Ecology of Asiatic Lions in Gir PA and the adjoining human dominated landscape of Saurashtra, Gujarat

भारतीय वन्यजीव संस्थान
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FINAL DRAFT

PROJECT REPORT (2011-2016)

A Collaborative Research Project between

Wildlife Institute of India
&
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(TR-2016/003)

Principal Investigator, WII: Yadvendradev V. Jhala

Principal Investigator (s), GFD: Bharat Pathak, Mayank Sharma, S. Chaturvedi, R.L. Meena, & A.P. Singh

Researchers: Kausik Banerjee, Parabita Basu, Stotra Chakrabarti, Subrata Gayen, Keshab Gogoi & Arnab Basu

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A juvenile male lion in Gir (Photo courtesy: Stotra Chakrabarti)

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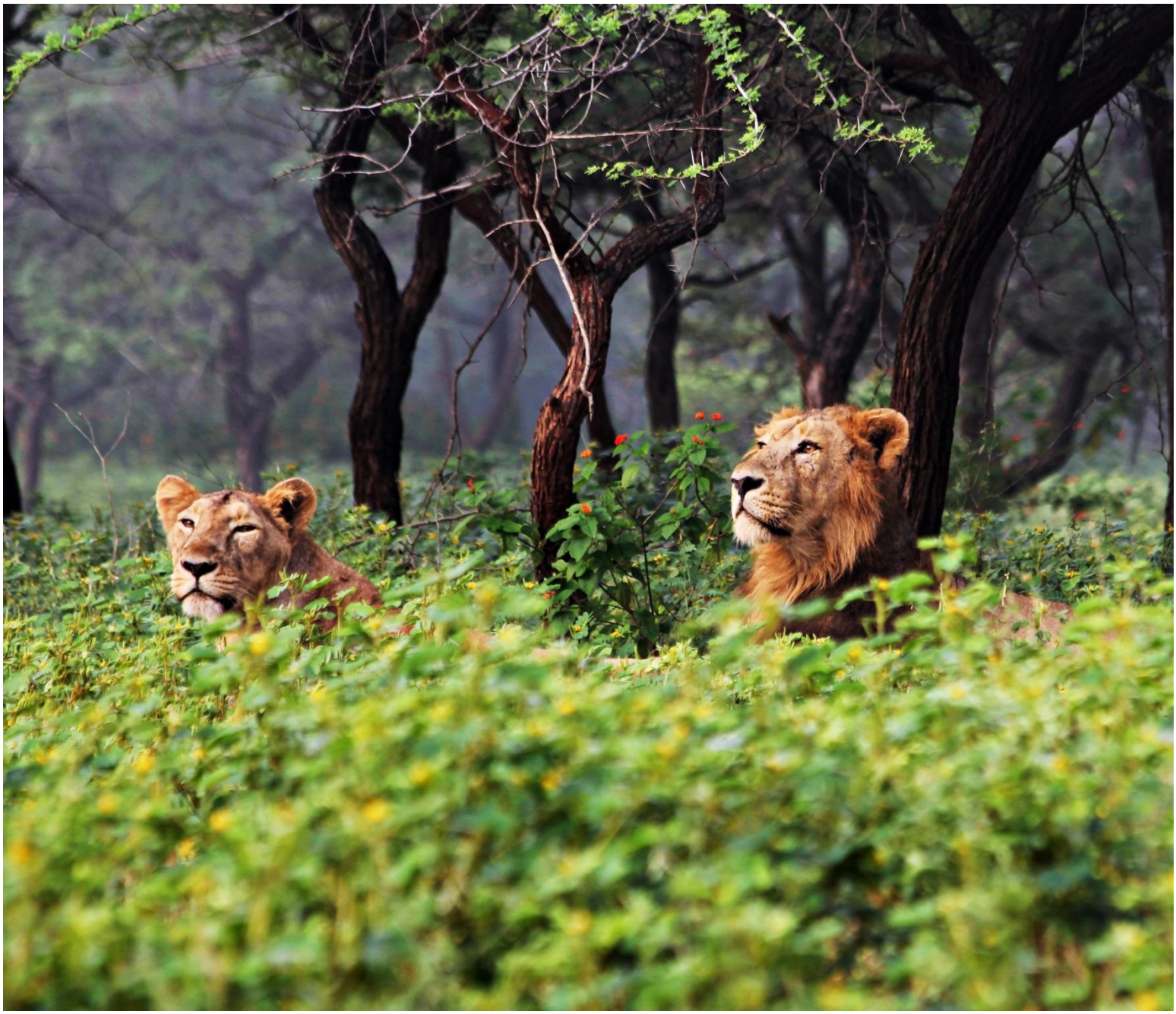
A mating pair of Asiatic lions looks curiously from within a green blanket after the rains
(Photo Courtesy: Stotra Chakrabarti)



Executive Summary

Asiatic lion (*Panthera leo persica*) is a conservation icon and elucidates a success story of conservation in modern India. With single isolated population and a small founder base, it typifies all the challenges of global carnivore conservation. Lions ranged from Persia to Palamau in eastern India till early 18th century, but were almost driven to extinction by indiscriminate hunting and habitat loss by late 1880's. A single relict population of less than 50 lions persisted in the Gir forests of Gujarat by 1890's. With stringent protection offered by the *Nawab*s of Junagadh and subsequently by the State run Gujarat Forest department, Gir lions have increased to a current population of over 500 accompanied by a subsequent range expansion. Lions were restricted to the Gir forests (1,800 km^2) till the early 1980's, but have since dispersed to occupy over 20,000 km^2 of human dominated agro-pastoral landscape of Saurashtra. Currently lions occupy the Gir Protected Area (PA), 180 km^2 Girnar forests and over 15,000 km^2 of coastal scrublands and agro-pastoral landscapes of Junagadh, Amreli, Gir Somnath and Bhavnagar districts. An in-depth understanding is required on how lions live within and outside the Protected Area. The magnitude and dimensions of conflict with human interests, and gene flow between different widely spaced breeding units in light of current and future development within the Greater 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 future lion conservation strategy for the landscape.

On submission of first phase's findings to the Gujarat Forest Department (GFD) and WII-TRAC through technical reports, an extension for the second phase of this project was procured in 2011 with the aim of assisting the managers to formulate landscape level lion conservation policies based on informed research and robust scientific approaches. During the tenure of this project, WII was mandated by the CWLW, Gujarat state to take up three additional research components – 1) assessment of potential habitat corridor landscape between Gir and Girnar and 2) estimation of leopard (*Panthera pardus*) abundance in Girnar and 3) ecological and social potential of Barda for reintroduction of Asiatic lions. All these components were successfully addressed and findings were communicated to the GFD as individual reports as well as summarized herein.

- **Landscape architecture and variation of vegetation cover of Gir Protected Area and its surroundings:** We used ordination technique (TWINSPAN) and supervised and unsupervised classifications of vegetation plot data (n = 900) using cloud free LANDSAT TM satellite imageries (Bands 1-5 and 7 for the years 1998, 2002 and 2009) to identify vegetation communities within Gir PA.

  Ten vegetation communities were identified in the Gir PA (**Figure E.1**) i.e. *Ziziphus mauritiana-Tectona grandis* community, pure *Tectona grandis* , mixed teak communities like *Wrightia tinctoria-Tectona grandis* and *Tectona grandis-Wrightia tinctoria* , *Terminalia alata-Tectona grandis-Lannea coromandelica-Acacia catechu* , *Boswellia serrata-Acacia catechu* , *Acacia catechu-Ziziphus mauritiana* , *Anogeissus latifolia-Boswellia serrata* , *Terminalia alata-Acacia leucophloea-Anogeissus latifolia-Butea monosperma* , and *Acacia nilotica-Butea monosperma-Ziziphus mauritiana* . Quality and quantity of different forest types varied substantially during the time period from 1998 to 2009. The trend in land use land cover changes showed thickening of teak dominated forest types inside the Gir PA till 2002 and it might be due to a response to the canopy opening and uprooting of trees after 1984 cyclone following succession of the respective vegetation communities.

  We quantified the rate of change in land use and vegetation patterns within Gir PA between 1998 and 2009 and based on the probability matrix obtained, we simulated land cover map for the Gir PA of 2020 (**Figure E.2**) with the cellular automata markov analysis tool (CA-MARKOV). Futuristic projections suggest a substantial increase in agriculture and development in the immediate surrounds of the Protected Area resulting in an increased tendency of insularizing the PA and restricting free movement of wildlife in and out of the PA.

Figure E.1: Cover map of 2009 for Gir PA and its neighboring areas

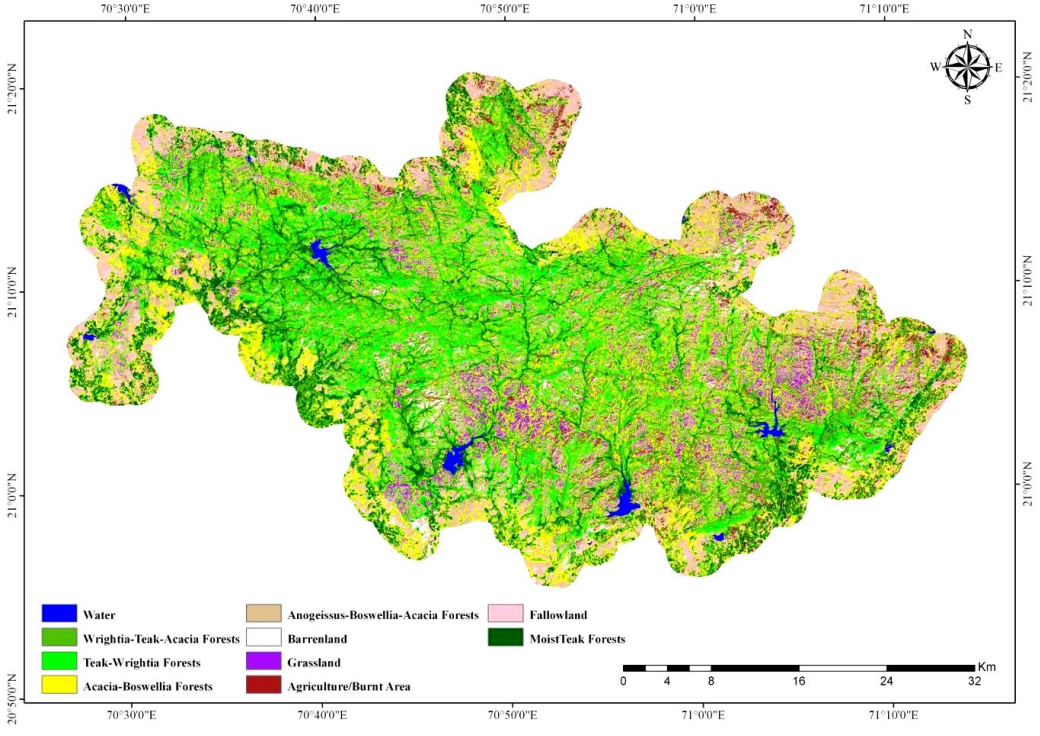
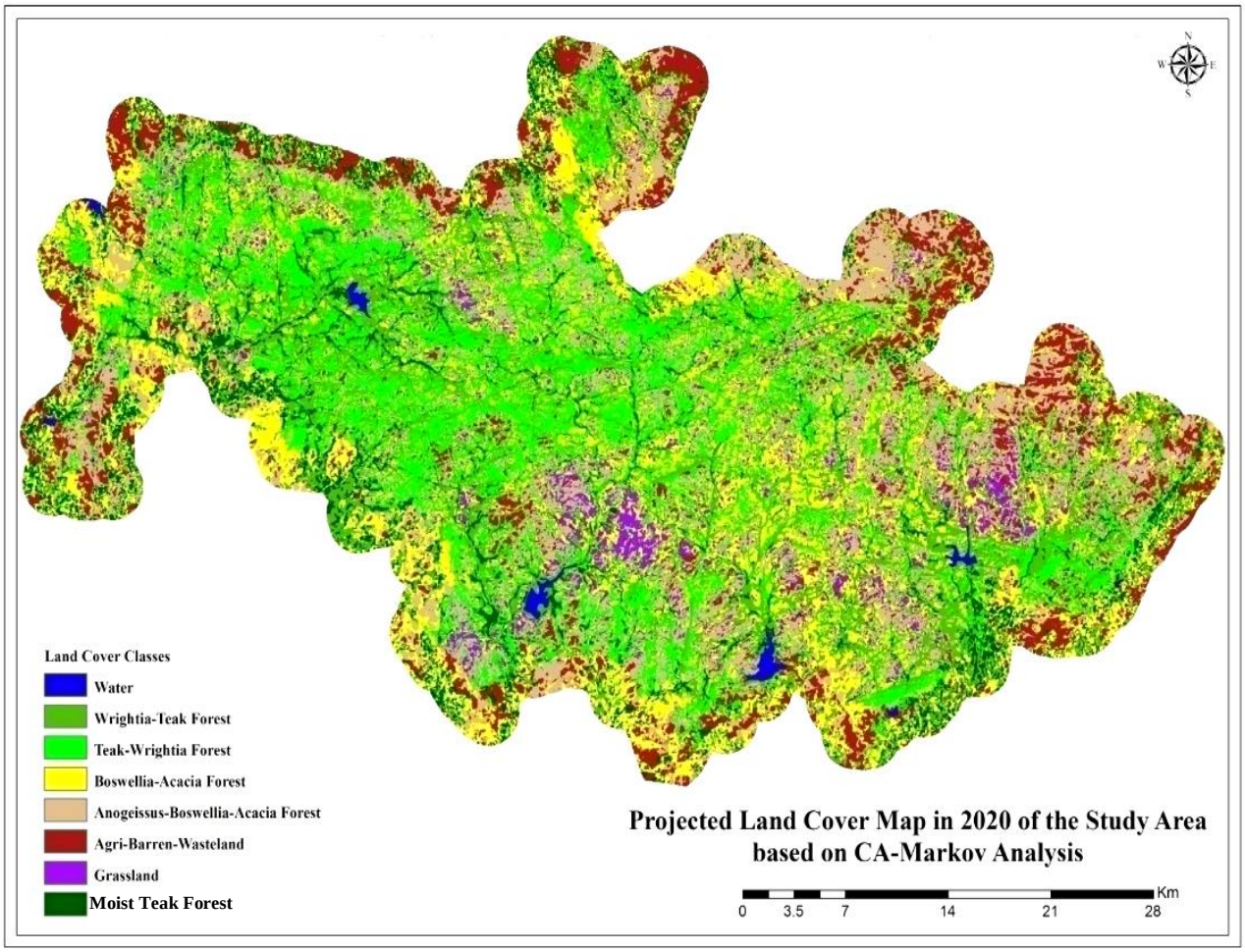


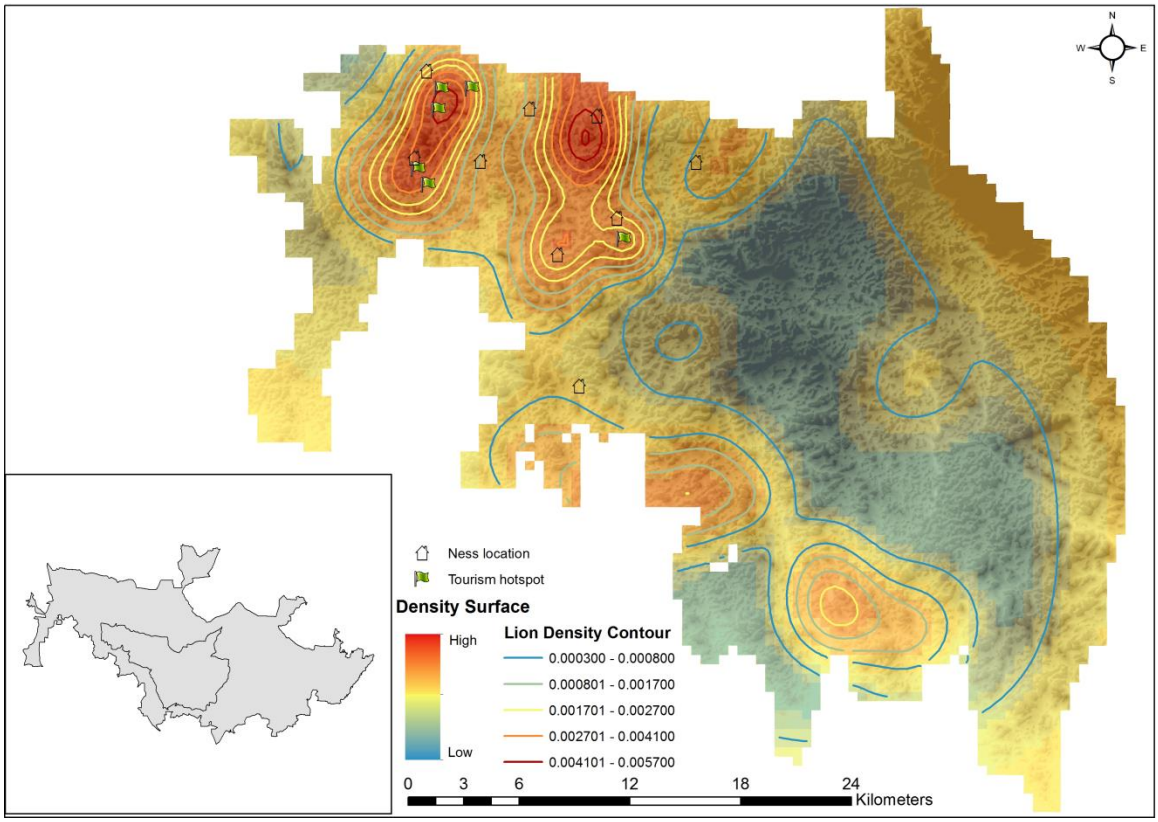
Figure E.2: Projected land cover map of Gir PA and its neighnoring areas for the year 2020.



- **Lion abundance and demography:** An objective scientifically credible population estimation of lions using individual ID based on conventional and spatially explicit (polygon search method) mark recapture framework was developed and implemented in the western part of the Gir PA, Girnar and human-dominated eastern landscape. Lion density of the west Gir PA was modeled with both biotic and abiotic eco-geographical factors based on their ecological significance. Demographic parameters of Gir lions were deduced by intensively monitoring 75 adult lions and 91 cubs from 38 litters of 31 females using telemetry and individual lion ID profiles. Record of opportunistic mortality events (n = 88) was used to understand the mortality causes. A population viability analysis (PVA) model was run for Girnar lions to understand the impact of various stochastic events (epidemics, loss of habitat, poaching) on their long-term persistence.

Average capture probability of lions in Girnar in 2010 was 0.31 while the capture probability of lions in the eastern landscape in 2012 was 0.65. Adult lion densities were estimated to be 5.6 (SE 0.7) lions/100 km^2 in Girnar and 2 (SE 0.1) lions/100 km^2 in the eastern landscape. Lion density in the Gir west PA estimated under a spatially explicit capture recapture (SECR) model as 8.5 (SE 1.1)/100 km^2 with the density of male of 3.1 (SE 0.6) /100 km^2 and density of female of 5.6 (SE 0.9) /100 km^2. Lion spatial density in the western Gir PA was not explained by spatial density of the principal wild prey species, chital or sambar. Lion density was rather found to be higher near livestock carcass dumping yards (**Figure E.3**).

Figure E.3: Lion density surface map in Western Gir alongwith *nesses* and tourism hotspots.



The practice of localizing lions by feeding them with carcasses were found to have the highest influence in determining the spatial density of lions in the tourism region of the park. This distribution pattern caused by providing easy food resources overrides the influence of natural prey and other ecological factors suggesting high local densities. These would enhance tourist viewing but could have serious implications on social organization of lions as well as enhanced predation pressure on wild prey in small pockets of artificially enhanced lion density.

Gir lions increased from about 177 in 1968 to about 523 by 2015 with an r = 0.022 (SE 0.001) translated into an annual population growth of 2.2%. A large proportion of the lion population was in recruitment classes indicative of a healthy growing population. Larger proportion of adult males (43%) than adult females (26%) in the eastern landscape was probably because of male biased dispersals from the 'source' Gir PA into the 'sink' eastern landscape and lower availability of suitable habitat patches for breeding lionesses in the human-dominated landscape. Male: female ratio was 0.63 (SE 0.04) while cub: adult lioness ratio was 0.37 (SE 0.02). Mating peaked in winter while birth peaked in late summer. Average litter size was 2.39 (SE 0.12). Inter-birth interval was 1.37 (SE 0.25) years (n = 7 lionesses) and was higher [2.25 (SE 0.41) years] when cubs of the previous litter survived to independence. Cub (< 1 year) survival was 0.57 (SE 0.04) while survival from cub to recruitment age (3 years) was 51% (SE 4%) with mortalities due to infanticide 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 Asiatic lions did not differ from those of African lions. Deleterious genes that would normally be selected against in an inbred population may continue to be propagated through ensured survival of unfit lions by health care interventions. These interventions need to be carefully evaluated for their need and effectiveness and should be scientifically implemented before being indiscriminately used in Gir.

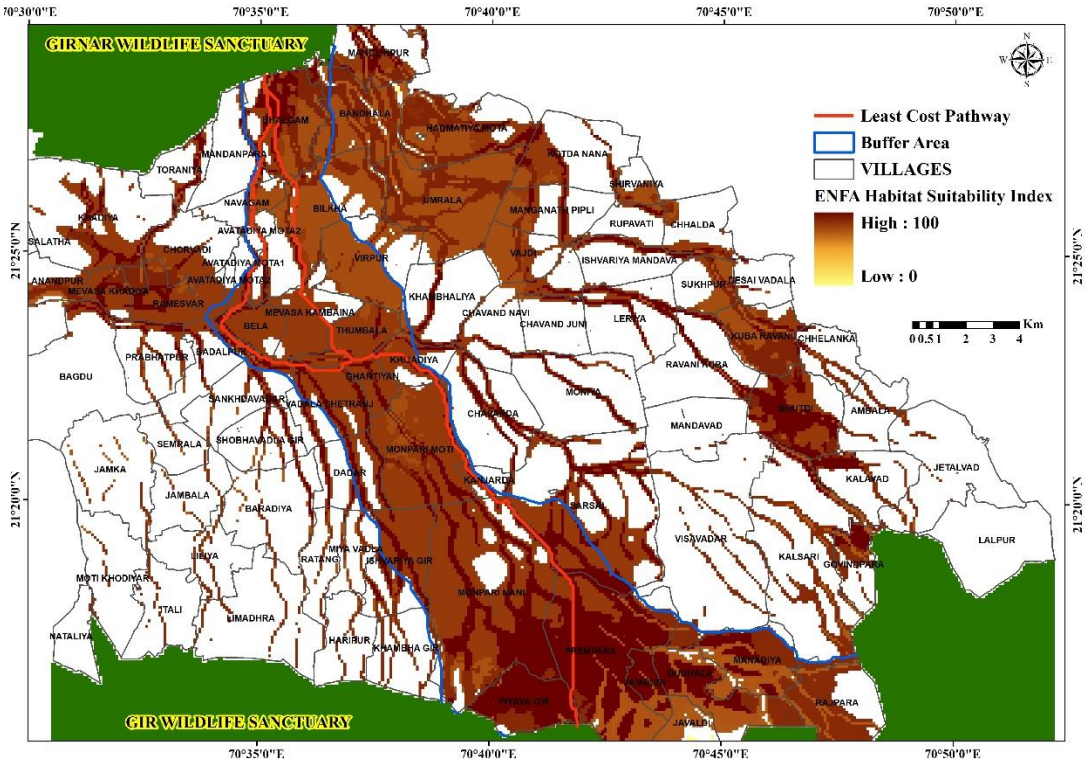
With a constant level of annual mortality, the long-term survival potential of the Girnar lions increased by 39% with habitat connectivity with the Gir PA in comparison to a non-connectivity scenario. To ensure long-term viability of Girnar lion population we delineated the potential habitat corridor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

- **Habitat suitability modeling and corridor identification between Gir and Girnar:** The habitat matrix between the two PAs was rapidly becoming hostile for lions and delineating the potential lion movement pathways therefore became imperative for maintaining corridor functionality of this matrix. We used Ecological Niche Factor Analysis (ENFA) with GPS fixes from radio collared lions, lion signs (scats, predation events etc.) and historical *ad-libitum* lion sightings as species presence data in the program Biomapper to model lion habitat in this landscape. Outputs of ENFA was then used to calculate the resistance matrix (Habitat Suitability

value) and program PATHMATRIX was used to delineate the most feasible passageway (least cost path) that lions were likely to use for movement in between these two protected areas and could be designated as minimal corridor for long term sustainability of biological linkage between Gir and Girnar lion populations.

Lions exhibited preference to river channels as their passage ways. The buffered least cost pathway (**Figure E.4**) provides the minimal corridor habitat that is required to be safeguarded in a manner that its permeability to lion movement is not compromised. Wooded and shrubby vegetation functioned similarly as day *refugia* as well as passage ways for the lions in this landscape. Regular use of mango orchards and *gauchar*s (pasture lands) indicated that such patches were important for lion movement in this fragmented landscape and serve as a link to other forested patches.

Figure. E. 4: Potential habitat corridor between Gir PA and Girnar Sanctuary



Following the recommendations of WII, part of this corridor area (adjacent to Girnar WLS) was declared as "ECOSENSITIVE" [under The Environment (Protection) Act 1986, Government of India] by Gujarat Government with restrictions on high impact industry and mining activities. However, the other part of the corridor (bordering the Gir PA) should be made eco-sensitive urgently since key habitat connections may be lost unless they are explicitly protected. Effective land-use plans and policies that incorporate conservation principles are

needed to retain landscape permeability. This would allow unaltered traditional use of gauchars (pasture lands), vidis (grasslands) and other important habitat *refugia* by local communities for livelihoods, but prevent their conversion into lion-hostile land uses. The agro-pastoral Gir-Girnar corridor landscape is now being modified into towns, dams, industries and roads. Our analyses of land use and cover change processes within this corridor suggests that forested riverine patches are vanishing at an alarming rate and the remaining patches are likely to be converted to agriculture or urban sprawls, unless controlled urgently.

- **Lion spatial organization and resource selection:** We used radio telemetry (n = 17 lions) to deduce lion space use, resource selection and activity patterns. Within the Gir PA, territorial males had 3.6 times larger range (average 95% MCP 122 km^2) than breeding females (average 95% MCP 34 km^2)**.** Breeding lionesses within the Gir PA had 7.5 times smaller ranges than the lionesses outside Gir [average 95% MCP 252 km^2] **(Figure E.5 ii)**.

Within the Gir PA, average (SE) outer and inner core areas of lions were estimated to be 79 (29) km^2 and 22 (7) km^2. Average core areas for breeding lionesses inside the Gir PA [10 (SE 3) km^2] were smaller than those for the lionesses outside the Gir PA [52 (SE 17) km^2].

Figure E.5 (i): 95% MCP home ranges (km^2) of Asiatic lions across the agro-pastoral Gir landscape, Gujarat, India.

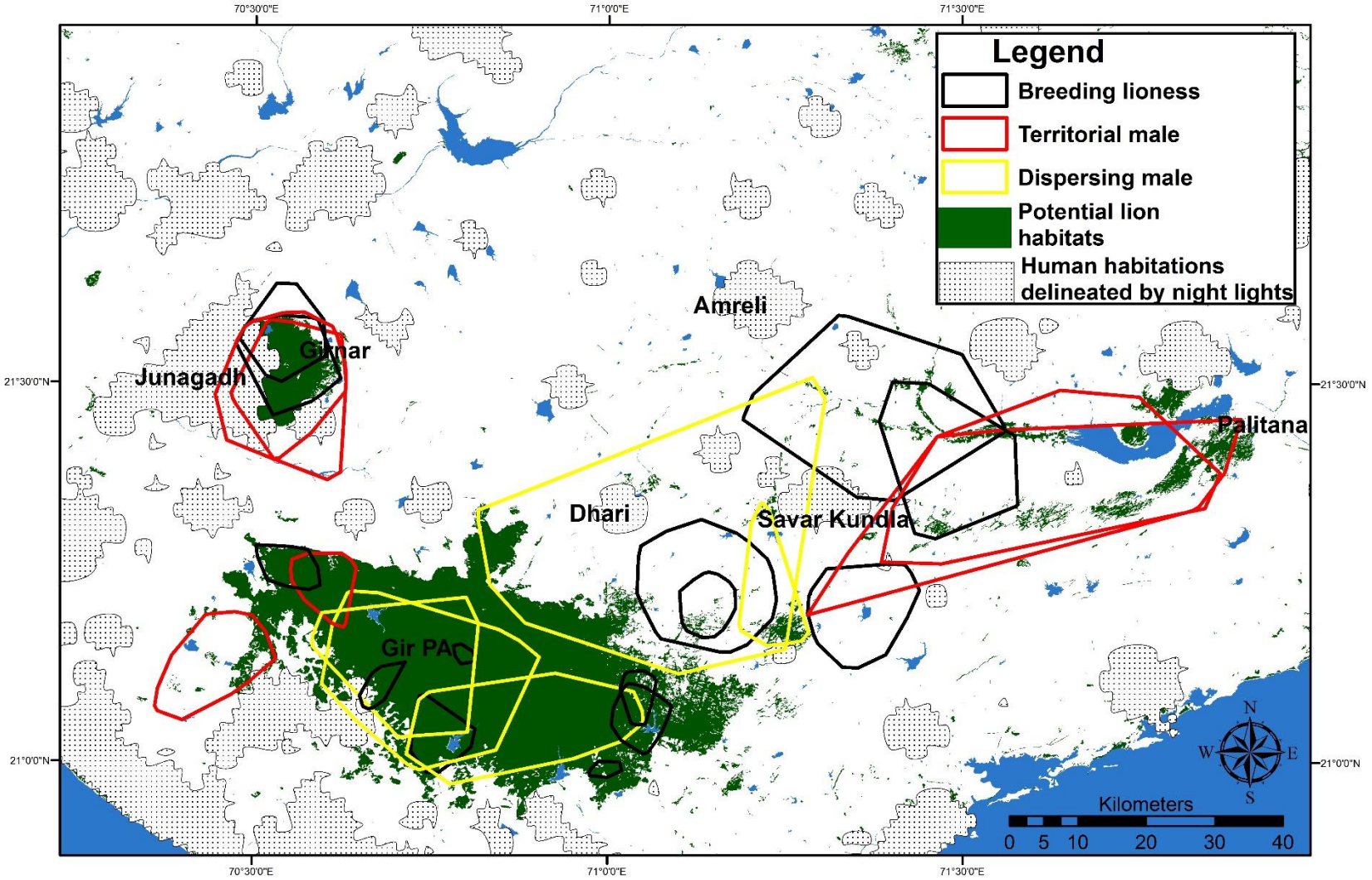
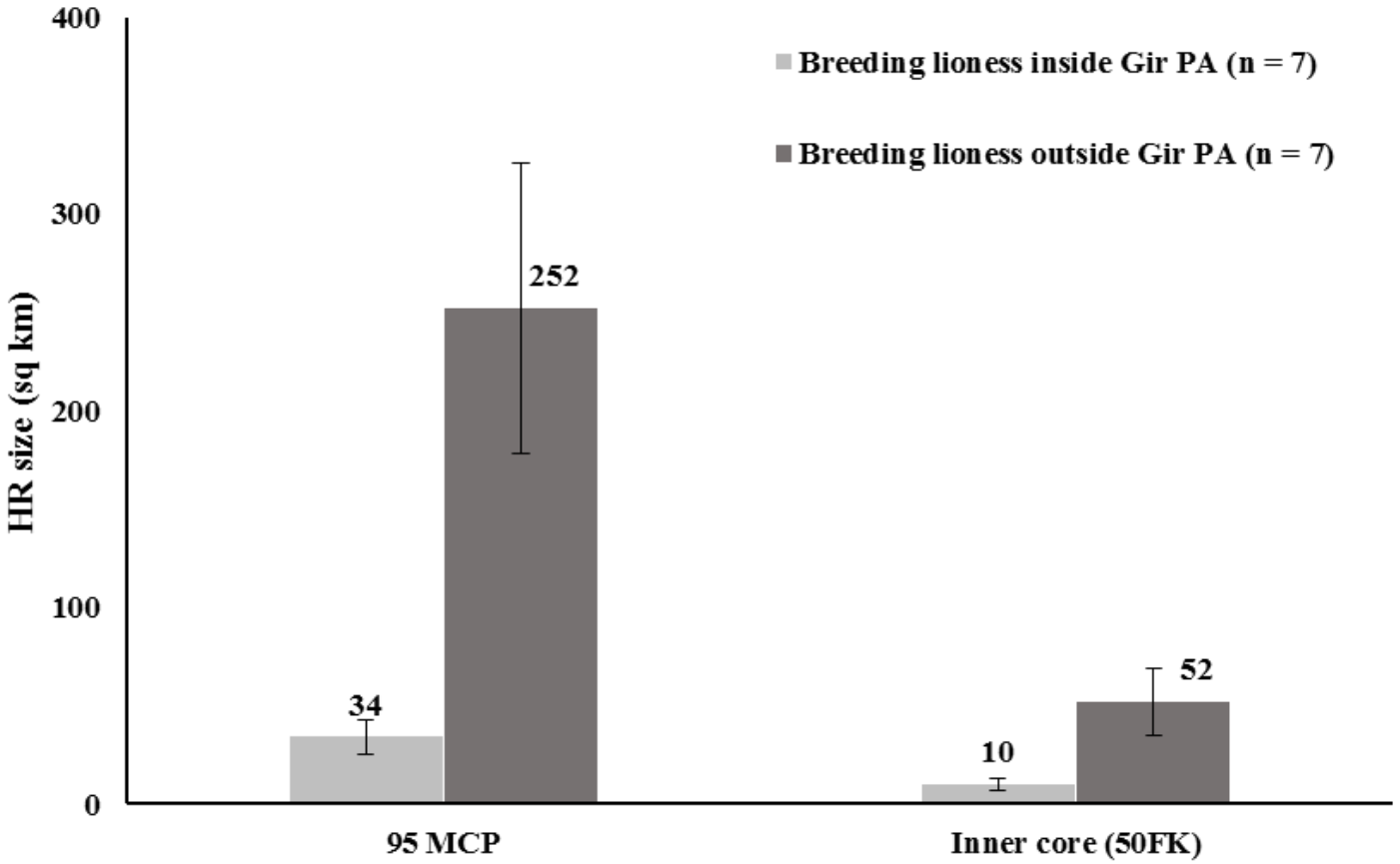


Figure E.5 (ii): Graph showing differences of home range sizes (95% MCP) and core areas of breeding lionesses in between Gir PA and outside the Gir PA.

Breeding lioness



Average territorial tenure of males (n = 7) was 36 (range 18 – 60) months while average estimated age at dispersal from natal pride for the sub-adult males (n = 6) was 3.9 (SE 0.13) years. Old displaced males were observed to successfully re-establish territories and father cubs after spending some time as nomads. 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 *Maldhari*s) till late evenings. Lion hunting peak coincided with the activity peaks of wild prey [chital (*Axis axis*) and sambar (*Rusa unicolor*)] as well as with the onset and end of livestock grazing time in the agro-pastoral landscape of Gir.

Agricultural areas and dense deciduous forests composed core areas of lions in the human-dominated eastern landscape. Lion core areas were observed to lie further from villages , townships but were closer to drainage and PAs. Average day time refuge patch size of lions in the eastern landscape was estimated to be 7.5 km^2 (SE 0.74; range: 0.07 km^2 – 21.5 km^2). Breeding lionesses had similar sized day refuge patches (3.8 km^2, SE 1.7; range: 0.4 km^2 – 5.5 km^2) like adult males (7.6 km^2, SE 0.77; range: 0.07 km^2 – 21.5 km^2). Minimum patch size in which a lioness reared her cubs successfully was 4.3 km^2.

The findings highlight the importance of even small vegetation patches as lion refuges. Patches greater than 4 km^2 were needed as breeding areas. If lions are to continue to persist in this landscape, an urgent land policy and management interventions are needed to safeguard these crucial habitats before they are removed for development as many of these patches are under private ownerships.

- **Prey availability and lion diet:** Lion prey abundance in the Gir landscape was quantified through Distance sampling based on trail transects (n = 91 spatial replicates with 315 km walk effort inside Gir PA and 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). Chital was the most predominant lion prey species inside Gir PA and Girnar (Table 1and 2 respectively), while nilgai and cattle were the most abundant wild and domestic lion prey respectively in the outer landscape (Table 3)

Lion feeding ecology was characterized through predation data (n = 175), scats (n = 185) and telemetry (5,880 hours of monitoring on 20 radio-collared lions) in order to address the inherent limitations of each method. Lions' food preference was computed by Jacob's Index. Majority (70%) of kills in Girnar was composed of wild ungulates while livestock dominated (69%) the lion kills in the eastern landscape. Sambar (29%) and nilgai (29%) were primarily predated 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%). 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.

Table 1: Estimates of density, ESW (effective strip width), average group size, encounter rate and biomass with their standard error s of lion prey species in Gir Protected Area, Gujarat. Unit weight of different species was taken from Banerjee (2012).

Prey categories	Species	Number of group observations	Model selected	Individual Density (SE)	Group Density (SE)	Effective Strip Width (meter) (SE)	Mean Encounter Rate [n/L] (SE)	Average Cluster Size (SE)	Unit Weight (kg)	Biomass density (kg)/km^2 (SE)
Wild prey	Chital	173	Half normal cosine adjustment 2, 3, 4	**56.1 (8.3)**	7.4 (0.9)	37.1 (2.7)	0.5 (0.04)	7.1 (0.5)	42	**2,356 (348)**
	Sambar	34	Uniform simple polynomial of adjustment order 2	**2.4 (0.5)**	1.4 (0.3)	38.3 (0.01)	0.1 (0.001)	1.7 (0.1)	119	**286 (60)**
	Nilgai	9	Half Normal	**0.3 (0.1)**	--	44.4 (12.1)	0.02 (0.01)	--	136	**41 (14)**
	Wild Pig	13	Uniform simple polynomial of adjustment order 2	**3 (1.3)**	0.7 (0.2)	30.9 (4.3)	0.04 (0.01)	3.8 (0.7)	28	**84 (36)**
	Chinkara	7	Uniform key	**0.6 (0.3)**	0.3 (0.1)	34.6 (0.01)	0.02 (0.01)	2 (0.4)	23	**14 (7)**
	Chowsingha	4	Uniform key	**0.2 (0.1)**	0.15 (0.07)	39.9 (0.01)	0.01 (0.03)	1.3 (0.3)	22	**4 (2)**
	Langur	30	Uniform simple polynomial of adjustment order 2	**9.1 (2.2)**	1.2 (0.2)	39.6 (3.5)	0.1 (0.02)	8.7 (0.8)	8	**73 (18)**
	Peafowl	71	Half normal cosine adjustment of the order 2	**10 (2)**	3 (0.5)	37.8 (3.3)	0.22 (0.03)	3.7 (0.4)	4	**40 (8)**
Domestic prey	Cattle	6	Half normal cosine adjustment of the order 2	**4.4 (4)**	0.5 (0.4)	19.8 (11.6)	0.02 (0.001)	8.8 (3)	136	**598 (544)**
	Buffalo	14	Half normal key	**9.4 (3.4)**	0.2 (0.06)	19.8 (11.6)	0.04 (0.01)	36.2 (5.8)	204	**1,918 (694)**

Table 2: 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 3: 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%)**

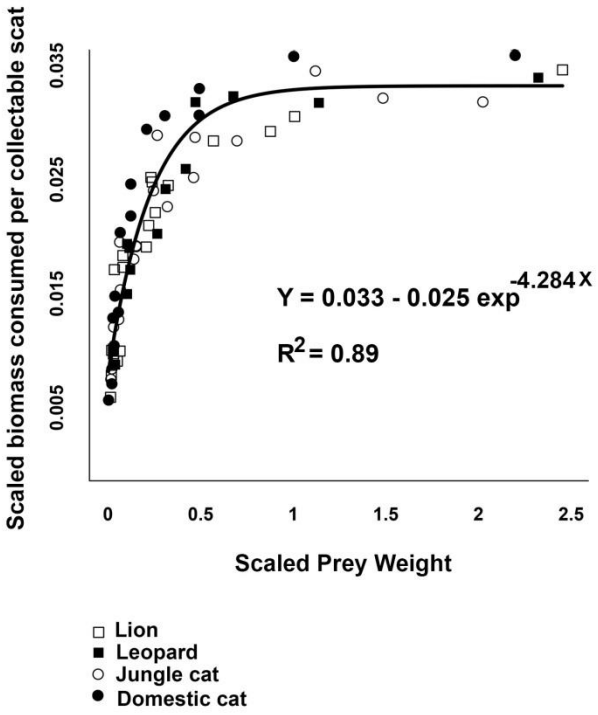
The results emphasize that despite lions' use of human dominated landscape, their predation on productive livestock and thus conflict with local communities was little. Rather, lions in the human dominated landscape mostly survive by predating on nilgai and scavenging on cattle carcasses.

- **Computing biomass consumption from prey occurrences in scats of tropical felids:** A thorough understanding of mechanisms of prey consumption by carnivores and the constraints on predation help us in evaluating the role of carnivores in an ecosystem. This is crucial in developing appropriate management strategies for their conservation and mitigating human-carnivore conflict. Current models on optimal foraging suggest that mammalian carnivores would profit most from killing the largest prey that they can subdue with minimal risk of injury to themselves. Wild carnivore diets are primarily estimated through analysis of their scats. Using extensive feeding experiments (n=68) on a wide size range (4.5 kg - 130 kg) of obligate carnivores - lion, leopard, jungle cat and domestic cat, we parameterize biomass models that best relate consumption to scat production. We evaluate additional constraints of gut-fill, prey digestibility and carcass utilization on carnivory that were hereto not considered in optimal foraging studies.

  Our results show that patterns of consumption to scat production against prey size are similar and asymptotic, contrary to established linear models, across these carnivores after accounting for the effect of carnivore size. This asymptotic, allometric relationship allowed us to develop a generalized model; biomass consumed per collectable scat/predator weight = $0.033 - 0.025\exp^{4.284\,(\text{prey weight/predator weight})}$, which is applicable to all obligate carnivores to compute prey biomass consumed from scats (**Figure E.6**). Our results also depict a relationship for prey digestibility which saturates at about 90% for prey larger than predator size. Carcass utilization declines exponentially with prey size. These mechanisms result in digestible biomass saturating at prey weights approximately equal to predator weight.

  Published literature on consumption by tropical carnivores that has relied on linear biomass models is substantially biased. We demonstrate the nature of these biases by correcting diets of tiger, lion and leopard in recent publications. Our analysis suggests that consumption of medium sized prey was significantly under-estimated, while large prey consumption was grossly over-estimated in large carnivore diets to date. We highlight that additional constraints of prey- digestibility and utilization combined with escalating handling time and risks of killing large prey, make prey larger than the predator size unprofitable for obligate carnivores.

Figure E.6: Generalized model to compute biomass consumed from scats of all tropical felids



- **<u>Economics of lion-Maldhari coexistence:</u>** Rarely do human communities coexist in harmony with large predators. Most often communities suffer due to predation on their stock while large carnivores suffer losses and at times extirpation due to retaliation. We examine the mechanisms permitting the coexistence of Asiatic lions and pastoral communities (*Maldhari*s) in the eastern part of the Gir PA. We monitored six *Maldhari* settlements during our study period to quantify seasonal livestock holding, density and losses due to predation and other causes. With free grazing rights within Gir forests, *Maldhari*s 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 *Maldhari*s seem to be beneficial to both lions and local pastoralists. Findings suggest that a combination of strict protection regime for lions, *Maldhari*s' traditional reverence towards lions and the livelihood economics permit the delicate balance of lion-*Maldhari* coexistence. Indefinite increase in human and livestock population within Gir might upset this equilibrium undermining the conservation objectives. We see no end to compensation

programs as they constitute a crucial element needed for human-carnivore coexistence. However, incorporating the loss in the opportunity cost within the compensation scheme may foster greater tolerance for *Maldhari*s, especially of the younger generations toward lions.

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

  Based on a questionnaire survey of 680 respondents from 254 villages across the Gir landscape, our study found that attitudes towards lions were more positive by younger generation, economically better off people, farmers and higher educated people (χ^2 = 86.7, df = 6, $p < 0.001$). Pastorals, lower income groups, older generation and ill-educated people were less tolerant to have lions in their neighborhood. It was interesting to note that residents of Bhavnagar district that has been recently colonized by lions and lions occur at very low densitiy, had positive attitude while in Junagadh the residents were less tolerant with a long history of lion presence and lions occurring at high densities. Economic reasons were found to be one of significant factors shaping people's attitudes about lion conservation. Communities making direct and indirect economic gains from lion conservation extended more support for lion conservation. About 10% of the respondents pointed to poaching as a probable threat to lion survival and we attribute this to their remembrance of of poaching that happened in Gir landscape. Due to high price of lion body parts in international markets especially in China, the possibilities of such incident in the future cannot be ruled out.

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

- **Assessment of Barda Wildlife Sanctuary for potential of lion reintroduction:** We assessed ecological and social potential of Barda Sanctuary (192 km^2) in western part of Saurashtra, Gujarat for developing strategies for lion reintroduction. The study mandated by the GFD aimed at quantifying prey, predators, human disturbances, land-use patterns and local people's perception towards lion reintroduction in Barda. Barda landscape was surveyed between October 2013 and March 2014. We used spatially explicit capture-recapture (n = 1,856 camera trap nights) and Distance sampling (n = 27 line transects) framework for estimating abundance of predators and prey respectively. Potential habitat

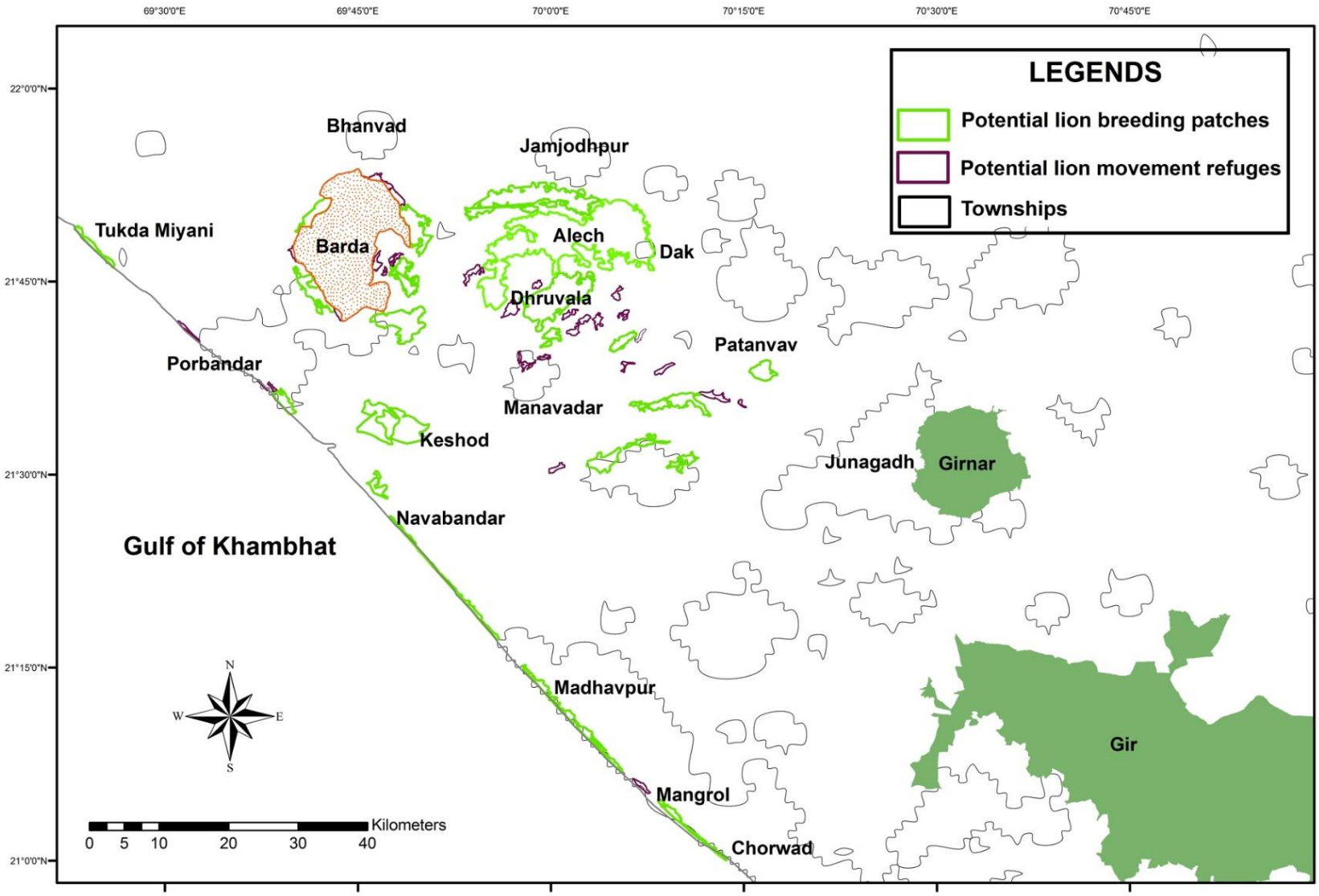
corridors between Gir and Barda were delineated using lion habitat-suitability models as cost surface in Circuitscape. Social perceptions about lion reintroduction were quantified through questionnaire surveys (n = 90 respondents). We used information on lion habitat use, home range and prey availability from eastern Gir (habitat similar to Barda) to estimate lion carrying capacity of Barda landscape.

Barda landscape (410 km^2) comprising of Barda sanctuary, Alech hills and grasslands and coastal *Prosopis juliflora* forests of Porbandar district was estimated to support between 26 - 35 lions. Wild prey density of Barda sanctuary was low, nilgai (0.3±0.02 km^{-2}) and wild pig (3.4±2.8 km^{-2}) being the only wild ungulates recorded on transects. Currently, with a sizable leopard density in Barda (7 ± 3 SE/100 km^2), reintroduced lions cannot be sustained exclusively by wild prey. Existing habitat connectivity between Gir and Barda was found to be extremely tenuous and unfavorable for regular lion movements. Majority (98%) of the pastoralists living inside Barda sanctuary were willing to resettle outside. Such willingness for 'voluntary resettlement' is a bonus for wildlife managers and maximum effort should be made to secure a large inviolate area for wildlife within Barda WLS by incentivized, voluntary relocation.

Gujarat Forest Department should first overtly decide their conservation goals. If the objective is to establish another separate free ranging lion population in Barda as a security against disease caused epidemics and natural calamities in Gir, then the natural movement corridors between Barda and Gir landscape is not desirable. Barda population then needs to be artificially managed as a separate metapopulation with supplementation and management mediated exchange of individuals from Gir after appropriate health checks. Alternatively, if Barda is desired to be a metapopulation of Gir to enhance long-term viability of lions then it would be judicious for the government to allocate and spend funds for restoring habitat corridors between Barda and Gir. In this case, the long-term viability of lions in the Saurashtra landscape is enhanced by adding Barda to the existing metapopulation structure of the Gir lions. However, after considering the current corridor connectivity to be extremely tenuous and the extensive investments, policy changes and management interventions required to restore the viable corridors, the first alternative (maintaining Barda lion population artificially as a metapopulation of Gir) seems to be more practical and desirable for lion conservation.

We also identified habitat refuge patches in the agro-pastoral landscape outside Barda sanctuary essential for supporting breeding lion nuclei in future **(Figure E.7)**. We propose that the habitat patches > 4 km^2 need to be legally protected and recommend them to be considered for 'conservation reserves' while smaller habitat patches need to be made 'eco-sensitive' so as to promote landscape scale lion conservation without compromising on traditional livelihood needs.

Figure E.7: Barda landscape showing potential habitat patches that could sustain breeding and serve as day refuges for lions.



Summarizing the ideal scenario of lion reintroduction in Barda: Soft release of 5-8 lions concurrent with incentive-driven voluntary resettlement of pastoralists from within Barda sanctuary to create inviolate area, building up prey by restocking and managing conflicts with appropriate compensation was considered to be a feasible strategy for making Barda a potential new home for lions. Restoring habitat corridors would require extensive investments and policy change, impractical to implement for establishing a breeding lion population representing the genepool of Gir..

Success of Barda reintroduction within a span of 5 years should be examined by the following indicators: 1) establishment of a population of about 15-20 lions that are breeding naturally with a good recruitment rate, 2) resettlement of all *nesse*s from inside Barda sanctuary, 3) building up of natural prey within Barda sanctuary by restocking programs to over 10 wild prey per km^2 and 4) landscape scale conservation through legislation (declaring community reserves and eco-sensitive areas) and eco-restoration. On the other hand, the project could be considered to be a failure if 1) an inviolate space of about 200 km^2 in and around Barda WLS is not established within 5 years, 2) failure of securing lion habitats in Barda landscape by declaring them as conservation reserves and/or eco-sensitive zones, 3) wild prey population occurring at a density of < 5 per km^2 after 5 years, 4) lions with less than 8 individuals after 5 years with no natural births and high mortality (>70%) of reintroduced lions due to human-induced causes. We conclude that if these occur then the project probably needs to be rolled back and reconsidered in terms of policy and alternative strategies.

- **Estimating leopard abundance in Girnar WLS:** Girnar WLS comprises of a circular forested patch surrounding Girnar hills. Majority of the WLS has steep terrains providing excellent refuge for leopards. Under intense pressures of urbanization, industrialization and agricultural expansion, Girnar has become an isolated forest patch surrounded by high human densities (including Junagadh city) in most sides. Girnar is an important pilgrimage site for Hindus, Jains and Muslims, leading to influx of devotees throughout the year, with numbers reaching upto 10 lakh during major religious events. The current study, mandated by the CWLW Gujarat state as an additional research work, therefore, aimed at estimating leopard abundance in Girnar. Till date the population estimation of leopards in Gujarat has been done based on "Pugmarks" at all instances. This study incorporates camera trapping in a mark recapture framework for the first time in the state, aiming to provide more reliable estimates.

We carried out camera trapping within an area of about 100 km^2 by distributing 34 camera trap pairs in 25, 5 km^2 grids, separated into two sampling blocks. Trapping was continued for 26 days in each sampling block, yielding total effort of 884 trap nights, and photo-capturing 26 distinct adult leopards. The M(b) model (i.e., behavioural differences between capture and recapture probabilities) best fitted the capture history data. It estimated adult leopard abundance ($\widehat{N}$) at $28.0_{Mean}\pm2.89_{SE}$ individuals. The traditional approach of computing the effective trapping area ($\hat{A}$ = sampling polygon + buffer width of

half mean maximum distance moved by leopards in successive recaptures) returned a density estimate ($\widehat{D}$) of $18.88_{Mean}\pm1.97_{SE}$ individuals/100 km^2. Using spatially explicit capture recapture technique with a habitat mask of 208.8 km^2, density was estimated at $17.17_{Mean}\pm3.48_{SE}$ individuals/100 km^2.

Girnar harbors one of the highest leopard densities in the country. Nonetheless, it is surprising that despite such high carnivore and human densities, magnitude of conflict between the two is low. However, the Girnar Management should explicitly address how to deal with problem leopards in a timely manner to prevent backlash and maintain the current tolerance of people.

- **Conservation Implications of the current research project:**

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

i. Concentrated effort to conserve all habitat patches larger than 4 km^2 and attempt to restore a mosaic of refuges (vegetation patches larger than 1 hectare) outside 1 kilometer radius from villages for breeding lionesses and daytime refuge for other lions. This will minimize confrontations and potential of conflicts with humans. All identified core zones of lion usage in the landscape need to be offered some level of legal recognition so that they are not lost to developmental activities.

ii. This study supported the long time debate of thickening of Gir following the cyclone of 1982 which might have happened in response to canopy opening within the protected area due to the uprooting of more than two million trees,. This trend of increase in canopy thickening was visible till 2002, after which it stabilized.

iii. Girnar population of lions exists as a metapopulation sink in connection with the Gir PA. The current study delineated a corridor between Gir and Girnar used by lions primarily for movement in between these two PAs. Vegetation cover provided by drainage network, gauchar (pasture lands), farmlands and scrublands are crucial for lion refuge and movement. Part of the delineated corridor area was promptly declared as an "ECOSENSITIVE" zone under The Environment (Protection) Act 1986, Government of India by Gujarat forest department with restrictions on

high impact industry and mining activities. The remaining part (towards the Gir PA) needs to be made eco-sensitive urgently. Already developmental activities have commenced here and irreversible damabge and habitat changes will happen soon.

iv. Riverine patches within the Gir-Girnar corridor are vanishing at an alarming rate and the remaining patches are likely to be converted to agriculture by 2020. Sustainable management of these forest fragments along the riparian corridors of tributaries of the river Ozat and other small rivers is urgent.

v. Although, no study is yet conceptualized on assessing the effects of highways on the movement of lions, however, few nodes (n = 12) have been identified, serving as bottlenecks (passageways across highways) and incorporation of crossing structures for wildlife is recommended in road-planning (widening or new road construction).

vi. *Gaushala*s and *Panjrapole*s are major food sources for lions outside the Gir PA and have significant role in minimizing conflicts with local people. Such practices need to be continued.

vii. 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.

viii. The compensation scheme implemented in Gir for livestock depredation was good in comparison to schemes elsewhere. But regular revision of the scheme, that includes capital loss and lost opportunity cost should be adopted. The scheme should be streamlined with participation of NGOs for prompt and transparent implementation.

ix. Illegal practice of using electric fences by many farmers in the landscape should be controlled and in the long term addressed by introducing compensation against crop damage. This would minimize accidental lion mortality by electrocution and reduce human-lion confrontations in the farmlands at night while farmers actively trying to defend their crops from wild ungulates.

x. 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, Hingolgadh, Wankaner, Chotila, Jasdan, Rampara and up to Sayla and Muli in the north; Kutiyana, Ranavav, Barda and Porbander in the west and toward Bhal and Vallabhipur in the east) while maintaining density of about 2-4 lions/100km^2.

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

CHAPTER I

INTRODUCTION

Large carnivores are k selected (characterized by low population density occurring at the high trophic level and wide ranging requiring relatively large tract of intact, contiguous habitats), sensitive to anthropogenic disturbances and with a propensity to conflict with humans (Woodroffe 2000). Although the world today is witnessing the highest concern society has ever shown towards conservation of large carnivores and their ecosystems (Mech 1996; Estes et al. 2011); nevertheless, the numbers and range of most large carnivores continue to decline (Ripple et al. 2014). For example, historically lions (*Panthera leo*) occupied a range in Africa of over 22,211,900 km^2 which has been currently reduced to less than 3,802,873 km^2 — a reduction of 83% (Ray et al. 2005; Riggio et al. 2013). Simultaneously, African lion numbers declined from little less than 100,000 in 1990 (Nowell and Jackson 1996) to a current estimate of continent-wide number of less than 40,000 (Chardonnet 2002; Bauer and Van Der Merwe 2004; Riggio et al. 2013). The situation is critical in West Africa where a recent estimate shows about 400 lions occupying about 1% of the species' historical range (Henschel et al. 2014).

However, at the same time, successful conservation management programs have contributed in the population recovery of many endangered carnivores in Europe (Chapron et al. 2014), USA (Bangs et al. 2001) and Asia (Singh and Gibson 2011). Population decline, crisis management, stabilization, precarious recovery and sustained recovery have been described as five stages of species restoration (Linklater 2003). Currently, carnivore conservation involves a sixth stage beyond population recovery, that of managing successful recoveries of target species that exceed the carrying capacity of protected areas (Hayward et al. 2007b). During this stage, space and conflict mitigation become the principal conservation concerns (Macdonald and Sillero-Zubiri 2002; Inskip and Zimmermann 2009).

The last free ranging population of Asiatic lions (*Panthera leo persica*) in the Gir forests of western India typifies all the above scenarios of carnivore conservation. With their origin in East and South Africa (**Figure 1.1**; Barnett et al. 2014; Antunes et al. 2008), Asiatic lions extended from the African Mediterranean coast into Eastern Europe, the Middle East, and into

India through during the Azilian period of the Neolithic age (**Figure 1.1**; Divyabhanusinh 2005; Schnitzler

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

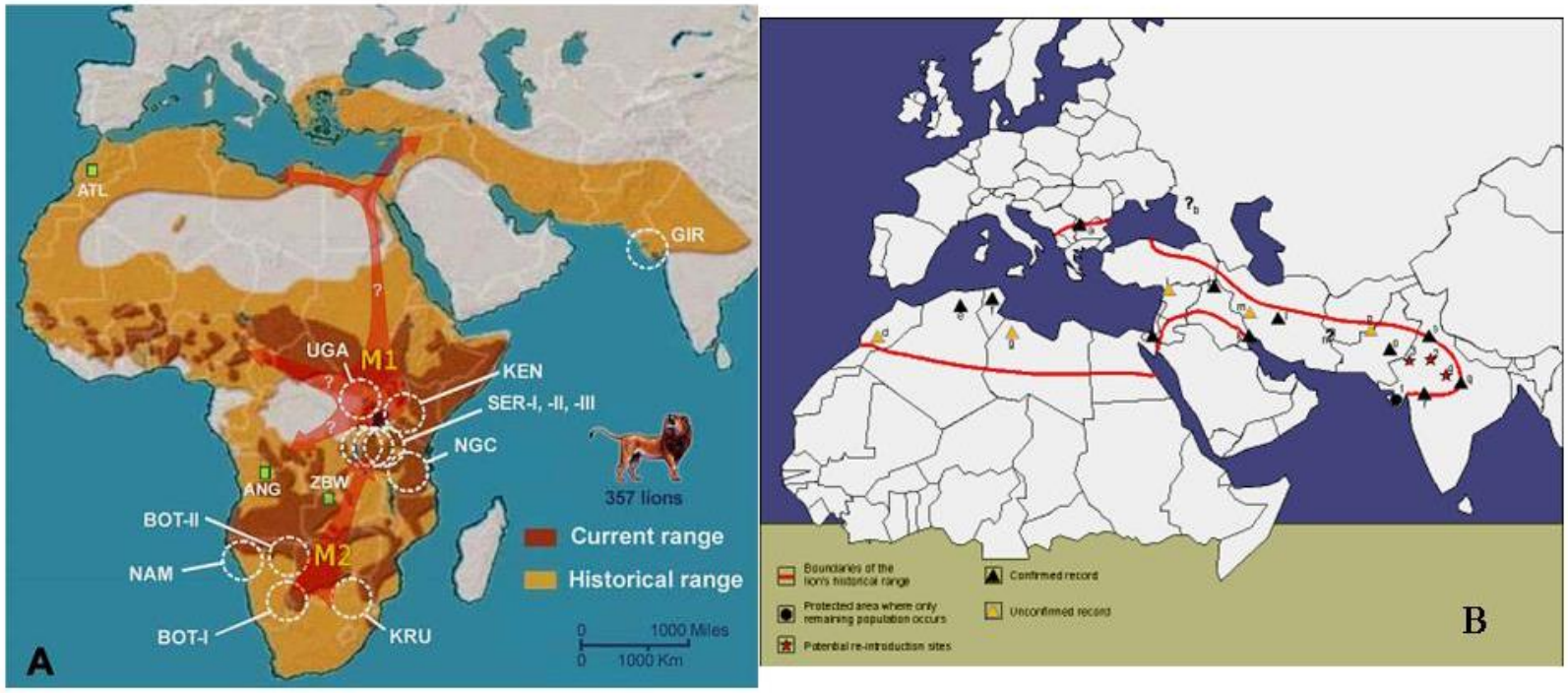
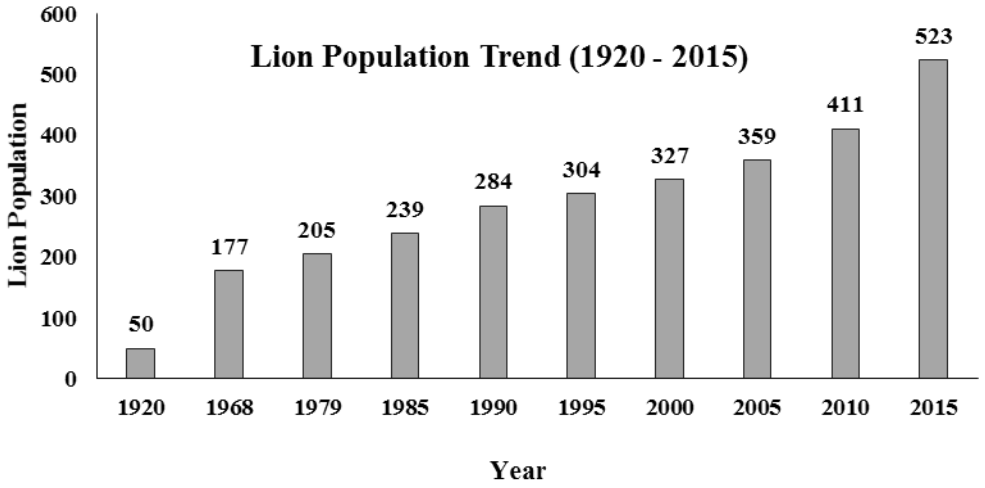


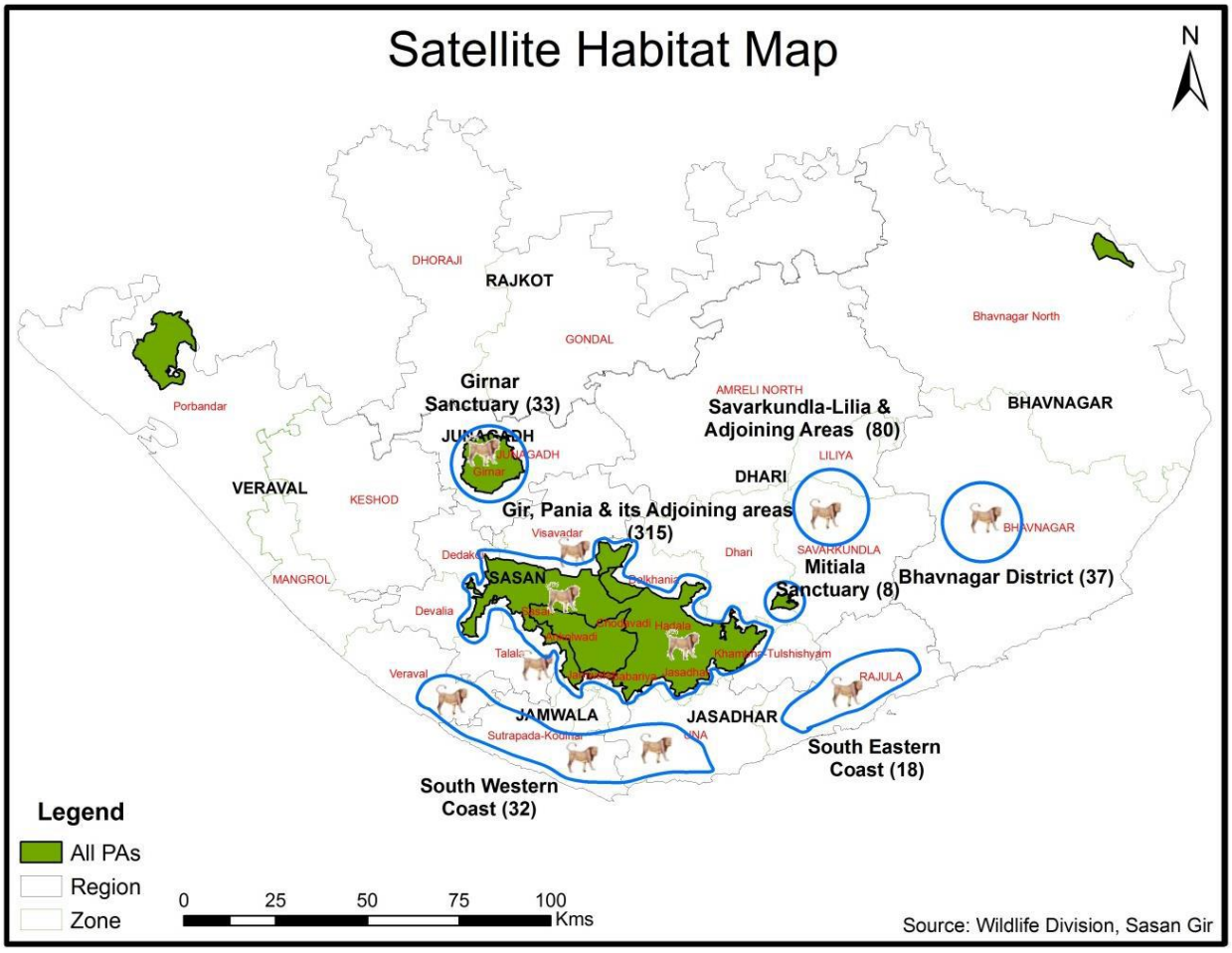
Figure 1.2: Population trend in Asiatic lion as per census report of the Gujarat Forest Department



2011). Driscoll et al. (2002) suggest that about 2,680 (range 1,081 – 4,279) years ago, the Kathiawar Peninsula where the Gir forest is located was separated from mainland India by rising sea level (Gupta 1972), causing the first genetic bottleneck that isolated the founders of the present Asiatic lion population, compelling them to inbreed for several generations (O'Brien 2003). A second, less-severe bottleneck occurred at the onset of the 19th century when lions became restricted to the Gir Forests and their number declined to around 50 individuals, due to hunting and habitat loss (Edwards and Fraser 1907; Kinnear 1920; Pocock 1930; Joslin 1973). However, due to the timely and stringent protection by the Rulers of Junagadh and subsequent habitat management by the State-run forest department, Asiatic lions have increased to about 520 **(Figure 1.2)** and dispersed into about 22,000 km^2 of agro-pastoral southern and eastern Saurashtra landscape adjoining the Gir forests comprising of the Gir Protected Area (PA), Girnar Wildlife Sanctuary and vast tracts of human-dominated eastern landscape comprising of revenue areas of Amreli, Bhavnagar, Junagadh and Gir Somnath districts (**Figure 1.3**; Singh and Gibson 2011; Banerjee and Jhala 2012; Meena and Kumar 2012; Ranjitsinh 2014). Drastic reduction in the numbers of isolated mammalian populations results in inbreeding which leads to an erosion of genetic diversity of the species thereby exposing it to increased risk of extinction (Terborgh and Winter 1980; Frankham et al. 2002). Apart from the negative impacts due to the loss of genetic diversity (O'Brien et al. 1987; Wildt et al. 1987) the Gir lion population also faces the multitude

of threats to which small and isolated populations of endangered species restricted to a single site are subject to (Gilpin and Soulé 1986).

