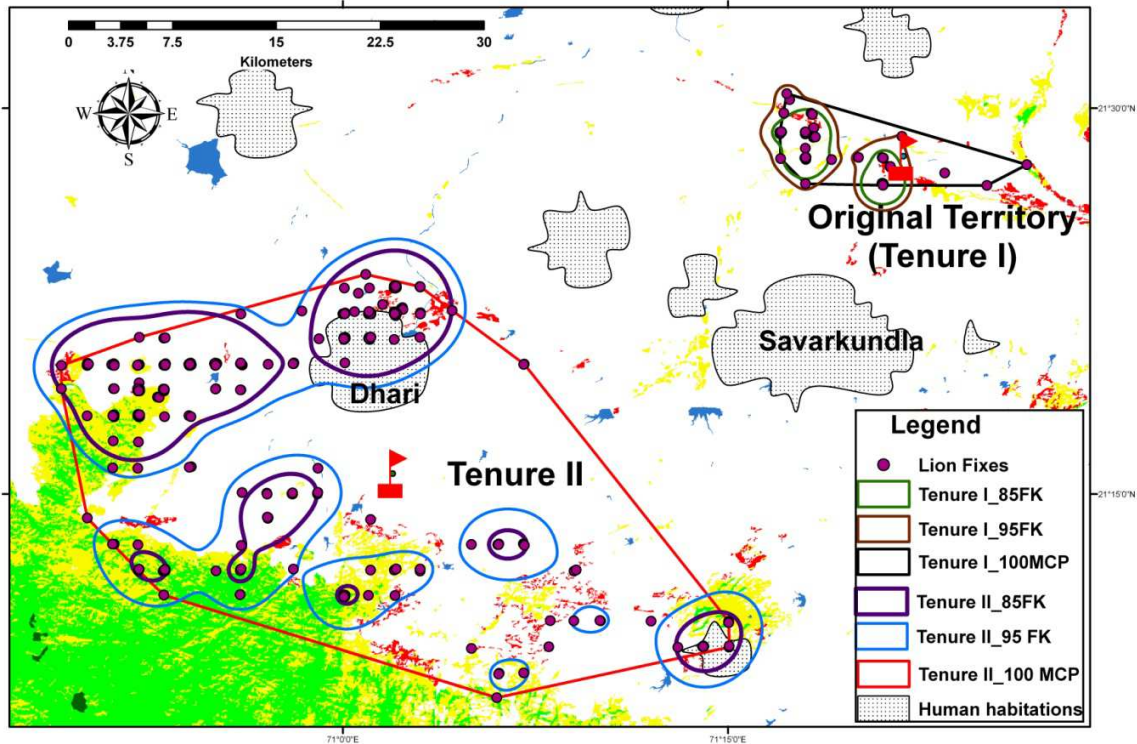
M2: M2 male was a part of a two male (prime adult, approximate age 7 years) coalitions radio-collared (VHF) in the central part of the Gir PA in December 2005. The male coalition ranged mostly in the Gir National Park areas of Kankai, Jamvala, Bantha, Banej, Janvadla and Chhodavadi and occasionally ranged 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 5.8**). 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 5.5**).

Figure 5.8: 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 27th March 2008 in the outskirts of village Chandgad, Amreli. The male was long ranging (**Table 5.2, Figure 5.9**) 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 Visavadar (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 5.5**). 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 5.9: 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 24th 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 I 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 5.2, Figure 5.10). 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 5.11). I lost contact with M12 in February 2011. However, M14 still holds his tenure alone in the Nani Vadal area.

Figure 5.10: Ranging of coalition males M4, M12 and M14 across the human-dominated eastern landscape. Human habitations demarcated by using night light satellite data.

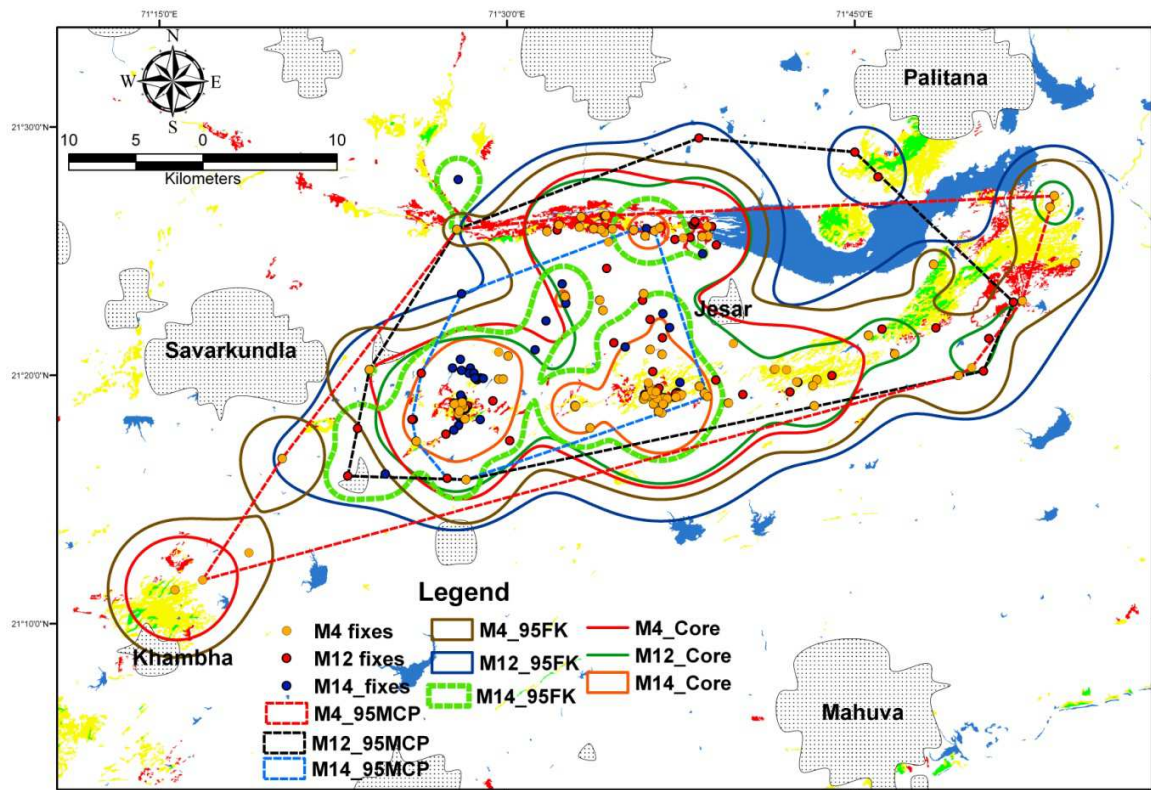
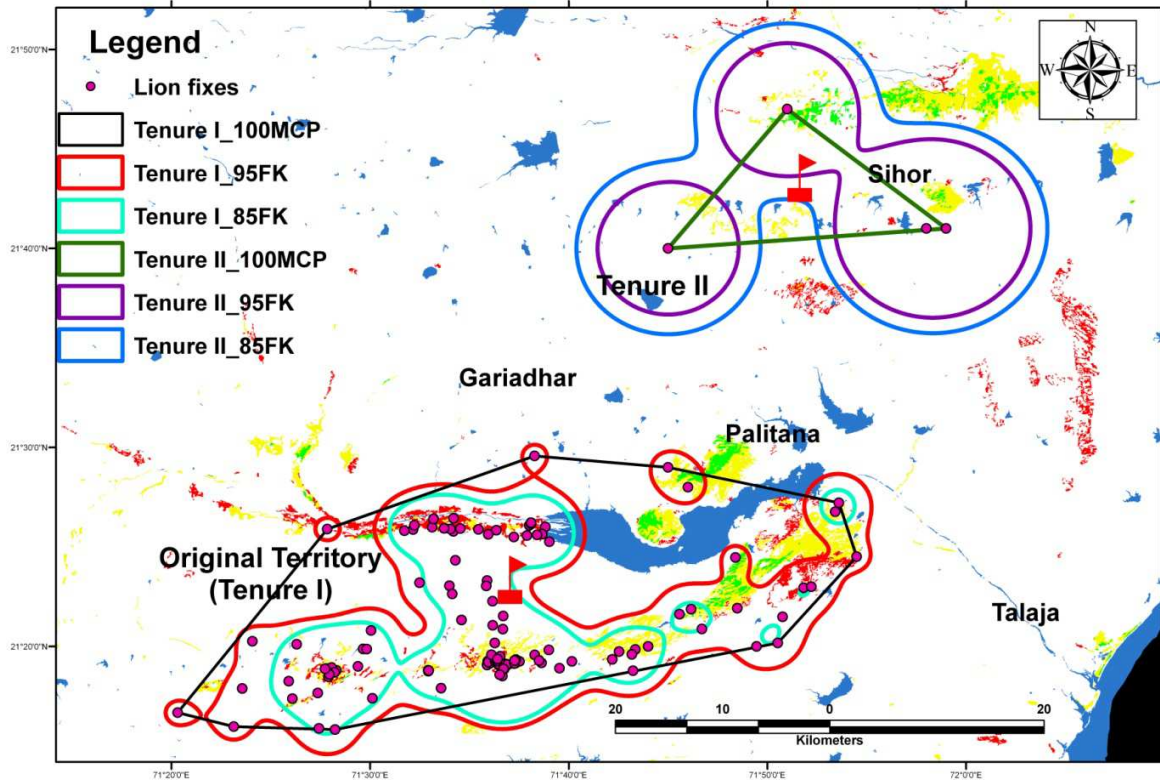
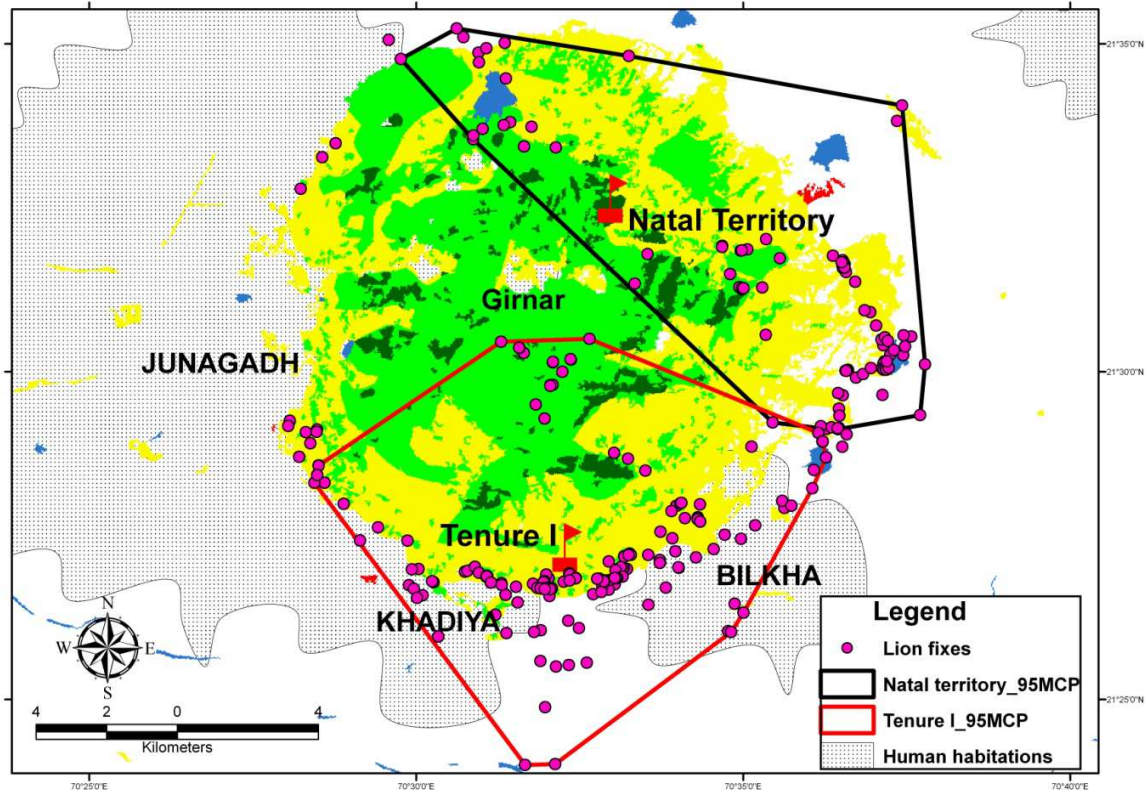


Figure 5.11: Tenure shift of prime adult male M12 in the eastern landscape. Tenure centroids shown by flags.



M5: M5 was a sub adult male (approximately 3.5 years old) fitted with GPS/VHF collar in the Girnar Wildlife Sanctuary on 3rd 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 5.12**). The dispersal distance was estimated to be 10 km (**Table 5.6**). The male often ventured into the revenue areas of Junagadh, Visavdar, Bhesan and Mendarda talukas.

Figure 5.12: Tenure shift of young adult male M5 in Girnar. Tenure centroids shown by flags.



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 12th 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 15th 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 19th June, 2010 (**Figure 5.13**). M6 and his coalition partners dispersed about 26 km from their natal territory and established new territory in central and

eastern Gir (**Figure 5.14**). The collar stopped working in August 2010. However occasional monitoring of the male was continued until January 2012.

Figure 5.13: Range use and dispersal of M6 within the Gir PA, India.

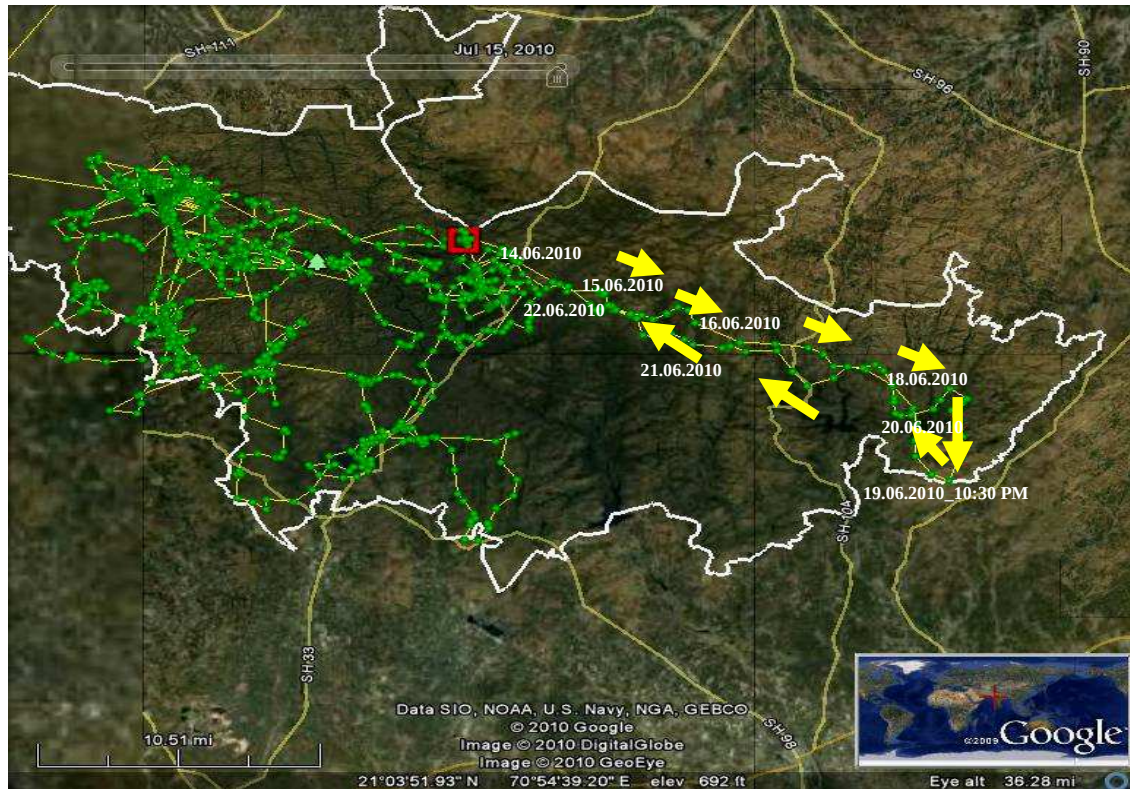
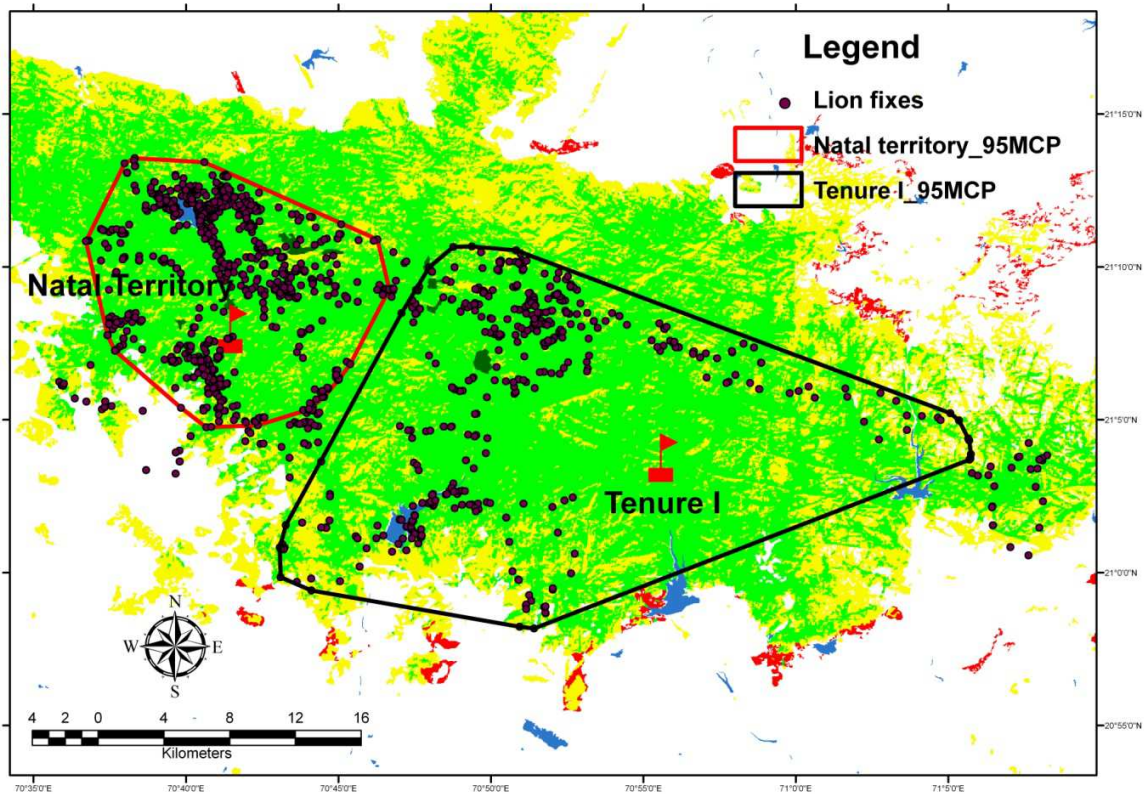
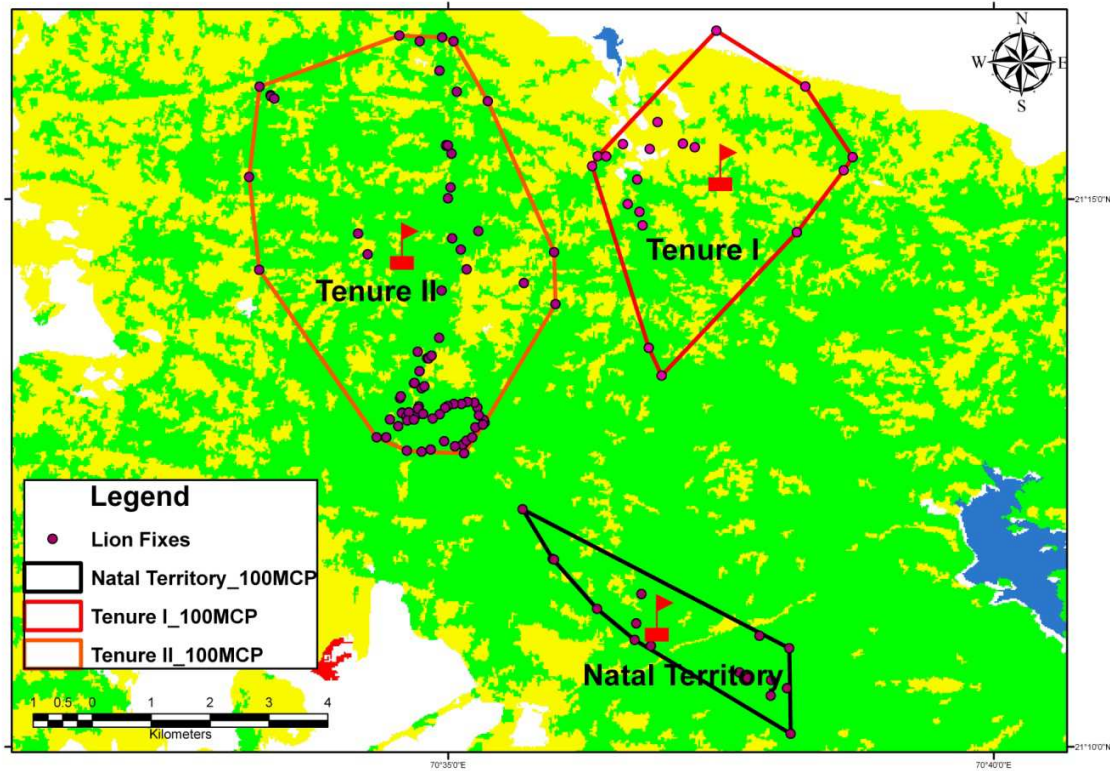


Figure 5.14: Dispersal of sub-adult male M6 in Gir PA. Tenure centroids shown by flags.



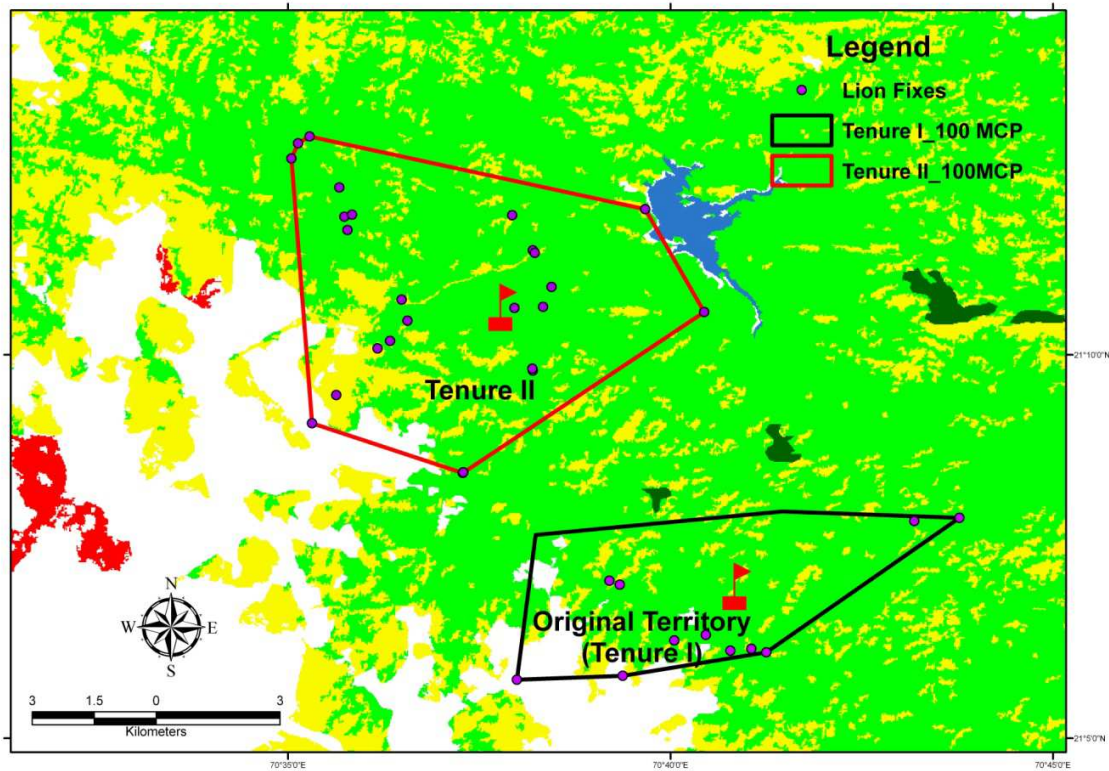
M7: M7 and his coalition partner had a natal territory near Kamleshwar dam of the western part of the Gir sanctuary. The male was fitted with a VHF radio in January 2006. I monitored the male until recently when the male died because of old age in June 2012. Immediately after the collaring the male shifted 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 5.15**). The coalition held this territory continuously for a period of more than five years (**Table 5.5**).

Figure 5.15: Tenure shift of prime adult male M7 in Gir PA. Tenure centroids shown by flags.



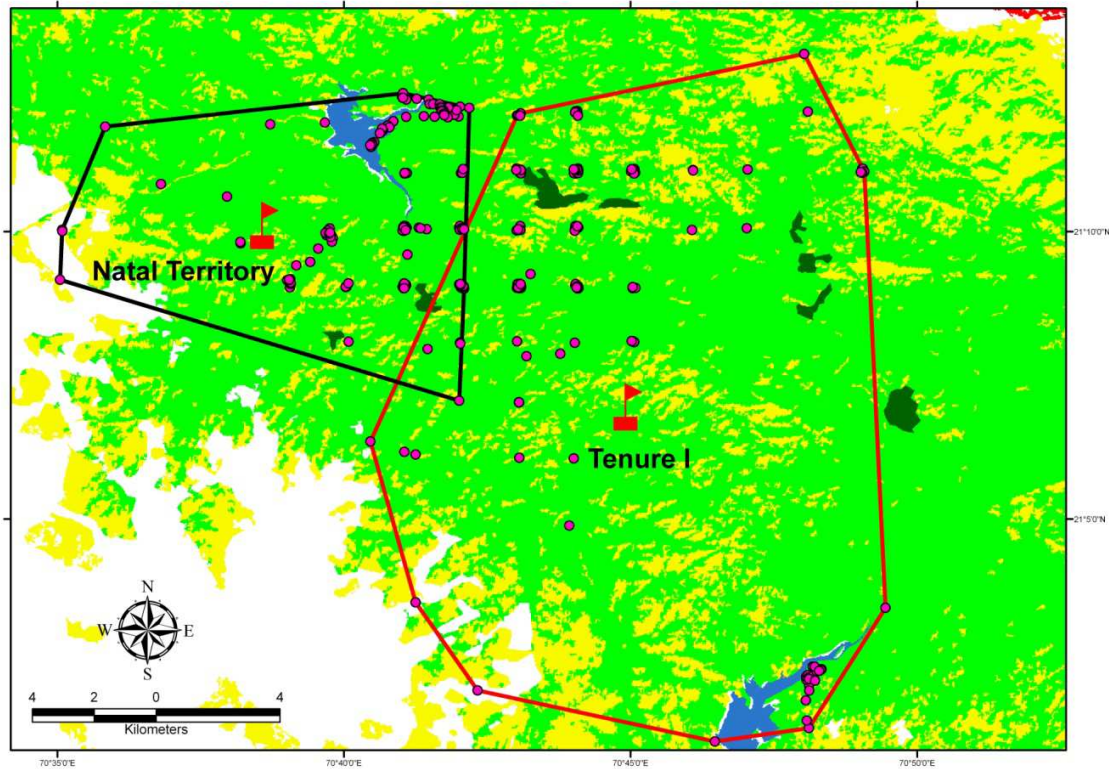
M8: I have been monitoring this non-collared prime adult male (about 6 years old) since January 2006 on the basis of vibrissae pattern. The male had a coalition partner which died in 2005. The male had an earlier territory (Tenure I) in the south-western part of the Gir PA (Sirwan, Kapuria, Khokhra). In December 2007 the male had a territorial strife and shifted his territory 8 km west (near Sasan, Kamleshwar and Amla hill parts; **Figure 5.16**) and still holds the tenure.

Figure 5.16: Tenure shift of prime adult male M8 in Gir PA. Tenure centroids shown by flags.



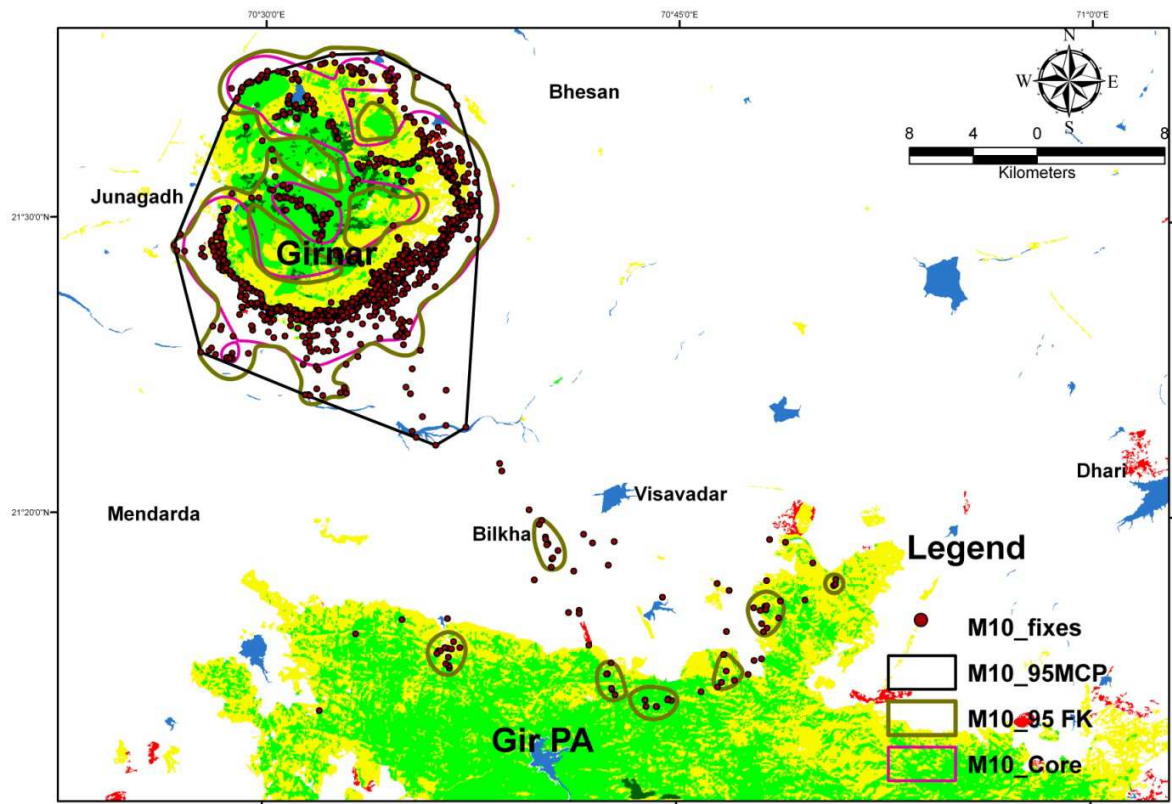
M10: M10 and his coalition partners were sub-adult males (about 3 year age) having a natal territory in the Gir National Park (Patararia, Kankai, Karamdadi, Vadvangra areas). The males were with their mother (prime adult lioness) and one of the males was collared in December 2005 as a part of the previous 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 5.17**).

Figure 5.17: Dispersal of sub-adult male M10 in Gir PA. Tenure centroids shown by flags.



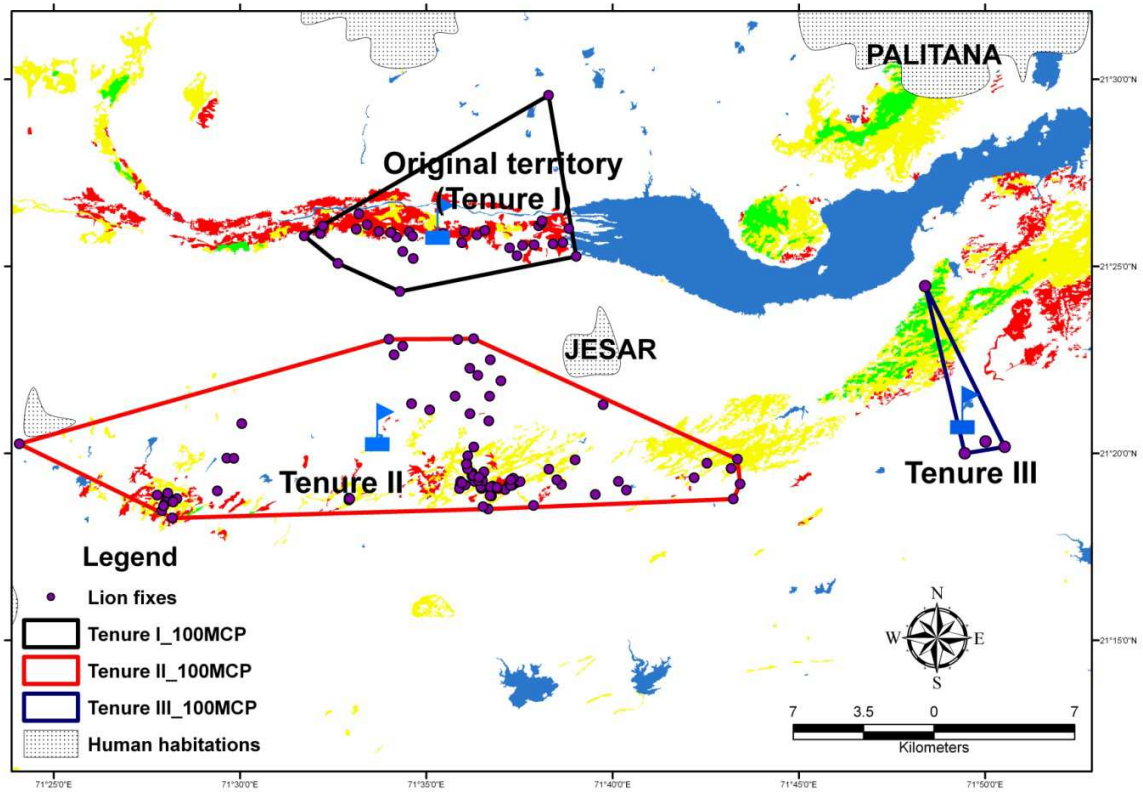
M11: This male was a sub-adult male (about 4 years old) fitted with a GPS/VHF collar in January 2010 near Ramnath temple in Girnar. This male provided an important insight into lion movements of between the Gir PA and the Girnar Wildlife Sanctuary (**Figure 5.18**). The male ranged Girnar and agro-pastoral 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 5.18: 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 I 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 5.5; Figure 5.19**). 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 5.5**).

Figure 5.19: 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.



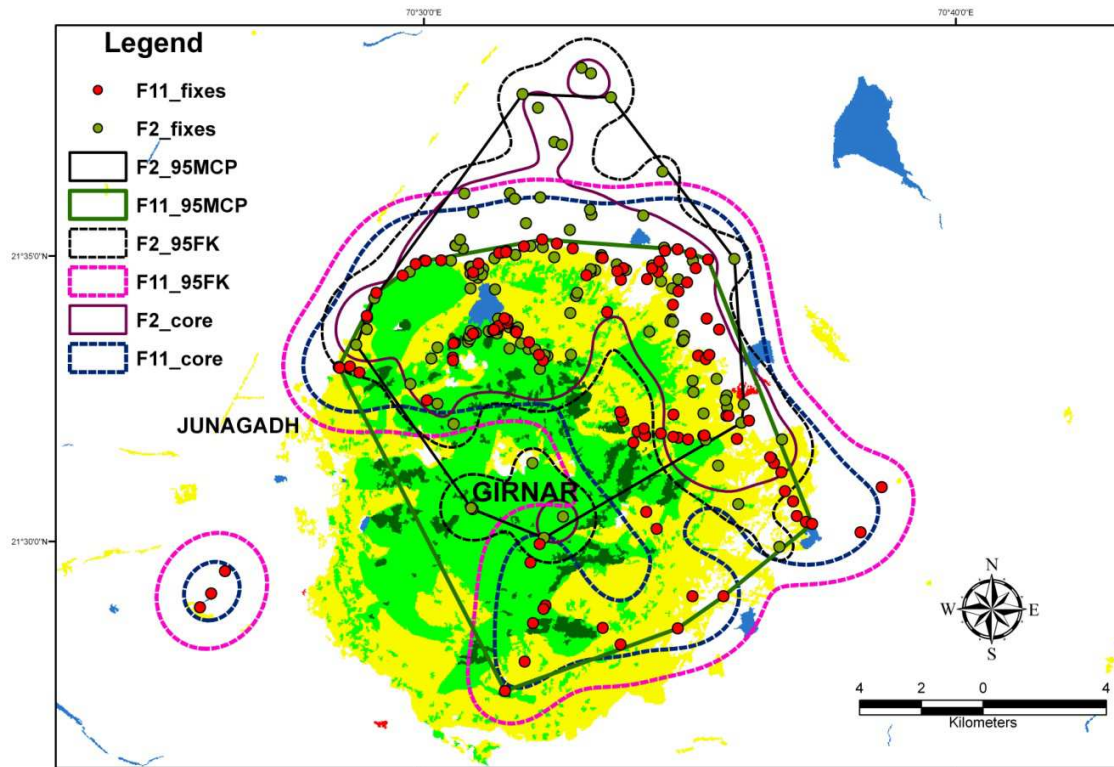
Female ranging

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 5.20**). During my study period 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 5.20**). She stayed mostly with her natal group, littered twice successfully raising two cubs during my study.

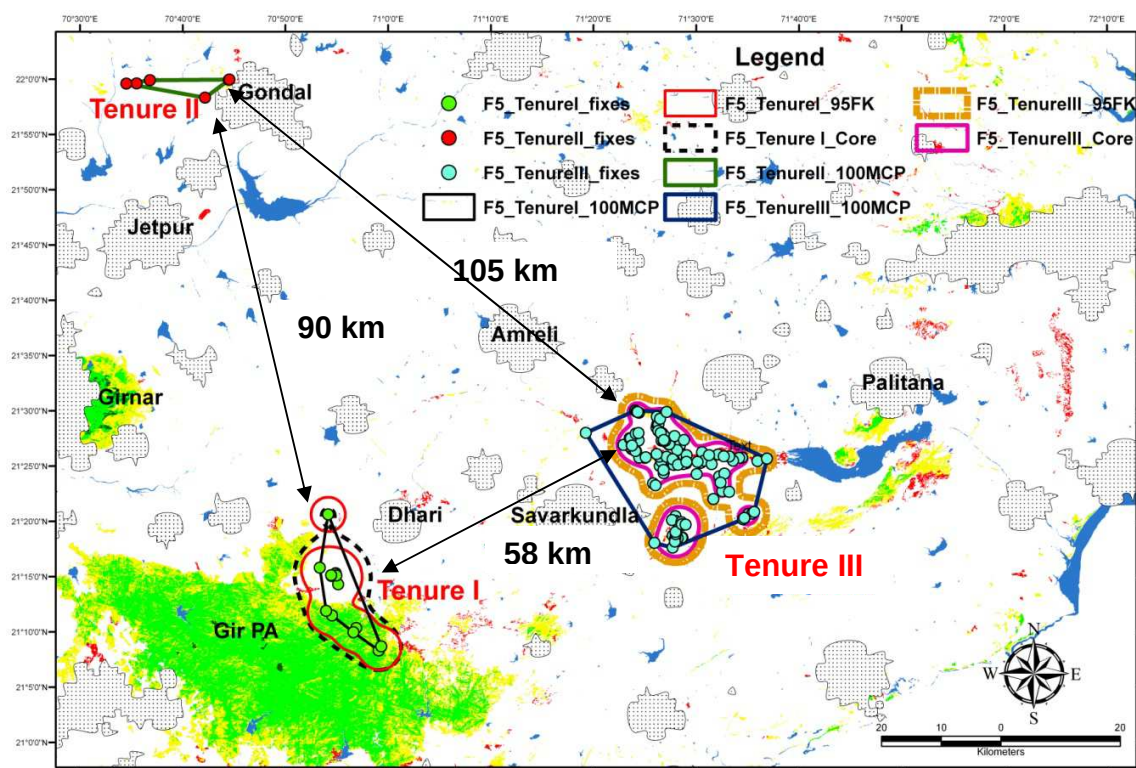
Figure 5.20: Ranging patterns of lionesses F2 and F11 in Girnar Wildlife Sanctuary.