Figure 1.3: Current distribution of Asiatic lions in 22,000 km^2 of agro-pastoral Saurashtra Landscape, Gujarat (reproduced from Gujarat Forest Department 2015)



While the recovery of Gir lion population elucidates a conservation success story; it also stances serious challenges for the wildlife managers and conservationists in terms of maintaining the long-term persistence of a minimum viable population [95% chance of persistence over several centuries (Soulé 1987) to 99% chance over 1,000 years (Shaffer 1981)]. A population gains more security with increasing size and number of protected demes with a viable population

needing a minimal area for survival (Soulé and Simberloff 1986). Gir PA with a lion population of about 300 is believed to have reached its carrying capacity (Singh 1997). With the land ownership being primarily private in the landscape, creation of new large or medium-sized PAs in Saurashtra is difficult. Maintaining the current population of about 500 lions as a minimum viable in long-term could only be achieved by protecting the source population (Gir PA) and at the same time providing dispersal opportunities by linking several metapopulations (Hanski 1994) across the agro-pastoral Saurashtra landscape. Coexistence with humans thus becomes an inevitable feature for maintaining future persistence of the Gir lions. With rapidly changing land-use pattern, ensuring long-term persistence of such meta-population framework and permitting human-lion coexistence demands robust understanding on lion ecology, conflict and socio-economic underpinnings.

One of the only long term research undertakings in India has been the Wildlife Institute of India's (WII) project in Gir operational since mid-1980's. This project has been providing crucial information on the dynamics of Gir ecosystems, prey-predator interactions and lion ecology which short term projects cannot provide. Information generated by WII's research projects contributed significantly in drafting various Biodiversity Management Plans, conservation legislations and policy documents for the Greater Gir landscape (Singh and Kamboj 1996; Pathak et al. 2002; Meena and Kumar 2012; Karn and Sahu 2014). The current project in collaboration with Gujarat Forest Department (GFD) was initiated in 2007 with the aim of assisting the managers to formulate landscape level lion conservation policies based on informed research and robust scientific approaches.

Research objectives: In recent times, WII had submitted two technical reports (Jhala et al. 2006; Jhala et al. 2011a) to the GFD communicating all past research findings. The findings were accepted by the Department and based on those WII's research permit in Gir was extended for 5 years in March 2011 (*vide letter number WLP/28/C/97-99/2011-12 from the office of CWLW, Gujarat State*). The research objectives of the current project were decided after discussing with the CWLW and the park managers. The research intended to address the following objectives:

1. Lion abundance, population structure and demography in the Gir landscape.
2. Lion ranging, dispersal and resource selection in the Gir landscape.
3. Lion diet in the Gir landscape.

4. Evaluating aspects of lion-human conflicts in the Gir landscape.
5. High resolution mapping of Gir Landscape to better understand the factors responsible for animal distribution patterns and land use patterns.
6. To develop habitat suitability models for lions and principal prey species.

During the tenure of this project, WII was mandated by the CWLW, Gujarat state to take up three additional research components – 1) assessment of potential habitat corridor landscape between Gir and Girnar and 2) estimation of leopard (*Panthera pardus*) abundance in Girnar and 3) ecological and social potential of Barda for reintroduction of Asiatic lions. All these components were successfully addressed and findings were already communicated to the GFD (Jhala et al. 2012 a, c; Jhala et al. 2014 a).

Organization of the current report

The current report is divided into following chapters:

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

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

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

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

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

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

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

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

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

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

Chapter 11: Computing biomass consumption from prey occurrences in scats of tropical felids – discusses parameterization of the *biomass models* that best relate consumption to carnivore scat production.

Chapter 12: Economics of living with lions – investigates aspects of lion-human conflicts and discusses drivers behind legendary lion-*Maldhari* (pastoral communities in Gir) coexistence.

Chapter 13: Assessment of people's perception for lion conservation in the Gir landscape

Chapter 14: Ecological assessment of Barda landscape for potential of lion reintroduction

Additional Chapter 15: Abundance of leopard in Girnar

CHAPTER II

STUDY AREA

The study was carried out in about 22,000 km^2 Greater Gir Landscape **(Figure 1.3)** spreading over four districts of southern and eastern Saurashtra peninsula of Gujarat, western India. The entire landscape is divided into:

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

1. Gir Protected Area

History, Location and Size

In general, 'Gir forest' term is used synonymously with the Gir National Park and Wildlife Sanctuary, but the ecological boundaries of Gir a couple of centuries before covered half of the Saurashtra peninsula (Divyabhanusinh 2005). Due to increased cultivation and developmental activities Gir forest has shrunk to almost the legal boundaries of the protected forest areas. Gir National Park and Wildlife Sanctuary lies between 21^0 20' N to 20^0 40' N and 70^0 30' E 71^0 15' E. The total area under protection as sanctuary (1153.42 km^2) and National Park (258.71 km^2) is 1412.13 km^2 **(Figure 2.1)**. Recently the Chachai-Pania wildlife sanctuary (39.64 km^2) at the northern boundary of Gir PA has also been included as part of the Gir Conservation Unit (GCU). Additionally, there is a buffer area of reserved forest (245.90 km^2), protected forest (107.51 km^2) and unclassed forest (77.19 km^2) comprising of valuable grassland and forests (Pathak et al. 2002). The Gir protected area is divided into three managerial zones viz. Sanctuary west, Sanctuary East and National Park. Due to a rainfall gradient increasing from east to west, these three zones differ ecologically which reflects in the vegetation types (Qureshi and Shah 2004) and associated productivity. The Gir reaches its greatest length of 80 km along the east-west axis, whereas north south width is 16-24 km, on an average, except eastern and western ends.

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 2,560 km^2 area under forest cover which was significantly contributed by the revenue forests. Later, Joslin (1973) reported 87% decline in forest cover outside the sanctuary area between 1872 and 1969, mostly for cultivation purpose.

Uncontrolled commercial exploitation of forest resources and increasing demand for cultivation land by the expansion of human settlement led to continuous decline in the area under the forest cover. It was not until 1920 that a small portion of Gir forest (Devalia Block in the south-western boundary of the Gir PA) declared as a lion sanctuary by the erstwhile *Nawab* of Junagadh. After independence, in 1965, the Government of Gujarat constituted the Gir Wildlife Sanctuary and later it was expanded in 1974 to present size of the PA. Subsequently, a tract of land nearly 150 km^2 was declared as a national park in 1975 and enlarged to its present size in 1978.

Topography

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

Geology and Soil

The chief geological formation of 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.

Climate, Seasons and Rainfall

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

The area experiences three distinct seasons as the other part of the country. There is cool dry winter in Gir from December to March (average minimum temperature 9 ^{0}C.) followed by a hot dry season (average maximum temperature 42^{0}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 1,000 mm and 800 mm, respectively (Khan et al. 1996). The rainfall gradient increases from east (850 mm at Jasadhar) to west (1,000 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

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).

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

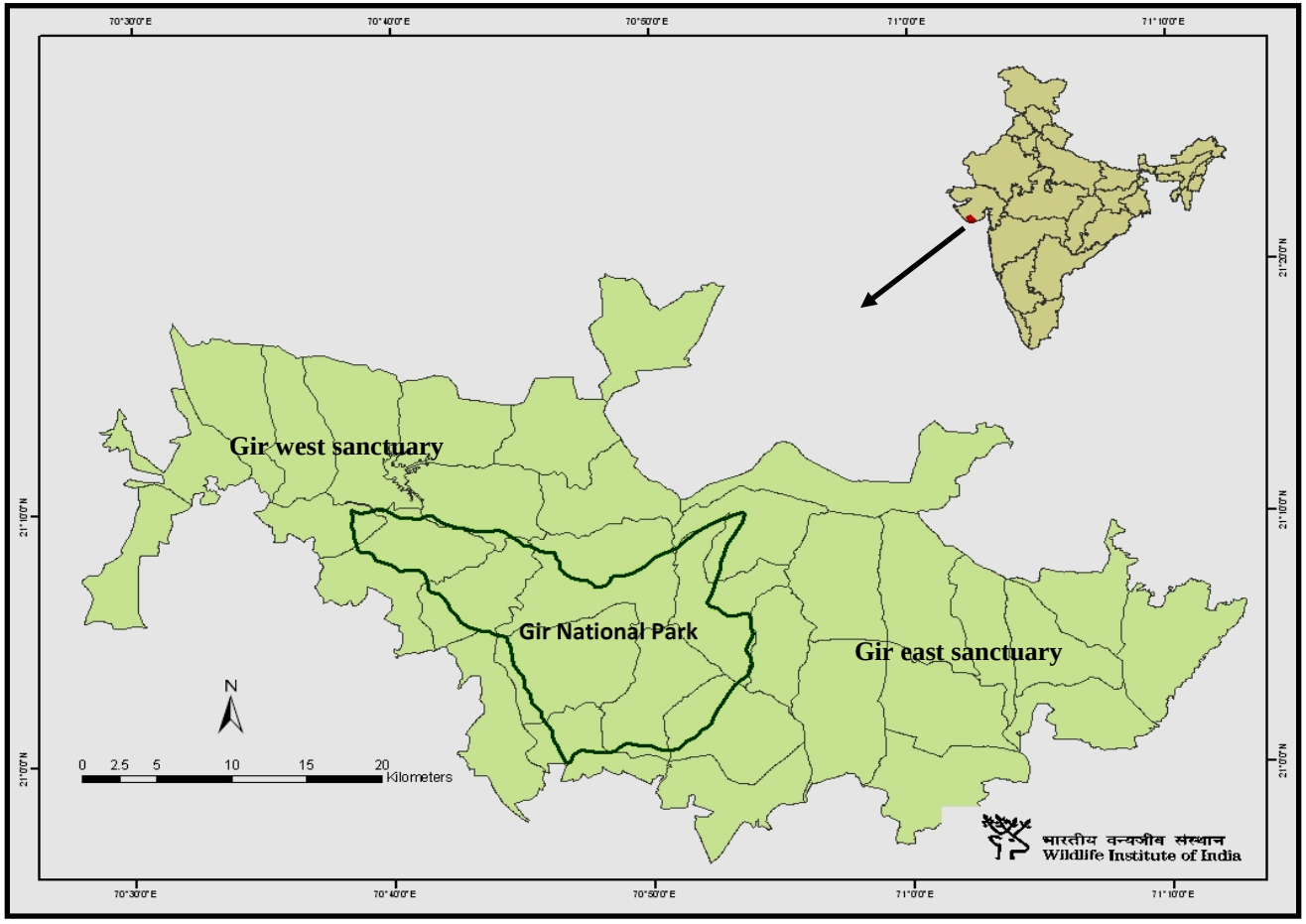


Table 2.1: Percent contribution land use within Gir Protected Area (after Qureshi and Shah 2004)

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-Boswelia	12.54
Thorn Forest	7.73
Scrublands	4.48
Savanna	1.38
Agriculture/Open Area	0.29

These habitat types were reclassified into seven categories that were relevant in terms of lion habitat use. These were:

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

Fauna

The Gir forest has a diverse assemblage of wild fauna harboring about 32 species of mammals, 26 species of reptiles and over 300 species of birds. Apart from the Asiatic lion some of the other carnivores are leopard (*Panthera pardus*), jungle cat (*Felis chaus*), striped hyena (*Hyaena hyaena*), jackal (*Canis aureus*), Indian fox (*Vulpes benghalensis*), ratel (*Mellivora capensis*), mongoose (*Herpestes edwardsi*), small Indian civet (*Viverricula indica*) and rusty spotted cat (*Prionailurus rubiginosus*). Major herbivores include chital (*Axis axis*), sambar (*Rusa unicolor*),

nilgai (*Boselaphus tragocamelus*), four horned antelope (*Tetracerus quadricornis*), langur (*Presbytis entellus*) and chinkara (*Gazella gazella*) (Singh and Kamboj 1996).

People and human settlements

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

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

2. Girnar Wildlife Sanctuary

History, Location and Size

This newly formed Protected Area (c.a. 180 km^2) (Government of Gujarat 2008) of Gujarat is a famous and historical site of pilgrimage for both Hindus and Jainas and the highest hill feature in Gujarat. Mount Girnar is visited by around 0.9 million pilgrims annually (Parmar 2005; Karn and Sahu 2014). The town of Junagadh is situated practically at the foot of these hills to their west. These hills lie between the parallels of latitude 21 .25' and 21 .35' N and longitude of 70.30' and

70.40’ E. Looked from above, the forest area looks like a circular disc of about 16 km (Parmar 2005) diameter **(Figure 2.3)**. Locally these forests are also known as *Dungar*. Girnar forests were once part of a major forest ecosystem comprising of Gir and Girnar. Gradually the urbanization and economic activities caused by major agricultural invasion and industrialization have isolated these two forests converting Girnar as an isolated compact patch of forested habitat.

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

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

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

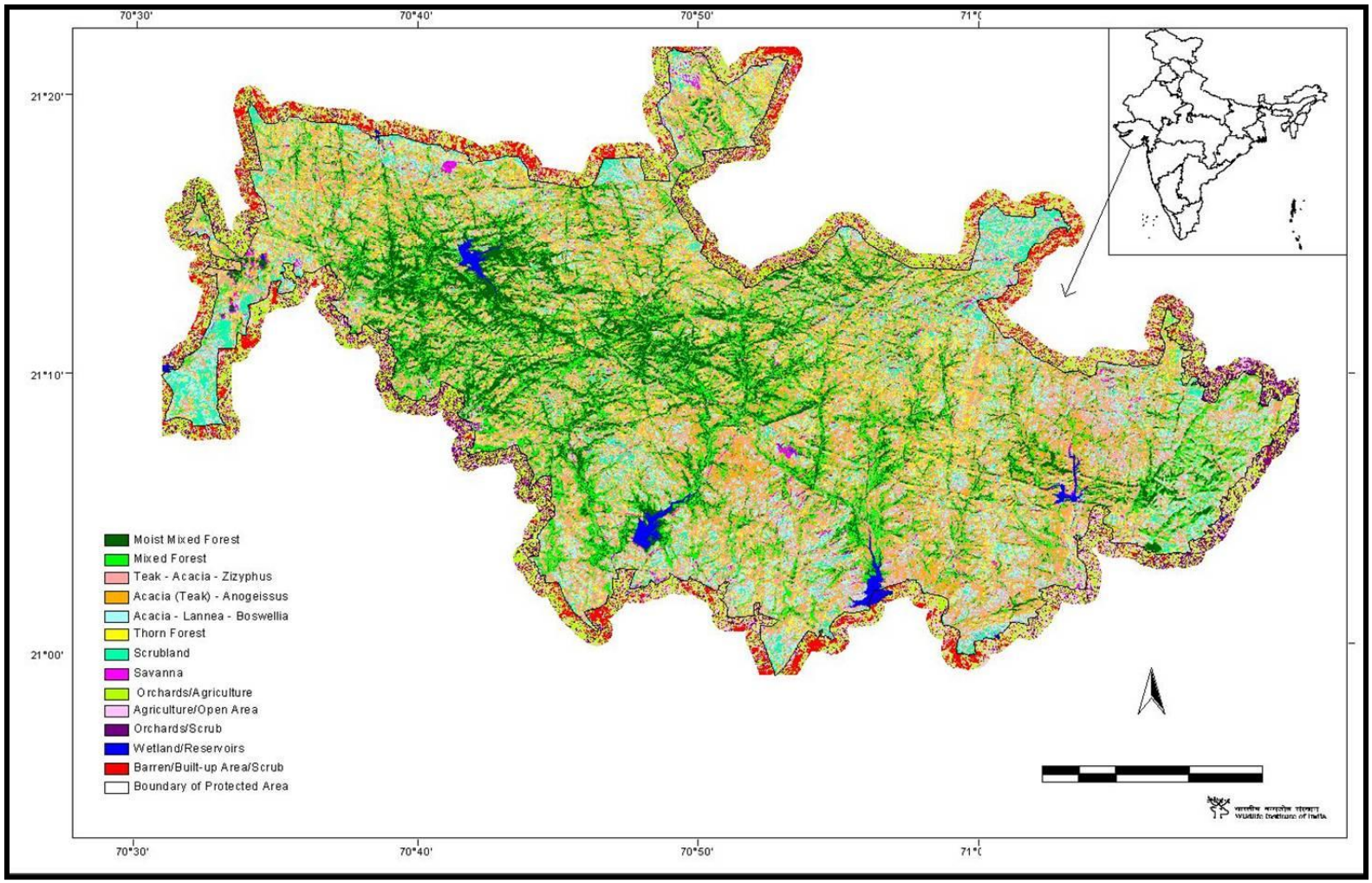
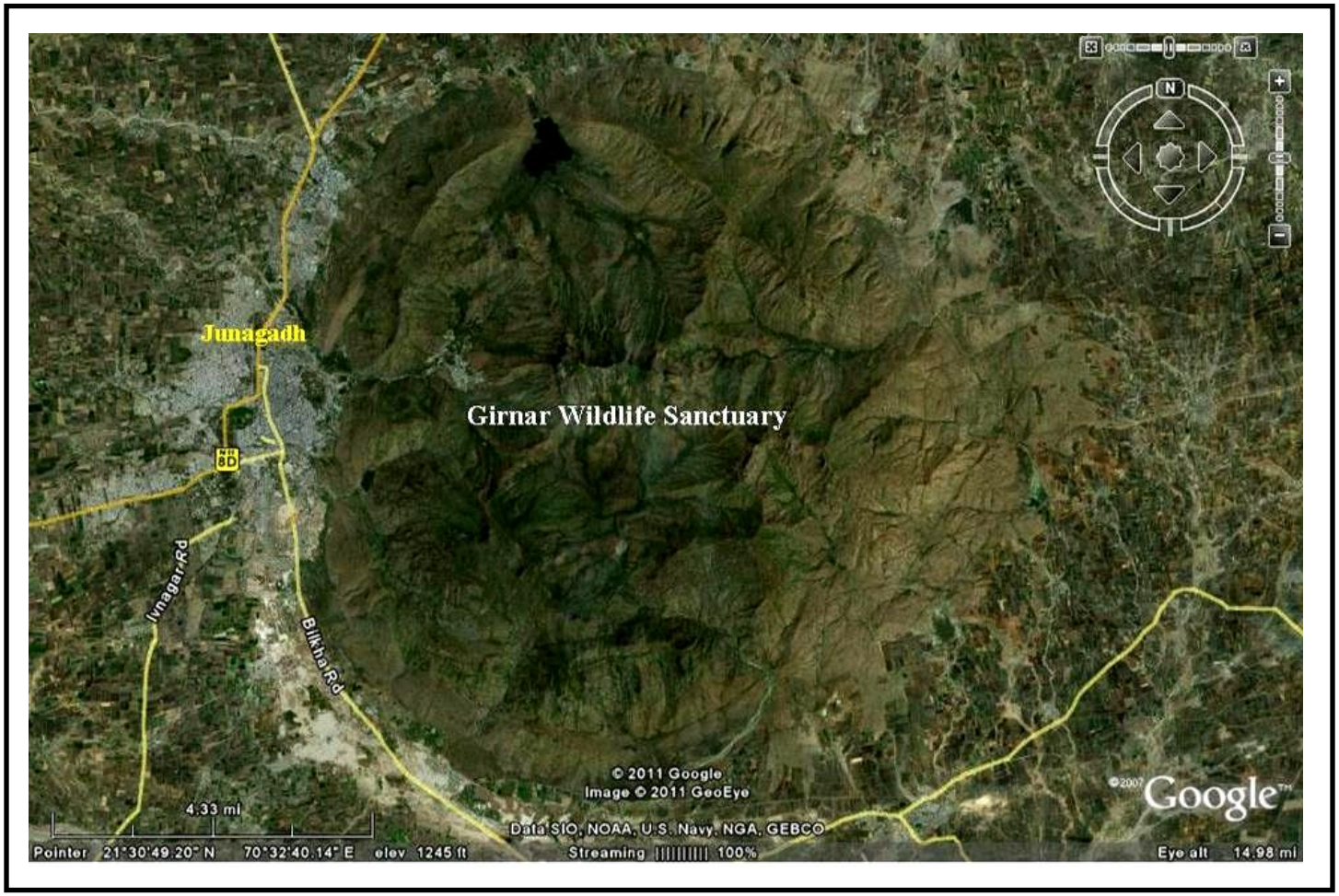


Figure 2.3: Google Earth image of the Girnar Wildlife Sanctuary. Junagadh city mark the western boundary of the sanctuary. Surrounded by human dominated landscapes from all sides, sanctuary boundary of the Girnar forms a 'hard' boundary (Banerjee et al. 2010)



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

Geology and Soil

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

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

Climate

Climate of the area is generally dry. The tract experiences, in fact, only two seasons hot and cold. The monsoon, which has few rainy days, merges with the hot period, which extends from the middle of February to the end of October, the remaining period from November to mid-February forming the cold season. Monsoon generally sets in by the first week of July. July and August are the two months when maximum, three-fourths, rain falls, June and September are the marginal months. The monsoon in the area is not dependable. The distribution of rainfall and number of rainy days vary widely over years. The average rainy days in a year were 43-65.

Monsoon generally breaks out by the end of June and continues up to middle of September, with maximum concentration in July and August. The monsoon is very irregular and erratic. Every fourth year is almost a year of drought. During the year 1989 to 2003 average rainfall of Junagadh was 697.11 m.m. Maximum rainfall was 1,164 m.m. in the year 1994 and minimum rainfall was 299 m.m. in the year 1999. The temperature range varies greatly. The mean variation in temperature is high and the maximum temperature is 41^{O} C and minimum 7^{O} 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, Emblica officinalis, Acacia arabica, Acacia catechu, Wrightia tinctoria* and *Dichrostachys cinerea*.

Type 3- Scrub forests and grasslands: This type is found all the degraded patches in the plain area on the hill tops and along the ridges. Bamboo occur scattered in pockets. *Nyctanthes arbortristia* bushes, *Strobilanathes* spp. and *Dichrostachys cinerea* are some of the typical species of the type. Along the outer boundary, *Butea monosperma* and thorny bushes are the main species of this subtype. Along nallas compositions is remarkably different where species like *Manikara hexandra, Mitragyna parviflora, Ixora arborea, Gardenia resinifera* and *Moringa oleifera* occur. Thorn forests on further deterioration turns into savannah forests characterized by

large grassy open blanks with very sparse and poor thorny scrub forests. Both annual and perennial grasses are found in these areas. Major grass species include *Iseilema prostratum, Dichanthium annulatum, Sehima sulcatum, Bothriochloa intermedia, Aristida funiculate, Iseilema laxum, Themeda cymbaria, Apluda mutica, Heteropogon contortus, Cymbopogon jawarancusa, Cymbopogon martinil,* and *Sorghum helepense*

Fauna

Girnar is rich in floral diversity with 537 plant species belonging to 97 families (Parmar 2005). 2015 lion census reported a resident population of 33 lions in this sanctuary **(Table 2.2)**, while a mark-recapture density of 6 adult lions/100 km^2 was obtained in 2008 (Banerjee et al. 2010). Apart from lions, Girnar forest harbors 37 other mammalian species, 38 species of herpetofauna and more than 300 species of birds (Parmar 2005).

Religious pilgrimage

Girnar and Datar hills are famous pilgrimages for Hindus, Jainas and Muslims. There are 19 religious places on top of the Mountain Girnar (Parmar 2005). In order to facilitate pilgrims to reach there easily, there are 9,999 stairs (locally known as *Pagathia*) from Bhavnath Taleti to climb Girnar. On an average 1,000 pilgrims climb Girnar daily, the number reaches as high as 5,000 on weekends and other holidays and a total of around 0.9 million pilgrims climb Girnar yearly (Parmar 2005). In 2009 an estimated 0.25 million pilgrims climbed Girnar during *Parikrama* (a festival held in October-November when pilgrims perambulate around the Mount Girnar in three days) and 0.15 million people visited Girnar during the *Maha Shiva Ratri Mela* (another week long big festival held during February-March) (Karn and Sahu 2014).

3. Agro-pastoral eastern landscape (EL)

This eastern revenue belt of Savarkundla-Palitana (including Ambardi Reserve Forests and 18 km^2 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 *Taluka*s with a total area of about 15,000 km^2 (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 *vidi*s). Highest hill feature is Mount Shetrunjaya (498 meter from msl) at Palitana. EL is connected with the Gir PA by drainage networks and patches of *Acacia-Zizyphus* scrub-forests. There are two existing habitat corridors between the EL and the Gir PA used by lions: one, river networks of Shetrunjee and Sel and second, Mitiyala and low hills running along the River Shetrunjee system (Singh 2007). The major prey base of lions included blue bull (*Boselaphus tragocamelus*), wild pig (*Sus scrofa*), chital (*Axis axis*) [in the reserve grasslands] and domestic livestock. An area of about 230km^2 of the landscape (chiefly *vidi*s) with the potential lion habitats have already been delineated and proposed to manage as a 'Conservation Reserve' (Wildlife Protection Act 1972; Ravenel and Redford 2005) by the Gujarat Forest Department (Singh 2007; Meena and Kumar 2012).

Land-use in this landscape is mixed and characterized mostly by private farms, orchards, industrial and pastoral lands with some government owned community grazing lands. Public lands are managed for multiple uses, including seasonal cattle grazing. Livestock grazing for dairy products, agriculture comprised of seasonal crops and horticulture are the main economics of the region. The entire landscape is interspersed by a good network of road (national and state highways, district and village level roads) and railway services. Recent lion census estimated a population count of eight lions in the Mitiyala Wildlife Sanctuary and 117 lions in the revenue areas of this landscape **(Table 2.2)**.

Table 2.2: Lion population estimate based on 2015 lion census (Gujarat Forest Department 2015)

Areas	Total lion number
Gir PA and adjoining areas	304
Girnar Sanctuary	33
Mitiyala Sanctuary	8
Paniya Sanctuary	11
Coastal areas (Una, Kodinar, Sutrapada, Rajula, Jafrabad and Nageshree)	50
Savarkundla, Liliya and its adjoining areas of Amreli and Bhavnagar districts	117
Total	**523**

CHAPTER III

LANDSCAPE ARCHITECTURE OF GIR PROTECTED AREA AND ITS SURROUNDINGS

Introduction

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

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

Previous vegetation studies in Gir

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

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

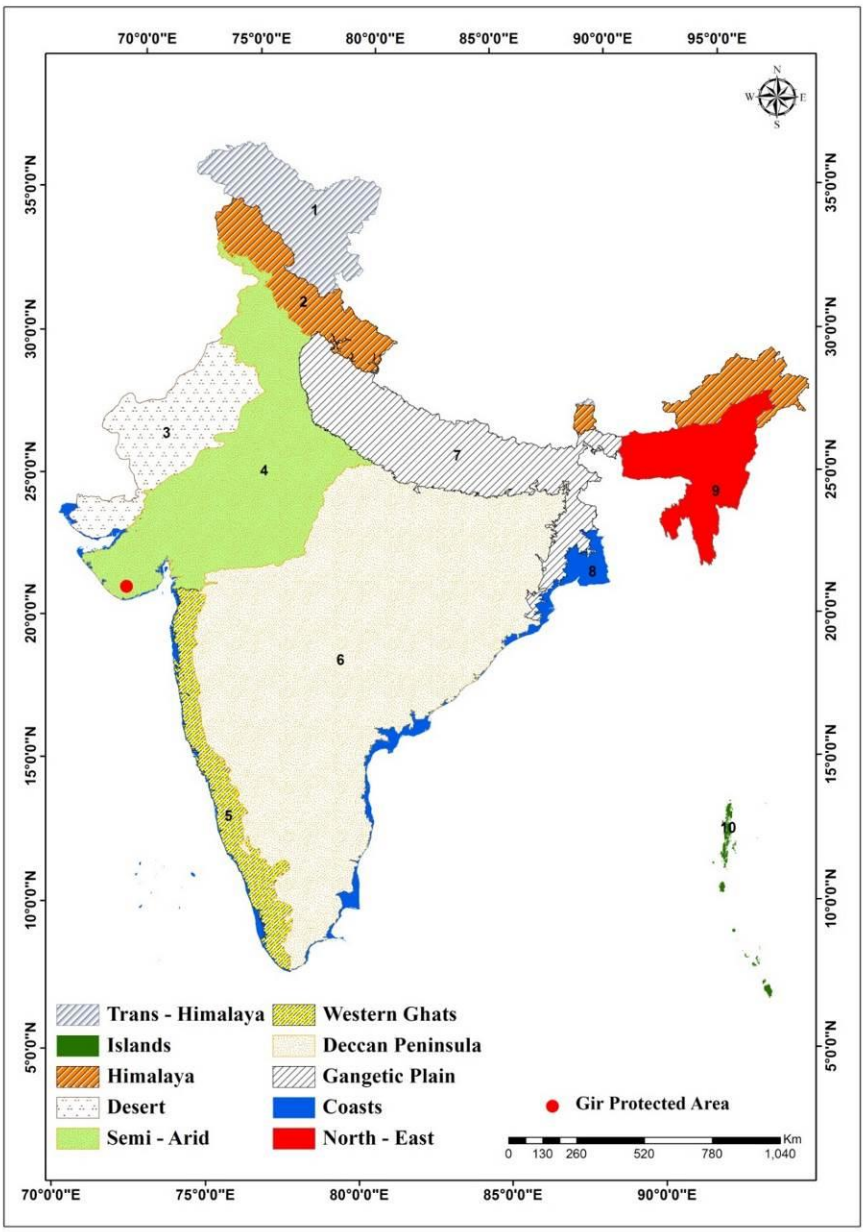
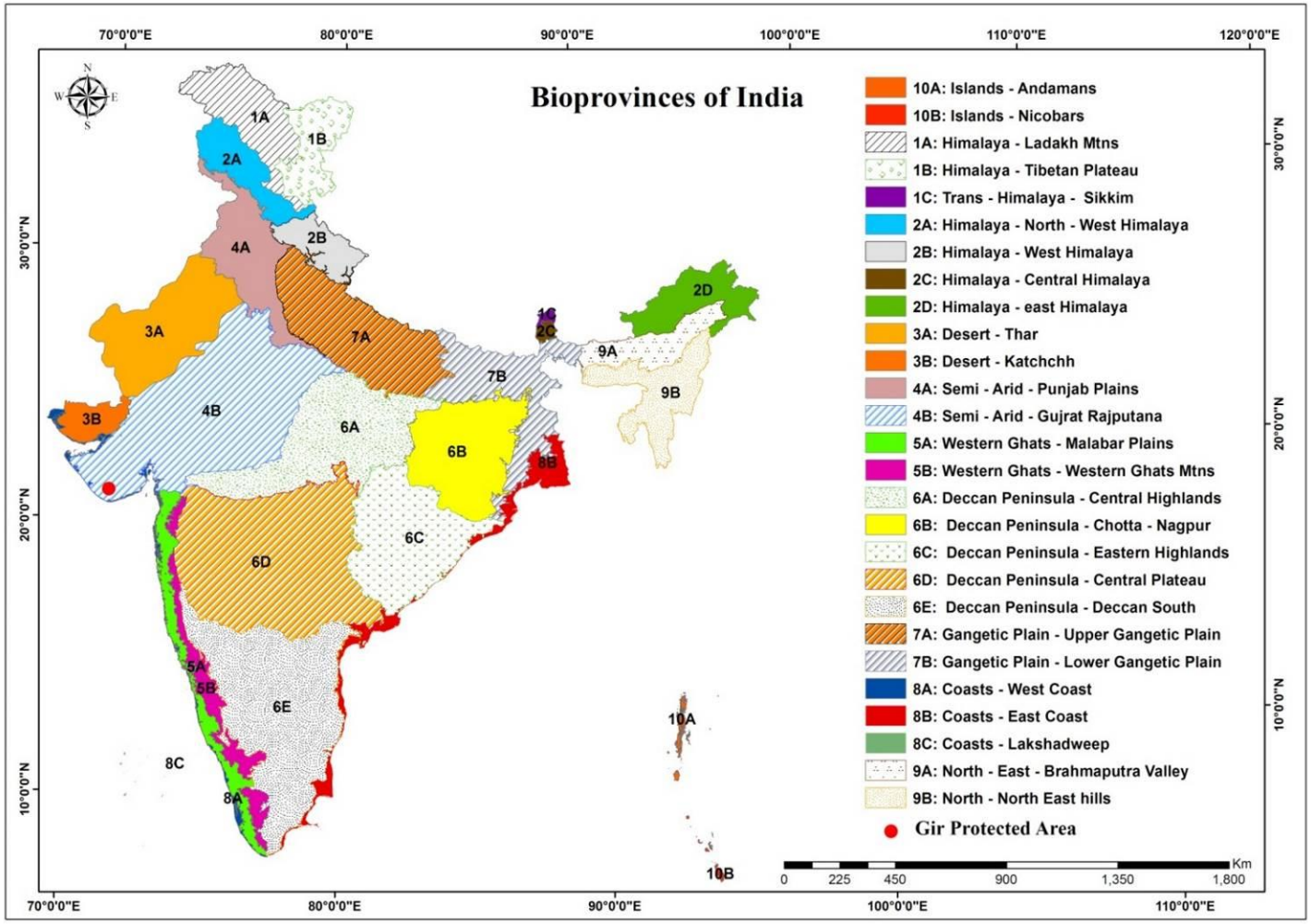


Figure 3.2: Biographic Provinces of India (source: Rodgers and Panwar 1988)



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

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

(i) Sub-type 5/DS1: Dry deciduous scrub forests

(ii) Sub-type 5/DS2: Dry savannah forests (locally known as *vidi*s)

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

(i) Teak forests : (Type 5A/CIa)

(ii) Non-teak forests : (Type 5/DS1 and 5/DS2)

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

study categorized 11 broad habitat types with distinctive tree species described in **Table 3.1** but identification of a tree and/or shrub was based on its height and not on its life form. Hence larger individuals of the same species were categorized as trees and smaller individuals as shrub based on height. Later the Gir forest was broadly divided into two major vegetation types (Chellam 1993). The western two-thirds of the forest were found dominated by stunted teak, in association with various other species, chiefly *Acacia, Zizyphus* and *Terminalia*. The remaining eastern portion consisted of a grassland savannah interspersed with patches of thorn (*Acacia* and *Zizyphus*) and dry deciduous forests (*Anogeissus latifolia* and *Boswellia serrata*), teak was absent in this region. The understorey was often sparse in the more densely wooded areas but shrubs like *Carissa opaca, Capparis sepiaria,* and *Helicteres isora* along with various grass species dominated the understorey in other areas. Evergreen riverine forests were found along the banks of most of the rivers and streams. *Syzygium rubicundum, Derris indica, Manilkara hexandra* and various other species were found in the riverine tracts. The eleven broad categories classified are mentioned in **Table 3.1**. Various forest types of Gir, were classified under 13 subtypes (Chavan 1993) and later in fifteen major vegetation associations (Sharma 1995) (**Table 3.1**). Most recently the forest was classified into three major classes (Qureshi and Shah 2004) which is described in **Table 3.1**.

Table 3.1: Previous vegetation studies in Gir

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

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

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

Objectives

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

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

Methods

Field Methods

Stratification and Sampling Units

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

Figure 3.3: Vegetation Sampling Design in Gir Protected Area

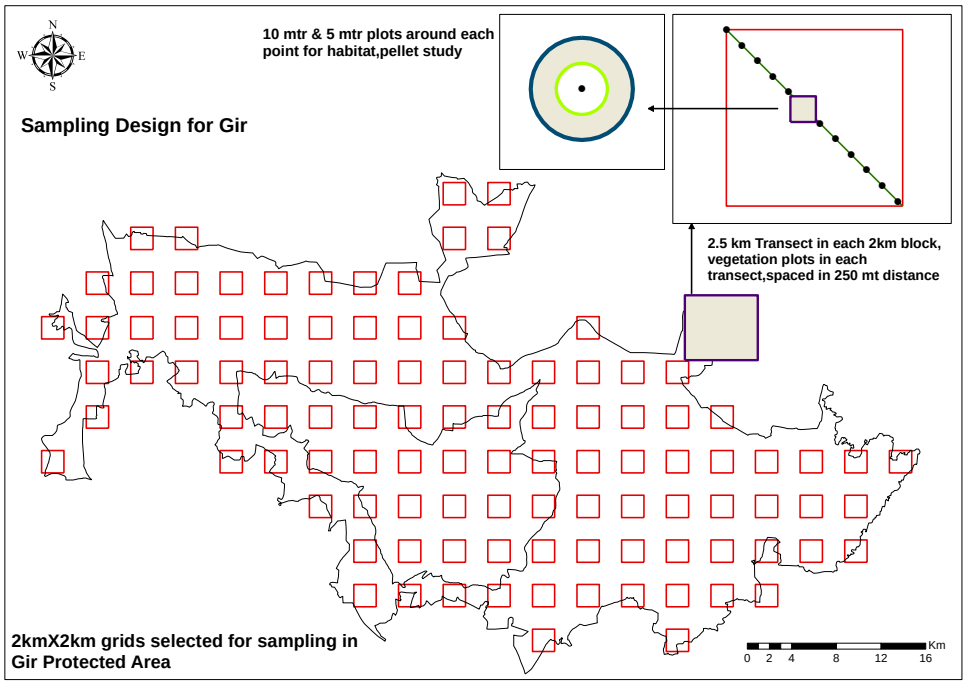
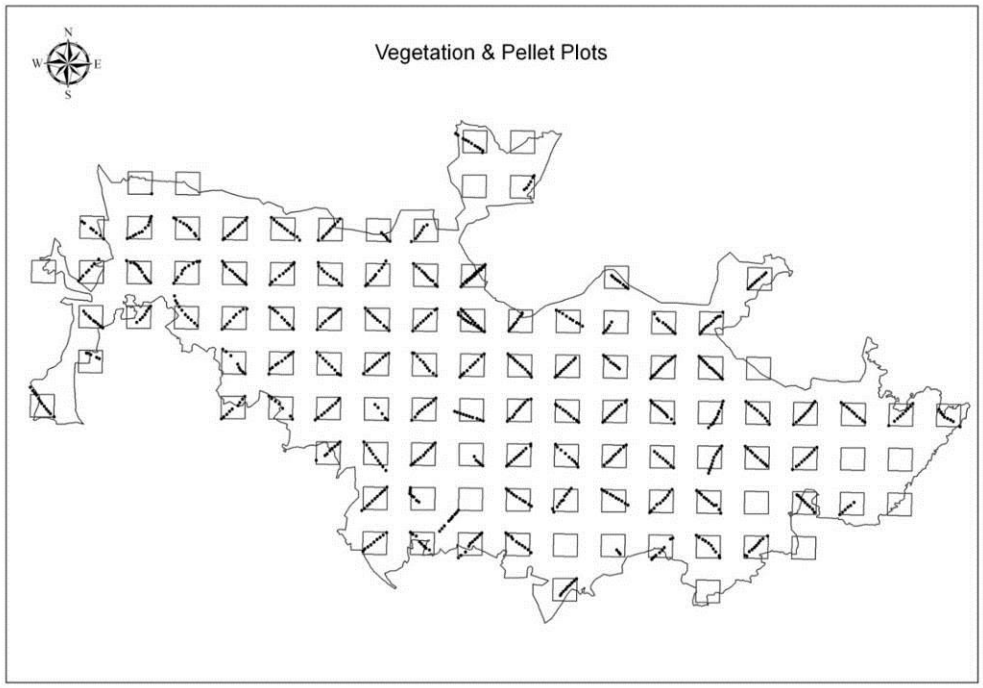


Figure 3.4: Distribution of vegetation sampling plots in Gir PA



Data Collection Protocols

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

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

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

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

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

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

1. If the evenness value is higher, the variation in communities between the species would be less.

Remote sensing approach

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

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

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

Table 3.2: Principal Component Analysis used for unsupervised classification

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

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

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

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

Results

TWINSPAN Analysis

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

Figure 3.5: Dendogram showing vegetation communities identified through TWINSPAN analysis

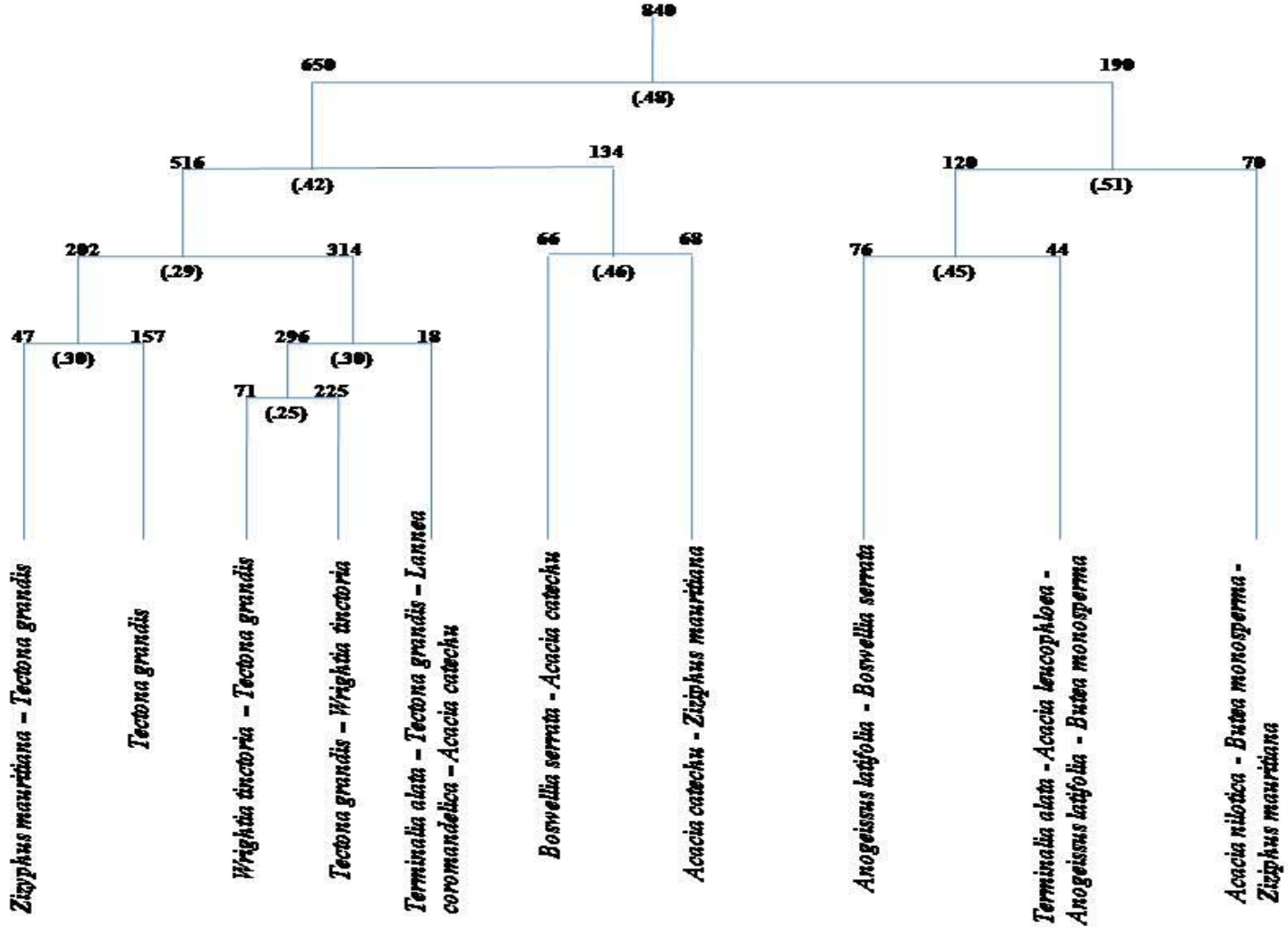


Table 3.3: Community wise distribution of vegetation sampling plots, dominant species, constant species, diversity, richness and evenness

Community	No of Plots	Name of the Community	Dominant Species (Based on IVI Value)	Constant Species (Frequency>25%)	Diversity	Richness	Evenness
1	45	*Ziziphus mauritiana, Tectona grandis*	*Ziziphus mauritiana* (85.00), *Tectona grandis* (81.02)	*Ziziphus mauritiana* (100.00), *Tectona grandis* (71.11), *Acacia catechu* (26.67), *Acacia auriculiformes* (26.67)	2.13	25	0.66
2	157	*Tectona grandis*	*Tectona grandis* (143.83)	*Tectona grandis* (94.90), *Ziziphus mauritiana* (37.58), *Acacia nilotica* (29.94)	2.09	51	0.53
3	71	*Wrightia tinctoria, Tectona grandis*	*Wrightia tinctoria* (68.11), *Tectona grandis* (46.86)	*Wrightia tinctoria* (92.96), *Tectona grandis* (59.15), *Acacia catechu* (35.21), *Ziziphus mauritiana* (38.03), *Bauhinia purpurea* (30.99)	2.84	48	0.73
4	223	*Tectona grandis, Wrightia tinctoria*	*Tectona grandis* (124.43), *Wrightia tinctoria* (29.12)	*Tectona grandis* (98.21), *Wrightia tinctoria (*44.39), *Acacia catechu* (27.80)	2.30	55	0.57
5	51	*Terminalia alata, Tectona grandis, Lannea coromandelica,Acacia catechu*	*Terminalia alata* (39.52), *Tectona grandis* (38.13), *Lannea coromandelica*(30.64),*Acacia catechu* (31.00)	*Terminalia alata* (47.06), *Tectona grandis* (45.10), *Lannea coromandelica* (45.10),*Acacia catechu (*43.14), *Boswellia serrata* (27.45), *Emblica officinalis*	2.92	40	0.79

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

1. *Ziziphus mauritiana- Tectona grandis* community

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

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

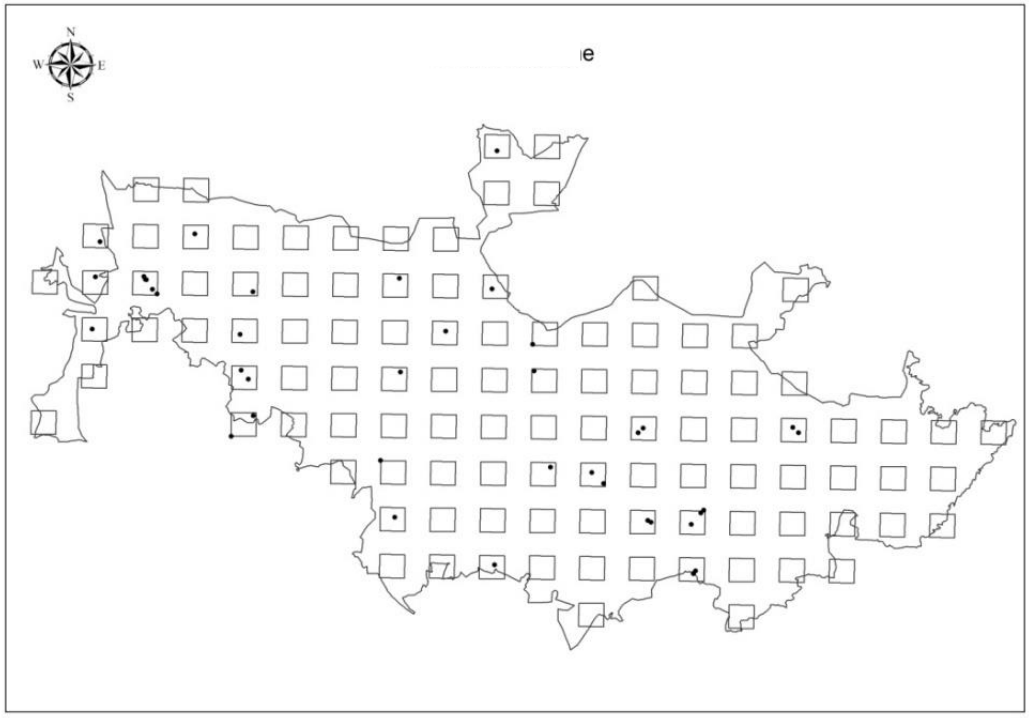


Table 3.4: Species composition and status in *Ziziphus mauritiana - Tectona grandis* community

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

2. *Tectona grandis* Community

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

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

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

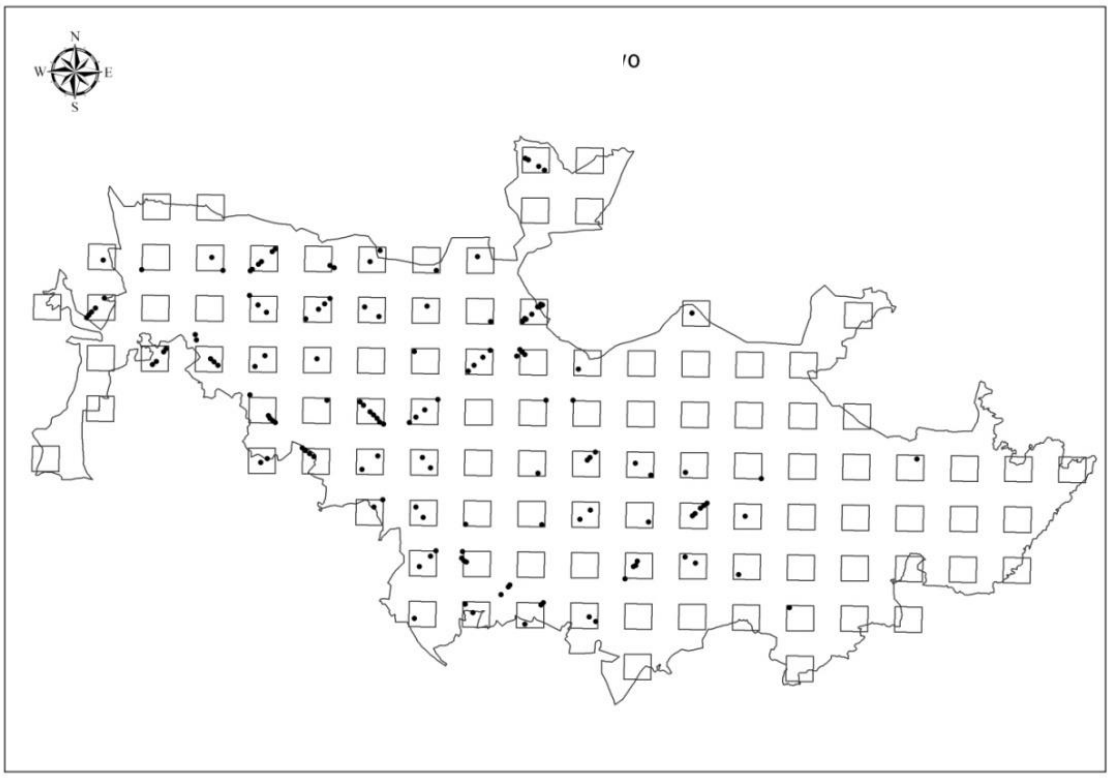


Table 3.5: Species composition and status in community *Tectona grandis*

Species	Density/ha	Frequency %	TBA	IVI	A/F Ratio
Bauhinia racemosa	0.20	0.64	0.00	0.28	1.57
Bauhinia purpurea	4.67	13.38	0.05	6.26	0.08
Emblica officinalis	1.83	5.10	0.05	2.83	0.22
Phyllanthus emblica	1.22	3.82	0.06	2.44	0.26
Tamarindus indica	2.03	3.18	0.10	3.14	0.63
Asparagus dumosus	0.20	0.64	0.00	0.31	1.57
Acacia sp	3.45	8.28	0.07	4.72	0.16
Terminalia bellirica	0.20	0.64	0.00	0.27	1.57
Acacia nilotica	12.98	29.94	0.17	15.73	0.05
Aegle marmelos	2.03	3.82	0.05	2.54	0.44

Species	Density/ha	Frequency %	TBA	IVI	A/F Ratio
Pterocarpus marsupium	0.20	0.64	0.00	0.27	1.57
Ziziphus mauritiana	14.81	37.58	0.28	20.17	0.03
Grewia tiliiaefolia	6.69	11.46	0.08	6.86	0.16
Anogeissus latifolia	0.81	0.64	0.02	0.79	6.28
Wrightia tinctoria	3.85	8.28	0.08	4.97	0.18
Grewia tenax	1.42	4.46	0.01	1.89	0.22
Cassia fistula	2.03	5.73	0.02	2.66	0.19
Acacia senegal	2.84	5.10	0.06	3.33	0.34
Zizyphus xylopyra	3.25	7.01	0.04	3.71	0.21
Haldinia cordifolia	0.20	0.64	0.01	0.40	1.57
Acacia leucophloea	5.88	14.01	0.09	7.45	0.09
Balanites aegyptiaca	1.22	3.18	0.02	1.62	0.38
Syzygium cumini	0.81	0.64	0.17	3.11	6.28
Holarrhena pubescens	4.06	8.28	0.03	4.26	0.19
Sterculia urens	0.41	1.27	0.02	0.84	0.79
Mallotus philippinensis	0.81	2.55	0.02	1.26	0.39
Mitragyna parvifolia	0.20	0.64	0.01	0.34	1.57
Derris indica	0.20	0.64	0.02	0.54	1.57
Acacia catechu	7.91	15.29	0.13	9.17	0.11
Butea monosperma	9.53	24.84	0.21	13.67	0.05
Azadirachta indica	0.61	1.91	0.01	0.98	0.52
Flacourtia indica	0.81	1.91	0.01	0.95	0.70
Dichrostachys cinerea	1.22	1.91	0.01	1.21	1.05
Catunaregam spinosa	2.64	6.37	0.02	2.98	0.20
Lannea coromandelica	1.22	3.82	0.04	2.14	0.26
Ficus arnottiana	0.20	0.64	0.25	4.15	1.57
Soymida febrifuga	0.20	0.64	0.01	0.38	1.57
Parkinsonia aculeata	0.41	1.27	0.01	0.58	0.79
Manilkara hexandra	1.01	2.55	0.03	1.54	0.49
Morinda pubescens	2.84	5.73	0.05	3.46	0.27
Tectona grandis	**151.73**	**94.90**	**3.84**	**143.83**	**0.05**
Terminalia alata	2.03	5.73	0.03	2.77	0.19
Boswellia serrata	0.41	1.27	0.02	0.74	0.79
Delonix elata	0.41	1.27	0.01	0.59	0.79
Holoptelia integrifolia	0.20	0.64	0.01	0.35	1.57
Dalbergia latifolia	0.20	0.64	0.00	0.28	1.57
Bombax ceiba	0.41	1.27	0.01	0.67	0.79
Diospyros melanoxylon	2.03	5.73	0.07	3.45	0.19
Schleichera oleosa	0.61	1.27	0.02	0.89	1.18
Ficus glomerata	1.01	3.18	0.01	1.39	0.31
Ehretia laevis	0.61	1.91	0.00	0.82	0.52

3. *Wrightia tinctoria-Tectona grandis* Community

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

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

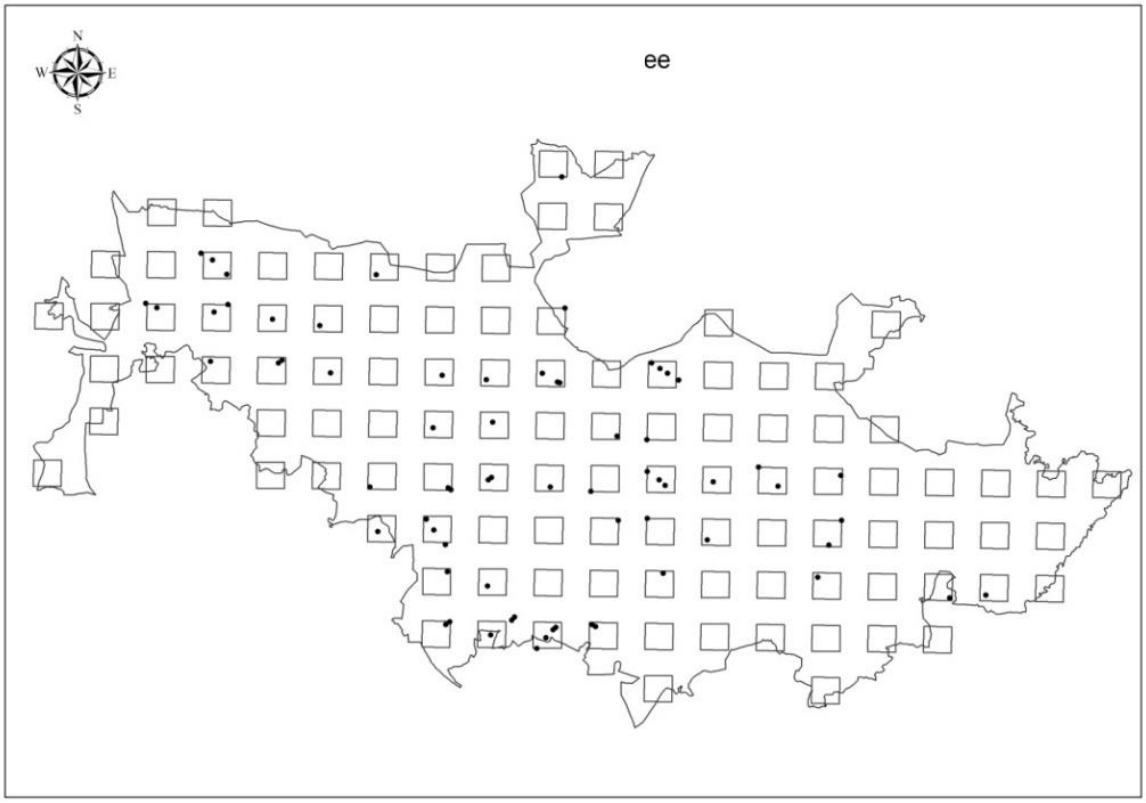


Table 3.6: Species composition and status in *Wrightia tinctoria-Tectona grandis* community

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

Species	Density/ha	Frequency %	TBA	IVI	A/F Ratio
Morinda pubescens	0.45	1.41	0.01	0.62	0.71
Tectona grandis	**40.82**	**59.15**	**1.07**	**46.86**	**0.04**
Terminalia alata	1.35	2.82	0.05	1.90	0.53
Boswellia serrata	3.59	8.45	0.18	6.20	0.16
Holoptelia integrifolia	2.69	8.45	0.04	3.49	0.12
Dalbergia latifolia	1.79	5.63	0.03	2.42	0.18
Bombax ceiba	0.90	2.82	0.04	1.54	0.36
Diospyros melanoxylon	12.56	23.94	0.22	13.60	0.07
Schleichera oleosa	1.35	4.23	0.01	1.57	0.24
Ficus glomerata	5.83	14.08	0.19	8.52	0.09
Ehretia laevis	1.79	5.63	0.01	2.09	0.18
Moringa oleifera	1.35	4.23	0.07	2.69	0.24

4. *Tectona grandis-Wrightia tinctoria* community

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

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

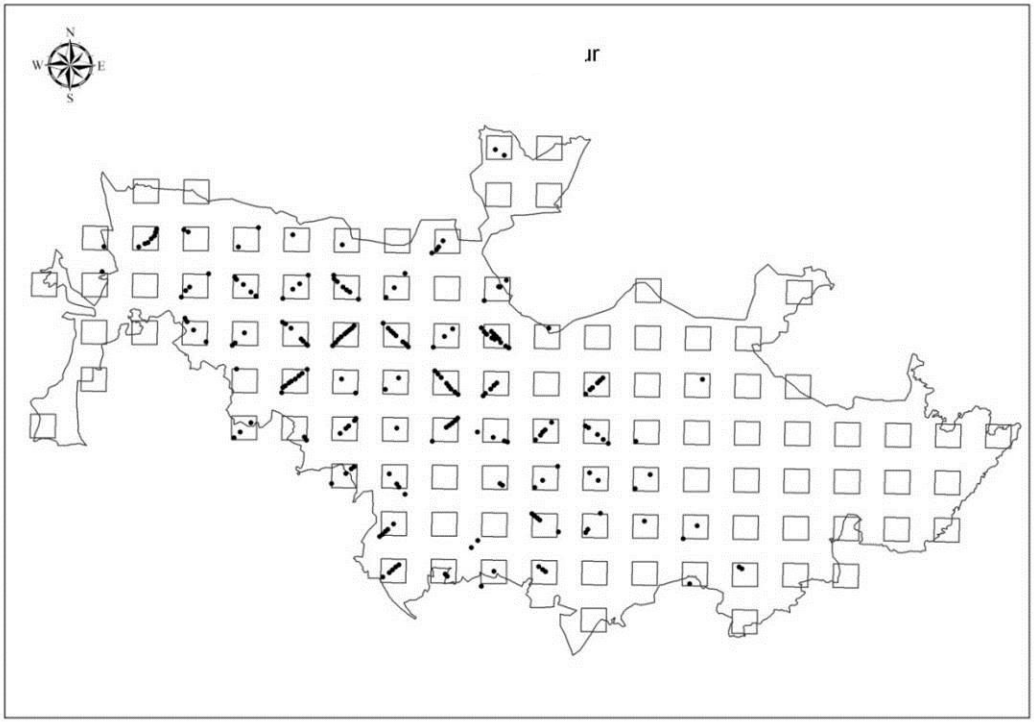


Table 3.7: Species composition and status in *Tectona grandis-Wrightia tinctoria* Community

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

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

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

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

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

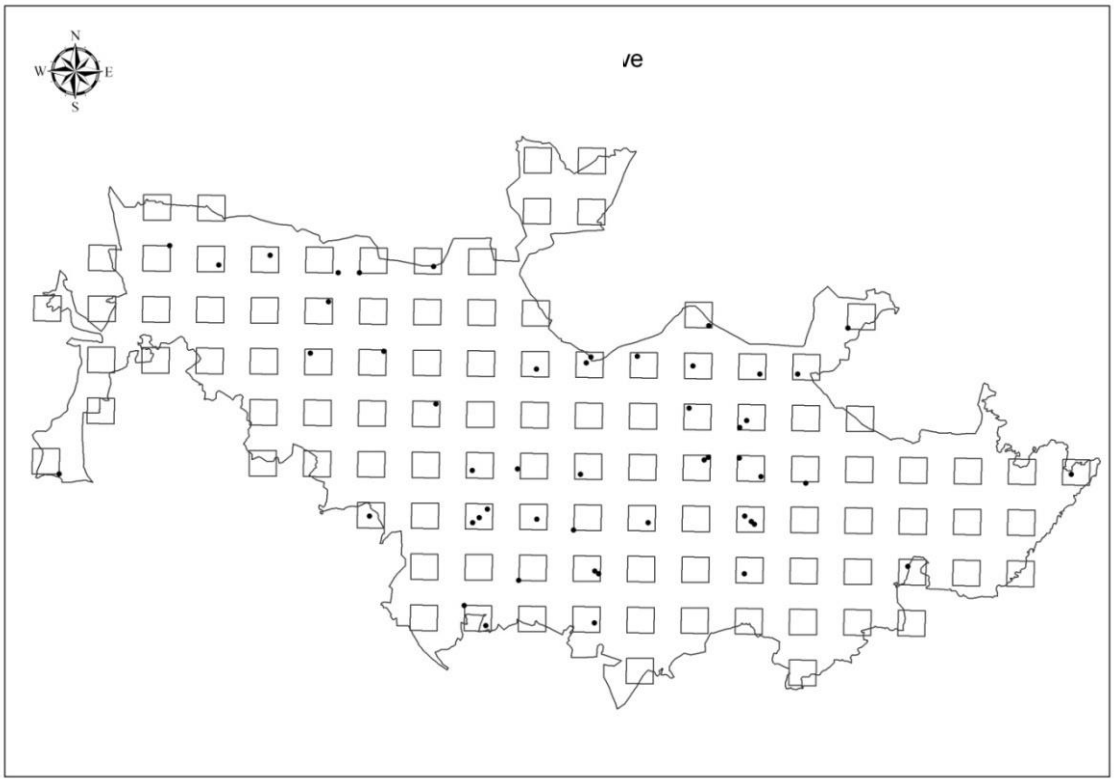


Table 3.8: Species composition and status in *Terminalia alata-Tectona grandis-Lannea coromandelica-Acacia catechu* Community

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

6. *Boswellia serrata-Acacia catechu* Community

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

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

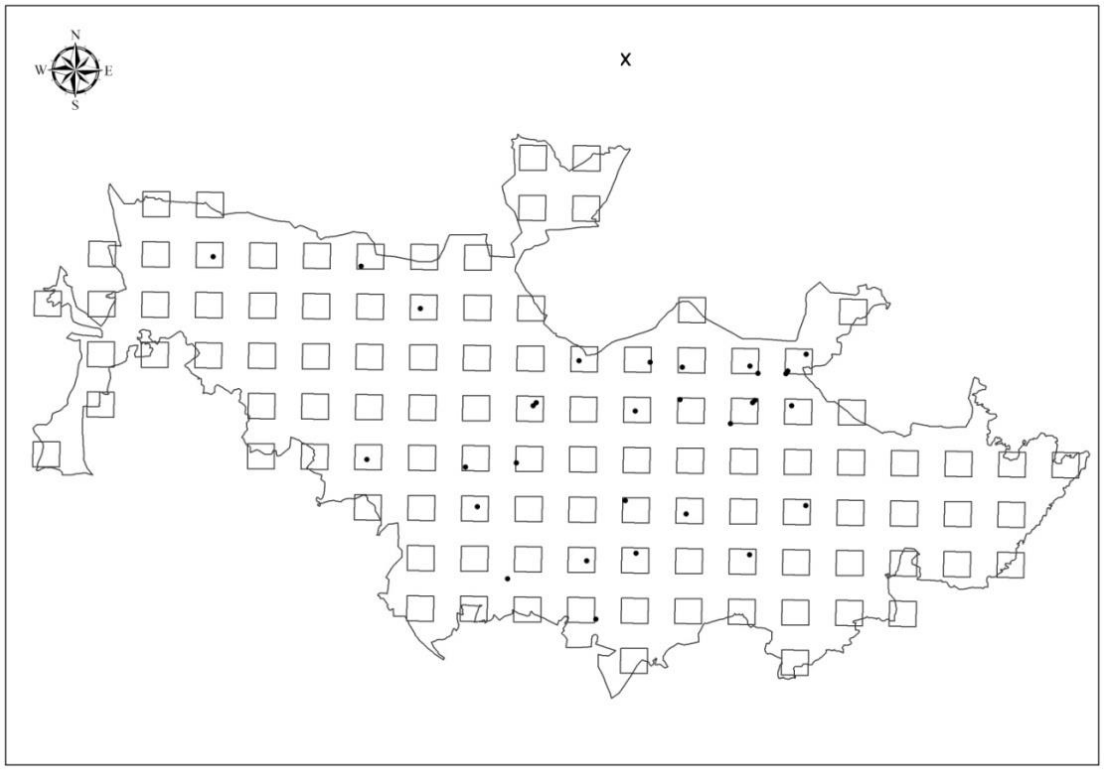


Table 3.9: Species composition and status in *Boswellia serrata-Acacia catechu* community

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

7. *Acacia catechu- Ziziphus mauritiana* community

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

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

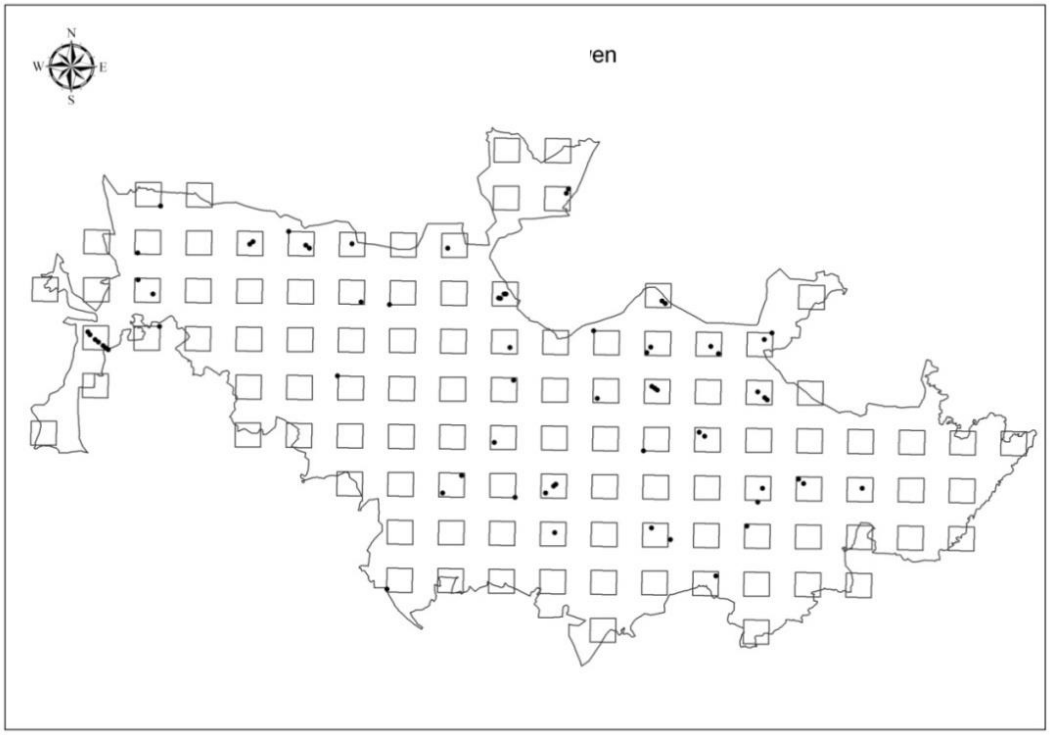


Table 3.10: Species status and composition in *Acacia catechu- Ziziphus mauritiana* Community

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

Species	Density/Ha	Frequency %	TBA	IVI	A/F Ratio
Derris indica	0.97	1.52	0.01	1.28	1.32
Acacia catechu	**95.06**	**100.00**	**1.24**	**131.10**	**0.03**
Butea monosperma	1.93	6.06	0.05	4.86	0.17
Azadirachta indica	0.48	1.52	0.01	1.20	0.66
Dichrostachys cinerea	1.93	4.55	0.02	3.26	0.29
Catunaregam spinosa	0.97	3.03	0.01	1.85	0.33
Lannea coromandelica	2.90	9.09	0.06	6.85	0.11
Grewia asiatica	0.97	3.03	0.01	1.99	0.33
Parkinsonia aculeata	0.48	1.52	0.02	1.36	0.66
Manilkara hexandra	0.48	1.52	0.11	4.58	0.66
Morinda pubescens	2.90	6.06	0.06	5.76	0.25
Tectona grandis	4.83	10.61	0.17	12.28	0.13
Terminalia alata	5.79	15.15	0.13	13.15	0.08
Boswellia serrata	5.31	9.09	0.20	13.00	0.20
Delonix elata	0.48	1.52	0.03	1.77	0.66
Holoptelia integrifolia	0.48	1.52	0.01	1.08	0.66
Dalbergia latifolia	0.48	1.52	0.01	0.99	0.66
Diospyros melanoxylon	2.90	6.06	0.06	5.70	0.25
Schleichera oleosa	0.97	1.52	0.02	1.65	1.32
Ficus glomerata	1.45	4.55	0.04	3.66	0.22
Moringa oleifera	0.97	3.03	0.02	2.13	0.33

8. *Anogeissus latifolia, Boswellia serrata* Community

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

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

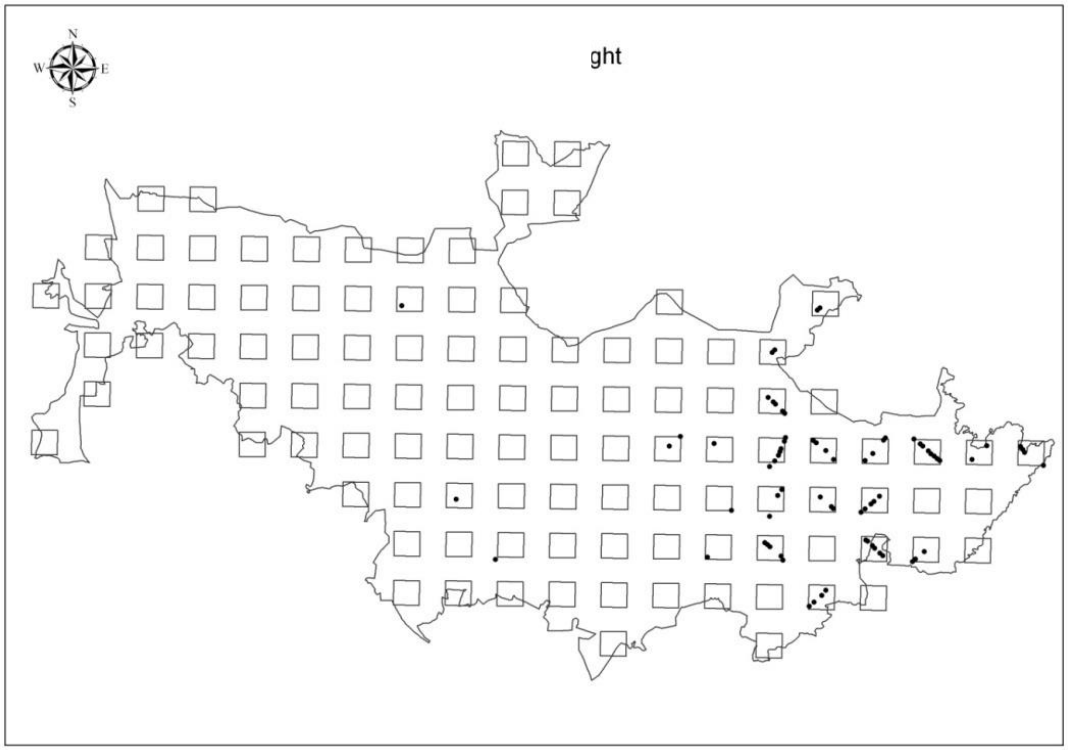


Table 3.11: Species composition and status in *Anogeissus latifolia, Boswellia serrata* Community

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

Species	Density/Ha	Frequency %	TBA	IVI	A/F Ratio
Phoenix sylvestris	0.85	1.33	0.02	1.20	1.50
Butea monosperma	2.98	9.33	0.04	5.25	0.11
Azadirachta indica	2.55	8.00	0.06	4.96	0.13
Dichrostachys cinerea	2.13	5.33	0.02	3.11	0.23
Catunaregam spinosa	0.43	1.33	0.00	0.63	0.75
Lannea coromandelica	4.68	12.00	0.14	9.41	0.10
Schrebera seietenioides	0.85	2.67	0.02	1.64	0.38
Grewia asiatica	0.43	1.33	0.02	1.03	0.75
Manilkara hexandra	8.09	21.33	0.22	15.75	0.06
Morinda pubescens	1.28	4.00	0.02	2.26	0.25
Tectona grandis	1.28	4.00	0.03	2.59	0.25
Terminalia alata	6.81	18.67	0.18	13.16	0.06
Boswellia serrata	**13.19**	**24.00**	**0.52**	**26.54**	**0.07**
Delonix elata	0.85	2.67	0.20	6.11	0.38
Holoptelia integrifolia	0.43	1.33	0.01	0.80	0.75
Dalbergia latifolia	0.43	1.33	0.01	0.73	0.75
Annona squamosa	0.43	1.33	0.00	0.65	0.75
Diospyros melanoxylon	6.38	16.00	0.18	12.36	0.08
Schleichera oleosa	0.43	1.33	0.01	0.86	0.75
Moringa oleifera	0.43	1.33	0.01	0.80	0.75

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

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

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

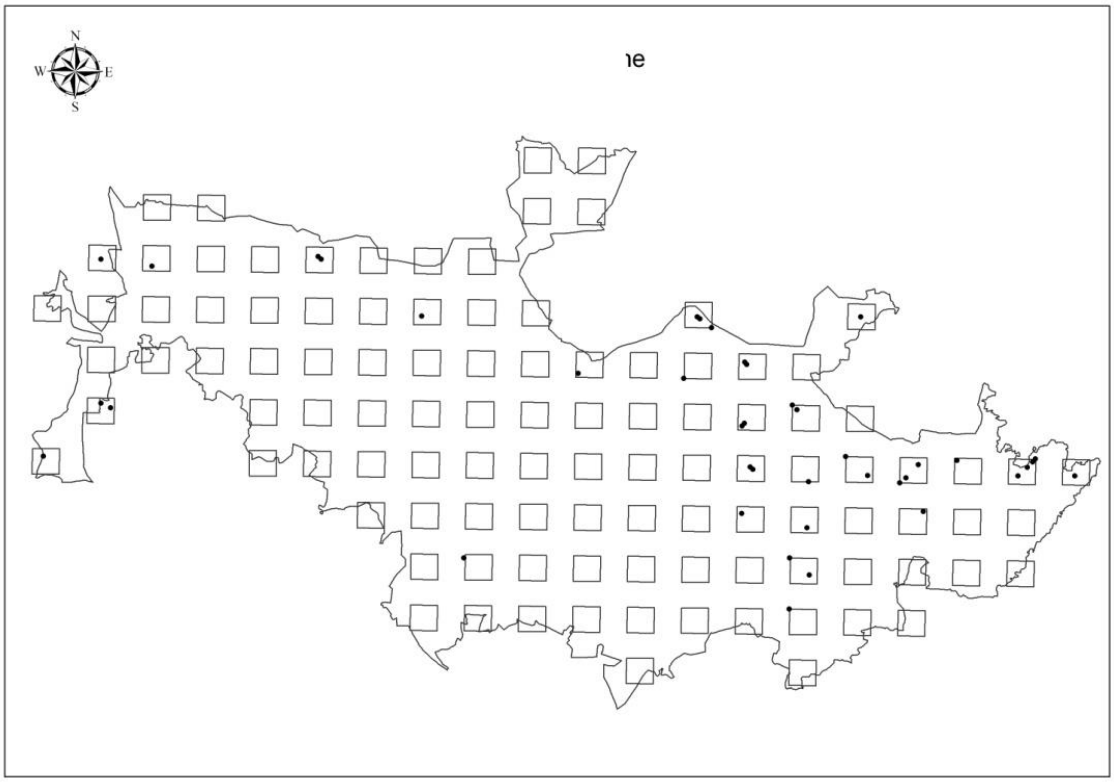


Table 3.12: Species composition and status in *Terminalia alata, Acacia leucophloea, Anogeissus latifolia, Butea monosperma* Community

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

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

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

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

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

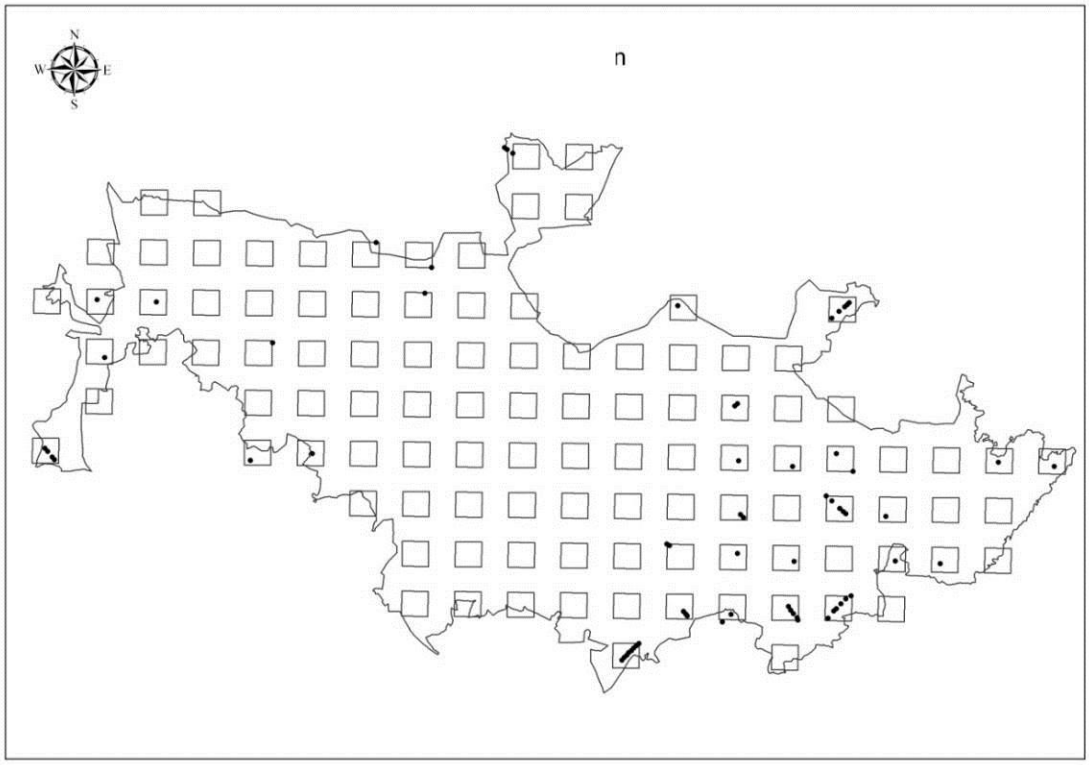


Table 3.13: Species status and composition in *Acacia nilotica, Butea monosperma, Ziziphus mauritiana* Community

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

Species	Density/Ha	Frequency %	TBA	IVI	A/F Ratio
Acacia catechu	6.92	13.04	0.08	9.68	0.13
Phoenix sylvestris	0.46	1.45	0.00	0.76	0.69
Butea monosperma	**24.46**	**39.13**	**0.39**	**34.55**	**0.05**
Azadirachta indica	6.00	14.49	0.13	10.82	0.09
Flacourtia indica	0.92	2.90	0.01	1.73	0.35
Dichrostachys cinerea	5.08	10.14	0.04	6.76	0.15
Lannea coromandelica	1.38	2.90	0.01	1.97	0.52
Schrebera seietenioides	0.92	2.90	0.01	1.65	0.35
Ficus arnottiana	0.92	2.90	0.23	7.35	0.35
Manilkara hexandra	0.92	2.90	0.02	1.88	0.35
Morinda pubescens	1.38	4.35	0.02	2.62	0.23
Tectona grandis	0.46	1.45	0.01	0.87	0.69
Terminalia alata	1.85	4.35	0.04	3.22	0.31
Delonix elata	0.46	1.45	0.01	1.02	0.69
Holoptelia integrifolia	2.31	7.25	0.06	4.93	0.14
Diospyros melanoxylon	5.54	13.04	0.10	9.33	0.10
Ficus benghalensis	1.38	4.35	0.06	3.58	0.23

Remote Sensing Approach

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

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

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

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

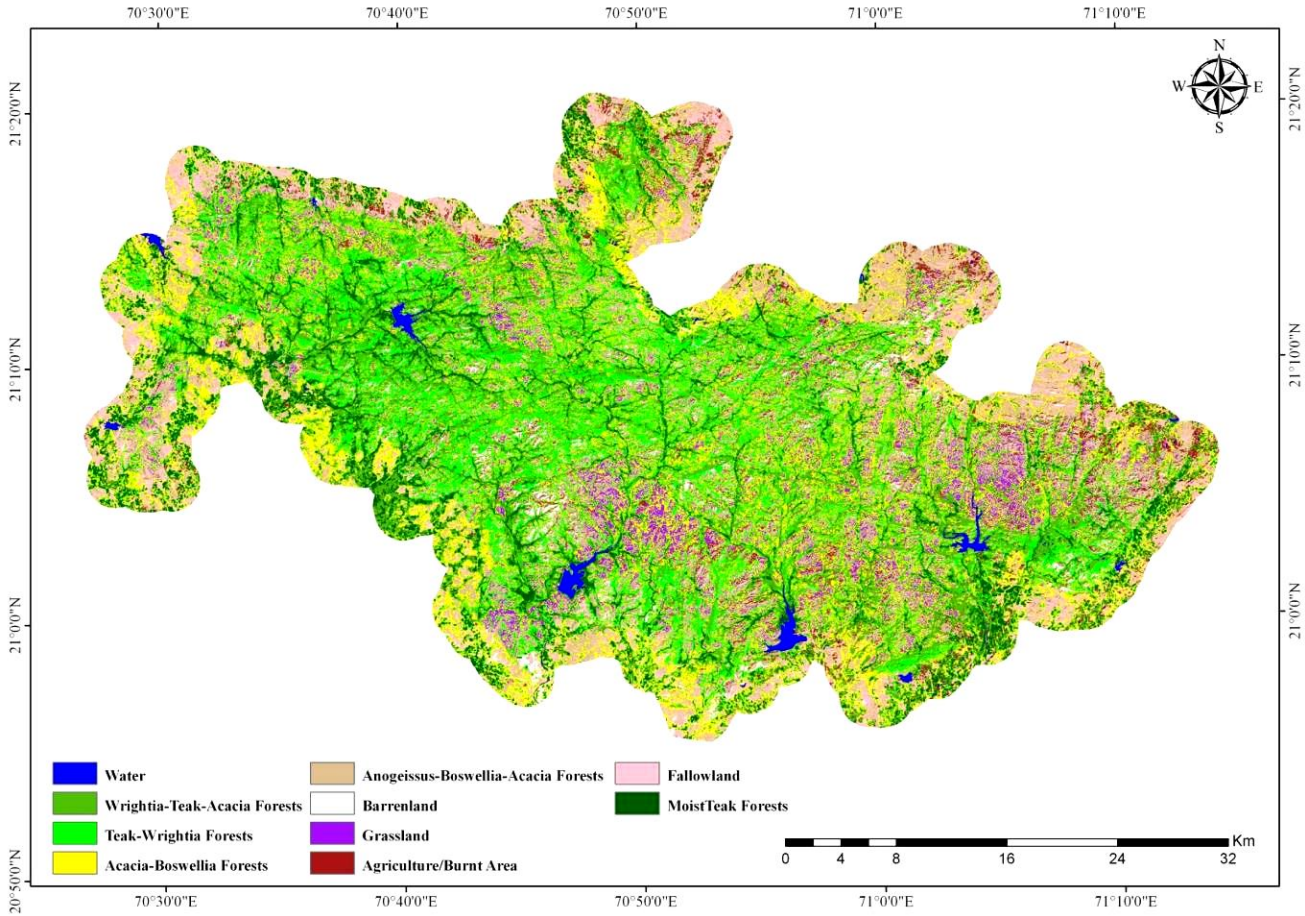
1. Moist Teak Forests,
2. *Wrightia*- Teak- *Acacia nilotica* Forests,
3. Teak- *Wrightia* Forests,
4. *Accacia-Boswellia* Forests,
5. *Anogeissus-Boswellia-Accacia* Forests,
6. Bare land representing soil that has almost no vegetation,
7. Water, where this class mainly represents water stored behind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

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

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

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

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



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

1. **Moist Teak Forests**

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

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

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

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

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

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

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

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

5. *Anogeissus-Boswellia-Acacia* Forests

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

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

Table 3.15: Kappa statistics showing accuracy of the image classification

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

Discussions

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

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

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

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

CHAPTER IV

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

Introduction

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

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

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

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

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

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

Junagadh Gir Forests

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Objectives

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

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

1. To assess the rate of change in land use and vegetation patterns over a 10-year period and to consider the implications of the rates and patterns of change on future ecological conditions. Main questions of interest were the following:
   (a) What is the pattern of change in the landscape?
   (b) What habitat types are vulnerable to change and why?

Hypothesis for the objective

H_o: Land use cover changes over years are similar across different habitat types or random.

H_a: Human driven land uses or land cover increases with time.

Methodology

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

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

Markov Chain analysis and transition suitability image collection, and applies a contiguity filter. Later images

of 1998 and 2009 was analyzed using Markov Change Analysis and based on the probability matrix obtained, simulated land cover map of 2020 was created with the cellular automata markov analysis tool (CA-MARKOV). First the probability matrix was obtained from Markov analysis and then assuming the transition probability matrix remain unchanged, simulated land cover map of 2020 was produced. FRAGSTAT (McGarigal and Marks 1995) was run on the classified image of 1998, 2002 and 2009. The trend of change observed in values of different indices with the change of land cover type is discussed.

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

Strategies used for Land use/cover change detection

Satellite Images and Reference Data

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

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

Classification of the 1998, 2002 and 2009 TM scene

All bands of the TM image except the thermal band were used in PCA to extract information and transforming a set of correlated spectral bands of image data into an equivalent set of uncorrelated components of the data. The stacked PC layers were initially classified using the Isodata algorithm (Unsupervised classification) into 100 classes and then regrouped into the ten major classes under investigation based on the field study (see chapter three for details). The 10 classification categories consisted of:

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

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

Classification accuracy analysis

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

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

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

The following indices are presented here:

(1) **The total number of landscape patches** was used as an overall measure of landscape fragmentation. This index exhibits a unimodal relationship with land cover proportions because maximum patch number occurs at intermediate levels and decreases at both high and low cover proportions (Gustafson and Parker 1992).

(2) **Mean patch size** (Area mean) is a similar measure of fragmentation but one that exhibits a pattern opposite to that of patch number because patch size is usually largest in homogeneous landscapes.

(3) **Total landscape edge** was calculated by summing the length of all patch boundaries in the landscape. Both the number of patches in a landscape and the complexity of patch boundaries influence the amount of edge in a landscape.

(4) **Patch density** is a limited, but fundamental, aspect of landscape pattern. Patch density has the same basic utility as number of patches as an index, except that it expresses number of patches on a per unit area basis that facilitates comparisons among landscapes of varying size. Of course, if total landscape area is held constant, then patch density and number of patches convey the same information. Like number of patches, patch density often has limited interpretive value by itself because it conveys no information about the sizes and spatial distribution of patches.

Results

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

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

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

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

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

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

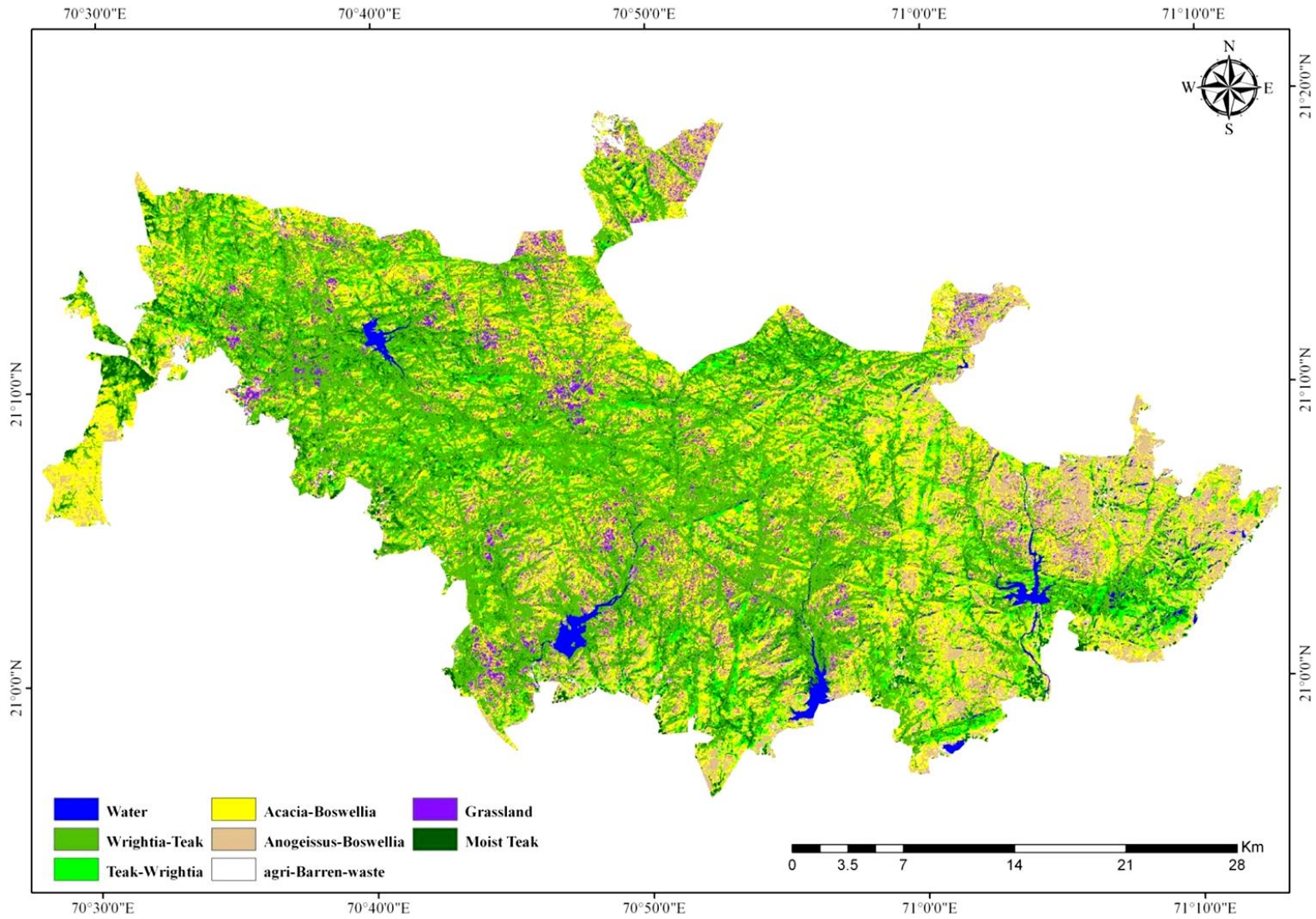


Figure 4.2: Land use/cover map of Gir PA in 2002

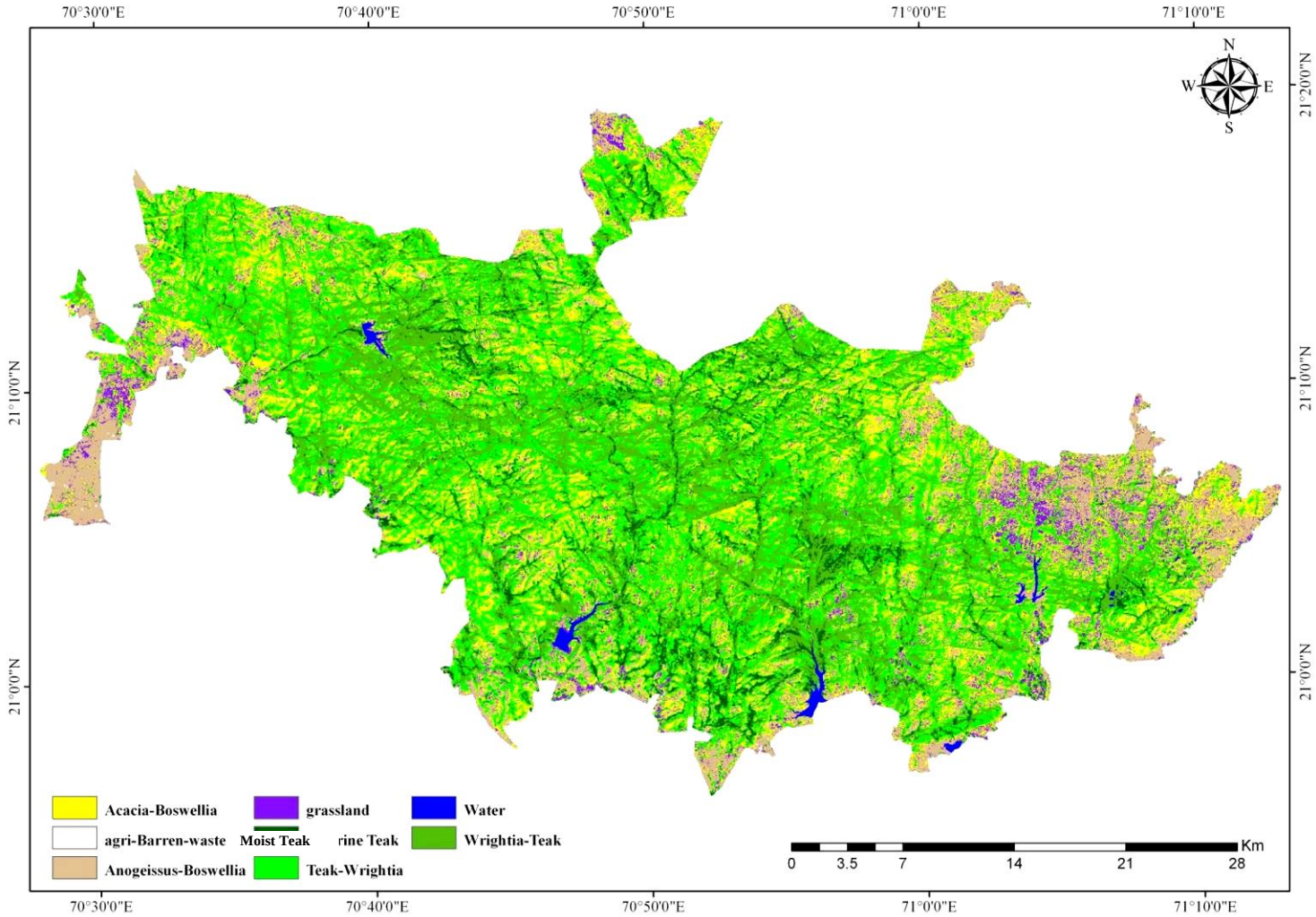


Figure 4.3: Land use/cover map of Gir PA in 2009

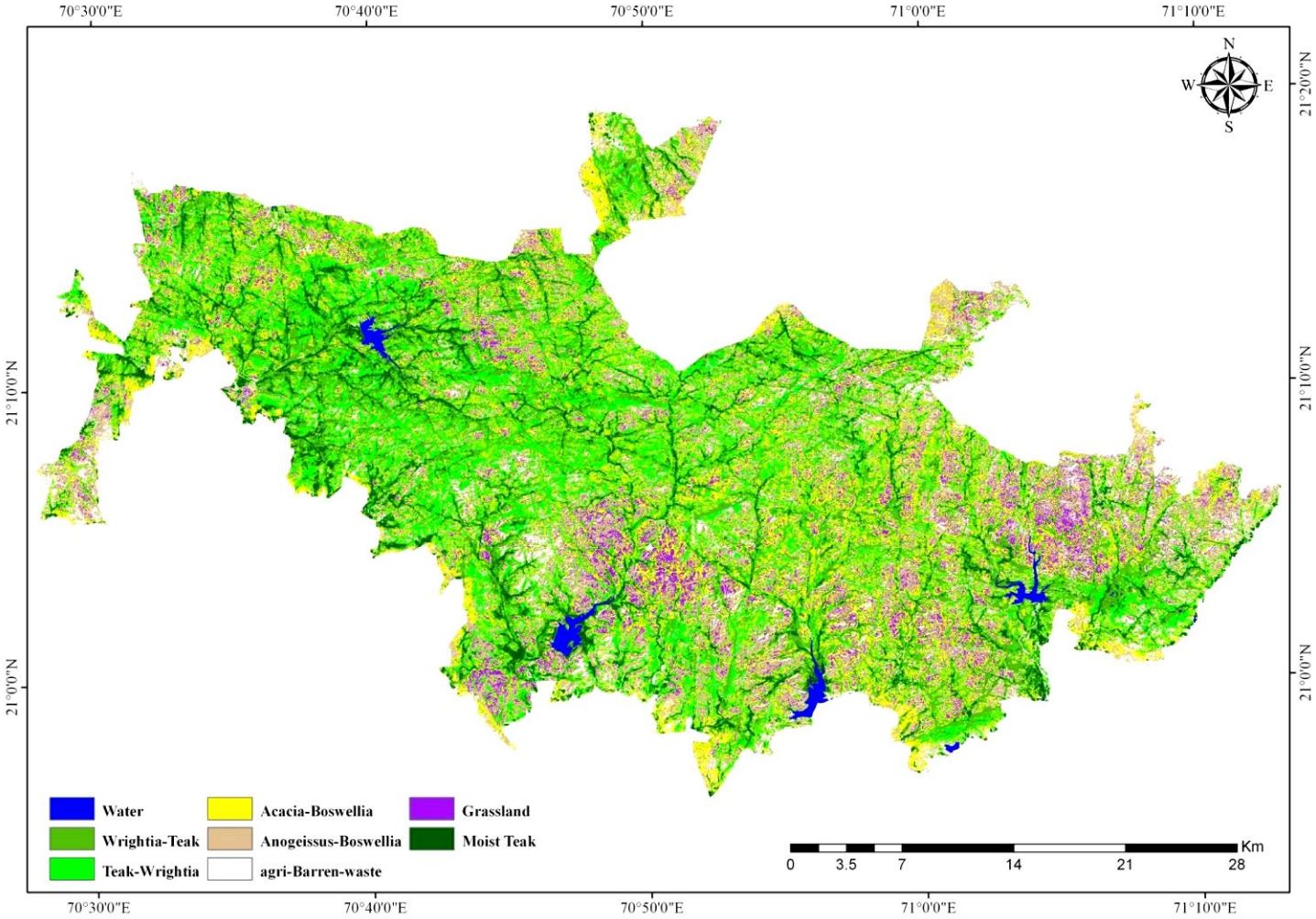


Figure 4.4: Trends in different land use/cover changes of Gir PA from 1998-2009.

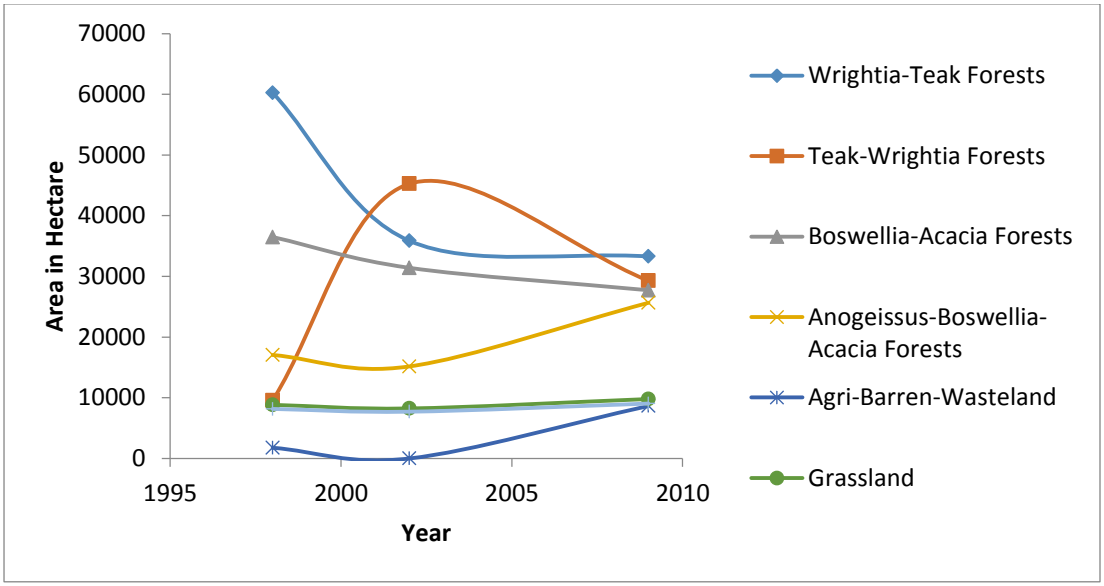
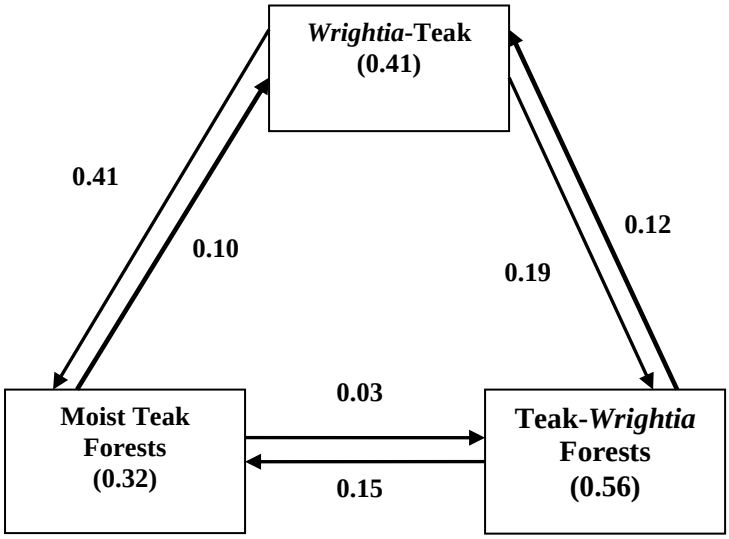
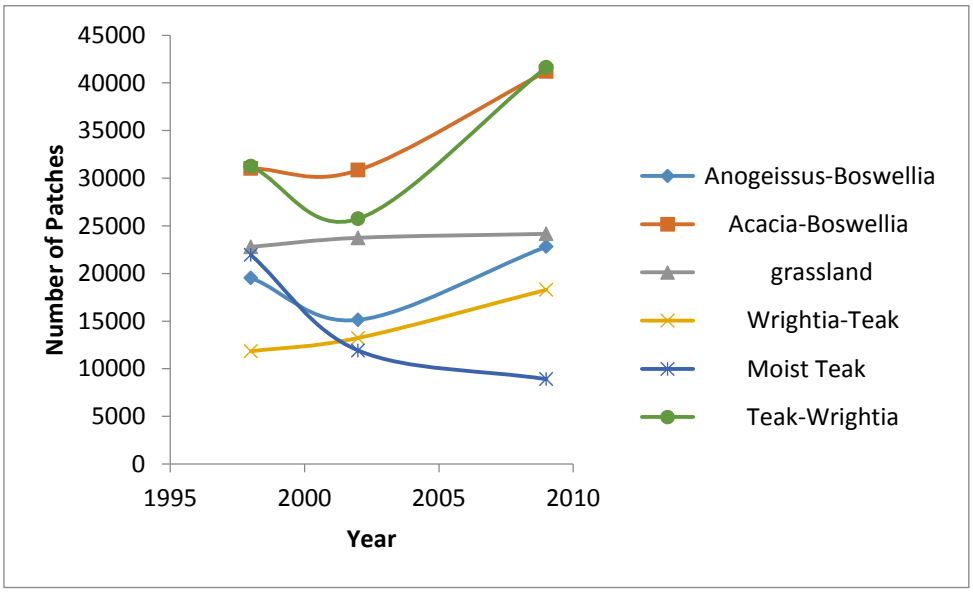


Figure 4.5: Box and arrow diagram illustrating land cover transition probabilities for the Gir PA from 1998-2009. Values within boxes are self replacement probabilities, whereas values positioned on arrows are transition probabilities.



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

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



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

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

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

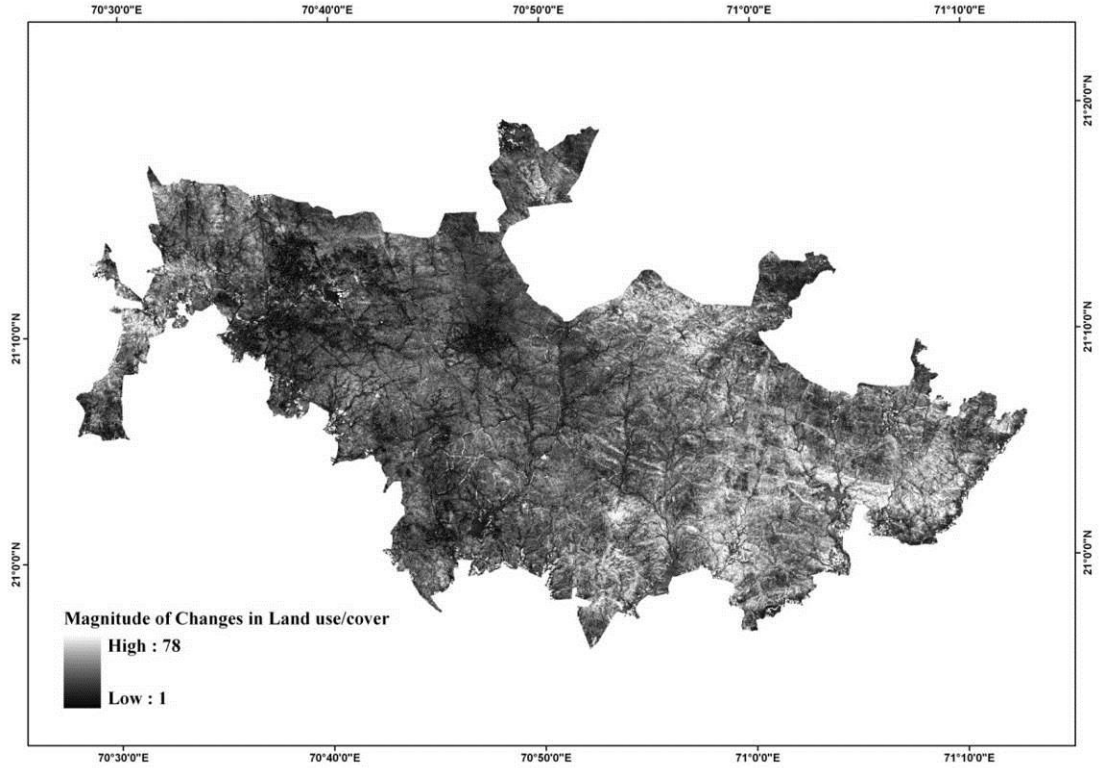
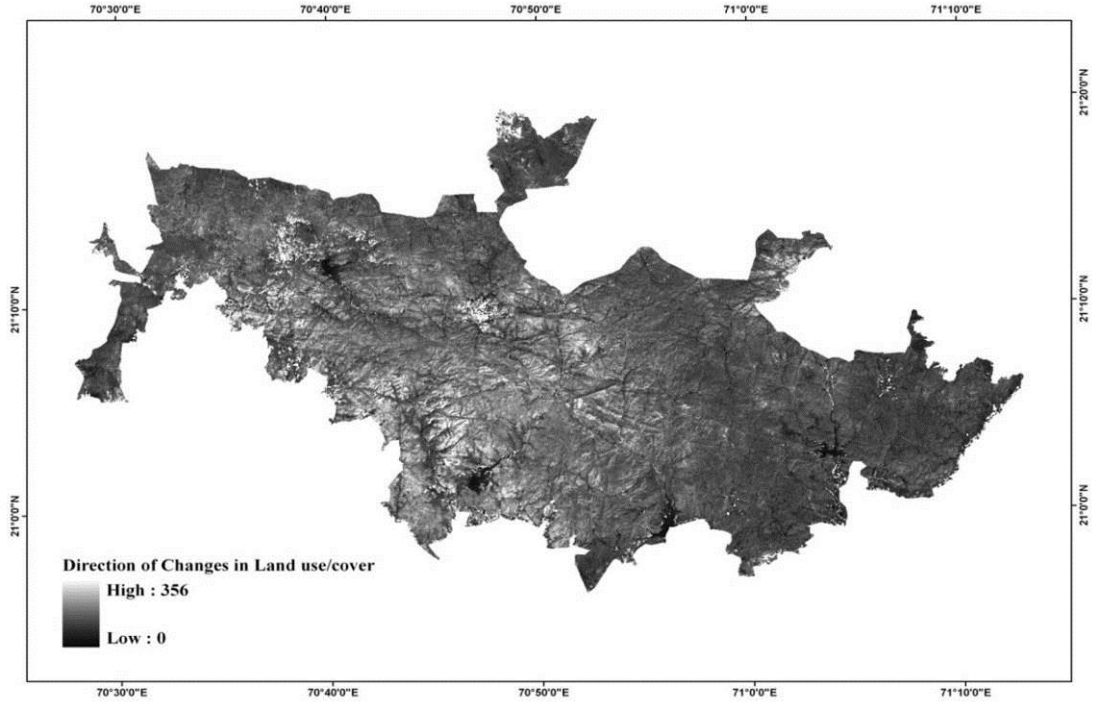
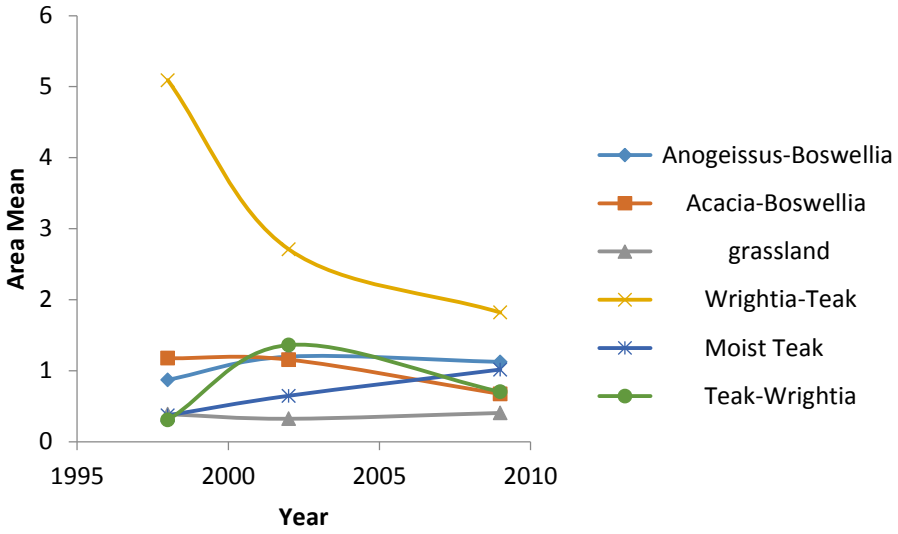


Figure 4.8: Magnitude of changes obtained from CVA of images of 1998 and 2009



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

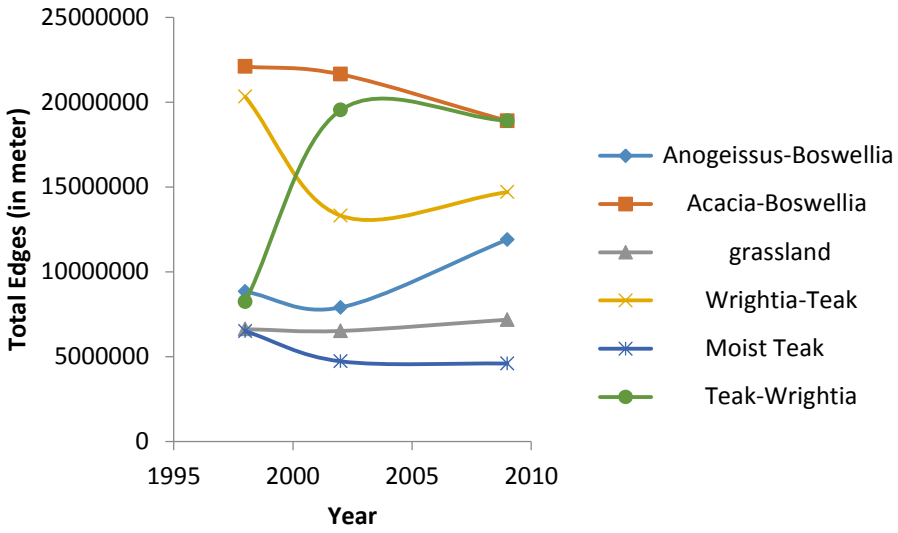
Figure 4.9: Changes in average size of patches from 1998-2009



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

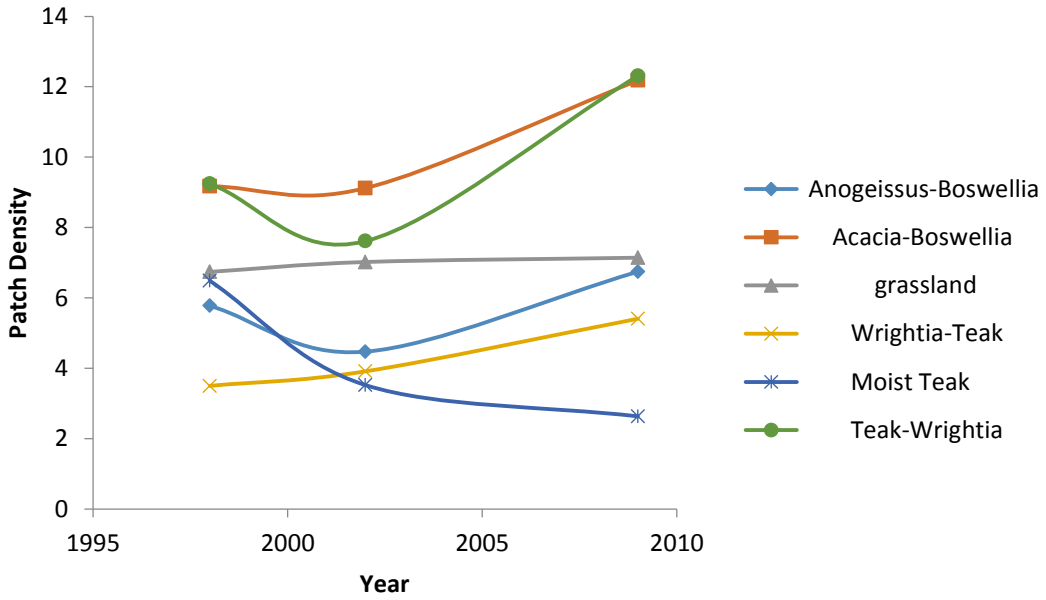
Changes in patch density of different forest types occurred as an accumulated effect of increase of area under specific vegetation type as it happened in case of increase of patch density of *Anogeissus-Boswellia* forests, result of succession of *Wrightia*-Teak to Teak-*Wrightia* and moist teak forests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

Figure 4.10: Changes in total edges from 1998-2009



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

Figure 4.11: Changes in patch density from 1998-2009



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

Discussions

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

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

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

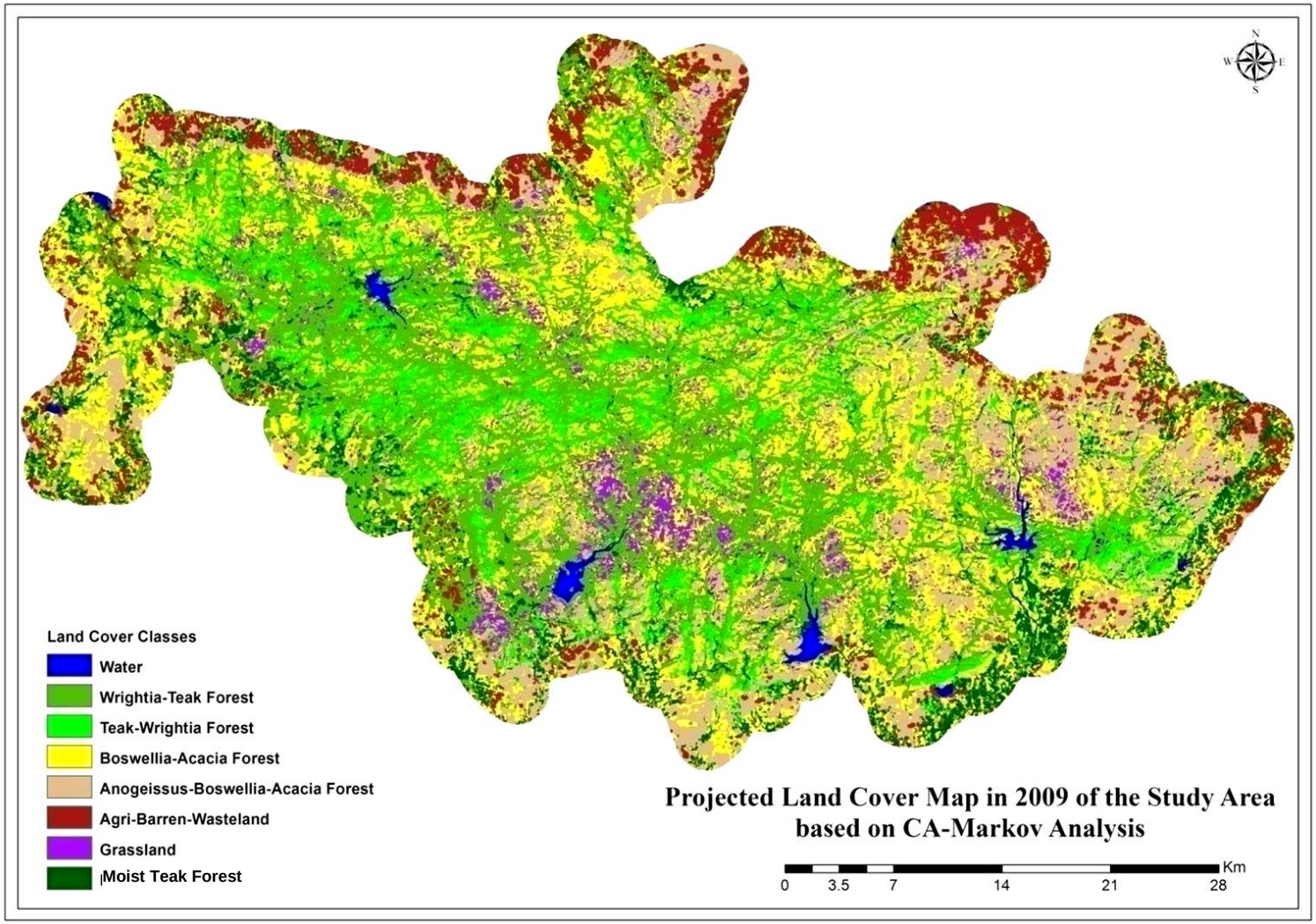


Figure 4.13: Projected land cover map of the study area of the year 2020, based on CA-Markov analysis

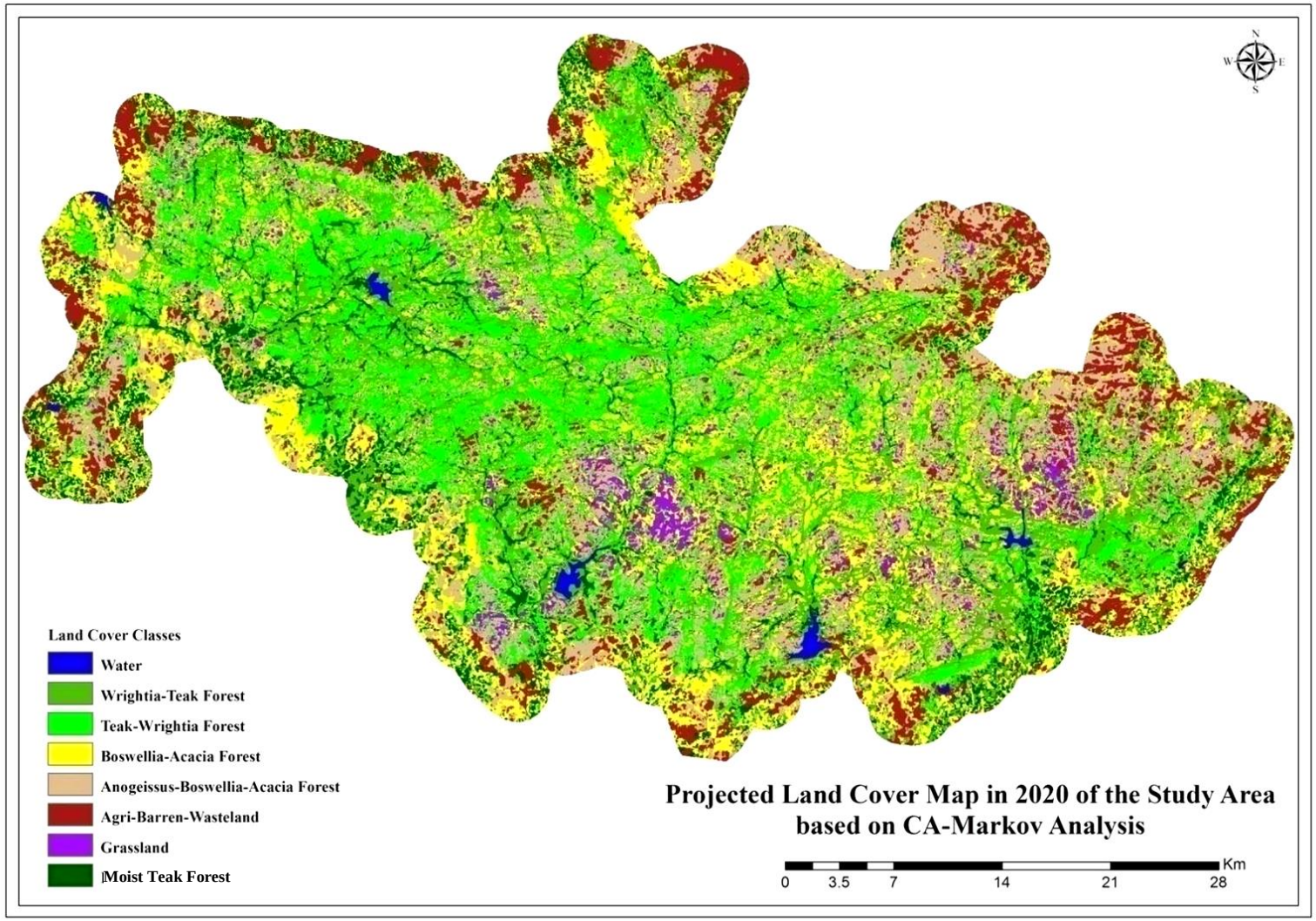


Table 4.2: Cross tabulation of simulated land cover map of 2020 with actual land cover map of 2009 (number of pixels)

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

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

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

CHAPTER V

LION ABUNDANCE AND POPULATION STRUCTURE IN GIR LANDSCAPE

Introduction

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). 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.

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

Assessing the abundance of low density, wide-ranging and cryptic carnivore species is extremely demanding in terms of time and resources (Garshelis 1992). Several approaches have been tried for estimating large carnivore numbers. These include a) total counts without correcting for detection bias (Choudhury 1970; Panwar 1980; Fuller 1989; Gore et al. 1993; Smallwood and Fitzbugh 1995; Rishi 1997), b) indices for relative abundance (Knowlton and Tzilkowski 1979; Palomares et al. 1996; Stander 1998; Houser et al. 2009; Funston et al. 2010), c) indirect methods of scaling and predicting (Carbone and Gittleman 2002; Karanth et al. 2004; Hayward et al. 2007a) and d) modern approaches to abundance estimation incorporating detection probabilities (Karanth 1995; Karanth and Nichols 1998; Garshelis et al. 1999; Grogan and Lindzey 1999; Poole et al. 2001; Soisalo and Cavalcanti 2006; Jhala et al. 2008; Kelly et al. 2008; Mondol et al. 2009; Sharma et al. 2010). Techniques used to date for abundance estimation of lions included mark recapture (Smuts 1976; Jhala et al. 1999, 2004; Ogutu et al. 2006; Banerjee et al. 2010) through individual lion identification (Pennycuick and Rudnai 1970), playback surveys (Ogutu and Dublin 1998; Mills et al. 2001; Ogutu et al. 2005), fecal DNA sampling (Tende et al. 2010) and helicopter surveys (Packer 2006). However, the methods for estimating endangered carnivores need to be practical and cost effective. Helicopter surveys are expensive and cannot be applicable for lion population estimation in the Gir landscape. Track counts (Sharma et al. 2005) although providing inexpensive measures of population estimation, this method cannot be applied in group living species like lions owing to the difficulty in identifying individual pugmarks. The potential variability of individual lions in their response to call-up sounds and other factors, however, need careful examination for a playback survey (Loveridge et al. 2001).

Total Counts of Gir lions: Since 1963, the Gujarat Forest Department has censused lions about every five years by a labor-intensive method using live baits for three days, until 1995 when this met with social and ethical opposition (Singh 2007). Most lions in Gir were familiar with killing livestock and readily approached buffalo bait. A daily record was kept of all lions that visited the baits. After accounting for possible double counts, the maximum number of lions recorded on any single day was considered to be the total population. Total counts are error prone as they lack measures of detection probabilities; require a careful sampling design, trained field staff and intensive field efforts (Williams et al. 2002). Two counts can be compared as an index only if detection remains constant. In Gir PA, the total count of lions obtained by the management using

buffalo baits was lower than the mark-recapture population estimate (Singh 1997; Jhala et al. 1999). This suggests that total counts were likely underestimates. However, since there was no objective way to determine the proportion of lions missed or counted multiple times, the total count method needs to be modified to incorporate detection probability of lions based on sampling (Karanth et al. 2003). The prevailing census method of the forest department by intensive search for lions can only be used to formulate a good index for lion numbers, provided it is calibrated against the more robust mark-recapture population estimation in a double sampling framework (Jhala et al. 2011b). The combination of individual identification by standardized protocols based on vibrissae patterns and permanent natural markings (Jhala et al. 1999, 2004), in a capture-recapture framework (Pollock et al. 1990) if done during the exercise of total counts, would estimate the lion population in a more robust manner.

Given the global importance of the single population of Gir lion, it is crucial that the population be regularly monitored using modern scientific methodologies, and its demographic parameters assessed for long term persistence. The first part of this chapter deals with capture-recapture population and density estimation of lions in the Girnar Wildlife Sanctuary and the human-dominated eastern landscapes of the Junagadh, Amreli and Bhavnagar districts. We deduced the demographic parameters of Asiatic lions 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.

The second part of the chapter applies spatially explicit capture recapture (SECR, Efford et al. 2009) to model lion spatial distribution and density in the Gir West PA. Studies have found strong influence of both intrinsic (Chardonnet et al. 2002) and extrinsic factors (Celesia et al. 2009) on numerical responses of lions, leaving profound impact on density and distribution of the species (Mackey and Lindenmayer 2001; Ogutu and Dublin 2004; Celesia et al. 2009). We hypothesized that the distribution and density of Asiatic lions in Western Gir Protected Area could be a function of prey distribution and density, habitat features, human disturbance and management practice and tested this herein.

PART I. LION ABUNDANCE OUTSIDE THE GIR PA

Methodology

Field method for individual identification of lions

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

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

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

lions (Schaller 1972) in comparison to our short sampling duration we assumed a demographic closure and formally tested for it using the program CloseTest (Stanley and Burnham 1999).

Data analysis

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

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

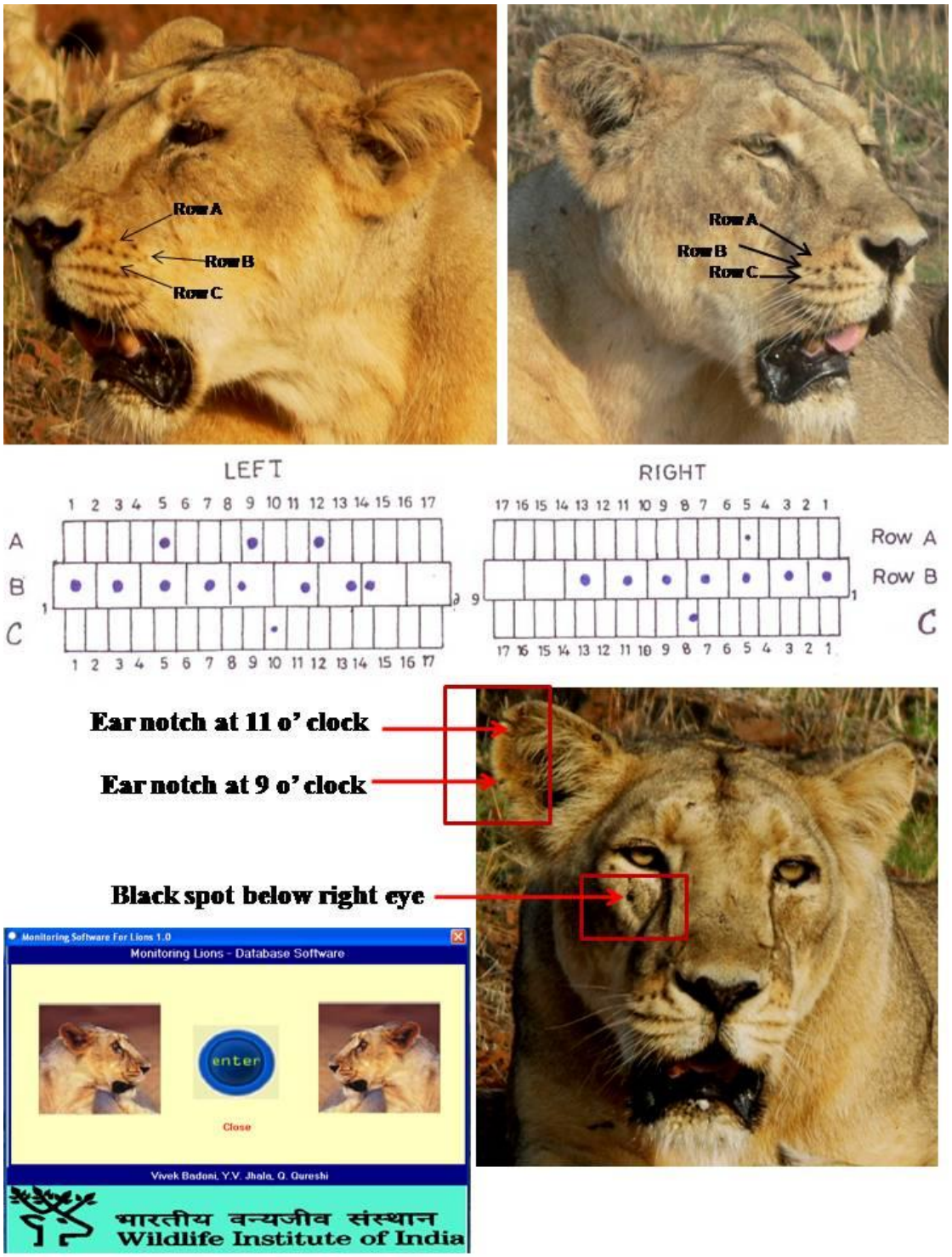
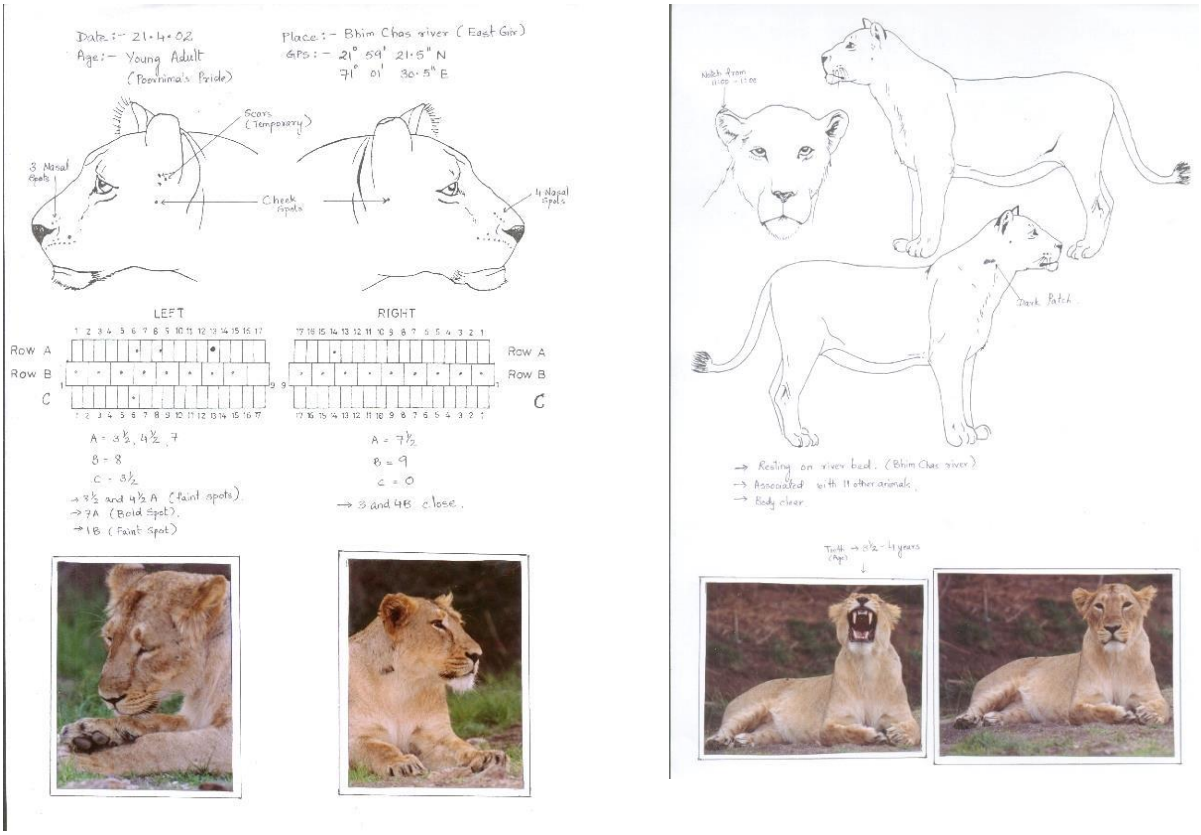


Figure 5.1: ii. Performa of the data sheet used in the field for individual lion identification. Vibrissae patterns are calibrated on a graph paper and position of additional body marks are recorded. (Source: Jhala et al. 2004).



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

Lion density estimation

Lion density in the eastern landscape was estimated as the population size divided by the effectively sampled area estimated by creating a minimum convex polygon over the lion capture points and a buffer width estimated as half the mean maximum distance moved (1/2 MMDM) by

recaptured lions added to the polygon (Karanth and Nichols 1998). Since lions even ventured inside the villages at nights in search of food; therefore village areas were not excluded from our analysis in the eastern landscape. However, townships (with a human population of > 50,000) and large permanent water reservoirs (Palitana Dam and Dhari Dam) were excluded from the eastern landscape lion density analysis. Girnar Wildlife Sanctuary, on the contrary, is surrounded by human habitations and private farmlands. Lions were observed to venture into the agricultural areas at night but seldom spent the daylight hours outside of the Girnar forests. We therefore considered the forested boundary (180 km^2) as a "hard edged boundary" while calculating lion density for Girnar (Banerjee et al. 2010) **[Figures 5.2 and 5.3]**.

Lion population structure

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

Population Viability Analysis (PVA) of Girnar lions

The examination and the analysis of the interacting factors that place a population or a species at risk is called population viability analysis or PVA (Burgman et al. 1993). PVA was carried out to identify the threats faced by the Girnar lions and to evaluate the likelihood that it will persist for a given time into the future. This type of analysis is often oriented towards the conservation and management of rare and threatened species, with the goal of applying the principles of population ecology to improve their chances of survival. PVA contributes in the two broad objectives of the threatened species management; i) the short term objective of minimizing extinction risks and ii) the long-term objective of promoting conditions in which species retain their potential for evolutionary change without intensive management (Lacy 1993).

Lion life history parameters were obtained either from the current study or published literature (Schaller 1972; Joslin 1973; Chellam 1993). Five hundred simulations for combinations of each of the stochastic scenario given in **Table 5.1** were run in program VORTEX 9.99 (Lacy et al. 2009). Various combinations of such scenarios assisted in judging

the relative contribution of different environmental/management factors towards long-term viability of Girnar lion population. All scenarios were run with the default inbreeding depression and density dependence option provided in VORTEX 9.99 wherein density dependence was modeled by limiting the breeding of lionesses to 40% at carrying capacity (Kissui and Packer 2004; Trinkel et al. 2010). We defined *quasi-extinction* at the critical lion population size below 10 individuals.

Relative densities using prey biomass can be used to estimate ecological carrying capacity of a site which can be used in a PVA (Van Orsdol et al. 1985; Gros et al. 1996; Carbone and Gittleman 2002; Hayward et al. 2007a). The carnivore density derived from this relationship works as long as no other mechanisms limit a carnivore population. Prey biomass was used for predicting lion carrying capacity in Girnar as other top-down limiting factors like trophy hunting and incidence of epizootics (Kissui and Packer 2004; Whitman et al. 2007) were not prevalent in Girnar (Pathak et al. 2002; Singh 2007). Predictive model suggested by Hayward et al. (2007a) based on lions' preferred prey species (chital, sambar, nilgai, cattle and buffalo) was used to estimate the ecological carrying capacity of Girnar for lions. The equation was $y = -2.158 + 0.377x$ ($r^2 = 0.71$, $n = 23$) where y is the $\log_{10}$ of lion density and x is the $\log_{10}$ of biomass of significantly preferred prey. Prey biomass were obtained from density estimates based on distance sampling (Buckland et al. 2001) done during the current study and deduced by multiplying unit body weights of various prey species taken from literature (chapter 10 for more details). Since all the domestic livestock were not available for lion predation, therefore a conservative proportion (24%) of the biomass of domestic livestock obtained from our estimates of the proportion of the vulnerable livestock to lion predation in the Gir (Banerjee et al. 2013) was incorporated in the model.