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 5.21**). 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 km²). 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 my study period 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 5.21: Ranging pattern and dispersal of prime adult female F5. Human habitations demarcated by night light satellite data.



5.3.6 Lion territoriality

I 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

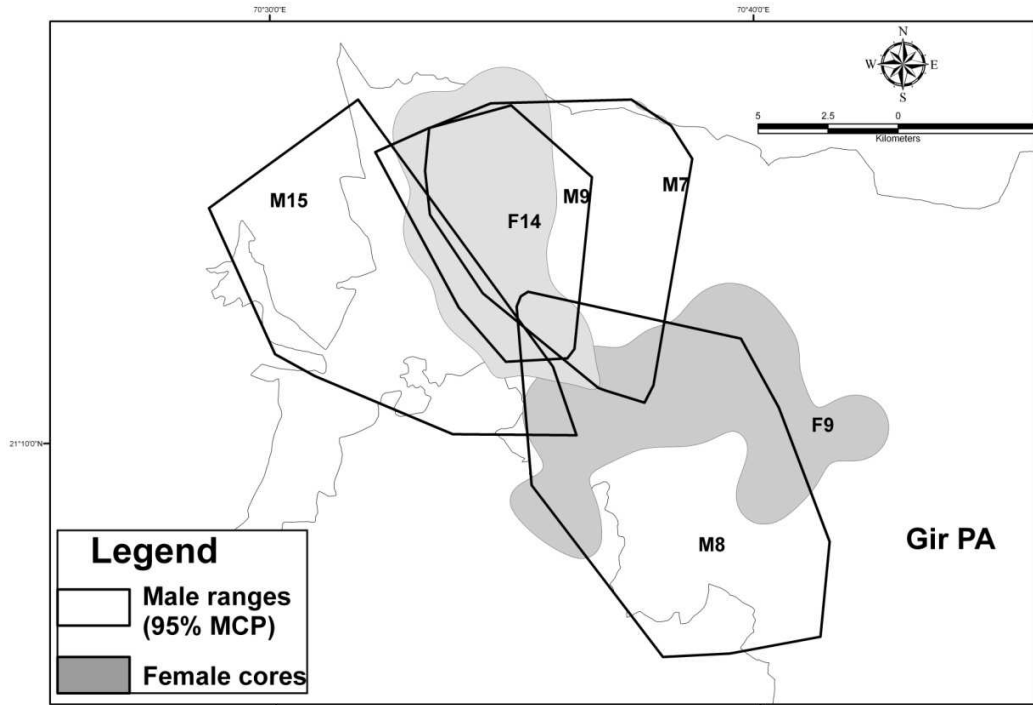
pride females [61 (SE 18) %] was much higher than that with neighboring females [3.5 (SE 0.05) %] ($t = 3.32$, $df = 3$, $p = 0.04$; **Table 5.7**). Coalition males had a higher overlap of range ($t = 5.98$, $df = 14$, $p < 0.001$) as well as of core area ($t = 6.19$, $df = 18$, $p < 0.001$) than neighboring males (**Table 5.7**). 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 5.22**).

Table 5.7: 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.

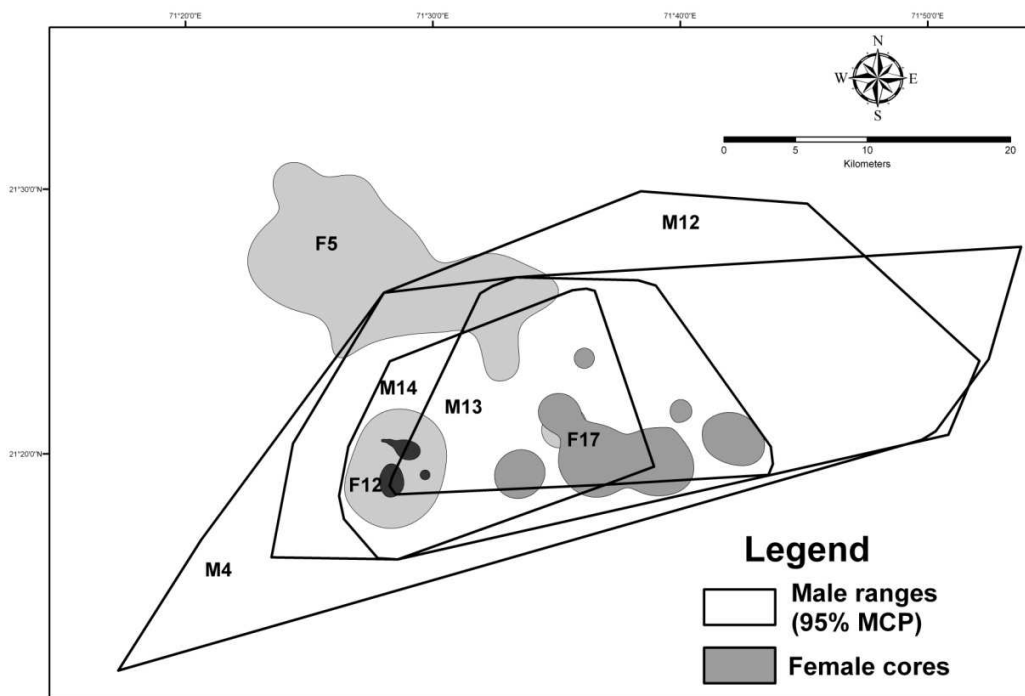
Lion categories	% overlap	
	95% MCP	Core area
Females (same pride)	51 (18)	61 (18)
Females (neighboring)	35 (16)	3 (0.05)
Coalition males	74 (5)	73 (6)
Neighboring males	20 (7)	21 (6)
Male-female (same pride)	63 (3)	56 (3)
Male-female (neighboring)	17 (6)	20 (3)

Figure 5.22: Male range and female core area (85% FK) overlap in i) Gir PA and ii) eastern landscape.

i)



ii)



5.3.7. 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 5.23**). Dispersing sub-adult male M6 moved from the western part to the eastern part of the Gir PA (**Figure 5.24**).

Table 5.8: 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
Overall lion	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)
Male Overall	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)
Female Overall	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)
Gir Males	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)
Girnar males	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)
Eastern landscape males	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)
Gir lioness	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)
Girnar lioness	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 5.23: Movement of M11 between Gir PA and Girnar Wildlife Sanctuary.

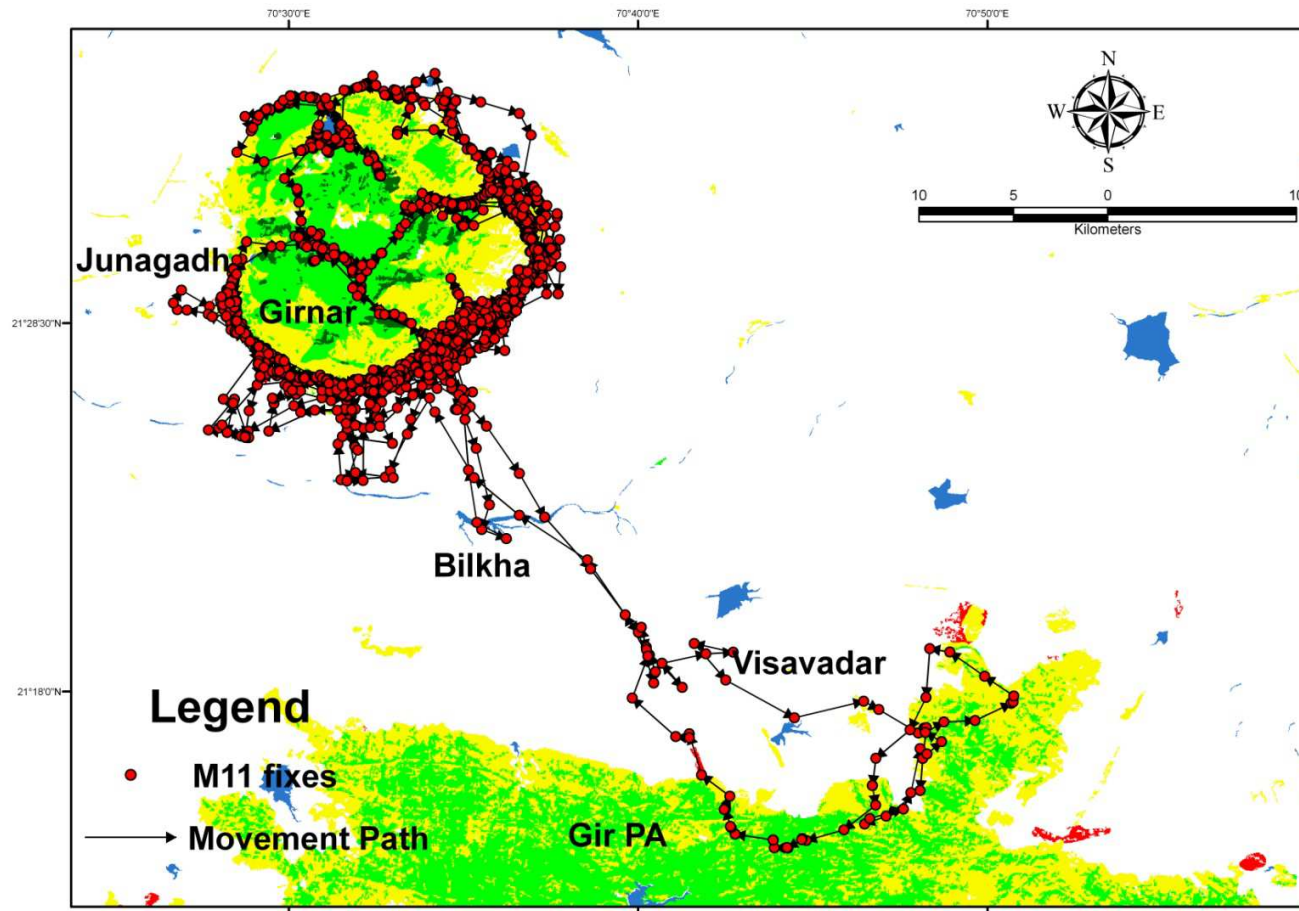
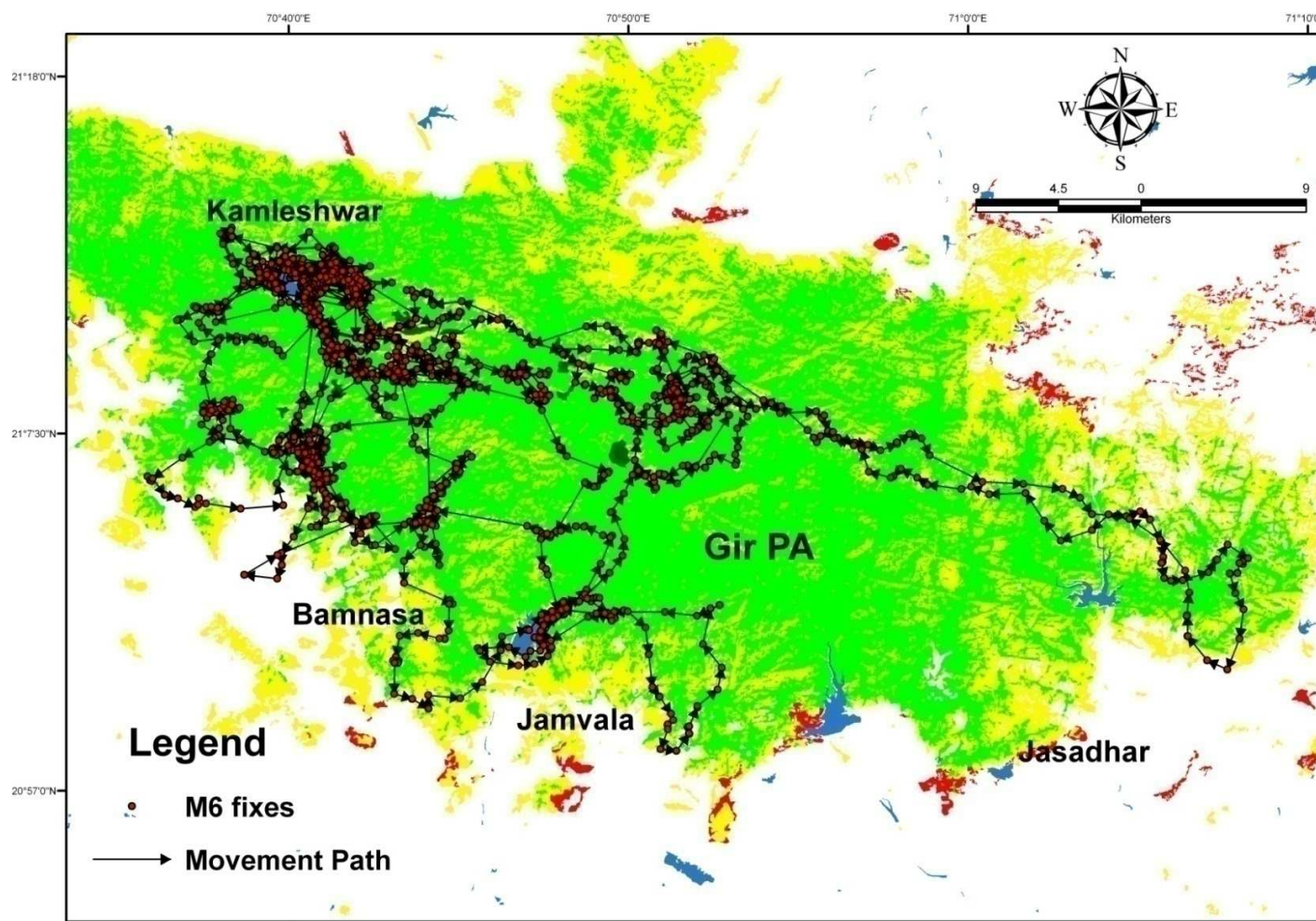


Figure 5.24: Movement of M6 from western Gir to eastern Gir.

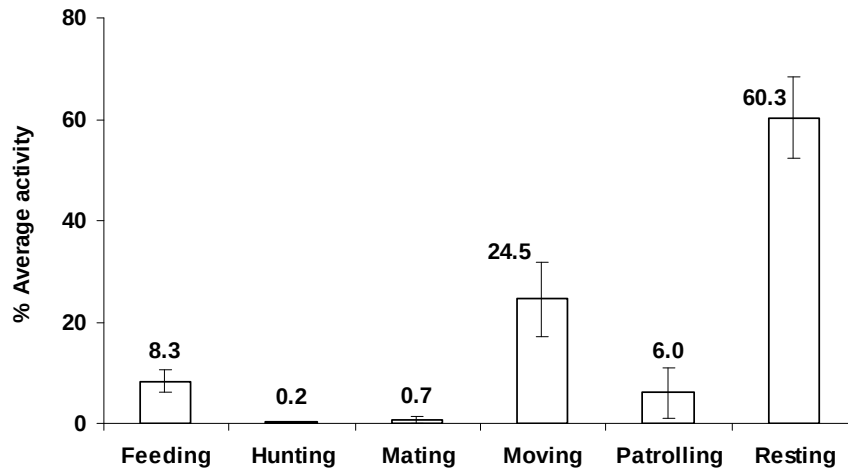


5.3.8 Lion time budget and activity pattern

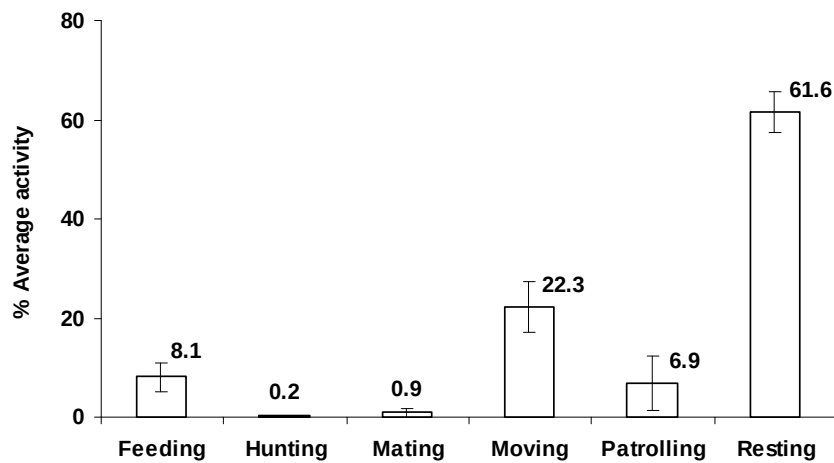
Overall lions spent a majority of their time resting (60%) followed by moving (24%) and I found no seasonal (wet and dry) variation ($\chi^2 = 6.13$, $df = 5$, $p = 0.29$, **Figure 5.25**). Males also spent majority of their time resting (62%) followed by moving (17%) and patrolling (13%) and no seasonal variation was observed ($\chi^2 = 3.81$, $df = 5$, $p = 0.57$, **Figure 5.26**). Females spent most on resting (59%) and no seasonal variation was recorded ($\chi^2 = 5.07$, $df = 5$, $p = 0.40$, **Figure 5.27**). 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 5.26 and 5.27**) 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 5.28**).

Figure 5.25: 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)

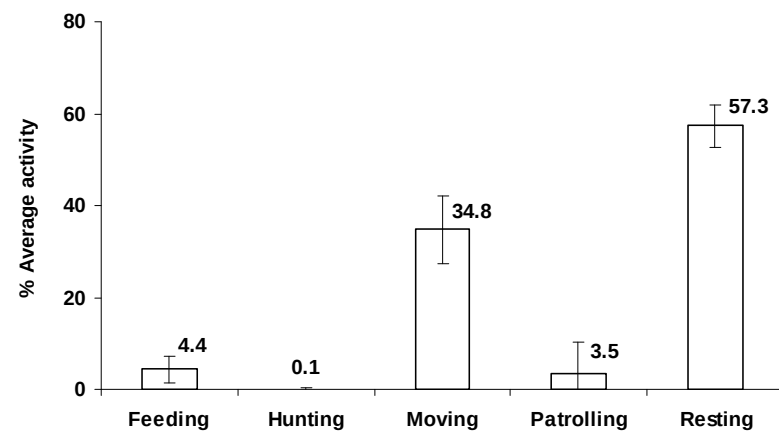
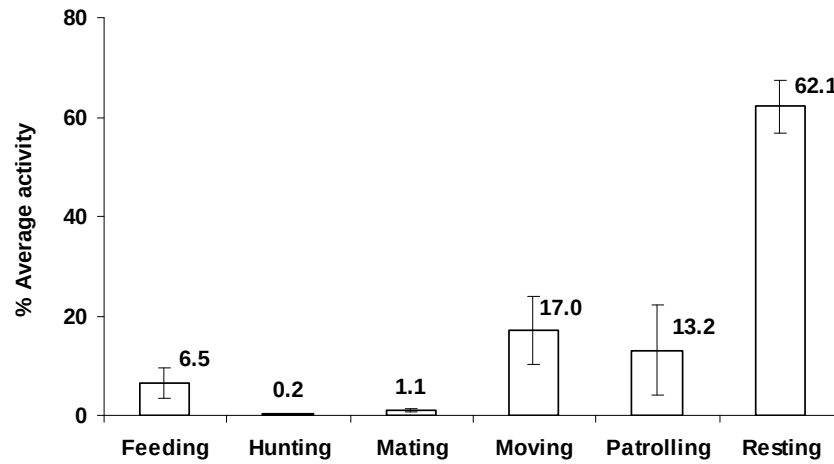
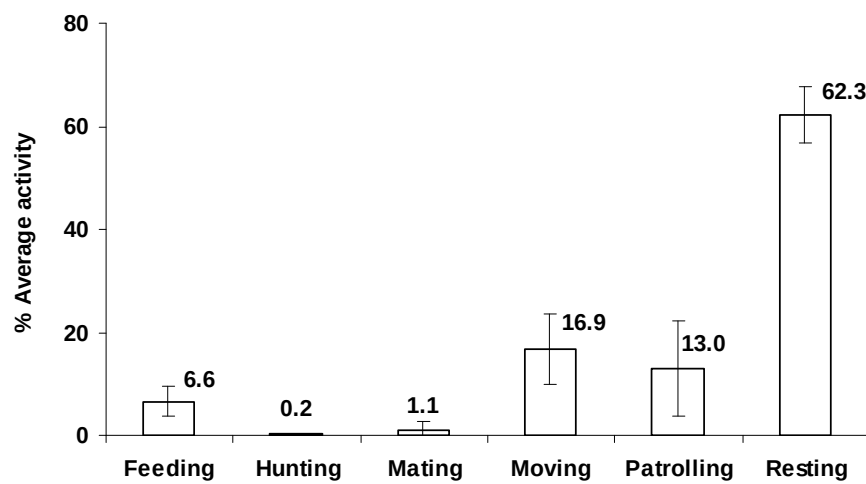


Figure 5.26: Time invested by male lions in different activities during continuous monitoring session i) overall, ii) dry season and iii) wet season. Error bars = 95% CI.

i)



ii)



iii)

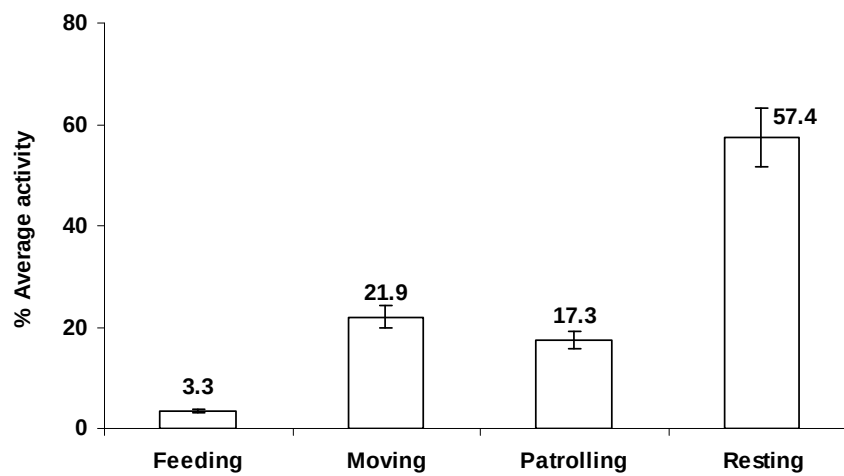
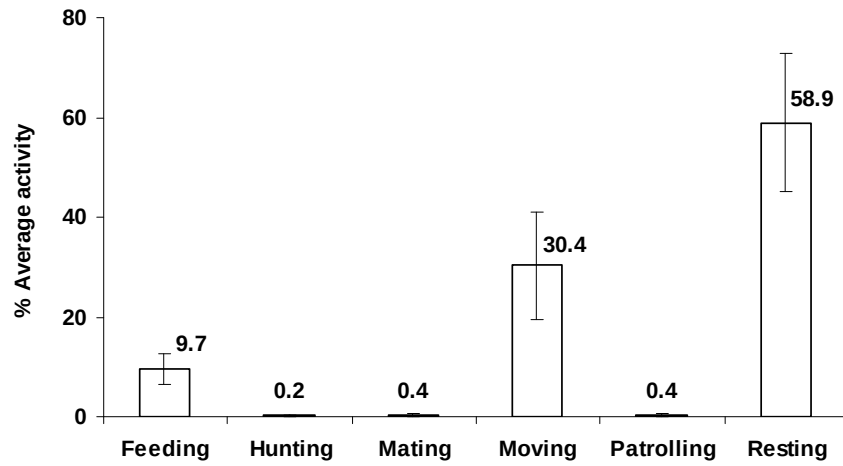
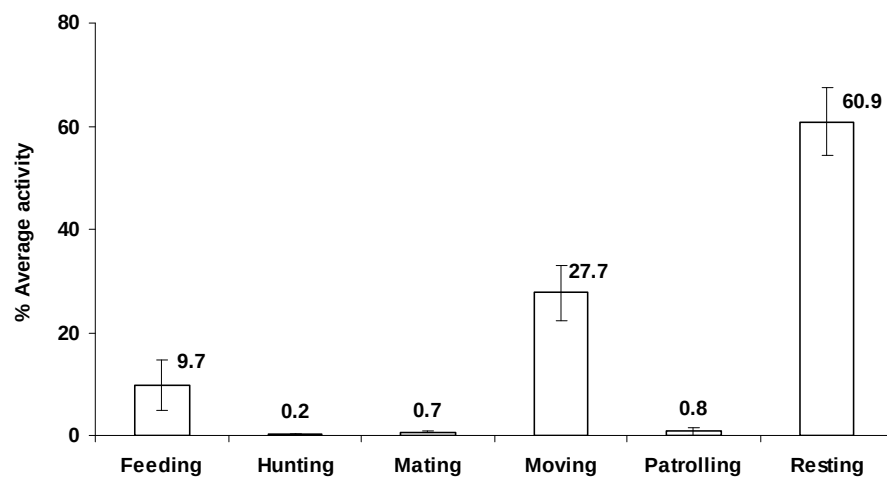


Figure 5.27: Time invested by female lions in different activities during continuous monitoring session i) overall, ii) dry season and iii) wet season. Error bars = 95% CI.

i)



ii)



iii)

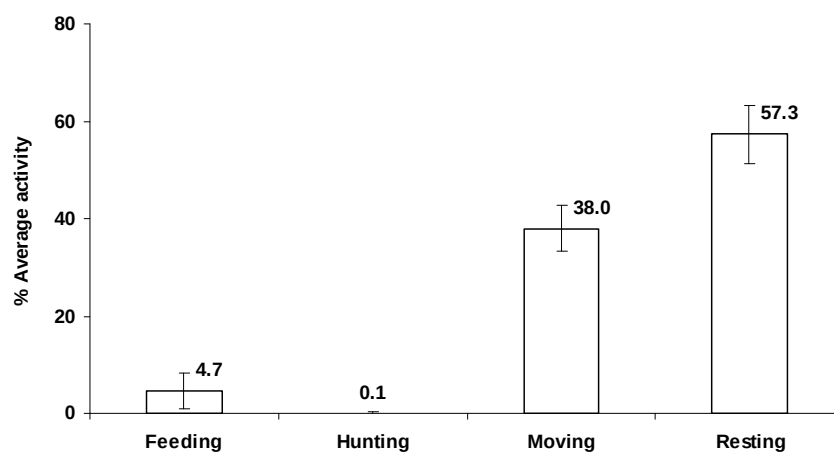
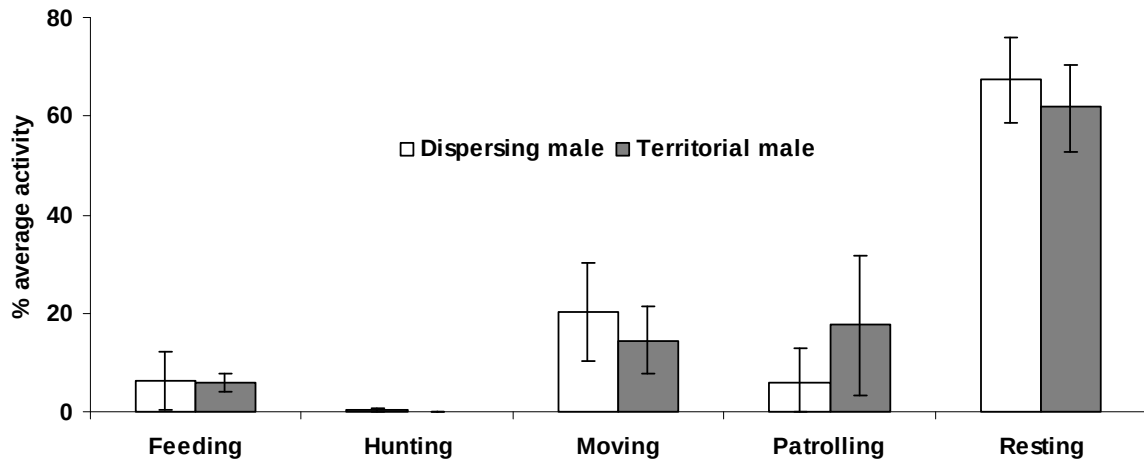


Figure 5.28: Time invested by territorial males and dispersing males in different activities. Error bars = 95% CI.



Lions were mostly active during night (moving and patrolling) while most of the day was spent in resting (**Table 5.9, Figures 5.29 - 5.39**). 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 5.9**). 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 5.29 - 5.39** 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 5:9: 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)
Lion overall						
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*
Lion dry season						
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*
Lion wet season						
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*
Male overall						
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*

Territorial male						
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*
Dispersing male						
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 5.29: 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.

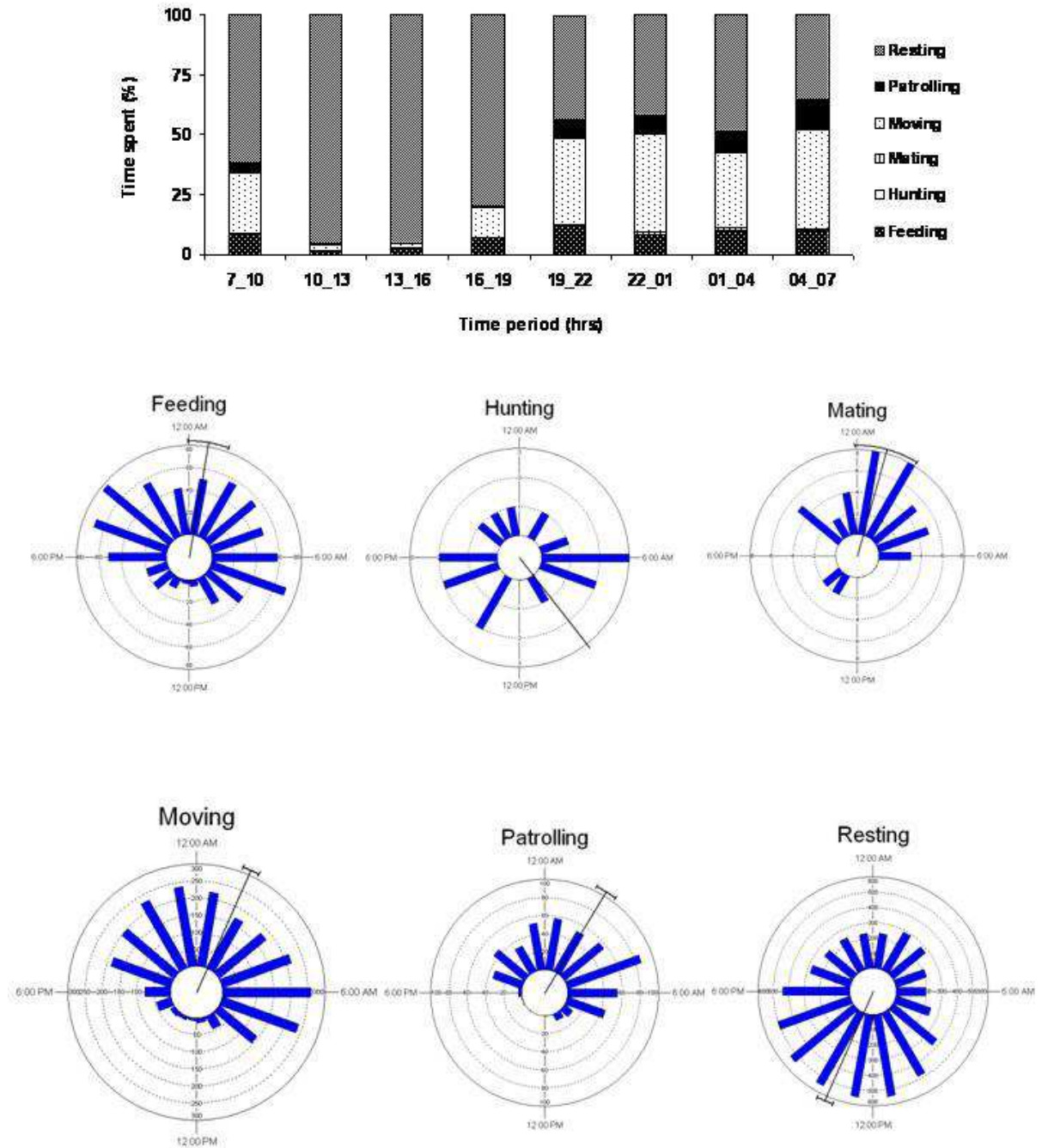


Figure 5.30: Proportional time spent by lions (males and females) in dry season in different activities during different times of the day and the related activity peaks deduced by program Oriana.

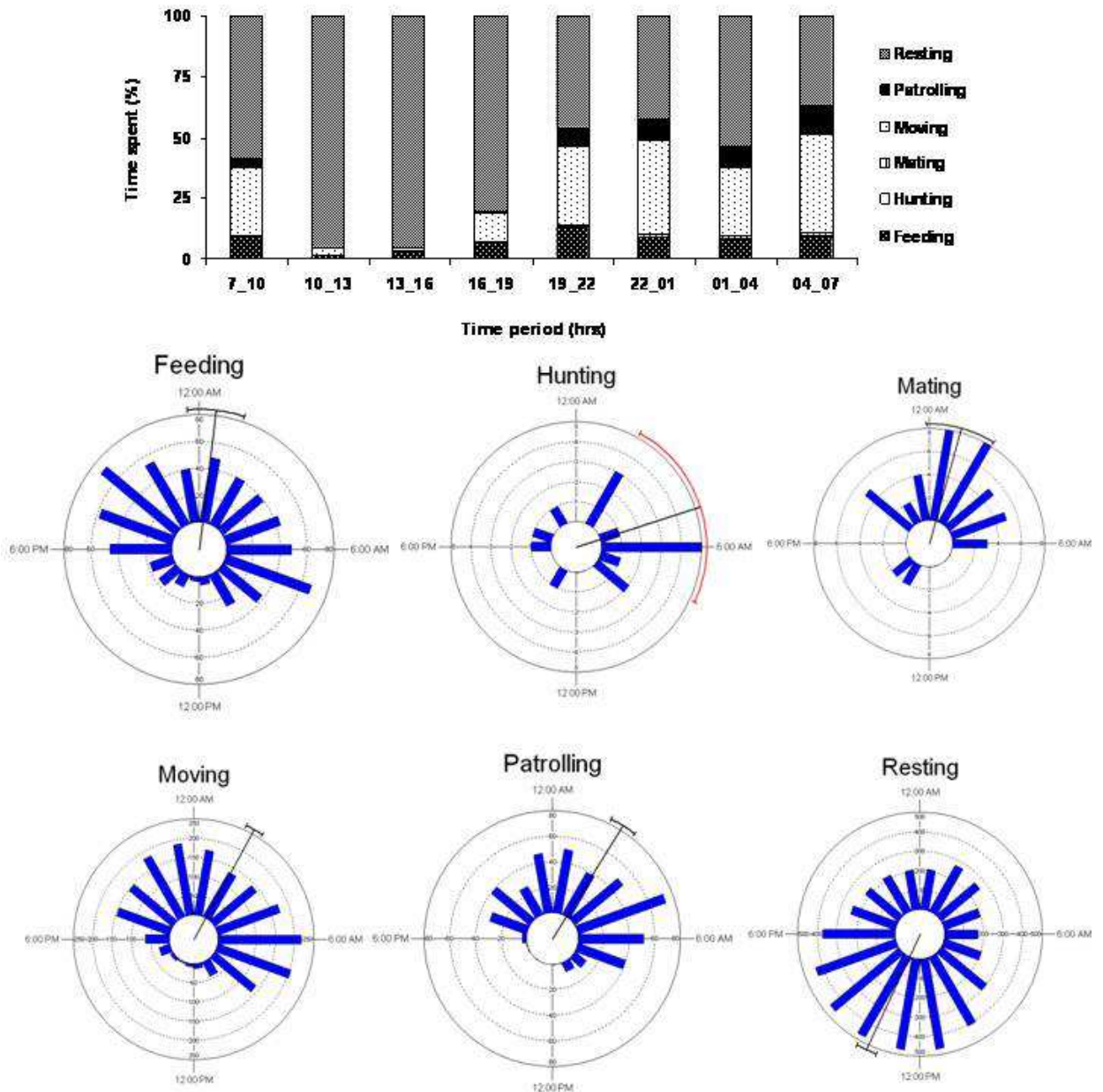


Figure 5.31: Proportional time spent by lions (males and females) in wet season in different activities during different times of the day and the related activity peaks deduced by program Oriana.

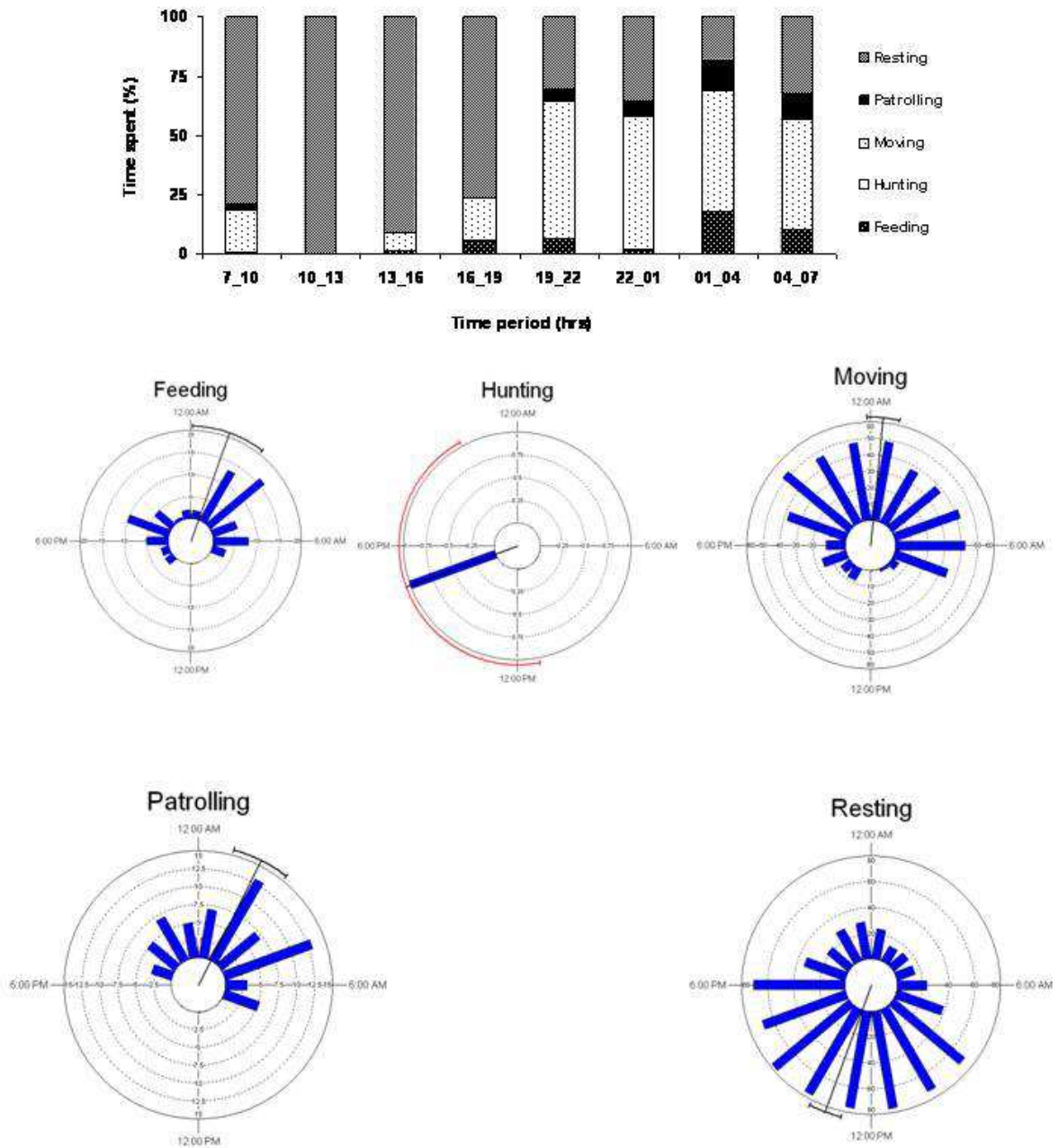


Figure 5.32: Proportional time spent by male lions in different activities during different times of the day and the related activity peaks deduced by program Oriana.