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

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

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

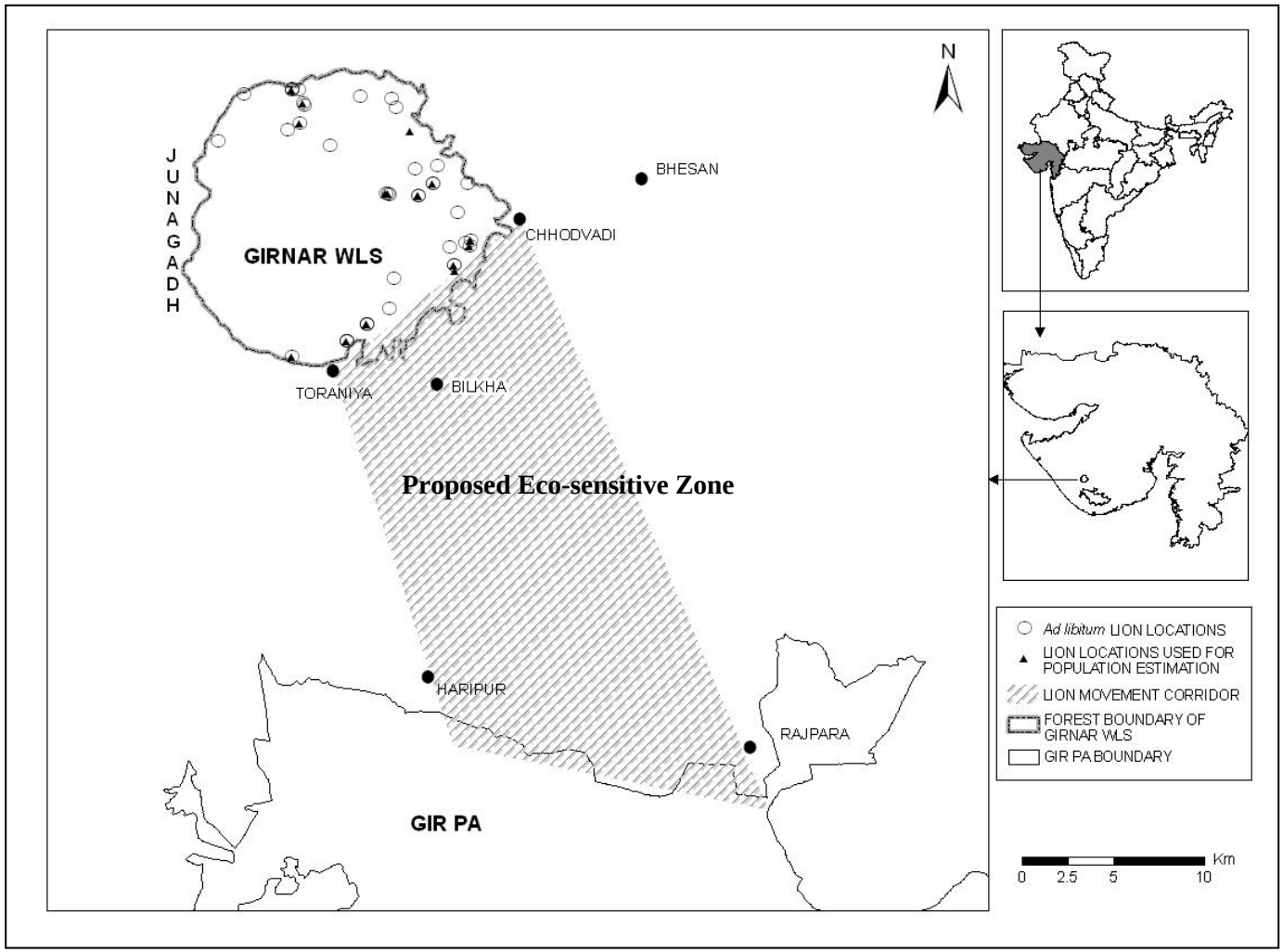
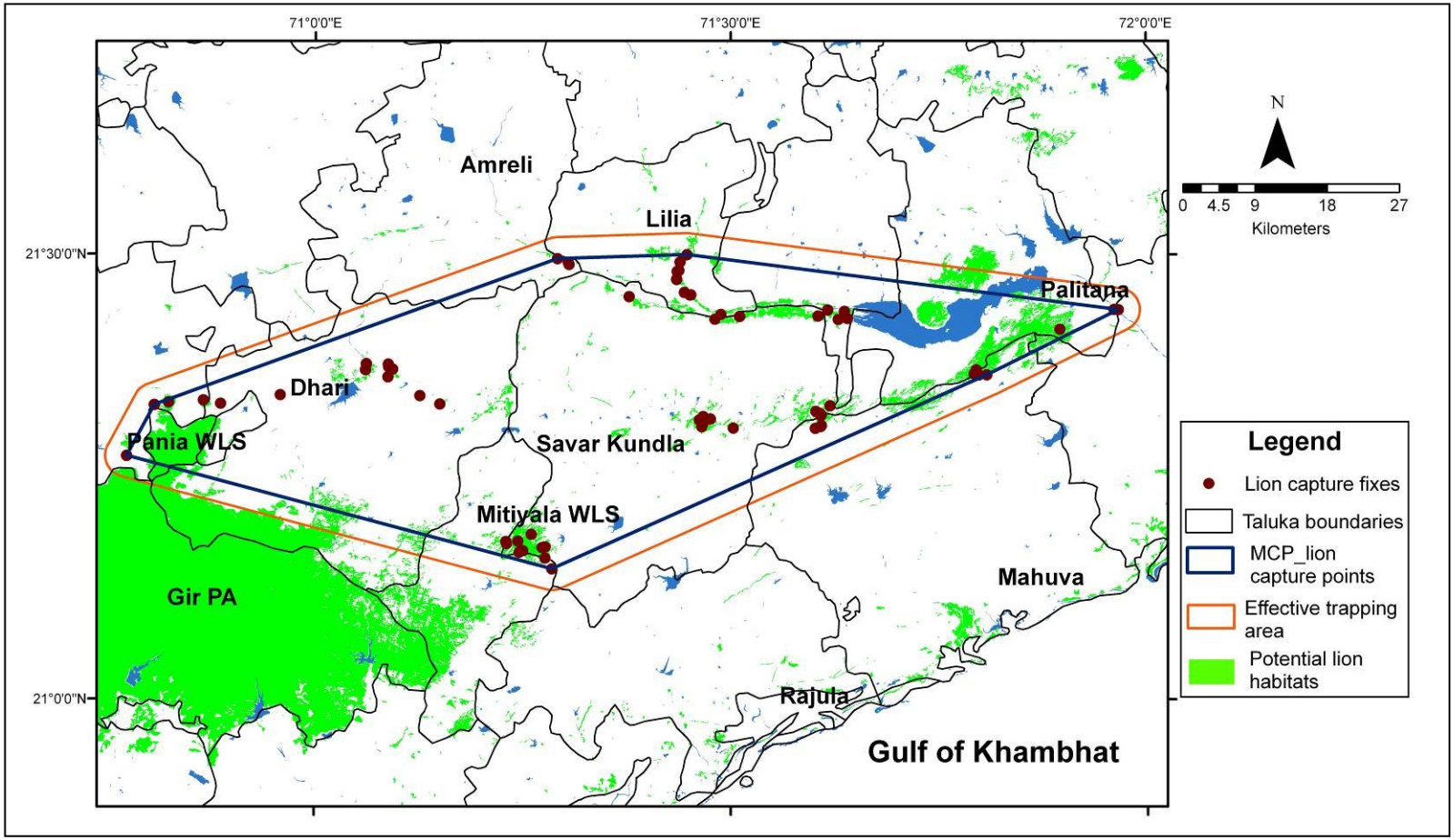


Figure 5.3: Minimum convex polygon defining lion search within the potential lion habitats of the Eastern landscape, buffered with half MMDM



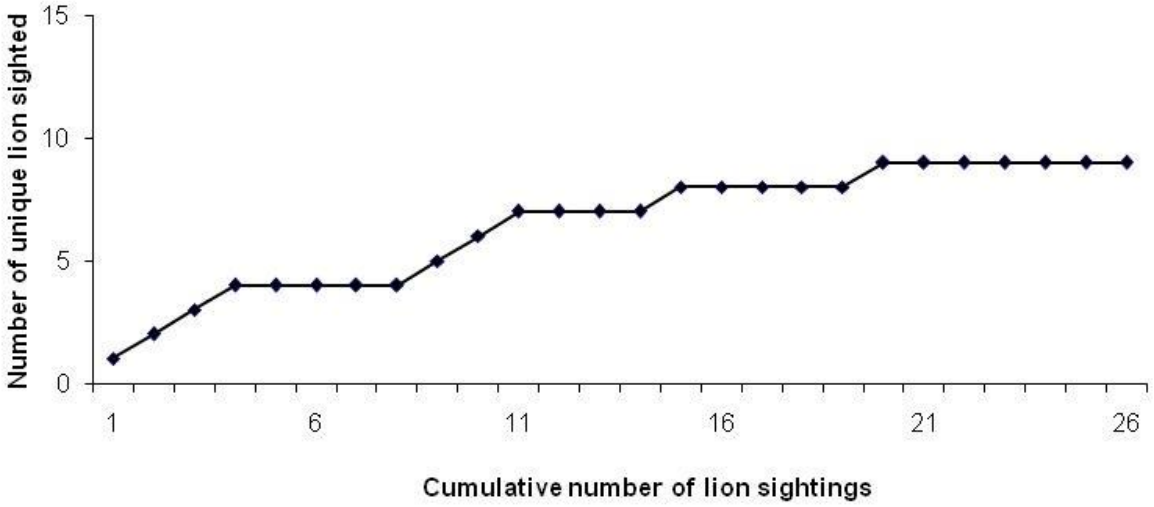
Results:

Lion population and density estimation

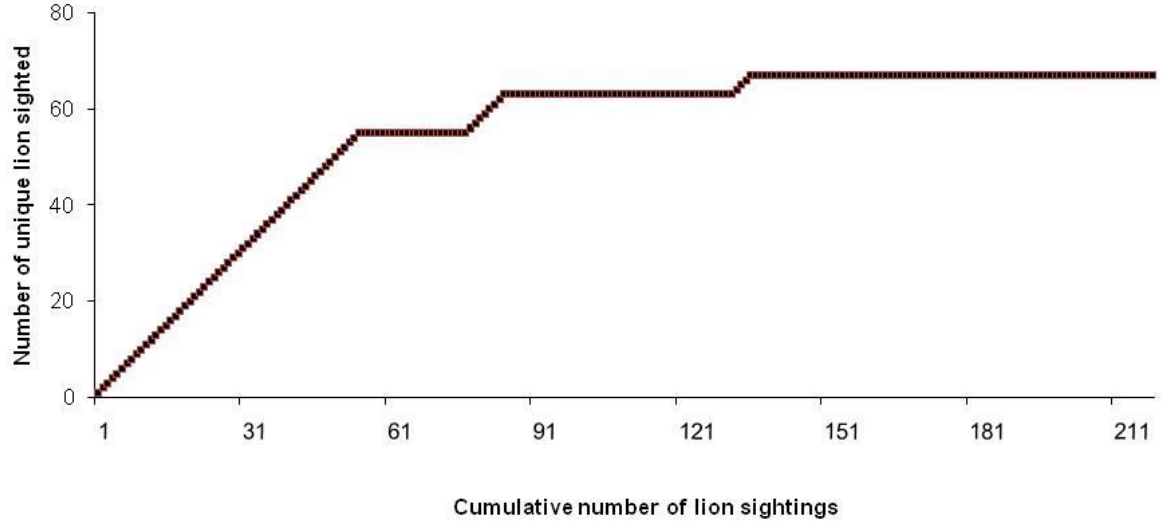
Number of unique lions sighted when plotted against cumulative lion sightings, reached an asymptote suggesting adequacy of sampling and population closure **(Figure 5.4)**.

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

i)



ii)



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

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

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

Table 5.2: Summary of lion density (lion/100 km^2) 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)	Lion Density (SE)
Girnar WLS	2008	9	26	6*	**10 (1.2)**	180	**6 (0.7)**
Eastern Landscape	2010	67	219	5**	**67 (1.1)**	3,292	**2 (0.1)**

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

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

i) Girnar Wildlife Sanctuary

Model	Population estimate	SE	95% CI	Model selection criteria score
M_o	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_o	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

Lion population structure

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

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

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

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

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

Population Viability Analysis of Girnar lions

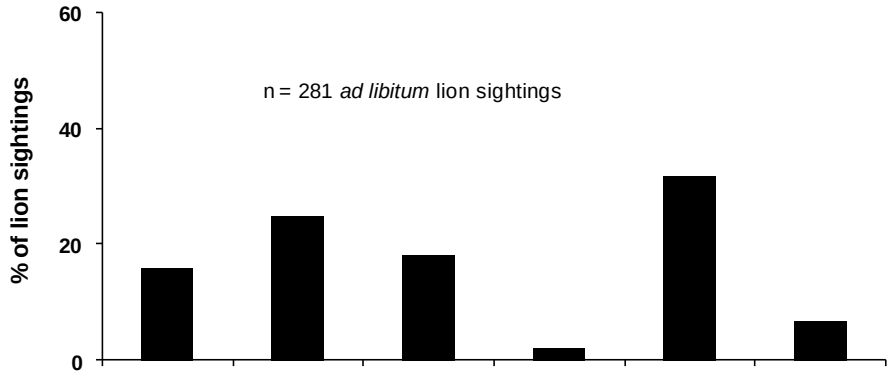
The carrying capacity of Girnar for lions was estimated to be 9 lions/100 km^2 which translated into about 16 lions in the sanctuary.

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

Effect of habitat linkage with the Gir PA: Girnar lions were found to be extremely sensitive to the habitat linkage with the Gir PA. In the absence of any poaching episode or accident, the long-term (100 years) survival probability of Girnar lions increased by 39% in comparison to scenario wherein there was no habitat linkage i.e. no immigration (**Table 5.4, Figure 5.7**). With lion poaching incident every year and with both the catastrophes; the median time to extinction of Girnar lions was 130 years when both the PAs were connected in comparison to the median time to extinction of 3 years in the absence of such habitat linkage (**Table 5.4**).

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

i)



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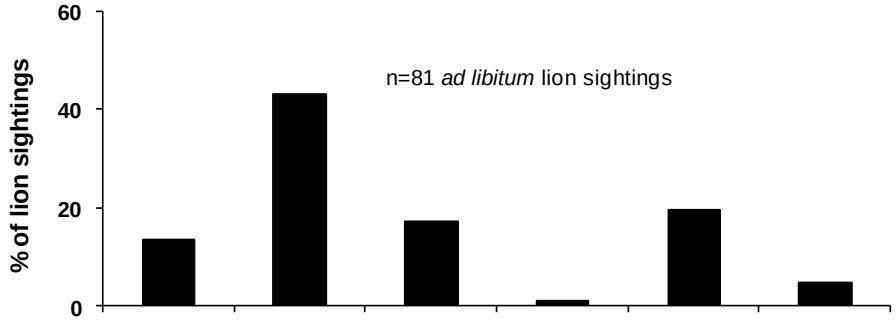

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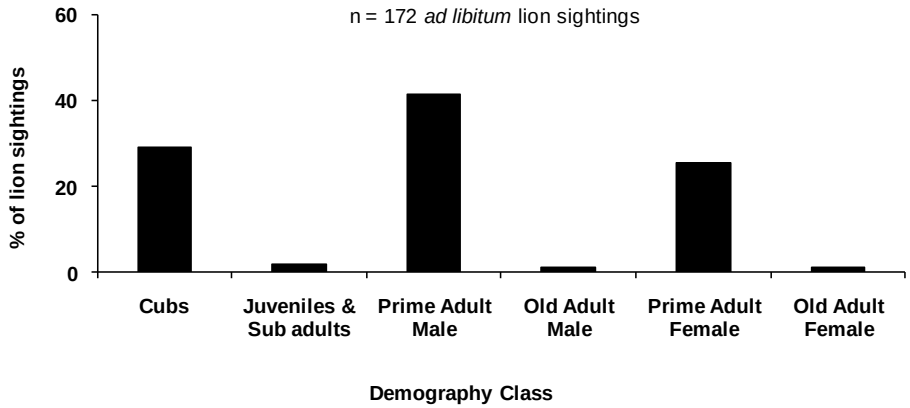
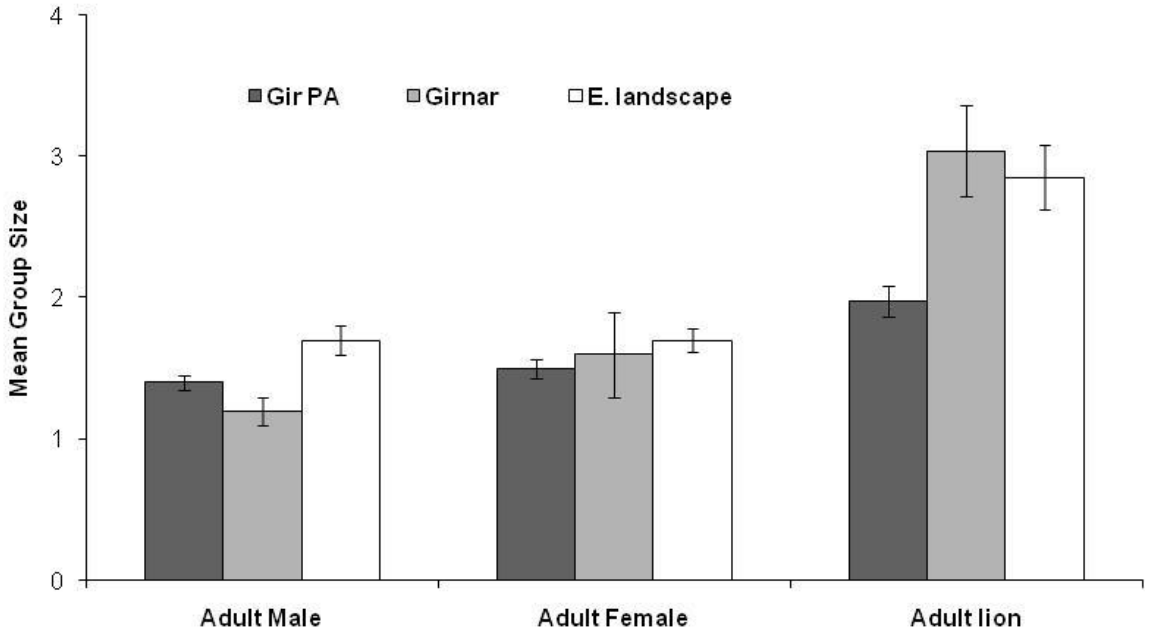


Figure 5.6: i) Mean group size (including cubs) and ii) Typical group size (including cubs) of Asiatic lions in the Gir PA, Girnar forests and the eastern landscape

i)



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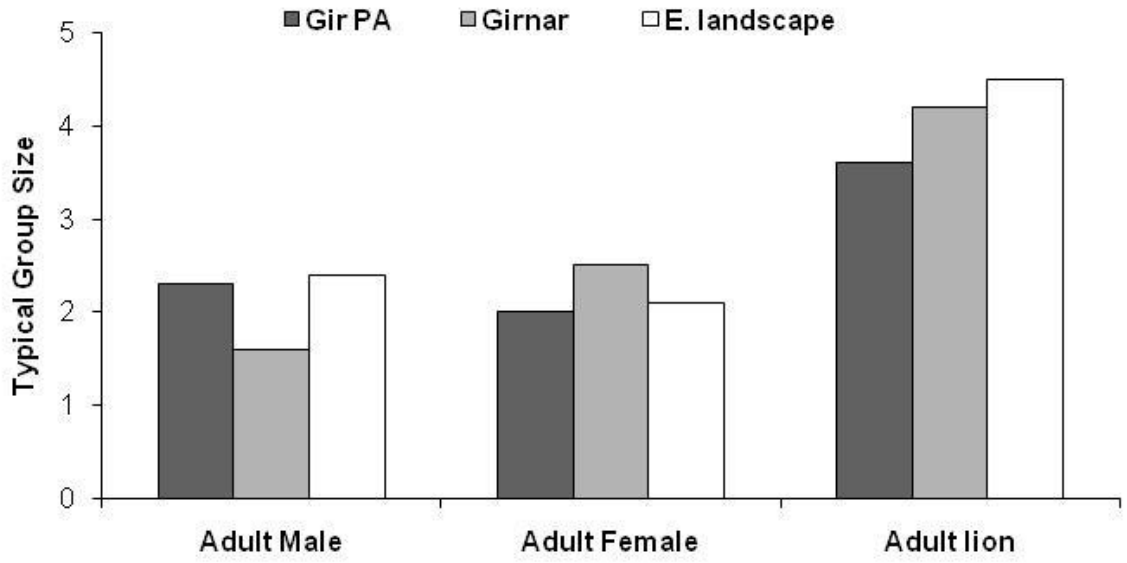


Effect of poaching and accidents: Girnar lion population persistence was sensitive to harvest due to poaching and accidents; but not to the extent that it was due to habitat linkage with the Gir

PA. With the worst case scenario wherein three lions were poached annually and with no habitat linkage with the Gir PA, the Girnar lions were found to survive for only three years. With the same level of harvest every alternative year, lions survived for five years but the population would not persist in long term (**Table 5.4**).

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

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

Modeled scenario	Extinction probability (SE)				Median time of extinction (year)
	25 year	50 year	75 year	100 year	
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 5.7: Long-term (100 years) extinction probability of Girnar lion population under different modelled stochastic scenarios in VORTEX. A – H correspond to the eight scenarios explained in Table 5.1. N = population size. I. Mean survival probability of Girnar lions under different modelled scenarios

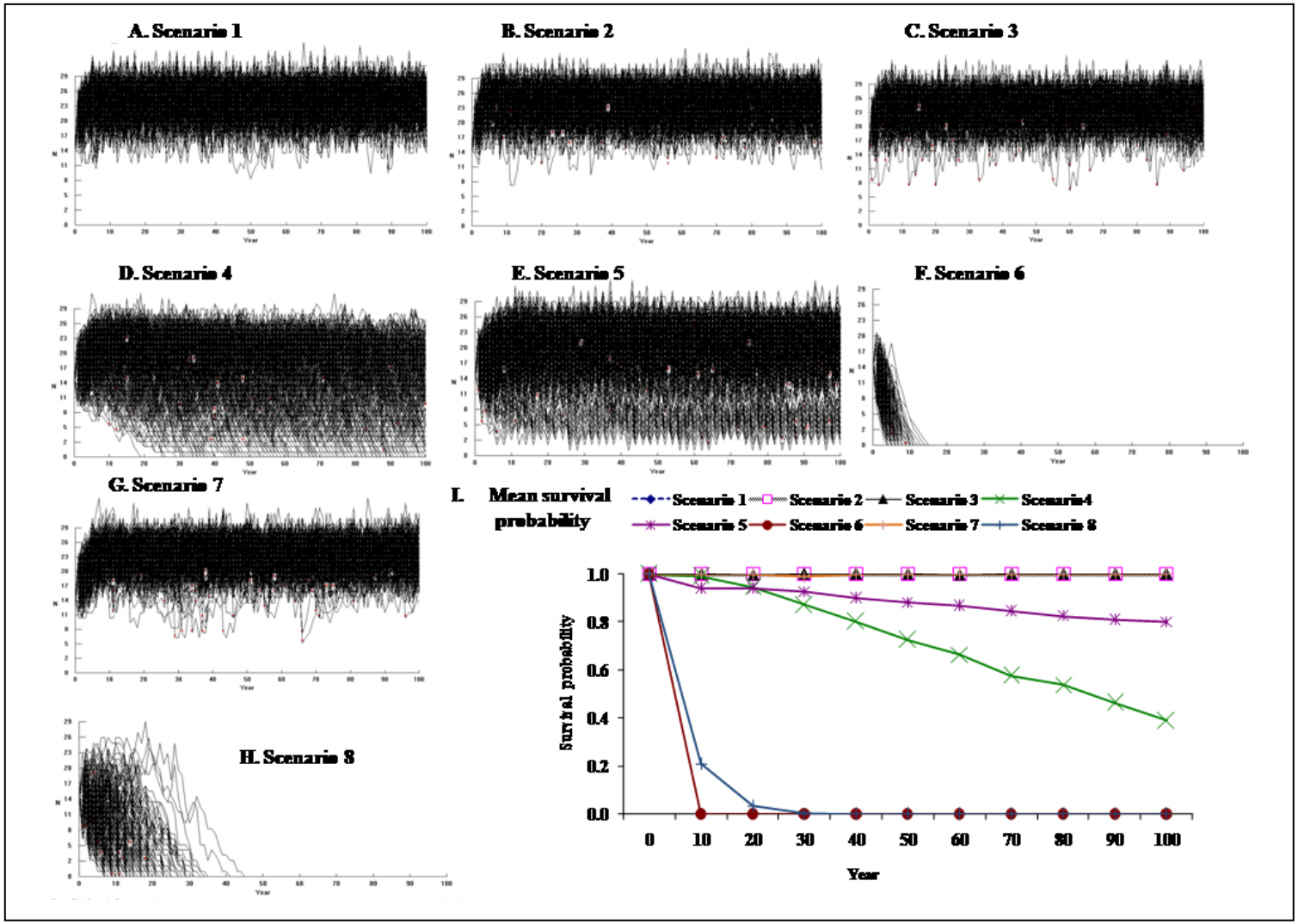
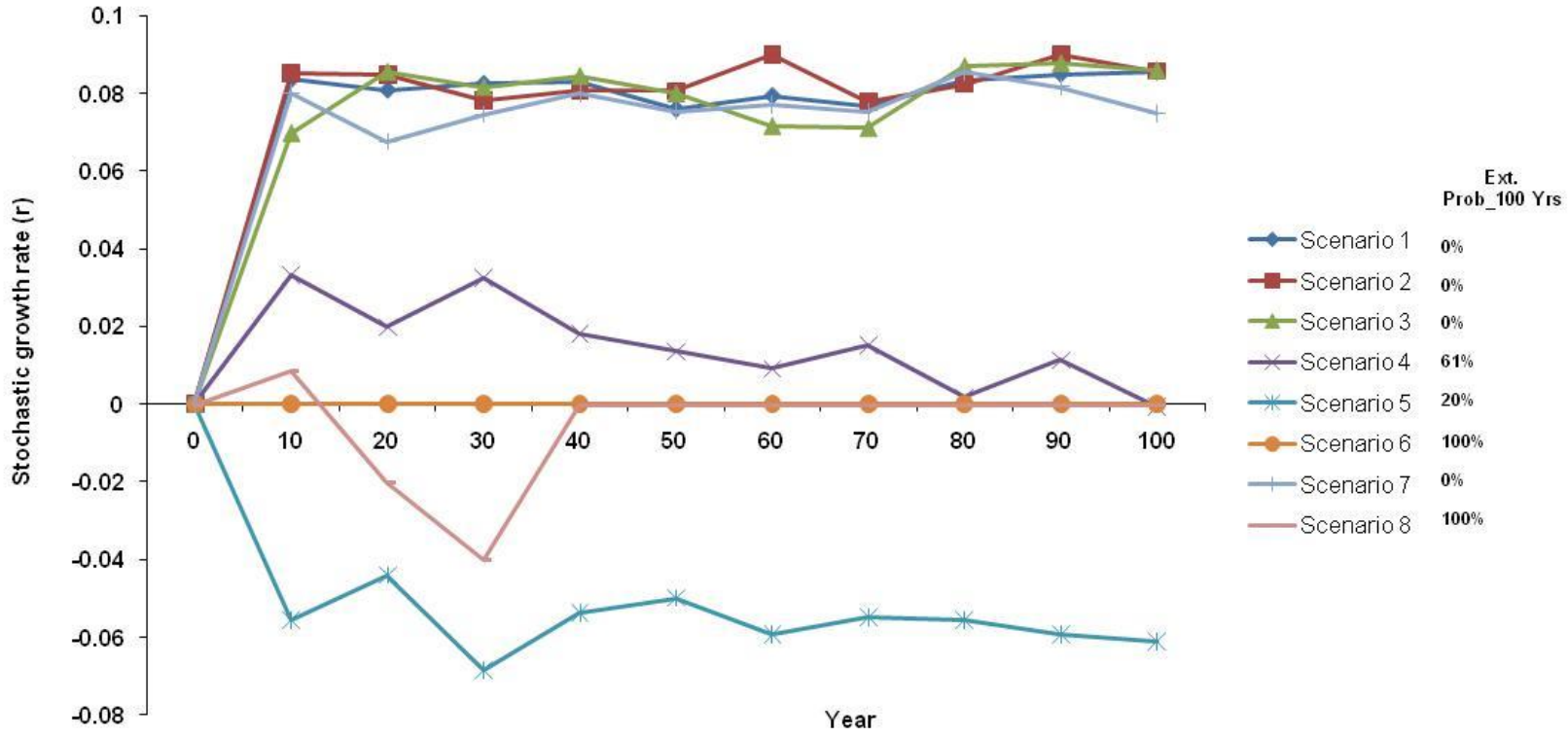


Figure 5.8: Mean stochastic growth rate (r) of the Girnar lion population under different modeled scenarios. Details of the scenarios are explained in Table 5.1



Part II. FACTORS GOVERNING THE SPATIAL DISTRIBUTION AND DENSITY OF LIONS IN WESTERN GIR PROTECTED AREA

Methodology

Sampling design:

A standard protocol of sampling design has been formularized based on the recently developed spatially explicit polygon search method by Efford 2011. The study site in Western Gir Protected area of about 725 km^2 was divided into grids of 25 km^2 , half the size of an average home range of female Asiatic lion i.e. 48.2 sq km (100 MCP home range) ((Jhala et al. 2009), to minimize the chance of missing an animal during search. Each of the grids were actively searched for lions on foot or by vehicle, during their high activity period *i.e.* morning and evening hours (Banerjee et al. 2013) between November 2014 and March 2015. With professional trackers, lions were located relied on fresh signs like pugmarks, roars, alarm calls of herbivores, crow assemblage, interacting with forest department people and other dwelling people, and visiting probable lion habitats. Once encountered, individuals were approached within 10-30m to get clear photographs of the vibrissae pattern, clicked at a right angle (90^0) to the face and other permanent body marks for identification, with a canon HX 50 zoom camera. The time, date, geographic coordinates, age, sex, associated animals, activity at that particular time and habitat covariates were recorded for each of the detections (Jhala et al. 1999, 2004). The sampling was carried out for 10 occasions. An occasion was considered while at least one visit to each of the sampling grids were made and repeated in the same fashion for the successive occasions. Exploratory data analysis was done to estimate the required sample size for precise estimates by plotting number of new lions being added with occasions. A continuous track of the search path was being recorded in the GPS device.

Spatially explicit capture recapture:

All the mark recapture techniques are inherently spatial in nature (Borchers 2011) but conventional mark-recapture (CMR) method does not give any spatial reference of the distribution and abundance of the species (Borchers and Efford 2008). Hence the estimated density is considered to be ad hoc (Royle et al. 2009). Spatially explicit capture recapture (SECR) (Efford 2004) in this regards advantageous over the CMR, for modelling animal capture-recapture data collected with an array of spatially referenced ‘detectors’ (Efford 2013), allowing

us to model the spatialdistribution and density of the species as well as to make inferences about the underlying ecological processes (Winiarski et al. 2013).

Covariates:

Lion density was modeled with both biotic and abiotic eco-geographical factors based on their ecological significance. Distribution and density of major prey species, human disturbance, ruggedness, euclidean distance to water, vegetation cover, elevation, NDVI and tourism hot spots were taken into consideration for the analysis. All the eco-geographical variables were obtained from various remote sensing database of Wildlife Institute of India repository while data on other biotic parameters were collected from the field and extracted at the 500 X 500 m grid. Data on livestock mortality and carcass dumping were collected from the nesses (Maldhari settlements) within the study area of western Gir PA. Distance sampling (Buckland et al. 2001) method based on line transect was used to collect data on herbivores and spatial abundance pattern was obtained by density surface modelling (Miller et al. 2013 a, b). Two line transects (2.5 – 4 km each) were laid per lion search grid (25 sq km), to get a good spatial representation of herbivore distribution and abundance in the landscape. Information on geographical location, date, time, radial distance, sighting angle, transect bearing, age, sex, group size, group composition and types of habitats were noted down.

Model formulation for lions:

We used maximum likelihood based SECR polygon search method (Efford et al. 2009) to estimate the spatial density of Asiatic lions. Density in this method is estimated as a point process model based on activity centres (latent in the data) (Borchers and Efford 2008; Efford and Fewster 2013; Royle and Converse 2014). These activity centres are considered to be randomly spread over space and follows a poison distribution model and intensity of these points may vary over space (Efford and Fewster 2013) and could give varieng hights of the fitted density model (Efford and Fewster 2013). The probability of capture in this method is modelled as a decreasing function away from its home-range centre (Borchers and Efford 2008).

The detectors in polygon search method are mobile and actively looks for the targeted animals in the sampling areas. The search is generally conducted along a path which could be either a priori defined or followed shortly depending on the field situations (Royle et al. 2013). A

complete track of each of the searches were recorded. Hence the collected data on detection history bears the actual geographical location of the detected individuals represented within each of the searched polygons instead of trap id and the "trap file" bears the geographical coordinates of the polygon vertices representing each of the polygons (Efford 2013). In this case the observer worked as a detector who actively searched for the lions in the sampling area. Records were made on group sizes, sex of the individuals and search efforts (Thompson et al. 2012), which were than used as covariates to model the detection probability. Group of the lions were distinguished based on the peaceful interaction of related animals found together in most of the detections (Schaller 1972). The actual number of individuals in the groups were estimated by calculating the $\hat{N}$ for each of the group with conventional mark recapture analysis. Sex of the individuals were identified on the field. Animals above the age of 2 years were only considered for the analysis, as survivability and independency of the cubs after 2^{nd} year is believed to be increased, and hence their contribution to the population. Search effort was obtained from the continuous tracks recorded in GPS device, which was then optimised for different grid sizes for the analysis. The collected data can also be represented as mentioned by Russell et al. 2012, where the detections made within each of the grids can be attached to the centroid of each of the polygon, so that the centroids of the polygons acts as arrays of stationary traps (proximity detector). SECR polygon search method is considered somewhat complex but biologically more realistic (Royle et al. 2014).

Model formulation for herbivores:

The spatial abundance pattern of herbivores were modelled with density surface modelling (Miller et al. 2013 a,b) where a detection function is fitted based on the distance data collected line transects (Hedley and Buckland 2004) and later a spatial abundance pattern is generated in response to spatial covariates based on Bayesian point process model (Miller et al. 2013 a,b). These allow animal density to be related to topographical, environmental, habitat, and other spatial variables, helping wildlife managers and ecologist to identify the factors that affect abundance and distribution. They also enable estimation of abundance for any area of interest within the surveyed region. The concept underlying density surface modelling is that a response variable is modelled as a function of predictor variables. However, the response variable for our purposes can be a count, an estimated density, or an estimated abundance within each transect segment.

Analysis:

Spatial density of lions:

We simulated the analysis using different grid sizes of 1km^2, 5 km^2 and 25 km^2 to see any potential difference in density estimation. Search effort per grid, sex of the detected individuals and group size were used as covariates to model spatial lion density. The analysis was carried out in R platform using maximum likelihood based SECR framework (Efford et al. 2009). We modelled the densities of both male and females using hybrid mixture models (Efford 2015). This particular model is useful when data falls under distinct categories, for example, the home range size of carnivores differs in both the sexes (Sandell 1989) therefore the hybrid mix model works best to estimate the density for both the sexes (Efford and Mowart 2014). On the other hand, in group living animal, capture of one individual increases the capture or recapture probability of other members of the groups which violates the basic assumptions of independent detection of mark recapture analysis. Therefore, we modelled the density taking group size as a covariate of detection probability (g0) and movement parameter (σ). A spatial density surface was then created using the resultant outcome in Arc Map 10.2. A predictive grid of 5 km^2 was used to extract the lion density information along with other covariates to model the factors governing spatial distribution and density of Asiatic lions using Generalised linear models in R platform.

Spatial density of herbivores:

Herbivore spatial density was modelled using density surface modelling (DSM) (Hedley and Buckland 2004). These allow to model herbivore density in response to topographical, environmental, habitat, and other spatial variables. The concept underlying density surface modelling is that a response variable is modelled as a function of predictor variables. The response variable in this case is an estimated abundance of herbivores within each transect segment.

As per the requirement of DSM we subdivided the line transects into segments of 400m along with its respective detections. A prediction grid of 500 m^2 is then created with eco-geographical covariates of elevation, distance to water, human disturbance, ruggedness, slope and NDVI. We ran the analysis for the two major prey species of our concern “chital” and “sambar” separately. First with conventional distance sampling (CDS; Buckland et al. 2001) we

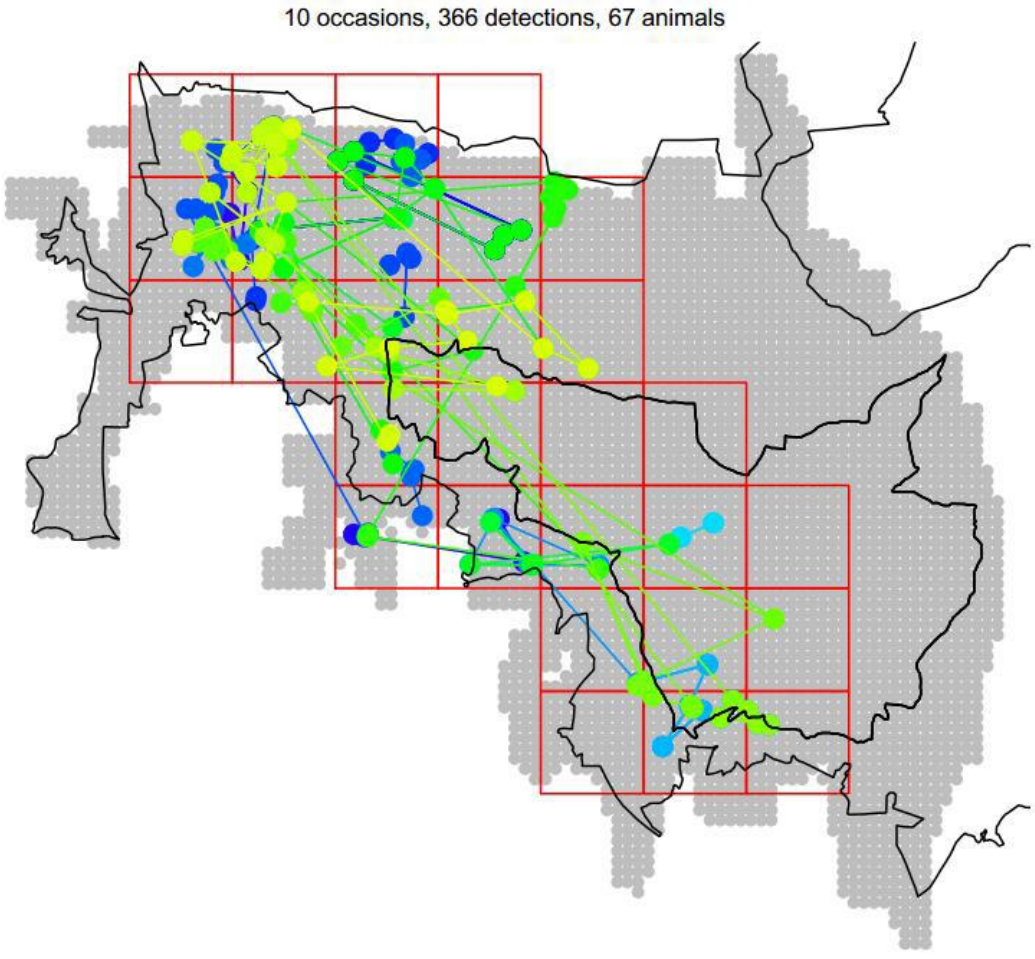
estimated per segment abundance of the herbivores. A hazard-rate detection function was fitted looking at the structure of the dataset. Then the density surface of the herbivores were modelled taking elevation as a covariate for both the species. The resultant density information was then used to create the density surface map of herbivores on Arc map 10.2 (ESRI 2011), and information were extracted on a 5 km2 grid which was used to extract lion density data for further analysis. Multivariate models in GLM (McCullagh and Nelder 1989) using program R were run to investigate the effects of different covariates on the spatial density of Asiatic lions. Best models were than selected based on their AIC values (Burnham and Anderson 2002).

Results:

Lion photo-capture:

We had 366 detections of 67 individuals with 28 males and 39 females, belonging to 31 groups with 163 detections of the groups (**Figure 5.9**).

Figure 5.9: Search grids and locations of lion captures within the study area of the Gir West PA.



Lion population estimation in the Gir West PA using conventional mark-recapture:

Population estimates by the conventional mark recapture Huggins models is 71.49 (SE 3.02), with M(t+1): 67 and population density is 9.87 (SE 3.02) individuals per 100 sq km. Number of female is 42.36 (SE 2.72) and number of male is 29.13 (SE 1.31) in an area of 725 sq km. Densities were calculated dividing the number of population by the total area of the polygons.

Lion density by SECR polygon search method:

Lion density ranged from 8.54 (SE 1.06) of our best model (g0~effort, sigma~1) to 8.31 (SE 1.03) individuals per 100 km^2 of the lowest model (g0~sex, sigma~1). We had a group size variation of adult lions from 1 to 6 individuals. Density of groups with only 2 individuals were found to be highest 2.96 (SE 0.63) followed by groups of four individuals 1.59 (SE 0.45), as shown in **Table 5.5**. The detection probability also varied across different groups. Groups with 6 individuals had a higher probability of detection, followed in a linear fashion by the successive group sizes.

Table 5.5: Density estimates of different lion group sizes

Lion Group size	Density estimate (D)	SE	LCL	UCL	CV (D)
1	1.23	0.41	0.65	2.32	0.33
2	2.96	0.63	1.96	4.48	0.21
3	1.47	0.44	0.82	2.62	0.30
4	1.59	0.46	0.91	2.77	0.29
5	0.66	0.30	0.29	1.52	0.45
6	1.05	0.37	0.54	2.06	0.35

The density of male is found to be 3.08 (SE 0.58) individuals per 100 km^2 and density of female is found to be 5.61 (SE 0.90) individuals per 100 km^2 according to the best model. The detection probability at the home range centre (g0) of males was found to be higher than the females, 1 (SE 0.18) and 0.55 (SE 0.06) [**Table 5.6**]. It could be due to their larger home-ranges covering more grids than the females, which increases their probability of encountering in the successive grids. Also due to their pronounced behavioural traits like roaring and higher rate of

movements for patrolling make the observer easier to detect them. These behavioural traits are also been reflected in the movement parameter sigma (σ) which was found higher in males 5.03 (SE 0.27) than females 2.64 (SE 1.50).

Table 5.6: Lion density estimates deduced from different models

Model	Density	SE	LCL	UCL	N-par	Log likelihood	g0	g0SE	sigma	Sigma SE	AIC
go~effort	8.54	1.06	6.71	10.87	3	-4263.72	0.63	0.05	3916.04	161.95	8533.43
g0~group size	8.32	1.03	6.54	10.59	3	-4282.25	0.73	0.07	3910.14	162.09	8570.49
g0~sex	8.17	1.01	6.42	10.39	4	-4390.56	0.79	1.10	4020.79	158.86	8789.13

Herbivore abundance:

Total 111.93 km of effort was put to sample 38 spatial transects. Only two catchable prey species *viz.* chital and sambar had detections >20 times on the transect lines fulfilling the minimum detection requirement for Distance. There were 100 detections of chital and it was found to be the most abundant prey in the study area (**Table 5.7**). **Figure 5.10** depicts density surface maps of the two major prey of lions (chital and sambar) against lion desnity contours using density surface modelling.

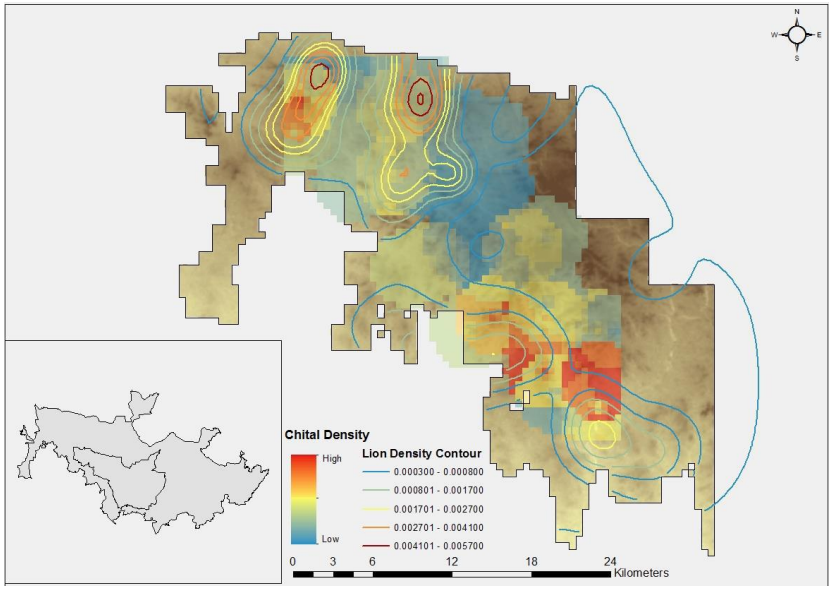
Effects of different eco-geographic variables in expalinaing lion abundance and distribution

Availability of livestock carcass dumping sites was found to be having the most significant negative impact on lion density in the study area. That means the density of Asiatic lions are higher around these sites (**Table 5.8**). Details of the multivariate models are presented in **Table 5.9**. It was found that the spatial density of Asiatic lions were neither explained by the density and distribution of its major prey species sambar and chital but was explained more by the distance to carcass dumping sites, elevation and water availability.

Table 5.7: Lion prey abundance in the Gir West PA

Species	Observation	ESW (meter)	SE (ESW)	Detection probability (p)	SE (p)	Model Fit	Chi-square P value	Group Density (Ds)	SE(Ds)	Individual Density (D)	SE (D)
Chital	100	64.8	3.4	0.75	0.04	Simple Polynomial	**0.94**	6.89	12.99	**57.77**	16.39
Sambar	25	56.4	8.5	0.72	0.11	Simple Polynomial	**0.98**	1.98	26.59	**3.48**	28.78
Nilgai	4	54.5	7.3	0.61	0.09	Simple Polynomial	**0.92**	0.68	46.43	**1.02**	50.26
Peafowl	24	46.4	3.2	0.54	0.04	Uniform Cosine	**0.63**	2.31	30.15	**7.80**	34.93
Langur	33	29.0	4.6	0.37	0.06	Half-normal Cosine	**0.63**	5.09	1.32	**21.18**	6.47

Figure 5.10: Density surface maps of chital and sambar with lion density contours in the Western Gir PA



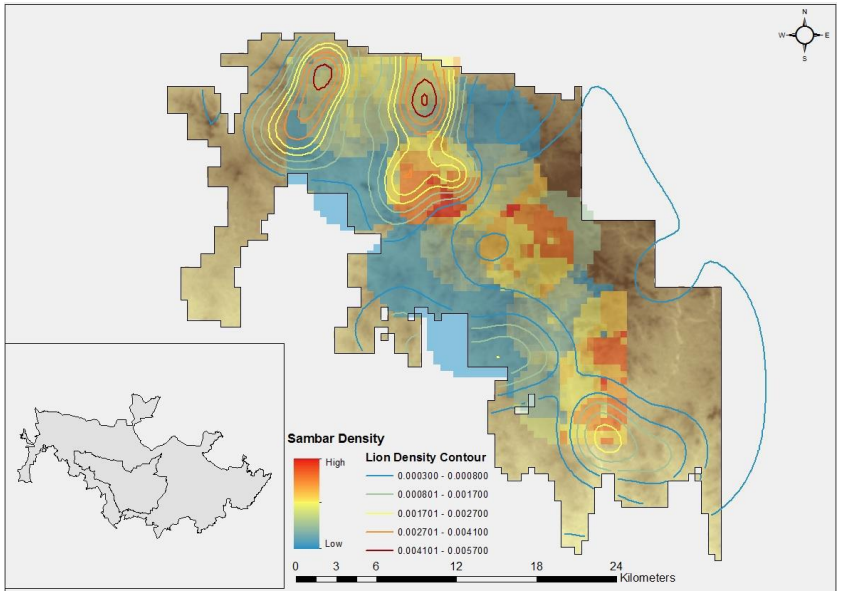


Table 5.8: Results of the regression analysis showing the effects of various covariates on lion density in the Gir West PA

Model	covariate	Estimate	SE	t	Pr(>|t|)	AIC	dAIC
lm(z.lion ~ z.distance from carcass dumping, data = lion)	z.distance from carcass dumping	-0.419	0.082	-5.09	1.32E-06	333.01	0.00
lm(z.lion~z.distance from human foot prints, data=Lion)	z. distance from human foot prints	0.294	0.087	3.40	0.000914	345.67	12.66
lm(z.lion~z.elevation, data=Lion)	z.elevation	-0.208	0.089	-2.35	0.0206	351.42	18.41
lm(z.lion~z.sambar density, data=Lion)	z.sambar density	-0.143	0.090	-1.60	0.113	354.33	21.31
lm(z.lion~z.distance from water, data=Lion)	z.distance from water	-0.096	0.090	-1.07	0.288	355.74	22.73
lm(z.lion~z.chital density, data=Lion)	z.chital density	0.052	0.090	0.58	0.563	356.55	23.54

Table 5.9: Hierarchical order of factors effecting spatial distribution of Asiatic lions in the Gir West PA

Models	Estimate	Std. Error	t	Pr(>|t|)	AIC	dAIC
Lion ~ z.distance from carcass dumping + z.elevation + z.distance from water	-4.933	0.1512	-32.621	<2e-16	-35719	0
	-3.392	0.1515	-22.38	<2e-16		
	-1.212	0.1429	-8.481	<2e-16		
Lion ~ z.distance from carcass dumping + z.elevation + z.sambar density	-5.018	0.1521	-32.992	2E-16	-35712	7
	-2.975	0.1565	-19.017	2E-16		
	-1.215	0.1503	-8.079	9.2E-16		
Lion ~ z.distance from carcass dumping + z.chital density + z.elevation	-4.695	0.163	-28.81	2E-16	-35660	59
	-1.736	0.5018	-3.46	5.4E-5		
	-4.884	0.4834	-10.11	2E-16		
Lion ~ z.distance from carcass dumping + z.chital density + z.distance from water	-5.142	0.1593	-32.283	<2e-16	-35631	88
	3.197	0.1598	20.014	<2e-16		
	-1.239	0.1452	-8.533	<2e-16		
Lion ~ z.distance from carcass dumping + z.distance from water + z.sambar density	-4.186	0.1523	-27.474	2E-16	-35420	299
	-1.07	0.1497	-7.148	1.0E-12		
	-1.994	0.1525	-13.078	2E-16		
Lion ~ z.elevation + z.distance from water + z.sambar density	-1.523	0.1728	-8.816	2E-16	-34820	899
	-1.086	0.165	-6.58	5.5E-11		
	-0.7406	0.1726	-4.292	1.8E-05		
Lion ~ z.chital density + z.sambar density + z.distance from water	0.7651	0.1732	4.418	1.0E-05	-34763	956
	-0.9849	0.1728	-5.699	1.3E-08		
	-1.055	0.1667	-6.331	2.7E-10		

Discussions

Population estimation and density

White et al. 1982 suggested a minimal capture probability of > 0.3 so as to ensure that CV% of ≤ 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% ofthe 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 our model and provided a scope of estimating the abundance of a 'superpopulation' (Kendall 1999). Moreover, the closure test in Program CAPTURE is a weak test because a failure of closure cannot be distinguished from changes in capture probabilities because of behavioral responses and insensitivity to temporary emigration occurring at the middle of the study period or from certain patterns of time-trends in capture

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

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

Gir PA holds the maximum potential for being a lion stronghold with a much higher lion density in comparison to the Girnar forest and the eastern landscape (Jhala et al. 2004; 2006; **Table 5.10**). Prey density is one of the key determinants of large felid abundance (Karanth et al. 2004). Lion density has a positive linear correlation with prey abundance (Van Orsdol et al. 1985; Carbone and Gittleman 2002; Hayward et al. 2007a). However, the current study did not find any significant correlation between lion abundance and prey biomass in different parts of the Gir landscape suggesting that there were other limiting factors.

Table 5.10: Lion density and prey biomass density from different Protected Areas across the World

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
West Gir PA	**India**	**725**	**0.08**	**1,732**	**2.1**	**3.6**	**Gogoi 2015; Current study**
Girnar forest	**India**	**180**	**0.06**	**953**	**1.4**	**1.9**	**Banerjee 2012; Current study**
Human dominated eastern landscape	**India**	**3,292**	**0.02**	**98**	**1.6**	**1.6**	**Banerjee 2012; Current study**

Lion population structure

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

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

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

Lion group sizes in the Gir PA estimated in the present study were small in comparison to earlier reports (Joslin 1973; Chellam 1993; Singh 2007). This is likely due to a major shift in the modal prey size from large bodied cattle (> 300 kg) in 1960's to 1980's to a medium size chital (60 kg) in 2000's (Meena et al. 2011; Banerjee 2012; Banerjee et al. 2013; Gogoi 2015). 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 (*Panjrapole*s and *Gaushala*s) and temples spread across the landscape.

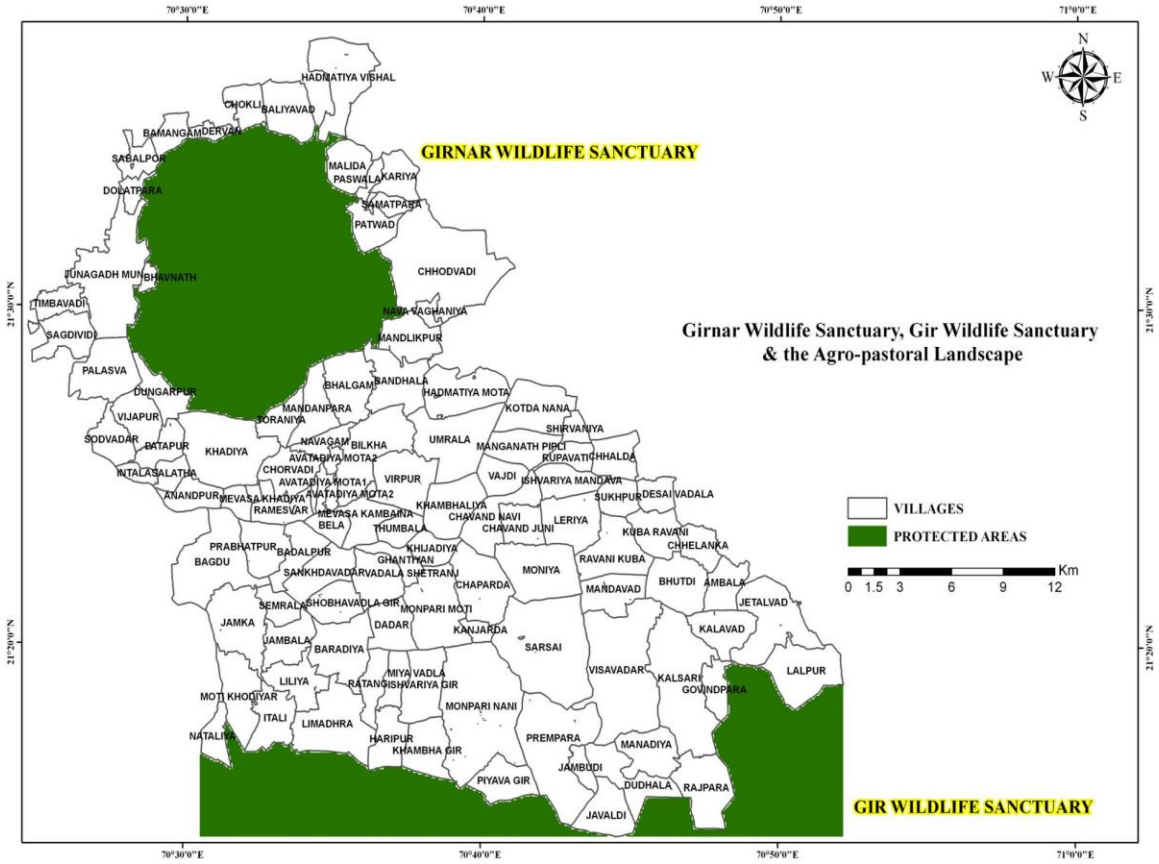
Population Viability Analysis of Girnar lions

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

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

The traditional land-use pattern in the Gir landscape is changing at an unprecedented rate. Agricultural intensification, sedentarization of pastoralism**,** diversification of livelihoods and land fragmentation through privatization of land tenure necessitate urgent strategic management interventions and legislations integrating the social, cultural and economic welfare of the region while simultaneously incorporating conservation of lions as an important goal in this landscape. The lion population is well protected within the Gir PA but its recent recolonization of human dominated landscape areas around the Gir PA has been a matter of concern as conservation is not the major land-use objective in these areas. A 1,400 km^2 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 *taluka*s) has been identified (**Figure 5.11**; Jhala et al. 2012a and chapter 6 of the current report) and has been proposed to manage as an '**eco-sensitive area**' (The Environment Protection Act 1986, Ministry of Environment and Forests, Govt. of India) so as to curtail adverse conversion of land uses to prevent further deterioration of this corridor habitat (Banerjee et al. 2010).

Figure 5.11: Location of Gir PA, Girnar forest and the connecting habitat corridor across the agro-pastoral landscape proposed as an eco-sensitive area



Based on the recommendations of this study, a part of the corrifor landscape (bordering Girnar) has already been declared as an 'eco-sensitive' by the GFD (Karn and Sahu 2014). However, the remaining part of the proposed landscape (boredering the Gir PA) needs to be declared eco-sensitive urgently with restrictions on high impact industry and mining activities. Infrastructure development needs to 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.

Factors governing the spatial distribution of lion in west Gir PA

Distribution of prey and tourism 'hot spot'

Lion spatial density was not explained by spatial density of the principal wild prey species, chital or sambar. Lion density was rather found to be higher near livestock carcass dumping yards. A similar pattern was observed by Banerjee et al. 2013 and Banerjee 2012 in the Gir east sanctuary and outside the Gir PA where lions at night frequently scavenge on the cattle carcasses dumped outside the human settlements. Live baiting is officially banned inside the Gir PA owing to ethical ground after 1995. However, lions in the western Gir PA which also coincided with the main tourism zone in the Gir PA were often fed with the carcasses (wild and domestic prey) by the GFD staff for maintaining their numbers and ensuring their locations for the high profile tourists visiting the park. Tourism hot spots tends to localise and habituate wildlife species to facilitate their observation. Lucrative attractants are provided to localize target specis around these areas, which is found to have significant ecological impact on the spatial distribution and habitat selection of wild animals (Massé et al. 2014). These animals are found to restrict their movements around these hotspots regardless of environmental conditions, habitat type or quality. These places are also found to have higher densities than naturally possible which might exceed their social carrying capacity and result in social strife (Massé et al. 2014). This practice of localizing lions by feeding them with carcasses was found to have the highest influence in determining the spatial density of lions in the region. This distribution pattern caused by providing easy food resources overrides the influence of natural prey and other ecological factors suggesting high local densities beyond what is ecologically possible at the study area of the western Gir. These would enhance tourist viewing but have serious implications on social organization of lions as well as enhanced predation pressure on wild prey in small pockets of artificially enhanced lion density.

CHAPTER VI

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

Introduction

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

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

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

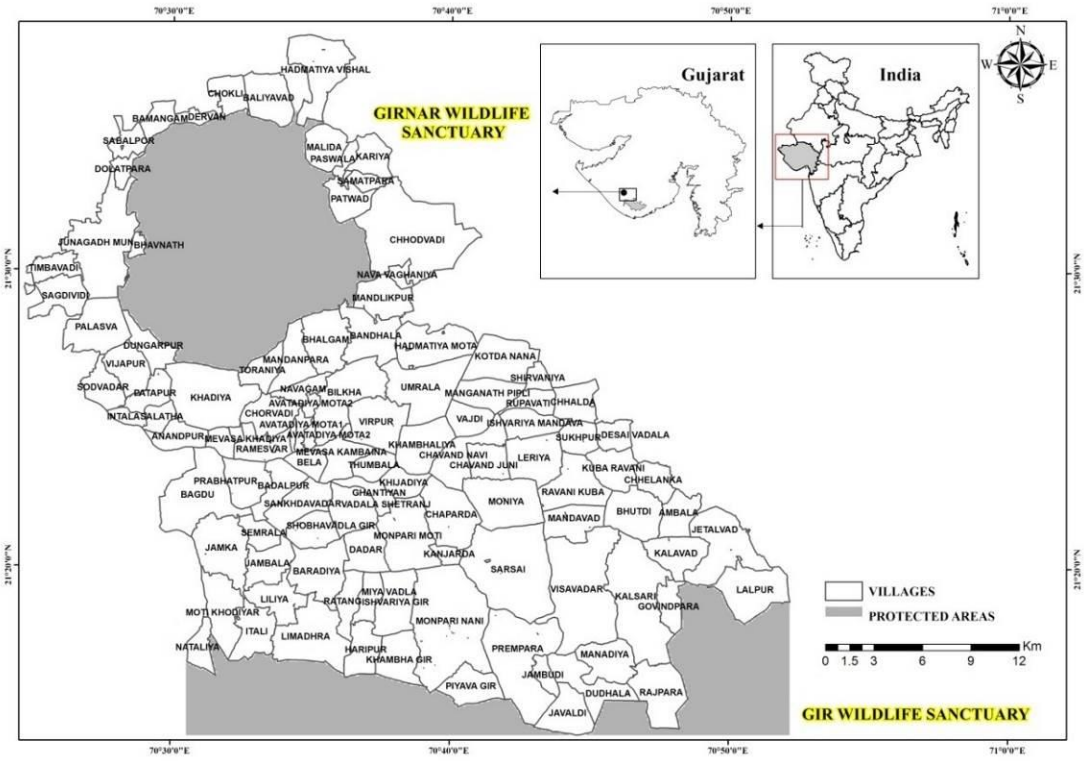
pilgrims each year, reduce the amount of available habitat for this increasing lion population. The approximate carrying capacity of Girnar as 25 individuals (a conservative estimate based on lion densities in Gir Protected Area; Jhala et al. 1999, 2004), natural barriers, anthropogenic disturbances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

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

Study Area

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

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



Methods

We used data from radio collared lions (n = 9) as species presence data to be used in Biomapper (Hirzel et al. 2006) predicting lion distribution in this landscape, identifying areas appropriate as passageways for the species in this sub optimal habitat. Biomapper uses ecological niche factor analysis (ENFA) to compute habitat suitability (HS) maps, and define the niche of a respective species based on few important habitat variables (Hirzel et al. 2002). The program has been used in studies on some terrestrial vertebrates (Dettki et al. 2003; Reutter et al. 2003; Brotons et al. 2004). We superimposed a 100m X 100m grid on the study area. The environmental variables in GIS format all pertain to the same geographic area, were extracted to grids to be useful in modeling method to predict environmental suitability for the species as a function of the given environmental variables. The grid size was considered suitable to obtain and understand habitat choice by lions and being sufficiently large to enable us to use freely available data sets on

environmental variables without compromising on spatial resolution. We extracted data of different eco-geographical variables such as Digital Elevation Model (DEM), Normalized Differential Vegetation Index (NDVI), Euclidean distance to available water sources, considering both the major rivers and dry river channels and Euclidean distance to major roadways as a disturbance factor to animal movement to model lion habitat use pattern and identifying crucial areas for corridor.

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

Results

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

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

species venture into development, they are less likely to do so during times of high human activity and occurred frequently in corridors, showing behavioral adjustments to habitat fragmentation and human activities.

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

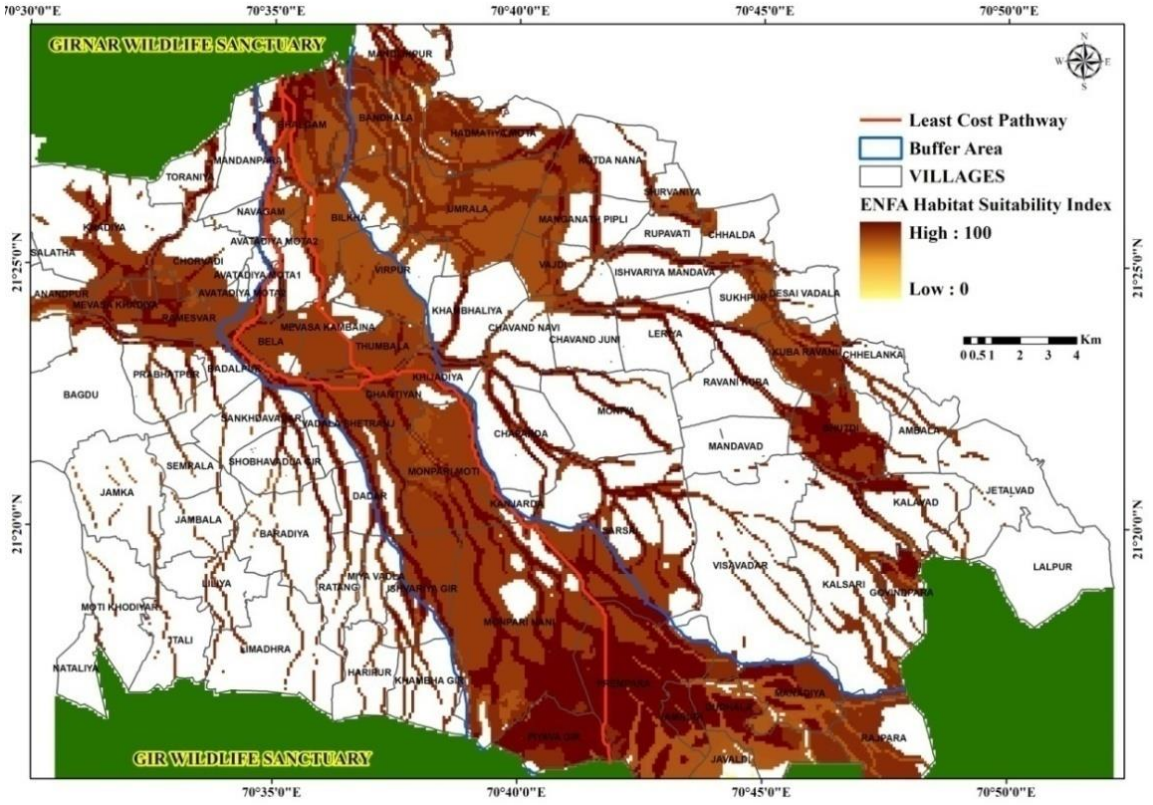


Table 6.1: List of villages within Gir-Girnar habitat corridor landscape

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

Discussion

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

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

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

The behaviour of species moving through the corridor within agricultural landscapes is expected to be influenced by the nature of the matrix, the type and spatial distribution of adjacent habitats, season, and interaction between same and other species. Wooded and shrubby

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

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

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

barriers to lion movements (industry, urban sprawl, linear infrastructure like highways, high agricultural boundary walls or power fences) are discouraged or appropriately mitigated so as not to compromise the corridor value of the habitat are essential. It would not be prudent to declare the corridor habitat as a Protected Area due to local livelihood dependencies, and it may not be needed, since lions are tolerant to traditional land-use practices. **However, based on WII's recommendations (Banerjee et al. 2010; Jhala et al. 2012a), some part of the corridor area (bordering Girnar WLS) is declared as an "ECOSENSITIVE" (under The Environment Protection Act 1986, by Gujarat Forest Department** (Karn and Sahu 2014) with restrictions on high impact industry and mining activities. However, the remaining part of the proposed landscape (boredering the Gir PA) needs to be declared eco-sensitive urgently. Infrastructure development needs to be kept at minimal and when essential should be mitigated with appropriate investments e.g. highways, roads, and railways need appropriately designed underpasses for wildlife, with funneling fences, sound and light barriers at strategic passage ways. Private property needs to remain permeable to wildlife movement, thus high walls, electric fences need to be restricted or designed for permeability of target species. Urban sprawl is difficult to regulate and can reduce the viability of the corridor significantly. The least cost corridor habitat currently passes through areas that have the least resistance to lion movement, declaring this as ecosensitive and by providing appropriate mitigation and incentives to local communities should assist in maintaining its permeability for future generations ensuring the metapopulation structure of lions in this landscape.

CHAPTER VII

LION DEMOGRAPHY

Introduction

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

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

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

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

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

Methodology

Data collection

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

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

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

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

Sex ratio

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

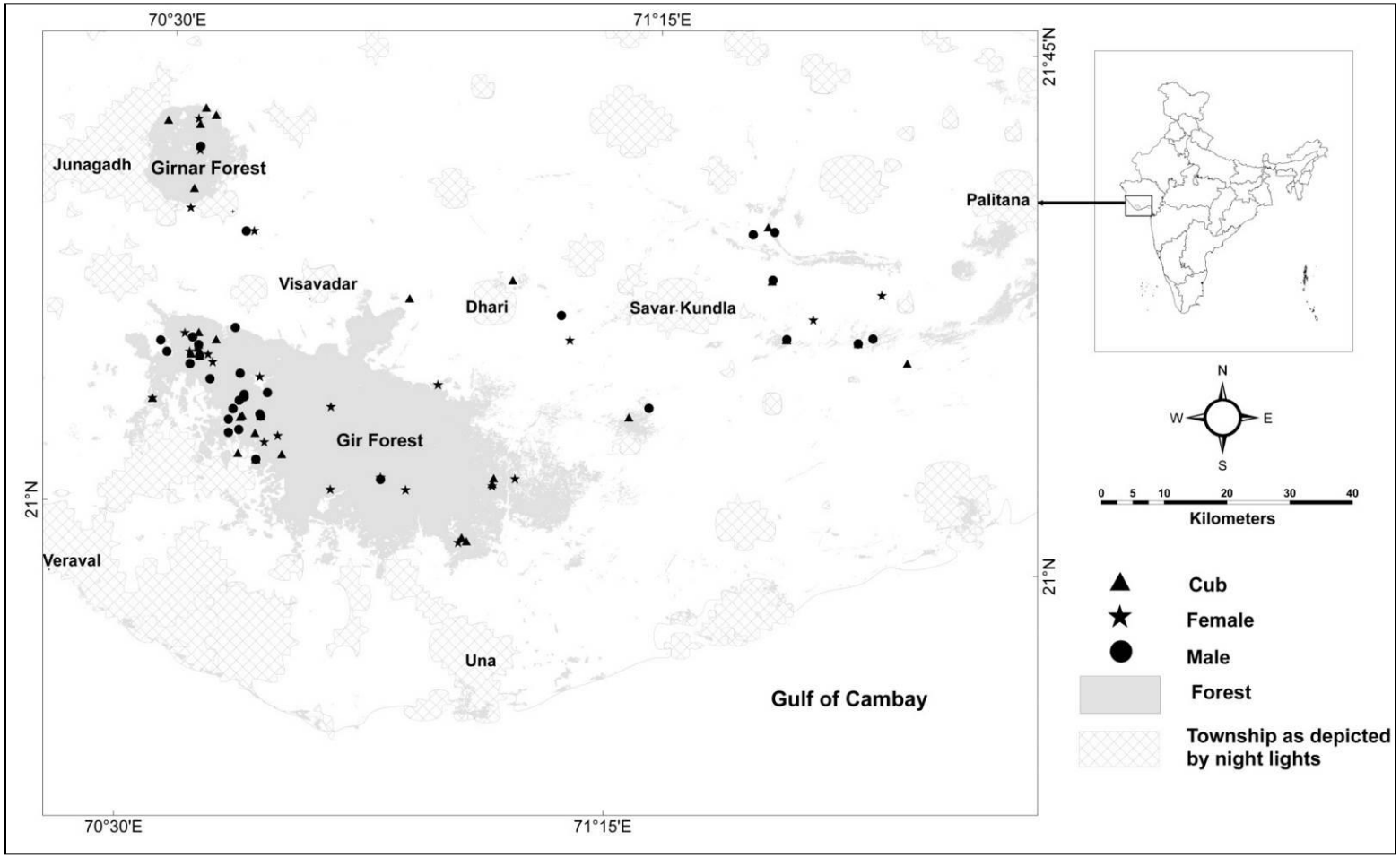
Reproduction and cub survival

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

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

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

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



Adult survivorship and annual mortality rate

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

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

non-overlapping confidence intervals on survival estimates were considered significantly different.

Realized rate of increase of Asiatic lion population

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

Comparing demographic parameters of African and Asiatic lions

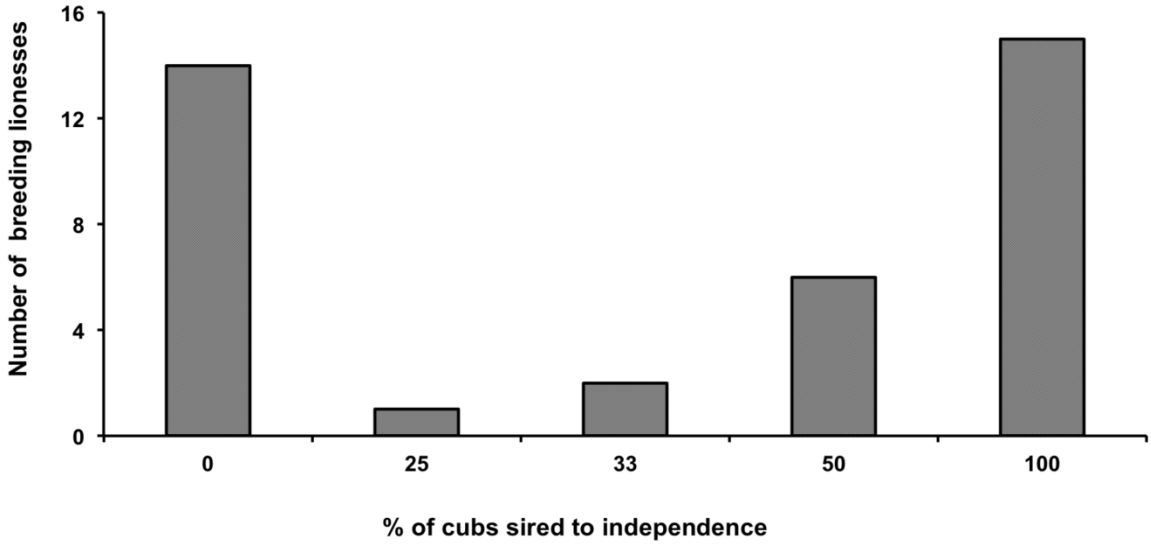
We surveyed published literature and obtained information from 19 studies on various demographic parameters of African lions. 95% confidence intervals on demographic parameters of Asiatic and African lions were constructed and considered them to be similar if the confidence intervals overlapped.

Results

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

39.66, P < 0.001). We could confirm age of first litter in seven lionesses which ranged from 4 to 5 years with an average age of 4.39 (SE 0.17) years. Of the 38 litters for which litter size was recorded with reasonable certainty, 12.7% had one cub, 50.9% had two cubs, 29.1% had three cubs, and 7.3% had four cubs. The average litter size was 2.39 (SE 0.12). Several lionesses were not successful at raising cubs to adulthood, while a few raised many (**Figure 7.2**).

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



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

Mortality of radio-collared lions (n = 8) was primarily natural (87.5%), mostly due to old age (50%) or intraspecific strife (33.3%). One radio-collared lioness died due to human causes (12.5%). Out of the 88 observed mortalities across the Gir Landscape inclusive of collared and non-collared lions, 54.5% were due to natural causes, 43.2% were due to human causes while the remaining 2.3% were due to unknown causes. A single episode of commercial poaching was responsible for 10.2% of the observed mortality while we observed retaliatory killing of lions due to livestock depredation twice (2.3%; **Figure 7. 4**).

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

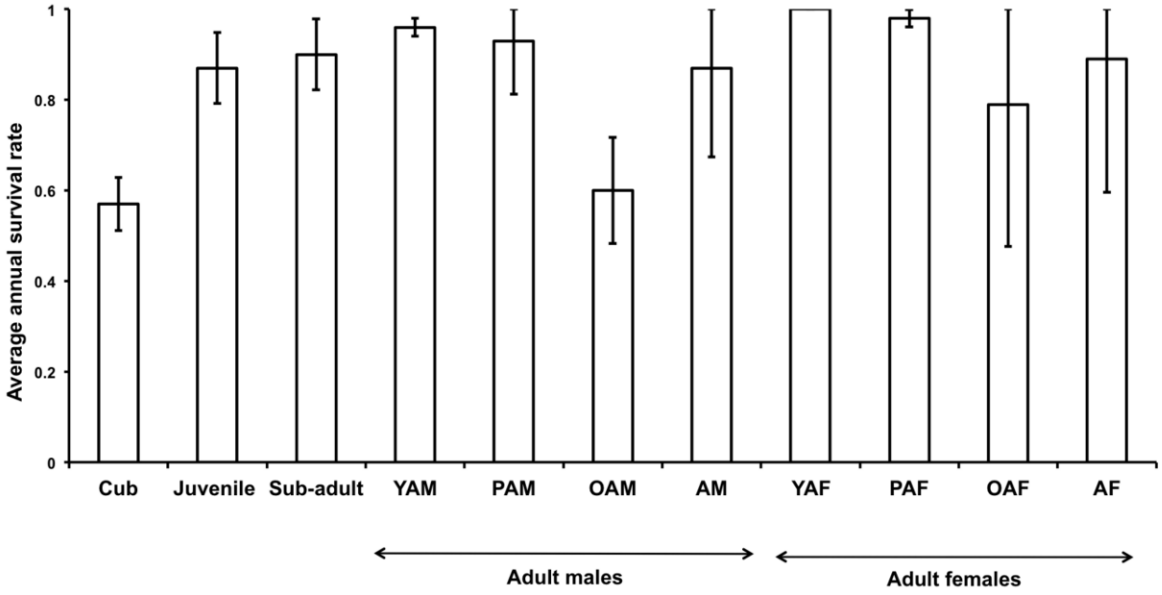


Figure 7.4: Cause specific mortality in Asiatic lions (n = 88) in the Gir Landscape between 2006 and 2010

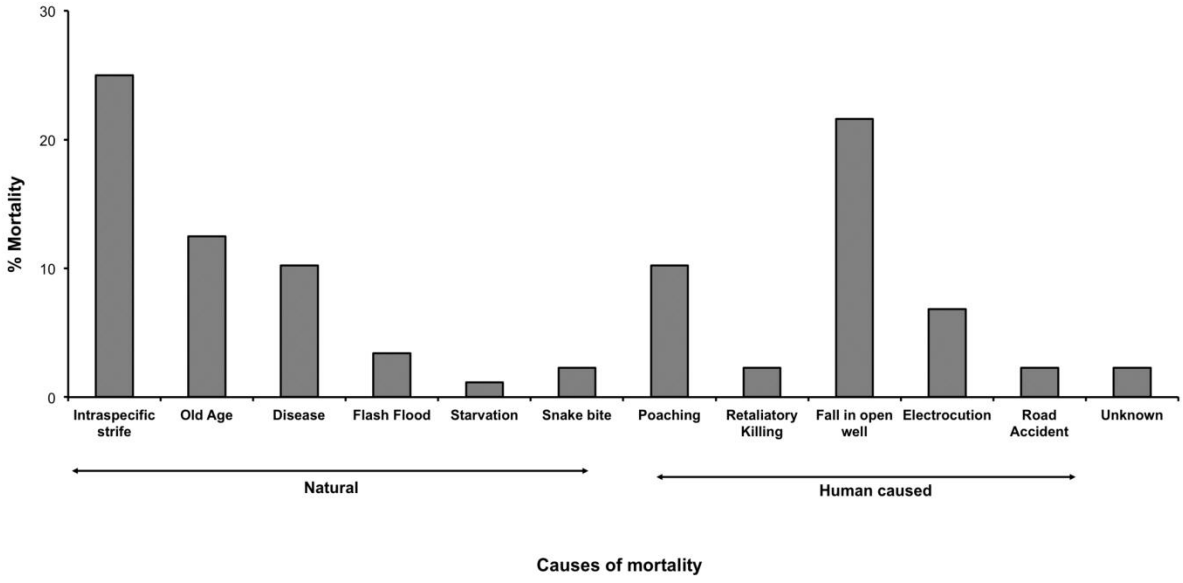


Table 7.1: Survival rates and cause specific mortality of Asiatic lions between 2000 and 2010 in the Gir Landscape, India.

Demographic Stage	Sample size	Average Annual Survival Rate (SE)	Annual Mortality Rates (SE)				Cohort-specific Span Survival Rate (SE)	Span Mortality Rates (SE)			
			Infanticides	Other natural causes	Human caused	Unknown		Infanticides	Other natural causes	Human caused	Unknown
Small cub (<6 m)	91	-	-	-	-	-	0.90 (0.03)	0.04 (0.01)	0.03 (0.01)	0.03 (0.01)	0
Large cub (6 m - 1 y)	83	-	-	-	-	-	0.63 (0.06)	0.27 (0.05)	0.07 (0.03)	0	0.03 (0.01)
Cub (1m - 1 y)	91	0.57 (0.03)	0.28 (0.05)	0.10 (0.03)	0.03 (0.01)	0.02 (0.01)	-	-	-	-	-
Juvenile (1-2 y)	56	0.87 (0.04)	0.09 (0.04)	0	0.04 (0.02)	-	-	-	-	-	-
Sub-adult (2-3 y)	42	0.90 (0.04)	0.05 (0.03)	0.03 (0.02)	0.02 (0.01)	-	-	-	-	-	-
Cub recruitment (birth-3 y)		0.51 (0.04)	0.30 (0.07)	0.13 (0.05)	0.06 (0.02)	-	-	-	-	-	-
Young adult male (3-5 y)	28	0.96 (0.01)	-	0.04 (0.01)	0	-	0.93 (0.004)	-	0.07 (0.001)	0	-
Young adult female (3-5 y)	15	1.00	-	0	0	-	1.00	-	0	0	-
Prime adult male (5-10 y)	28	0.93 (0.06)	-	0.05 (0.001)	0.02 (0.001)	-	0.66 (0.01)	-	0.29 (0.01)	0.05 (0.002)	-
Prime adult female (5-10 y)	24	0.98 (0.01)	-	0.01 (0.001)	0.01 (0.001)	-	0.93 (0. 03)	-	0.035 (0.003)	0.035 (0.003)	-

Old adult male (> 10 y)	15	0.60 (0.06)	-	0.40 (0.007)	0	-	0.06 (0.007)	-	0.94 (0.007)	0	-
Old adult 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)	-

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

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

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

Discussions

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

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

Location	Population Growth Rate (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)**	**Banerjee & Jhala 2012; Present study**

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

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

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

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

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

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

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

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

CHAPTER VIII

LION SPATIAL ORGANIZATION

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 we investigate ranging, movement and activity pattern of Gir lions and discuss their underlying ecological implications for long-term lion conservation.

Hypotheses and background of the chapter

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

source population (Gir PA) and at the same time providing dispersal opportunities by linking various satellite populations (Linkie et al. 2006). Gujarat is an economic progressive state with the annual growth rate of Gross Domestic Product being about 21% in the year 2011-12 (higher than India's national average of 7%) (http://planningcommission.nic.in, accessed August, 2012). The traditional land use pattern in the Gir landscape is changing at an unprecedented rate due to lopsided developments, agricultural intensifications, sedentarization of pastoralism and privatization of land ownerships. Understanding lion space use therefore becomes a significant tool for mitigating conflicts and planning long-term lion conservation policy (Gibbs et al. 1999).

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

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

Methodology

Field methods

Lion telemetry

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

Nineteen lions (11 males, 8 females) ranging between approximately 2.5 and 12 years, from different prides spaced throughout the Gir Landscape, were radio-collared (5 lions in the Gir PA, 4 lions in the Girnar Wildlife Sanctuary, one lion in Babra vidi and 9 lions in the eastern landscape) in between 2005 and 2016 **(Figure 8.1; Table 8.2)**. 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. GPS fixes obtained from seven additional lionesses radio collared in an earlier collaborative research project on lion population monitoring with GFD (Gir Monitoring; Jhala 2004) have also been re-analyzed for the current study to have a better understanding on lion spatial ecology.

Lions were anaesthetized using a combination of Ketamine hydrochloride (2.5 - 3 mg/kg body weight) and Meditomedine (0.04 - 0.06 mg/kg body weight; Kreeger 1996) injected intramuscularly using a gas powered projectile (Telinject Inc., CA, USA) dart delivery system. Reversal agent Atipamezole (0.05 - 0.1 mg/kg body weight) was used resulting in the total recovery of anaesthetized lions within 3 – 10 min. Anaesthetized lions were shaded or swabbed with water to prevent hyperthermia. Each lion's head was covered with a cloth to prevent damage to its dilated pupils and to minimize stress related to human presence. Each sedated lion was sexed, aged, measured, weighed, ecto-parasites collected and photographed according to standard protocol. Females were examined for evidence of recent lactation, as indicated by large pigmented nipples. Lions were classified into seven age categories (Jhala et al. 2004) based on body size, coloration, secondary sexual characteristics, tooth eruption and wear (Schaller 1972) [for detail see chapter 7 of the current report].

Lions were equipped with combination of VHF (n = 12; Telonics Inc., Arizona, USA and Wildlife Materials Inc. Illinois, USA), GPS (n = 12; HABIT Research Ltd., Victoria, Canada and Vectronics Aerospace GmbH, Berlin, Germany) and GPS Plus satellite (n = 2; Vectronics Aerospace GmbH, Berlin, Germany) radio collars. The collar weights were <1% of the body weight of the lions.

Data collection

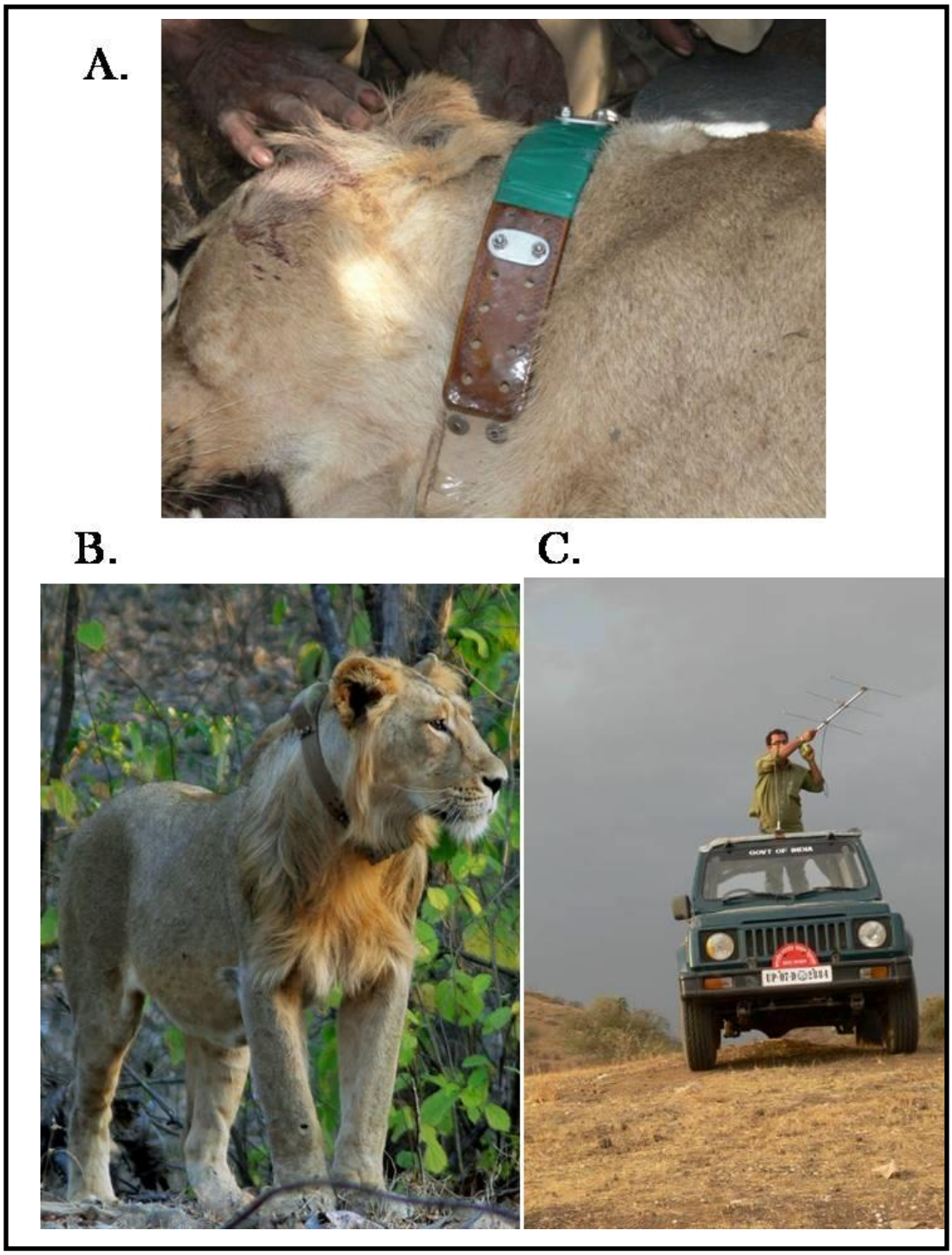
The radio collared lions were tracked and monitored on a fixed schedule to cover all time periods of the day either on foot or from a motorcycle or from a four wheel vehicle. As there was considerable distance between each of the satellite pockets and Gir, we spent a week in each month in each population and in Gir. The lions were tracked with the help of a hand held directional 3-element Yagi directional antennae with radio receivers (HABIT receiver model HR 2600, Telonics TR 2 receiver, Wildlife Materials TRX-1000S and Vectronics GPS Plus Handheld Terminal Unit) **(Figure 8.1)**. Attempts were made to locate at least one and when possible two animals on a daily basis. GPS fixes were recorded for locations of every lion. Lions were primarily located by homing in and direct sightings. Once activated, GPS and GPS-satellite collars provided 6-8 daily locations either via IRIDIUM (Iridium Communications Inc., McLean, VA, USA) two-way satellite network using low earth orbit satellites or via UHF (ultra high frequency) based ground download facility. The data from the GPS collars were downloaded at fixed intervals (generally once bi-weekly).

Continuous monitoring

We monitored each radio-collared lion continuously on foot and/or four-wheel drive for 30 sessions ranging from continuous 120 hours to 360 hours per session, seasonally. A total of 5,880 hours of monitoring data was analyzed to understand lion activity pattern and related ranging and movements. This methodology was similar to the all-occurrences sampling methodology (Altmann 1974) where specific animals were observed during 24- hour periods to record various ‘states’ and ‘events’. We defined a state (like moving, resting, sleeping, feeding, patrolling etc.) as any activity > 2 minute duration and measured them in time duration. We measured events (like urination, defecations, scent marking, roaring etc.) as frequencies. Although continuous monitoring was difficult to execute, it could be an efficient method to study feeding and consumption rates and behavior of large carnivores exhibiting a ‘starve-feed’ cycle

of several days (Schaller 1972; Jethva and Jhala 2004). During this duration, we kept lions in view or within 100

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



meter during the day and night. Lions were initially habituated for 1-3 days prior to data collection and care was taken not to disturb the 'normal' behavior of the lions. The observation teams were relayed so that everyone in the team got sufficient rest. We chose a continuous period of 10-12 days to incorporate 'starve-feed' cycle of large predators giving lions enough time to make/scavenge at least three major kills. We hoped to obtain data on at least two large kills and the associated behaviors and movement during this period, besides being able to get data on the smaller kills and be able to differentiate between predation, scavenging, and kleptoparasitism.

Data analysis

Initial data screening and classification

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

Minimum Sample size requirement and effects of autocorrelation

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

Kernohan et al. 2001). For 100% MCP sample size estimation, we randomized the locations and added 10 locations at every increment (Harris et al. 1990). We also computed the sample size adequacy for non-collared lions for estimating home range size.

The main debate related to the effects of autocorrelation on home range estimates is that autocorrelated observations yield less information than independent observations (Swihart and Slade 1985 a, b). When data are autocorrelated, the distance moved between consecutive observations decreases resulting in a lower proportion of the home range traversed. This causes an underestimation of home range size and movement rates. Most of the early literatures asserted independence of observations for an unbiased estimate of the Utilization Distribution (Worton 1987; Harris et al. 1990; White and Garrott 1990; Cresswell and Smith 1992; Kenward 1992). However, there is an unavoidable trade-off between sampling interval and sample size (Hansteen et al. 1997). As the time between locations becomes longer and data presumably become more useful for home range estimation, the number of locations that may be collected is inherently reduced. Since most of the telemetry studies are subject to fiscal and manpower constraints, an optimum combination of the number of animals (N) and the number of locations recorded per animal (n) should be conceived (Otis and White 1999). Eliminating autocorrelated fixes from the data set not only reduces the sample size, but may also limit the biological significance of the analysis (Reynolds and Laundre 1990). More recently it has been argued that in using only one fix per day, a great deal of biologically valuable information is lost (Börger et al. 2006). de Solla et al. (1999) emphasized that as long as the sampling remains systematic with the time interval between successive observations remaining relatively constant, autocorrelation should not reduce the validity of home range estimate. They further argued that with non-random fashion of movement of animals (Lair 1987), areas with autocorrelated observations are often associated with important resources (Weatherhead and Robertson 1990) and thus autocorrelated data are often required to sufficiently model animal movement and space use (Goodrich et al. 2010). In the current study along with home range estimates for lions, other ecological information like movement, feeding events and social behavior were inferred from the radio fixes. Therefore, we used all the GPS fixes from the GPS and satellite collars as they were recorded systematically at regular intervals causing no bias of higher or lower sampling by time on location. The sub-sampling was done only with the continuous monitoring dataset as spells of short interval

locations gave higher weigthage of of space use (fixed kernels) during this period compared to other locations.

Average lion home range (100% MCP) size was 419 km^2 **(Table 8.2)**. Diameter estimated after converting this into an equivalent sized circle was 23 km. Travelling with an average speed of 1.2 km/hr, it will take 19.2 hours by lions to traverse the entire home range from one end to other. We reanalyzed this after excluding all the lions outside the Gir PA and dispersing males within the Gir PA. The average home range size was estimated to be 63 km^2 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 19.2 or 7.9 hour interval was impractical; as substantial numbers of the study lions would have had deficient number of locations compelling their exclusion from the analysis, resulting in unrealistic values and loss of information. Therefore for our continuous monitoring dataset, we chose the fixed interval of three hours for diurnal fixes and two hours for the nocturnal locations for all subsequent analyses (de Solla et al. 1999).

Home range estimators

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

Recent advances in home range modeling culminated in the use of contouring methods for estimating complex probability density distributions (Dixon and Chapman 1980; Worton 1989). Kernel density estimation (KDE) is widely viewed as the most reliable contouring method

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

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

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

increments) until a single polygon home range (subjectivity by eye) was evident (Kie et al. 2010; Rodgers and Kie 2010).

Thus, the reference bandwidth was reduced to a fixed proportion of 0.60 in the current study for fixed kernel estimates.

We used Home Range Tools (HRT; Rodgers and Kie 2010) in ARCGIS 9.3 (ESRI, Redlands, CA: Environmental Systems Research Institute, USA) to calculate annual, diurnal, nocturnal and seasonal MCP and Fixed Kernel home ranges. Data from continuous monitoring on radio-collared lions and GPS fixes obtained from satellite/GPS collars at fixed intervals were analyzed to arrive at diurnal and nocturnal range use patterns. One-way ANOVA and t-tests were used to test the significance of differences in home range sizes between time of the day, seasons and gender (Zar 2010). Lions have been observed to venture inside villages at night. Therefore we did not exclude village areas from the home range calculation. However, townships with a human population of over 50,000 were subtracted from the analysis using habitat masking operation available in the GIS package.

Lion Core area estimation – inner and outer core

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). We considered 50% KDE isopleths as inner core area for the current study. However, given that different processes underlie space use patterns for different individuals and species, it is probably not valid to assume that an arbitrary rule will adequately define a core area. Rather, methods used to delineate animal space use patterns should have logic (Samuel et al. 1985). We used fixed kernel home ranges with isopleths at 5% increments from 5% to 100% (Powell 2000). We created area/probability curves by plotting the home range area within each isopleths as a function of the isopleths. Area/probability curves are typically concave, indicating clustered use of space (Bingham and Noon 1997; Seaman and Powell 1990; Burdett et al. 2007). The point at which inflection of line (slope) changed was identified as the outer core area (Powell 2000).

Lion land tenure system

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

Quantifying lion territoriality

Home ranges of conspecifics often overlap, sometimes extensively. Subsets of a population may exhibit different patterns of simultaneous use. Relatives, for example, may use their areas of overlap more than expected from random use, whereas nonrelatives may avoid each other and use areas of overlap less than expected. For large carnivores, territory defense is difficult or impossible to document but patterns of home range overlap can be documented (Mech 1970; Nicholson et al. 2011). Such patterns of overlap can often be used to deduce territorial behavior (Powell 2000).

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

Lion movement

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

periods for both males and females and compared between genders, periods of the day and landscape part.

Lion activity pattern

We used 5,880 hours of day and night continuous monitoring (30 sessions ranging from 120 hours to 360 hours) data on 20 radio-collared lions to understand lion time budget pattern. All-occurrence behaviour states (any mutually exclusive activity continuing for more than 2 minutes) and events **(Table 8.1)** of lions were recorded. The time of the day was divided into eight periods of three hours each and proportional time spent in different activities was calculated for each period. We also calculated the percentage of time spent by lions in different activities. The circular statistics software for Windows, Program Oriana version 3.0 (Andersen et al. 2000) was used to compute mean (95% CI) peak time for different activities. Comparisons were made among different lion demography classes and across seasons (dry and wet). We performed Rayleigh's uniformity test and Rao's spacing test (Mardia and Jupp 2000) to calculate the probability of the null hypothesis that the data is uniformly distributed across time intervals. A probability less than 0.05 indicated that the data showed a preferred time period.

Results

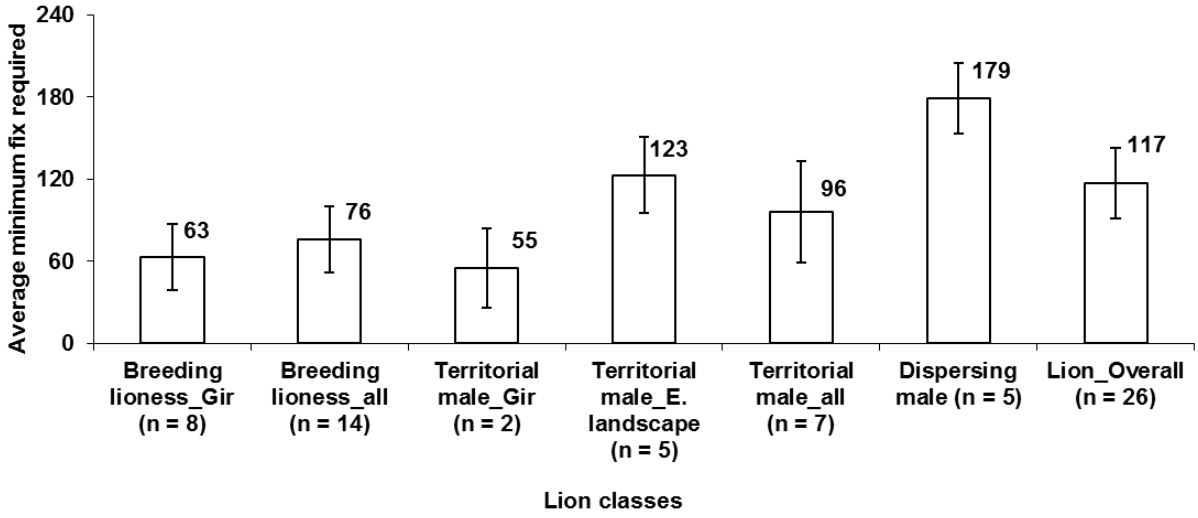
Sample Size Adequacy for Home Range Analysis

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

Lion home ranges

A mean of 769 (SE 197) locations (range 38 – 3,865) was used in the home range analysis (**Table 8.2**).

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



Within the Gir PA, territorial males had 3.6 times larger range (average 95% MCP 122 km^2) than breeding females (average 95% MCP 34 km^2; one tailed t = 3.19, df = 7, p = 0.007; **Figure 8.3i**). Dispersing males had 12 times larger range (average 95% MCP 436 km^2) than breeding females (one tailed t = 10.3, df = 8, p < 0.001) and 3.5 times higher range than territorial males (one tailed t = 3.6, df = 3, p = 0.02) within the Gir PA.

Breeding lionesses within the Gir PA had 7.5 times smaller ranges than the lionesses outside Gir [average 95% MCP 252 km^2] (one tailed t = -2.94, df = 12, p = 0.006; **Figure 8.3ii**).

The average single day home range (95% FK) size [10.4 (SE 3.2) km^2] was almost 3.5 times smaller than the average single night range sizes [36.2 (SE 12.4) km^2] (t = 2.36, df = 13, p = 0.03; **Table 8.3)**. Territorial males had larger night range sizes compared to day range sizes **(Table 8.3)** while breeding females and dispersing males had similar day and night ranges.

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

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

Behaviour states and events	Definition
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.

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

Lion ID	Gender	Demography Class	Part of the Landscape	Monitoring Period	100 MCP	95 MCP	50 MCP	95 FK	Outer Core (85 FK)	Inner Core (50 FK)	Collar type	Fixes (n)	Fate
Gir Protected Area													
Poornima	F	Breeding Female	Gir East Sanctuary	2001 - 2005	86	60	26	83	49	17	VHF	356	Dead
Jamri	F	Breeding Female	Gir East Sanctuary	2001 - 2007	33	30	10	32	23	9	VHF	351	Dead
Ramzana	F	Breeding Female	Gir West Sanctuary	2001 - 2009	45	38	12	10	3	1	VHF	783	Dead
Sukhi	F	Breeding Female	Gir West Sanctuary	2001 - 2002	24	22	3	37	19	6	VHF	96	Dead
Sonal	F	Breeding Female	Gir East Sanctuary	2002 - 2004	11	8	5	19	12	4	VHF	40	Dead
Kankawati	F	Breeding Female	Central Gir	2002 - 2004	19	7	1	11	6	2	VHF	108	Dead
Devrani	F	Breeding Female	Devalia Safari Park	2002 - 2005	4	4	-	-	-	-	VHF	38	Dead
Patarariya	M	Dispersing Male	Central Gir	2005 -2012	395	363	30	211	120	43	Satellite-GPS	382	Collar Dropped, Unknown
Kamleshwar I	M	Territorial Male	Gir West Sanctuary	2005 - 2013	76	73	8	95	51	14	VHF	140	Dead
Bhuatirath	M	Dispersing Male	Central Gir	2005 - 2009	425	389	33	355	213	64	GPS	183	Dead
Kamleshwar II	M	Dispersing Male	Gir West Sanctuary	2010 - 2012	975	557	153	635	333	78	GPS	2,776	Collar Dropped, Unknown
Mundachowk	**F**	**Breeding Female**	**Central Gir**	**2015 - ongoing**	**157**	**70**	**16**	**56**	**45**	**14**	**GPS**	**643**	**Alive**
Outside Gir PA													
Ranigalo	M	Territorial Male	Eastern Landscape	2008 - 2010	1,889	821	22	951	488	77	GPS	230	Dead

Chandgadh	M	Dispersing Male	Eastern Landscape	2008 - 2010	1,688	1,400	218	866	469	115	GPS	1,216	Dead
Jambudi	F	Breeding Female	Girnar	2008 - 2014	142	120	19	132	84	26	VHF	166	Collar Battery Exhausted, Alive
Dholikui	M	Territorial Male	Eastern Landscape	2008 - 2009	942	909	73	991	558	129	VHF	168	Dead
Krakanch I	F	Breeding Female	Eastern Landscape	2008 - 2012	417	311	128	377	242	78	VHF	153	Collar Battery Exhausted, Alive
Jambudi	M	Territorial Male	Girnar	2009 - 2011	252	227	66	222	137	45	GPS	337	Collar Dropped, Unknown
Morapani	F	Breeding Female	Girnar	2009 - 2012	203	144	127	217	153	58	VHF	180	Collar Battery Exhausted, Alive
Ramnath	M	Territorial Male	Girnar	2010 - 2013	1,126	342	100	343	190	54	GPS	2,362	Collar Dropped, Unknown
Ambardi	M	Dispersing Male	Eastern Landscape	2010	374	121	69	195	142	32	Satellite-GPS	386	Dead
Lhasa	**F**	**Breeding Female**	**Eastern Landscape**	**2014 - ongoing**	**100**	**60**	**11**	**44**	**25**	**6**	**GPS**	**3,865**	**Alive**
Krakanch II	**F**	**Breeding Female**	**Eastern Landscape**	**2014 - ongoing**	**671**	**642**	**153**	**593**	**404**	**136**	**GPS**	**669**	**Alive**
Ingorala	**F**	**Breeding Female**	**Eastern Landscape**	**2014 - ongoing**	**347**	**303**	**67**	**250**	**160**	**49**	**GPS**	**2,191**	**Alive**
Jabal	**F**	**Breeding Female**	**Eastern Landscape**	**2014 - ongoing**	**303**	**184**	**69**	**106**	**48**	**8**	**GPS**	**1,922**	**Alive**
Babra	M	Territorial Male	Babra Vidi	2016	178	170	25	151	79	13	GPS	263	Collar removed, **Alive**

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

Lion demography class	Diurnal home range (km^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 8.4: Seasonal home range sizes (km^2) of Asiatic lions in Gir landscape, Gujarat, India. 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	
Chandgadh Male	Eastern landscape	696	612	389	881	678	643	--
Dholikui Male	Eastern landscape	851	1,392	931	523	480	287	--
Jambudi Male	Girnar	243	224	138	98	181	123	--
Jambudi Lioness	Girnar	130	151	102	59	68	44	--
Morapani Lioness	Girnar	204	207	143	26	83	54	--
Krakanch Female I	Eastern landscape	170	267	232	169	326	302	--
Kamleshwar Male II	Gir PA	599	378	338	314	410	365	--
Kamleshwar Male I	Gir PA	54	79	70	68	101	92	--
Ranigalo Male	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 8.3 (i): 95% MCP home ranges (km^2) of Asiatic lions across the agro-pastoral Gir landscape, Gujarat, India.

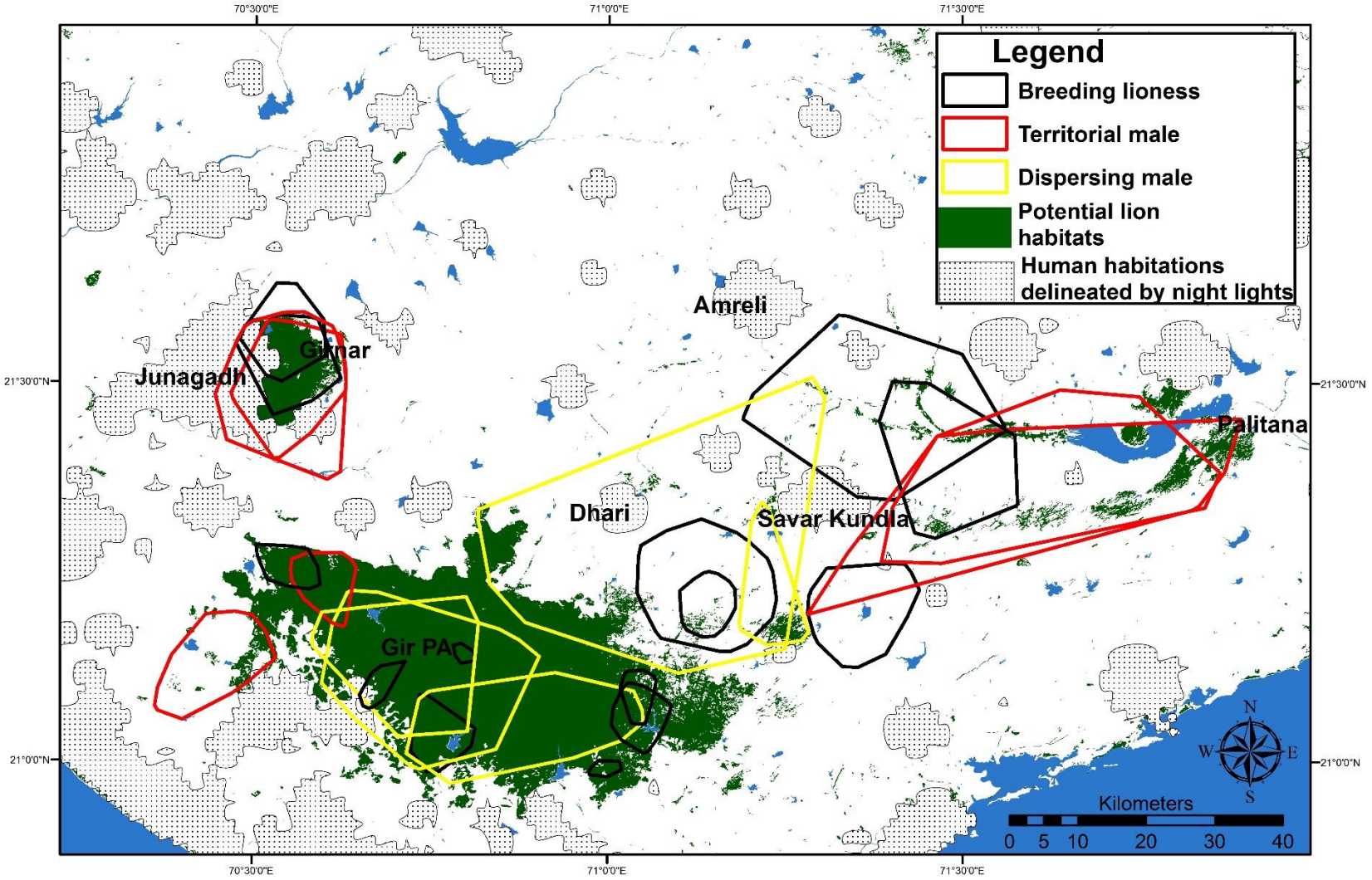
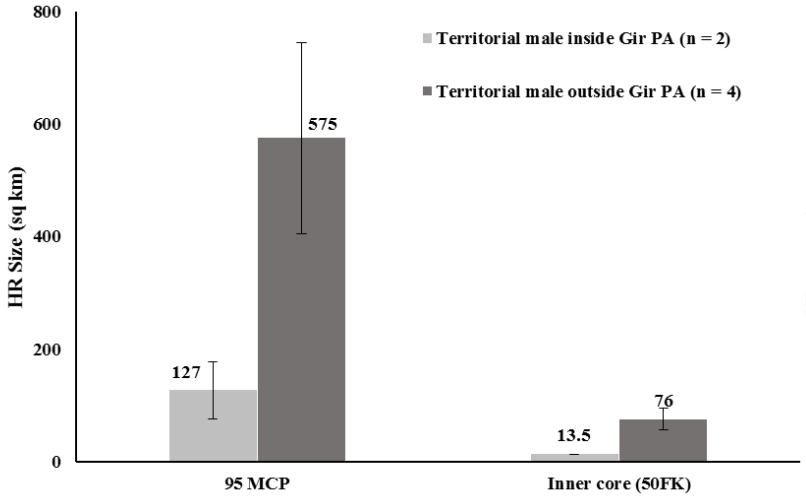
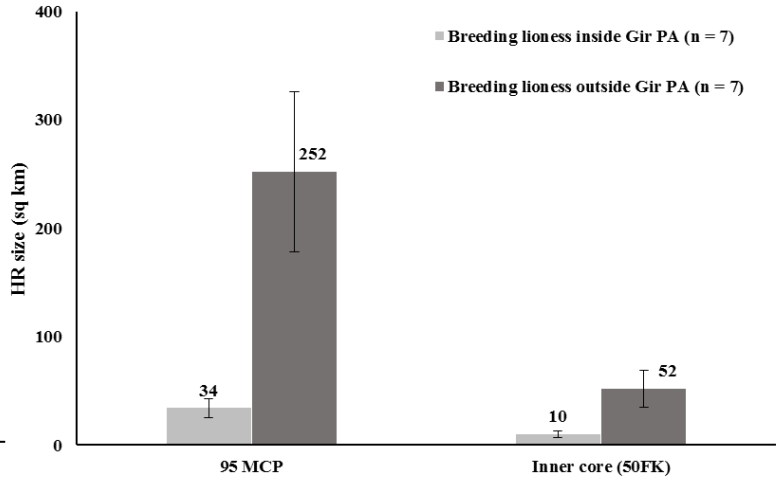


Figure 8.3 (ii): Graphs showing differences of home range sizes (95% MCP) and core areas of territorial males, breeding lionesses and dispersing males in between Gir PA and outside the Gir PA.

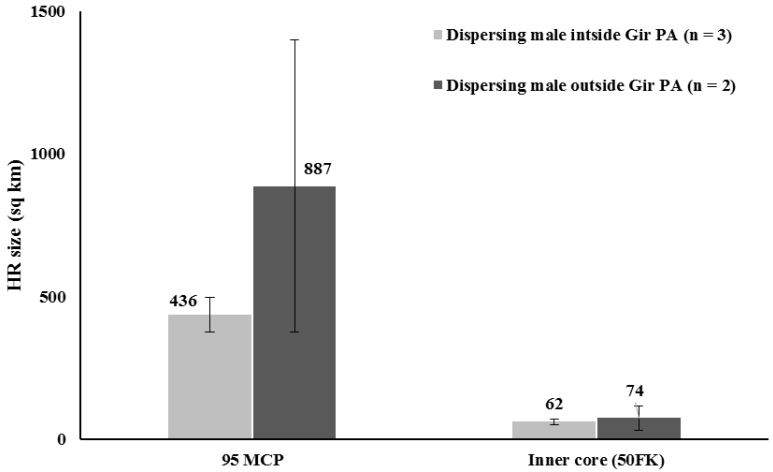
Territorial male



Breeding lioness



Dispersing male

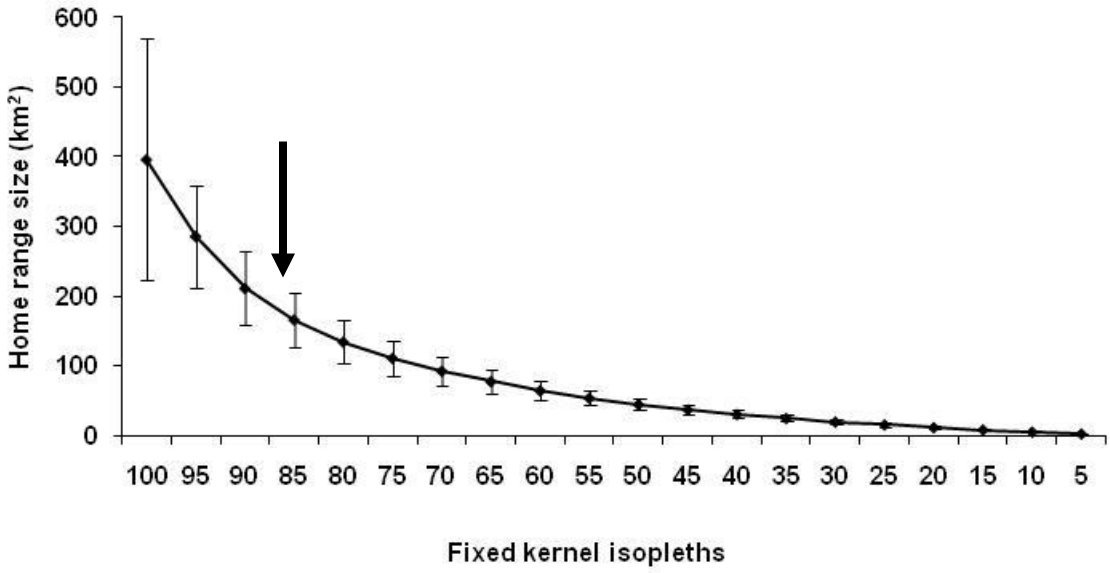


Average single day home range (95% FK) size [10.4 (SE 3.2) km^2] was almost 3.5 times smaller than the average single night range sizes [36.2 (SE 12.4) km^2] ($t = 2.36$, $df = 13$, $p = 0.03$; **Table 8.3)**. Territorial males had larger night range sizes compared to day range sizes **(Table 8.3)** while breeding females and dispersing males had similar day and night ranges.

Outer and inner core area estimation

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

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



Within the Gir PA, average (SE) outer and inner core areas of lions were estimated to be 79 (29) km^2 and 22 (7) km^2 **(Figure 8.5, Table 8.2)**. Average core areas for breeding lionesses inside the Gir PA [10 (SE 3) km^2] were smaller than those for the lionesses outside the Gir PA [52 (SE 17) km^2] (**Figure 8.3 ii**). However, dispersing males outside and inside the Gir PA had almost similar core areas (**Figure 8.3ii**).

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

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

Lion land tenure system

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

Figure 8.5: Google Earth image of the lion inner core areas (km^2) [50% fixed kernels] in the Gir landscape, Gujarat, India. Red, black and yellow polygons represent core areas of the territorial males, breeding lionesses and dispersing males respectively. Lion core areas outside the Gir PA are spread along broken terrains and dry river networks characterized by *Prosopis juliflora* thickets.

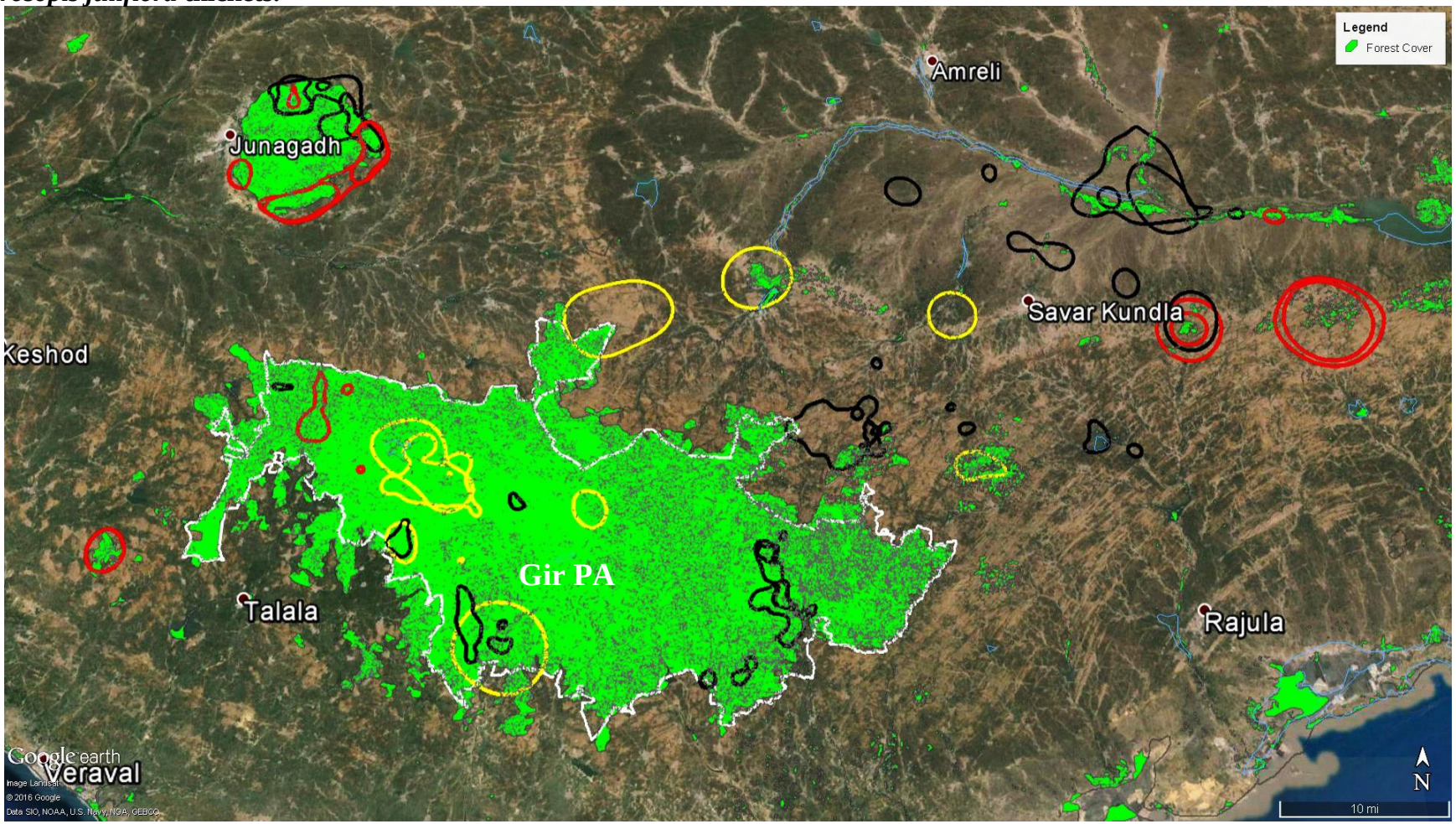
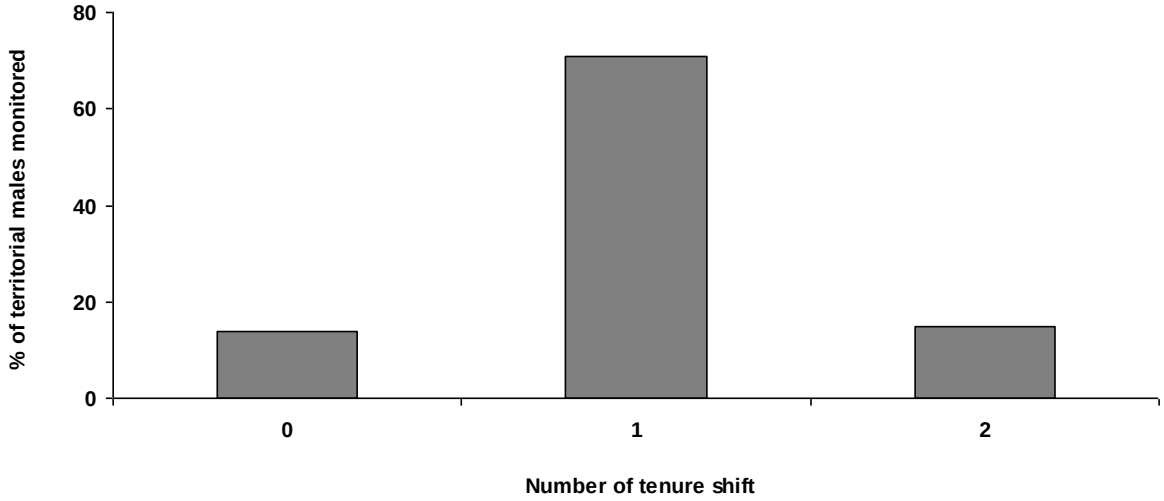


Table 8.5: Land tenure duration and distances between successive territories of adult male Asiatic lions.

Male ID	Part of the landscape	Tenure I duration (months)	Distance (km) between Tenure I & Tenure II	Minimum number of Cubs successfully sired to sub-adult stage	Tenure II duration (months)	Distance (km) between Tenure II & Tenure III	Minimum number of Cubs successfully sired to sub-adult stage	Tenure III duration (months)	Minimum number of Cubs successfully sired to sub-adult stage
Bhuatirath Male	Gir PA	23	22.8	3	30	--	4	--	--
Chandgadh Male	Eastern landscape	29	40.4	0	14**	--	5**	--	--
Kamleshwar Male	Gir PA	44	7.5	5	10***	9.2	--	60	12
Kapuria Male	Gir PA	29	8.3	3	48	--	10	--	--
Ranigalo Male	Eastern landscape	43	44.1	4	24	--	0****	--	--
Dholikui Male II	Eastern landscape	29	27.1	2	18	30.5	4	7	--
Nani Vadal Male	Eastern landscape	56	--	5	--	--	--	--	--

**Chandgadh male 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. ***Kamleshwar male 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. ****Ranigalo male became a nomad during his tenure II after losing a territorial strife with Dholikui male II and losing his coalition partner (Dholikui male I) and could not further breed with lionesses until he died after 24 months.

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



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

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

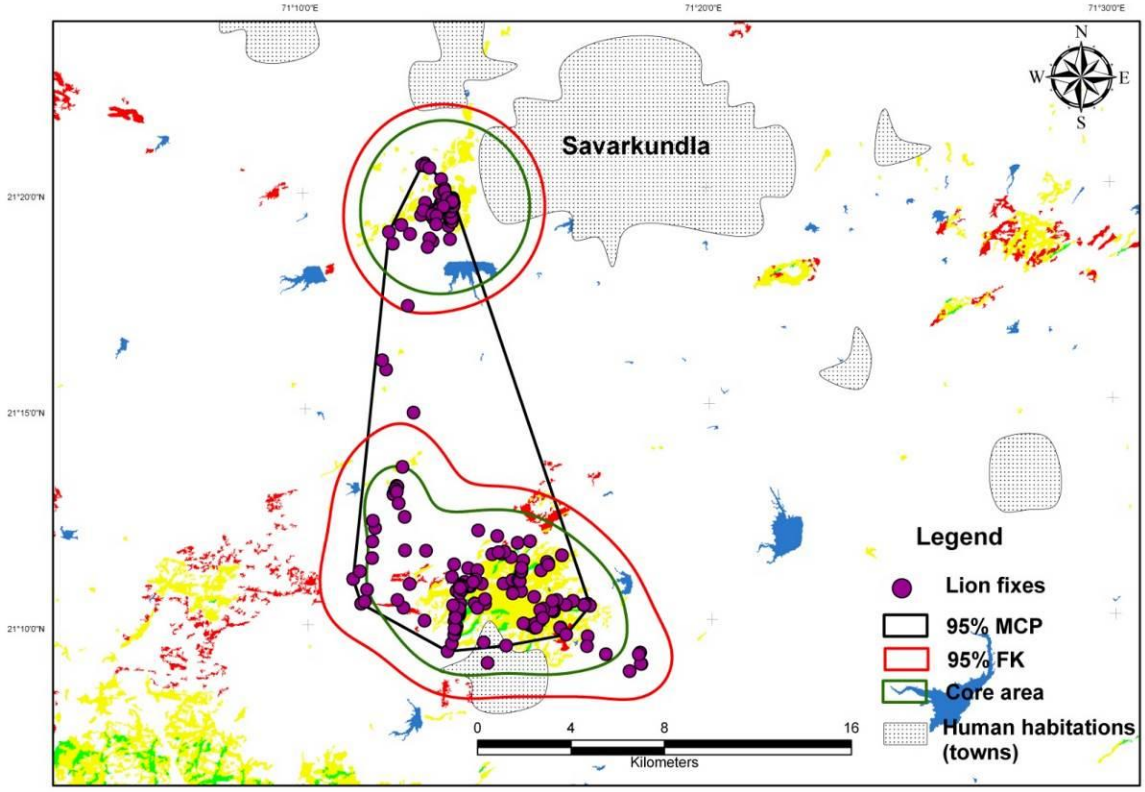
Male ID	Part of landscape	Age (year) at dispersal	Dispersal distance (km)	Age (year) of 1st reproduction
Jambudi Male	Girnar	3.7	9.9	4
Kamleshwar Male II	Gir PA	4	25.7	4.5
Patarariya Male	Gir PA	4.2	12.3	4.5

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

Male ranging and land tenure system

Ambardi male: 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 8.7)**. The male was part of a three male coalition. The range size (95% FK) of the male was estimated to be 195 km^2 **(Table 8.2)** and showed range overlap with other radio-collared lions of the region. The male sustained a severe injury on his face and leg in March 2010 due to territorial fight with other two males of another coalition and was taken to Sakkarbaug Zoo, Junagadh for treatment but succumbed to his injuries on 23rd March, 2010.

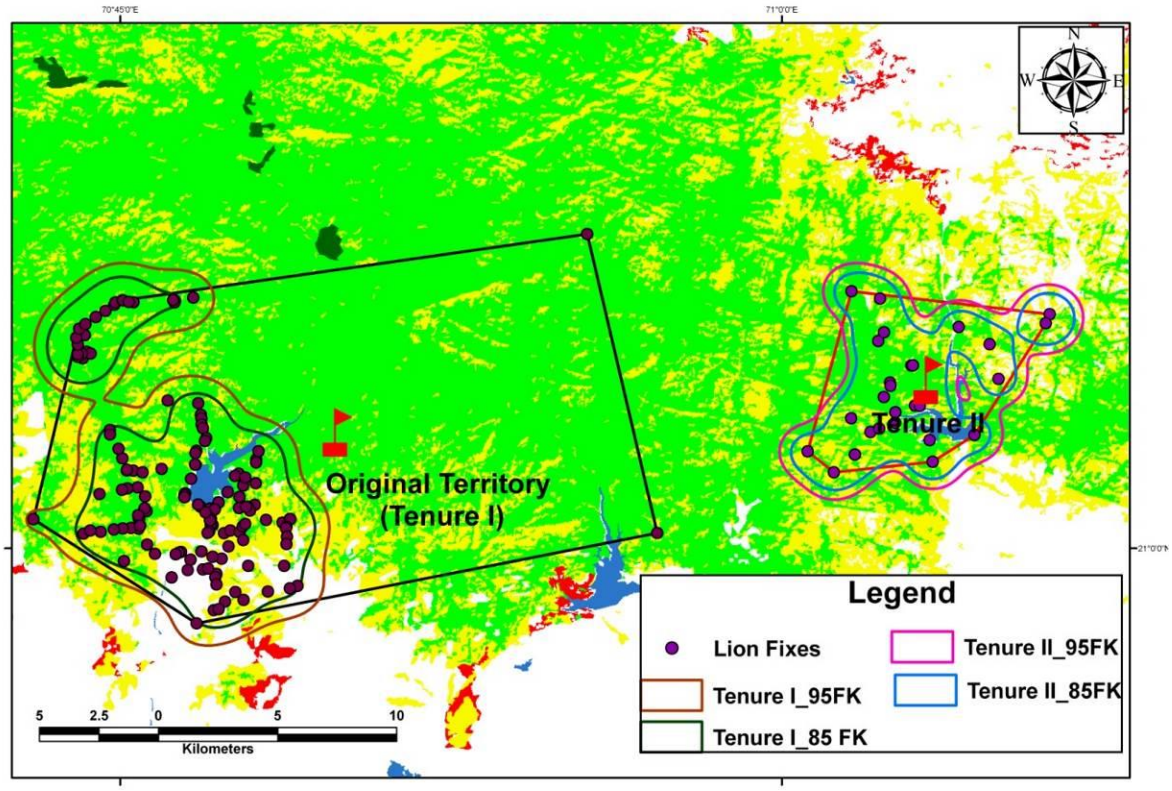
Figure 8.7: Ranging pattern of radio-collared Ambardi male. Extent of major human habitations demarcated by using night light satellite data.



Bhuatirath male: Bhuatirath 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 Bhuatirath male started nomadic movement. In April 2007 the male permanently dispersed to the eastern part of the Gir sanctuary and roamed mostly in and Tulsishyam and Jasadhar areas. It often ranged in the revenue areas of Khambha and Dhokadwa **(Figure 8.8)**. After spending few months of nomadic life, M2 further dispersed to the north-eastern part of the sanctuary (Hadala, Bankajambu) and once again became territorial. On one occasion the male was even observed to share a kill with three other males. During his tenure II, the male sired at least four cubs successfully to sub-adulthood near Bhimchas, Hadala part. The male died of old age in winter 2009 **(Table 8.5)**.

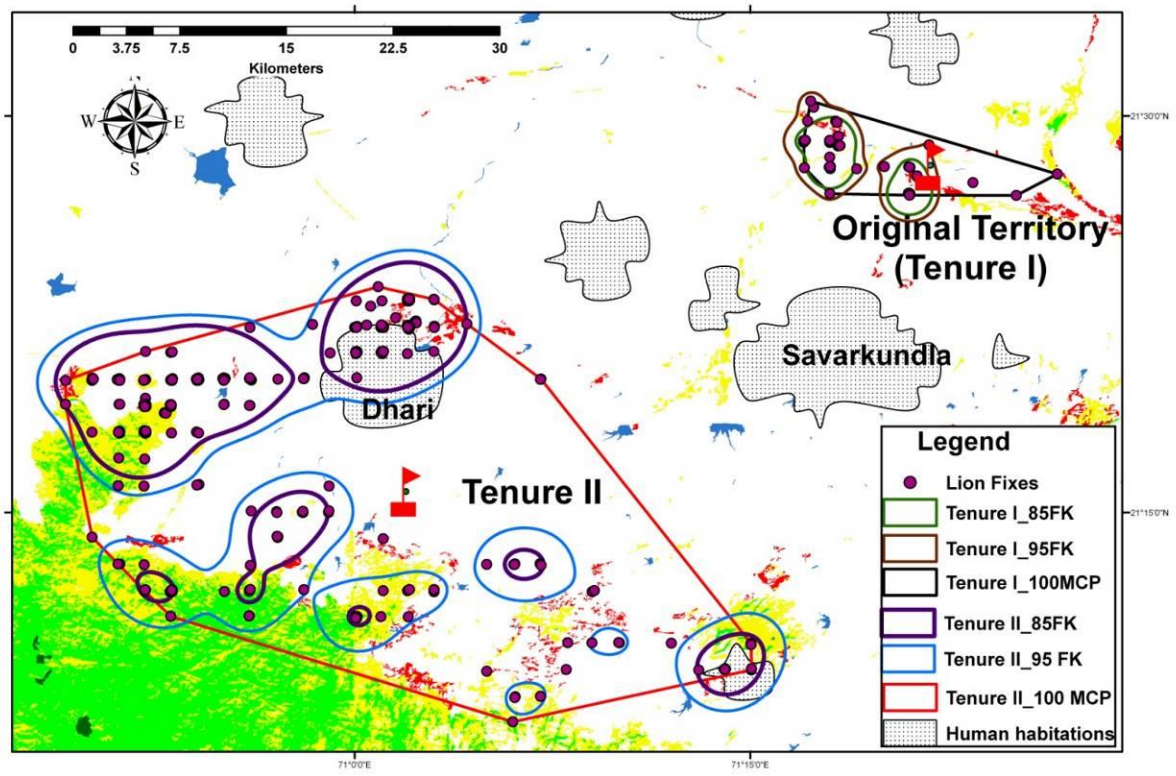
Figure 8.8: Tenure shift of prime adult Bhuatirath male in the Gir PA, India. Tenure centroids shown by flags.



<u>Chandgadh male:</u> 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 outskirt of village Chandgadh, Amreli. The male was long ranging (**Table 8.2, Figure 8.9**) with regular movement to the Gir

PA. The male ranged in the human-dominated landscape of Amreli, Savarkundla, Chalala, Khambha, Dhari and Visavadar. The landscape was characterized by farmlands, human settlements, industry, mining and government wastelands. The male after dispersing to Dhari and Visvadar (Tenure II) became territorial as he settled down with Ambardi pride, mated and gave birth to cubs. The male was seen with five cubs regularly during 2009-2010 **(Table 8.5)**. The collar failed in August 2009 and the male died due to old age in May 2010 at the Jasadhar Animal Rescue Centre when the cubs were juveniles and all surviving.

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



<u>Ranigalo, Dholikui and Nani Vadal male coalitions:</u> 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 (Dholikui male), 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 (Dholikui male II and his partner). Nani Vadal male was a non-collared prime adult male (approximately 7 years old) whom we monitored for four years on the basis of vibrissae pattern. These males had large territories ranging from Mitiyala to Palitana along the private and government owned grasslands and revenue village lands of Khambha, Savarkundla, Palitana, Mahuva and Gariadhar talukas of Amreli and Bhavnagar districts (**Table 8.2, Figure 8.10**). Ranigalo and Dholikui males stayed together for most of the time and had 64% overlap of their range and 100% overlap of their core areas. Nani Vadal male on the other hand ranged mostly in the Nani Vadal *vidi* near Savarkundla. Ranigalo and Dholikui males successfully sired four cubs to sub-adulthood while Nani Vadal male successfully sired five cubs to sub-adulthood. After losing his coalition partner (Dholikui male), Ranigalo male dispersed from Ranigalo-Dholikui Reserve Forest further north-east in the revenue landscapes of Bagdana and Talaja and finally to the areas of Sihor and Songadh **(Figure 8.11)**. We lost contact with this male after February 2011. However, Nani Vadal male continued to range in the Nani Vadal area for quite sometime.

Figure 8.10: Ranging of Ranigalo, Dholikui and Nani Vadal coalition males across the human-dominated eastern landscape. Human habitations demarcated by using night light satellite data.