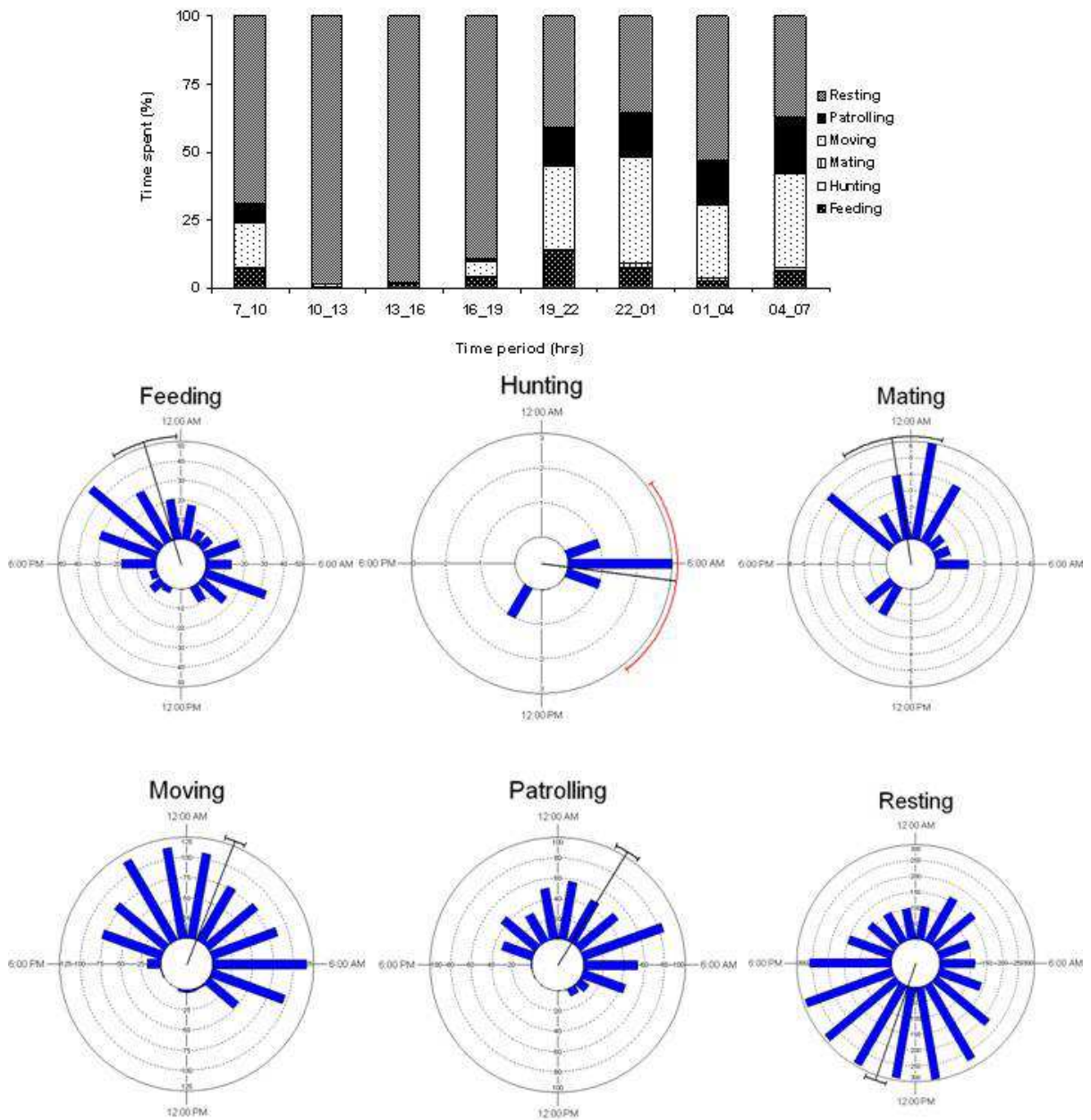


Figure 5.33: Proportional time spent by male lions in dry season in different activities during different times of the day and the related activity peaks deduced by program Oriana.

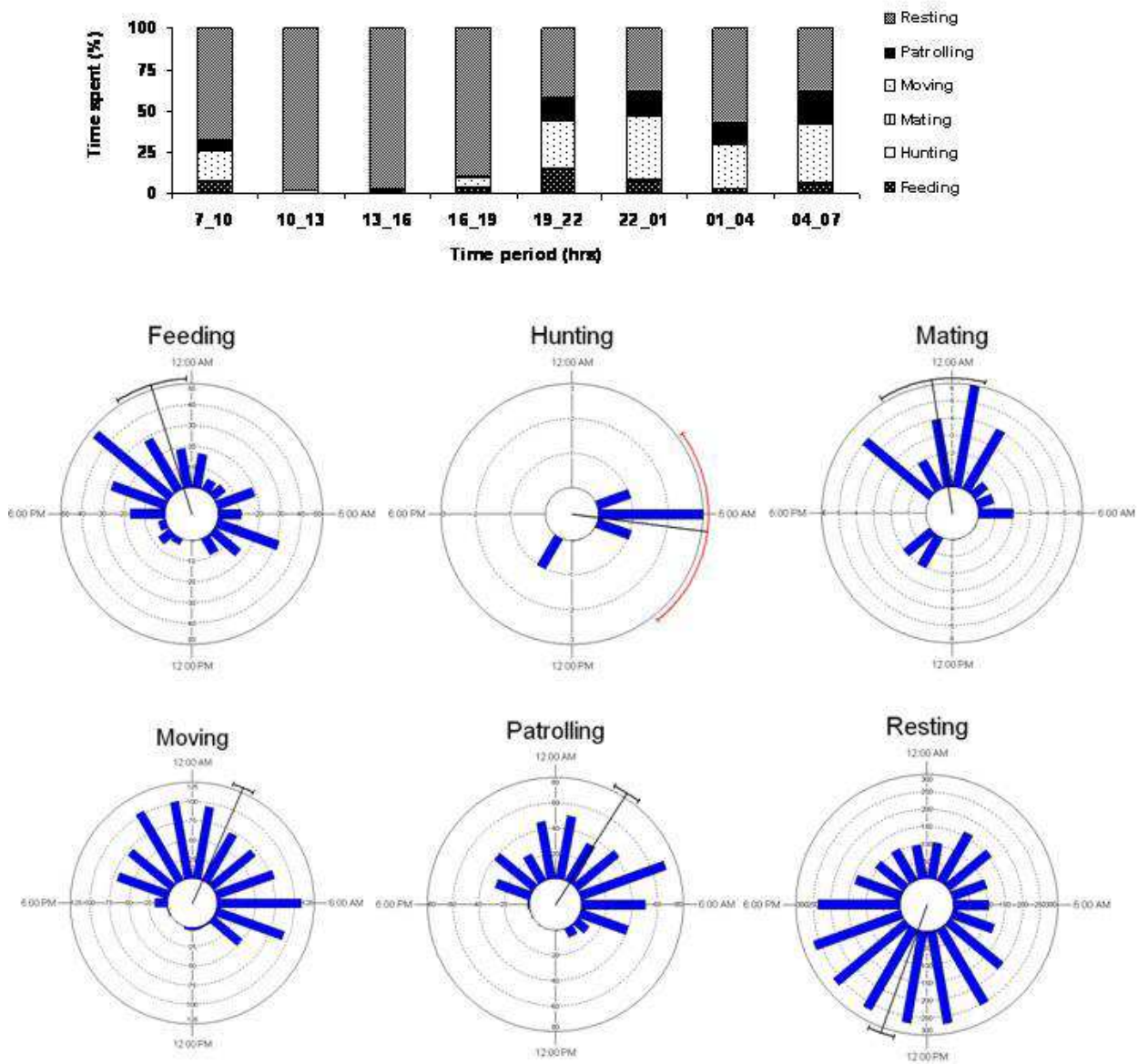


Figure 5.34: Proportional time spent by male lions in wet season in different activities during different times of the day and the related activity peaks deduced by program Oriana.

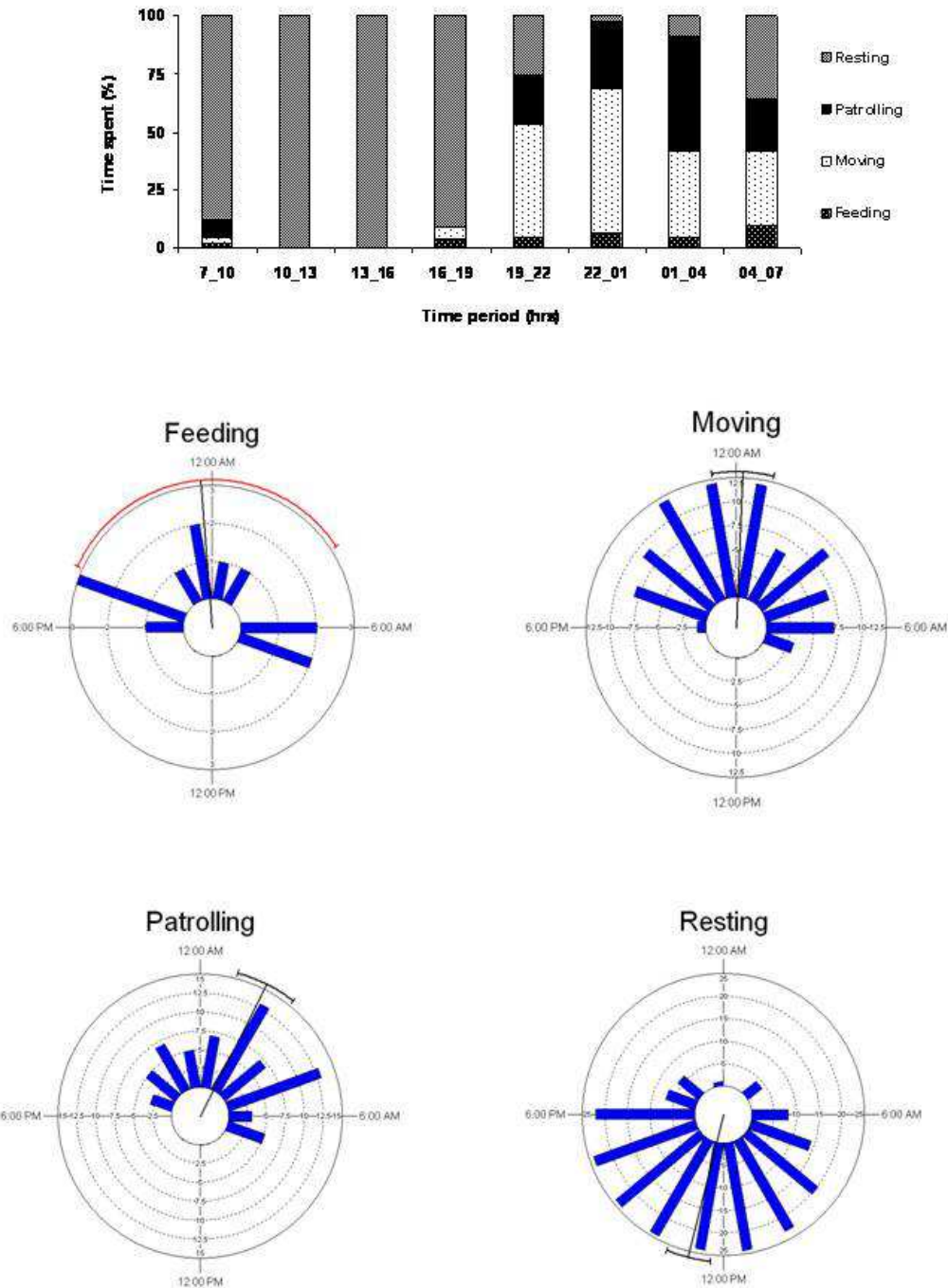


Figure 5.35: Proportional time spent by female lions in different activities during different times of the day and the related activity peaks deduced by program Oriana.

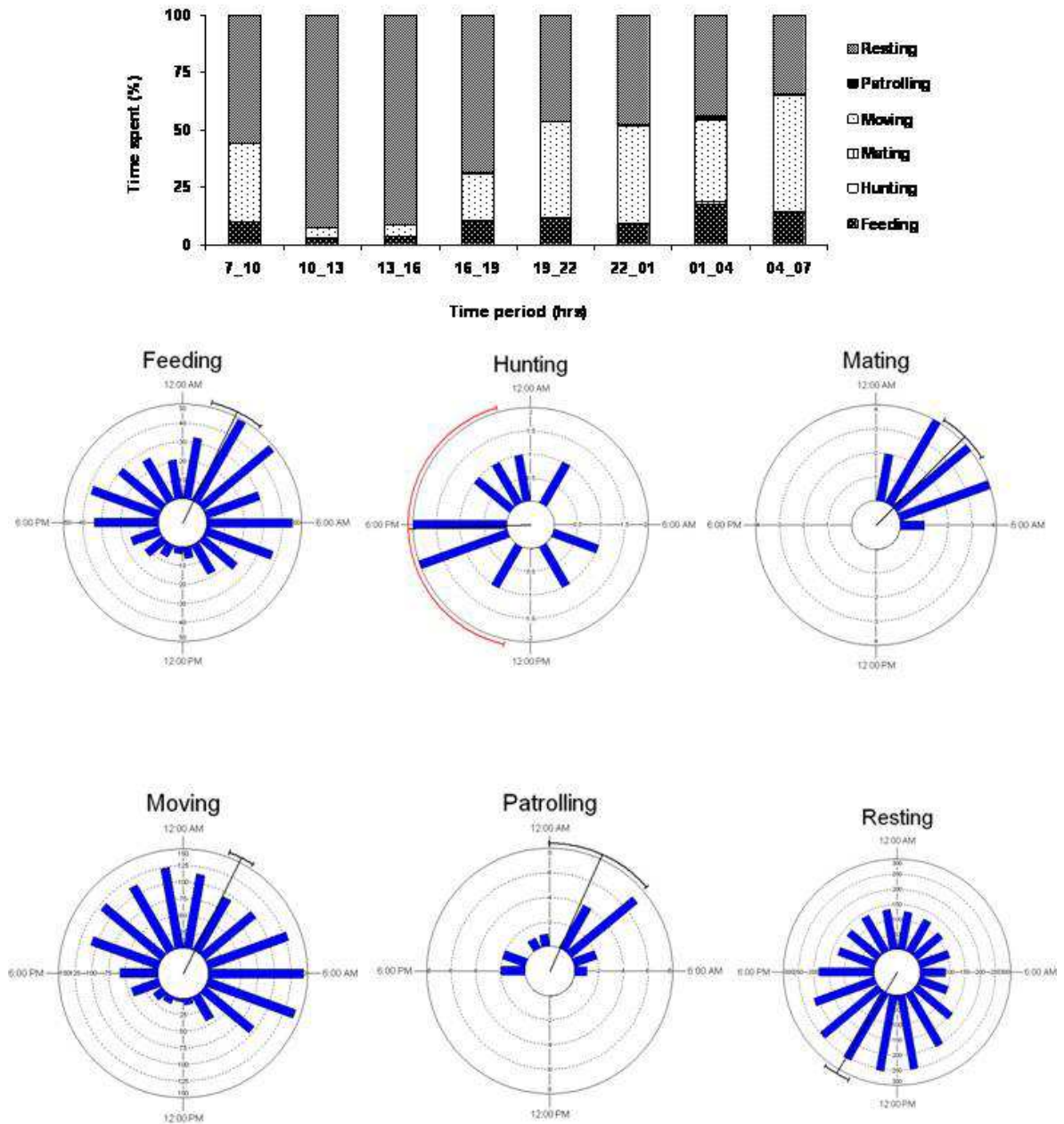


Figure 5.36: Proportional time spent by female lions in dry season in different activities during different times of the day and the related activity peaks deduced by program Oriana.

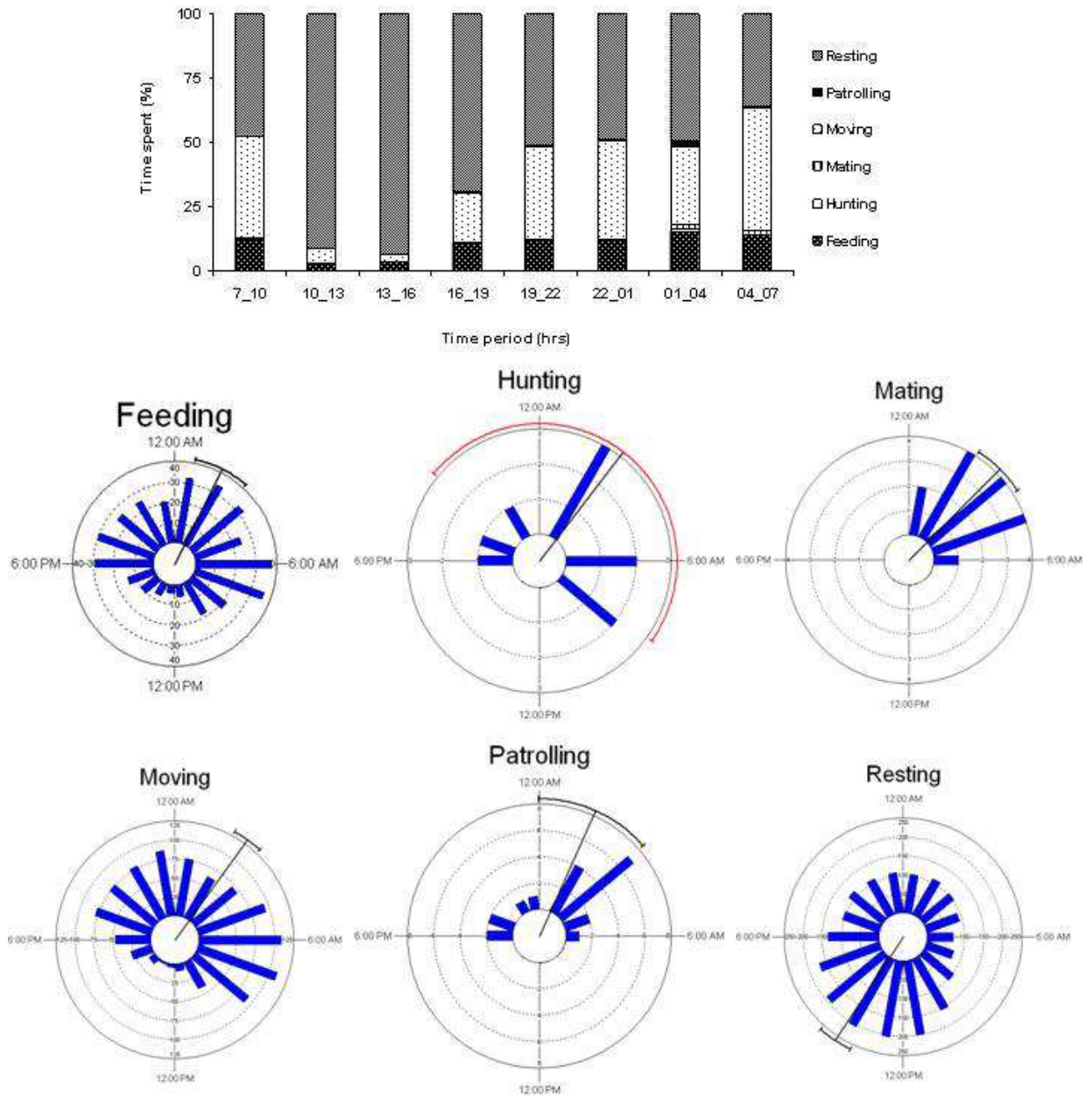


Figure 5.37: Proportional time spent by female lions in wet season in different activities during different times of the day and the related activity peaks deduced by program Oriana.

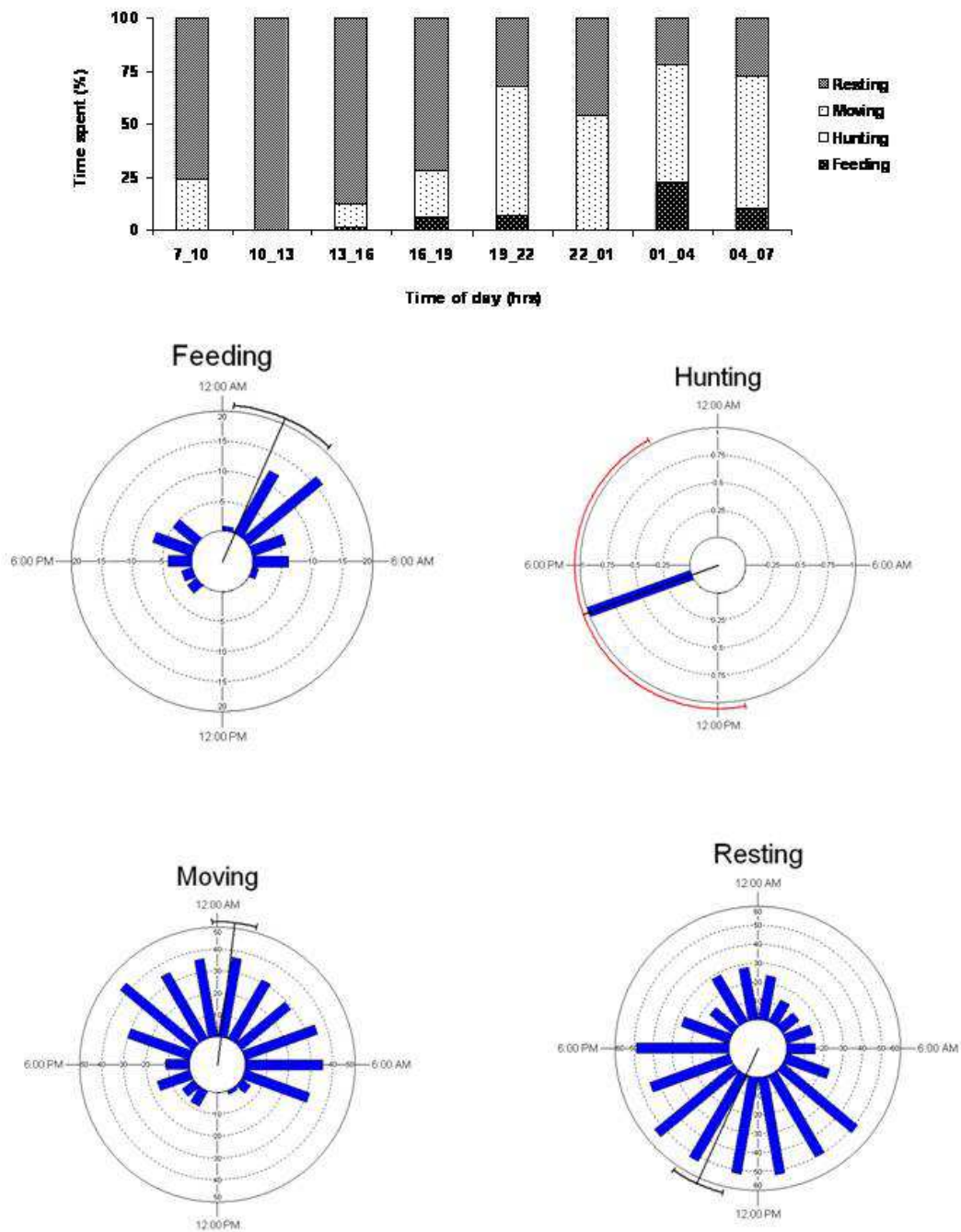


Figure 5.38: Proportional time spent by territorial males in different activities during different times of the day and the related activity peaks deduced by program Oriana.

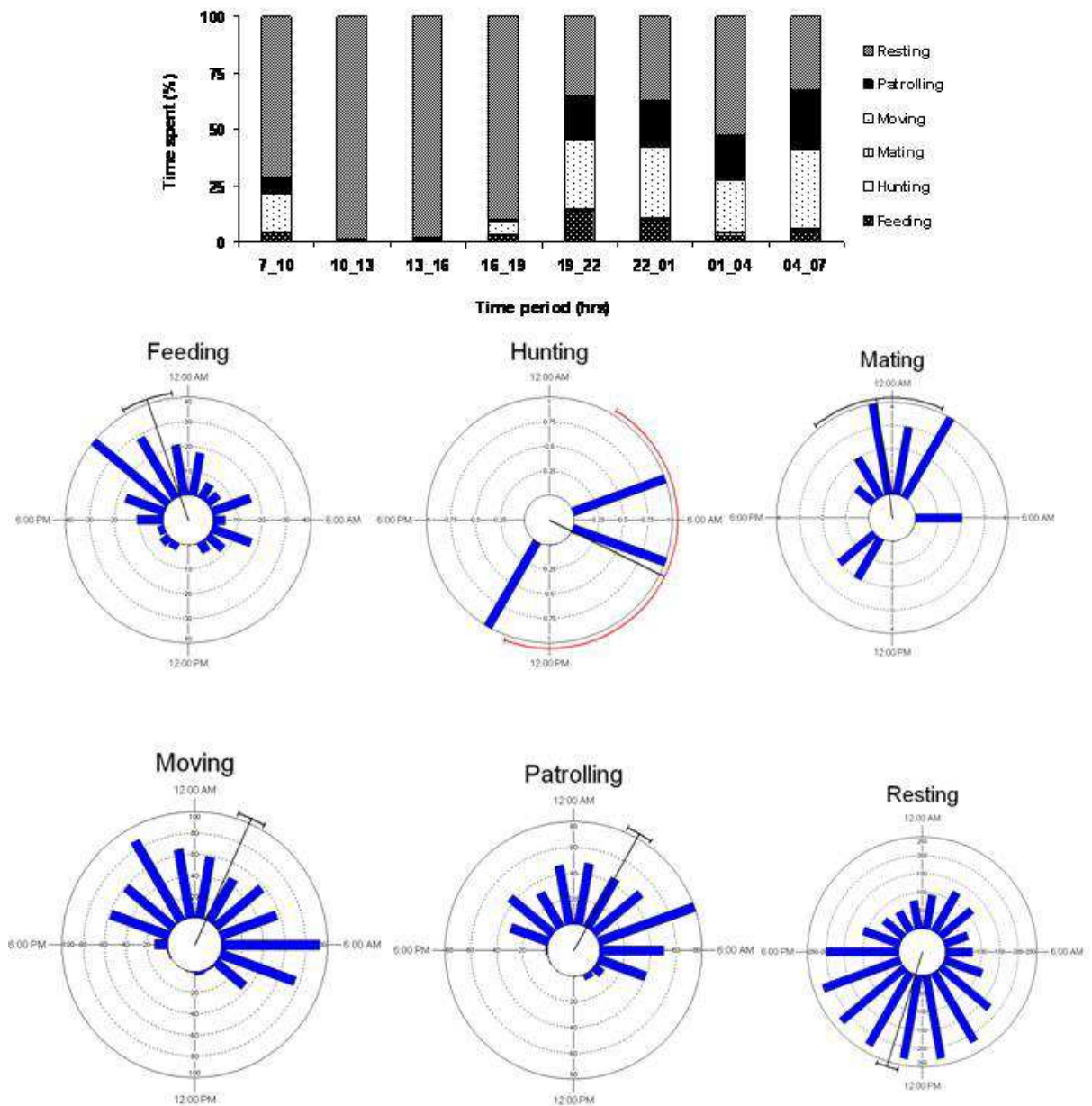
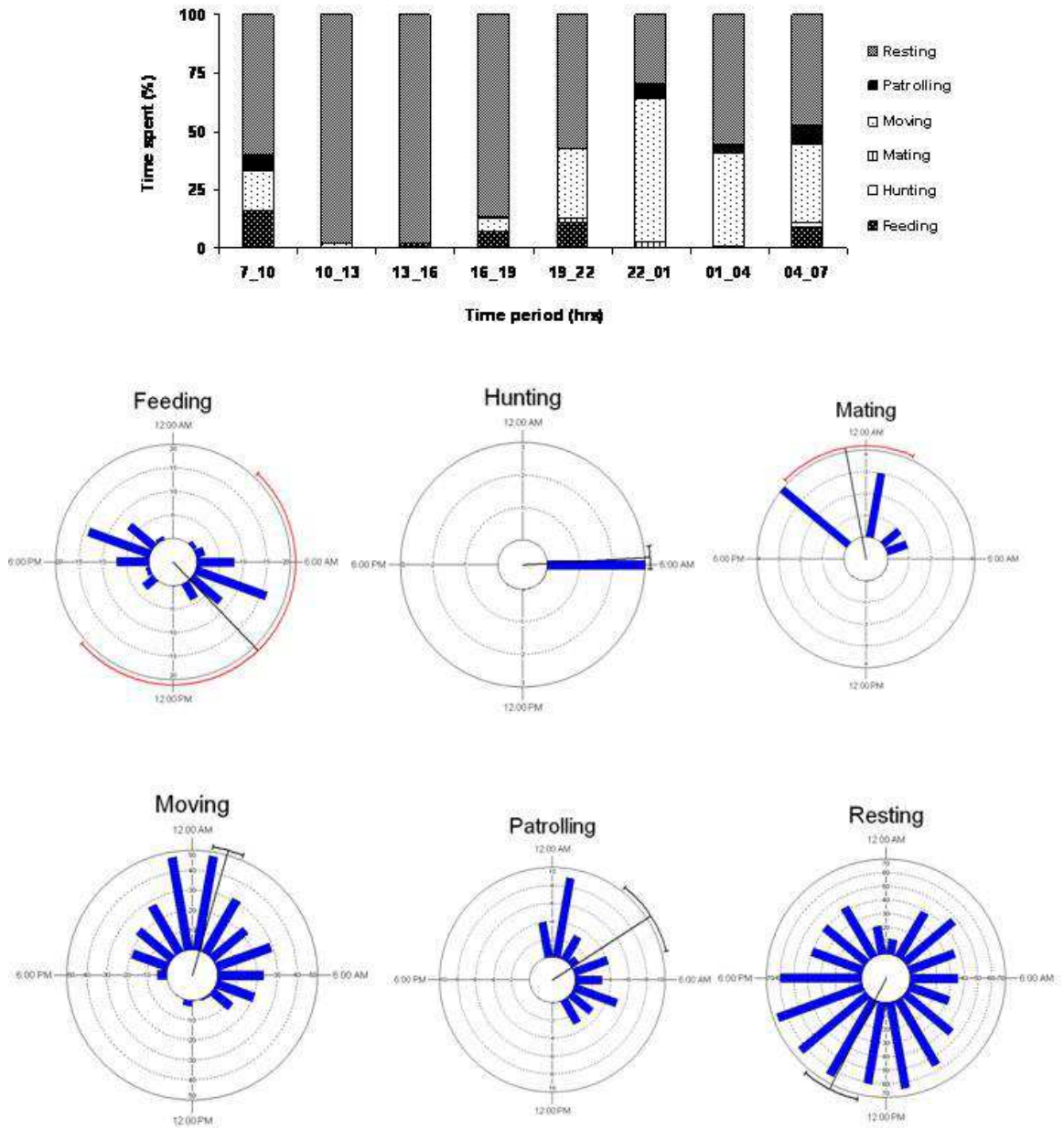


Figure 5.39: Proportional time spent by dispersing males in different activities during different times of the day and the related activity peaks deduced by program Oriana.



5.4. Discussion

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 5.2**). 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 5.2**), 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)]/km² and livestock [25-31]/km² densities (Dave 2008) compared to Girnar [9 (SE 1)]/km² and the eastern landscape [19 (SE 1)] /km² (Chapter 7, current thesis).

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 km²) and Girnar (180 km²) 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) km² and that of breeding lionesses was 85 (SE 17) km². 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 (Chapter 6, current thesis) 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 5.11**). Joslin (1973) based on sightings of his study prides estimated the male (n = 2) ranges to be 131 km² and female ranges to be 77 km² within Gir PA. Chellam (1993) estimated average annual male (n = 2) range to be 217 km² and female range to be 122 km². Meena (2008) estimated average male (n = 7) 100% MCP range area to be 74 km² and core area (50% FK) as 10 km² in Gir. Females (n = 4) had an average range (100% MCP) size of 34 km² and core area of 5 km². Jhala et al. (2009) estimated average breeding lioness range (100% MCP) in Gir PA as 48 (SE 10) km². 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) km², 56 (SE 12) km² and 577 (SE 182) km² 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 5.10**). 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.

Table 5.10: 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 ²)	Prey biomass density (kg/km ²)	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. 2009
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
Girnar	India	Male: 243, Female: 170	953	Present study
Eastern landscape	India	Male: 621, Female: 129	1,212 (including domestic prey)	Present study

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

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 km² in the Gir PA, Jhala et al. 2004 and 12/100 km² 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 5.22**), a pattern also observed 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 km^2 ($38 \text{ bigha} = 88,426 \text{ sq. meter}$ ($@ 2,327 \text{ m}^2/\text{bigha}$) = 0.1 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 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 3, present thesis), 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 (*personal observation*) and expressed antagonism against lion conservation (Chapter 8 for

more details). 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 Rijssel 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 (Chapter 7 and 8 for more details). *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 5.32 and 5.35**) 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) I 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 (chapter 8 for more details).

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. 2011a). 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). 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 6) 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.

Lion Habitat Use & Resource Selection

LION HABITAT USE & RESOURCE SELECTION

6.1 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 km² 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 3) 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 5). 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, I 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 I 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. I 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. I 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.

Habitat

Resource selection is a multilevel and hierarchical process in response to various environmental factors, starting from the geographic range of a species till the selection of particular elements within the territory of the species (Johnson 1980). Animal behavioral responses in resource selection are influenced by habitat types and prey availability (Creel 2001; Punjabi 2010), the presence of habitat edges (Woodroffe and Ginsberg 1998), disturbance effects (Kaartinen et al. 2010), and interspecific competition (Caro and Stoner 2003; Vanak and Gompper 2009). Before carrying out any sort of habitat analysis, it is thus important to briefly define the concept of habitat and the factors that are involved in its selection.

There is often a great deal of confusion when it comes to the terms “niche” and “habitat”. Niche is often used when describing the role or function of an organism in a particular environment and it can therefore be seen as the mechanistic interaction that arises between an individual and the area it utilizes. Consequently, this interaction is indirectly related to the fitness of an individual. Habitat, on the other hand, does not have this association between environmental variables and its effect on fitness. It is therefore a descriptive, rather than a mechanistic, concept that depicts the biotic and abiotic variables at a given place and time (Kearney 2006). When a habitat assessment is carried out for a species, vegetation and the associated characteristics, such as type, density, shape and size, are often perceived as being the key components that define a habitat (Poole et al. 1996; Mysterud and Ims 1998; Hirzel et al. 2002; Manly et al. 2002; Morrison et al. 2006; Rotenberry et al. 2006). In a sense, when choosing what components to use to describe a habitat, vegetation is the obvious choice as it is linked to various biotic and abiotic factors and therefore determines the physical composition of the environment. In the case of terrestrial animals, vegetation is important as it provides cover (Caro and Collins 1987; Yamaguchi et al. 2003), breeding sites (Lack 1933) and it is either directly a food source for herbivorous animals or indirectly as a fundamental part of predator-prey dynamics (Spong 2002). It is however important to realize that there are also many non-vegetative factors that make up a habitat (Lack 1933; Morrison et al. 2006) such as water sources, soil structure, elevation, temperature gradients, prey availability and annual rainfall only to name a few (Tracy and Christian 1986; Guisan and Zimmermann 2000).

6.2. Methodology

6.2.1. Field Methods and Analyses

I used radio-telemetry data to evaluate lion habitat use and resource selection in the Gir landscape (data collection methods described in details in chapter 5). 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, I used ANOVA ($\alpha = 0.05$; Zar 2010) on each of the variable with a 5 km² 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. I 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, I 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. I followed this and reclassified these LULC classes which are applicable for the Gir region and relevant for lion conservation (**Figure 6.1**). 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, I 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). I used DEM data (mean and variance of elevation) from the website 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 μm) 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.

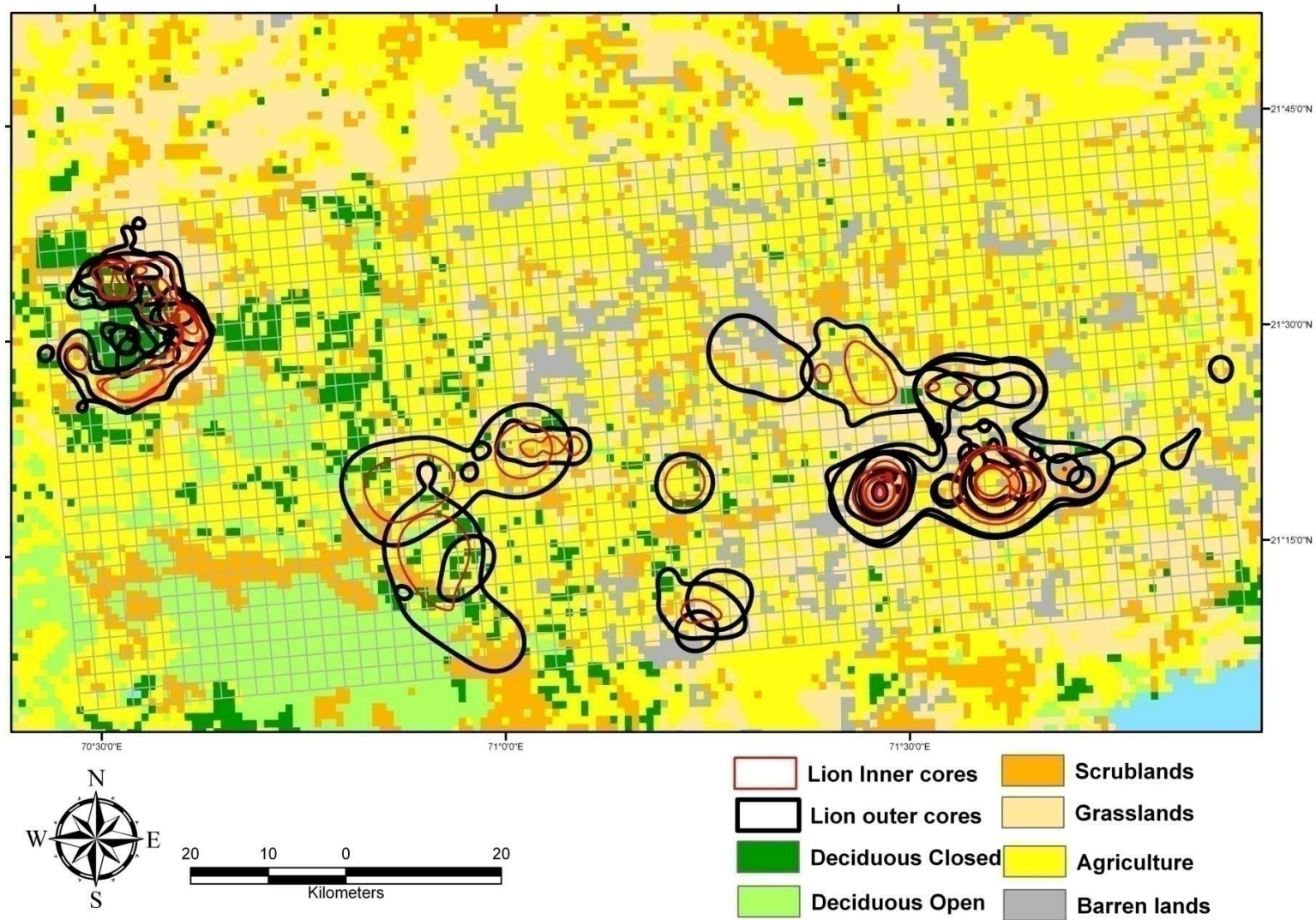
Compositional analysis

Second order resource selection function was used to understand the habitat selection of lions in the study area. I 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 (Millspaugh 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 (Millspaugh 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. I 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 6.1: Various land-use classes in the Gir landscape showing distribution of lion core areas (85%FK and 50% FK).