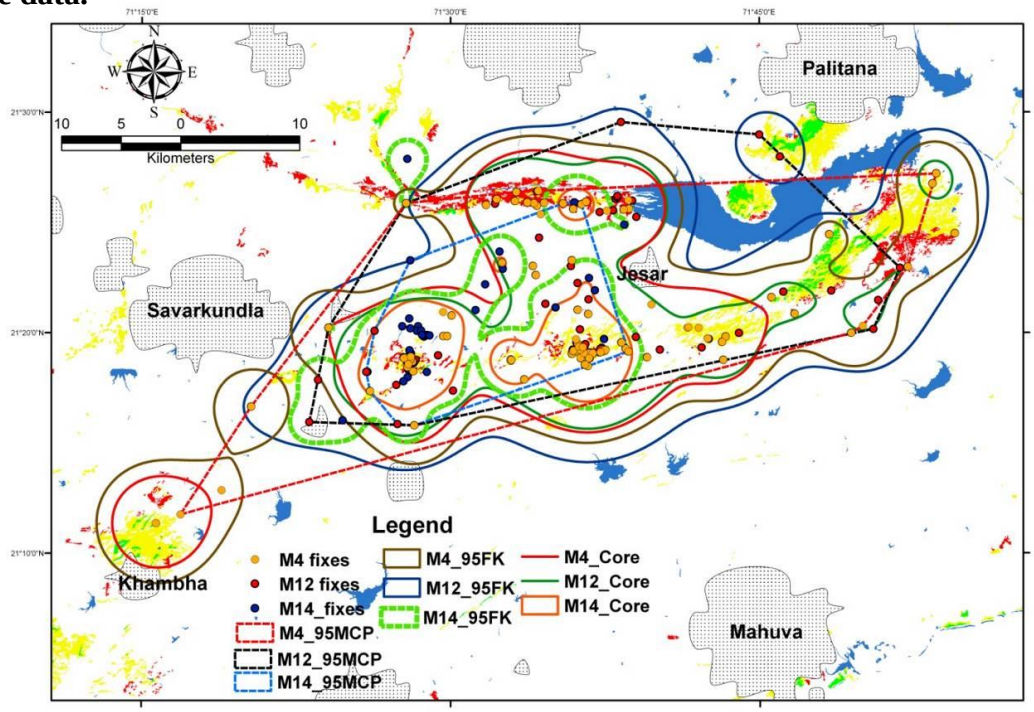
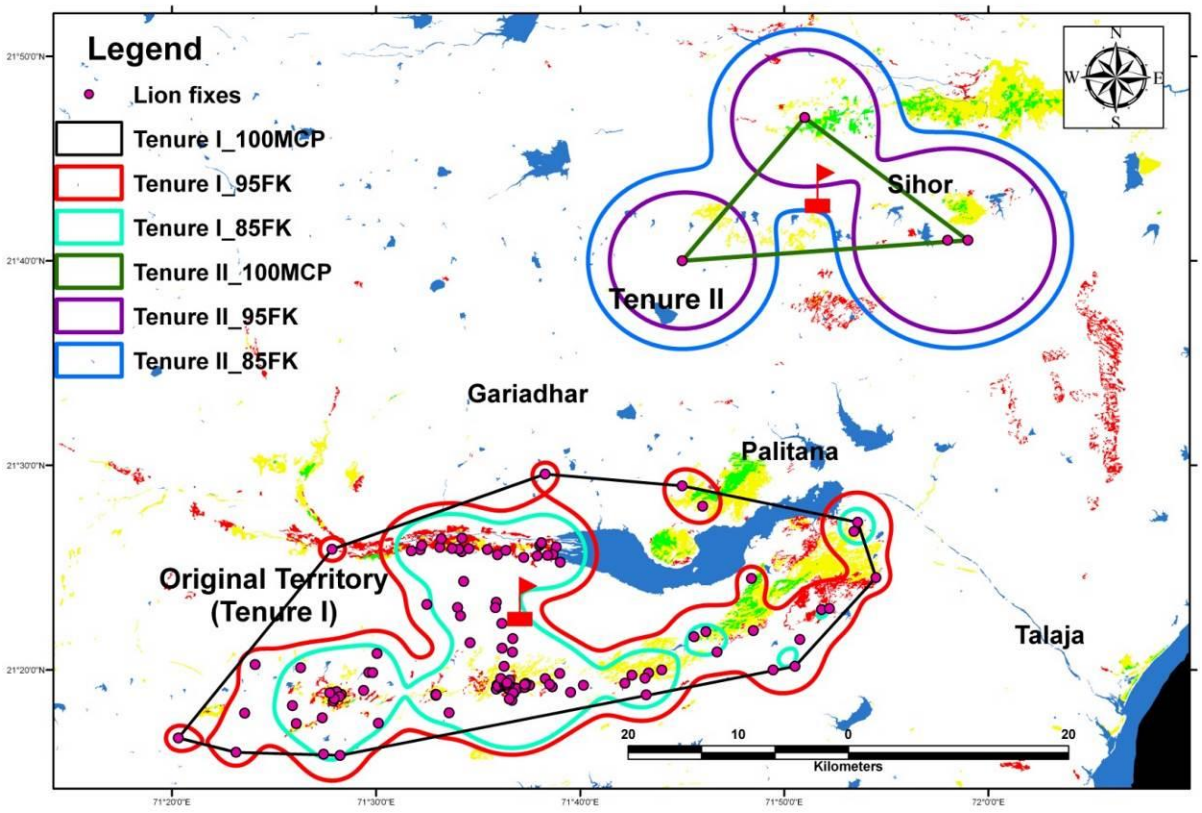


Figure 8.11: Tenure shift of prime adult Ranigalo male in the eastern landscape. Tenure centroids shown by flags.



Jambudi male: Jambudi male 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 (Ramnath male) established territory in the south-eastern part of the sanctuary **(Figure 8.12)**. The dispersal distance was estimated to be 10 km **(Table 8.6)**. The male often ventured into the revenue areas of Junagadh, Visavdar, Bhesan and Mendarda talukas.

Kamleshwar male II: Kamleshwar male II 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 8.13**). This male and his coalition partners dispersed about 26 km from their natal territory and established new territory in central and eastern Gir **(Figure 8.14)**. The collar stopped working in August 2010. However occasional monitoring of the male was continued until January 2012.

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

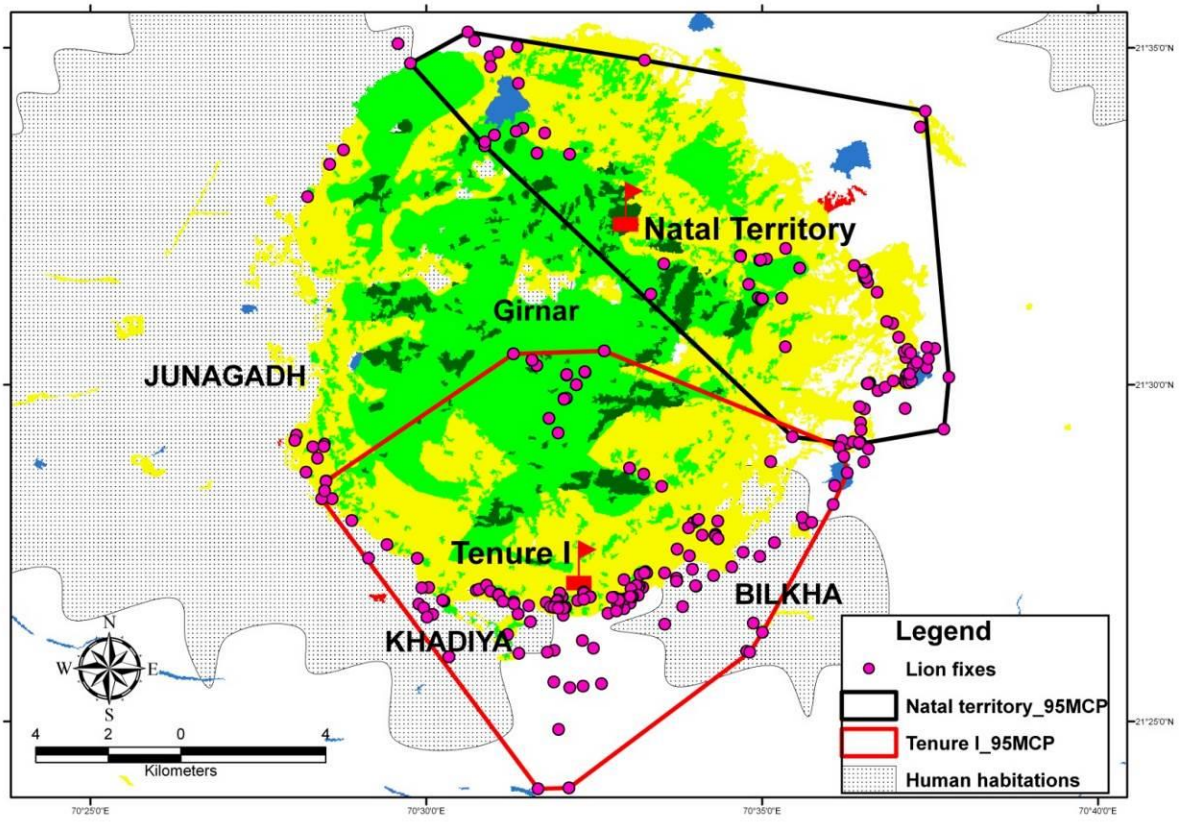


Figure 8.13: Range use and dispersal of Kamleshwar male II within the Gir PA, India.

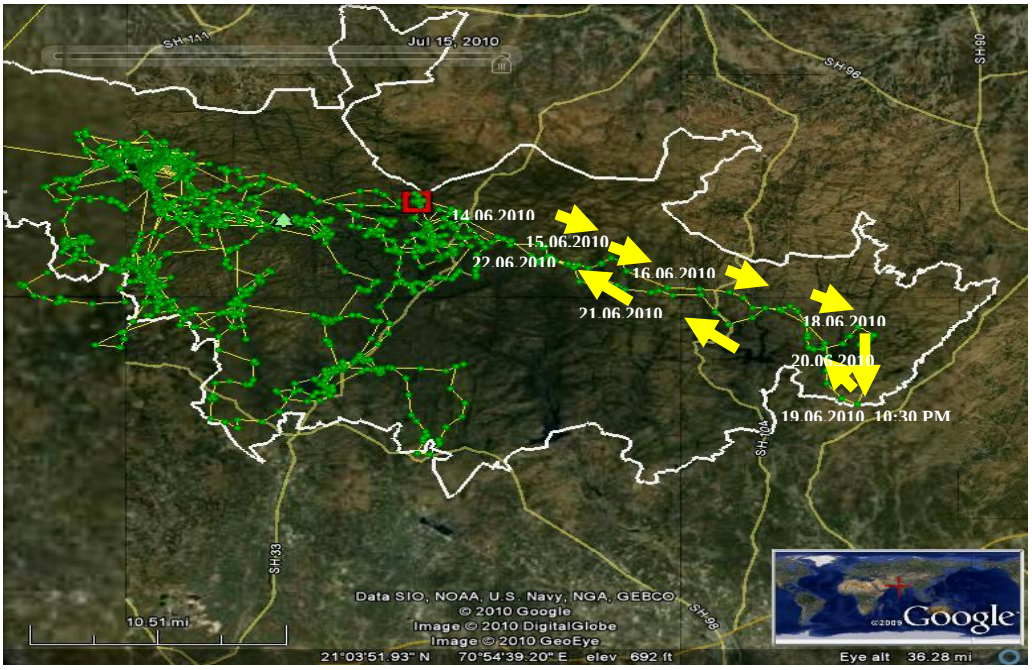
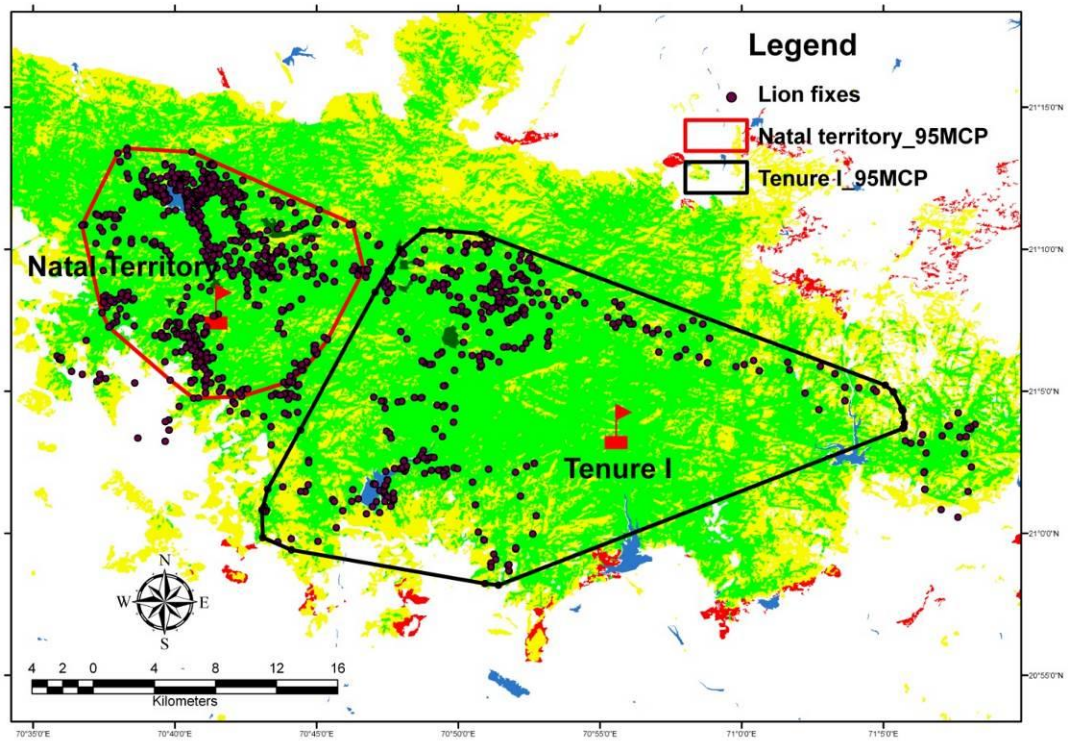
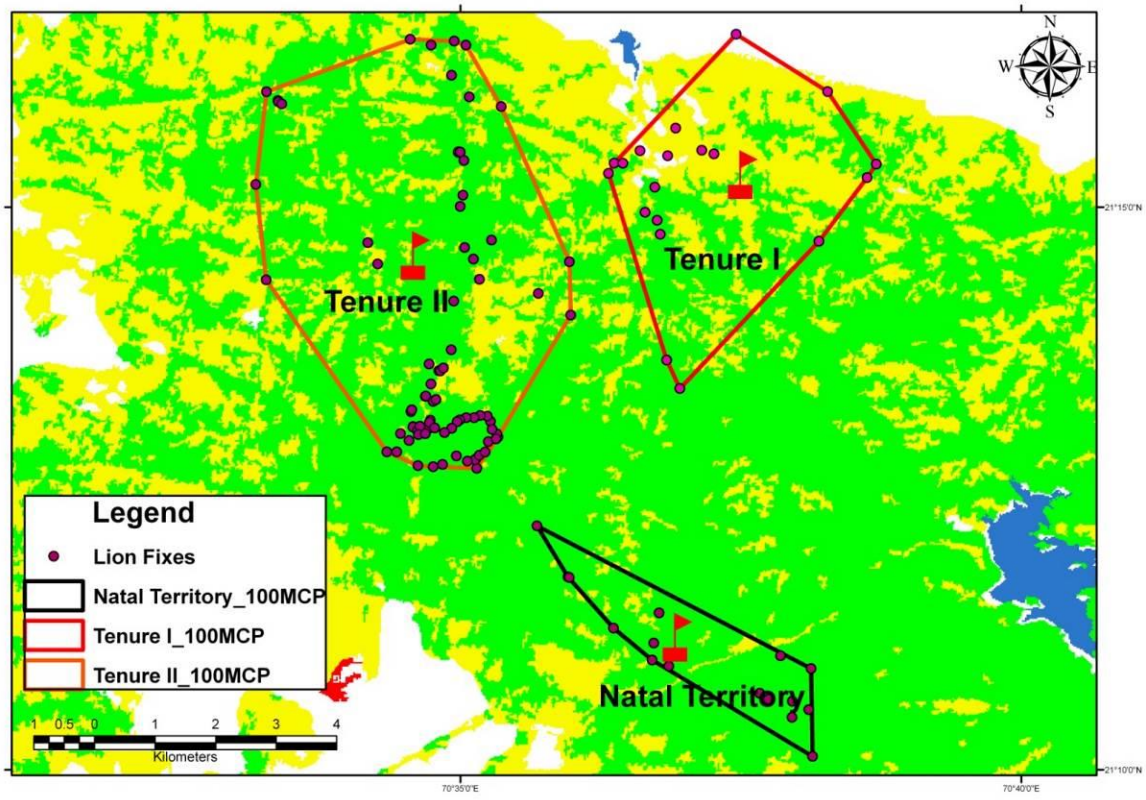


Figure 8.14: Dispersal of sub-adult Kamleshwar male II in Gir PA. Tenure centroids shown by flags.



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

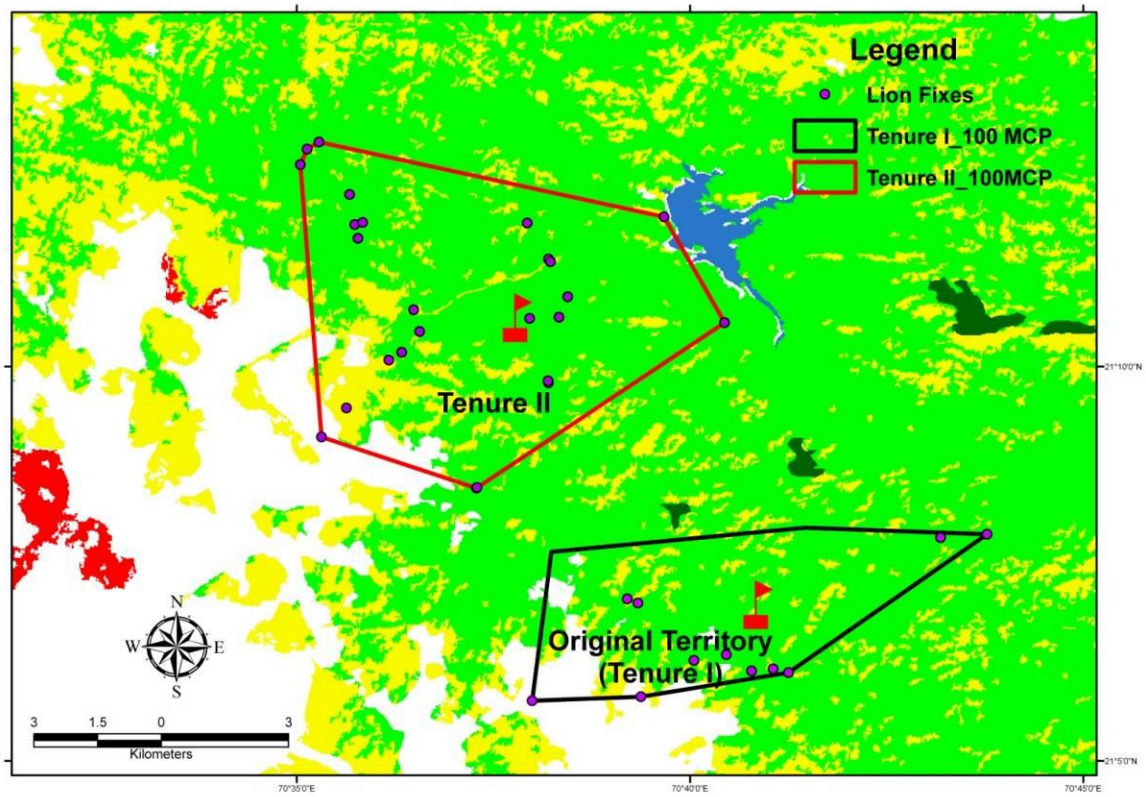
Figure 8.15: Tenure shift of prime adult Kamleshwar male I in Gir PA. Tenure centroids shown by flags.



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

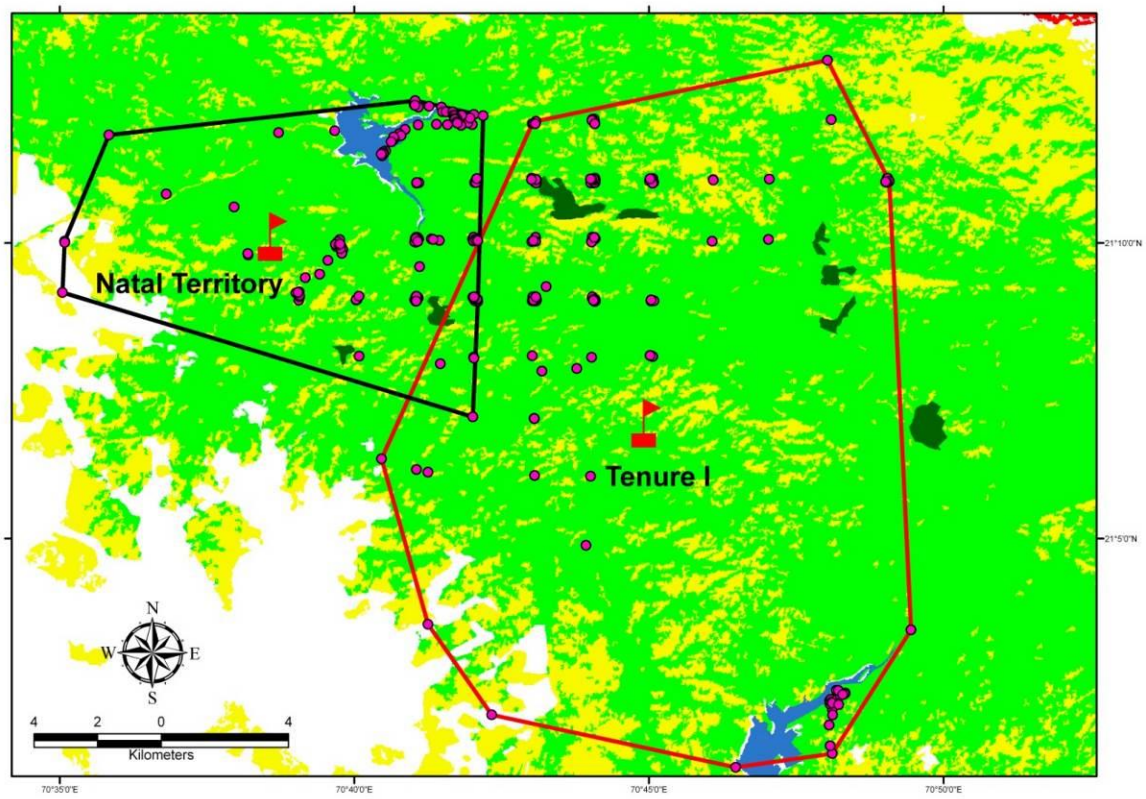
territory 8 km west (near Sasan, Kamleshwar and Amla hill parts; **Figure 8.16**). The male was last spotted by our research team in 2012.

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



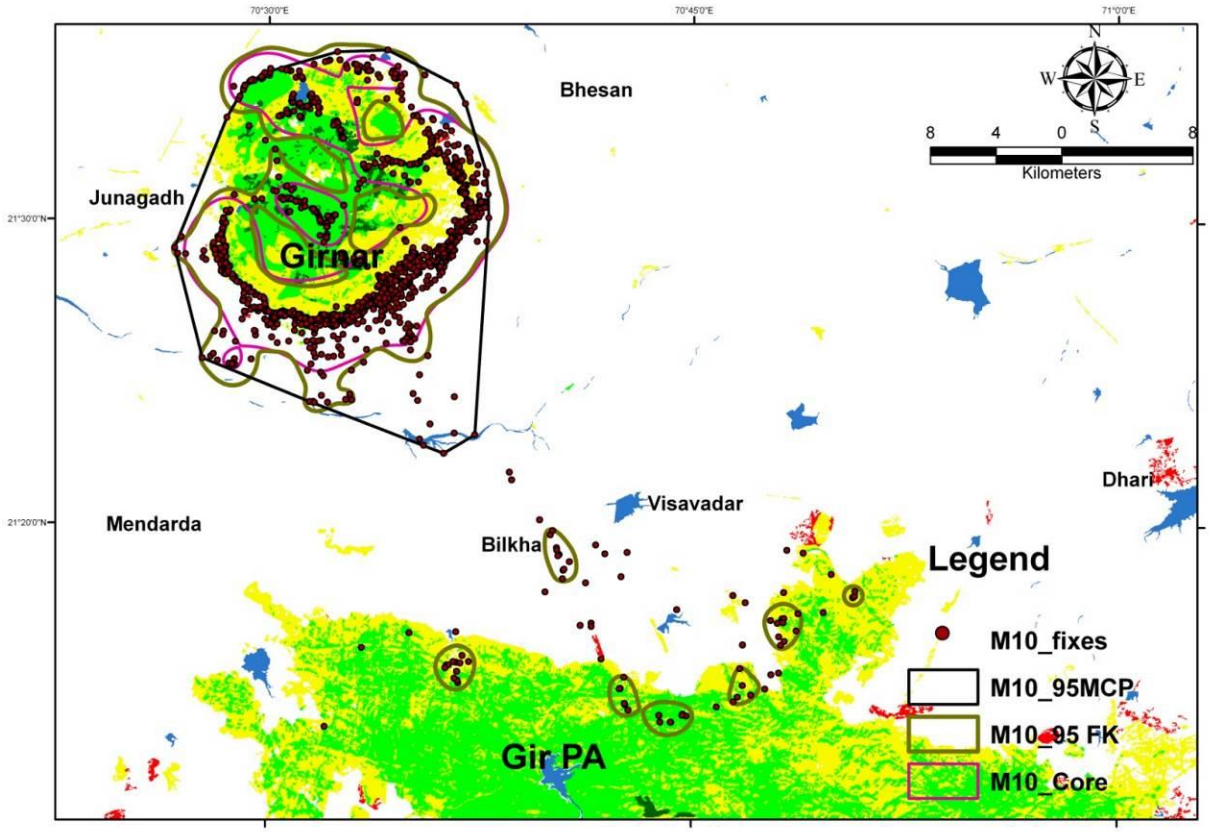
Patarariya male: M10 and his coalition partners were sub-adult males (about 3 year age) having a natal territory in the Gir National Park (Patararia, Kankai, Karamdadi, Vadvangra areas). The males were with their mother (prime adult lioness) and one of the males was collared in December 2005 as a part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

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



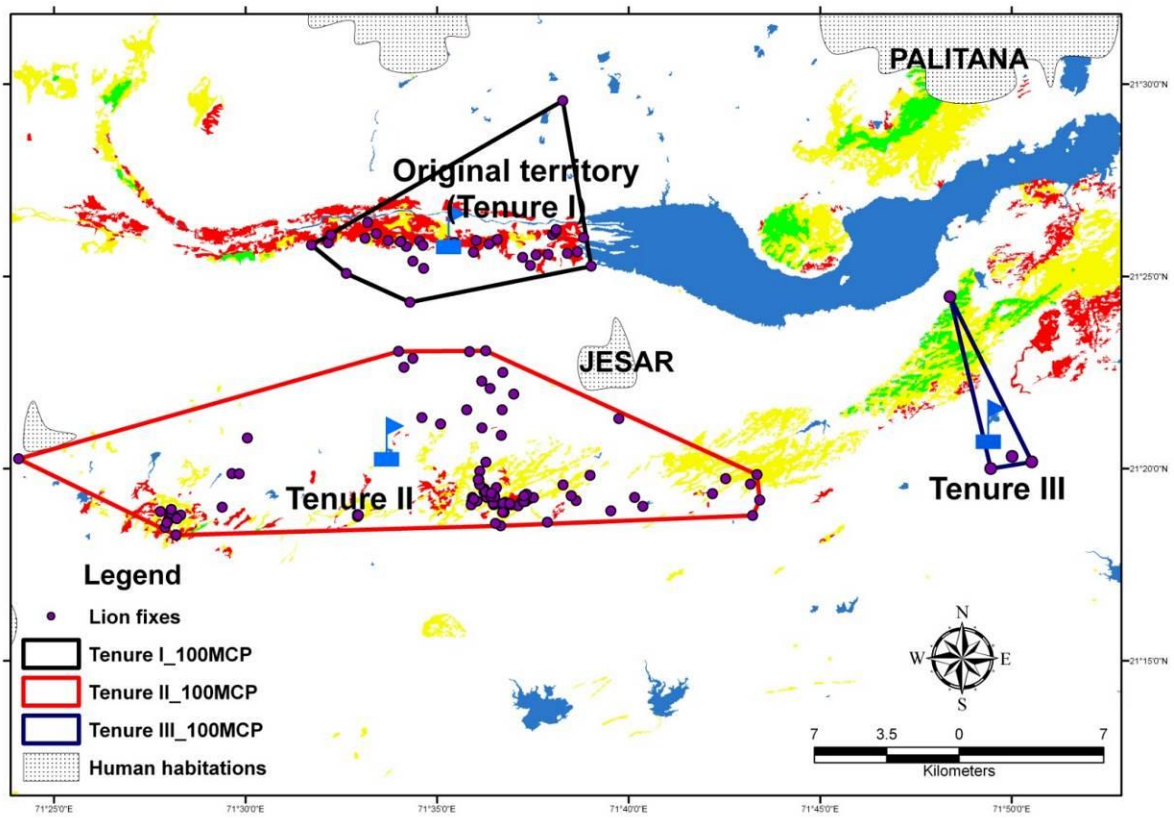
Ramnath male: This male was a sub-adult male (about 4 years old) fitted with a GPS/VHF collar in January 2010 near Ramnath temple in Girnar. This male provided an important insight into lion movements of between the Gir PA and the Girnar Wildlife Sanctuary **(Figure 8.18)**. The male ranged Girnar and agro-pastoral tracts of Junagadh, Mendarda, Bhesan and Visavadar talukas. The collar stopped functioning in November 2010 when the male was located with two prime adult females near Dedakadi, western part of the Gir sanctuary. After that, the male was located several times by our research assistants in the revenue areas of Sasan, Bhalchhel, Chitrod, Haripur and Chitravad till 2013.

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



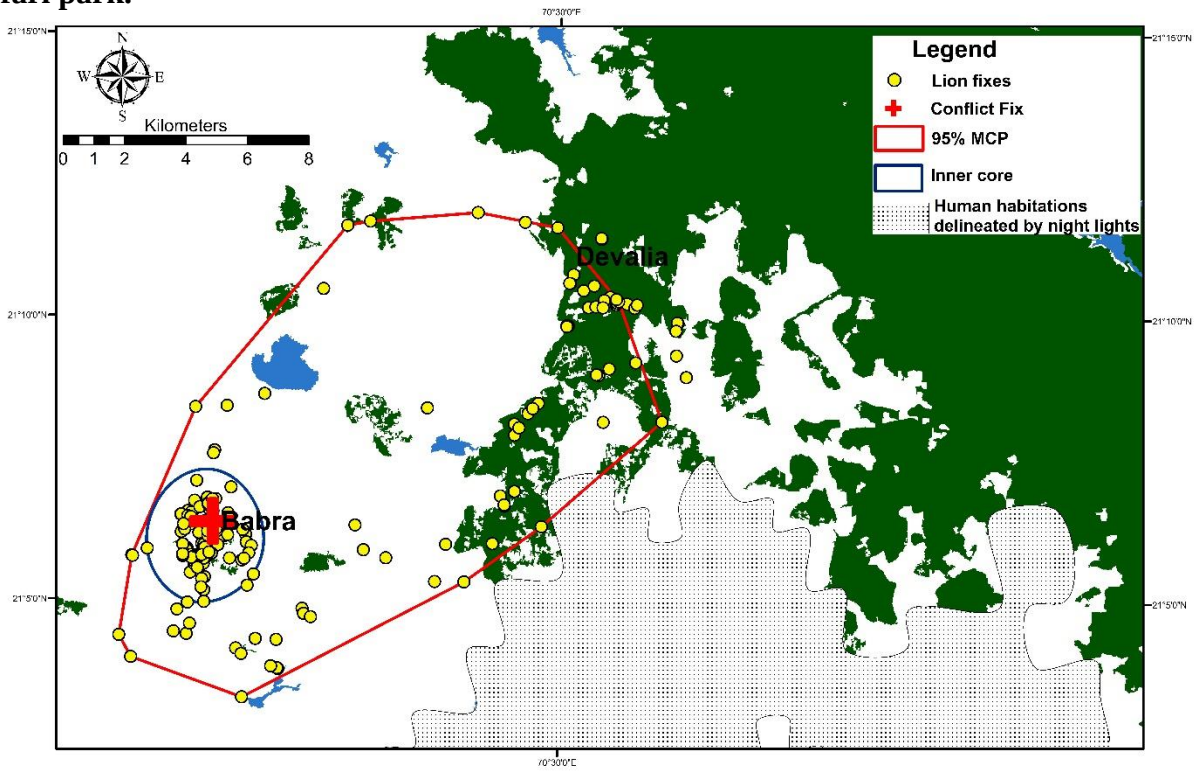
Dholikui male II: This male and his coalition partner (two prime adult males of about 8 years old) had a breeding territory (tenure I) near lower Shetrunjee basin. The males were non-collared whom we monitored on the basis of vibrissae pattern. The males ranged mostly in the *Prosopis juliflora* dominated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

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



Babra male: This young male in a coaltion of another 4 males was fitted with a GPS collar in Babra vidi on 18th November, 2015. The male ranged between Babra vidi and Devalia traversing through the revenue areas of Malia Hatina, Abudi, Ladudi, Amrapur etc. (**Figure 8.20**). The male attacked and killed one 7 year old boy on the 26th December, 2015 after which it was captured and translocated in Sasan veterinary hospital by the GFD staff and the collar was removed.

Figure 8.20: Ranging pattern of young adult Babra male in between Babra and Devalia safari park.

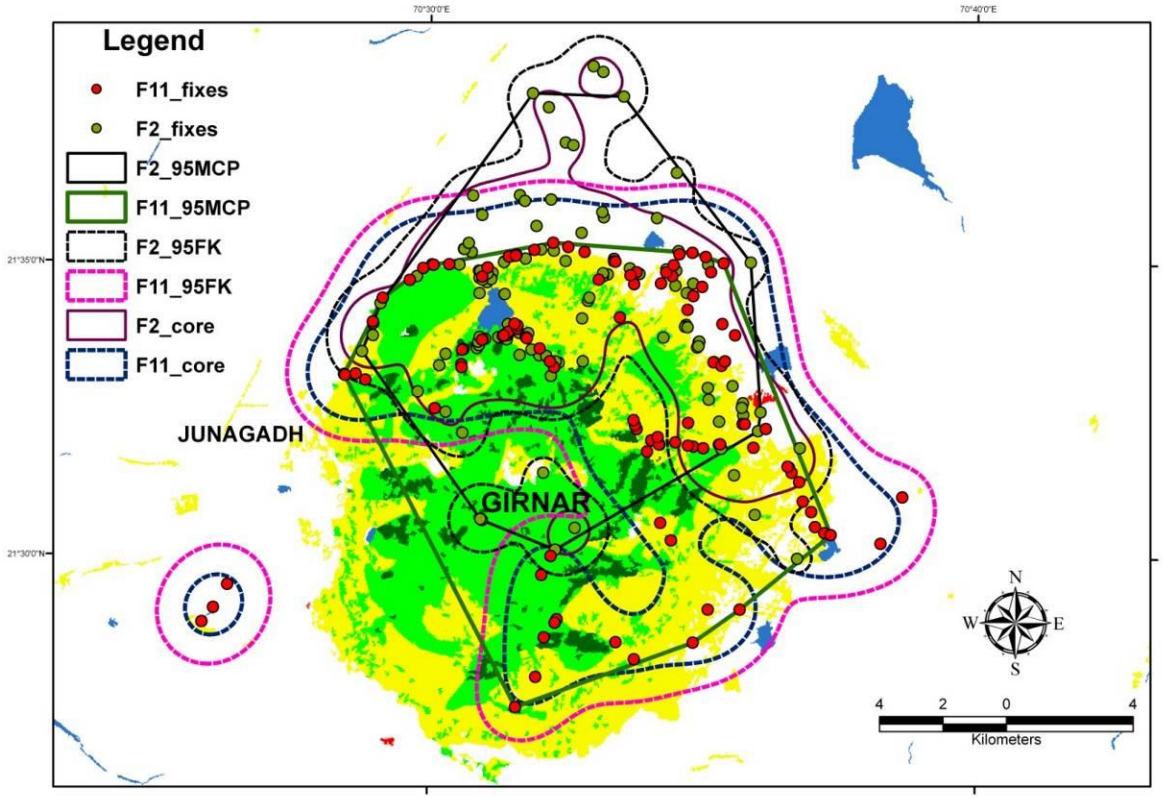


Female ranging

<u>Jambudi and Morapani lionesses:</u> These two females belonged to the same pride in the Girnar sanctuary. Jambudi, a prime adult female (about 6 years old) in the Girnar Wildlife Sanctuary was fitted with VHF radio collar in July 2008 in Sakkarbaug Zoo, Junagadh and released back to the sanctuary. The female was found to be interacting with her own group of lionesses and two males till December 2008 and was found to be ranging almost the entire lion habitats of the Girnar and adjoining village lands of Junagadh, Jetpur and Bhesan talukas **(Figure 8.21)**. During our study period in between 2008 and 2012 she littered thrice and successfully raised two cubs.

Morapani lioness was a sub adult female (about 3 years old) fitted with GPS/VHF collar in the Girnar Wildlife Sanctuary during January 2009. She ranged mostly within the lion habitats of the Girnar though occasionally frequented to the adjacent revenue areas of Junagadh, Bhesan and Bilkha **(Figure 8.21)**. She stayed mostly with her natal group, littered twice successfully raising two cubs during our study.

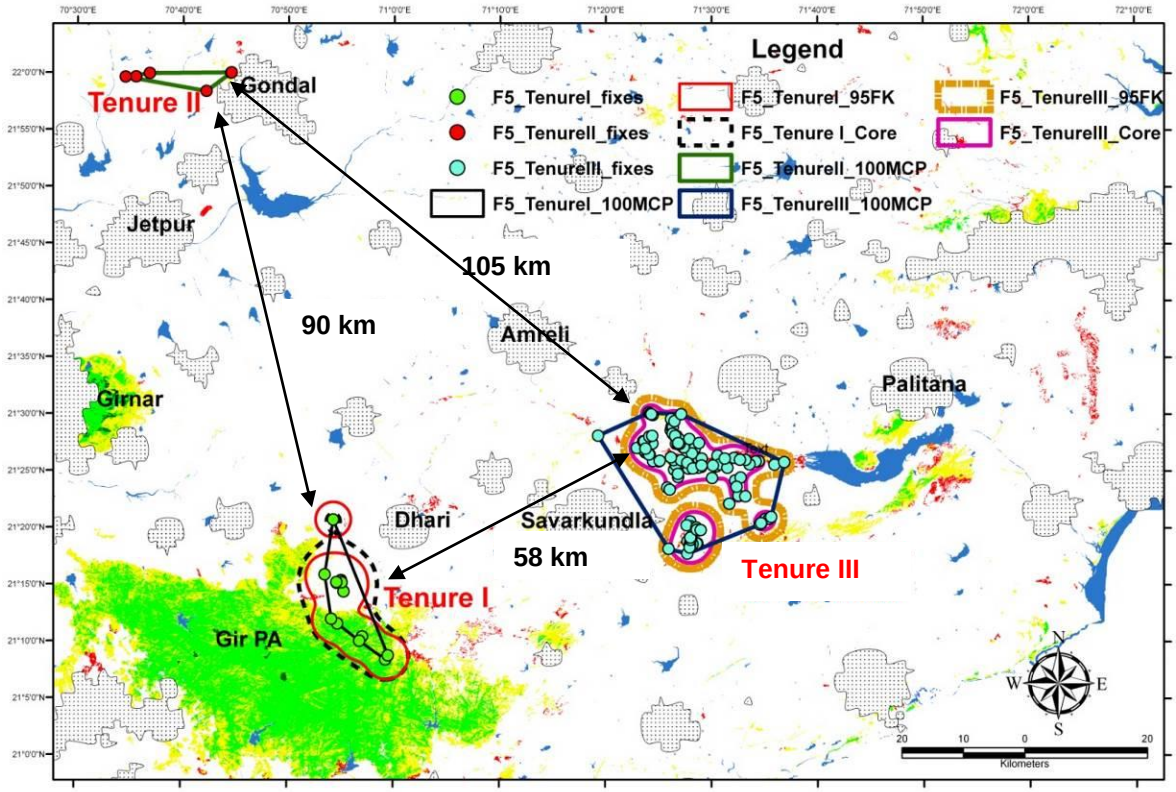
Figure 8.21: Ranging patterns of Jambuid and Morapani lionesses in Girnar Wildlife Sanctuary.



Krakanch lioness I: This was a prime adult female (approximately 7 years old) with three small cubs (3-4 months) and had a natal area near lower Shetrunjee basin (Krakanch, Lilia, Ghoba area). She was captured by the Gujarat Forest Department in anticipation of danger from flashfloods within her territory at the onset of monsoon 2008. The lioness was fitted with VHF radio collar in July 2008 prior to her release. However, she was released 58 km from her natal territory near Hadala, north-eastern boundary of the Gir PA (Tenure I). She stayed inside the Gir PA for a week, moved out and started ranging in the revenue areas of Dalkhaniya and Mithapur villages of Dhari and Visavadar talukas. She made a kill there and was last seen near Molvel village of Visavadar. Subsequently the female was lost and located almost a month after near Gondal city, 50 km from Rajkot (Tenure II; **Figure 8.22**). The linear distance was found to be 89.5 km from her tenure I and 105 km from the original territory (tenure II range use of 27 km^2). 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, this female along with her cubs was released back at her original territory (Tenure III). The female lost two of her cubs in

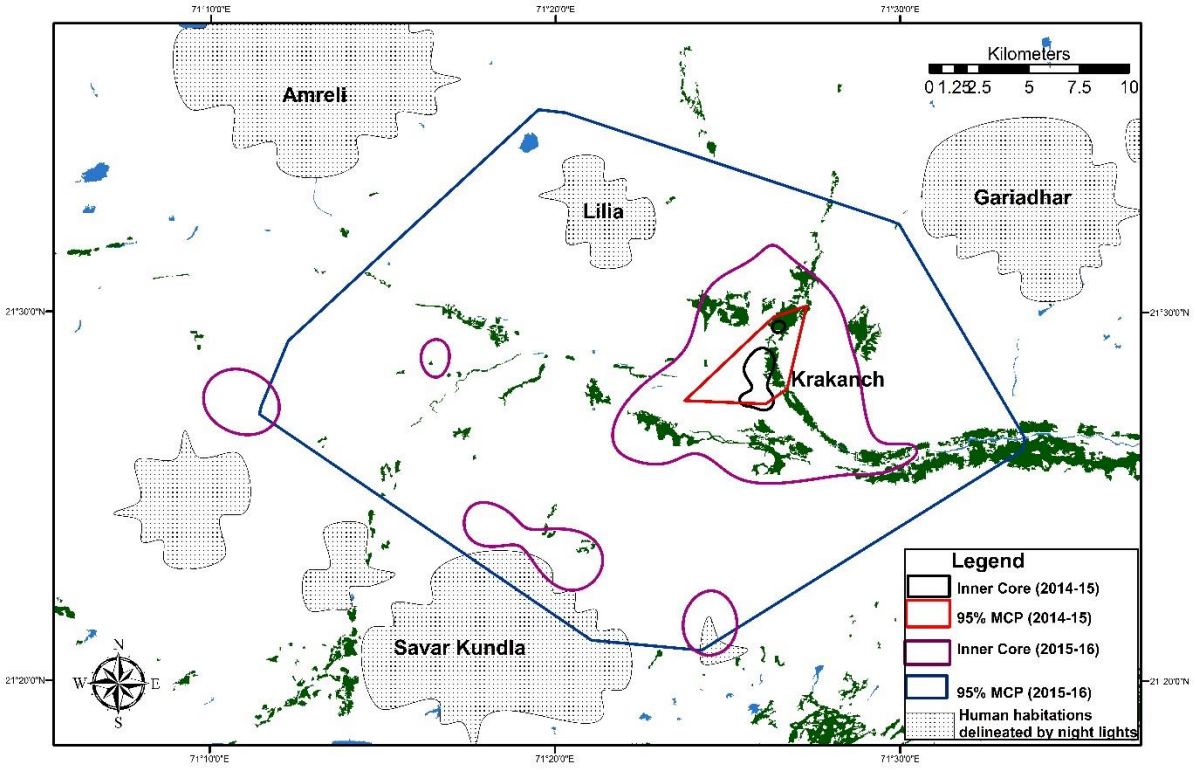
April 2009 due to an infanticidal resident male. Thereafter, she littered thrice during our study period till 2012 and successfully raised three cubs. The female was long ranging. In 2011 she expanded her territory further east and ranged in the revenue areas of Savarkundla, Jesar and occasionally reaching near Ranigalo *vidi*.

Figure 8.22: Ranging pattern and dispersal of prime adult Krakanch female I. Human habitations demarcated by night light satellite data.



<u>Krakanch lioness II:</u> This was a prime adult female fitted with a GPS-VHF collar in May 2014. GPS attachment failed within a month and we could monitor her only through conventional VHF tracking. She became pregnant immediately after the collaring and littered (3 cubs; 2 males and 1 female) in August 2014. Owing to presence of small cubs, she had a very small range (95% MCP range 20 km^2; inner core of about 4 km^2) restricted in the revenue areas of Krakanch during 2014-15 (**Figure 8.23**). Her range expanded about 32 times thereafter and she was found to range in an area of 642 km^2 (95% MCP) of Amreli, Lilia and Savarkundla (**Figure 8.23**). The female again came into estrous during February 2016.

Figure 8.23: Annual home ranges of Krakanch lioness II during 2014 – 2016. Human habitations demarcated by night light satellite data.



Lion territoriality

We examined home range overlap for pairs of same pride/coalition and neighboring lions (n = 3 pairs of same pride females, n = 3 pairs of neighboring females, n = 4 pairs of coalition males, n = 14 pairs of neighboring males, n = 16 pairs of coalition male-females and n = 14 pairs of neighboring male-females). Lionesses had a higher range overlap with their pride females than neighboring females ($t = 0.7$, $df = 4$, $p = 0.51$). Average core area overlap of pride females [61 (SE 18) %] was much higher than that with neighboring females [3.5 (SE 0.05) %] ($t = 3.32$, $df = 3$, $p = 0.04$; **Table 8.7**). Coalition males had a higher overlap of range ($t = 5.98$, $df = 14$, $p < 0.001$) as well as of core area ($t = 6.19$, $df = 18$, $p < 0.001$) than neighboring males **(Table 8.7)**. Male home ranges overlapped extensively with those of sympatric females [mean: 63 (SE 3) %], but little with neighboring females [mean: 18 (SE 6) %] ($t = 6.91$, $df = 26$, $p < 0.001$). Male ranges overlapped in the areas where female cores were concentrated **(Figure 8.24)**.

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

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

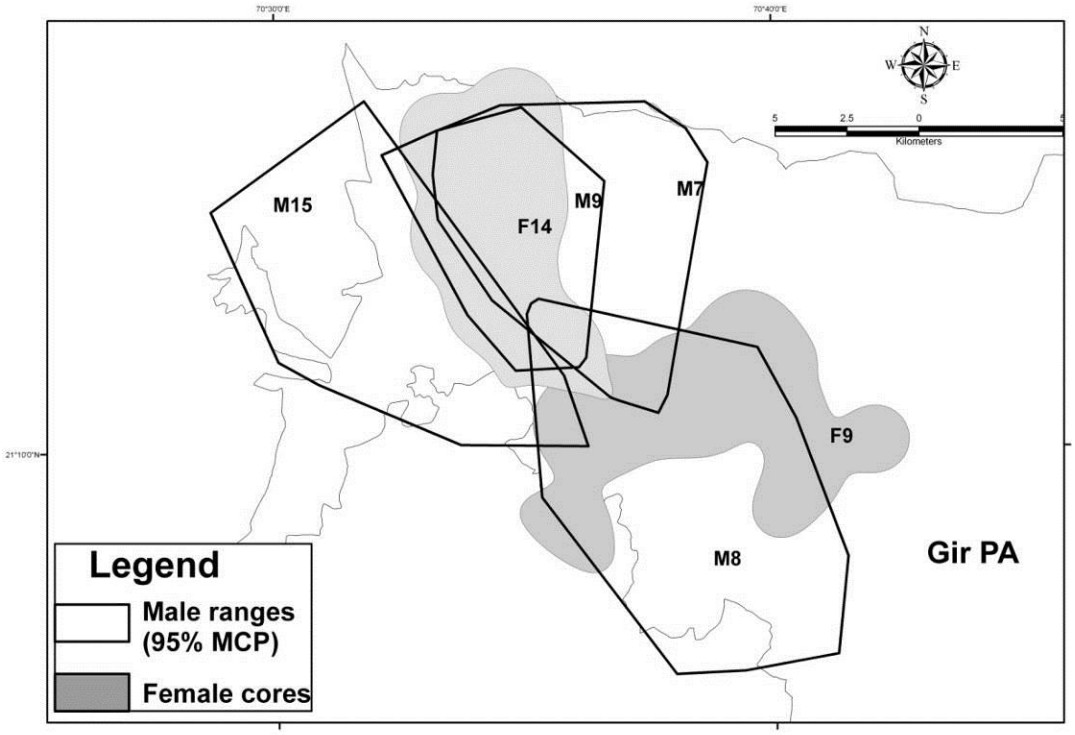
Lion movement

The average diurnal distance travelled by lions [2.3 (SE 0.4) km] was smaller than the average nocturnal distance traversed [7.1 (SE 2) km] ($t = 2.56$, $df = 17$, $p = 0.02$; **Table 8.8**). 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 ($t = 26.5$, $df = 2$, $p = 0.02$).

Ramnath male moved between the Gir PA and the Girnar Wildlife Sanctuary thrice in between January 2010 and October 2010 **(Figure 8.25)**. Dispersing sub-adult Kamleshwar male II with his coalition partner moved from the western part to the eastern part of the Gir PA **(Figure 8.26)**.

Figure 8.24: Male range and female core area (85% FK) overlap in i) Gir PA and ii) eastern landscape.

i)



ii)

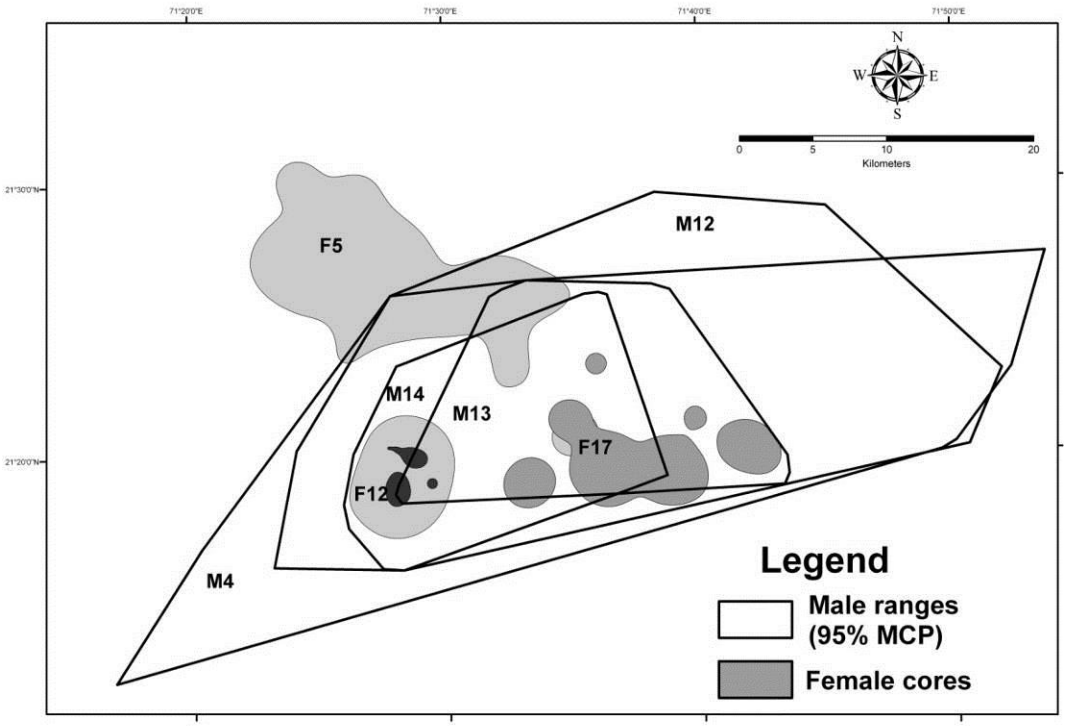


Table 8.8: Average movement parameters of Asiatic lion in the Gir landscape. Figures within parentheses are standard errors.

Lion ID	Diurnal				Nocturnal			
	n (day)	Distance travelled (km)	Hour	Speed (km/hr)	n (night)	Distance travelled (km)	Hour	Speed (km/hr)
Girnar Jambudi lioness	14	1.16	4.69	1.11	15	5.50	6.54	0.80
Krakanch lioness I	11	1.68	4.75	0.75	11	3.48	2.41	1.61
Girnar Morapani lioness	10	3.57	4.75	0.89	12	7.64	6.90	1.19
Ambardi male	26	1.93	9.22	0.21	26	3.99	9.30	0.44
Bhuatirath male	21	5.86	8.16	0.64	22	3.63	7.85	0.67
Chandgadh male	114	3.39	10.30	0.40	112	9.04	9.17	1.10
Dholikui male I	18	1.11	8.07	0.17	20	31.75	9.19	3.53
Girnar Jambudi male	15	1.14	4.83	0.51	19	5.40	5.50	0.91
Kamleshwar male II	186	2.36	9.50	0.24	187	3.12	9.70	0.31
Patarariya male	63	2.14	9.10	0.23	61	2.55	3.86	0.65
Ramnath male	157	2.62	9.00	0.31	158	6.57	9.66	0.70
Ranigalo male	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 8.25: Movement of Ramnath male between Gir PA and Girnar Wildlife Sanctuary.

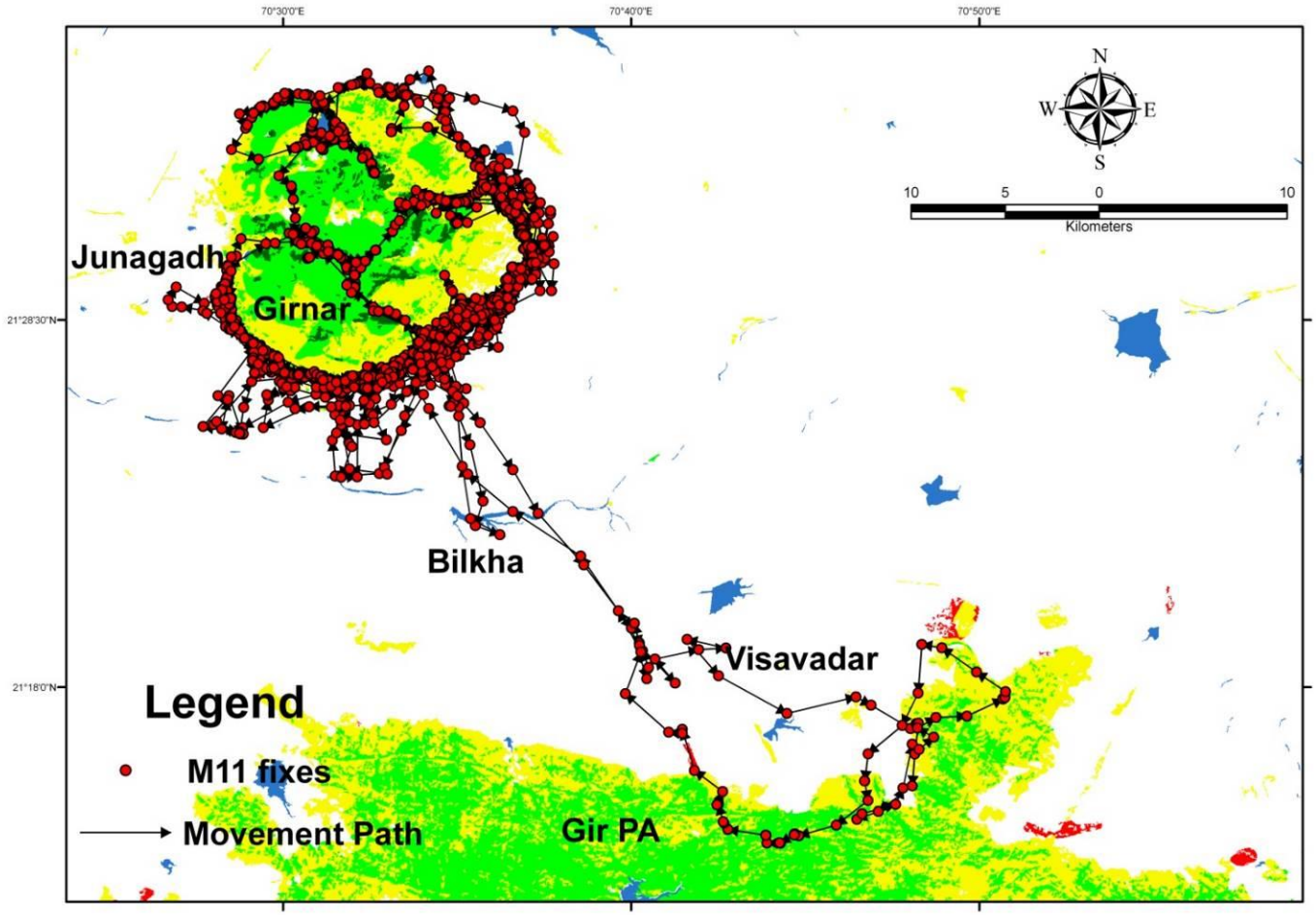
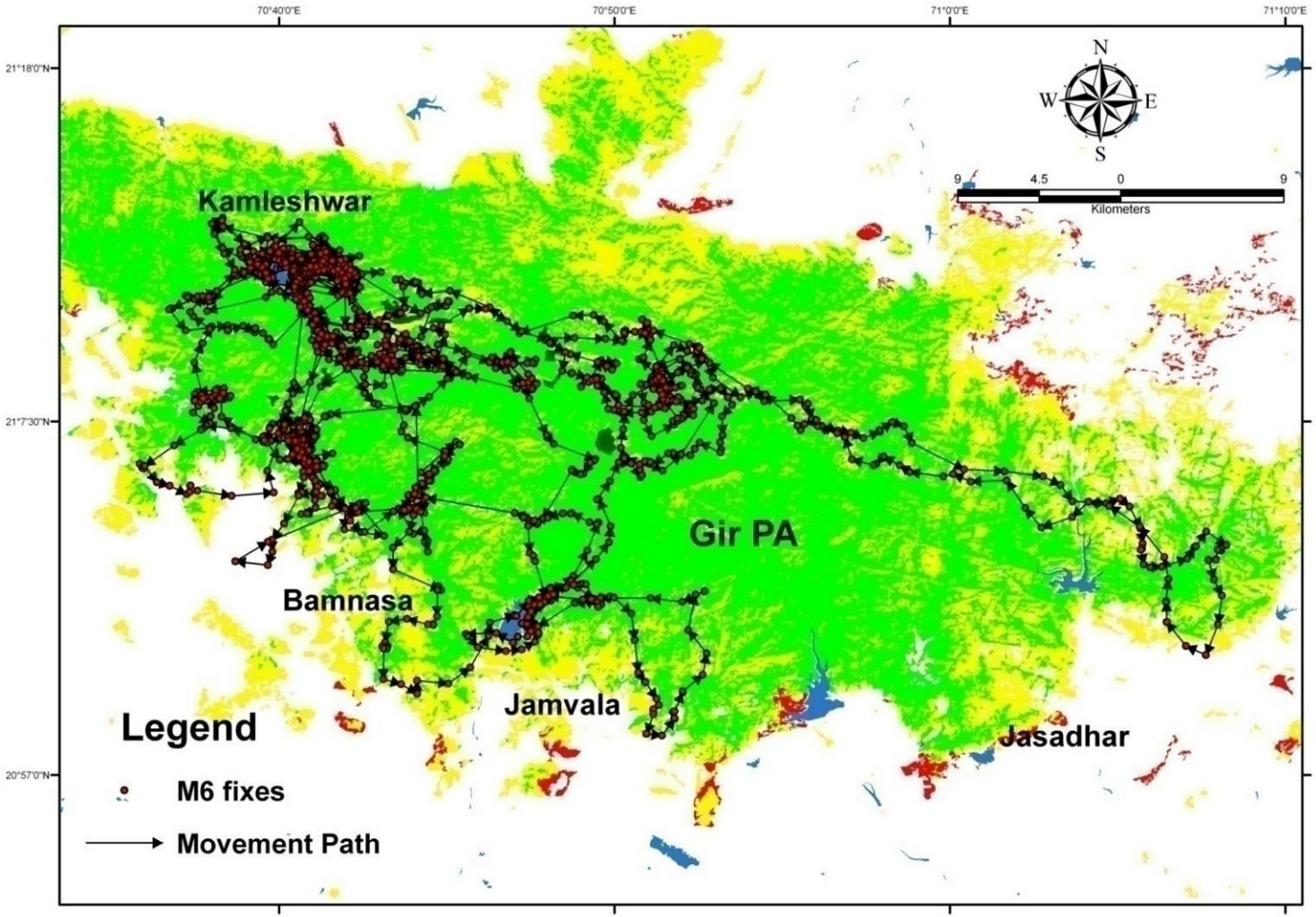


Figure 8.26: Movement of Kamleshwar male II from western Gir to eastern Gir.

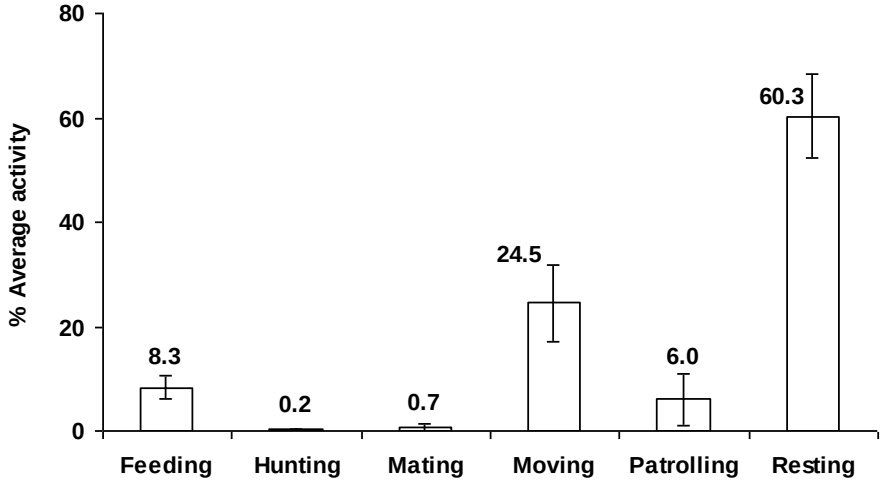


Lion time budget and activity pattern

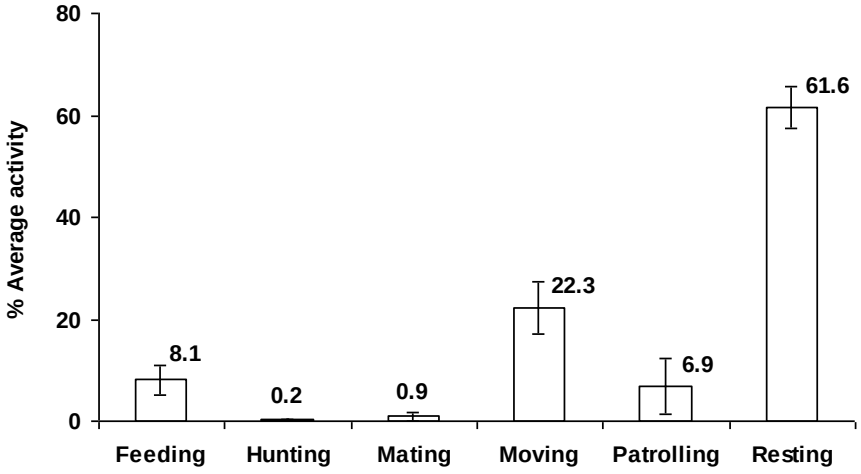
Overall lions spent a majority of their time resting (60%) followed by moving (24%) and we found no seasonal (wet and dry) variation (χ^2 = 6.13, df = 5, p = 0.29, **Figure 8.27**). Males also spent majority of their time resting (62%) followed by moving (17%) and patrolling (13%) and no seasonal variation was observed (χ^2 = 3.81, df = 5, p = 0.57, **Figure 8.28**). Females spent most on resting (59%) and no seasonal variation was recorded (χ^2 = 5.07, df = 5, p = 0.40, **Figure 8.29**). However there was a significant difference of time invested in different activities by males and females (χ^2 = 16.74, df = 5, p = 0.005; **Figure 8.28 and 8.29**) 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 **(**χ^2 = 7.86, df = 5, p = 0.16, **Figure 8.30)**.

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

i)



ii)



iii)

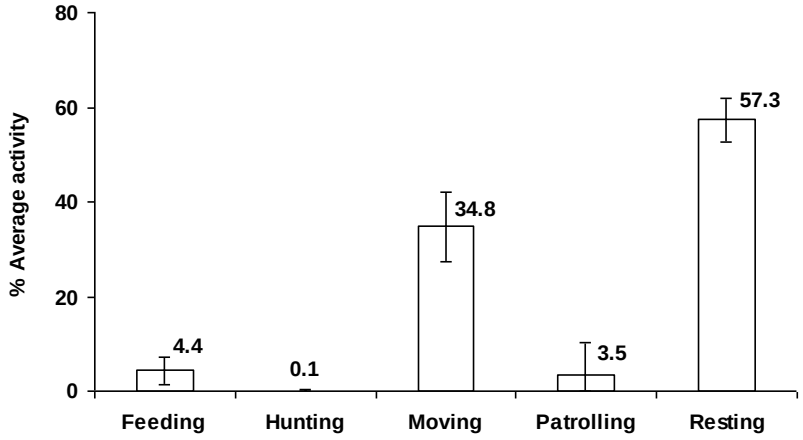
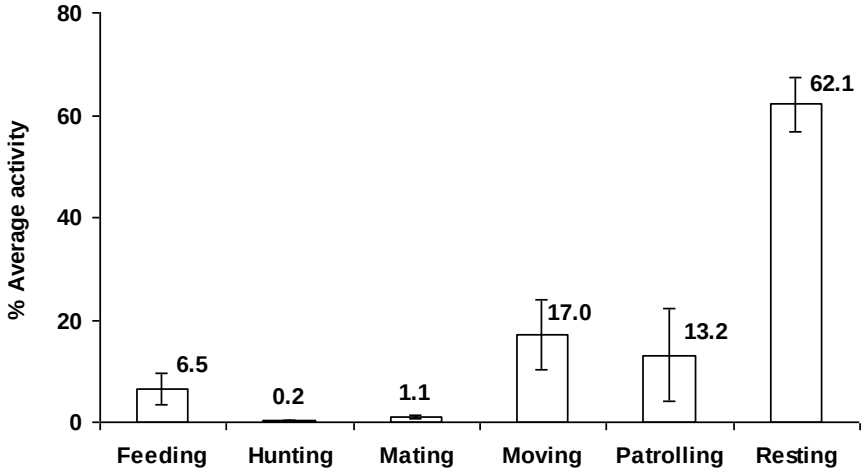
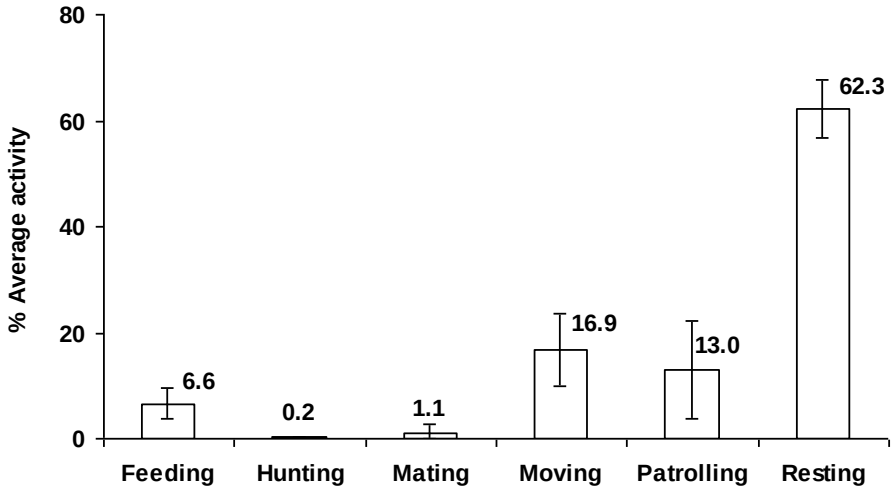


Figure 8.28: Time invested by male lions in different activities during continuous monitoring session i) overall, ii) dry season and iii) wet season. Error bars = 95% CI.

i)



ii)



iii)

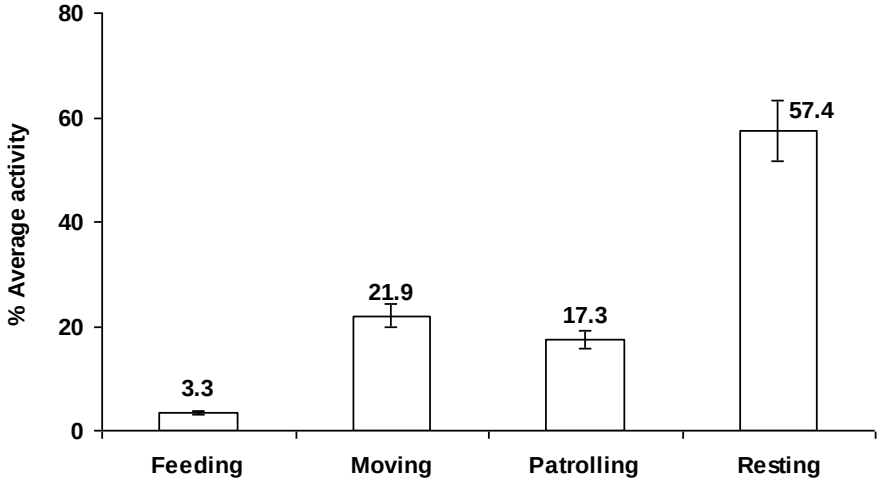
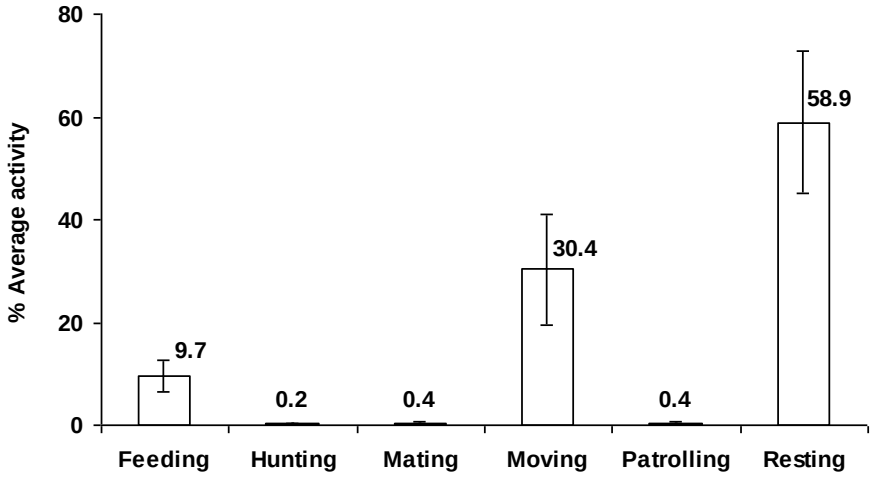
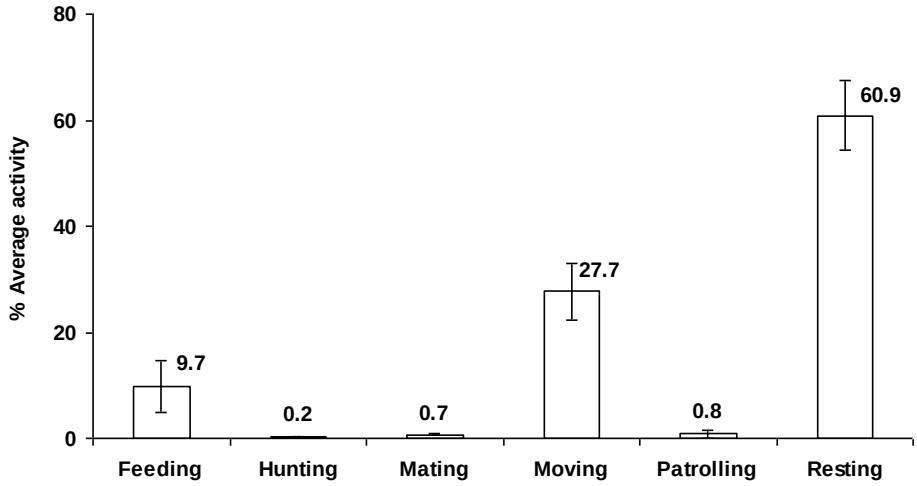


Figure 8.29: Time invested by female lions in different activities during continuous monitoring session i) overall, ii) dry season and iii) wet season. Error bars = 95% CI.

i)



ii)



iii)

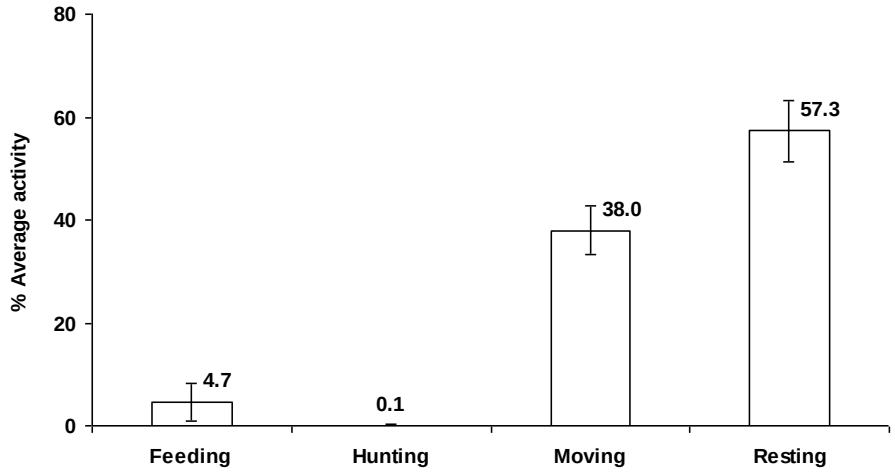
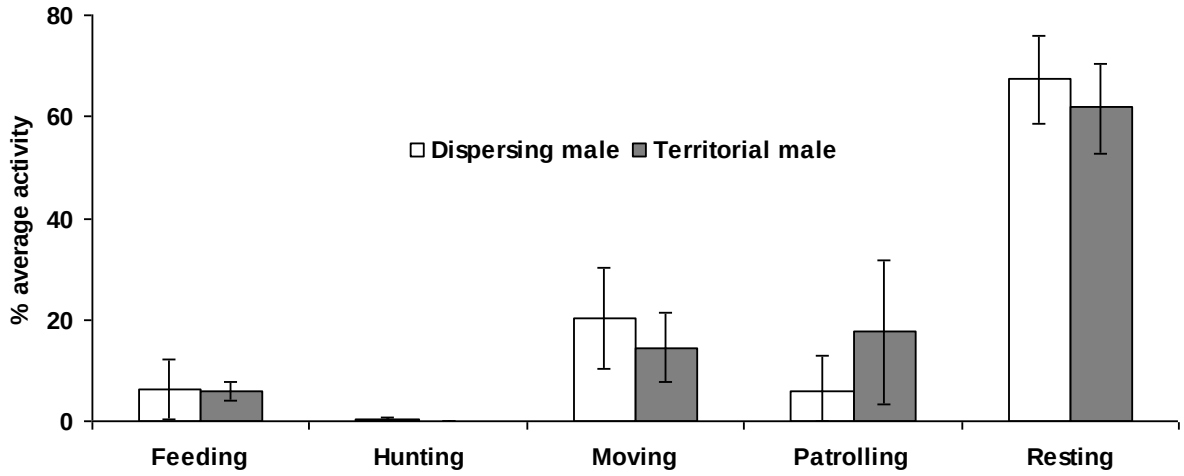


Figure 8.30: Time invested by territorial males and dispersing males in different activities. Error bars = 95% CI.