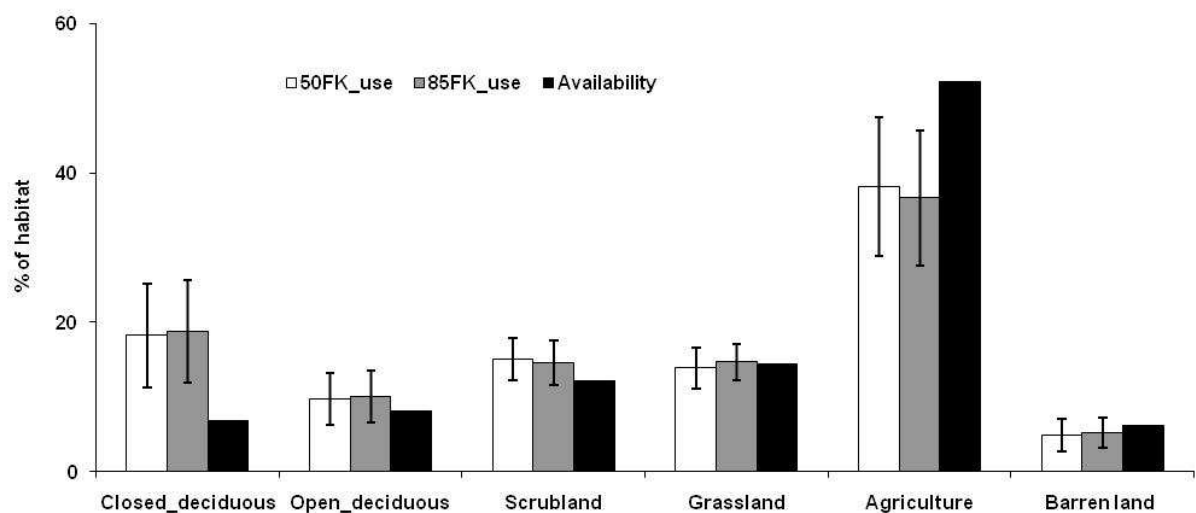


6.3. Results

6.3.1. Compositional Analysis

The total area of available lion geographic range was estimated to be 5,475 km² in the Gir landscape. Lions in the Gir landscape mostly used agriculture followed by closed deciduous forests within their inner and outer cores (**Figure 6.2**). 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 6.2: Use and availability of different land-use types for lions' core areas in the Gir landscape. Error bars are standard errors.



6.3.2. 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 6.3 – 6.8**). The cores were at higher elevations but with less rugged terrain (**Figure 6.9 and 6.10**).

Figure 6.3: Influence of villages explaining lions' core selection in the Gir landscape.

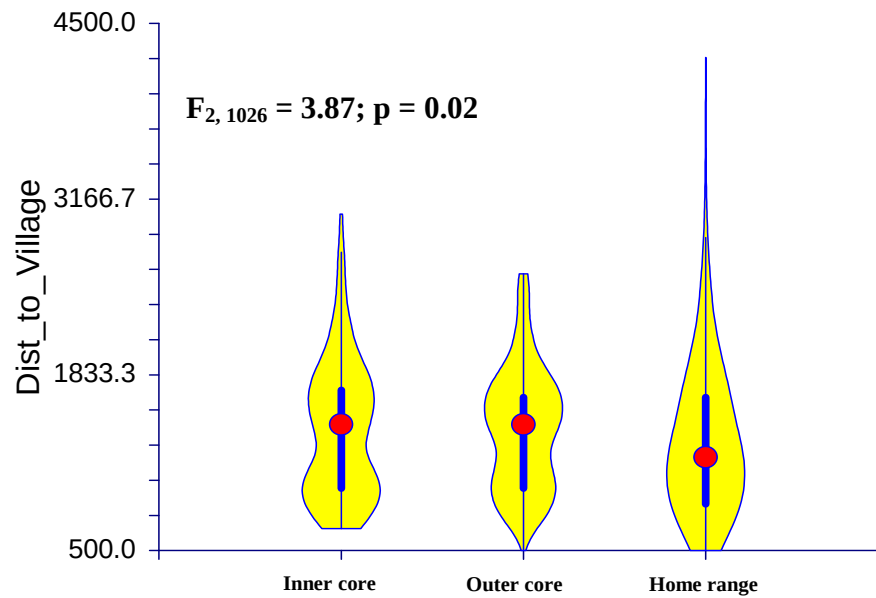


Figure 6.4: Influence of roads explaining lions' core selection in the Gir landscape.

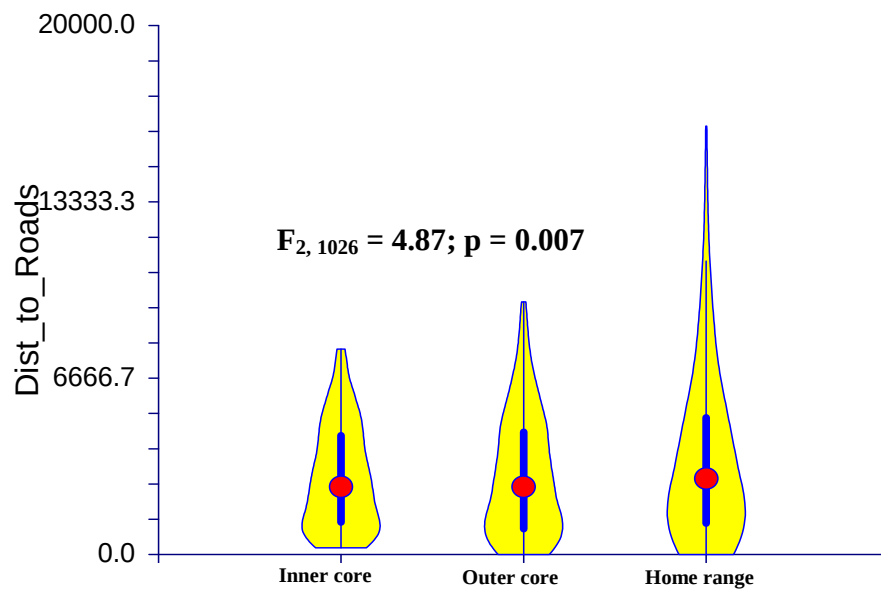


Figure 6.5: Influence of rivers explaining lions' core selection in the Gir landscape.

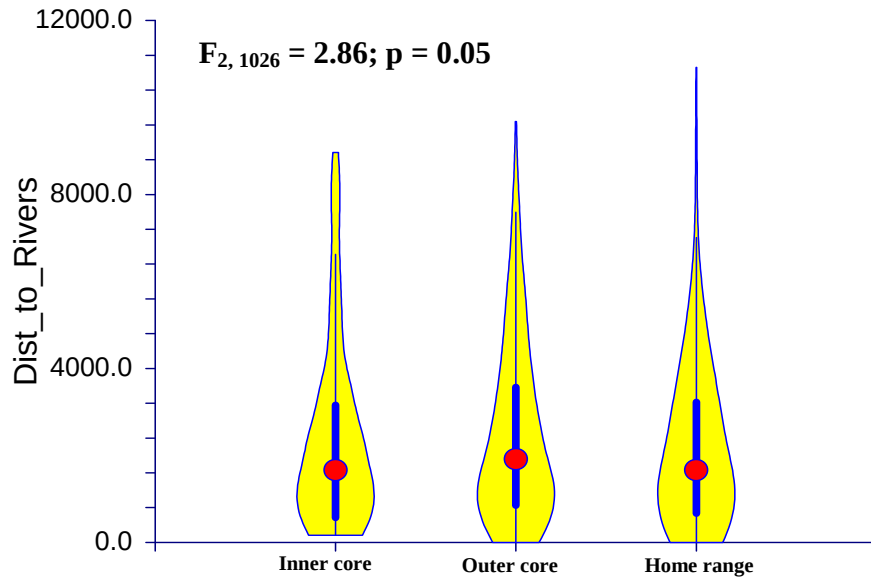


Figure 6.6: Influence of human habitations (delineated by night lights) explaining lions' core selection in the Gir landscape.

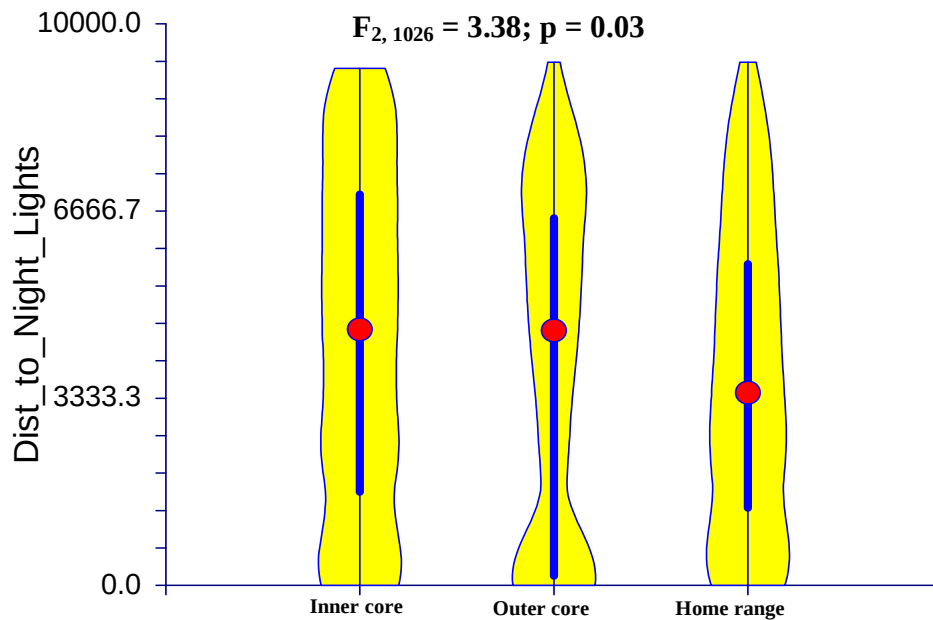


Figure 6.7: Influence of Protected Areas explaining lions' core selection in the Gir landscape.

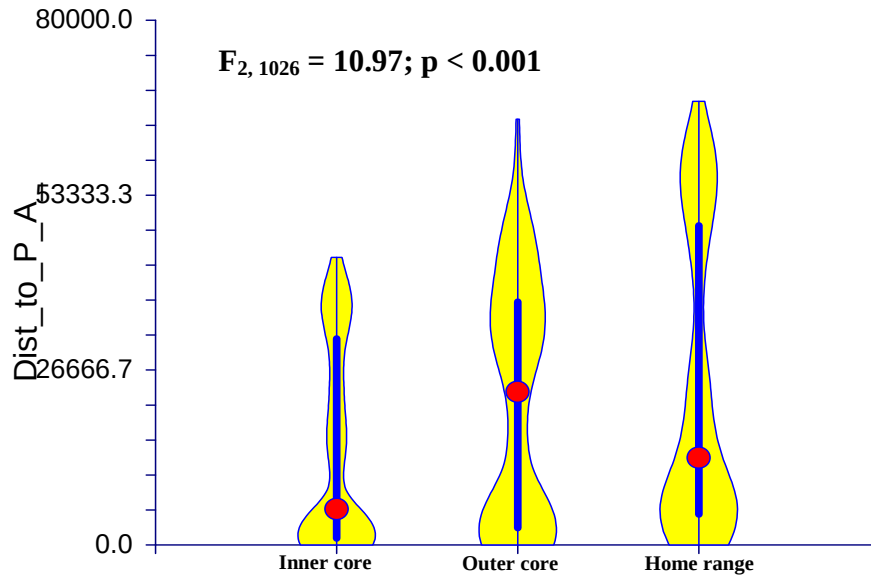


Figure 6.8: Influence of pre-monsoon NDVI explaining lions' core selection in the Gir landscape.

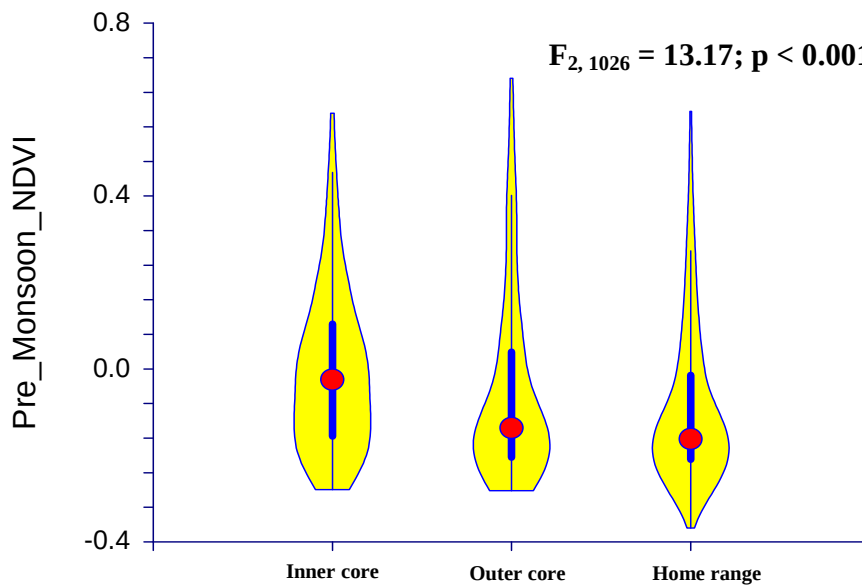


Figure 6.9: Influence of elevations explaining lions' core selection in the Gir landscape.

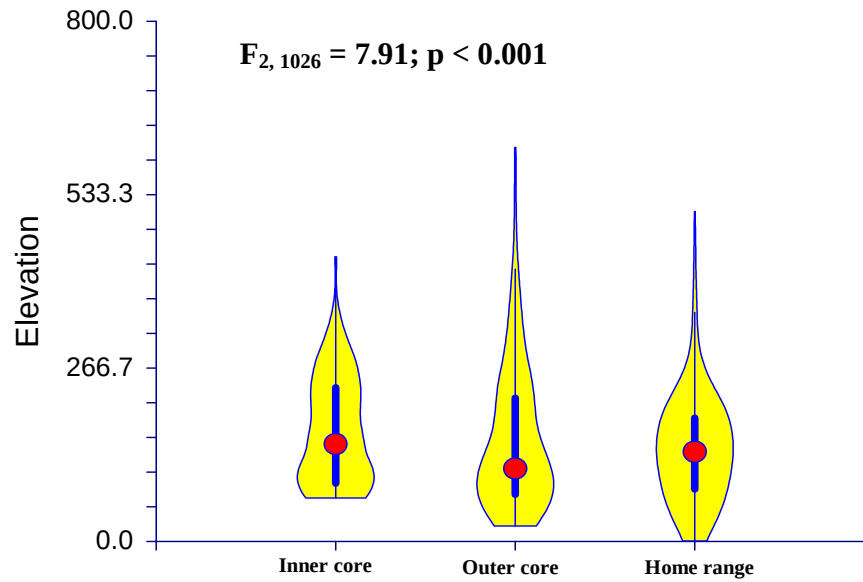
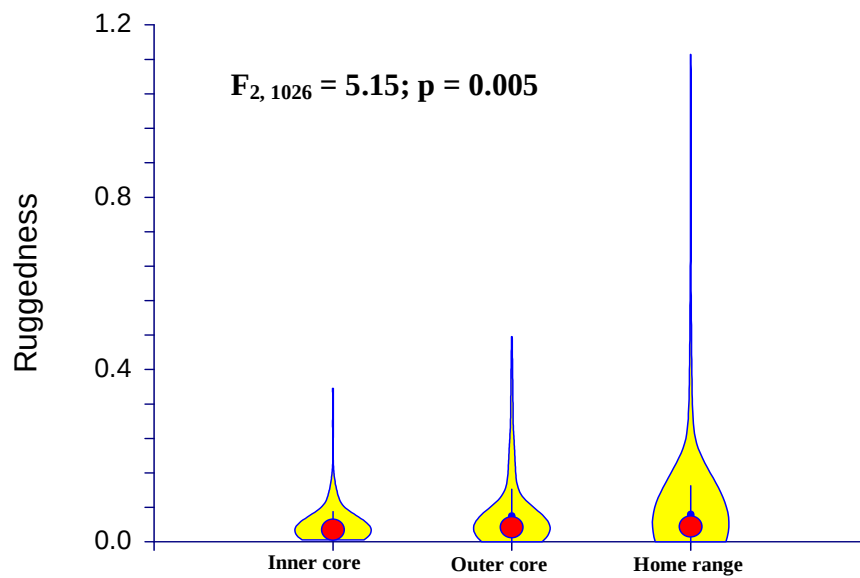


Figure 6.10: Influence of terrain ruggedness explaining lions' core selection in the Gir landscape.



Lion day time refuge patches size: Average day refuge patch size of lions in the eastern landscape was estimated to be 7.5 km² (SE 0.74; range: 0.07 km² – 21.5 km²). Breeding lionesses had similar sized day refuge patches (3.8 km², SE 1.7; range: 0.4 km² – 5.5 km²) like adult males (7.6 km², SE 0.77; range: 0.07 km² – 21.5 km²) [$t = 0.95$, $p = 0.34$]. Minimum patch size in which a lioness reared her cubs successfully was 4.3 km². Refuge patch size did not vary in size for lion locations proximal (9.5 km², SE 1.71; range: 0.33 km² – 21.5 km²) or distant (7 km², SE 0.82; range: 0.07 km² – 21.5 km²) to human habitations ($t = 1.25$, $p = 0.21$). **Figure 6.11** 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 6.12**).

Figure 6.11: Minimum day time habitat refuge patch (0.07 km²) for lions in the Gir landscape embedded within human habitations, road network and rivers.

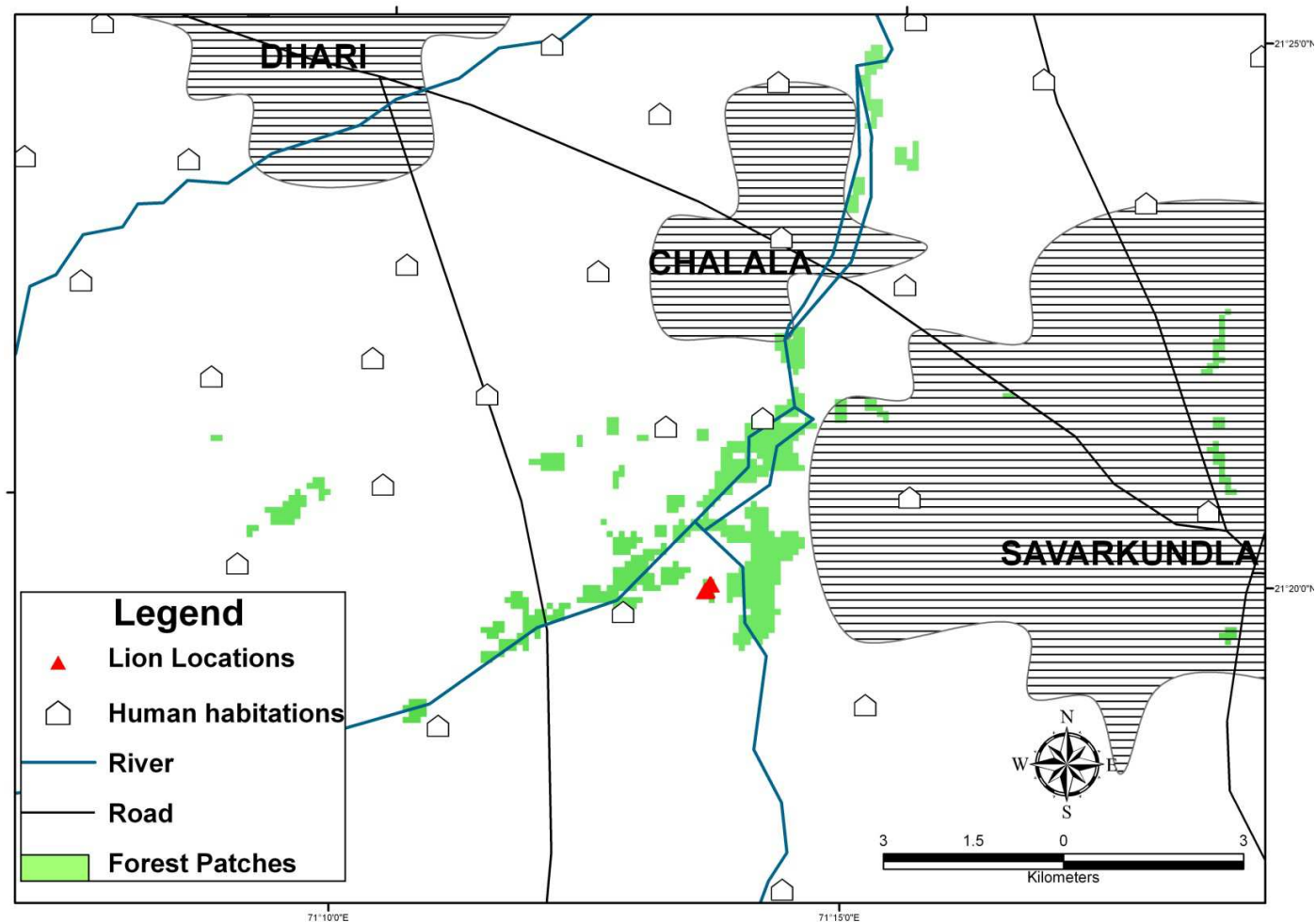
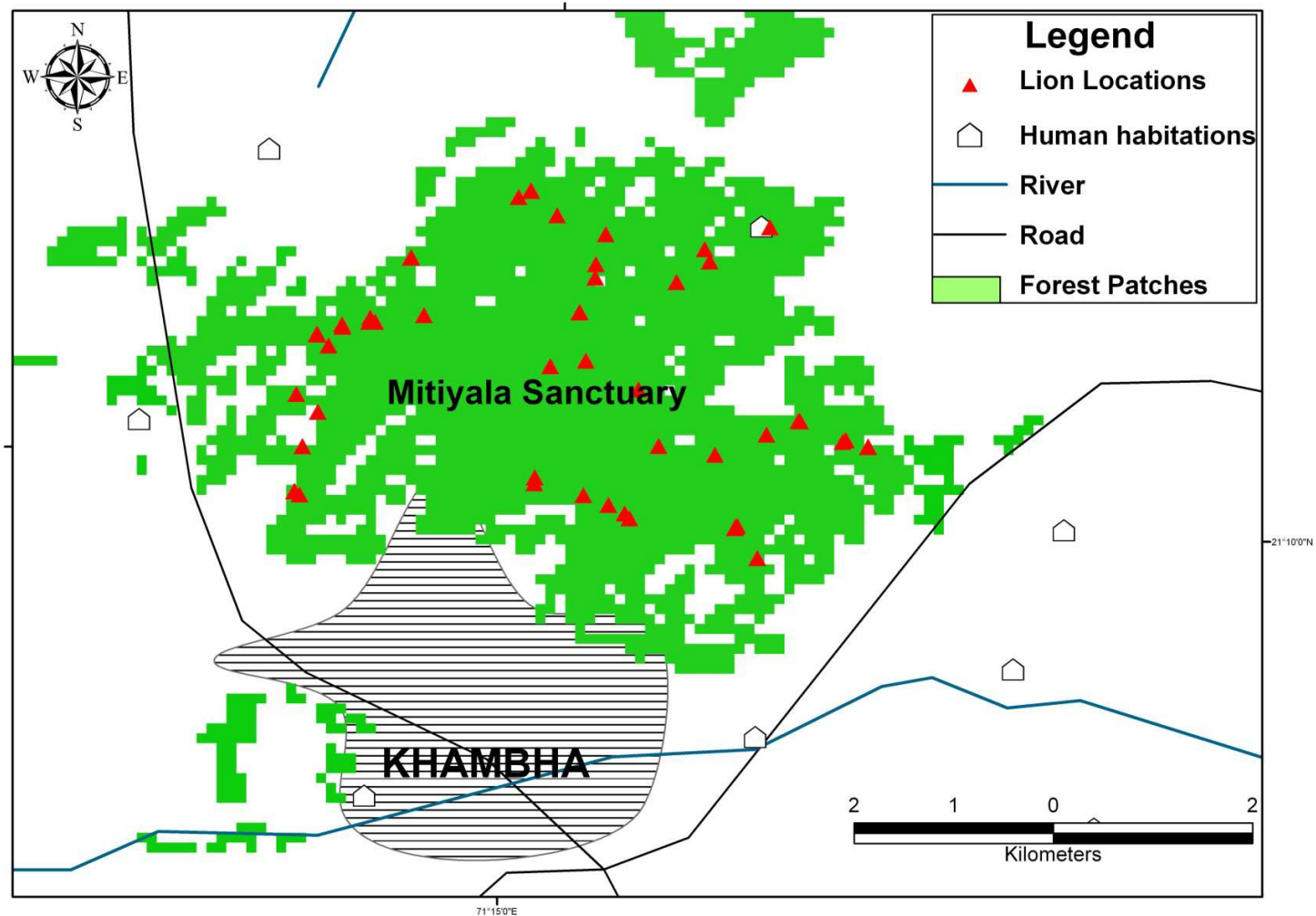


Figure 6.12: Largest day time refuge patch (21.5 km²) of lions in the Gir landscape represented by Mitiyala Sanctuary.



6.4. Discussion

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 6.2). 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 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, I 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 7). Wild ungulates form the majority of lion's kills in Girnar (chapter 7 for more details). Although sambar population in Girnar has increased in the past one decade (chapter 7 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 km²; Banerjee et al. 2010) and leopard (19/100 km²; 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. I 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 (details in Chapter 7, 8A; 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 *Panjrampoles*) housing thousands of ill and abandoned cattle and lions obtained a substantial part of their diet by scavenging the carcasses (chapter 7 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 (see chapter 8 for more details).

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 23rd 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.

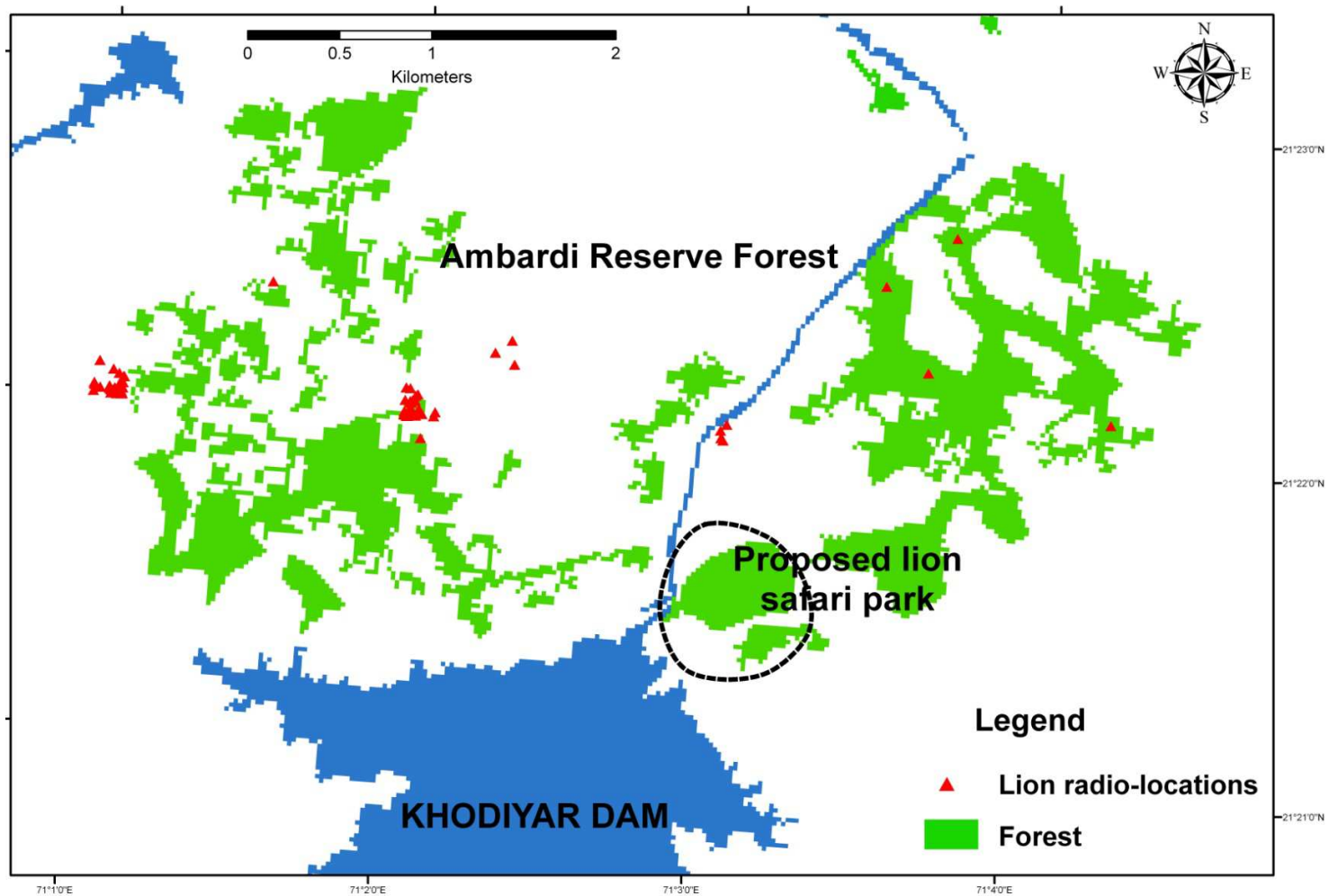
The minimum patch size in which lions took daytime refuge was found to be as small as 0.07 km² whilst the largest forested area was represented by Mitiyala wildlife sanctuary (21.5 km²). Mitiyala is a legally protected sanctuary which would likely to continue to exist even in future. However, most of 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 6.13**) and a habitat corridor between Visavadar, Dhari and Khambha. I 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.

Figure 6.13: 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.



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 km² 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 Vadai, Hipavadi, Ranigala, 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.

Lion's Diet in the Gir landscape

LION'S DIET IN THE GIR LANDSCAPE

7.1. 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 8). In the larger human-dominated landscape of Gir, this becomes even more crucial as lions live in close proximity with humans (chapters 5 and 6) 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, I evaluate lion food habit in Girnar and human-dominated eastern landscape based on scat analysis, telemetry and information on predation. I use this knowledge to assist the management in developing a conflict mitigation strategy for lions in the Gir landscape.

7.2. Methodology

7.2.1. Lion prey base estimation in Girnar

For estimation of lion prey abundance in the Girnar Wildlife Sanctuary, I 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 7.1**). 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, I 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.

7.2.2. Lion prey base estimation in Eastern Landscape

Considering the vastness and good road network of the human-dominated corridor landscape, I 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 7.2**). 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. I differentiated between cattle and feral cattle on the basis of presence of herder, ornamentation, tethered rope, behavior and body condition of the individual cattle.

I 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). I 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, I 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; Prater 1971; Berwick and Jordan 1974; 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).

7.2.3. Lion kills

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.

7.2.4. 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 5 and 6) across the Gir landscape (**Figure 7.3**). Lion scats were distinguished from those of other predators, particularly leopard scats, based on associated signs, tracks and size (Joslin 1973). I did not include ambiguous scats (n = 5) in the analysis.

Figure 7.1: Distribution of the trail transects (n = 21) for prey base enumeration in Girnar forests.

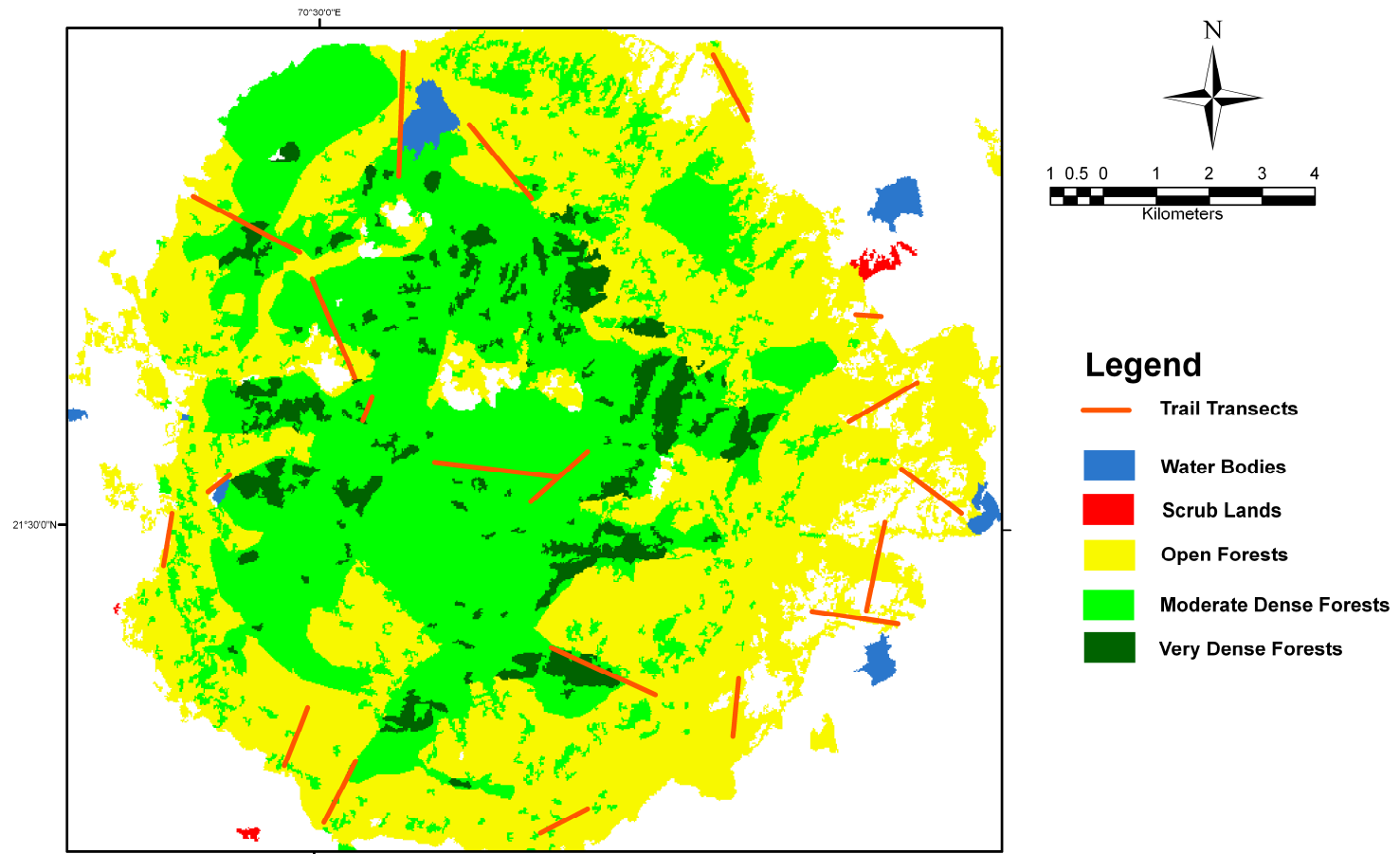


Figure 7.2: Distribution of the vehicle transects (n = 33) for prey base enumeration in the agro-pastoral eastern landscape.

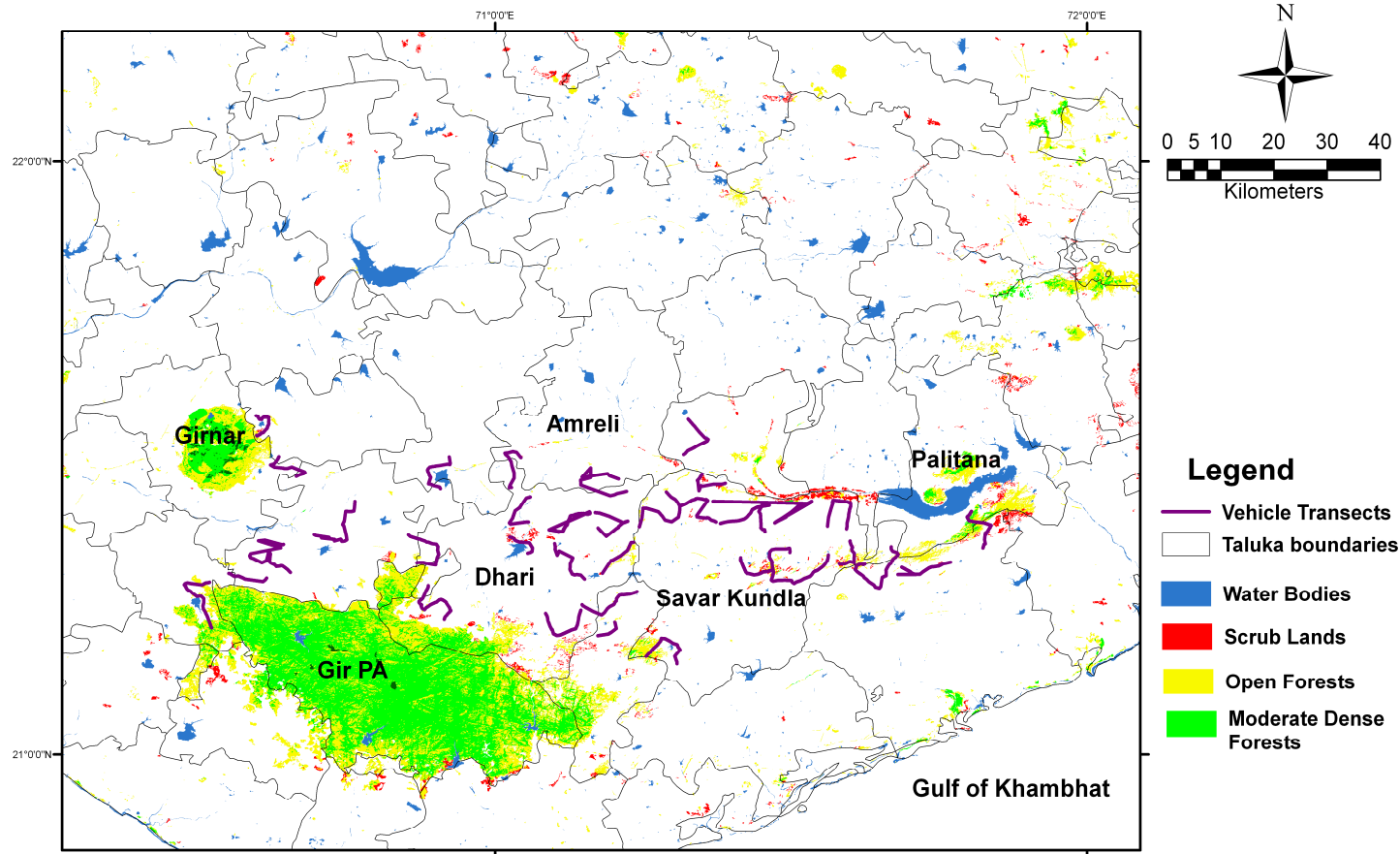
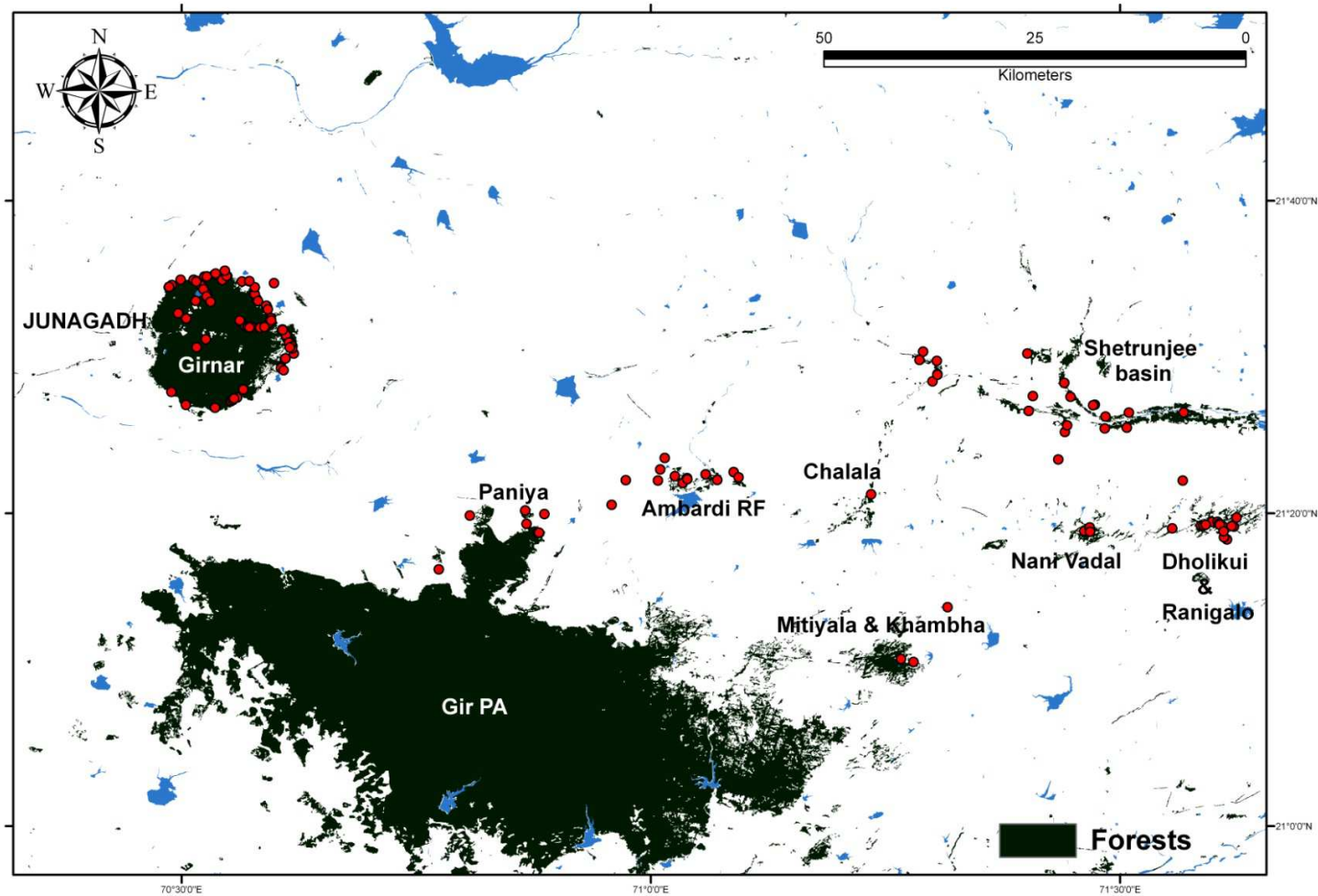


Figure 7.3: Lion scat collection fixes spreading in all potential lion habitats across the Gir landscape.



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. I 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). I 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). I 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 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. I 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).

7.2.4. Continuous monitoring of radio-collared lions (n = 4,104 hours of observation on seven radio-collared lions) to determine the amount of food consumed through predation and scavenging (**Figure 7.4**) as well as interval between feeding events.

Figure 7.4: Monitoring radio-collared lions to distinguish between i) lion predation (photo courtesy: Y.V. Jhala) and ii) lion scavenging events.

i)



ii)



7.3. Results

7.3.1. Lion prey abundance

In Girnar, density of lion prey (chital, sambar, nilgai, buffalo and cattle) was 8.7 (SE 1.2)/km² (**Table 7.1**). Sambar with a density of 3.8 (SE 0.7)/km² was the most abundant lion prey species in Girnar (**Figure 7.5**). 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 7.5**). In human-dominated eastern landscape, cattle contributed maximum in lion prey density and biomass (**Figure 7.5**) while wild prey constituted 3% of lion prey biomass (**Table 7.2**).

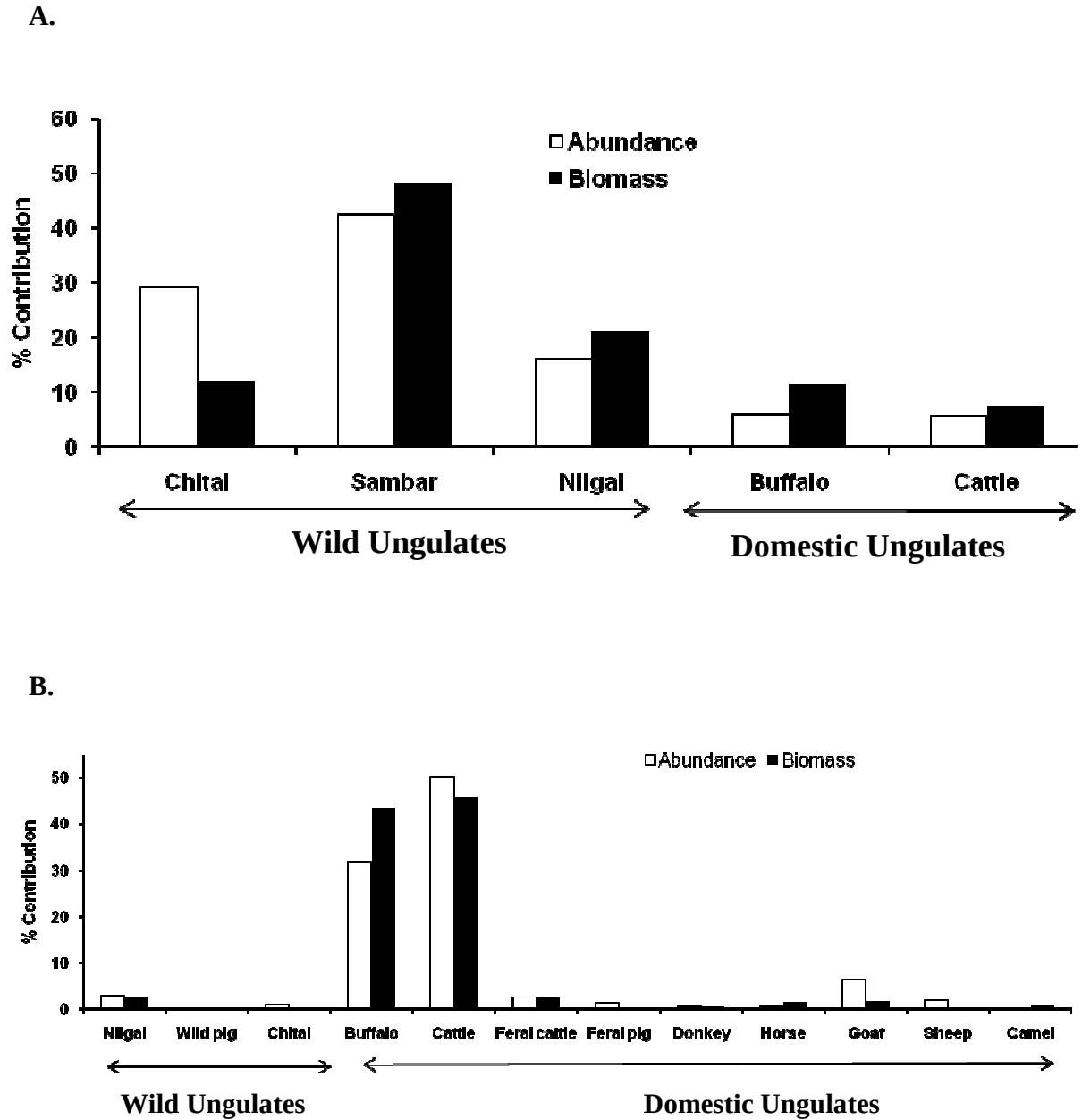
Table 7.1: Estimates of density, ESW (effective strip width), average group size, encounter rate and biomass with their standard errors of lion prey species in Girnar forest. Lion prey encompasses chital, sambar, nilgai, buffalo and cattle while wild prey constitutes of chital, sambar and nilgai. Percentage figures along total biomass represent contribution of different prey species/category in the total lion prey biomass.

Prey species	Unit weight (kg)	Density/km ²	ESW (meter)	Average group size	Encounter rate/km	Biomass density (kg/km ²)	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%)
Lion prey	--	8.7 (± 1.2)	44.1 (± 4.5)	7.1 (± 1.1)	0.77 (± 0.08)	--	171,516
Wild prey	--	6.2 (± 0.8)	45.3 (± 2.9)	3.2 (± 0.3)	0.57 (± 0.05)	--	138,871 (80%)

Table 7.2: 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 ²	ESW (meter)	Average group size	Encounter rate/km	Biomass density (kg/km ²)	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%)
Lion prey	--	18.9 (± 1.4)	97.6 (± 3.9)	--	3.68 (± 0.3)	--	4,001,645
Wild prey	--	0.8 (± 0.1)	95.3 (± 7.9)	--	0.2 (± 0.02)	--	118,948 (3%)

Figure 7.5: Percent contribution of different lion prey species in total prey abundance and biomass in A) Girnar forest and B) eastern landscape.



7.3.2. Lion kills

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 7.6**). I 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 7.7**).

Figure 7.6: Composition of lion kills in Girnar Wildlife Sanctuary and the eastern landscape.

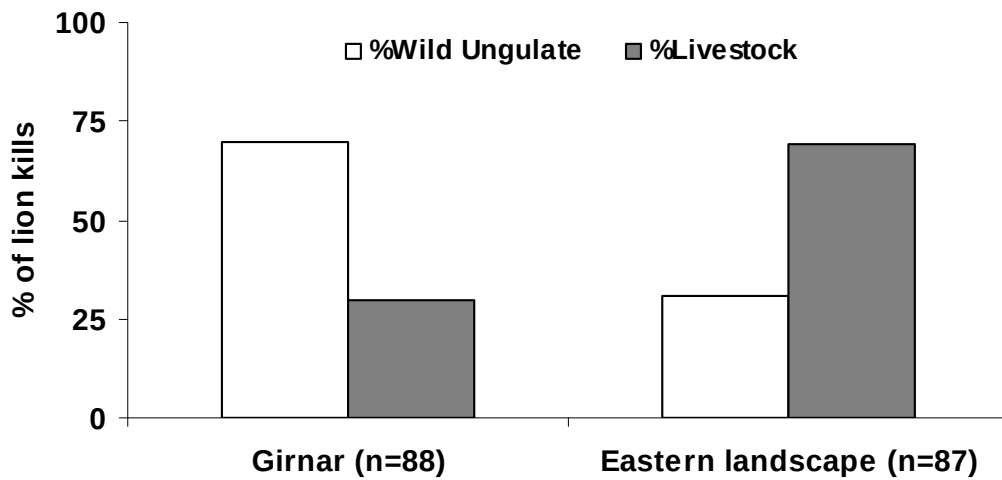
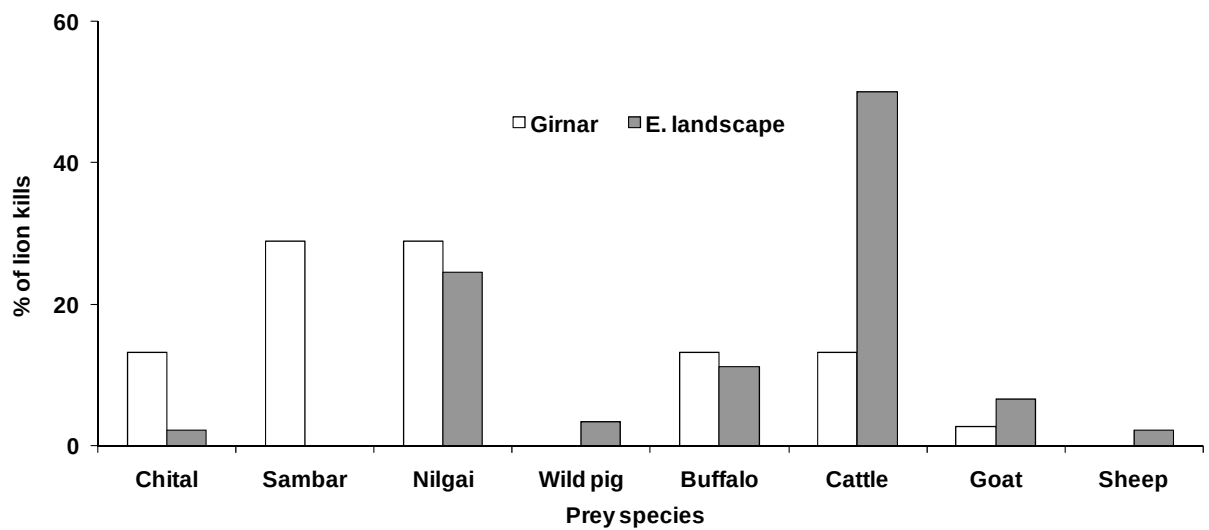


Figure 7.7: Percent contribution of different prey species among lion kills in Girnar and the eastern landscape.

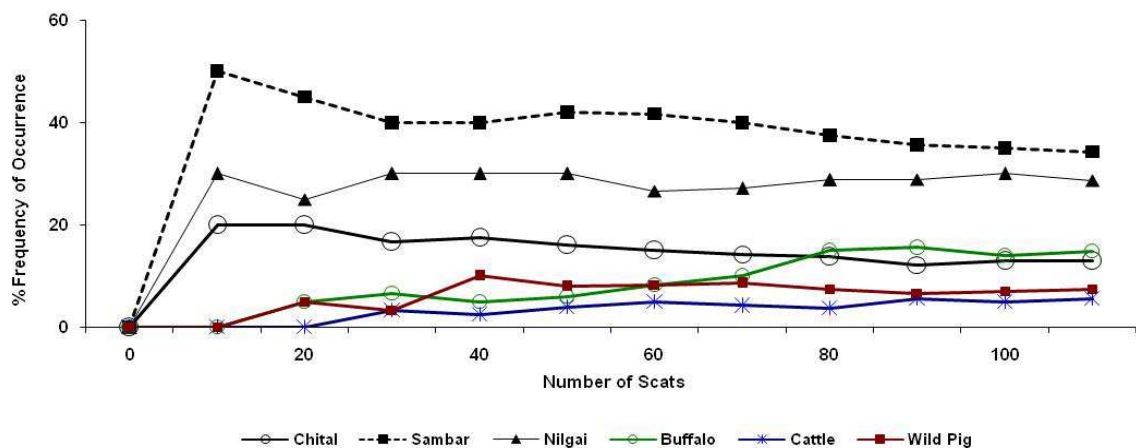


7.3.3. Lion diet

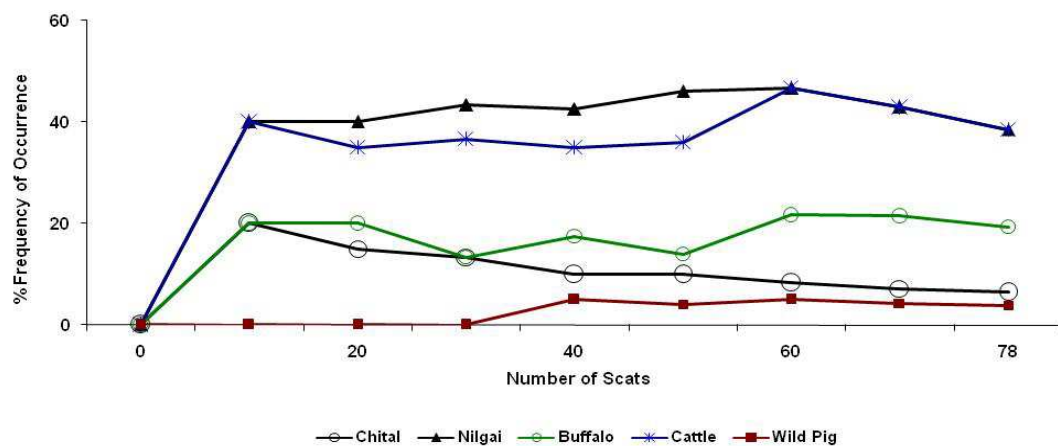
Frequency of occurrence of all prey items in scats reached an asymptote after sampling about 40 – 60 scats both in Girnar and the eastern landscape (**Figure 7.8**); so the sample sizes of 107 and 78 scats were deemed sufficient. A total of six prey items (chital, sambar, nilgai, wild pig, cattle and 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 7.8: 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 7.3**). 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 7.4**).

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 7.9**).

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 7.10**).

Table 7.3: 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 7.4: Prey species composition in Asiatic lion scats and their relative biomass contribution to lion diet in 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 7.9. 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.

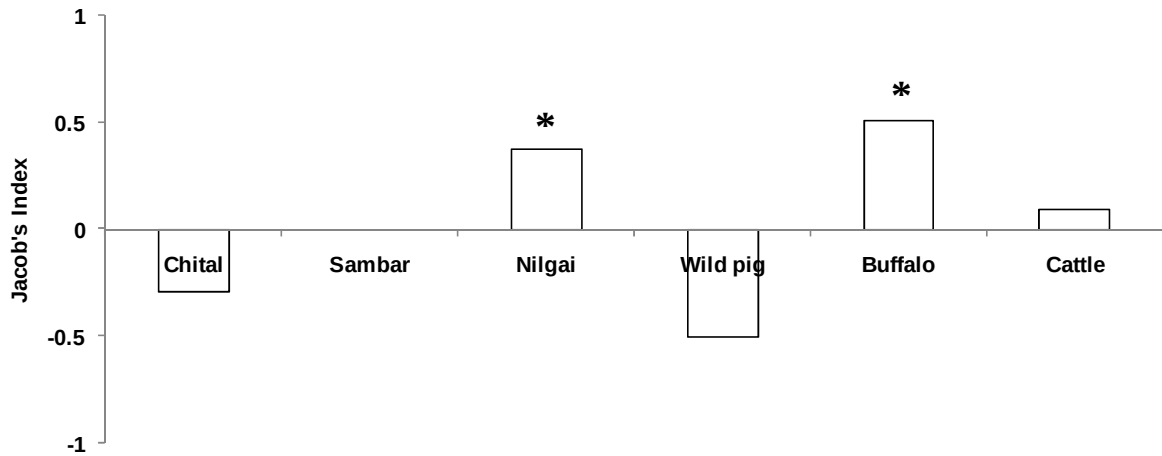
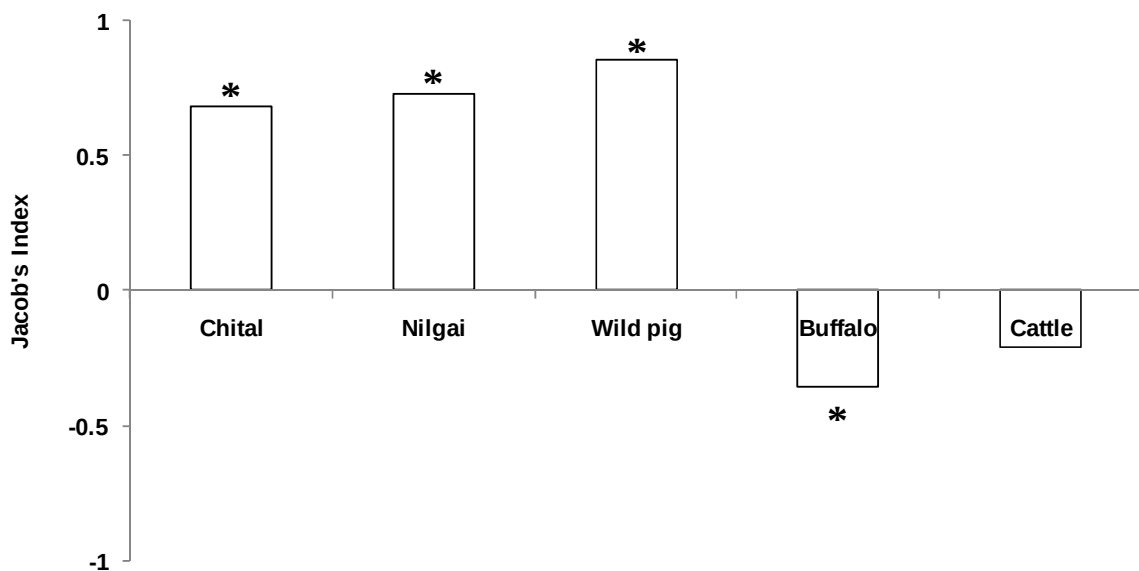


Figure 7.10. Food preference of lions in the eastern landscape based on Jacob's index (Jacob 1974). At 10% CV (Hines and Link 1994), * Chital ($p < 0.001$), *nilgai ($p < 0.001$) and *wild pigs ($p < 0.001$) were used more than their availability while *buffalo ($p < 0.001$) were underused. Cattle ($p = 0.33$) were used according to their availability.



7.3.4. 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 7.11**). In the eastern landscape, livestock composed 71% (20% from predation and 51% from scavenging) of lions' feeding events. I did not record any lion scavenging event on wild ungulates during the continuous monitoring sessions in this landscape (**Figure 7.12**).

Figure 7.11: Lion feeding events quantified through continuous monitoring on radio-collared lions (n = 720 hours observation on 3 radio-collared lions) in Girnar.

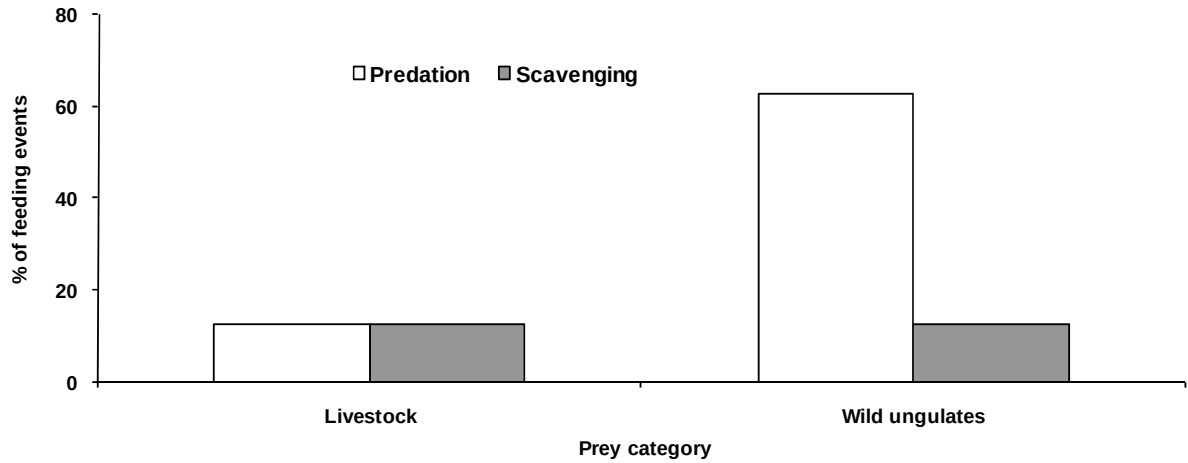
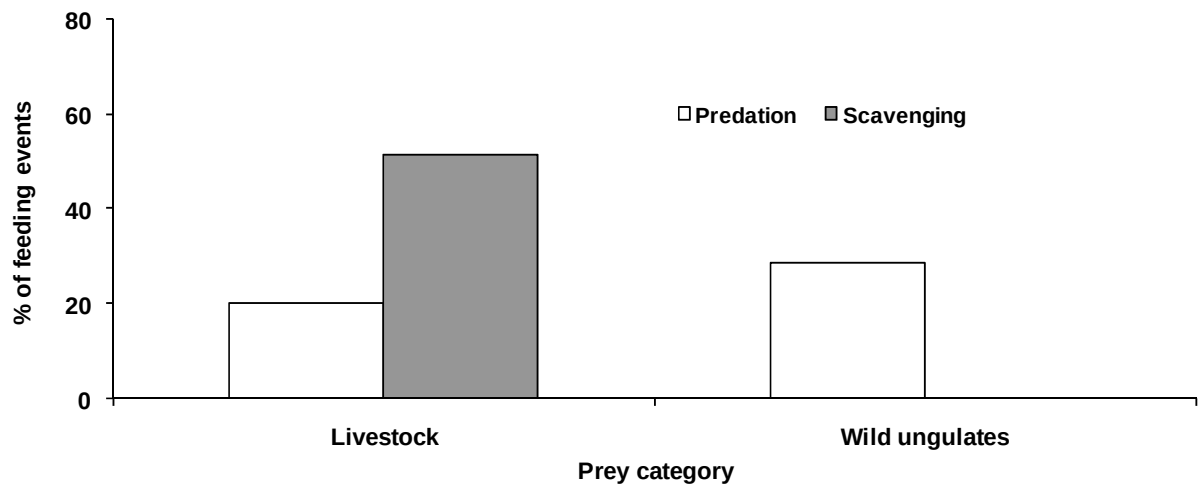


Figure 7.12: Lion feeding events quantified through continuous monitoring on radio-collared lions (n = 3,384 hours of observation on 4 radio-collared lions) in the eastern landscape.



Discussion

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 5 and 6). 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/km² estimated in an earlier 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, I

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 my 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 km² (chapter 3) while the current estimates of adult lion population is 6/100 km² (chapter 3; 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 km²; 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 increases 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 6 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 size 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 my 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 *Panjrapoles*) 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 8). 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 6) 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 my 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 8; Banerjee et al, 2013). The pattern within the Gir PA was found to be substantially contributing in shaping *Maldhari*-lion coexistence and I 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 (chapter 8). However, it should be kept in mind that lions' hunting peaks are early mornings and evenings (chapter 5) 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 (chapter 8).

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 8). *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 8). 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 (see chapter 8; Banerjee et al. 2013) and maintaining viable populations of other carnivores elsewhere on the Globe.

Aspects of Human-lion Conflict in the Gir
Landscape

*Economics of Lion-Maldhari Co-existence in
the Gir Forest*

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

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8.1.1 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 (Ogada et al. 2003; Inskip and Zimmermann 2009). Understanding people-carnivore relationship, therefore, becomes crucial especially for the conservation of large carnivores (Treves and Karanth 2003; Karanth and Chellam 2009). Although large carnivores sometimes 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 and the legal status of carnivores (Goldman et al. 2010). Reactions range from total extermination of large carnivores (Mech 1991), occasional removal of problem animals (Karanth and Gopal 2005; Athreya et al. 2011) to tolerance and coexistence (Raval 1991).

In a country like India which is home to approximately 1.2 billion people (Census of India 2011), the 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 (Rangarajan 1996; Saberwal and Rangarajan 2003). 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 (Adams and Hutton 2007). The contrary view by preservationists is that consumptive use by an increasing population of forest dwelling communities is unsustainable and detrimental to biodiversity conservation (Guha 2003; Datta et al. 2008).

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). 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 (Wildlife Protection Act 1972; Gadgil and Thapar 1990; Thapar 1994; Renugadevi 2012). 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 (Manfredo et al. 2003). 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 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). 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 (Singh and Gibson 2011; Banerjee and Jhala 2012).

The Gir Forests have been inhabited by semi-nomadic pastoral communities called *Maldharis* for the past one and a half century (Casimir 2001). Their religion is Hinduism and they have strong ethics and sentiments towards nature and natural resources (Raval 1991). 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 I quantify predation losses of livestock, estimate lion densities and diet and evaluate the economics of rearing livestock in lion habitats. I examined the notion that the tolerance of the *Maldharis* towards lions (Raval 1991) is not solely due to their beliefs and cultural sentiments but also because it is economically more profitable to live with lions.

8.1.2. Methodology

8.1.2.1. *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 dromedarius*) are kept for carrying fuel wood and fodder. The sale of dairy products has always been the mainstay of *Maldharis'* traditional economy (Varma 2009). My 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 8.1.1**).

8.1.2.2. Lion density estimation

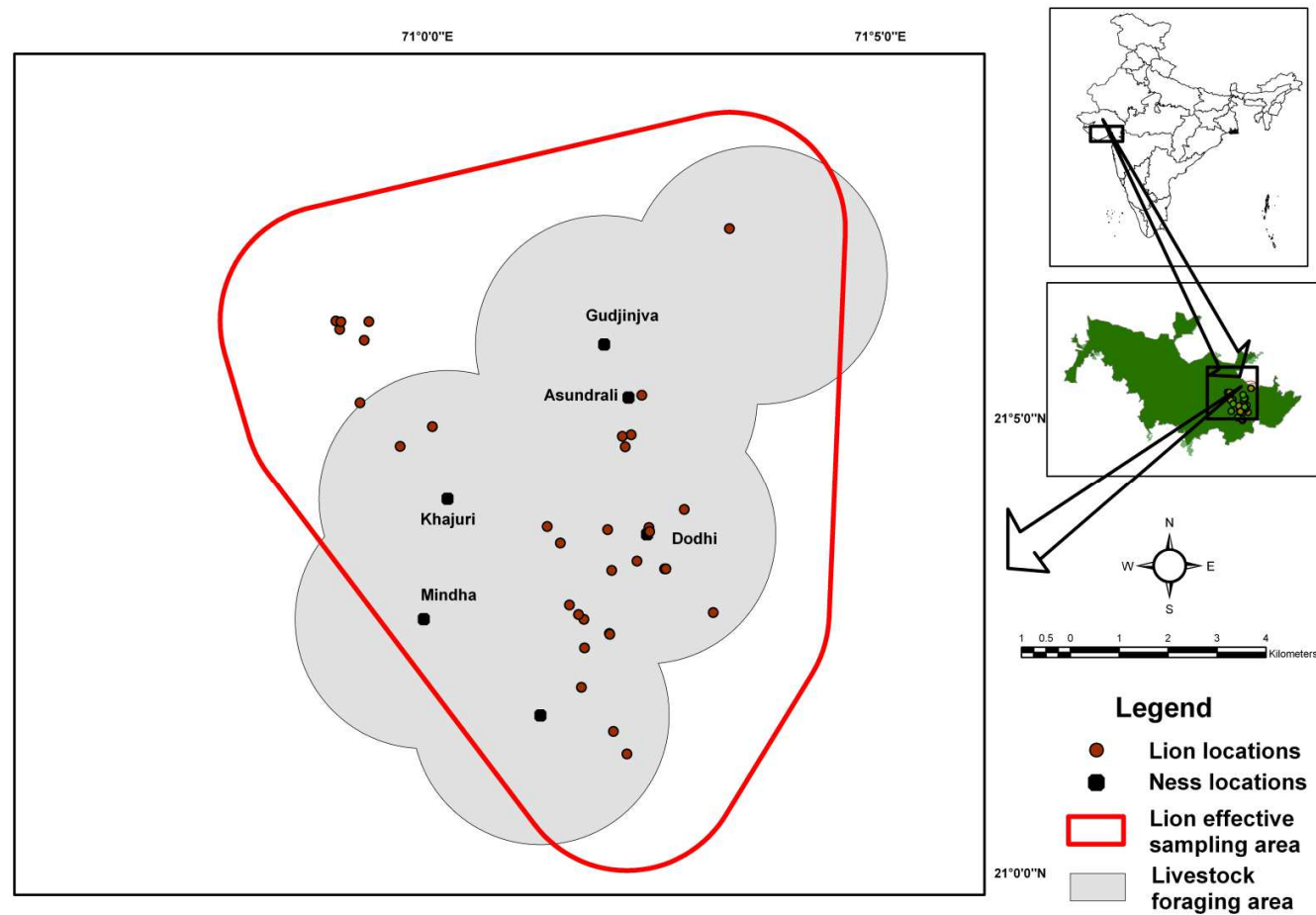
Lion population was estimated using closed-population mark-recapture (Pollock et al. 1990). I used cues, including tracks, roars and alert behavior of prey to locate lions. The entire study area of eastern Gir PA was systematically searched by vehicle and on foot within a period of 3-4 days which represented 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. I 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; see chapter 3 of the current thesis for more details). 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. 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 8.1.1**).

8.1.2.3. 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*. I 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 8.1.1: 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.



8.1.2.4. Lion diet

Lions' diet was determined by analysis of 165 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). I 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). I 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. I 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).

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 (Jethva and Jhala 2004). Consequently derived predation rates may be unreliable and an invalid basis to predict lion-*Maldhari* conflict levels. Therefore, I 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). I estimated livestock contribution to lion diet from lion numbers in the study area obtained from lion density multiplied by average daily intake requirement (7.3 kg/day, Joslin 1973) per lion, scat analysis and continuous monitoring of radio-collared lions in the study area.

8.1.2.5. 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 me or 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*. I 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 8.1.1**). I compared this with the present compensation scheme provided by the Gujarat State Forest Department (**Table 8.1.1**) 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.

8.1.2.6. Lion carrying capacity

In order to understand the relative significance of wild ungulates and *Maldhari* livestock in maintaining lion density in the study area, I used a regression model (Hayward et al. 2007) 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. I 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. 2007) 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). I 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, I 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 I considered all carcasses of dead livestock and a proportion of dry females, sub-

Table 8.1.1: 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)

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 me to examine the relative importance of different levels of livestock biomass in sustaining lion population in the study site of eastern Gir sanctuary.

8.1.2.7. Cost of lion predation on *Maldharis*' livestock husbandry

I 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. I developed a deterministic economic model (**Table 8.1.4**) where I 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 8.1.4**).

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. I 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 8.1.4**). I 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.

8.1.3. Results

8.1.3.1. Lion density

I 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^2 . Lion density was estimated at 15.2 (SE 0.1) lions/100 km^2 .

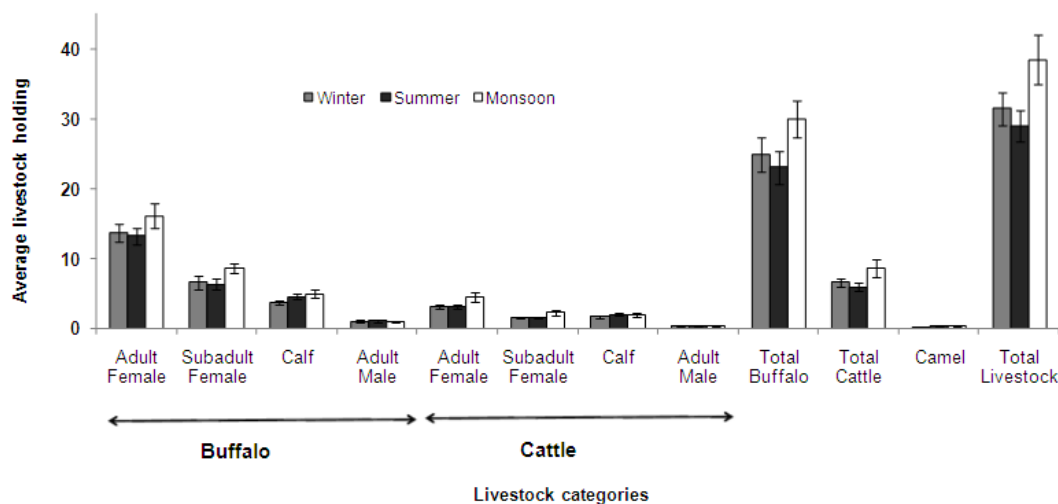
8.1.3.2. Livestock density, demography and holding

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^2) in pre-monsoon followed by 76.3 km^2 during summer and minimum foraging area during winter (65.9 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/ km^2 in winter, 30.1/ km^2 in monsoon and 24.7/ km^2 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 8.1.2**). 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 herdsmen 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 herdsmen were usually mobile sometimes leading and at times pushing the herd from the rear.

Figure 8.1.2: Average seasonal livestock holding of *Maldhari* family within the Gir forest (error bars are standard errors).

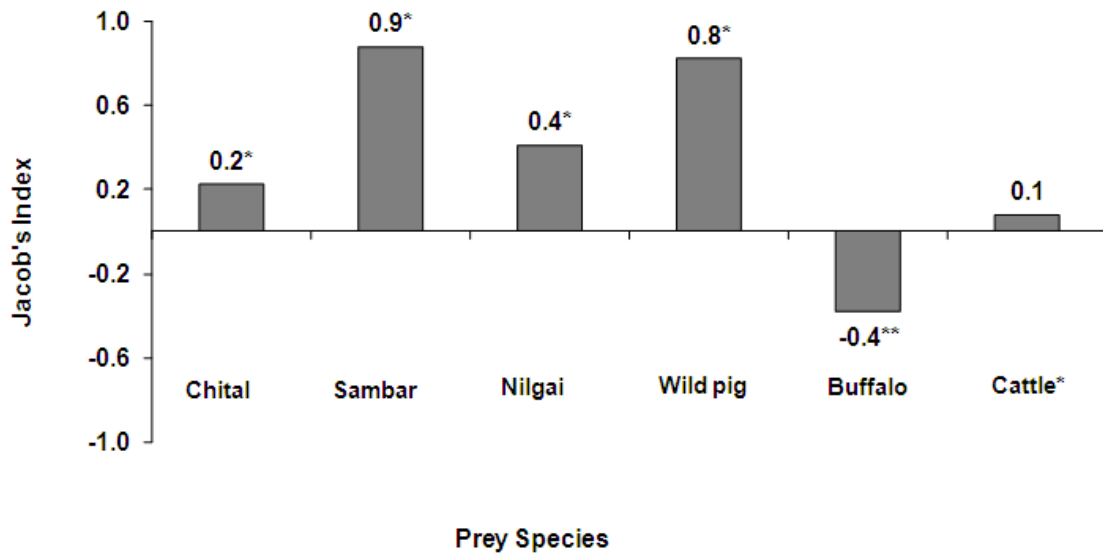


8.1.3.3. Lion food habits

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 8.1.2**). 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 8.1.3**).

Figure 8.1.3: 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.



8.1.3.4. Livestock depredation pattern

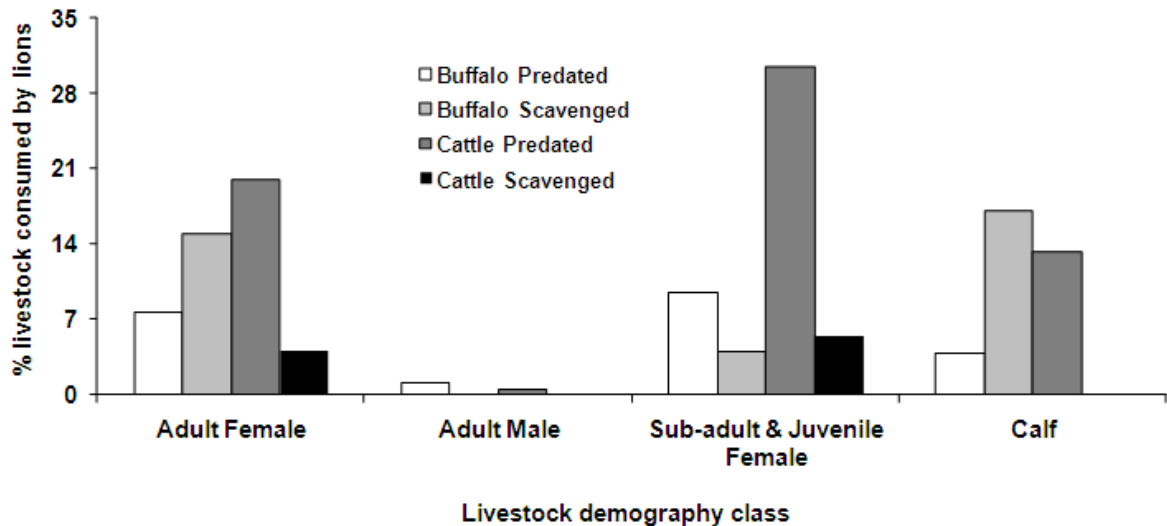
I recorded a total 308 livestock mortality from the six *nesses* during my study period, of which 58.4% was due to lion predation, 3.2% was due to predation by leopards and 38.4% was due to other natural causes. Lion predation was mostly on cattle (69.4%) followed by buffaloes (29.4%) and camels (1.2%). Non-productive cattle dominated lion kills (**Figure 8.1.4**). 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.

Table 8.1.2: 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 $y = 1.98 + 0.035x$ (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

Figure 8.1.4: 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.



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. I 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).

8.1.3.5. 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 km² while with no availability of livestock, the carrying capacity was 12 (95% CI 9-15) lions/100km². Lion carrying capacity with 24% of livestock population available for lions were 16 (95% CI 13-18) lions/100km² (**Table 8.1.3**).

8.1.3.6. 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 8.1.4**). 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 8.1.4**).

Table 8.1.3: 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 ²	Body weight (kg)	100% livestock biomass available			No livestock biomass available			24% livestock biomass available		
			Biomass density/km ²	Log (prey biomass)	Predicted lion carrying capacity (lions/100 km ²)	Biomass density/km ²	Log (prey biomass)	Predicted lion carrying capacity (lions/100 km ²)	Biomass density/km ²	Log (prey biomass)	Predicted lion carrying capacity (lions/100 km ²)
Chital	35.1 (16.0 – 54.5)	42	1473.4 (673.7 – 2,289)	3.2 (2.8 – 3.4)	22 (20 – 25)	1473.4 (673.7 – 2,289)	3.2 (2.8 – 3.4)	12 (9 – 15)	1473.4 (673.7 – 2,289)	3.2 (2.8 – 3.4)	16 (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 8.1.4: 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 (with Govt. compensation) 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 (without Govt. compensation) 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 with Govt. compensation	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 and 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*20*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 $(12-3.9)*(8.4-0.4)*[(5 \times 20 \times 200) + 845] * 0.28 * 0.36$	136,156 (129,432 – 142,880)
E	Lost Opportunity cost without compensation	Same as equation D but with 100% of the cost being uncompensated. Therefore the final equation becomes $(12-3.9)*(8.4-0.4)*[(5 \times 20 \times 200) + 845] * 0.28$	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>)	1 person extra for a herd of 25 therefore for 100 LS the cost is of 4 persons@ ₹. 142 ^s /day for a year	207,320

	in lion habitat)		
G	Total revenue loss to <i>Maldhari</i> by lion predation and extra guard cost when Govt. compensation is availed for lion predation	B+D+F	355,626 (353,979 – 357,275)
H	Total revenue loss to <i>Maldhari</i> by lion predation & extra guard cost when Govt. compensation is not availed for lion predation	C+E+F	619,283 (614,705 – 623,861)
I	Profit of living in lion habitat with Govt. compensation for lion predation	A-G	1,104,373 (1,102,725 – 1,106,021)
J	Profit of living in lion habitat without Govt. compensation for lion predation	A-H	840,717 (836,139 – 845,295)
K	% of cost offset by living in Gir forest with Govt. compensation	100*(I/A)	75.6 (75.5 – 75.7)
L	% of cost offset without compensation	100*(J/A)	57.5 (57.2 – 57.9)
Average livestock holding in a <i>Maldhari</i> family			33
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.