Lions were mostly active during night (moving and patrolling) while most of the day was spent in resting **(Table 8.9, Figures 8.31 - 8.41)**. Feeding peak was at midnight while the hunting peak was during the early morning. However, during wet season the feeding peak was delayed by about 2 hours. Male feeding peak was before midnight while female feeding peak was found to be after midnight. Males were found hunting mostly during dawn while females were found to hunt mostly during dusk **(Table 8.9)**. Patrolling peak for territorial males was found to be at late night (2:20 AM) while for dispersing males the patrolling peak was dawn (4 AM). No seasonal variation among activity peaks was observed for males or females. **Figures 8.31 - 8.41** show proportional time spent by lions in different activities during different times of the day and the related activity peaks.

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

Table 8:9: Activity statistics of lions in different seasons deduced by the program Oriana. * indicates significant probability of directionality of data at α = 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).**

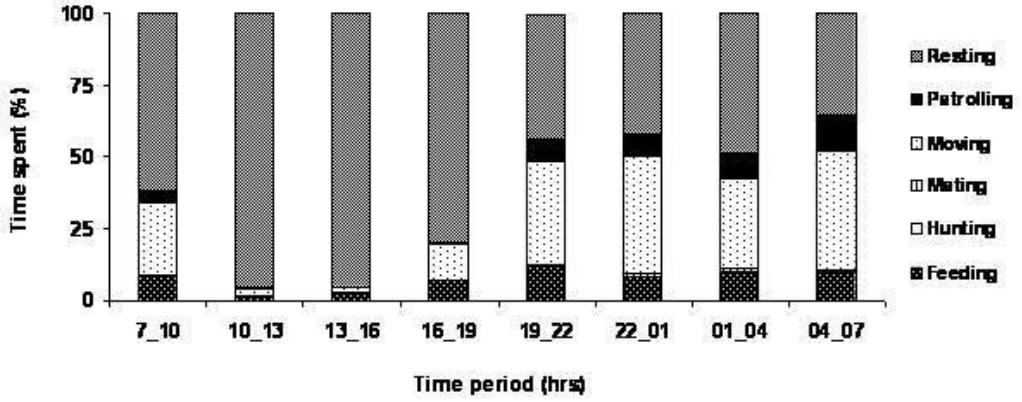
Activity	Median	95% CI	Rayleigh Z statistics	Rayleigh p value	Rao spacing test (U)	Rao spacing test (p)
Lion overall						
Feeding	12:40 AM	11:56 PM – 1:18 AM	57.2	< 0.0001*	325.8	< 0.01*
Hunting	6:40 AM	5:28 AM – 7:18 AM	0.05	0.95	122.9	0.90 > p > 0.50
Mating	1: 00 AM	11:54 PM – 2:09 AM	17.2	<0.0001*	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*

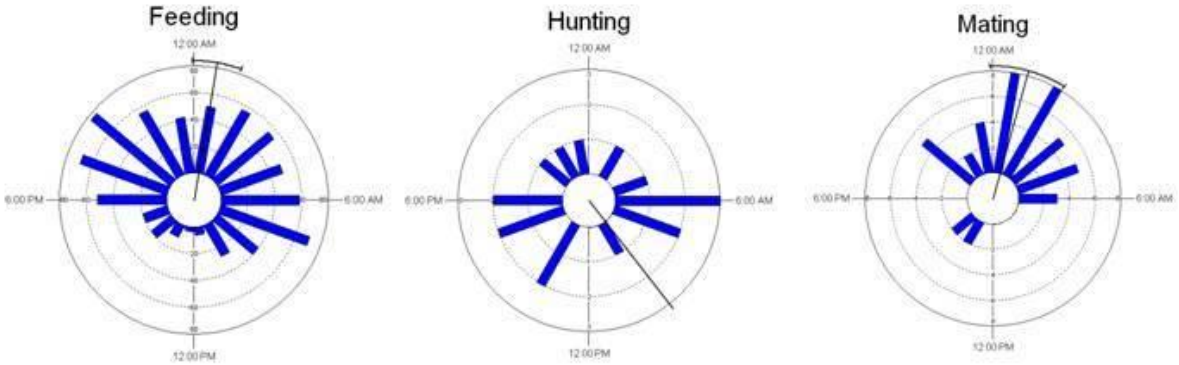
Male dry season						
Feeding	10:40 PM	9:47 PM – 11:50 PM	25.3	<0.0001*	278.6	< 0.01*
Hunting	5:50 AM	3:34 AM – 9:24 AM	3.5	0.02*	210	< 0.01*
Mating	11:20 PM	9:53 PM – 12:56 AM	9.7	<0.0001*	190.5	< 0.01*
Moving	1:20 AM	1:14 AM – 1:53 AM	231.2	<0.0001*	338.1	< 0.01*
Patrolling	2:20 AM	1:44 AM – 2:33 AM	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 8.31: Proportional time spent by lions (males and females) in different activities during different times of the day and the related activity peaks deduced by program Oriana.





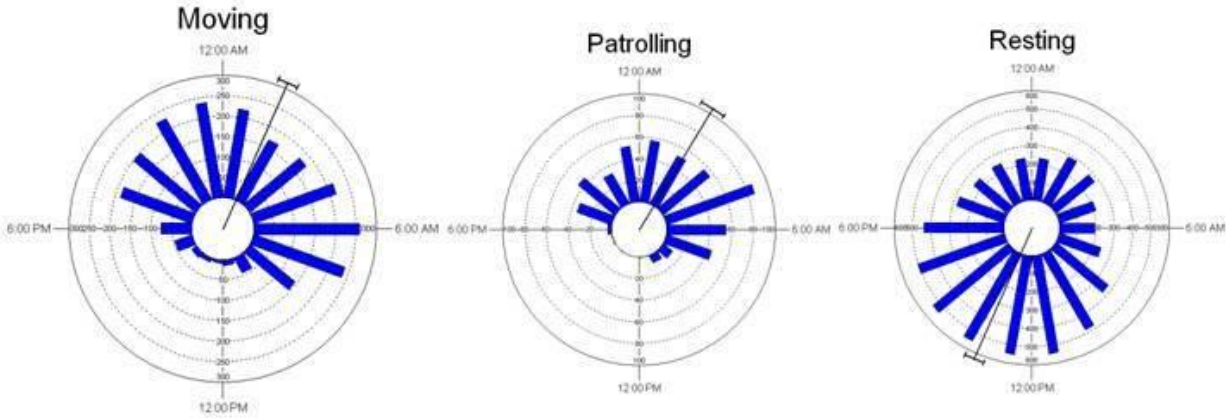


Figure 8.32: Proportional time spent by lions (males and females) in dry season in different activities during different times of the day and the related activity peaks deduced by program Oriana.

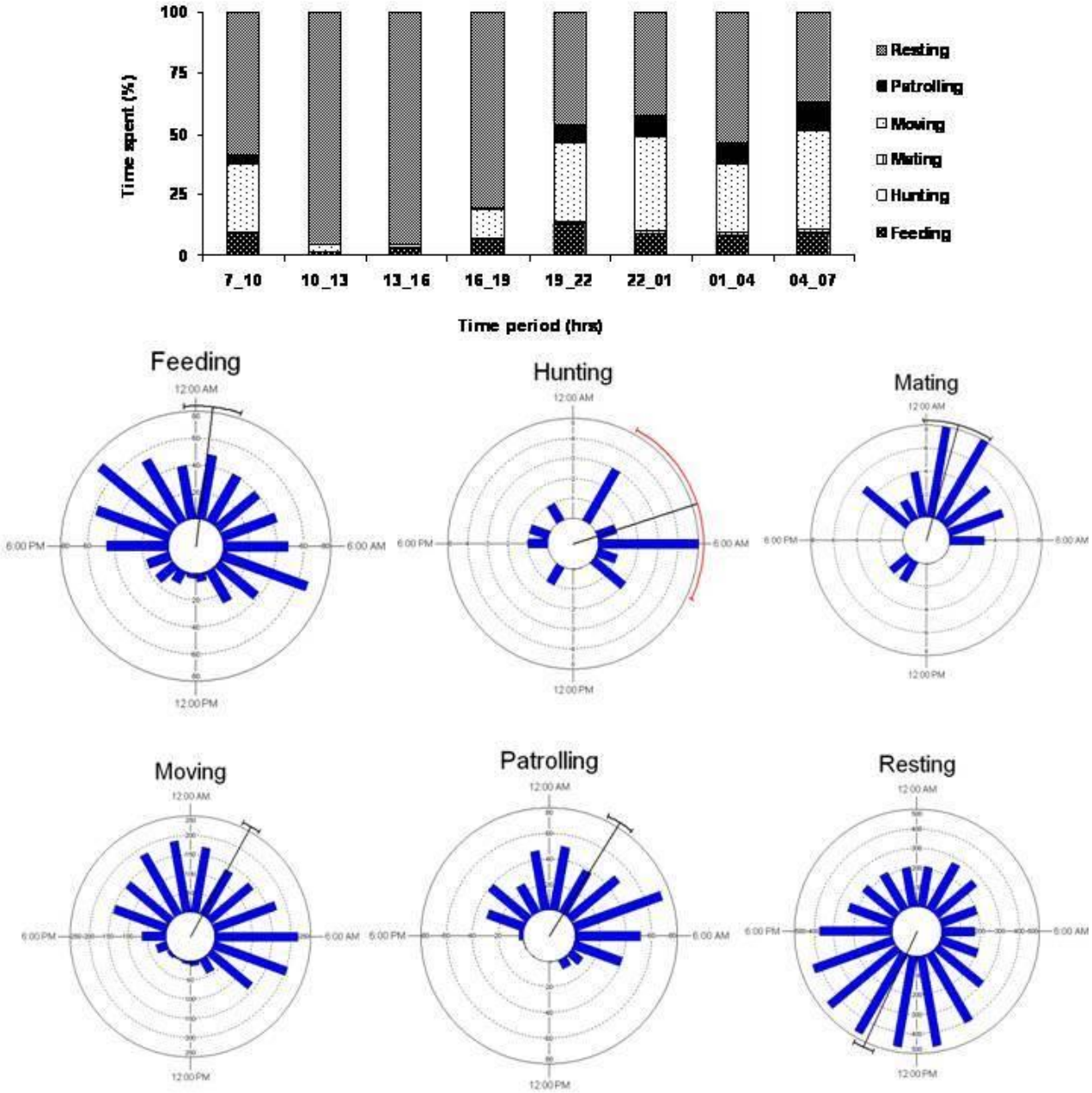


Figure 8.33: Proportional time spent by lions (males and females) in wet season in different activities during different times of the day and the related activity peaks deduced by program Oriana.

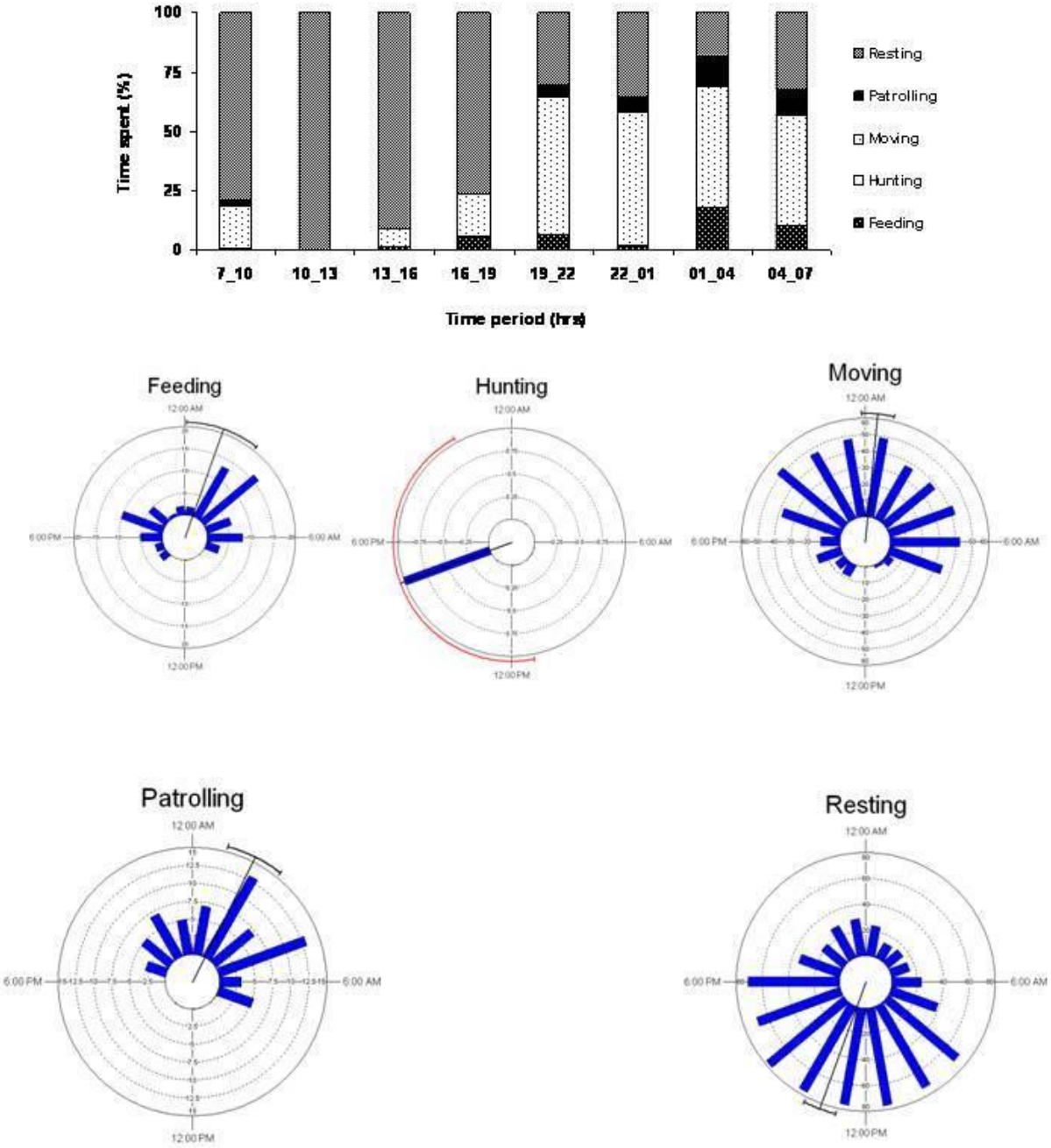


Figure 8.34: Proportional time spent by male lions in different activities during different times of the day and the related activity peaks deduced by program Oriana.

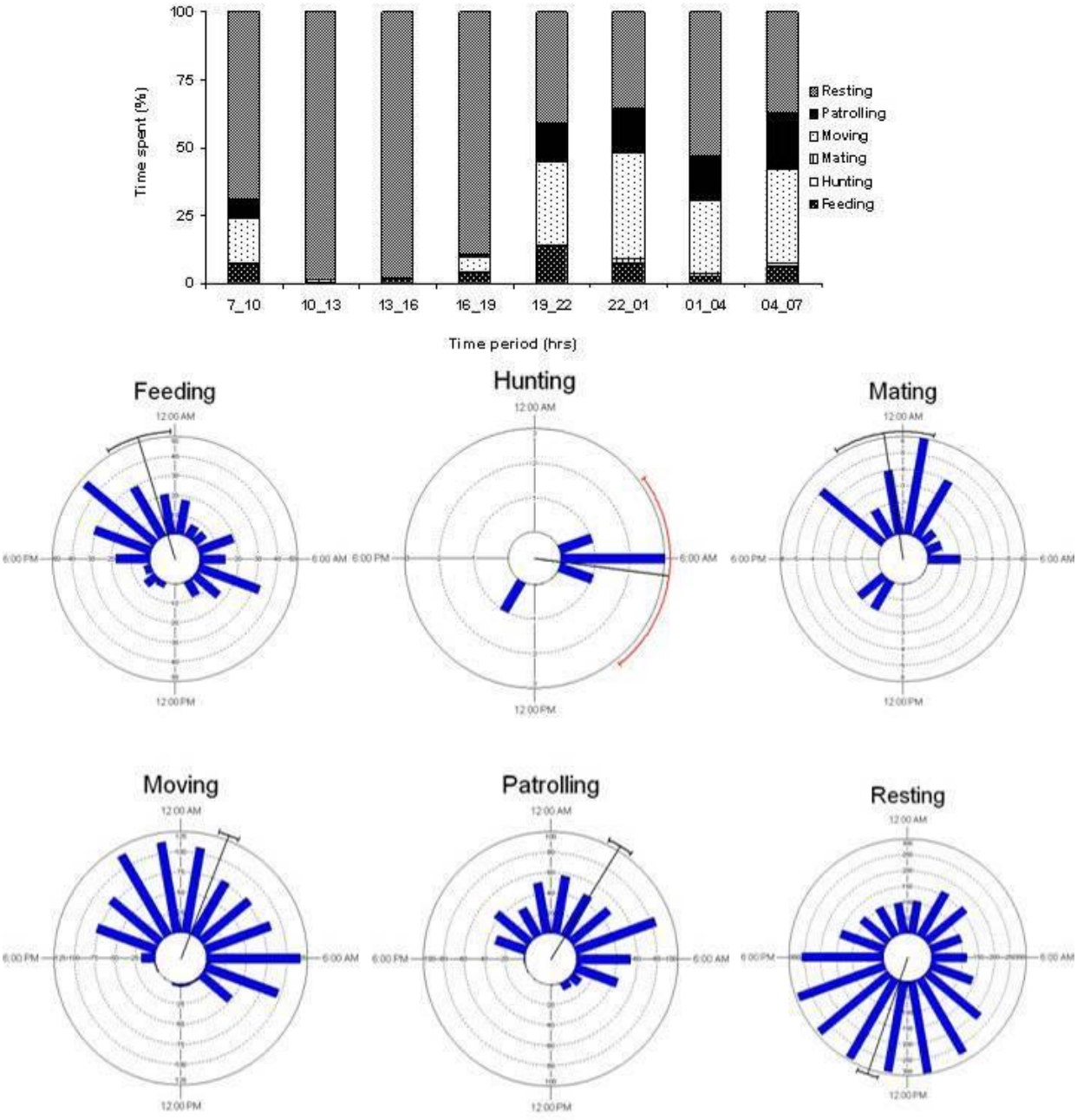
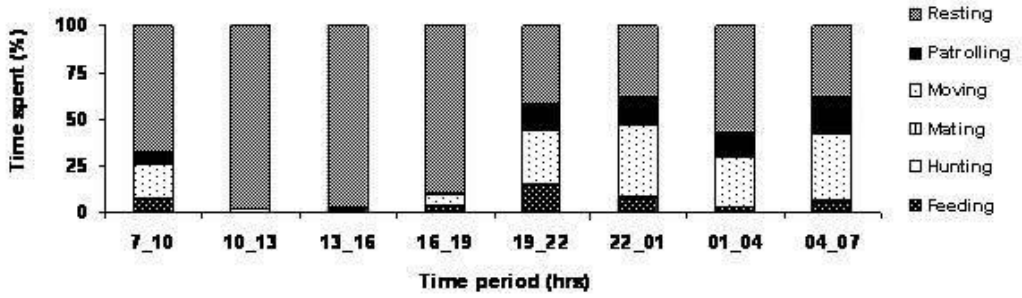


Figure 8.35: Proportional time spent by male lions in dry season in different activities during different times of the day and the related activity peaks deduced by program Oriana.



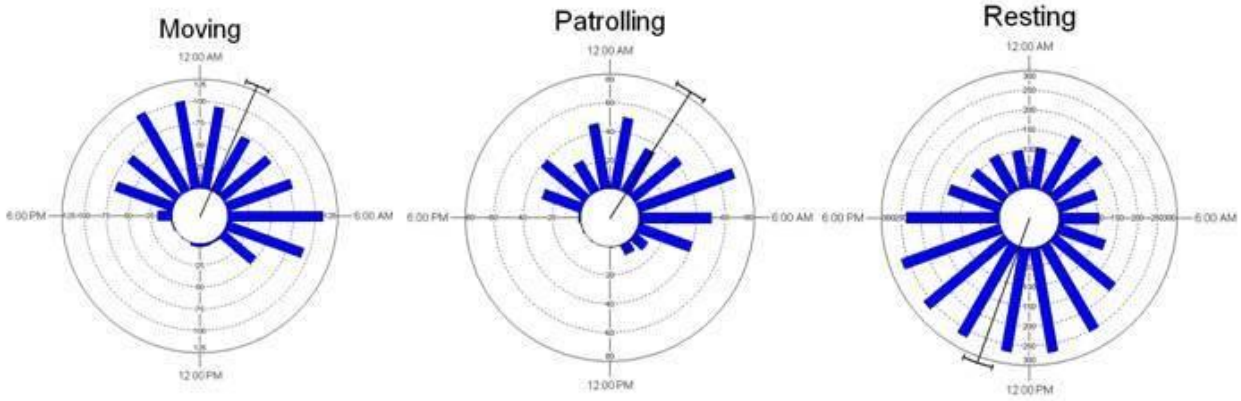
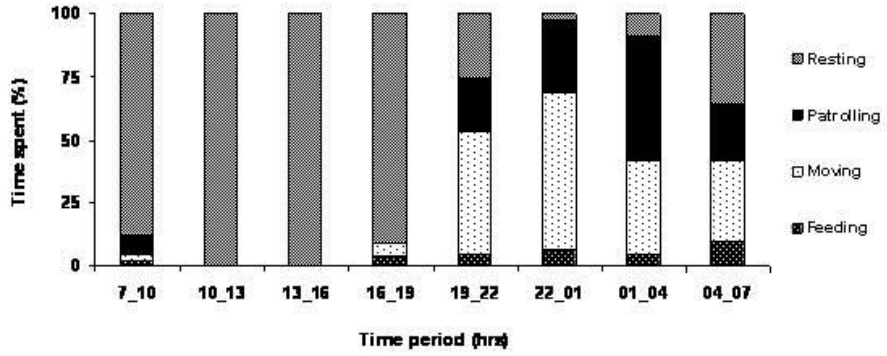
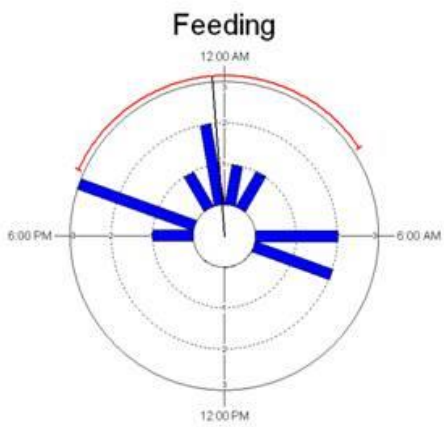
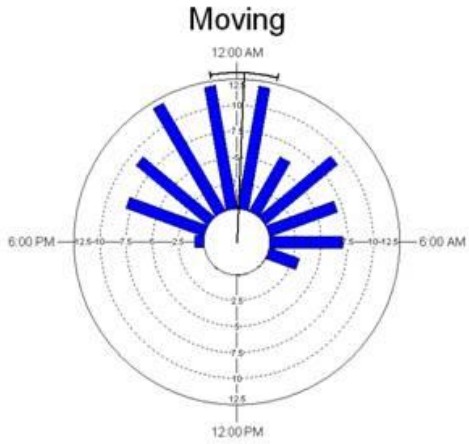
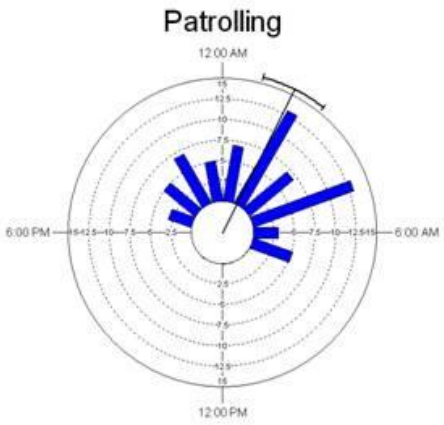


Figure 8.36: Proportional time spent by male lions in wet season in different activities during different times of the day and the related activity peaks deduced by program Oriana.









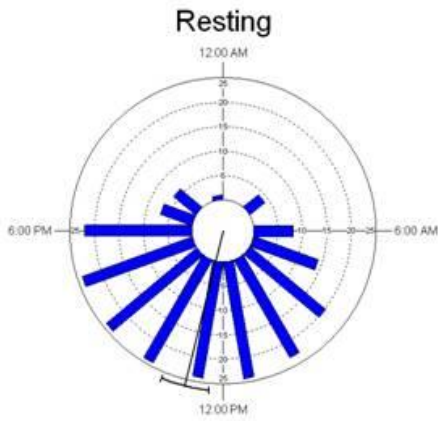


Figure 8.37: Proportional time spent by female lions in different activities during different times of the day and the related activity peaks deduced by program Oriana.

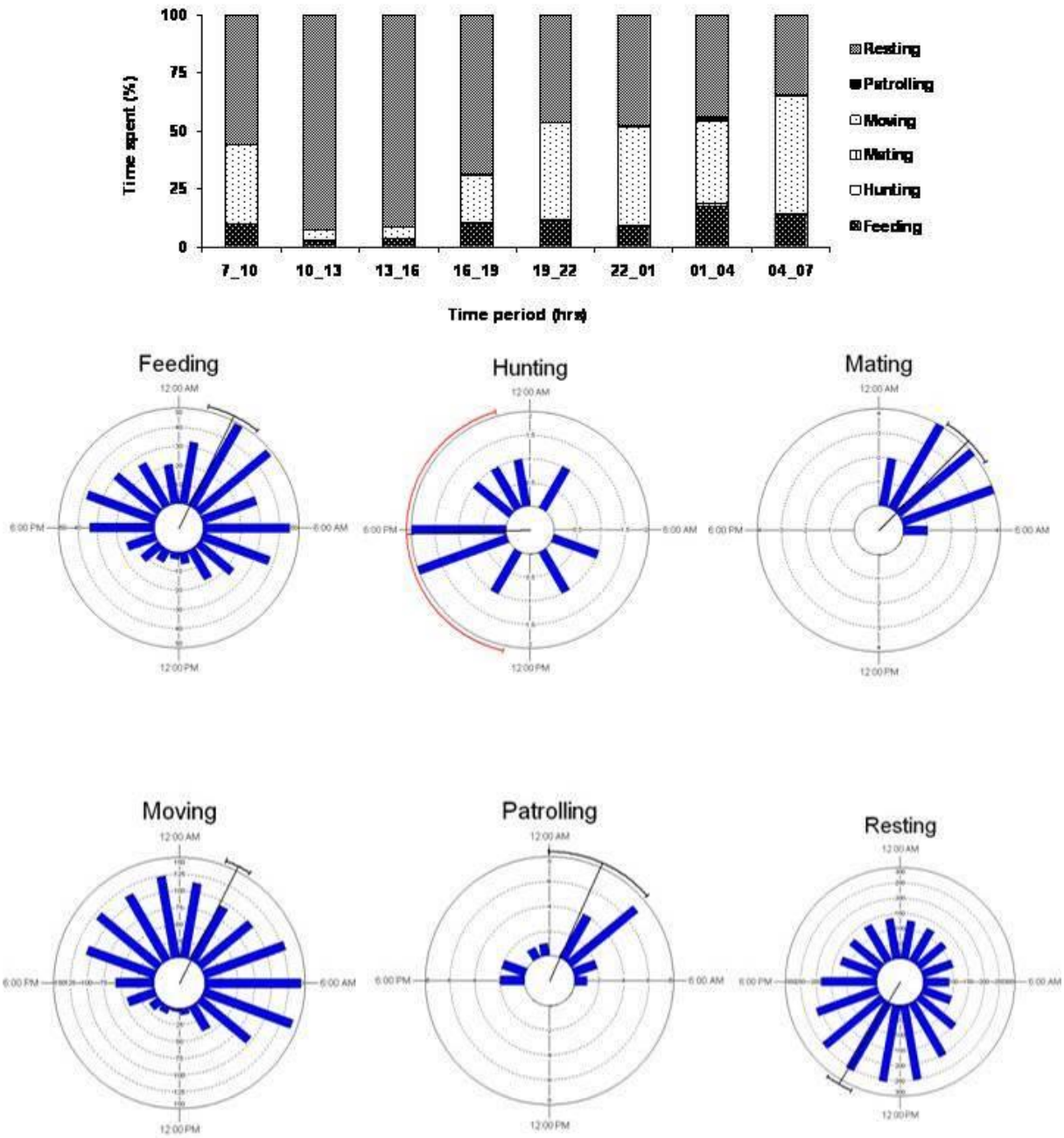


Figure 8.38: Proportional time spent by female lions in dry season in different activities during different times of the day and the related activity peaks deduced by program Oriana.

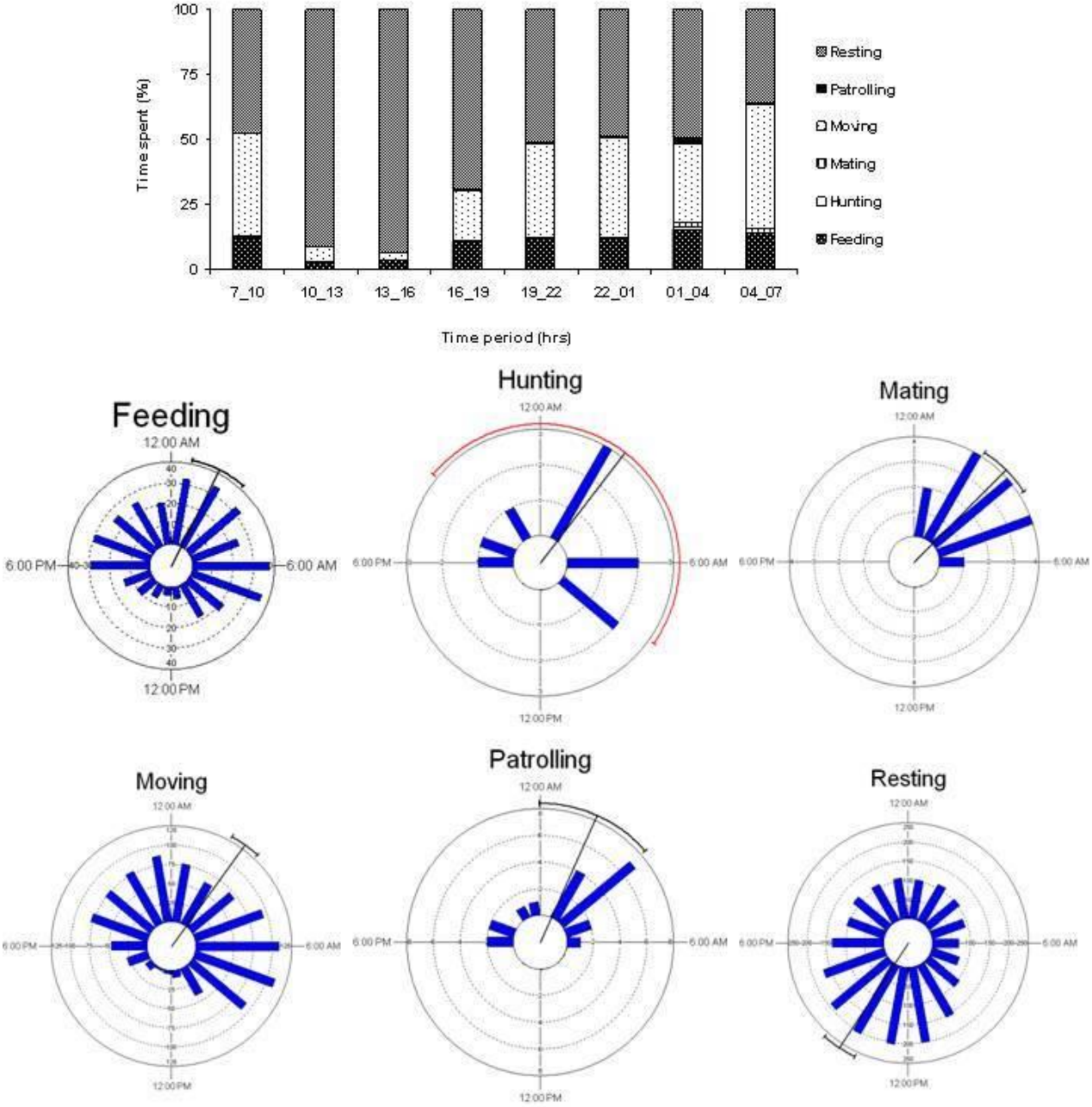


Figure 8.39: Proportional time spent by female lions in wet season in different activities during different times of the day and the related activity peaks deduced by program Oriana.

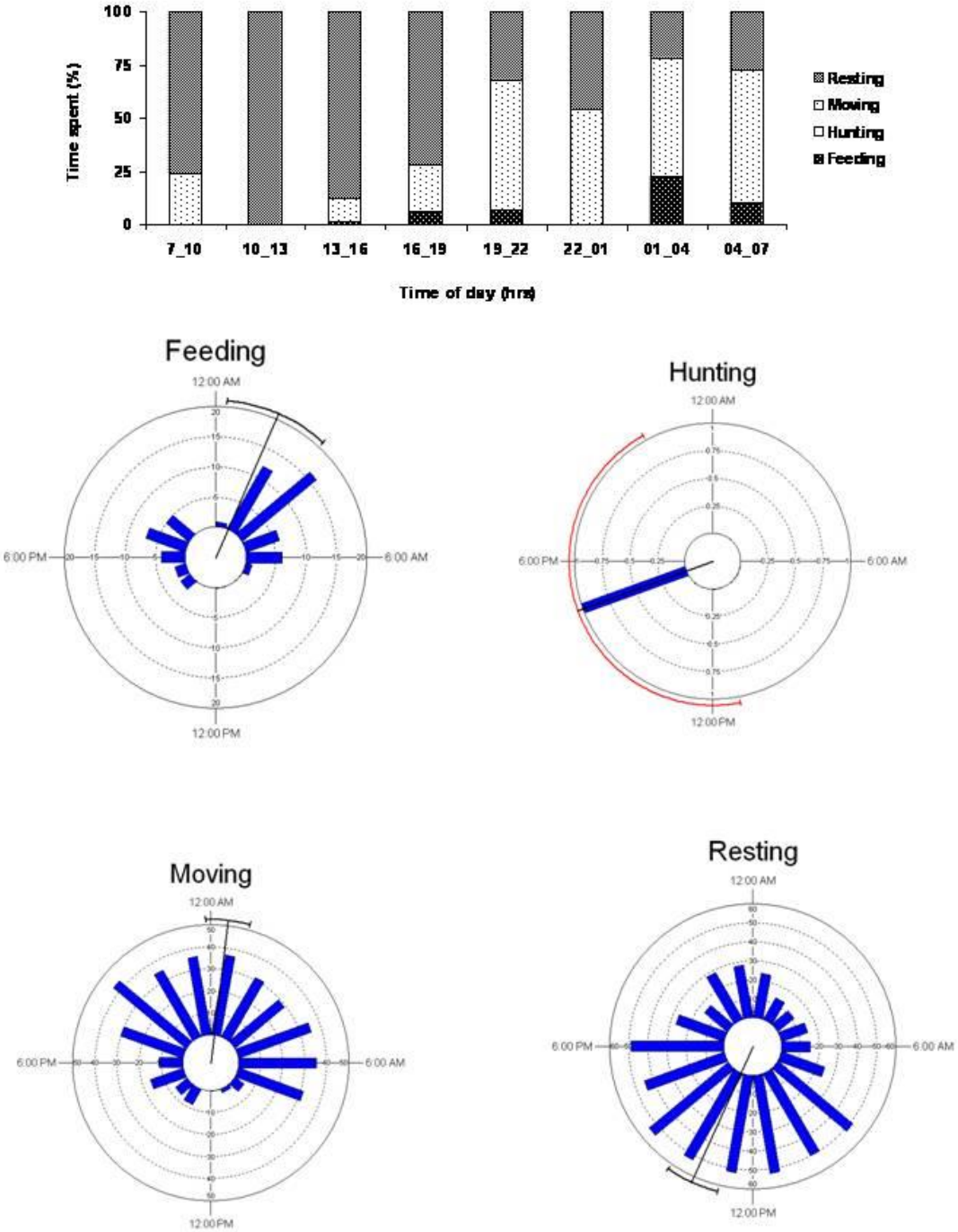


Figure 8.40: Proportional time spent by territorial males in different activities during different times of the day and the related activity peaks deduced by program Oriana.

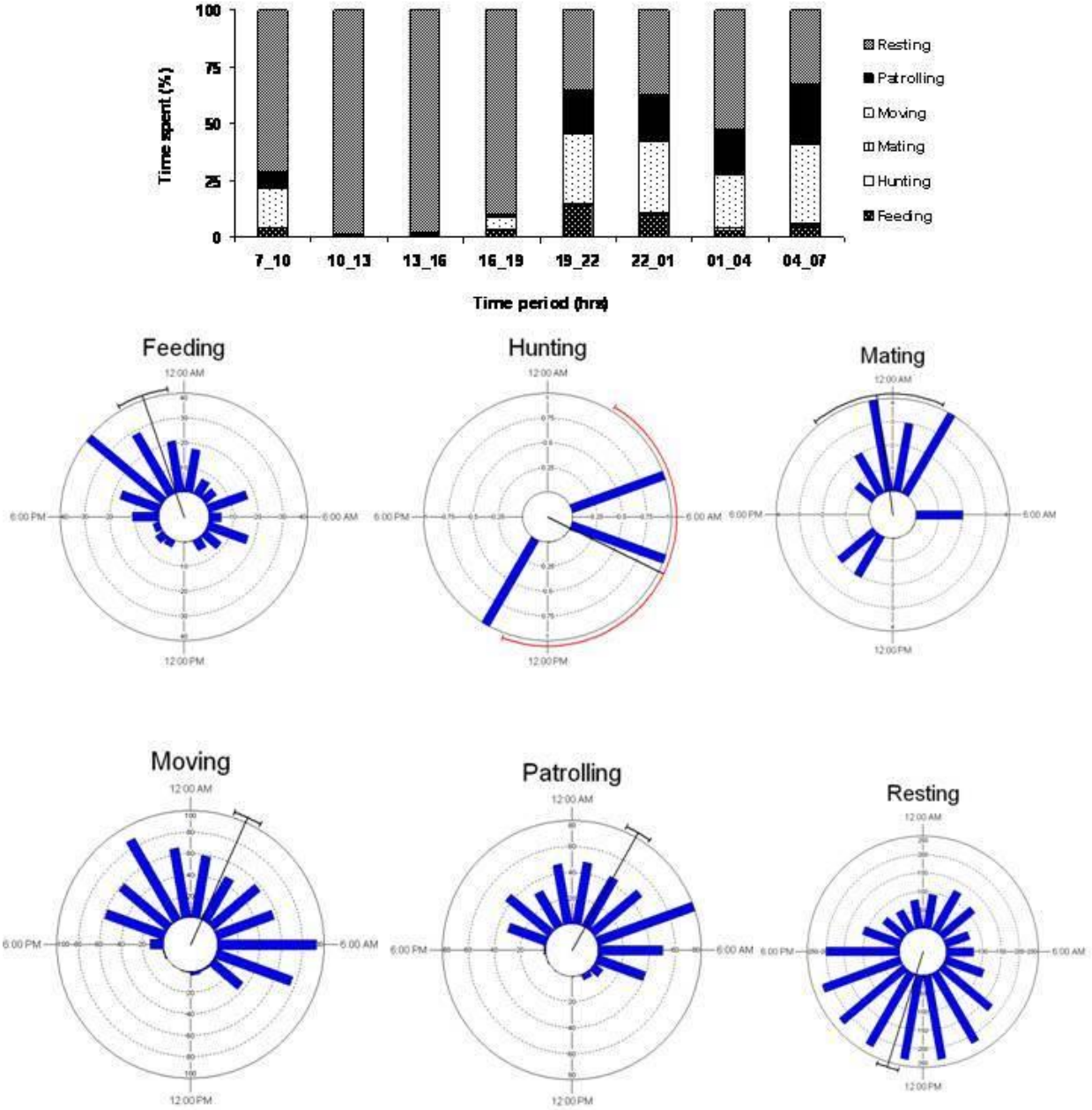
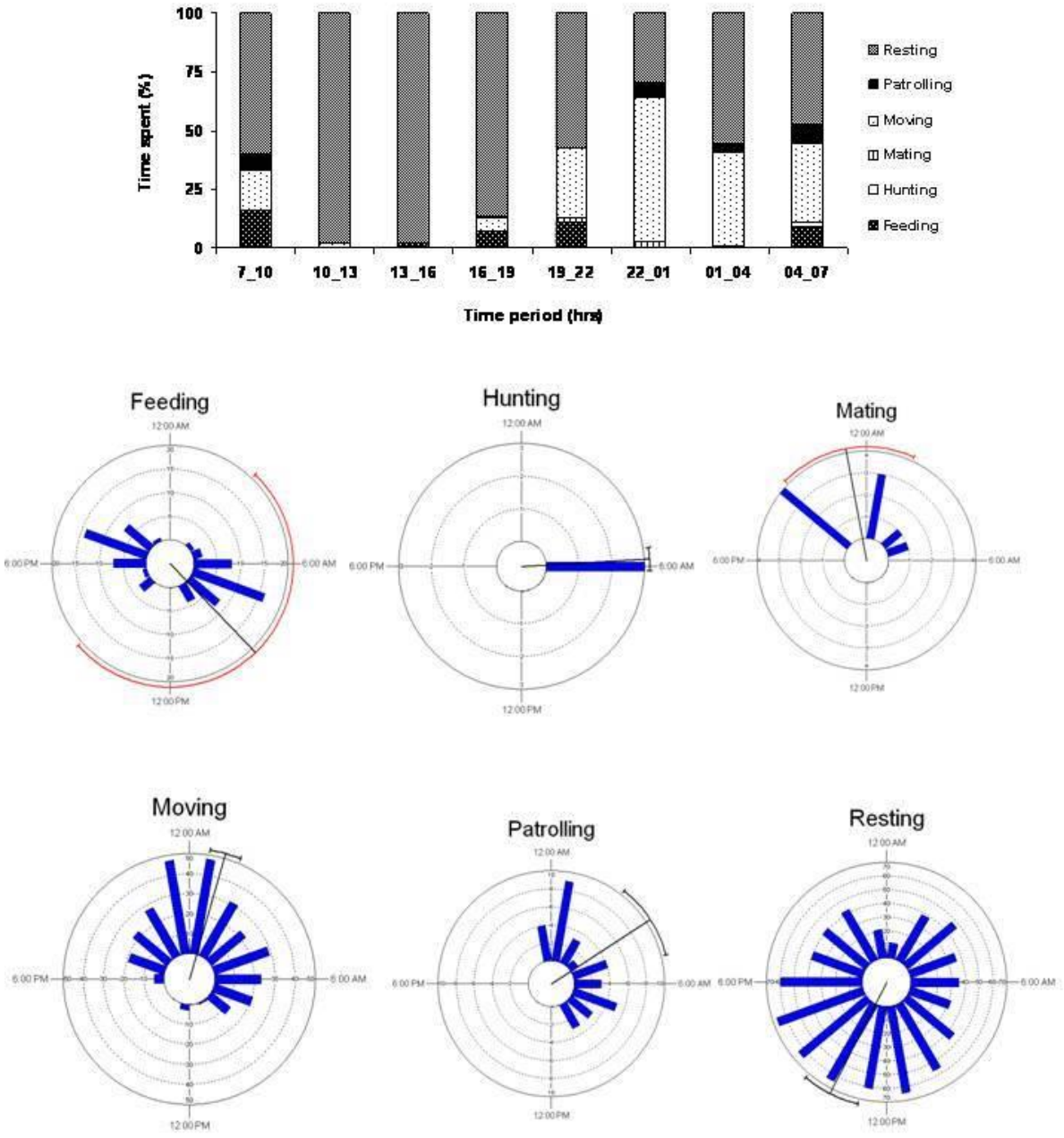


Figure 8.41: Proportional time spent by dispersing males in different activities during different times of the day and the related activity peaks deduced by program Oriana.



Discussions

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

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

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

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

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

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

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

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

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

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

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

After successfully gaining a pride territory and fathering a cohort of cubs, male coalitions only retain possession for a few years before they are either driven out by another coalition, or give up their pride. Large coalitions may retain tenure over two or three adjacent prides simultaneously, but sometimes abandon one pride as soon as they claim another (Schaller 1972; Pusey and Packer 1987). Thus, territorial males may be expected to maintain two or more prides simultaneously, and most Gir coalitions did so as suggested from their range overlap with female cores from the adjacent prides. Old male lions in the Gir have been found to become territorial and father cohorts of cubs even after spending the whole life as nomads. In Gir, male ranges showed remarkable overlap (25% range overlap and 20% core overlap) in the case of two pairs of neighboring coalitions. Although ranges of the adjacent female prides showed overlap, Gir lionesses were more exclusive in defending their core area **(Figure 8.24)**, a pattern also observed

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

Lion reserve	Country	Lion home range size (km^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. 2007
Gir Protected Area	India	Male: 131, Female: 77	3,876*	Joslin 1973
Gir Protected Area	India	Male: 217, Female: 122	20,389; 7,506 (wild ungulates) **	Chellam 1993
Gir Protected Area	India	Male: 74, Female: 34	8,511***	Meena 2008
Gir Protected Area	India	Male: 84, Female: 56	8,511***	Present study; Banerjee 2012
Girnar	India	Male: 243, Female: 170	953	Present study; Banerjee 2012
Eastern landscape	India	Male: 621, Female: 129	1,212 (including domestic prey)	Present study; Banerjee 2012

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

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

Distribution of conspecifics is known to influence ranging patterns as much as the habitat characteristic, dispersion and availability of prey (Sunquist 1981). This was evident in the Gir PA and the eastern landscape where areas occupied by males till mid-phase of our 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 *bigha* = 88,426 sq. meter (@ 2,327 m^2/bigha) = 0.1 km^2). 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 5, present report), this would lead to an estimate of 9,200 ‘lion-farm encounters’ in one home range alone. Bearing in mind the degree of female range overlap (30%), this would rise to about 12,000 ‘lion-farm encounters’ within one home range annually. Sightings of lions on multiple, discontinuous farms could mistakenly be taken as evidence for many lions in an area, whereas it could easily be the same lion or group of lions simply moving through its range. It would overestimate local lion

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

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

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

The general mechanisms that decrease inbreeding (described by Pusey and Packer 1987) seem to be maintained in Gir lions even though males do not disperse far. All the sub-adult males during our 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 *refugia*s) 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 Rijjsel et al. 2008; Visser et al. 2009). Schaller (1972) reported that the activity patterns of both nomadic lions and pride members are remarkably similar. It peaks between 17.00h and 8.00h, although hunting, feeding and mating may occur at all times of the day (Schaller 1972). According to Schaller (1972) lions spent on average, two hours a day walking and 40 to 50 minutes of a day are spent eating. The rest of the day, between 20 to 21 hours, the lions are largely inactive (Schaller 1972). Hayward and Hayward (2007) found that lions were active throughout the day with crepuscular peaks around sunrise and sunset. They reported a lion activity of 41% during the day and hypothesized this high percentage to be caused by the lack of a pride. Gir lions spent majority (60%) of their time in resting and remained active for the rest 40% of the time. No seasonal difference was observed among lion activities. Males expectedly patrolled more than females. Hunting peaks of males and females coincided with the activity peaks of chital and sambar (Schaller 1967); two most preferred prey species of lions in the Gir PA. Moreover it also coincided with the onset and end of livestock grazing time in Gir. Livestock constituted a significant part of the Gir lions' diet (Banerjee 2012; Banerjee et al. 2013). *Maldhari*s corral their livestock for night inside the nesses and livestock herds start grazing in the forest in the early morning. Lions mostly attacked grazing herds during this period as most of the livestock remained relatively inactive and herders remained unprepared. Again, during evenings some livestock became tired after whole day grazing and trailed behind the herd providing with the hunting opportunity for lions. The separated hunting peaks of males (early mornings) and females (evenings) **(Figures 8.34 and 8.37)** is likely to have evolved in the Gir lions so as to reduce kleptoparasitism as observed in the Serengeti cheetahs (Schaller 1972).

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

activity pattern would thus be helpful in formulating future management policies aimed at regulation of human activities within the Gir PA. In the larger landscape this has immense contribution in understanding spatio-temporal patterns of conflicts, especially lion attacks on humans (Banerjee 2012).

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

CHAPTER IX

LION HABITAT USE & RESOURCE SELECTION

Introduction

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

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

between conservation goals and livelihood needs in an agrarian country like India having a substantial amount of biodiversity in the human-dominated landscapes (DeFries et al. 2010; Karanth and DeFries 2010).

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

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

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

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

Methodology

Field Methods and Analyses

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

Habitat and landscape data:

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

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

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

A. Tree Cover, broadleaved, deciduous, closed (abbreviated as closed deciduous): Represented mostly by riparian habitats in Girnar and plantations and government nurseries. The dominant species is *Tectona grandis* with association of *Anogeissus latifolia*, *Dendrocalamus strictus*, *Butea monosperma*, *Mitragyna parviflora*, *Syzigium*

cumini, *Terminalia* spp., *Dalbergia* spp., *Ficus* spp. and *Diospyros melanoxylon*. The understory is dense and mainly composed of *Helicteres isora*, *Carissa carandas*, *Capparis sepiaria* etc. This LULC class is the densest and has the highest canopy cover.

B. **Tree Cover, broadleaved, deciduous, open (abbreviated as open deciduous):** Represented by *Acacia nilotica*, *Acacia senegal*, *Acacia catechu* and *Acacia leucophloea* with association of *Ziziphus* spp., *Sterculia urens*, *Lannea coromandalica*, *Pongamia pinnata*, *Holeptelia intigrifolia*, *Boswellia serrata* and *Terminalia* spp occurring in Girnar, Mitiyala, Pania sanctuaries and reserve forests in the landscape.

C. **Scrubland:** Represented by thorny woodlands and scrublands in the landscape. This LULC class is mostly dominated by *Zizyphus nummularia*, *Acacia senegal* and *Prosopis juliflora* occurring in the reserve forests and their peripheries, wastelands and fallow lands of the landscape.

D. **Grasslands:** Represented by government and private owned *vidi*s in the landscape. The major grass species include *Sehima sulcatum*, *Apluda mutia*, *Heteropogon contortus* and *Cymbopogon* spp.

E. **Agriculture:** Represented by irrigated and rainfed agricultural lands and natural vegetation outside a PA. This is the major land-use pattern in the landscape characterized by sparsely covered seasonal crops and orchards. Main crops include ground nut, cotton seed, wheat, sugarcane, pulses and spices. Saurashtra is famous for indigenous *Keshar* breed of mangoes and these orchards however provide good refuge covers. In some part of the landscape (Shail and Shetrunjee basins) most of the agricultural lands are fallow as farming becomes expensive for farmers due to lower rainfall and lack of proper irrigational facilities. These farmlands are chiefly dominated by *Prosopis juliflora* thickets which are used for charcoal manufacturing and serve as good refuge for lions.

F. **Barren lands:** Includes rocks and escarpments is mostly represented by the limestone mines in the landscape. Abandoned mines are often known to provide shelter to lions and other wildlife in the Gir landscape.

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

AVHRR-NDVI: Normalized difference vegetation index (NDVI) composites with a 10 day interval were derived from a the 1 kilometer advanced very high resolution radiometer (AVHRR) data acquired by National Oceanic and Atmospheric Administration's (NOAA) Television Infrared Observation Satellite (TIROS; Townsend 1994). The relationship between NDVI and photosynthesizing vegetation is well documented (Eidenshink 1992). NDVI has been used to monitor vegetation response and to determine changes in vegetation cover over time. NDVI maps have been used to locate urbanizations, forests, vegetation phenology, crop cycles, and agricultural practices.

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

Digital elevation model (DEM): The Shuttle Radar Topography Mission produced the most complete, highest resolution digital elevation model of the Earth (Rodriguez et al. 2005). It used dual radar antennas to acquire interferometric radar data, processed to digital topographic data at 1 arc-sec (approximately 30m X 30m) resolution. The data has linear vertical absolute height error of less than 16 meter (Rodriguez et al. 2005). We used DEM data (mean and variance of elevation) from the website www.glcf.umiacs.umd.edu/data/srtm 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.

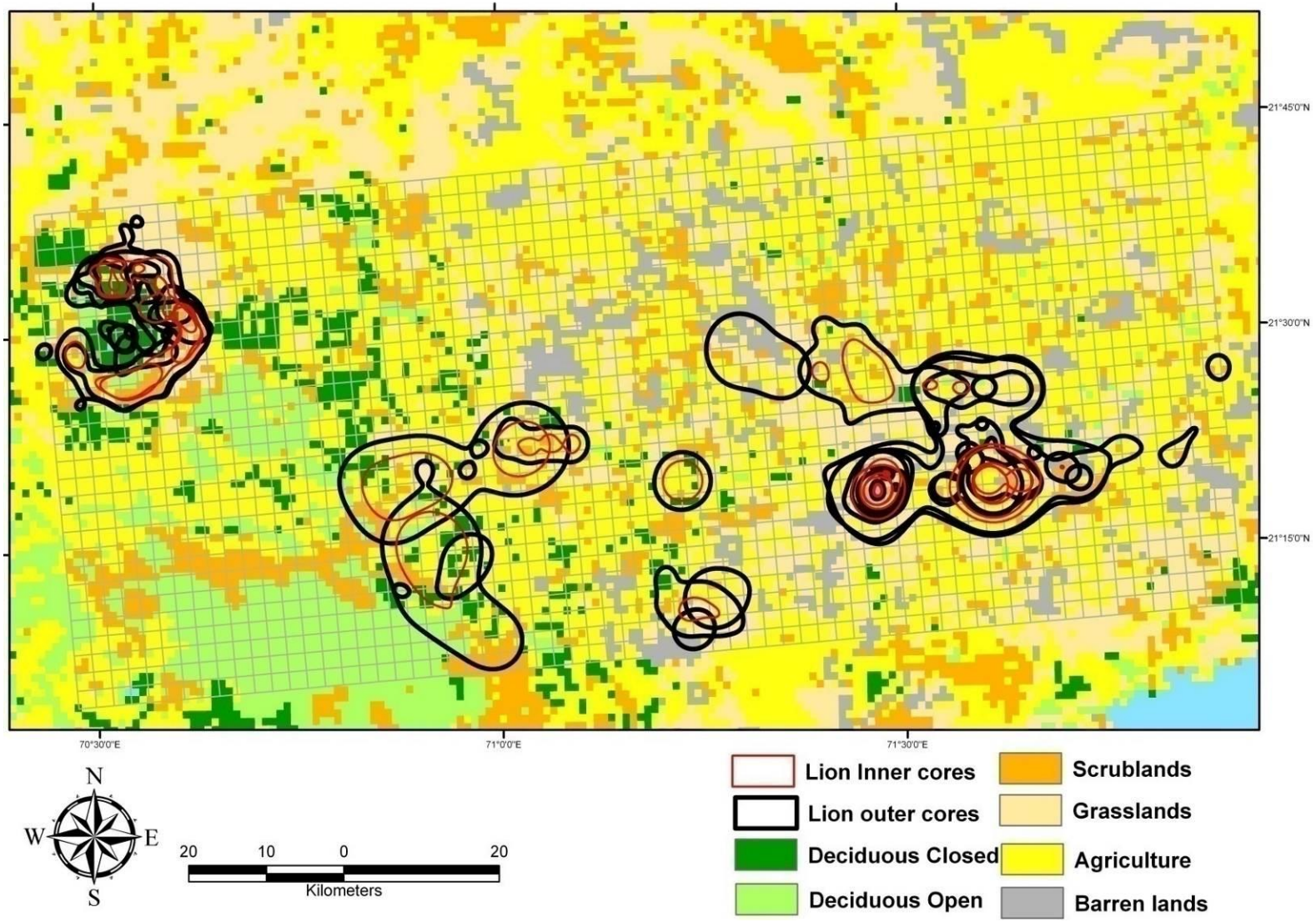
Compositional analysis

Second order resource selection function was used to understand the habitat selection of lions in the study area. We defined the extent of our 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. We compared the mean patch sizes for locations proximal (< 1 km) to human habitation centroids with patch sizes for distant (> 1 km) locations by non-parametric tests.

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

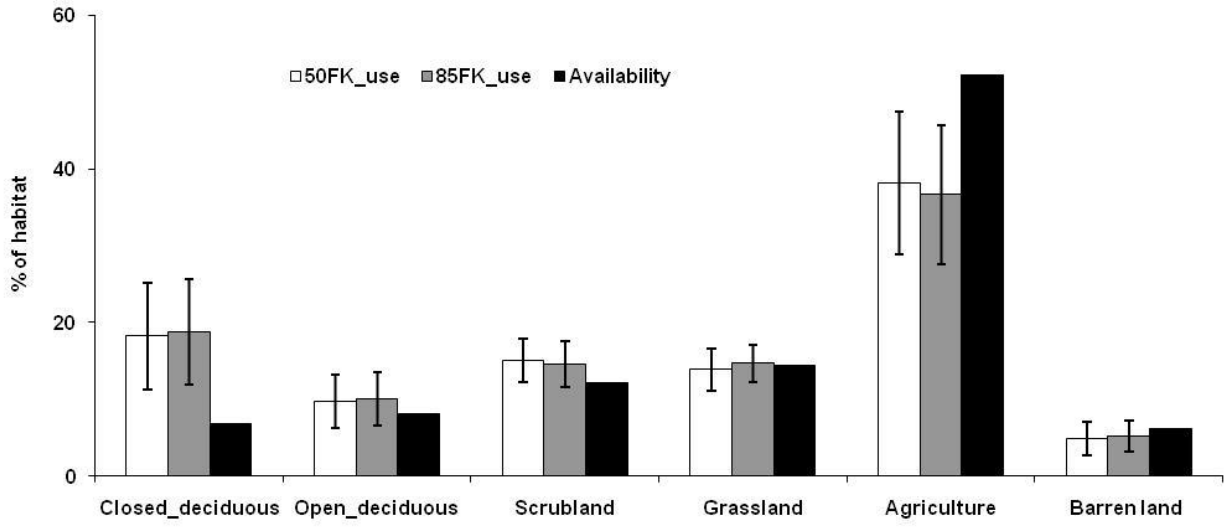


Results

Compositional Analysis

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

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



Influence of different habitat variables on lions' core area selection

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

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

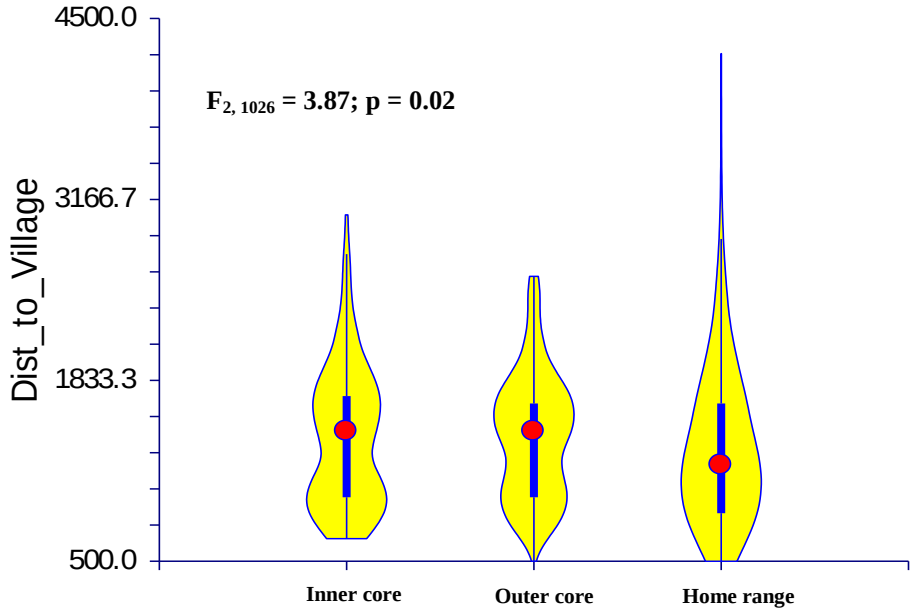


Figure 9.4: Influence of roads explaining lions' core selection in the Gir landscape.

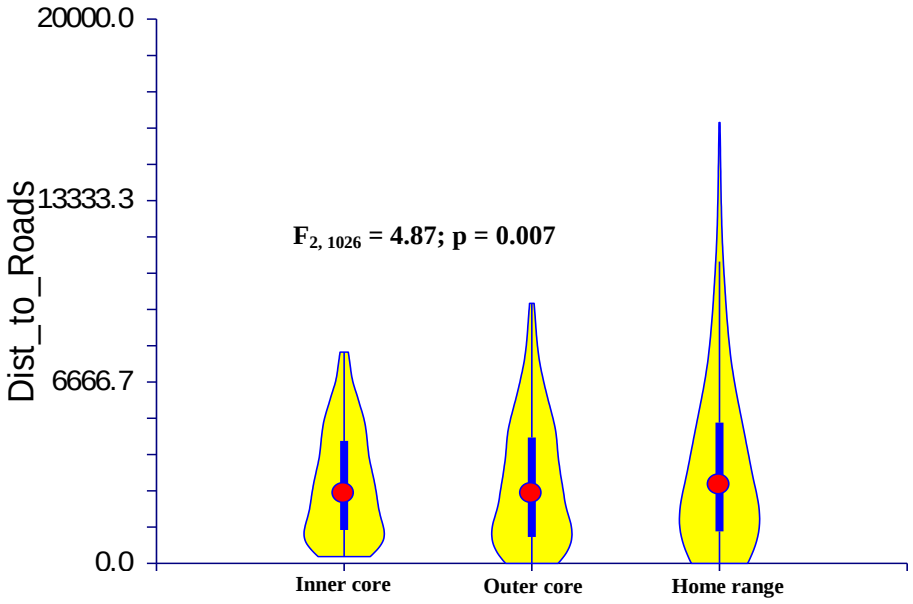


Figure 9.5: Influence of rivers explaining lions' core selection in the Gir landscape.

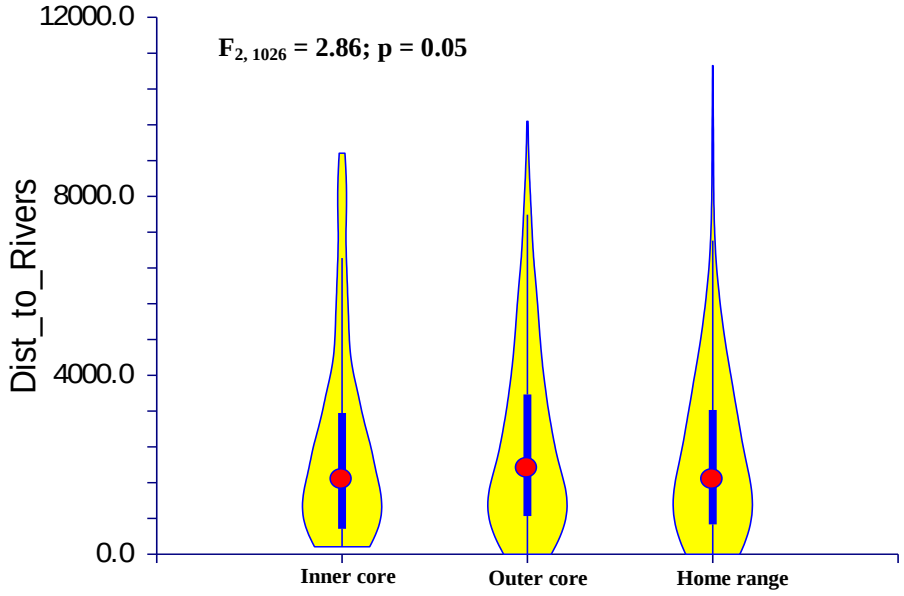


Figure 9.6: Influence of human habitations (delineated by night lights) explaining lions' core selection in the Gir landscape.

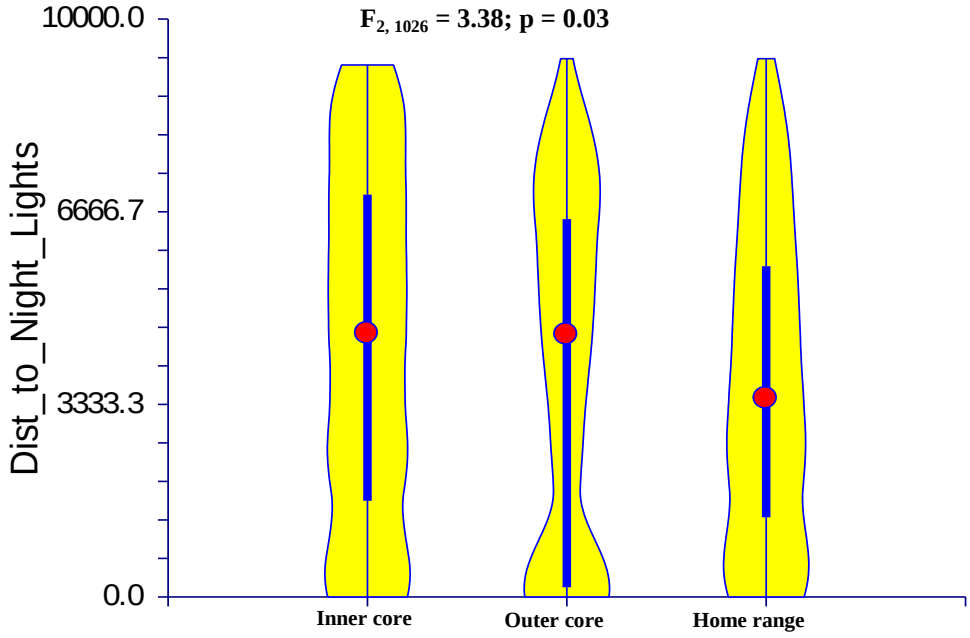


Figure 9.7: Influence of Protected Areas explaining lions' core selection in the Gir landscape.