8.1.4 Discussion

I 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 advantage of 21 man-day wages to a no-compensation scenario (**Table 8.1.4**). I 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). I 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 km²). However, when I 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 km²), 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 (Røskaft et al. 2003; Athreya 2006; Rahalkar 2008), 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. I 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-accompli*. I 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). I 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. I 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; Maclellan 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. I 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.

I 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 km² 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 7 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 (Karanth 2003; 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. I 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.

*Spatio-temporal pattern of lion attacks on
humans in the Gir Landscape*

***SPATIO-TEMPORAL PATTERN OF LION ATTACKS ON HUMANS IN THE
GIR LANDSCAPE***

8.2.1 Introduction

Across the globe, human activities in recent years have caused declines in carnivore population levels and contraction of their geographic ranges (Woodroffe 2000). Even where carnivores are not directly persecuted, they are often vulnerable to incidental declines owing to their large area and energy requirements and hence small population sizes (Gittleman 1993). Human population growth has led to encroachment into wildlife areas, alteration of carnivore habitat, and depletion of prey populations, while successful conservation has allowed for the recovery of several carnivore populations (Bagchi and Mishra 2006; Treves and Karanth, 2003). Most severe example of human wildlife conflict is *direct* carnivore attacks on people for which there is currently a lack of knowledge and global awareness. This, along with the emotions such attacks elicit, makes direct human carnivore conflict one of the most damaging types of conflict for wildlife populations and people (Quigley and Herrero 2005). When carnivores attack humans, campaigns to eradicate them are inevitable (Young and Goldman 1946; Seidensticker et al. 1999; Woodroffe 2000). Understanding the circumstances surrounding carnivore attacks and mitigating them is a crucial issue for conserving and managing many apex predators (Herrero 1985; Frank, 1998).

Attack by large carnivores on humans has been widely reported from several regions and in several species; lion *Panthera leo* (Patterson 1907; Guggisberg 1961; Alderton 1993; Yamazaki and Bwalya 1999; Baldus 2006; Packer et al. 2005; 2011; Begg et al. 2007; Kushnir et al. 2010) in Africa, leopard *Panthera pardus* (Inskip and Zimmermann 2009) and spotted hyenas *Crocuta crocuta* (Balestra 1962) in Africa, grizzly bear *Ursus arctos* (Kaniut 1983, 1989; Herrero 1985), polar bear *U. maritimus* (Herrero and Fleck 1990), American black bear *U. americanus* (Herrero 1985) and cougar *Felis concolor* (Young and Goldman 1946; Hansen 1993) in North America, brown bear *U. arctos* (Vaisfeld and Chestin 1993) in Russia, wolves (*Canis lupus*) in Europe (Linnell et al. 2003) and tiger *Panthera tigris* (Corbett 1954; McNeely and Wachtel 1988; Sunquist and Sunquist 1988; Montgomery 1995;

Goodrich 2010) in Southeast Asia and Russian far east. In India such *man-eating* incidents have been reported for leopards (Goyal 2001; Athreya et al. 2007), tigers (Sanyal 1987); sloth bears (Rajpurohit and Krausman 2000), peninsular wolves (Jhala and Sharma 1997) and lions (Saberwal et al. 1994). Saberwal et al. 1994 reported 193 attacks by lions on humans in between 1978 and 1991 in the peripheral areas of the Gir PA. Gir lions' intra-specific competition for space and food and change in cropping pattern surrounding the Gir PA were some of the main reasons identified behind those attacks. The study also called for translocation of 'problem' lions to other suitable habitat areas within the former range of the Asiatic lions and even culling of problem lions against commercial game license (Saberwal et al. 1994).

Gir and its lions highlight India's conservation commitments and elucidate a success story (Singh and Gibson 2011; Banerjee and Jhala 2012). Strong protection regime and active management by the Gujarat state forest department has increased lion numbers and range in the past two decades. Gir lions have increased to about 400 and dispersed into a large tract of agro-pastoral landscape adjoining the Gir forests. Lions are occupying landscapes where people have no recent memorable experience of living with them and with no idea of 'how to behave during sudden encounters with lions'. These escalate hitherto less known incidents of lion attacks on humans in the Gir landscape in recent years and are likely to increase as lion number increases and lion range expands further. Currently lion translocation proposal (Chellam 1995; Johnsingh et al. 2007) is under official red-tape and its implementation is doubtful due to legal and political battle of ownership between the State of Gujarat and Central (Federal) Government in India (Jackson 2006). Killing of problem lions cannot be a viable option in a state like Gujarat where lion conservation is an emotive issue for majority of people and the animal welfare lobby is strong. Repeated application of lethal control may even lead to population extirpation (Woodroffe et al. 2005). Furthermore, in a free-ranging population, particularly in the larger landscape, it may become very difficult to specifically target the 'actual' problem lion; several lions may have to be killed before the 'actual' problem lion gets eliminated. In such situations local wildlife managers are often criticized leading to conflicts with local communities. In this context an unprejudiced understanding of the ecology of such attacks becomes vital. Because human-lion conflicts occur over vast geographical areas, and resources for protecting people and livestock are limited, predicting

high-risk areas is important in setting management priorities. In the current sub-chapter I therefore aimed to determine the landscape factors and temporal patterns leading to such attacks in the Gir landscape. Examining these factors at the district-level will therefore provide a more nuanced view of the risk factors for lion attacks and assist in developing an ecology based policy framework for future lion conservation.

8.2.2 Methodology

8.2.2.1 Field data collection

I defined 'lion attack' as any interaction between a lion and a human causing physical injury to the latter (after Saberwal et al. 1994). I, however, did not consider the attack by lions on forest department staff during various rescue and treatment operations. Data on lion attacks was collected from January 2007 through July 2012 from the Gir landscape. Whenever there was a lion attack on human, the information was instantly obtained because of the good rapport with the forest department and my research team's stay at the park head quarter. I attempted to visit majority of the attack sites ($n = 58$) within 24-36 hours to ascertain the identity of the carnivore on the basis of signs and tracks. Information on the incidents which could not be personally investigated was collected from trustworthy team members of the forest department (range officer, veterinary officer or rescue team member) involved in dealing those. In 50% ($n = 2$) cases of fatal attack events the spot could be visited after the local repercussions got settled while for the rest I could not visit the spot but obtained the information from the abovementioned trustworthy team members of the forest department. Any ambiguous record was not included in the analysis. Primarily, the victim, family members of the victim and the local people (only when the victim or his/her family was unwilling to cooperate) were informally interviewed to obtain the details about the demographic profile of the victim, human activity patterns during the lion attacks and a brief description about the attack event (location, time, nature, body parts attacked etc.). Information on body parts attacked and extent of injury was used to develop an index of severity of injury. An injury was defined as mild when relatively less important body parts (like legs, hips etc.) were attacked. A medium injury was defined as an injury involving at least two parts of the body. A severe injury involved multiple injuries or injuries on multiple and vital body parts (like head, chest, stomach, face etc.). Information on critically mauled

victims were collected from their family and/or neighbors for two months to ascertain if they died at subsequent stages owing to injuries caused by lions attacks. I did not record any such deaths during my study period in the Gir landscape. Fatal lion attacks during the study involved instantaneous deaths of the victims.

To understand the human context involved in attack events, I classified them into three major categories as 1) deliberate, 2) accidental and 3) provocative. Deliberate attacks are generally made by sick, old and dispersing lions due to their aggressive reactions (Chardonnet et al. 2010). Accidental attacks involved attacks by lions being suddenly surprised at human encounters (La Grange 2005) and risks associated with human activities like crop and livestock guarding (Packer et al. 2005), walking alone or sleeping outside at nights in a lion area (Skuja 2002) and going to latrines away from house at nights (Packer et al. 2005). A provoked attack was defined as one in which a person approached a lion too closely or tried to touch, injure or kill it, thus provoking an attack (Quigley and Herrero 2005).

Whenever possible, I corroborated the victim's or his/her kins' accounts from witnesses or people who visited the scene shortly after an attack (mostly for rescue) to avoid bias and exaggeration of facts. Victims' ages were classified into four classes, viz. children (< 14 years), youth (15-44 years), middle age (45-59 years) and elderly/old (> 60 years). I used Global Positioning System (GPS) readings translated into Universal Transverse Mercator coordinates to map the location of lion attacks. District-level human demography data was extracted from the office of the Registrar General, India for census data 2011 under the section Primary Census Abstracts (also available at http://www.censusindia.gov.in/2011-prov-results/prov_data_products_gujarat.html).

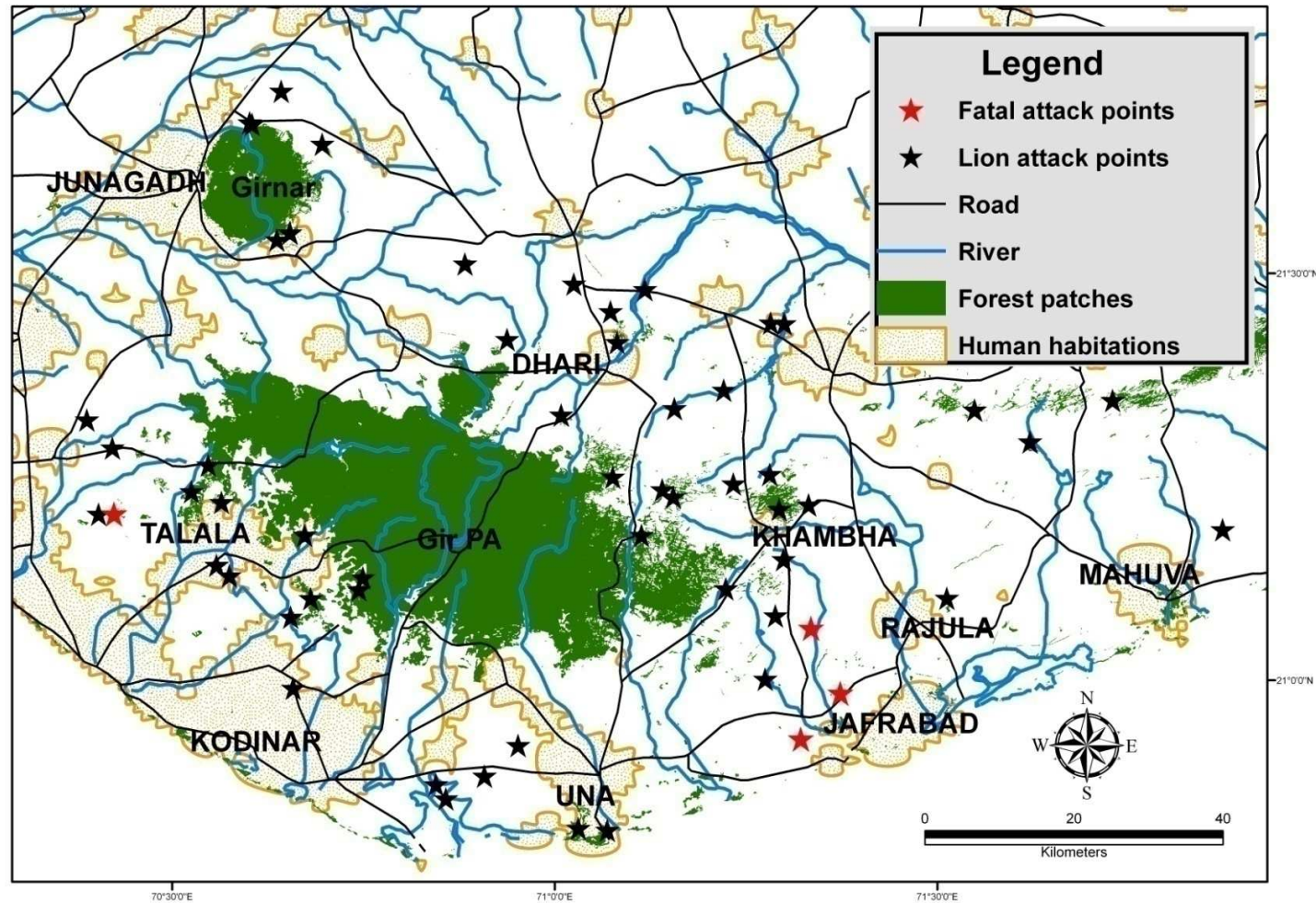
8.2.2.2 Data analysis

The attack data was analyzed to arrive at the spatio-temporal pattern of such attacks. I used chi-square analysis [$\alpha = 0.05$] (Zar 2010) to compare attack events between districts, seasons, months of the year, time of the day and different human demography classes. I estimated district specific attack frequencies to map relative intensity of such events. The Gir region, like other parts of India, is predominantly agrarian and has a discrete seasonal cropping pattern (Vijayan and Pati 2002). Therefore, I investigated the seasonal variation of lion attacks among summer (February – May), monsoon (June – September) and winter (October

– January) as human activities in the region considerably varied in these seasons in reflectance with farming activities.

The road and drainage maps of the digital chart of the world (ESRI 1992) for the country at a scale of 1:1000, 000 were used for mapping rivers and roads in the study area. Forest cover map was obtained from the Forest Survey of India (FSI 2009) based on digital interpretation of the satellite data for the entire country. LISS-III sensor data of IRS 1C satellite has been used to map forest cover. Human habitations were delineated on the basis of night light data obtained from NOAA/NGDC using the Defense Meteorological Satellite Program's Operational Line-scan system (DMSP/OLS) (Croft 1973, 1978; Elvidge et al. 1997). Habitation centroids were calculated using sampling tools in Hawth's Analysis Tools add-on for ArcGIS (Beyer 2004). Distance of each attack point to the nearest river, road and human habitation was calculated to understand the spatial context of the attack events.

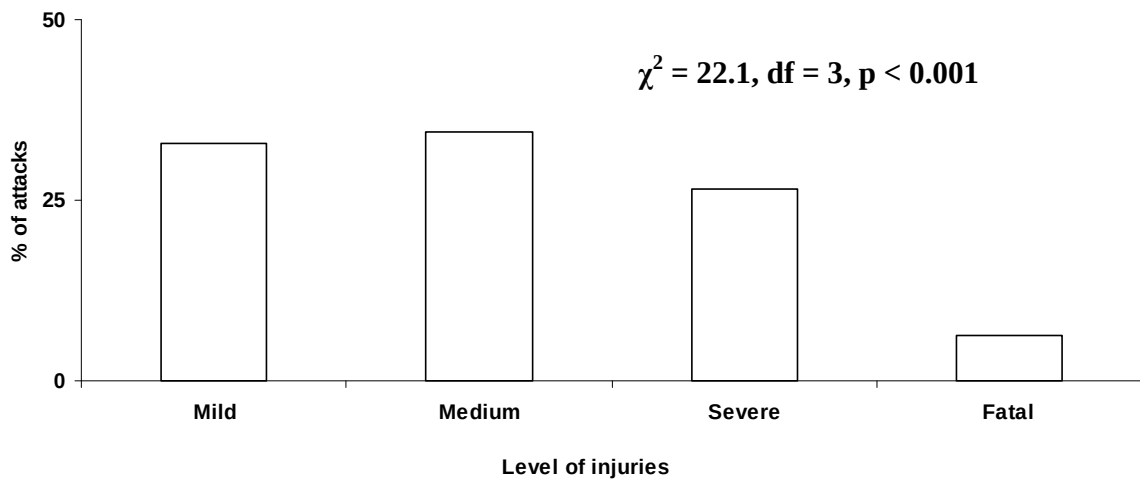
Figure 8.2.1: Gir landscape, showing lion attack points (n = 76) on humans between 2007 and 2012. Fatal attack points (n = 4) are marked in red. Human habitations delineated on the basis of night light data.



8.2.3. Results

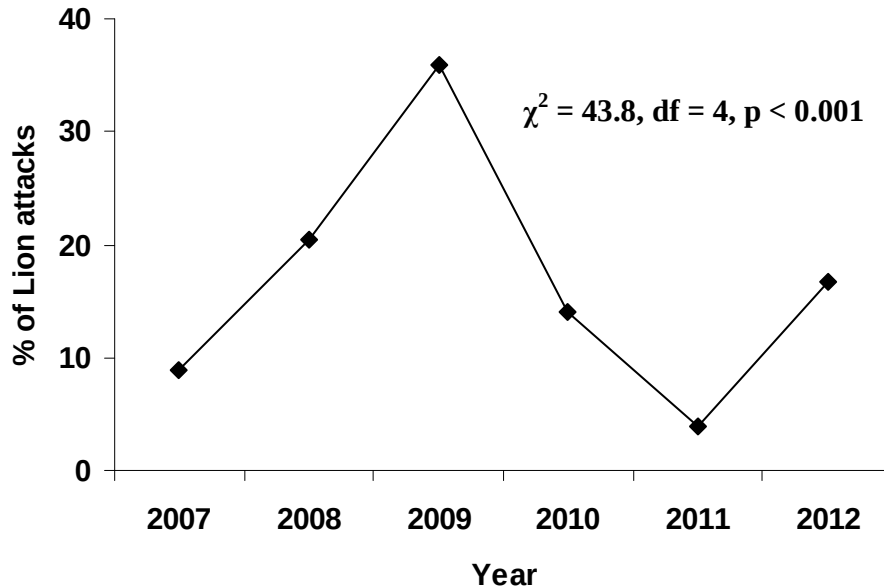
A total 76 (13.6 attacks/year) lion attack events on humans have been recorded between January 2007 and July 2012 in the Gir landscape (**Figure 8.2.1**). Most attacks (67%) resulted in mild to medium mauling; 28% of the attacks resulted into severe injuries while only four attacks (5%; 0.7/year) were fatal ($\chi^2 = 22.1$, $df = 3$, $p < 0.001$; **Figure 8.2.2**). Only 8% of the attacks were recorded inside the Protected Areas (Gir PA and Mitiyala wildlife sanctuary) and the rest were in human dominated landscape.

Figure 8.2.2: Extent of the victims' injuries due to lion attacks in the Gir landscape during the study period of 2007 and 2012.



Lion attacks varied across the study years with the majority of attack events recorded in 2009 (36%) and 2008 (21%) ($\chi^2 = 43.8$, $df = 4$, $p < 0.001$; **Figure 8.2.3**). Until mid July 2012, I recorded 13 lion attack events.

Figure 8.2.3: Year-wise variation of lion attacks on humans during the study period (2007-2012) in the Gir landscape.



Lion attacks were biased toward males (96%) compared to women ($\chi^2 = 57.4, df = 1, p < 0.001$). Most of the victims were middle aged, with the average age of the victims being 39.3 years (SD 14, median 40 years, range 8 -72; $\chi^2 = 52.6, df = 4, p < 0.001$). The youngest were two boys of 8 years; while the oldest person was a lady of 72 years who was attacked by a sub-adult male lion while working in the farmhouse.

Lion attack incidents were higher in summer compared to monsoon and winter ($\chi^2 = 5.02, df = 2, p = 0.08$; **Figure 8.2.4**). Majority of attacks (35.2% each) were recorded during evening (4 PM – 6 PM) and night hours (6 PM – 10 PM) and again in the morning between 7AM to 10 AM [$\chi^2 = 92.3, df = 4, p < 0.001$; **Figure 8.2.5**].

Figure 8.2.4: Seasonal pattern of lion attacks on humans in the Gir landscape between 2007 and 2012.

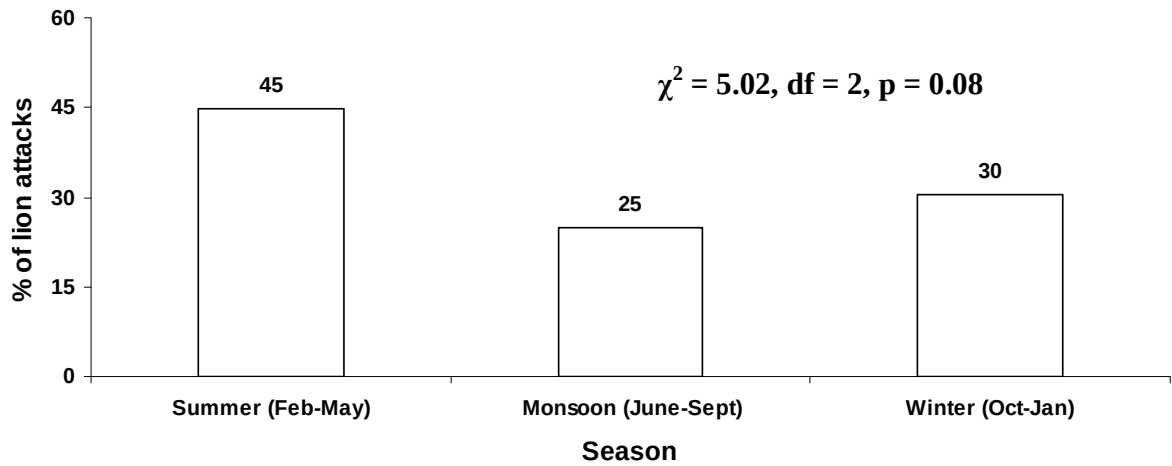
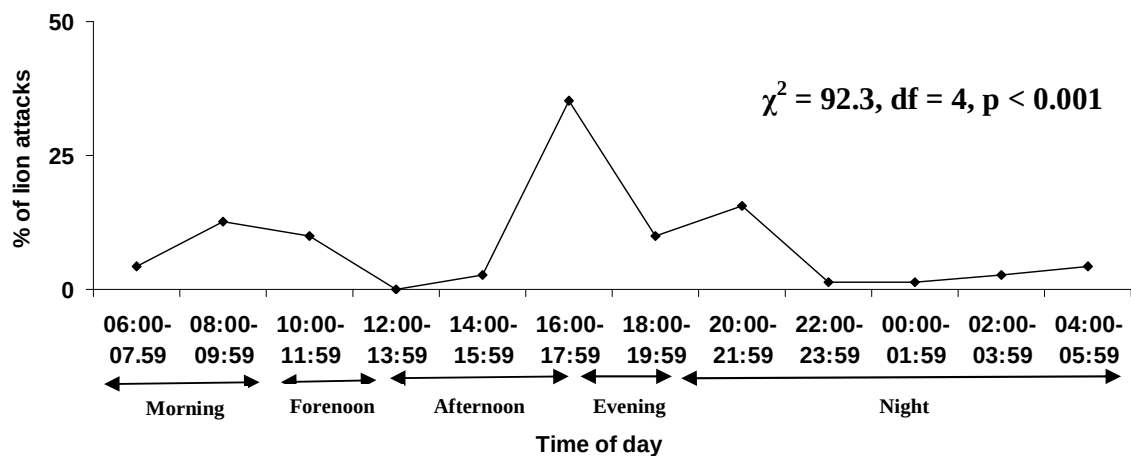


Figure 8.2.5: Temporal variation of lion attacks on humans in different times of the day in the Gir landscape between 2007 and 2012. Time is in Indian Standard Time (IST: + 5:30 hrs GMT).



In 56 cases the group sizes and social group composition of attacking lion(s) could be unambiguously ascertained. Mostly single lion was involved in attacking humans in the Gir landscape [average group size of attacking lion: 1.4 (SE 0.11); **Figure 8.2.6**]. Male coalitions and female groups were more (43% each) involved in attack events in comparison to mixed group (male and female; 9%) lions or lionesses with cubs (5%; **Figure 8.2.7**). Fatal attacks were mostly made either by single male (75%) or mixed groups (25%).

Figure 8.2.6: Group size of lions attacking humans in the Gir landscape between 2007 and 2012.

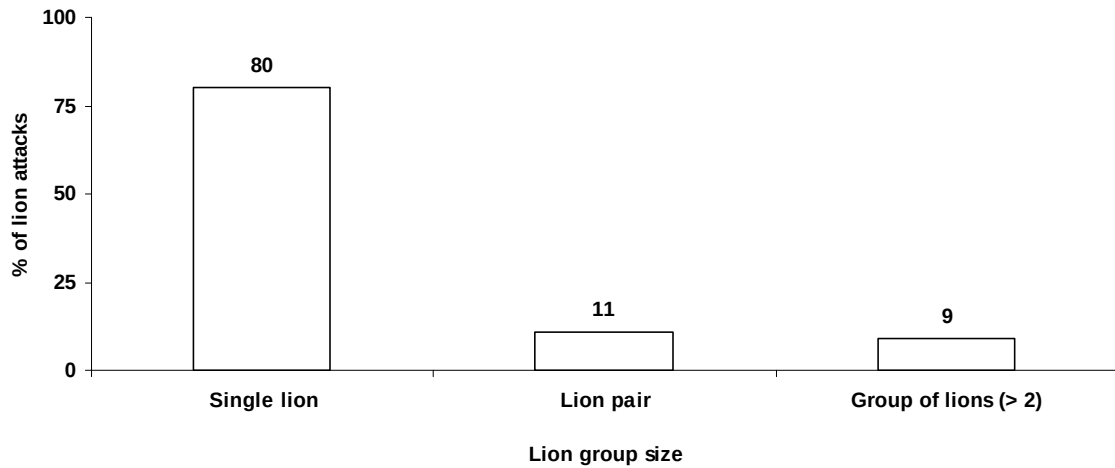
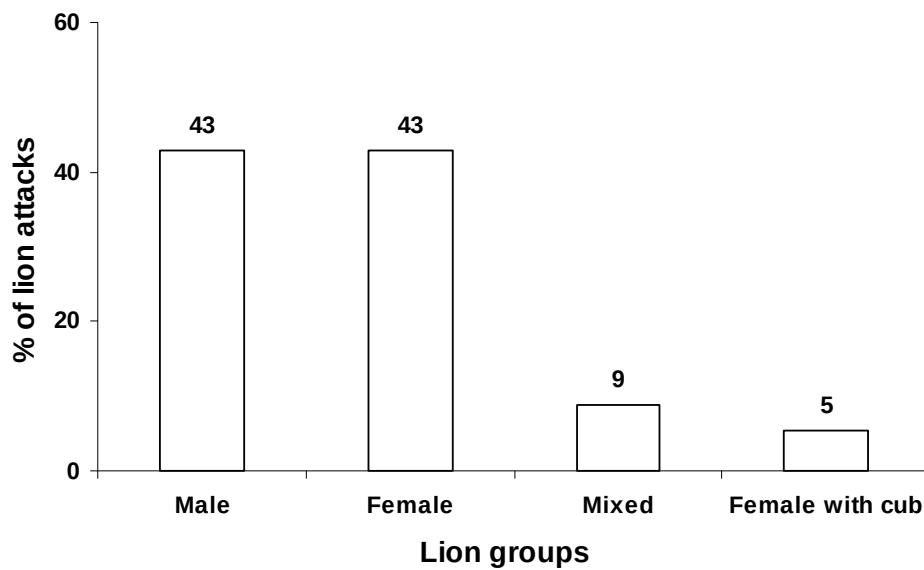
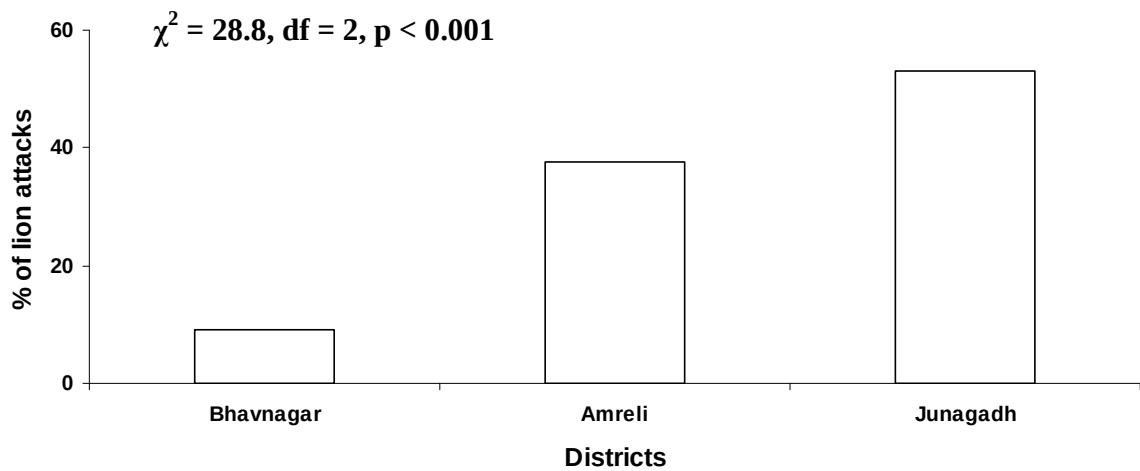


Figure 8.2.7: Group composition of the lions attacking human in the Gir landscape in between 2007 and 2012.



Over half (53%) the attack events were recorded from Junagadh district compared to 38% from Amreli district and 9% from Bhavnagar district ($\chi^2 = 28.8$, $df = 2$, $p < 0.001$; **Figure 8.2.8**).

Figure 8.2.8: District-wise lion attack events on humans in the Gir landscape between 2007 and 2012.



Location and activity of the victims during attacks varied significantly. Majority of attacks occurred in the outskirts of villages when the victims were either outside home in the agricultural fields or in other open areas ($\chi^2 = 101.7, df = 6, p < 0.001$; **Figure 8.2.9**). Majority of attacks occurred when the victims were working in agricultural fields or guarding and grazing their livestock ($\chi^2 = 62.1, df = 7, p < 0.001$; **Figure 8.2.10**).

Majority of lion attacks were accidental (80%; **Figure 8.2.11**). Illegal trespassing and provoking lions either on kills or mating contributed substantial proportion (15%) of lion attacks in the Gir landscape. Fifty percent of the fatal lion attacks were provocative either on kills or during mating while the remaining 50% were accidental and occurred inside hutments in agricultural fields.

The average distances of the nearest village, road, water body and forest patch from the lion attack sites were estimated to be 1.3 (SE 0.1) km, 2.7 (SE 0.2) km, 2.3 (SE 0.2) km and 1.5 (SE 0.2) km respectively.

Figure 8.2.9: Locations of the victims during lion attacks in the Gir landscape between 2007 and 2012.

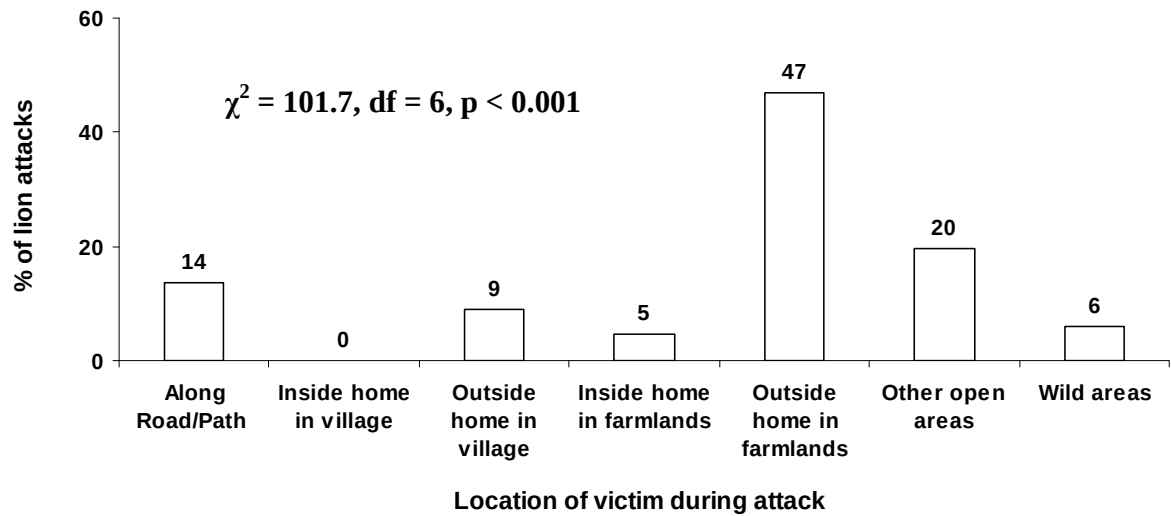


Figure 8.2.10: Activity of the victims during lion attacks in the Gir landscape between 2007 and 2012.

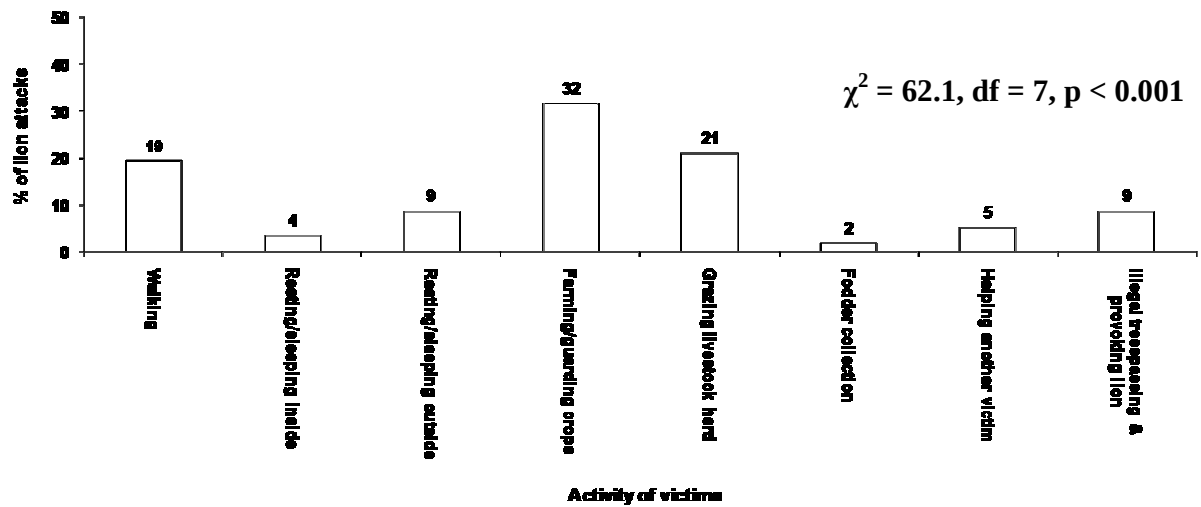
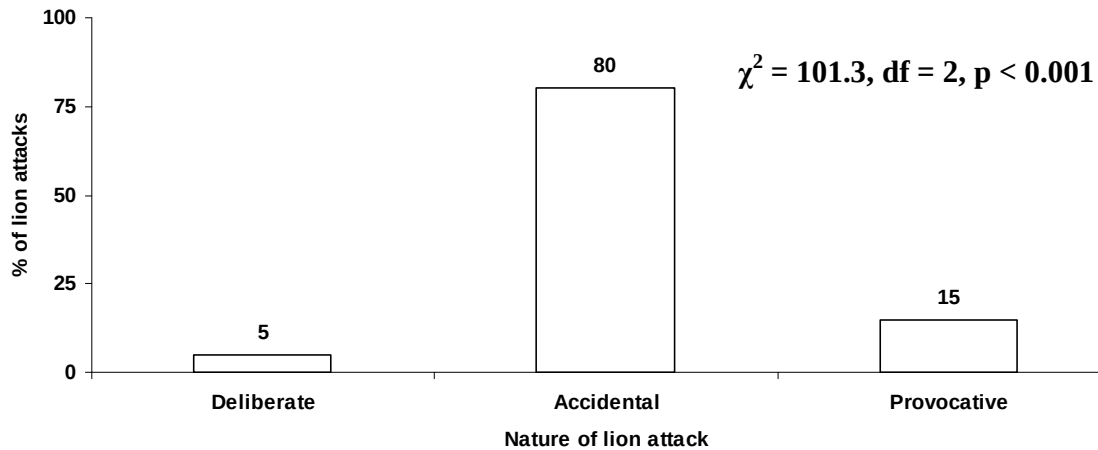


Figure 8.2.11: Nature of lion attacks in the Gir landscape between 2007 and 2012.



8.2.4. Discussion

Globally four species of large felids (tiger, lion, mountain lion and leopard) have been found to show a propensity to attack humans (Inskip and Zimmermann 2009). Although the trend of attack on humans is diminishing, often attributed to decline in felid populations (Treves and Naughton-Treves 1999); in some Asian and African countries such attacks are still common (Thirgood et al. 2005). For example attacks on humans by lions have increased significantly in Tanzania over 1990-2005 (Packer et al. 2005); an increase in puma (*Puma concolor*) attacks on humans has also been reported in the USA and Canada in recent decades (Beier 1991). In India the carnivore species mostly involved in attacks on humans are leopard and tiger and there is plenty of literature on these (Sawarkar 1986; Sanyal 1987; Goyal 2001; Athreya et al. 2007; 2011) and on pattern of their increase in recent years (Negi 1996). Gir lions are also known to attack humans (Saberwal et al 1994), this poses a serious challenge for their conservation in the human dominated landscape. severely undermining their conservation prospectives. However, the study could not determine the spatio-temporal variations behind those attack events and variations of human activities linked to risk. With lions living in proximity with humans, lion-human conflicts are inevitable. Lion attacks on humans negatively influences local people's perceptions of risk factors and subsequently their attitudes toward lion and other wildlife. The current study provides a glimpse of spatio-temporal variation in the attack events at a resolution of district level. The findings in

conjunction with the local people's perception toward lion conservation in the Gir landscape (chapter 8.3 for more details) have substantial role in mitigating future lion-human conflicts in the long term.

Lions' use of human dominated Gir landscape has increased in the past two decades. Nevertheless, the lion attack rates on humans (13.6 attacks/year) remained almost the same in the same period (14.8 attacks/year; Saberwal et al. 1994). Encounters between humans and lions in the Gir landscape are very common. Fifty six percent of the respondents in my interview survey reported a lion encounter rate of once in a week while 39% reported encountering lions 2-4 times/week and 5% reported a weekly lion encounter rate of more than four times. A conservative estimate suggests that a person in the Gir landscape on an average encounters lions a minimum 52 times in a year. But rarely do these encounters result in an attack. This is further supported by the radio telemetry data. Although I did not have information on the exact number of times a radio-collared lion encountered a person; but to be on a conservative side I calculated the number of times a lion got nearer (< 200 meter) to a human habitation or a farmland during a continuous monitoring session. This gave me an estimation of a minimum lion-human encounter in the landscape. Mean daily lion-human encounter in my study area was estimated to be 15 (SE 5) which translates into about 5,475 such encounters in a year. For example, radio-collared lioness F2 in Girnar had a mean minimum human encounter rate 21/day. Considering her monitoring period of 3.3 years (June 2008 – November 2011), a negligible part of these (only three incidents of attacking humans) encounters however resulted into an attack on human. Similarly, radio collared male M12 of the human dominated eastern landscape had a mean minimum human encounter rate of 7/day while only one of them resulted into an attack during his monitoring period of 2 years 10 months. Lioness F5 when migrated to densely populated Gondal city in 2008 (a human population of 112,064 as per 2011 census) near Rajkot, had a high human encounter rate of 26/day; but none of them translated into a human attack. This information depicts the actual magnitude of lion attacks on humans in the Gir landscape and becomes extremely crucial for the park management to negate exaggerated reporting by the local press, irrational beliefs of the local people and unjustified campaigning of the anti-conservation lobbies. These incidents of attacks, however few, can severely undermine the future lion conservation efforts.

Annual rate of lethal lion attacks in Gir also decreased from 2.2 to 0.7 during last two decades. A higher rate of fatal lion attacks in Gir was attributed to a severe drought in 1987-88 causing a considerable depletion of lions' natural prey (Singh and Kamboj 1996). Several cattle camps were constructed within the Gir PA to cater for the needs of livestock owners from other parts of Saurashtra and Kacchh (Singh and Kamboj 1996). According to Singh (2007) lack of protection due to a prolonged protest work strike by the frontline staff during this period resulted into uncontrolled influx of livestock within the Gir PA and this increased lions' dependence on livestock for their diets (Chellam 1993). After removal of the extra livestock from the Gir, lions started raiding the peripheral villages in search for livestock causing such high fatal attacks on humans (Saberwal et al. 1994). Pathak et al. (2002) ascribed revival of wild ungulate population within the Gir PA owing to wildlife management interventions by the park authority behind lions' diminished dependence on livestock in subsequent years.

The decline in the proportion of lion attacks on humans within the protected area from 18% reported in the earlier study to 8% in the current study could be attributed to state government driven relocations and voluntary resettlements of *Maldharis* from the Gir PA. Gir PA had a more than 129 *Nesses* until mid 1970s with a human population of 6,700 and a livestock population of about 25,000 (Berwick 1974; Singh 2007). With livestock constituting about 75% of lions' diet in the Gir PA (Joslin 1973); lion-*Maldhari* conflict was high. After declaration of a National Park in 1975, the Gujarat Government started a relocation plan for *Maldharis*. Moreover, many *Maldhari* families resettled voluntarily outside the Gir PA and engaged themselves in agricultural works. These caused almost 50-60% decline in human and livestock population inside the Gir PA in two decades (50 *Nesses* with a human population of about 2,300 and a livestock population of about 12,330 in 2005; Singh 2007). In addition, living in proximity of lions for generations *Maldharis* within the Gir PA have become experienced and mastered the art of responding to lions, when encountered. All these resulted in a reduced level of lion attacks on humans within the Gir PA.

The most frequent sex and age class of lions that cause conflict outside conservation areas has been found to be young males (Anderson 1981) of the social status which Schaller (1972) termed nomads. In Gir majority of attacks on humans have been observed to be made

by single lions. Male and female lions were found to be equally responsible for the human attacks. These males are animals that have been driven from a pride territory by the pride females and territorial males (or male) and are progressively forced out to areas which are unsuitable for lions because of a low prey density. Where these nomads eventually find safety from other lions, is usually in areas where there are people, livestock and a low biomass of wild prey animals. On the other hand, females in the human dominated landscape need to procure food to enhance their reproductive success and cub siring. Since the wild prey density is low in the landscape therefore it is inevitable that, in order to survive, lions will be forced to kill livestock and thus come into direct conflict with people.

I ascribe growing lion-human interfaces in the Gir landscape due to development induced paradigms as one of the major reasons for lion attacks on humans. With a human population of 1.22 billion, India represents 17.3% of the world's population and with a population growth rate of 1.58% is predicted to have 1.53 human population by 2030 (World Bank 2012). The situation is even more worrying in an economic progressive and developed state like Gujarat where decadal population growth rate is about 20% (Census of India 2011). With such intense human population explosion development is an essential requirement failure to meet which would mean progressive impoverishment. Since "Green Revolution" in 1960s, most of the increasing demand for food in India has been met through intensified agriculture and husbandry compared to increased production areas. So far, the increase in production in the country cannot be secured by greater productivity because technical progress does not match the rate of demographic increase. Continued expansion of agriculture and husbandry areas will have various impacts on traditional land-use patterns, habitats and biodiversity: at this stage, rural development in Gujarat inevitably involves accelerated transformation of natural landscapes at the expense of wilderness that sustains biodiversity, particularly lions and their wild prey base. Besides, being the highest milk producer in the world the livestock population in India has increased from 293 million in 1951 to 511 million in 2007 (www.indiastat.com). During the same period the livestock population in Gujarat has increased from 2 million to 13.3 million (www.indiastat.com). In order to meet the increasing need for these, a number of forested patches, *Gauchars* (pastoral lands) and grasslands have been converted into agricultural and industrial areas in the Gir landscape. Gir lion population is also increasing at an annual rate of 4% since past four

decades and increasing their ranges in newer parts of the Gir landscape (Singh and Gibson 2011; Banerjee and Jhala 2012). If not addressed appropriately, the trend of lion attacks on humans in the Gir landscape is likely to escalate in future.

Lion attacks on humans in the Gir landscape were biased for men in comparison to women and majority of the victims were middle aged. A similar pattern has been observed for lion attacks on humans in Tanzania (Packer et al. 2005). This is presumably because men are more likely to engage in occupations like tending livestock and farming that make them more prone to lion encounters while women mostly do household works. Women's outdoor activities mostly involved carrying food in the farmhouses, washing clothes in nearby ponds or reservoirs and collecting fodder and fuelwood from the vicinity of the villages and these do not coincide with lion activity peaks. Farming and livestock rearing bag overlap lion habitats and activity periods. The farmlands in Saurashtra are looked after mostly by middle aged farmers. Similarly grazing herds of livestock in the landscape are mostly guarded by middle aged herdsmen. Younger generation (infant and young) remains either indulged in study or other household works and older generation stays in houses. These make the middle age group men more exposed to lions in comparison to women and other age groups.

The study did not reveal any seasonal pattern of lion attacks on humans. This could be best explained by change in cropping pattern by the farmers in the region during past three decades. Wheat (*Triticum aestivum*), ground nut (*Arachis hypogaea*) and cotton seeds (*Gossypium* spp) were the traditional crops for the region. But owing to good monetary returns, high market values, year around production and less investment local farmers are inclining to more sugarcane (*Saccharum* spp.) production and mango (*Mangifera indica*) orchards (Vijayan and Pati 2002). This trend has given rise to vast thick cultivation of sugarcane and mango orchards in the landscape providing year-long daytime shelter for lions and leopards. However, as expected in other predators attacking humans (Goyal 2001; Löe and Röskft 2004) lion attacks on humans in the Gir landscape peaked in evenings, nights and early mornings. A similar pattern has been reported from Tanzania where majority of attacks were observed within two hours from sunset (Packer et al. 2005, 2011; Kushnir et al. 2010). Gir lions are primarily nocturnal with most of the lion activities (like moving, patrolling and hunting; see chapter 5 for more details) peaked during evenings, nights and early mornings. For example, lion hunting peaks in Gir are early mornings and evenings.

These time periods also coincide with onset and completion of livestock grazing period. In the human dominated landscape lions' attempts to kill livestock during these periods are often deterred by livestock owners and herders and these cause increased attacks on humans during evenings and early mornings.

An examination into the locations of the victims and human activity patterns during lion attacks provides further information for understanding the temporal context of such attacks. Most of the lion attacks happened outside a house in farmlands when the victim was engaged in agricultural activities at nights. Crops invite various unwanted species like nilgai and wild pigs. Typical lion preys like chital and sambar cannot survive in the croplands due to poorer habitat qualities. Highly disturbed habitats are on the other hand are ideal for nilgai and wild pigs. These nocturnal ungulates remain in thick vegetation in edge habitats during the daytime and emerge as voracious crop raiders at night. In the absence of any Government compensation scheme for crop raiding by the wild ungulates in the Gir landscape, nilgai and wild pigs increase the risk of lion attacks in two ways. First, they force farmers to sleep in makeshift huts in the middle of crop fields and even leave the huts in the middle of the night to chase them away. Secondly, in the absence of other wild prey in the human dominated area they attract lions nearer to the farmhouses. Both the species are prolific breeders and religious sentiments in the region prohibit their lethal control making the population controls for nilgai and wild pigs almost impossible.

Lion attacks on humans in the Gir landscape are predominantly accidental. This gets further support from the patterns of the victims' injuries. A deliberate attack by a lion with an intention to predate on a human should supposedly result into human death or severe mauling. Contrarily, majority of the victims suffered either mild or medium injuries. Fatal lion attacks were mostly (50%) provocative. In the Gir landscape most of the farmhouses are outside the village and the farmers generally stay the whole day at farmhouse, return to villages for dinner with livestock during evening and go back to farmhouses at late evening for watering and guarding the crops. Local pastoralists also return to their villages with their livestock herds during late afternoon or early evening. These coincide with lion activity especially hunting peak. Lions attempting to kill a livestock often get challenged by the livestock owners (depending upon their economic stature, perception toward livelihood securities and materialistic views) and this enhances the likelihood of lion attacks on humans.

The current study documented provoked attacks mostly by disturbing lion on kill and during mating. Human injuries due to illegal trespassing in the forested areas were substantial. Lion attacks on humans due to kleptoparasitism (kill defense) have however, been described in details by Treves and Naughton-Treves (1999).

Fatal lion attacks have other sociological significance too. The confirmation that such killings are being done by lions and not by humans is crucial. Sharma and Jhala (1997) reported such type of incidents from the eastern Uttar Pradesh, India where several people were killed and injured and the blame was put on the wolves. In Gir, even old feuds and enmities can be settled and lions can be alleged for doing so. Although such incidents have not happened during my study period but some people in the region have been found to believe that an earlier (2006) woman death in Sutrapada area was a murder case and was not because of a lion attack. This has importance in the local law and order enforcement as well as for future lion conservation. This problem can however be solved by careful scrutiny of a fatal attack site by the State police, forensic and forest officials and a non-manipulated post-mortem examination report of the dead body.

Differences in both ecology and culture provide a framework for understanding risk factors for lion attacks. This potentially describes the district level difference of lion attacks on humans. Lion density and movement are higher in Junagadh and Amreli districts because they house all the protected areas in the landscape (Girnar, Mitiyala and Pania) including the 'source' Gir PA. This is the primary cause of such difference. Besides, intensive farming and landscape alterations are more rapid and intense in Junagadh and Amreli districts in comparison to Bhavnagar which is chiefly agro-pastoral. Majority of the cattle camps (*Gaushalas* and *Panjrampoles*) are also located in Bhavnagar district which provide lions with carcasses of unproductive cattle reducing lions' dependence on priced livestock and diminishing attack events on humans.

Lion attacks on humans were nearer to villages and forest patches in comparison to roads and rivers. These forest patches are day time refugias for lions. Although lions use the landscape uniformly but they do need specific refuge habitat patches especially for respite from daytime heat. Lions patrol their territories for whole night and take shelter under these patches in the early morning and again move out in the next evening. Moreover these patches also give shelter to lion prey species like wild pigs and nilgai. Therefore lion distribution

becomes clustered in these habitat refuges for the daytime. In the Gir landscape, these patches are mostly grasslands, agricultural covers and *Prosopis juliflora* thickets, small in sizes ($0.07 \text{ km}^2 - 21.5 \text{ km}^2$) and are surrounded by human dominated areas from all sides. Any human activity within these patches during daytime (like fodder and fuelwood collection, grazing, and charcoal manufacturing) are likely to increase the chance of lion attacks on humans. Moreover, lion movement in the adjacent areas to these patches is maximum during early morning (lions taking shelter in the refuge) and after sunset (lions moving out in search of kill) when agro-pastoral activity also reaches its peak and increase the probability of attacks on humans. Lions which were not able to find a suitable daytime refuge patches by early morning (7 AM - 8 AM) are more prone to come into conflicts with humans while the lions within a refuge patch may comfortably stay for the whole day even with all sorts of human activities around. More attacks on humans near human habitations are likely due to lions' ranging in the periphery of the villages in search of food, higher human density and higher level of human activities.

Our conception about increasing trend of human-wildlife conflict probably does not apply to lions as it is more probable that the co-evolution of humans and lion was always difficult and might have been even more difficult in the past. Long before becoming major predators themselves, human beings were "hunted or chased" by lions, as described by palaeontologists (Ehrenreich 1999). However, it is only with the advent of modern communication facilities, reporting and recording of such incidents became easier. Therefore comparing the recent incidents with historical data for predicting a trend is difficult. Nevertheless it is crucial to have understanding on the socio-ecological contexts of conflicts for ensuring a co-existence model between humans and carnivores. An animal becomes a problem when it competes at an unacceptable level for human foods, becomes a nuisance or is a danger to human life (La Grange 2005). That definition would no doubt be different for each type of land use and associated management. The issue is to define the degree of acceptance, which may differ from one area to another. The "social carrying capacity" – human tolerance of predators – is a major element in mitigating carnivore/human conflict. Acceptance of losses varies among cultures, but in general villagers and pastoralists view large carnivores as a nuisance and see little financial or aesthetic value in them. According to Chardonnet et al. 2010 "human-eating and livestock-raiding lions might be seen as normal

lions expressing their carnivorous nature in particular circumstances. Contemporary lions are not wilder or crueler or more dangerous than before: it is just that these particular circumstances seem to be recorded more frequently. Furthermore, a problem lion seems to have a greater psychological impact than a problem crocodile: a lion incident might be perceived as an intrusion into the human environment, whereas a crocodile incident might be viewed as a human intrusion into the crocodile environment. The result is that the lion might be regarded as more at fault than the crocodile, even though the consequences are the same.”

Linnell et al. 2001 found that conservation of large carnivores is possible even at high human densities provided the management policies are favorable. Gir management has historically played an instrumental role in the conservation of lion and habitat recovery (Pathak et al. 2002) but the situation becomes altogether different in a human dominated landscape. In an agro-pastoral landscape lion attacks on humans, although less may be perceived as a serious threat for human safety; as happened in many places in Africa even causing local extirpation of lions (Chardonnet et al. 2010). Conserving lions at the expense of people might produce “enemies of conservation” in the Gir landscape, as identified elsewhere on the globe (Dowie 2006). Understandably, a state like Gujarat has political priorities other than lion conservation, so to be effective the mitigation measures chosen must be pragmatic and acceptable. A sound understanding of the problem is a step towards the cure and the current study attempted that by addressing the spatio-temporal pattern of such attacks. Currently there is a compensation for human deaths and injuries by lions and leopards in the Gir landscape (Singh 2007). Although I do not have quantitative data, but my personal observations suggest that this may not be sufficient for securing people’s support in lion conservation. About 8% of the interviewees in the study area perceive lions as direct threats to human safety. For example, a person may lose his working ability permanently due to critical injuries caused by lions and one-time payment may not be able to replenish his livelihood. Therefore provision for job with the forest department may alternatively be thought upon for relatives of the deceased or seriously injured victims; as prevalent in other government sectors in India (like railways). Present lack of any government compensation scheme for crop raiding in the Gir landscape compels the farmers to guard their crops at night when lion activities are at peak. A crop damage compensation scheme and subsidized damage control measures may substantially lessen the financial burden of the local farmers

and subsequently incidents of lion attacks on humans. Similarly the government compensation paid for livestock depredation in the Gir landscape does not incorporate the loss in opportunity cost by the pastoralists and is not prompt in payment (see chapter 8.1 and 8.3 for more details). This pressurizes pastoralists to take more risks for defending their livestock when a grazing herd is attacked by lions and increases lion attack incidents on humans. Moreover, in some part of the study area it has been observed that electricity connection for irrigating farmlands are provided to the farmers only during late night to early morning. This coincides with lion activity peaks resulting into many incidents of lion attacks on humans and many respondents in my socio-economic survey have even opposed this (see chapter 8.3 for more details). It is therefore recommended that such connection should be provided to the farmers during daytime so as to minimize human-lion conflicts. This could be possible only through a collaborative step between the forest department, state electricity board and agriculture department. Gir *Maldharis* have experience of staying with lions since past one and a half centuries and have mastered the craft of reducing conflicts. In the larger landscape, however, people have no experience of staying with lions in their memorable histories; may be unaware of lions' behavior, ecological needs, activity patterns and may totally lack knowledge about how to respond on sudden encounters with lions. Education awareness programs at villages and institutional levels are likely to address this wherein local people especially the younger generation should be taught about the time of the day when they should be alert or move in groups while going and returning from farmhouses and many other relevant issues on lion conservation.

Lions in the Gir landscape do not view humans as food. This is probably because of better food availability and active health care system of the forest department whereby ill, injured and distressed lions having greater dependence on livestock are either treated or removed from the area. Moreover, local communities have a traditional reverence toward lions and view the species as an icon of regional pride. Therefore at most of the times they do not even actively prevent lions from raiding stocks. Most attacks on humans were accidental encounters wherein humans acted as deterrents. However, 5% of the attacks were deliberate. These lions should be carefully identified and removed from the landscape to better ensure people's support for lion conservation. It is often argued that in the case of endangered species that are highly visible, it is often difficult to refrain from capturing conflict animals

due to public pressures (Karanth and Gopal 2005); although the situation is different for lions in Saurashtra where most of the local people are found to dislike such captures. Nonetheless, the state forest department captures the lions known to have involved in attacking humans. Such interventions may result in disruption of lions' social dominance and cub survival (Whitman et al. 2004) and are also at odds with the guiding philosophy of managing protected landscapes (Lockwood et al. 2006). This approach should therefore be kept restricted to lions involved in deliberate attacks only and not to the other individuals. The importance of considering social factors in the long-term mitigation of conflicts cannot be overemphasized (Dickman 2010). Increasingly innovative, interdisciplinary and pragmatic mitigation measures in conjunction with suitable land-use policies in the Gir landscape will thus only be enable agro-pastoral communities to move from conflict to coexistence with lions.

*People's Perception on Lion Conservation in the
Gir Landscape*

***ASSESSMENT OF LOCAL PEOPLE'S PERCEPTION TOWARD LION
CONSERVATION IN THE GIR LANDSCAPE***

8.3.1 Introduction

Conservation is rapidly becoming one of the humanity's major land-use objectives (Ogra and Badola 2008) resulting into establishment of *sanctum sanctorum* or formal Protected Areas (PA) supported by national and international agencies (Sekhar 2003). Successful conservation policies have resulted in recovery of several previously endangered species (Marcelli and Fusillo 2009) often leading into population spill over of many species outside the formal PA boundaries (Karanth and DeFries 2010). The effective long-term conservation of wildlife in and around PAs requires the support of the people who experience the direct impacts of the establishment and management of those areas (Kiss 1990). Local people cannot be expected to provide this support if the costs of doing so outweigh the benefits, i.e. if the existence of the protected areas and its wildlife have negative impacts on local livelihoods; even at the perceived level (Murphree 1996). An understanding of the relationship between a PA and its surrounding human population in terms of these costs and benefits is therefore crucial when conservation has to go hand in hand with development (Newmark et al. 1994).

Large carnivores being at the apex of the trophic level occur at low densities and have large ranges (Schaller 1996). Therefore, they require vast tracts of habitats for maintaining viable populations (Bixby 1992). Carnivores' protein rich diet and large ranges draw them into recurrent competition with humans, who have almost similar needs (Schaller 1996). Thus occurrence of large carnivores can cause significant damage (Macdonald and Sillero-Zubiri 2002) and raises human-wildlife conflicts (Wang and Macdonald 2006) under diverse socio-economic and bio-political landscapes. Such conflicts can be particularly contentious when the resources concerned have economic value and the predators involved are legally protected (Thirgood et al. 2000). Situation becomes even more complex when there is occasional loss of human lives due to attack by large predators (Sillero-Zubiri and Laurenson 2001) resulting into retaliatory extermination of the latter. Despite the growing relevance of such conflicts, a theoretical framework to integrate understandings of dynamics of

economics, alteration of land-use and landscaping patterns and competitive interactions between prey and predators into conflict management is still limited (Conover 2002) and such an approach becomes imperative for policy making and legislation for the successful management of the last free-ranging population of the Asiatic lions in the Gir landscape.

Humans have a dynamic relationship with carnivores: one or more events may strongly affect people's attitudes and thereby shape their responses to future interactions with particular species (Beedell and Rehman 1999; Conover 2002; Woodroffe et al. 2005). Large carnivores possess the capacity to cause considerable harm to humans and damage to their property (Naughton-Treves 1998; Treves and Karanth 2003; Linkie et al. 2007; Inskip and Zimmermann 2009). When such losses occur, the experiences may cause increasingly negative attitudes of local people toward the species responsible for the damage (Nyhus and Sumianto 2000; Riley and Decker 2000; Naughton-Treves et al. 2003; Bagchi and Mishra 2006). People with negative attitudes toward certain carnivore species may be more prone to respond to future damage by killing (or support killing by others, e.g., Don Carlos et al. 2009), which can contribute to the decline of these populations (Kellert et al. 1996; Ogada et al. 2003). Conversely, people with positive attitudes tend to be more accepting of conservation or management actions that enable carnivore populations to grow (Andersone and Ozolins 2004; Kaczensky et al. 2004). Accordingly, understanding and addressing local people's attitudes and behavior toward human-wildlife conflicts is thought to be imperative to successful conservation of many species, and has thus been a major research focus (Wang et al. 2006; Palmeira et al. 2008; Ogra 2009).

The impact of personal value orientations on normative beliefs identified by Zinn et al. (1998) represents important insight into human cognitive processing of attitudes toward aspects of our natural environment. However, our personal values and attitudes are parts of a wider socio-political complex (Bjerke and Kaltenborn 1999; Kaltenborn and Bjerke 2002). The question may be raised whether the personal and social/political interests of these groups influence their value and attitude structure. Therefore, it will be of interest to identify variables that not only affect the social acceptability of large carnivore behaviour, but that simultaneously have been shown to play a central role in the socio-political conflicts surrounding these species. There are two obvious candidate variables in this respect. Firstly, previous research has shown that the personal importance of an issue is an important variable

in studies of attitude–behaviour relations (Fishbein and Ajzen 1975; Bright and Manfredi 1996). Secondly, the controversy about large carnivores may have involved a rural protest against control by central political authorities over land use (Wilson 1997). A positive association was found between an external locus of control and negative attitudes toward large carnivores (Bjerke et al. 2000). In view of this association, people experiencing an external locus of control should also be expected to be less tolerant of large carnivores and to accept a more limited range of carnivore behaviour.

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; Divyabhanush 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 (see sub-chapter 8.1 for more details). 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 7). Although lions mostly scavenged on carcasses and mostly preyed on unproductive cattle but local communities might perceive otherwise. Local tolerance towards lion populations is determined by several factors but I 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). Currently park management and conservation communities may be elated by the success story of the Gir lions (Lenin 2011; Singh and Gibson 2011) but I 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 I 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.

8.3.2. Methodology

8.3.2.1. 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 8.3.1**) 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 8.3.1**). 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 I could not interview women sufficiently (n = 4) and excluded them from my dataset.

8.3.2.2. 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 8.3.1**. 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.

Table 8.3.1: Questions asked to sampled households in the 254 villages of the Gir landscape to assess socio-economic status and community perception towards lion conservation.

Section A: Personal/Demographic	
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 clothings 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>kutch</i> /semi- <i>pucca</i> tinned/cement sheet roof, 3 = <i>kutch</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
Section B: Occupation	
Pastoralist	If yes, holding pattern of buffaloes, cattle, shoa (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 ²
	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 ₹.)
Section C: Attitude and perception about wildlife & lion conservation	
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, 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 occasionally kill livestock = 0 and does not kill humans or livestock = 1

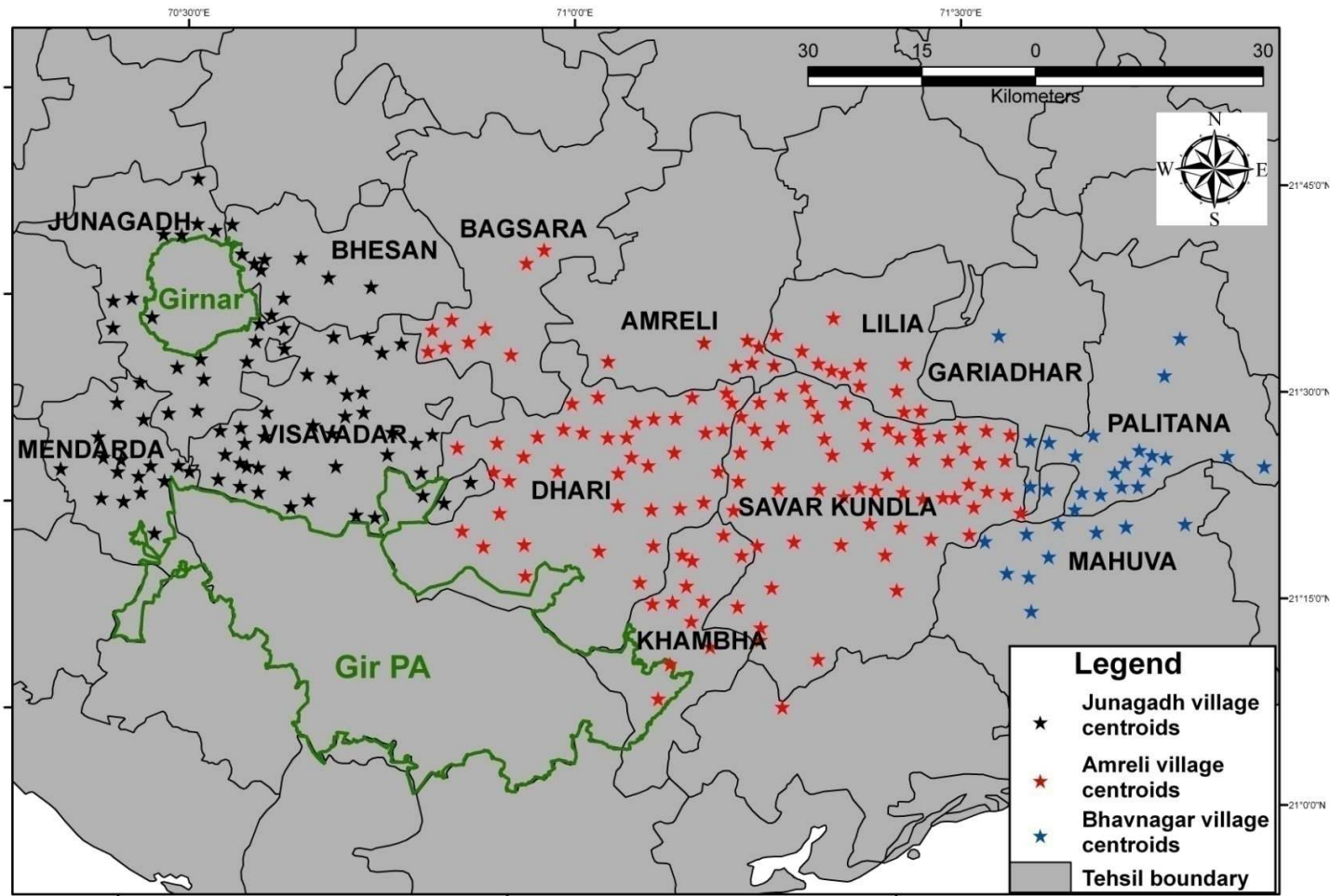
Table 8.3.1 Contd.

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
Section D: Livestock predation compensation scheme	
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

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, I 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).

I divided my dataset into two categories; i) attitude and perception towards lion conservation (like to have lions or not; section C of **Table 8.3.1**) and ii) perception about the government compensation provided for livestock depredation (section D of **Table 8.3.1**). To explore the interrelatedness of socioeconomic variables for both the data sets (i and ii), I 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. I 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). I 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, I constructed each candidate model based on the plausibility of a priori hypothesis (Burnham and Anderson 2002). I used information-theoretic approach to select between candidate models (Kullback and Leibler 1951); either selecting the one with the smallest ΔAIC value (Akaike 1974) or conducting multi-model averaging (Burnham and Anderson 2002), if competing non-nested models had similar ΔAIC values (< 5). Model averaging was performed in R environment using lme4 (Bates et al. 2011) package.

Figure 8.3.1: 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.



8.3.3. 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 8.3.2**). 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 8.3.3**). 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 8.3.2**).

Majority (56%) of the respondents were of view that lions living in their surroundings for more than 10 years (**Figure 8.3.3**) with more elderly people saying this compared to the younger groups ($\chi^2 = 8.7$, df = 4, $p = 0.06$). I 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 8.3.3**).

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 8.3.4**). 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 8.3.4**). I 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 8.3.2: 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 8.3.3: 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 8.3.2: Awareness of risks of 680 respondents from 254 villages in the eastern landscape to question on having lions in the vicinity of their villages.

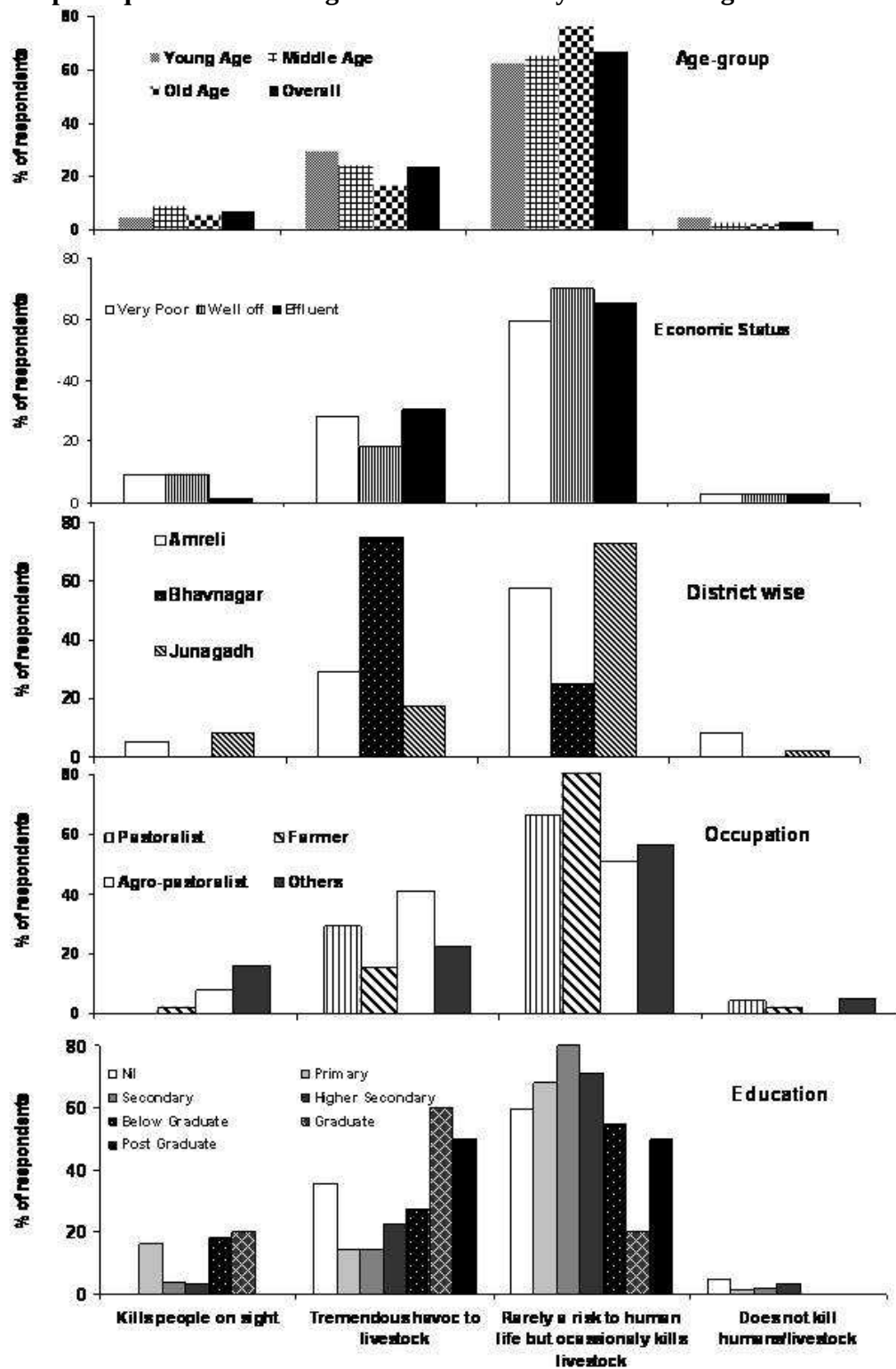


Figure 8.3.3: Views of 680 respondents from 254 villages in the eastern landscape to question on when lions started to live in their vicinity.

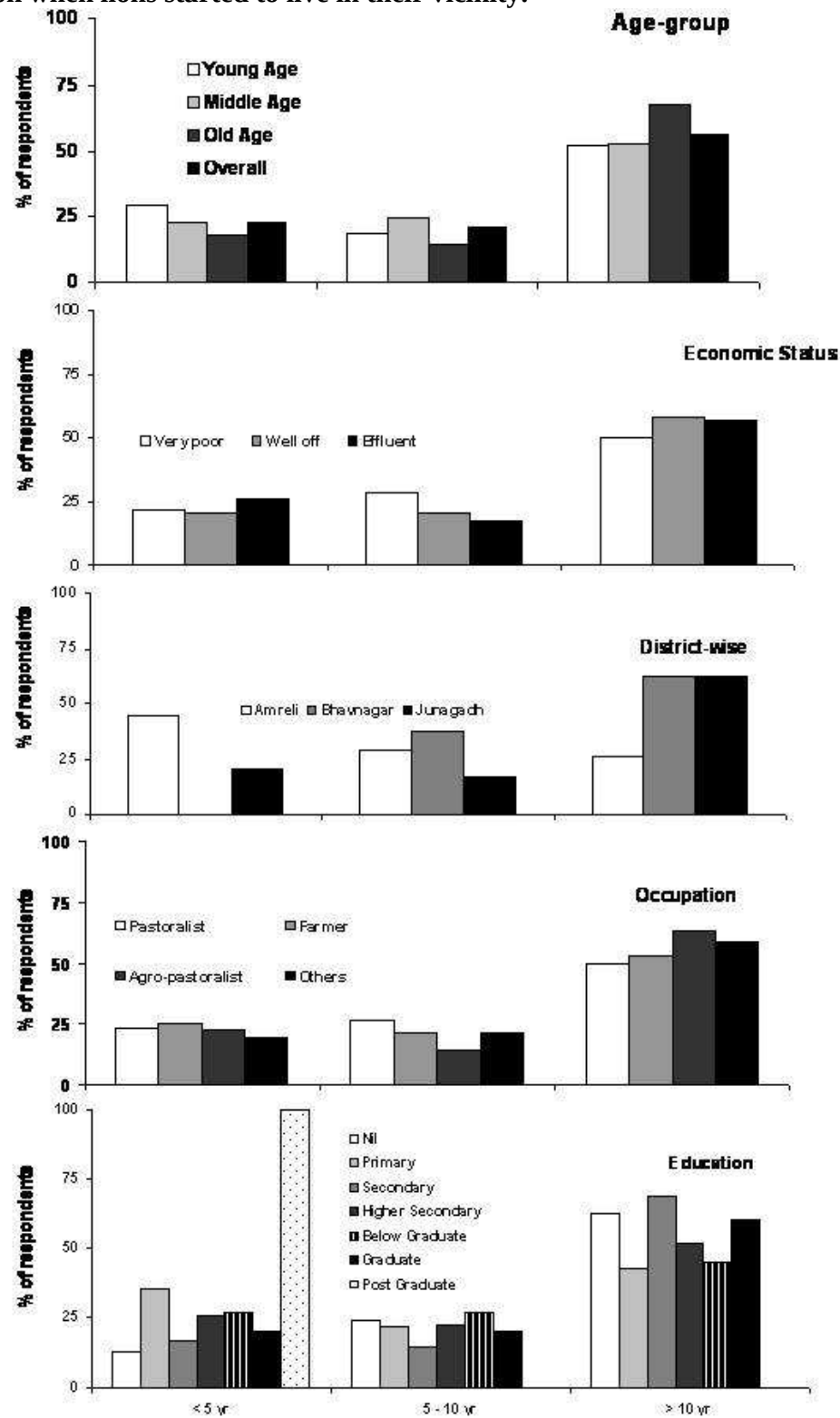
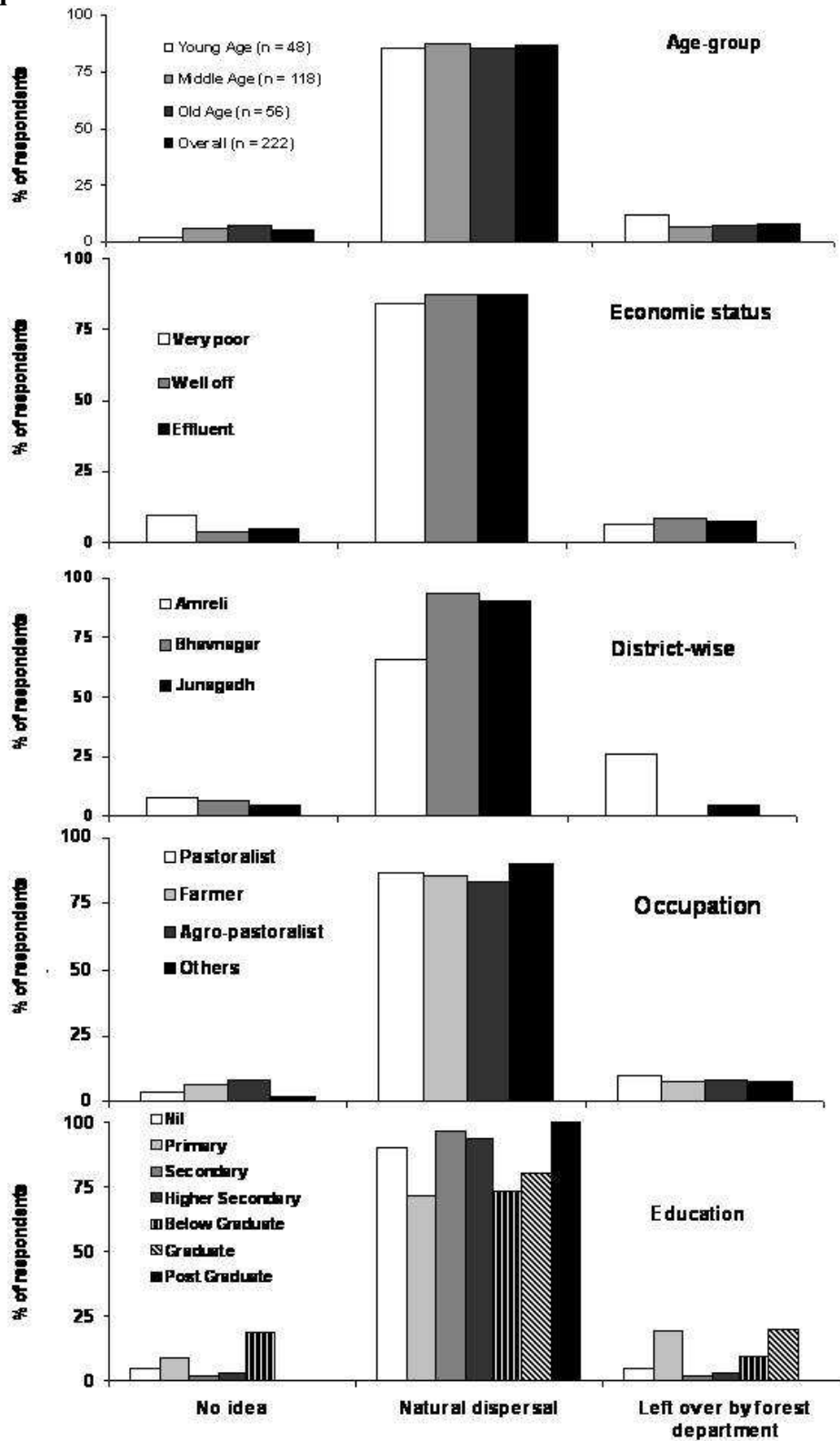


Figure 8.3.4: Views of 680 respondents from 254 villages in the eastern landscape to question on how did lions reach in their localities.



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 8.3.5**). 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 8.3.5**). 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 8.3.6**].

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 8.3.7**). 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 8.3.7**). Pastoralists (17%) and agro-pastoralists (31%) wanted lions to be released back to the Gir PA while majority of the farmers (21%) opined that the 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 8.3.7**).

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 8.3.8**). 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 8.3.8**) 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 8.3.8**). 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 8.3.8**).

Figure 8.3.5: 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.

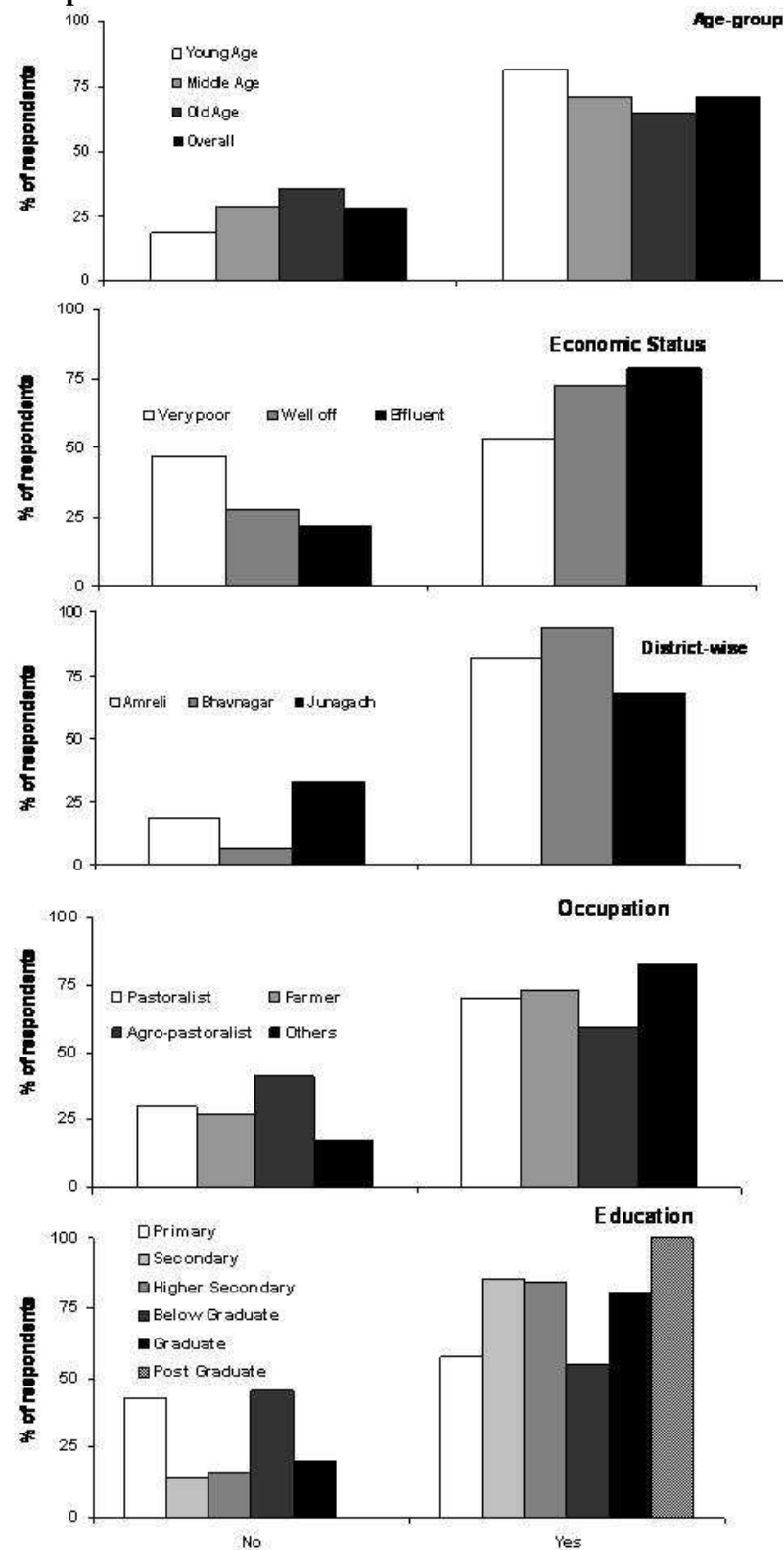


Figure 8.3.6: Views of 680 respondents from 254 villages in the eastern landscape to question on the reasons behind their liking/disliking lions to continue to live in their neighborhoods.

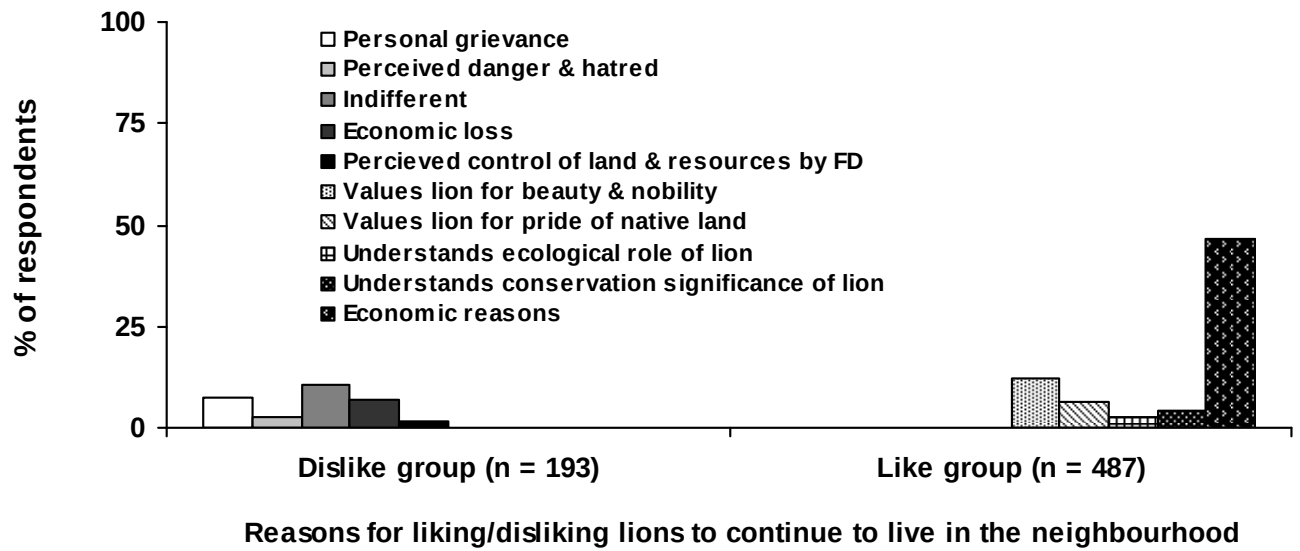


Figure 8.3.7: Views of 680 respondents from 254 villages in the eastern landscape to question on their recommendations for future lion conservation.

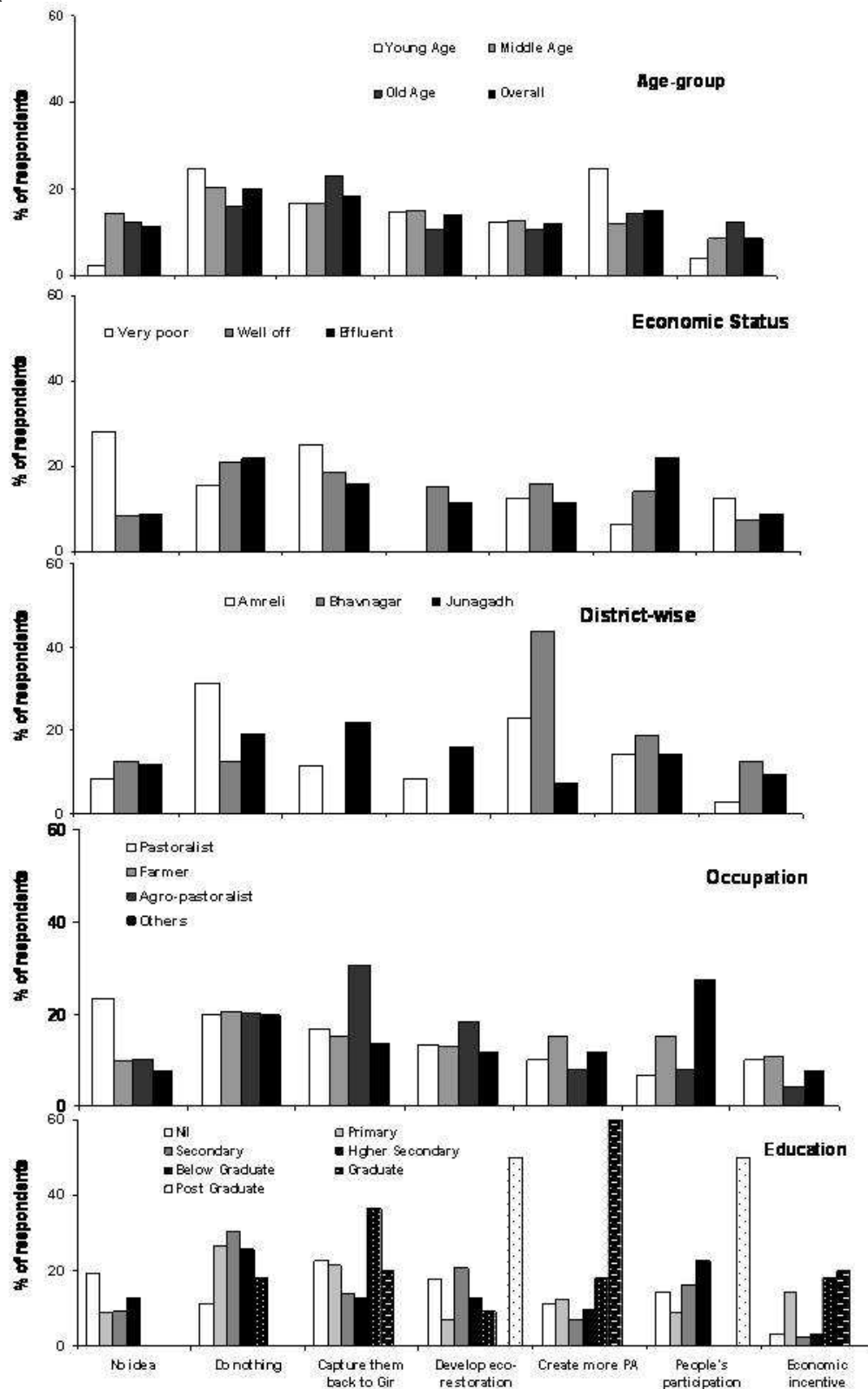
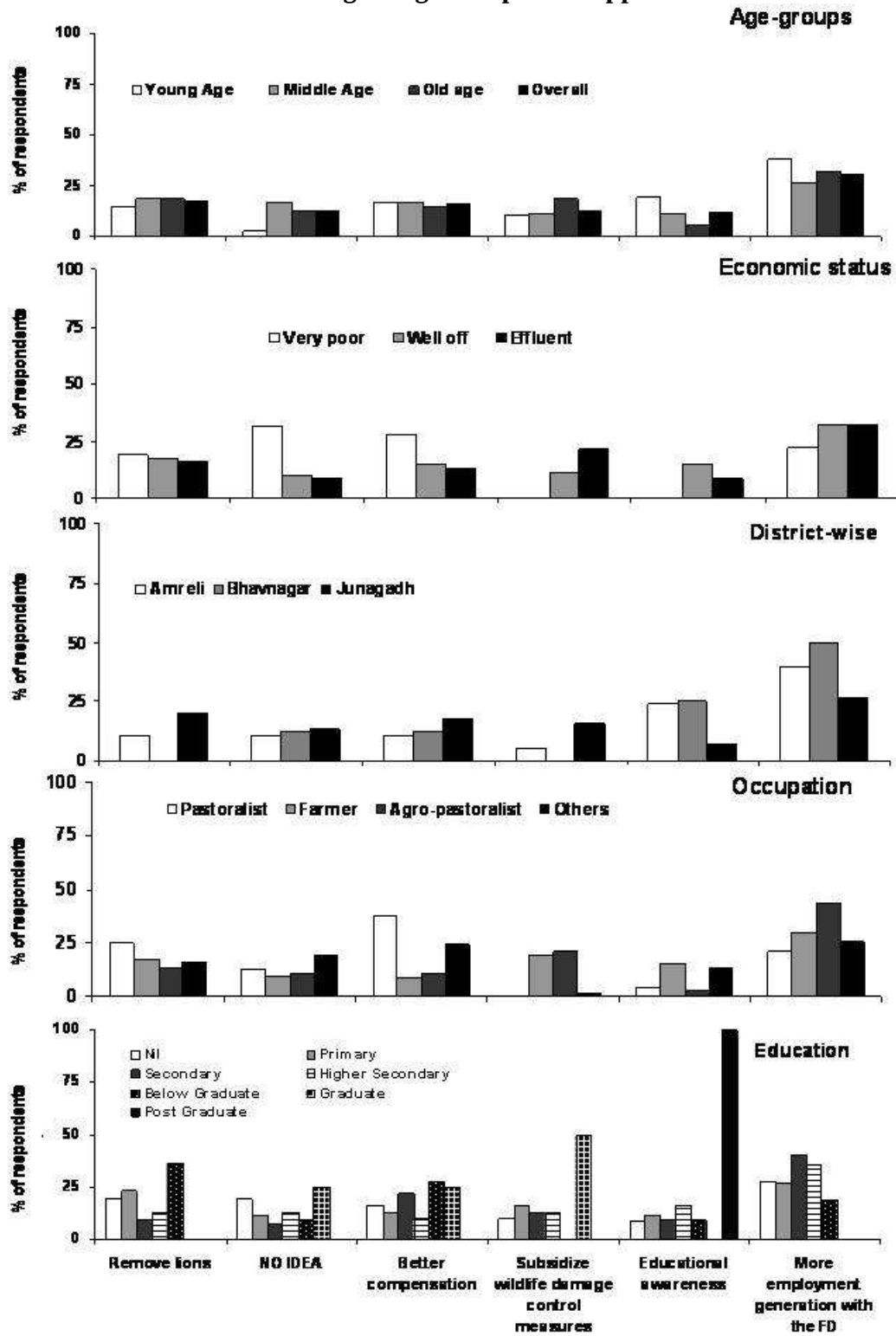


Figure 8.3.8: Views of 680 respondents from 254 villages in the eastern landscape to question on their recommendations gaining more public support for lion conservation.



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 8.3.9**). 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 8.3.9**). 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 8.3.9**) 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 8.3.9**).

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 8.3.10**]. 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 8.3.10**]. I 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 8.3.9: 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.

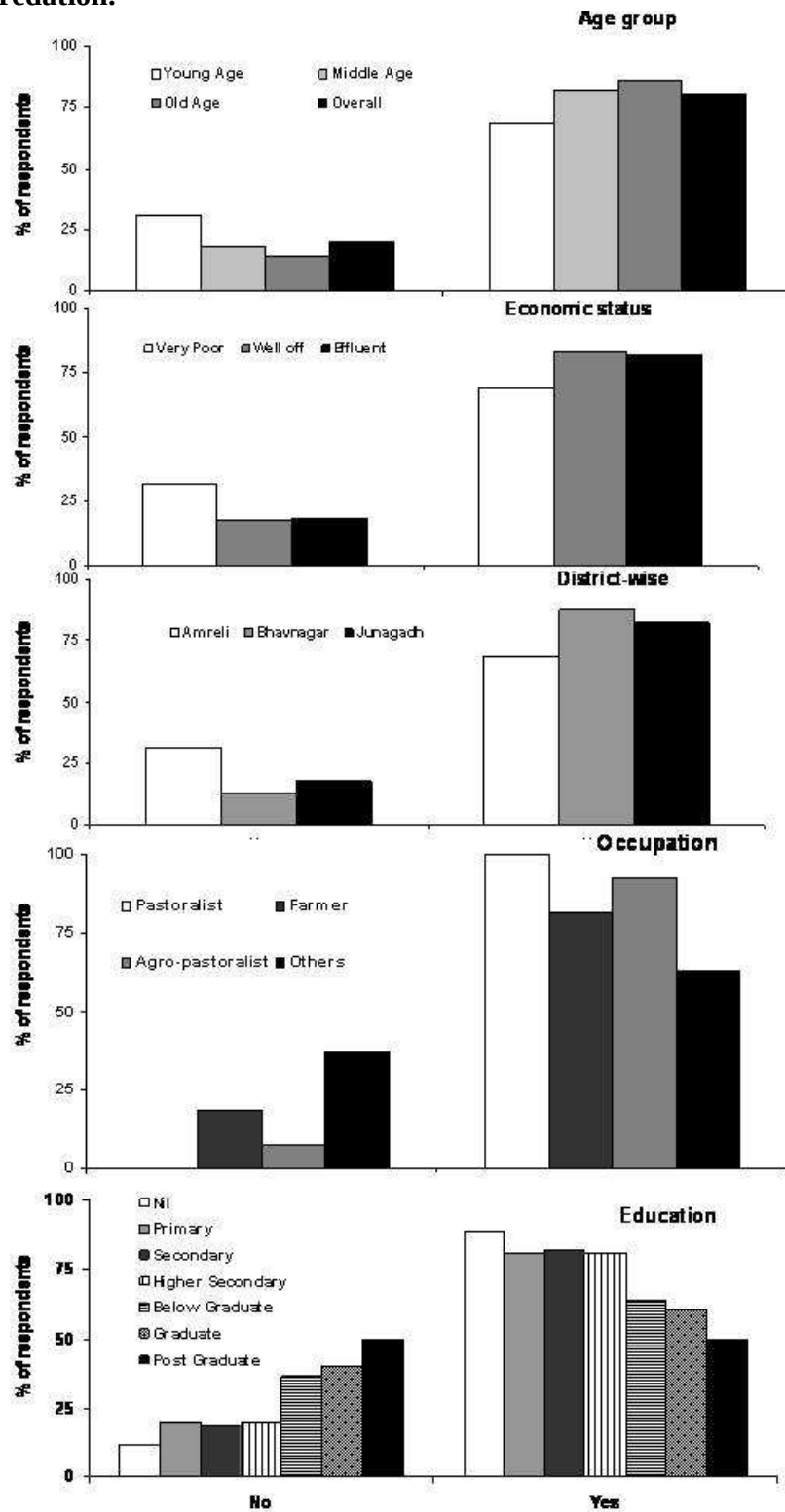
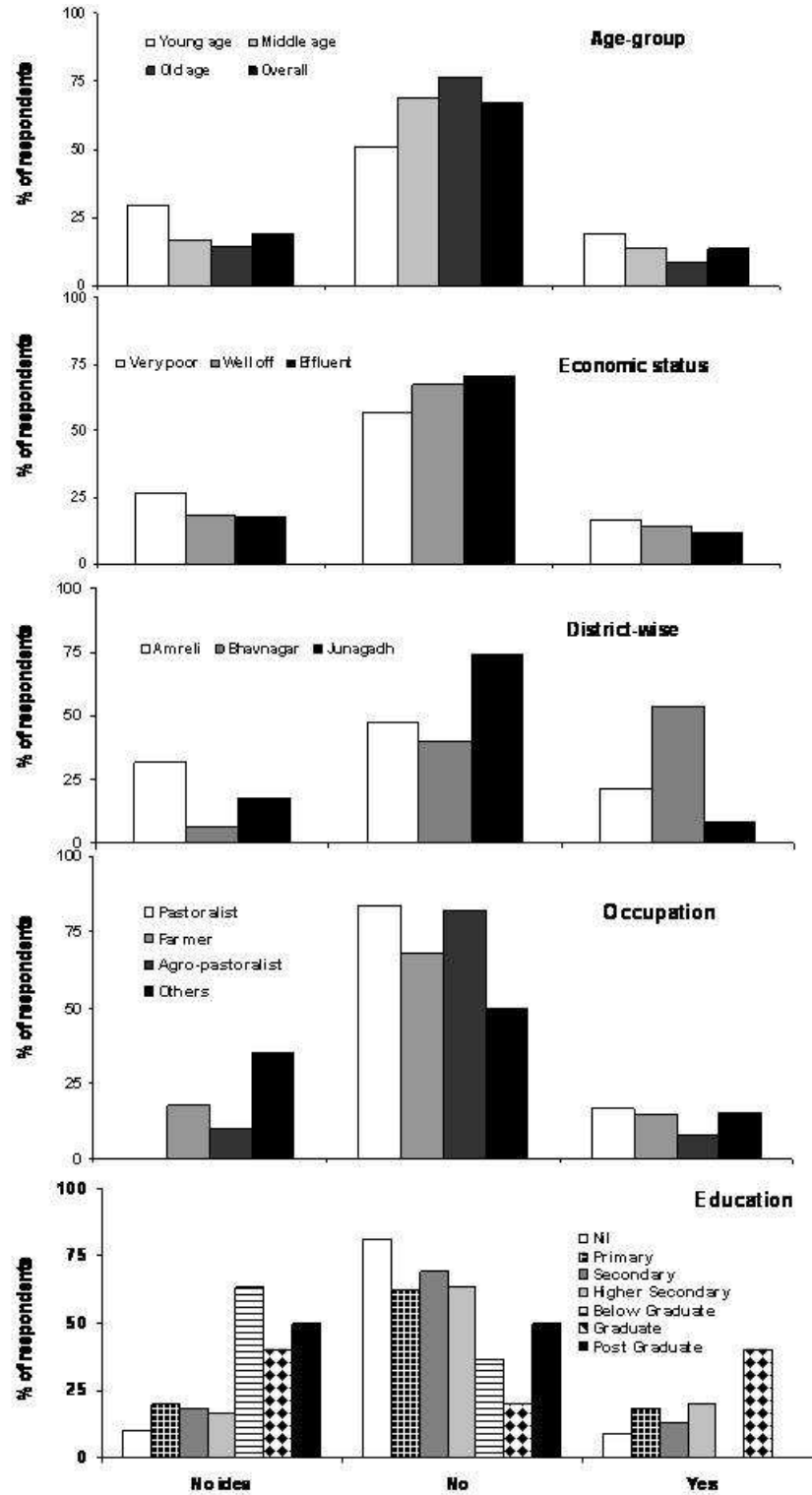


Figure 8.3.10: Views of 680 respondents from 254 villages in the eastern landscape to question on financial appropriateness of the Government compensation scheme for livestock predation.



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 8.3.11**). 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 8.3.11**). I 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 8.3.12**). 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 8.3.12**). 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 8.3.12**). 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 8.3.11: 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.

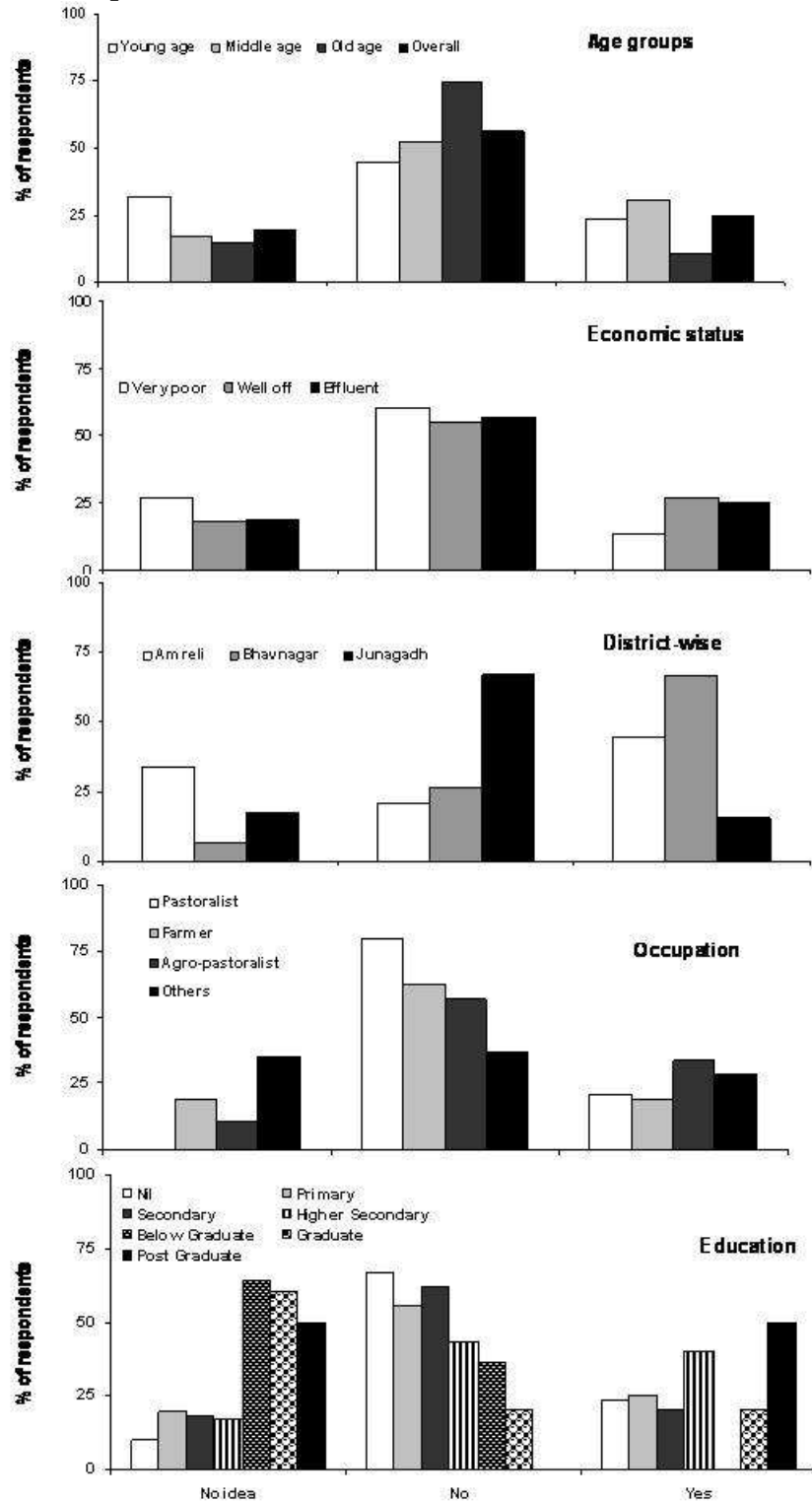
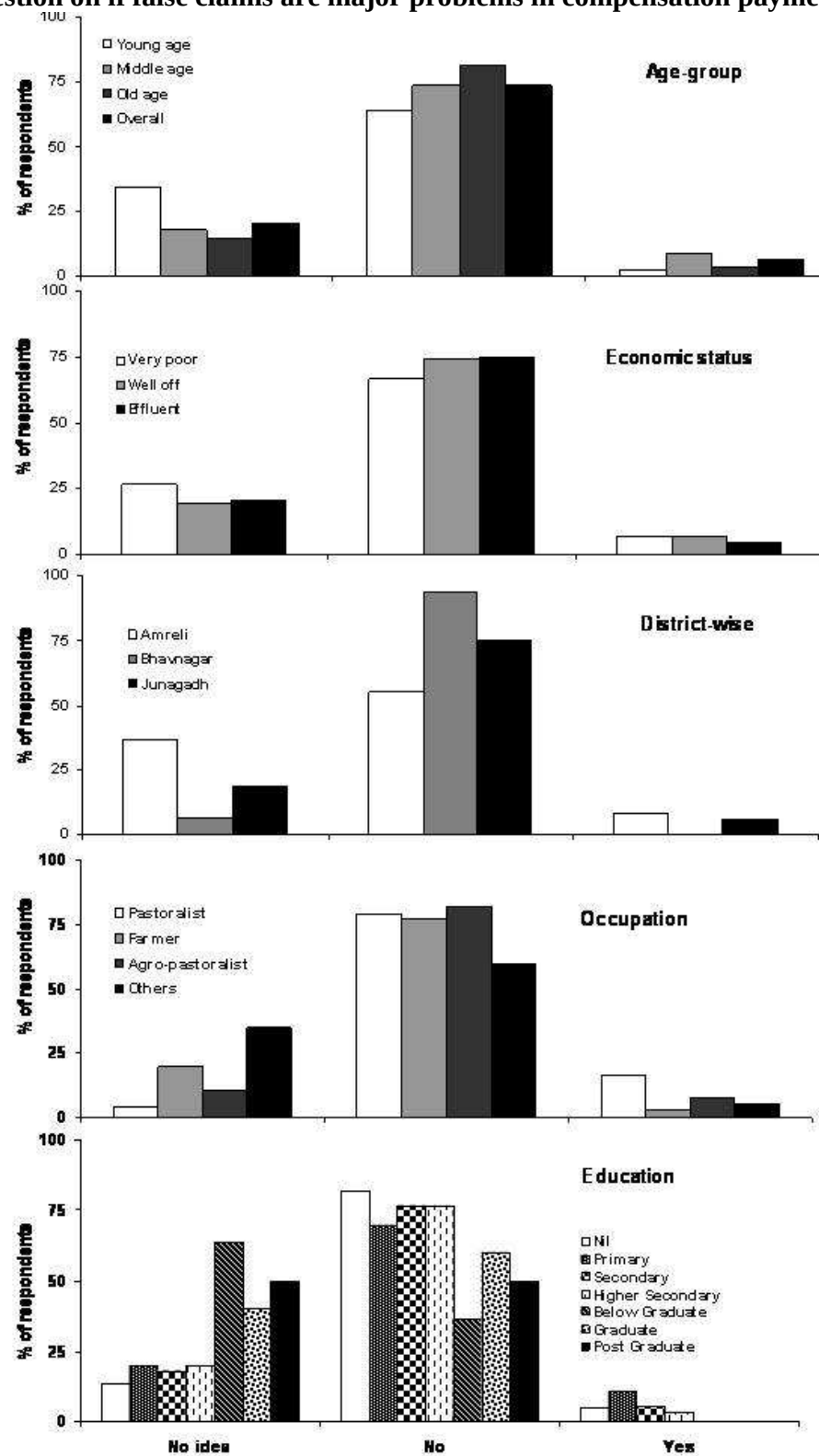


Figure 8.3.12: Views of 680 respondents from 254 villages in the eastern landscape to question on if false claims are major problems in compensation payments.



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 8.3.13**). 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 8.3.13**). 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 8.3.14**). 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 8.3.14**). Agro-pastoralists (72%) wanted monetary increment in the scheme more than respondents from any other occupation ($\chi^2 = 59.8$, df = 9, $p < 0.0001$). I 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 8.3.14**).

Figure 8.3.13: 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.

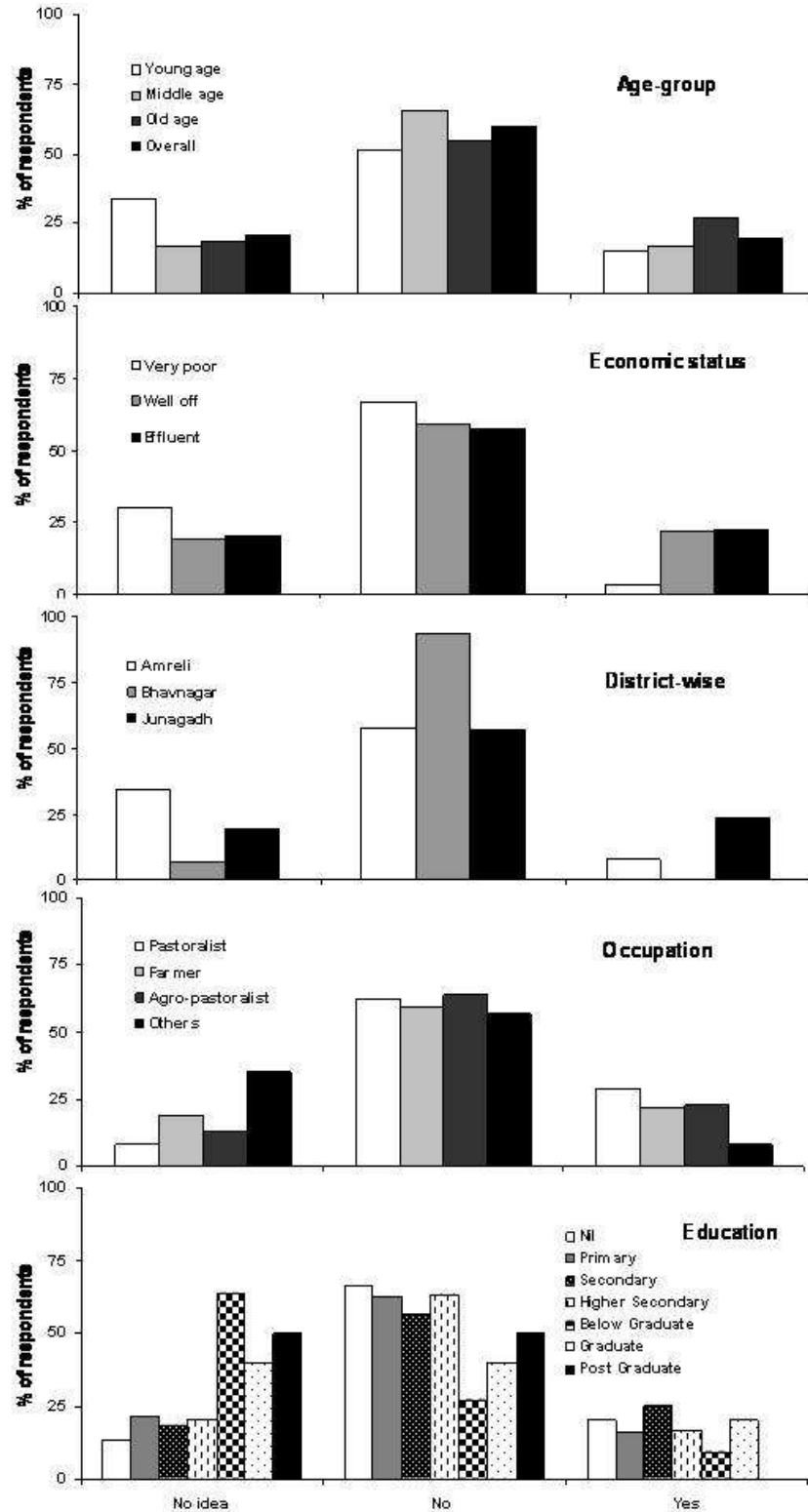
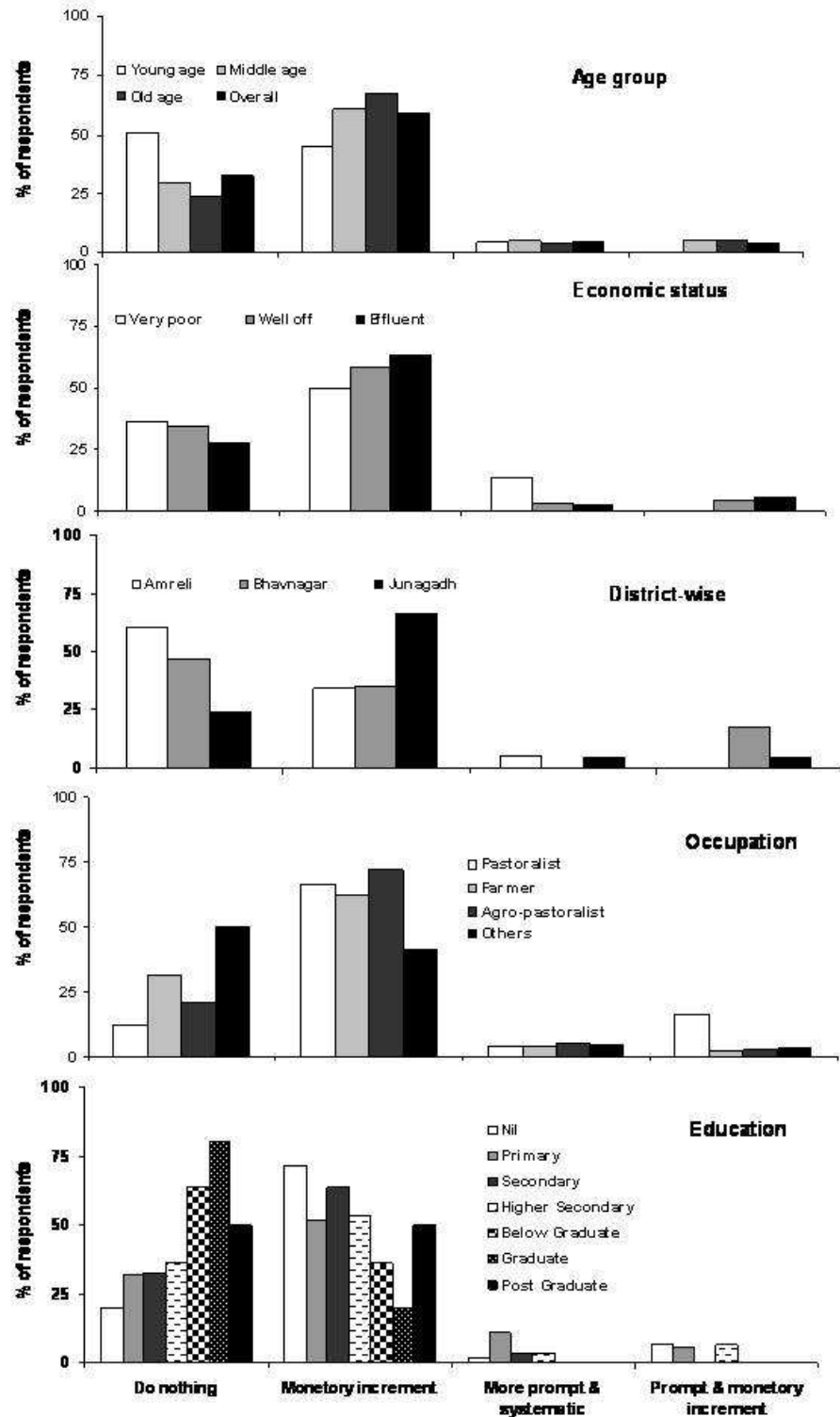
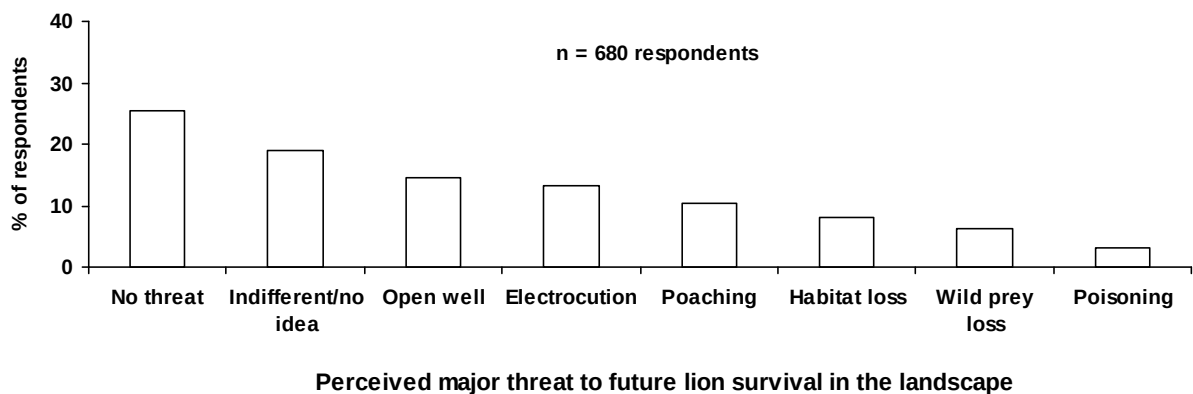


Figure 8.3.14: Views of 680 respondents from 254 villages in the eastern landscape to question on suggestion to improve the Government compensation scheme for livestock predation.



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 8.3.15**). 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 8.3.15: 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 8.3.4**). 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 8.3.4: 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

I 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 8.3.5**). Model with the lowest AIC value was considered to be the best approximating model in the set of candidate models considered.

Table 8.3.5: 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
1	OC+ARL	2	41.51	7	< 0.01	1,363	0
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 8.3.5**). **Table 8.3.6** shows the parameter estimates for the best model (Model number 1, **Table 8.3.5**). 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 8.3.6**). 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 8.3.6: 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			
Occupation							
Pastoralist	-0.43	0.14	-0.70	-0.17	10.01	0.002*	0.65
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						
Awareness of risks in having lions in the vicinity							
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

ΔAIC values of the top ranked models (model 1 and 2; **Table 8.3.7**) 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 8.3.8**.

Table 8.3.7: 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	ΔAIC
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 8.3.8**). 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 8.3.8: 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	β Estimates	SE	Odd ratios	Z	P
Age	0.018	0.05	1.01	0.374	0.71
Idea about irregularities in compensation payment	-0.117	0.03	0.88	3.272	0.001*
Occupation	-0.038	0.03	0.96	1.139	0.25

8.3.4. Discussion

Human ecology is concerned with how the various interest groups perceive the environment and adapt to it (Catton 1987). 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 8.3.3**). 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 8.3.5 and 8.3.7**); 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 8.3.4**) 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 8.3.5**). Poor people being less educated are unaware of their rights and various ongoing government schemes (**Table 8.3.4 and Figure 8.3.9**) 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 8.3.14**). 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 8.3.4** 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 (Røskft 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; Maclellan 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 I 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 8.3.4**). 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 8.3.2**) and more unwilling to continue to live with lions in future than the latter (**Figure 8.3.5**).

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). Sub-chapter 8.1 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 sub chapter 8.1. I, 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 ($2/100 \text{ km}^2$) 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 (already discussed in chapter 8.2). I, 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 (chapter 8.2 for more details). 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 my 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, my 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 7 for more details). I 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 I 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, I 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.

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