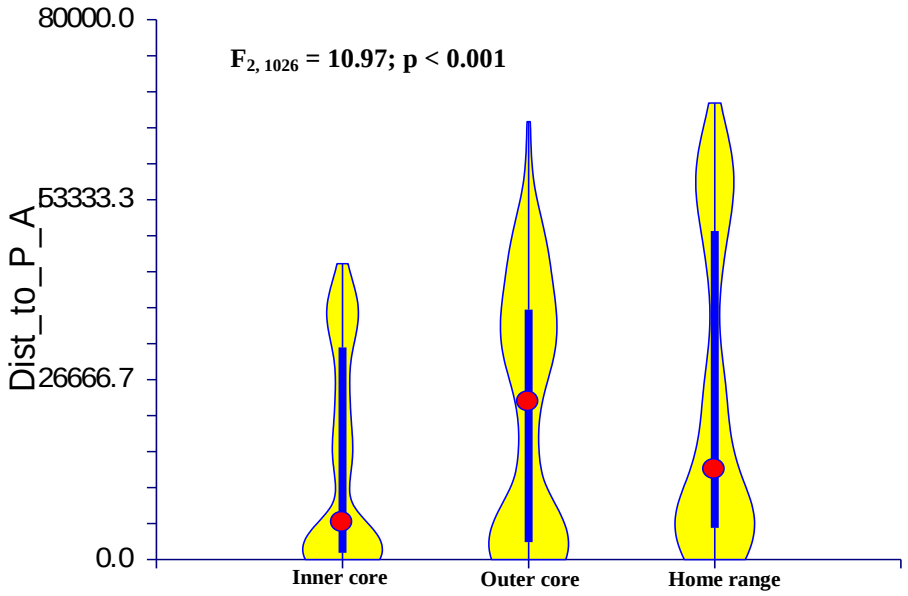


Figure 9.8: Influence of pre-monsoon NDVI explaining lions' core selection in the Gir landscape.

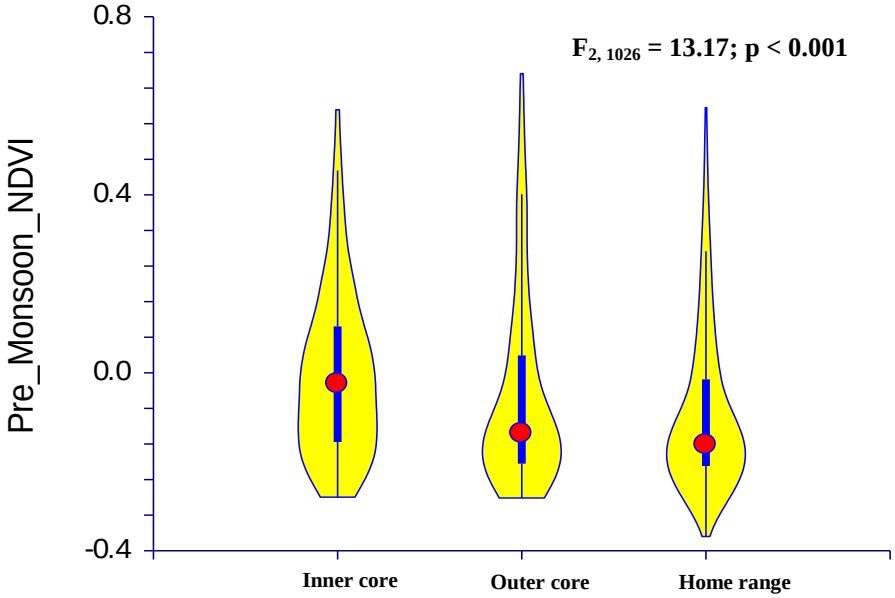


Figure 9.9: Influence of elevations explaining lions' core selection in the Gir landscape.

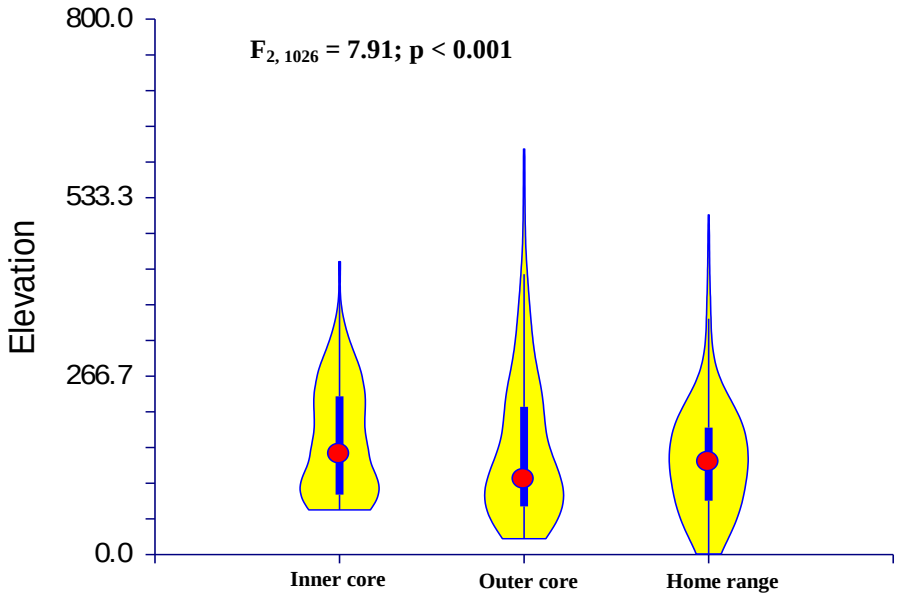
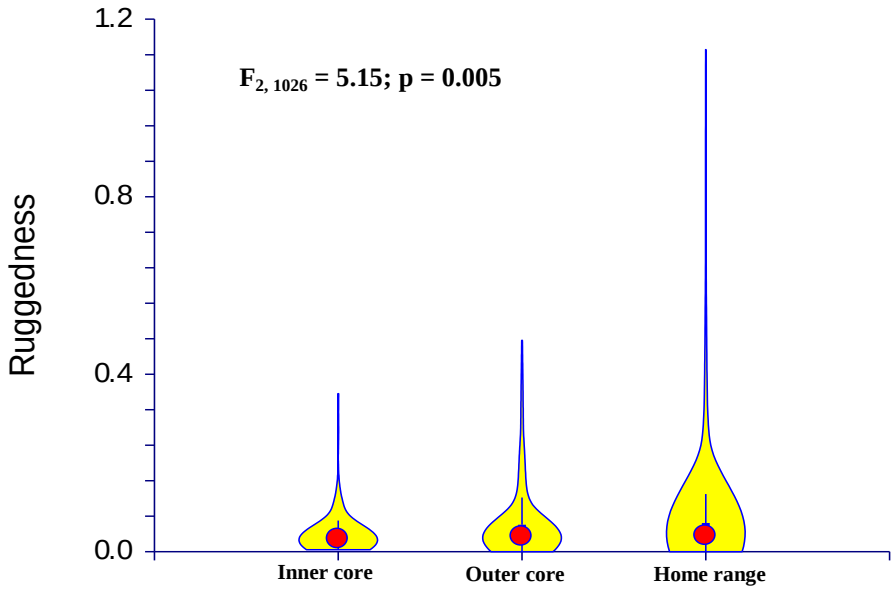


Figure 9.10: Influence of terrain ruggedness explaining lions' core selection in the Gir landscape.



Lion day time refuge patches size: Average day refuge patch size of lions in the eastern landscape was estimated to be 7.5 km^2 (SE 0.74; range: 0.07 km^2 – 21.5 km^2). Breeding lionesses had similar sized day refuge patches (3.8 km^2, SE 1.7; range: 0.4 km^2 – 5.5 km^2) like

adult males (7.6 km^2, SE 0.77; range: 0.07 km^2 – 21.5 km^2) [t = 0.95, p = 0.34]. Minimum patch size in which a lioness reared her cubs successfully was 4.3 km^2. Refuge patch size did not vary in size for lion locations proximal (9.5 km^2, SE 1.71; range: 0.33 km^2 – 21.5 km^2) or distant (7 km^2, SE 0.82; range: 0.07 km^2 – 21.5 km^2) to human habitations (t = 1.25, p = 0.21). **Figure 9.11** shows the smallest day time refuge patch size of lions near Savarkundla and Chalala while the largest day time refuge patch was represented by Mitiyala wildlife sanctuary near Khambha **(Figure 9.12)**.

Discussions

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

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

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

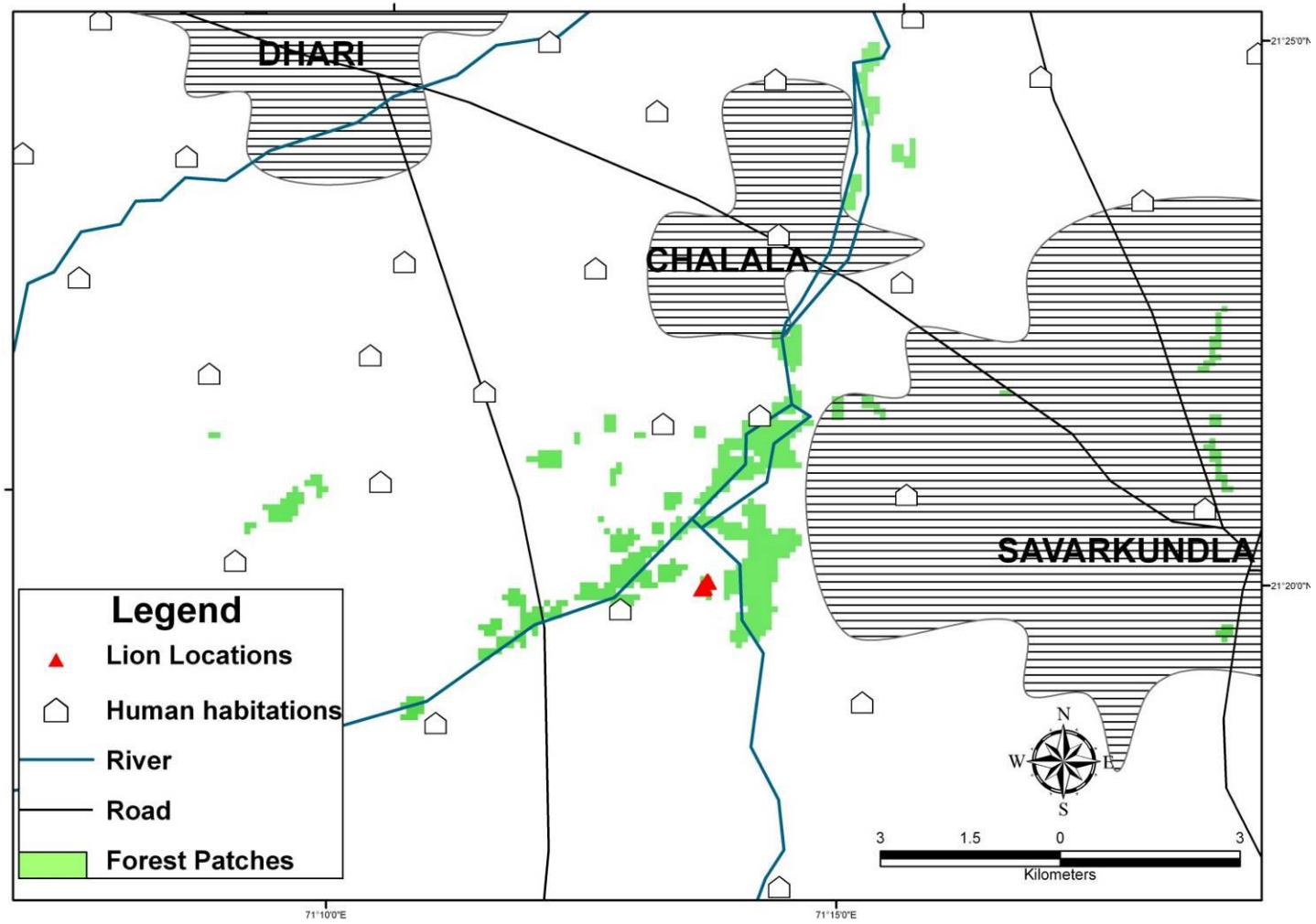
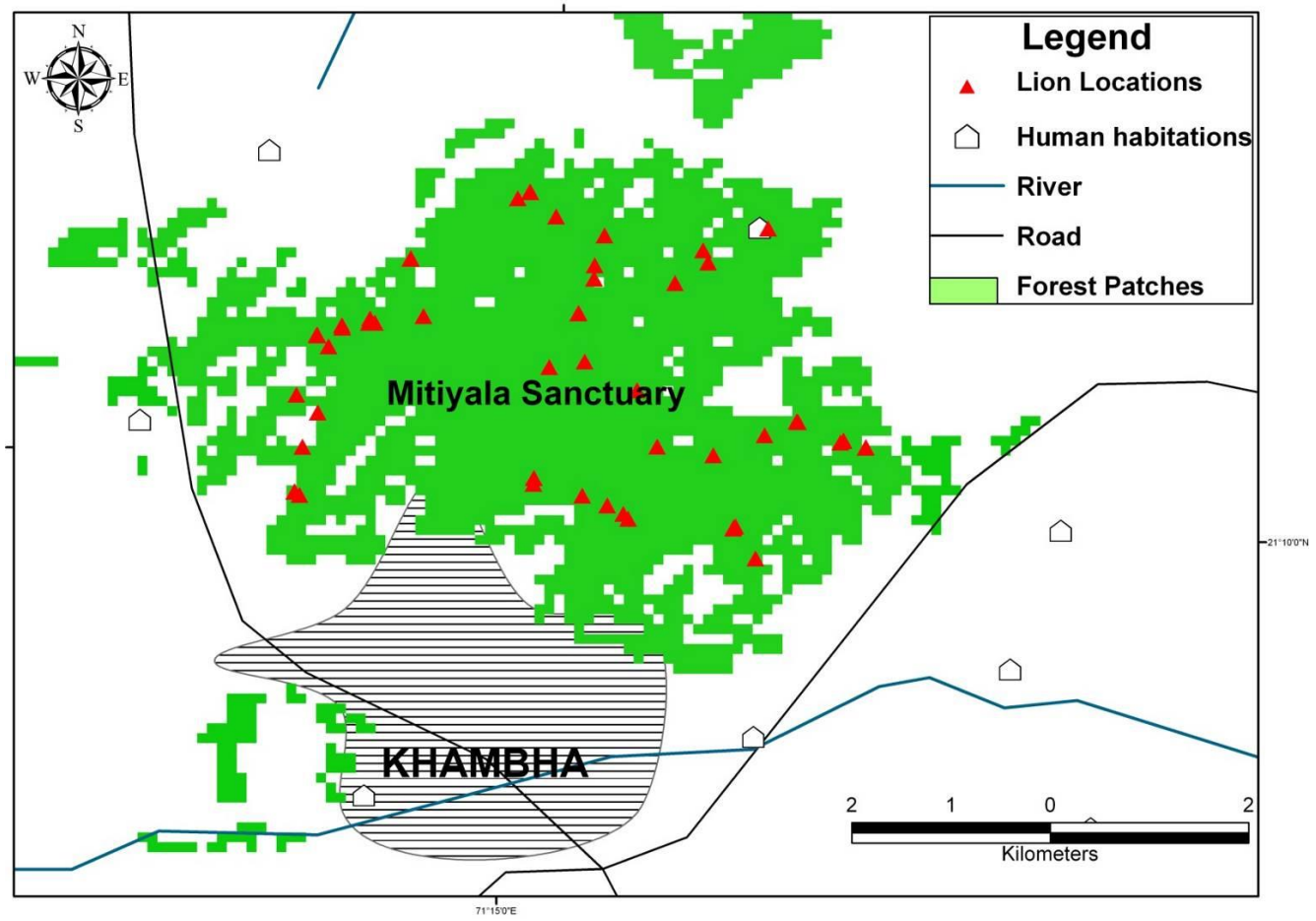


Figure 9.12: Largest day time refuge patch (21.5 km^2) of lions in the Gir landscape represented by Mitiyala Sanctuary.



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

Considering the high biodiversity value and ecological role of this forest type, we recommend conserving this land-cover type against all possible threats. However, dense habitat types in Girnar could be planted with miscellaneous species like *Zizyphus* spp., *Acacia* spp. and *Terminalia* spp, having forage value for wild ungulates. This will likely increase the nutritional carrying capacity for native wild ungulates which in turn will be beneficial for lions and leopards.

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

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

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

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

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

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

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

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

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

labors engaged in sowing in the field. Finally at 10:30 AM the lionesses were able to get inside the Girnar Sanctuary.

The minimum patch size in which lions took daytime refuge was found to be as small as 0.07 km^2 whilst the largest forested area was represented by Mitiyala wildlife sanctuary (21.5 km^2). 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 our study period, this has been specially observed in the areas like Shivatali and Hothalio-Monvel (Visavadar *tehsil*), Dhari and Dholilui-Nal-Rabarika (Savarkundla *tehsil*) where vast tract of waste lands and community lands have been converted for agricultural purposes. Without any clear state level wildlife tourism policy, the situation is more worrying near Sasan (Talala *tehsil*) where new resorts are coming up almost every day. Upcoming lion safari park at the Ambardi Reserve Forest also resulted into construction of resorts and hotels near Dhari causing loss of such refuge patches. Gujarat forest department's proposal on Ambardi safari park is welcoming as it is likely to reduce tourism pressures on the park's current tourism zone at Sasan. But Ambardi acts as a significant refuge patch for lions **(Figure 9.13)** and a habitat corridor between Visavadar, Dhari and Khambha. We also observed consistent use of this patch by a resident group of about 12-15 lions during our study period. Fencing a substantial part of this crucial habitat patch may have detrimental effect on the demography, population dynamics, behaviour and survival of the resident lions. This could be partially addressed by compensatory afforestation (Forest Conservation Act 1988) on nearby government wastelands which would potentially act as refuge habitat patches for lions in future.

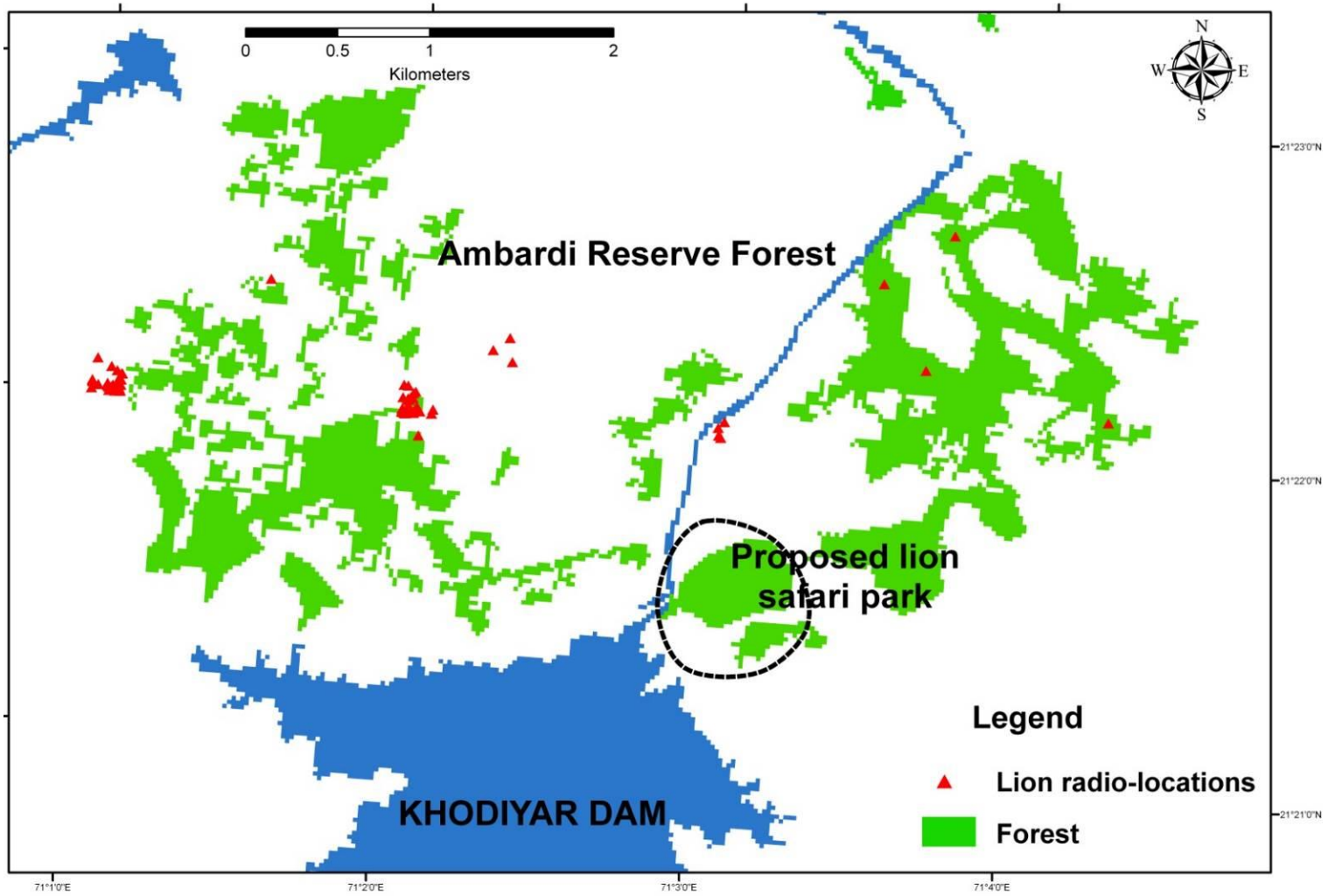
Like many parts of Gujarat, Saurashtra is a producer of charcoal. Charcoal is generally produced from *Prosopis juliflora* and has a good market price and creates local employment. Moreover, *Prosopis juliflora* is a chief source of fuelwood in majority of the agro-pastoral

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

Since land ownership in the Gir landscape is primarily private, the Government has little control over loss of many potential lion habitats in the Gir landscape. However, community lands and fallow lands could be acquired fast even at a higher market price and be legally protected before they go in the hands of land mafias. Conservation of all vegetation patches larger than 4 km^2 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 (*vidi*s) and Reserve Forests in Dhari, Khambha, Nani Vadal, Hipavadli, Ranigalo, Dholikui, Kantrodi, Jesar, Bagdana and Talaja of Amreli and Bhavnagar districts should immediately be declared as 'conservation reserves' and managed through eco-restorative measures so as to enhance their capacity of supporting more lions in future. Similarly, potential lion habitats and refuge patches surrounding the major river basins in the region should be declared as 'eco-sensitive zones' so as to curb any further habitat deterioration. An innovative land-use policy should be introduced wherein local people should be given incentives for maintaining traditional land-use patterns. A stringent and transparent tourism policy curtailing any development within five km from forest boundaries should be considered. Compensation to the local farmers for crop depredation by wild ungulates should be immediately introduced as it will prevent decline of the wild ungulate densities in the larger landscape and help in future lion conservation. Dispersal of daytime habitat refuges within the larger landscape and education campaigns for local people not to enter into such thickets would benefit both lions and humans by reducing conflicts. To ensure lion conservation in a metapopulation framework, a landscape level policy with a concerted

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

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



CHAPTER X

LION'S DIET IN THE GIR LANDSCAPE

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 (*Maldhari*s; more

detail in chapter 12). In the larger human-dominated landscape of Gir, this becomes even more crucial as lions live in close proximity with humans (chapters 8 and 9) enhancing the likelihood of conflicts predominantly by stock raiding. In the absence of any scientific information on lions' food habits outside the Gir PA, it often becomes difficult for the managers to defend the polarized conservation arguments by the pro-people lobbies mostly based on assumptions and hypotheses. Such contentious issues easily get support from the local political groups and may have significant role in shaping local communities' attitudes toward lions; by large negatively. With globalization; human values, people's custodian role for nature and natural resources and levels of tolerance toward damage caused by wild animals may lose irrevocably. All these may even lead to extirpations of lion populations in small pockets of the Gir landscape; as happened with many carnivore populations elsewhere in the world (Treves and Karanth 2003). Information on i) what are the food habits of lion populations in the Gir landscape, ii) how often do lions predate on livestock and iii) what part of a lion's diet is actually obtained by predating livestock and what proportion by scavenging dead livestock therefore becomes crucial for ensuring long-term survival of the Gir lions by minimizing conflicts. Herein, we evaluate lion food habit in Girnar and human-dominated eastern landscape based on scat analysis, telemetry and information on predation. We use this knowledge to assist the management in developing a conflict mitigation strategy for lions in the Gir landscape.

Methodology

Lion prey base estimation in Girnar

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

demarcating 1-2 trails in each forest round. Each 1.2 - 3.2 km trail was sampled 1-3 times by two experienced observers during early morning hours (6:30 AM – 8:30 AM) when ungulate activity was the highest.

Lion prey base estimation in Eastern Landscape

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

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

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

Ripley 1983; Karanth and Sunquist 1995; Singh et al. 2002; Bhatt et al. 2005; Mehta et al. 2007; Pandey and Singh 2010).

Lion predation events

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

Lion scat collection and analysis

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

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

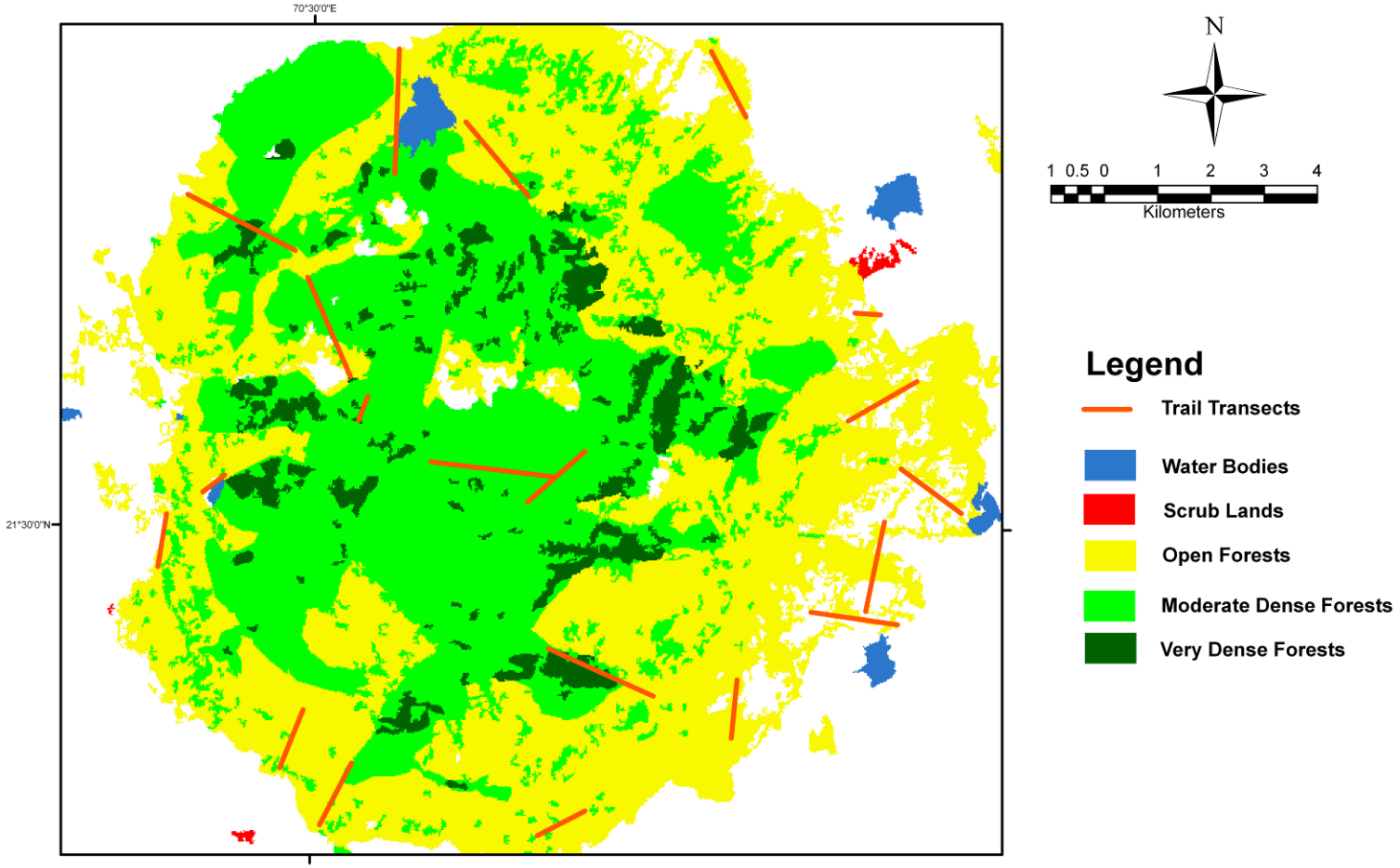


Figure 10.2: Distribution of the vehicle transects (n = 33) for prey base enumeration in the agro-pastoral eastern landscape.

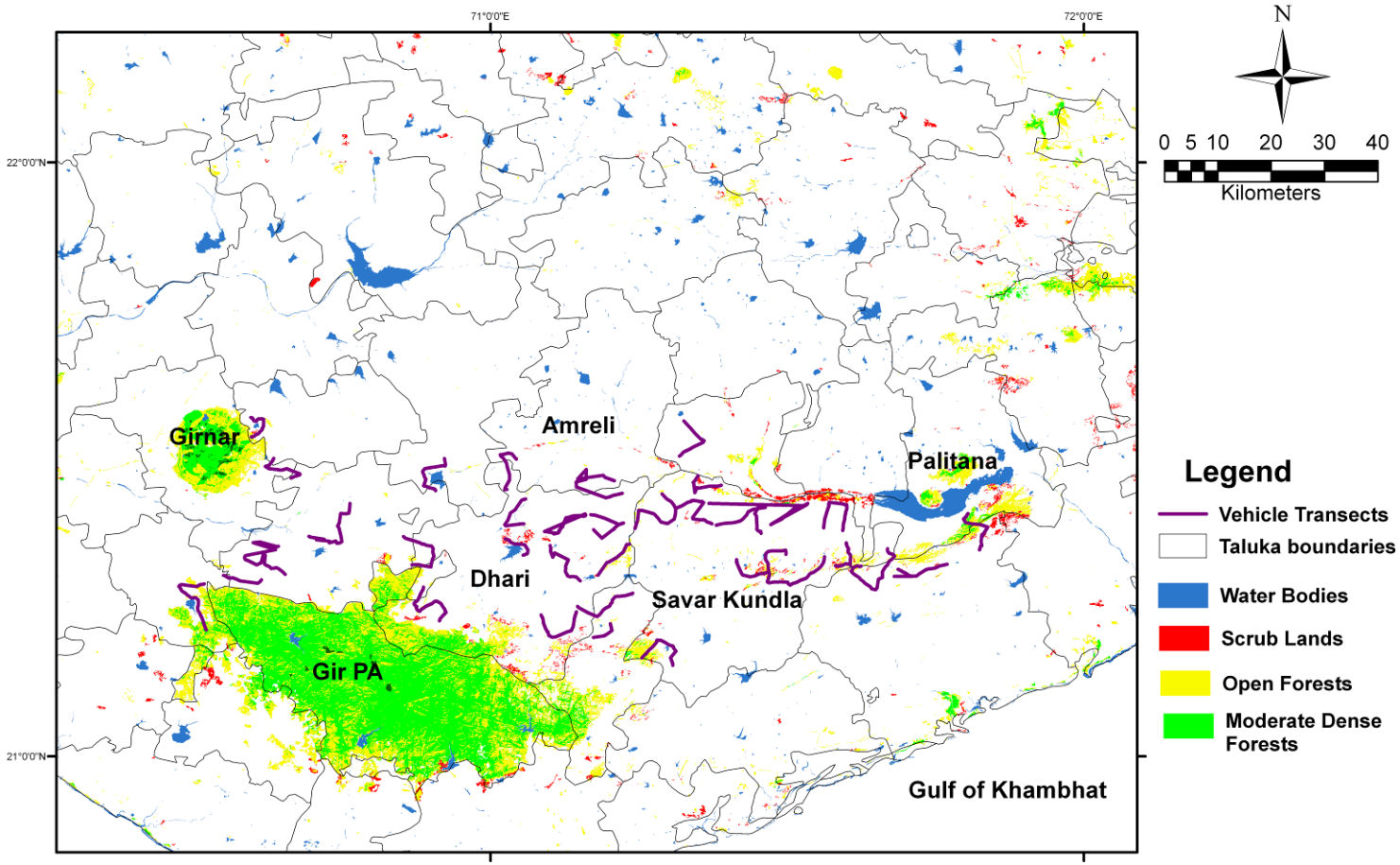
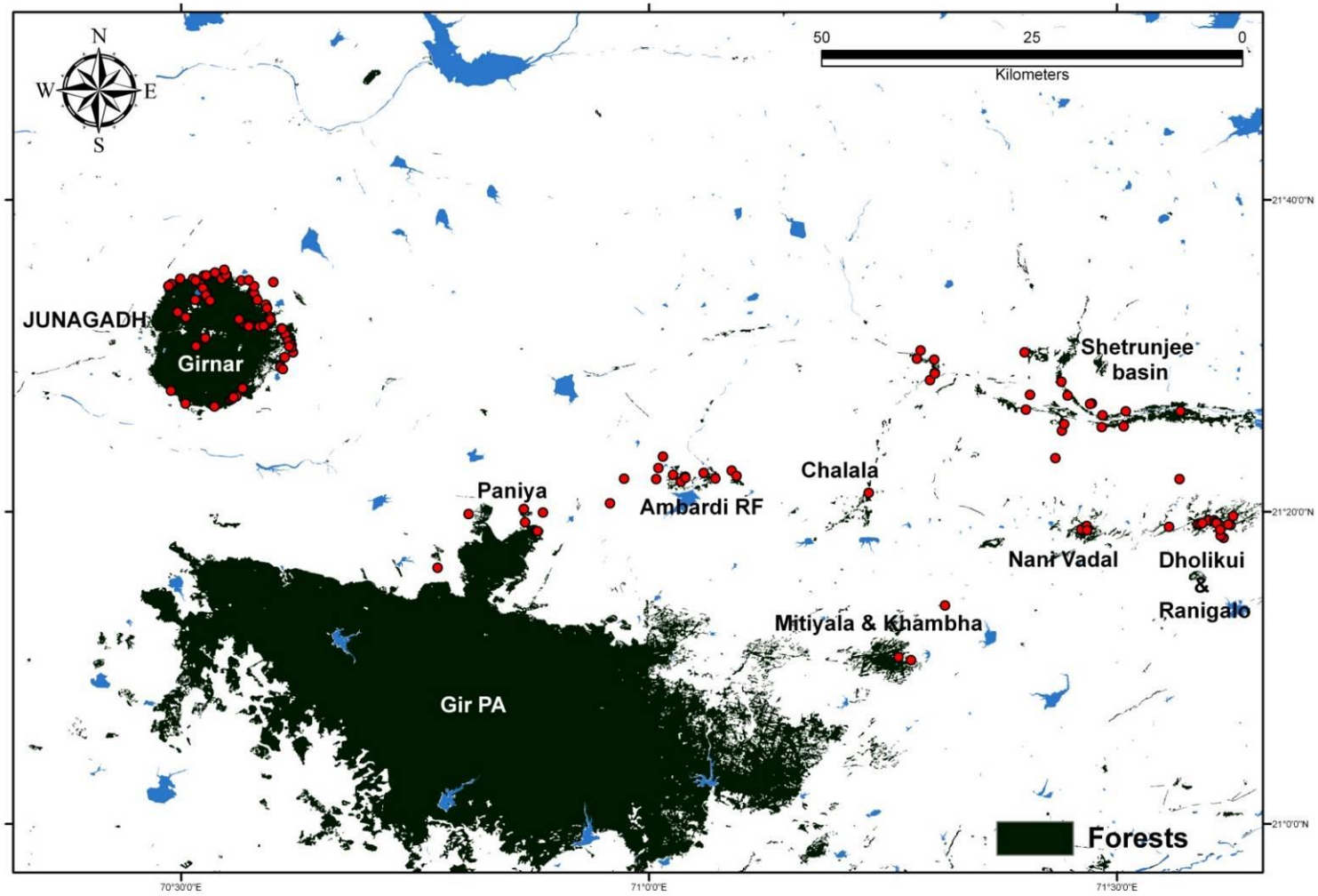


Figure 10.3: Lion scat collection fixes spreading in all potential lion habitats across the Gir landscape.



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

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

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

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

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

Results

Lion prey abundance

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

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

i)

ii)

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

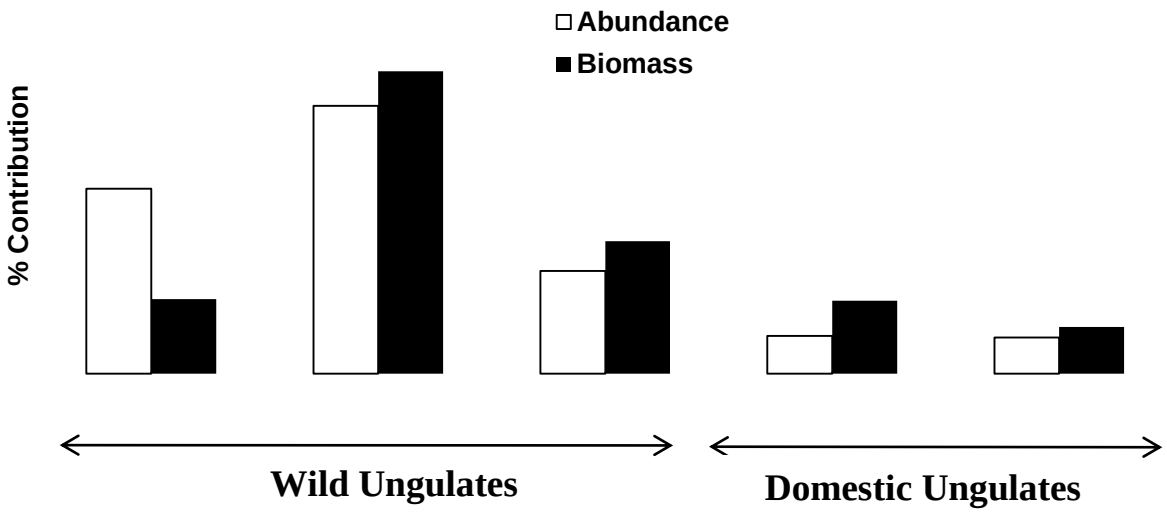
Prey species	Unit weight (kg)	Density/km^2	ESW (meter)	Average group size	Encounter rate/km	Biomass density (kg/km^2)	Total biomass (kg)
Chital	42	2.7 (± 0.9)	27.9 (± 6.2)	4.9 (± 0.7)	0.14 (± 0.05)	112.9 (± 56.1)	20,320 (± 10,093, 11.8%)
Sambar	119	3.8 (± 0.7)	38.5 (± 5.0)	2.3 (± 0.2)	0.29 (± 0.05)	458.1(± 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 10.2: Estimates of density, ESW (effective strip width), average group size, encounter rate and biomass with their standard errors of lion prey species in human-dominated eastern landscape. Lion prey encompasses nilgai, wild pig, chital, buffalo, cattle, feral cattle, feral pig, donkey, horse, goat and sheep while wild prey constitutes of chital, wild pig and nilgai. Percentage figures along total biomass represent contribution of different prey species/category in the total lion prey biomass.

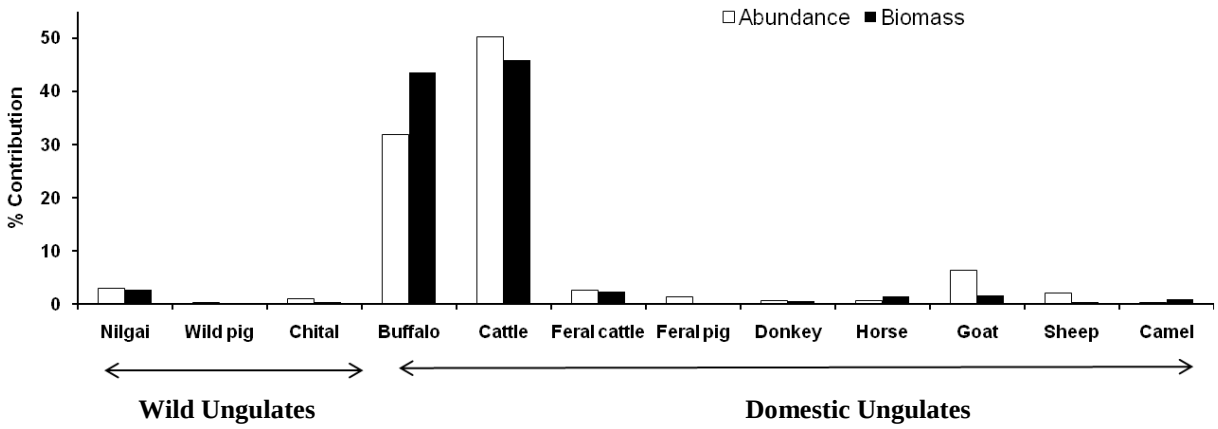
Prey species	Unit weight (kg)	Density/km^2	ESW (meter)	Average group size	Encounter rate/km	Biomass density (kg/km^2)	Total biomass (kg)
Nilgai	136	0.55 (± 0.1)	104.8 (± 8.7)	3.3 (± 0.3)	0.11 (± 0.02)	74.8 (± 12.2)	105,169 (± 17,209; 2.6%)
Peafowl	4	1.9 (± 0.3)	76.7 (± 4.8)	2.5 (± 0.2)	0.28 (± 0.05)	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 10.5: Percent contribution of different lion prey species in total prey abundance and biomass in A) Girnar forest and B) eastern landscape.

A.



B.



Lion predation events

A total of 88 lion kills in Girnar and 87 lion kills in the eastern landscape were recorded. Majority (70%) of kills in Girnar was composed of wild ungulates while livestock dominated

(69%) the lion kills in the eastern landscape **(Figure 10.6)**. We did not observe any sambar kill in the eastern landscape and wild pig kill in Girnar. Sambar (29%) and nilgai (29%) predominated in lion kills in Girnar while cattle (50%) constituted majority of eastern landscape lion kills **(Figure 10.7)**.

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

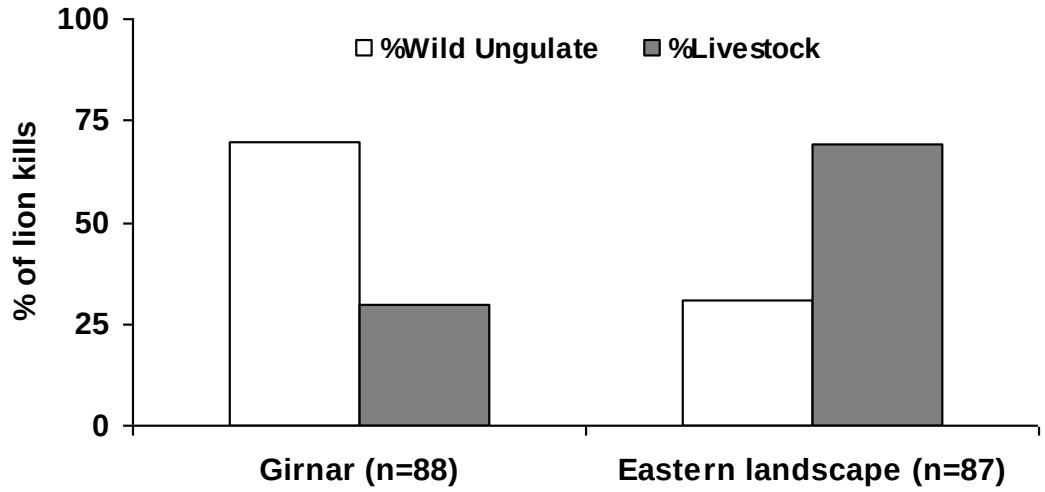
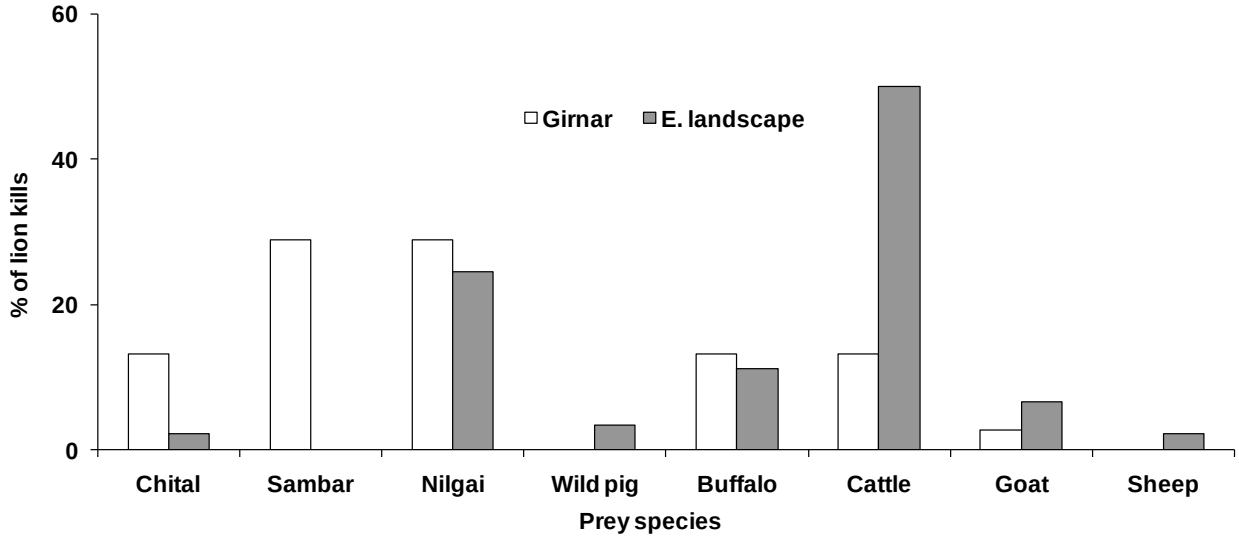


Figure 10.7: Percent contribution of different prey species among lion kills in Girnar and the eastern landscape.

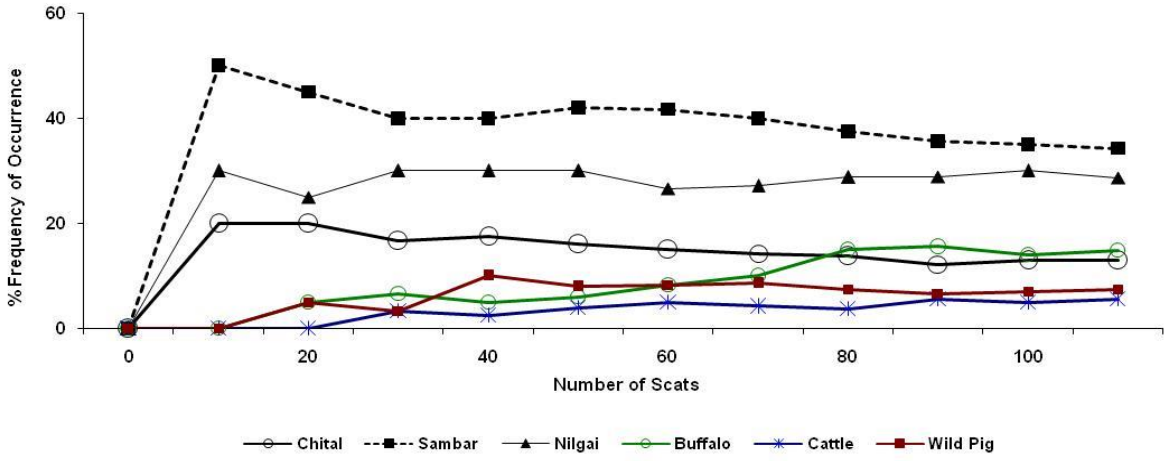


Lion diet

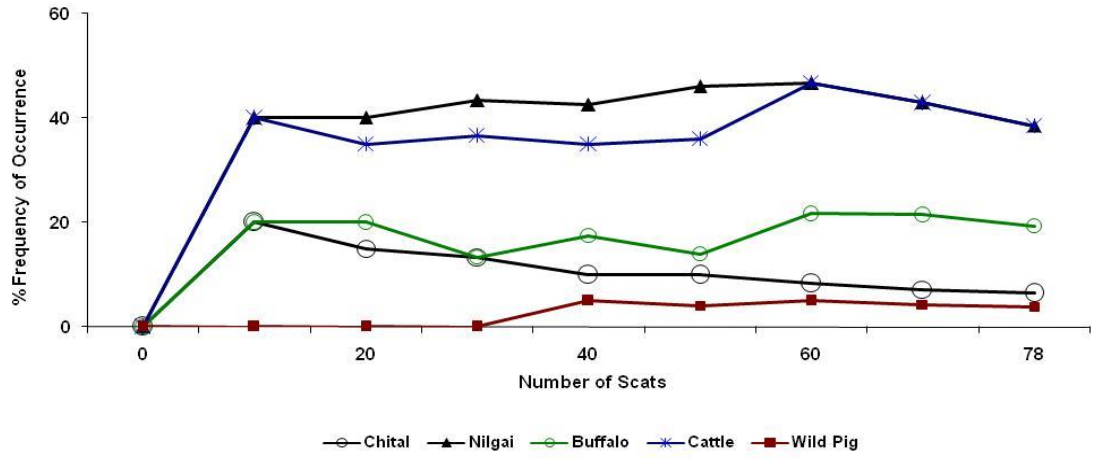
Frequency of occurrence of all prey items in scats reached an asymptote after sampling about 40 – 60 scats both in Girnar and the eastern landscape **(Figure 10.8)**; so the sample sizes of 107 and 78 scats were deemed sufficient. A total of six prey items (chital, sambar, nilgai, wild pig, cattle and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

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

i) Girnar



ii) Eastern Landscape



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

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

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

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

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

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

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

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

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

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

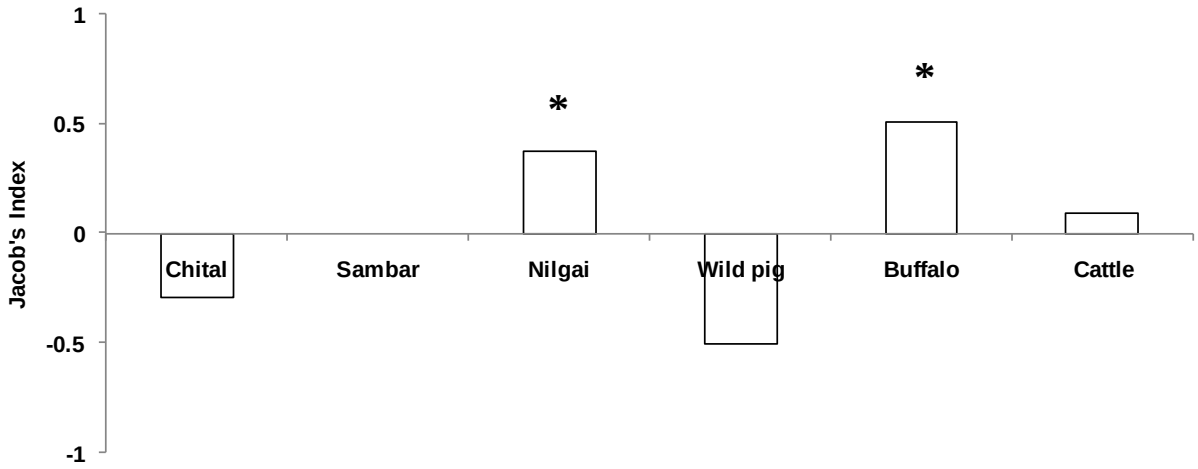
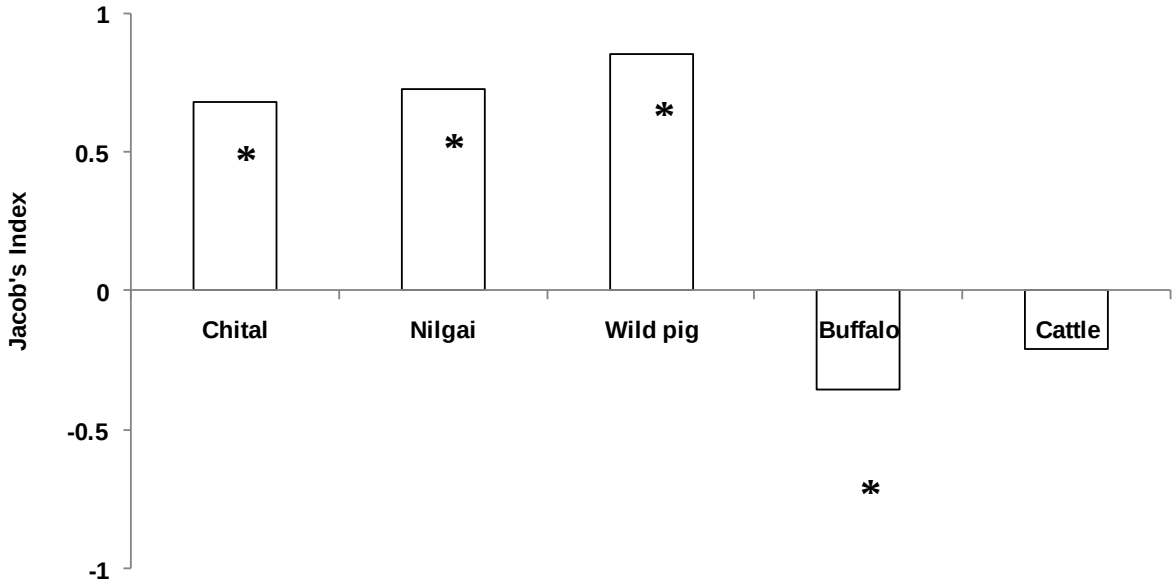


Figure 10.10. Food preference of lions in the eastern landscape based on Jacob's index (Jacob 1974). At 10% CV (Hines and Link 1994), * Chital ($p < 0.001$), *nilgai ($p < 0.001$) and *wild pigs ($p < 0.001$) were used more than their availability while *buffalo ($p < 0.001$) were underused. Cattle ($p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



Lion predation and scavenging through telemetry

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

Discussions

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

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

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

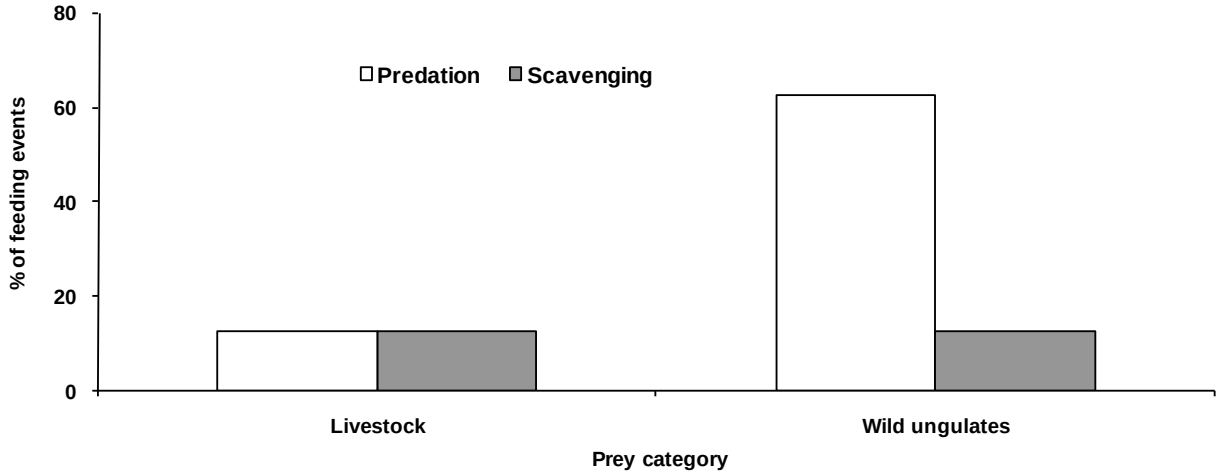
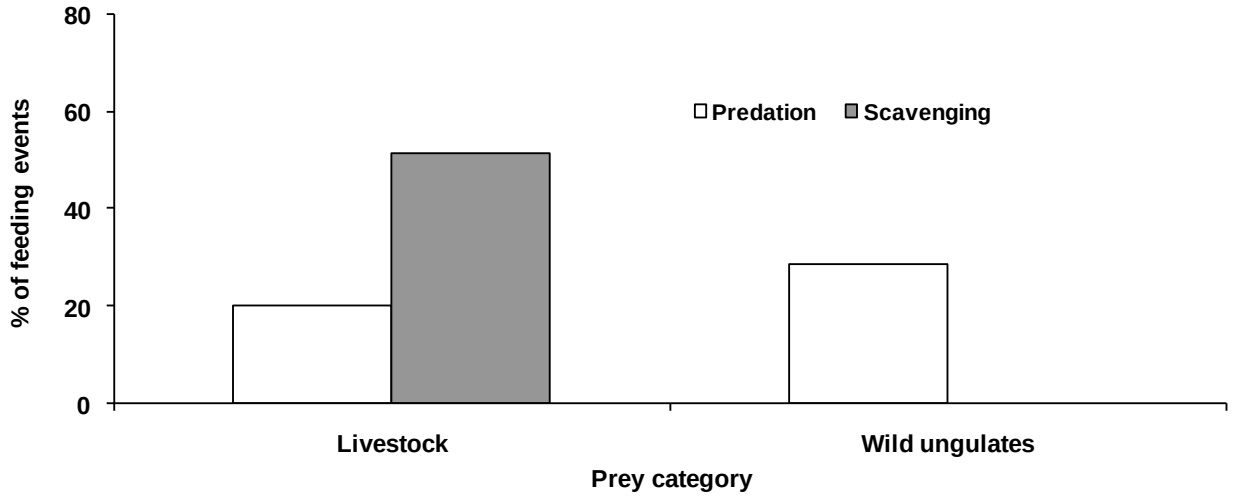


Figure 10.12: Lion feeding events quantified through continuous monitoring on radio-collared lions (n = 3,384 hours of observation on 4 radio-collared lions) in the eastern landscape.



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

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

Prey selectivity being an index of prey uses *vs*. availability precludes relevant information which may be crucial for understanding lion feeding ecology. For instance, although sambar and chital composed a major component of lions' kills and biomass consumption, they are not being preferred by Girnar lions. Even lion feeding events showed that Girnar lions substantially depend on wild ungulates as a source of their food. This has significance on management of Girnar lion populations. Currently, wild ungulates have low densities in Girnar. Based on lion prey base, the predicted carrying capacity for Girnar lions was 9/100 km^2 (chapter 3) while the current estimates of adult lion population is 6/100 km^2 (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 9 for more details) the possibilities of restocking Girnar with wild ungulates (especially chital and sambar) after necessary ecological considerations.

Prey body size, density and the prey capture efficiency were found to be the major ecological determinants of group sizes in social carnivores (Krukk 1972; Schaller 1972; Van Orsdol et al. 1985). In areas where small to medium sized prey are consumed, such as in the Kalahari, lions exist in small group sizes or are solitary (Eloff 1973). In Etosha, lion group sizes fluctuate seasonally with respect to changes in prey availability (Stander 1991). The current study clearly demonstrates this. Smaller group 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 our study area of the eastern landscape, livestock comprised about 69% of lion kills; an indicative of conflict with human communities. But scat analysis suggests that livestock contributes 56% in lions' biomass consumption. Besides, analysis of feeding events showed that although livestock constitutes 71% of lion feeding events, only 20% are predated and the rest (51%) are scavenged. Under the influence of Jainism and Hinduism, this part of the landscape holds several charitable cattle camps (locally known as *Gaushala*s and *Panjrapole*s) 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 *Maldhari*s (chapter 11). Moreover, most of these cattle camps take annual or biennial lease of parts of government owned

grasslands (*vidi*s) which happened to be one of the most preferred lion habitats and crucial refuge patches (chapter 9) and thereby have higher lion densities than other parts of the landscape. Lions in this landscape take cue into this 'free' resource of livestock carcasses (by scavenging them) to optimize their energy economics by maximizing the net food intake per unit time available for foraging. This gets further support from our predation data which suggests that a significant part (30%) of the livestock predation events were recorded on *Gaushala* cattle (unproductive), 3% on feral cattle of the villages and rest (36%) on domestic livestock of economic value. Often, demands have been made by local forest officials about removal of such cattle camps from the landscape. Such steps may have detrimental impact on lion biology and more importantly on the extent of lion-human conflicts. Rather the current practice of grass plantations and soil-moisture-conservation works by the forest department in these *vidi*s may be beneficial for lion conservation in future. However, monitoring of illegal grazing, cutting, lopping and grass cutting should be done regularly. Some crucial *vidi*s 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 *vidi*s 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 12; Banerjee et al. 2013). The pattern within the Gir PA was found to be substantially contributing in shaping *Maldhari*-lion coexistence and we expect the same mechanism to be operating in the larger landscape too. Furthermore, lions' dependence on nilgai in the larger landscape for their diet would be able to foster greater tolerance of the local farmers toward lions. Nilgai, wild pigs and other wild ungulates cause financial loss of varying extents to the local farmers. In the absence of any compensation scheme for crop damage, farmers consider lions as a mechanism of crop damage control. This gets additional support from our questionnaire survey and socio-economic data which indicates that most of the farmers wanted to have lions in future in the landscape

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

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

The study elucidates the biological basis of human-lion coexistence in the agro-pastoral Gir landscape. Within the Gir PA, lion-*Maldhari* coexistence is delicately balanced on a fulcrum of protection, livelihood economics and traditional value systems (chapter 12). *Maldhari*s' 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 12). Incorporation of lost opportunity cost, prompt and systematic payments and timely revision of the Government Compensation Scheme therefore become extremely crucial for

maintaining the goodwill of the communities towards lion conservation (Banerjee et al. 2013) and sustaining viable populations of other carnivores elsewhere on the Globe.

CHAPTER XI

COMPUTING BIOMASS CONSUMPTION FROM PREY OCCURRENCES IN SCATS OF TROPICAL FELIDS

Introduction

The phenomenon of predation links trophic levels and is responsible for important ecological and evolutionary processes (Fryxell et al. 2007). Crucial among these processes are microevolution of prey (Réale and Festa-Bianchet 2003), intra-guild competition (Fedriani et al. 2000**)** and trophic cascades (Mclaren and Peterson 1994). Resulting from these interactions is conflict between carnivores and humans, where carnivores cause losses to human life and livestock in shared habitats (Treves and Karanth 2003). Owing to these ecological roles of carnivores coupled with expanding human-wildlife interface, managing their populations at socially acceptable and ecologically viable limits has become ever more contentious (Mech 1996). Since predator densities are determined by available prey biomass, understanding of predator consumption patterns allows estimation and scientific management of their populations (Carbone and Gittleman 2002; Hayward et al. 2007a). These factors warrant comprehensive understandings of *what and how much carnivores eat.* Although answers to these questions may be sufficient for carnivore management, our understanding of carnivore ecology is enhanced by addressing the question of *why carnivores eat what they eat.*

Owing to the elusiveness of carnivores that preclude direct observations of predation events, the first problem: *what and how much carnivores eat* is usually addressed by characterizing undigested prey remains in carnivore scats (Korschgen 1980). This technique reveals the variety of prey items, but not their quantity in the diet, as biomass consumed to excrete a scat is not uniform across prey sizes (Floyd et al. 1978). Compared to small prey, large prey have lower surface area-to-volume ratio resulting in less indigestible matter per unit biomass (Floyd et al. 1978) and more digestible body parts for carnivores to selectively feed on flesh over skin, bones and hide (Wachter et al. 2012). Consequently, unit biomass of large prey have more digestible matter (more flesh and less skin, bones and hide) and thus, produces relatively fewer scats compared to smaller prey. This has given rise to models calibrating biomass consumption to number of scats with varying prey weights, referred to as *biomass*

models (Ackerman et al. 1984; Jethva and Jhala 2004; Wachter et al. 2012). Such models have been developed for carnivores by feeding them known prey weights under controlled environment (feeding trials) (Floyd et al. 1978; Ackerman et al. 1984; Zielenski 1986; Baker et al. 1993; Weaver 1993; Jethva and Jhala 2004; Marker et al. 2003; Rühe et al. 2007). These studies have typically assumed that biomass consumed to excrete a scat increases linearly with prey weight, which accounts for the aforementioned inverse relationship between surface area-to-volume ratio (surrogating the proportion of indigestible matter) and prey size. More recently, Wachter et al. (2012) has shown that biomass models are more likely asymptotic, reaching a ceiling at large prey weights. This is because predator's physiological constraints like gut fill and limited feeding time along with selective feeding on large prey, cap consumption and digestibility. Earlier studies have restricted feeding trials to relatively small prey sizes, thereby documenting only the linear response in biomass models. Indiscriminate use of linear models to assess real world prey consumption by carnivores can bias results that may misguide ecological understanding and conservation policy decisions.

The second problem: *why do carnivores eat what they eat* is often viewed as an active selection mechanism, explainable through optimal foraging theory (Carbone et al. 1999; Troost et al. 2008). Optimally foraging carnivores are expected to choose prey that provide higher benefits in terms of net biomass intake while minimizing handling costs (chasing and subduing prey) and injury risks (Griffiths 1980; Mukherjee and Heithaus 2013). The hitherto assumed linear biomass models indicate that, with increasing prey size, proportion of digested matter, i.e., energy gain would increase linearly. Although the cumulative costs of handling and potential injuries from securing prey would also increase with prey size, these are more difficult to quantify (Mukherjee and Heithaus 2013). However, if processes like gut fill and carcass decomposition within ecological feeding time cap digested biomass, then energy gains from predation should level off with increasing prey weight. This adds further constraints on energy gain, an aspect which has not been investigated in literature on optimal prey choice by carnivores to date.

Thus, the underlying mechanism of biomass models forms a common link between the problems of *what and how much carnivores eat* and *why do they eat what they eat*, rendering their accurate characterization imperative. Importantly, these biomass models have been widely applied to predator-prey systems other than those for which they were developed, since it is

logistically difficult to conduct feeding trials on all carnivores. Consequently, several authors have used model developed for cougar *Puma concolor* to compute biomass consumption of tiger *Panthera tigris* (for eg. Karanth and Sunquist 1995; Sankar and Johnsingh 2002; Bagchi et al. 2003; Andheria et al. 2007; Harihar et al. 2011), lion *Panthera leo* (for eg. Meena et al. 2011; Banerjee et al. 2013) and leopard *Panthera pardus* (for eg. Karanth and Sunquist 1995; Edgaonkar and Chellam 2002; Andheria et al. 2007; Mondal et al. 2011). However, consumption to defecation patterns could potentially differ between carnivores, limiting transferability of biomass models across systems.

In this regard, an issue yet to be tested despite several established biomass models is: *how do these models compare across carnivores?* Consumption per scat for any carnivore is an outcome of prey digestibility (biomass digested in proportion to what is consumed), which is primarily governed by prey size. While closely related obligate carnivores of varying sizes have similar diets (Nowak 2005) and digestive physiology, they chiefly differ in their prey weight range. Since prey weight roughly scales linearly with predator weight (Earle 1987; Carbone et al. 1999), we explored if the factors determining consumption per scat follow a general relationship with prey-to-predator size ratio among obligate carnivores. Such an allometry would set the stage for developing a generalized biomass model for carnivores.

We examine this possibility by conducting feeding trials on four species which represent a wide size spectrum of tropical felids - a family of obligate carnivores: the Asiatic lion *Panthera leo persica*, Indian leopard *Panthera pardus fusca*, jungle cat *Felis chaus* and domestic cat *Felis cattus*. Our results reveal similar patterns of prey- digestibility and biomass consumed per scat against prey weight in obligate carnivores. We propose a generalized biomass model that is applicable across tropical felids. By applying our species-specific and generalized biomass models on published diet studies, we demonstrate how using inappropriate models across systems have translated into biased inferences about predator-prey interactions, carnivore feeding ecology, and human-carnivore conflict issues. Additionally, our results add to the theory of optimal foraging by showing that benefits from consuming prey levels off at large prey sizes and this, coupled with escalating costs, makes such prey suboptimal to obligate carnivores.

Methodology

Study site

We conducted the study at Sakkarbaug Zoological Park (21˚32'30.12"N, 70˚27'54.06"E) in Junagadh (Gujarat, India) from January 2013 to November 2014.

Ethics

Our study was approved by the Gujarat Government under the provisions of Wildlife Protection Act, 1972 (permit number WLP/28/C/665-66) and the Central Zoo Authority, Government of India (permit number 9-3/2005-CZA (Vol.III) (NA)/2757). During trials, we replaced the captive carnivores' regular diet of dressed meat (cut chunks of meat without skin, hide and long bones) with whole carcasses of wild and domestic prey. Trial carnivores were housed in observation enclosures with *ad libitum* access to water. Wild prey carcasses were obtained from road kills and natural mortalities. Domestic livestock were bought from their owners without coercion, euthanized, and offered to carnivores as per the prevalent practice at Sakkarbaug zoo, except that these carcasses were not dressed for the study. Our feeding trial protocols were approved by Sakkarbaug Zoo Animal Welfare Committee and conducted under the supervision of veterinary officers.

Feeding trials

We conducted 68 feeding trials on three individuals each of lion (n=19), leopard (n=14), jungle cat (n=19) and domestic cat (n=16) (**Table 11.1**) following Floyd et al. (1978) and Wachter et al. (2012). Prey species used in feeding trials covered the entire weight range of prey taken by these carnivores in wild, and also we offered prey exceeding the size these carnivores would normally hunt in the wild, in order to fully parameterize the biomass models (following Wachter et al. 2012). Each trial was divided into three phases: 1) Carnivores were fasted (60-120 hours) till no scats were produced for 24 hours to ensure that their digestive tracts were clear of the previous meal, and these scats were removed from enclosures. 2) Whole prey carcasses were weighed and offered to carnivores. For relatively small prey (weighing <3 kg for lion and leopard, 0.1 kg for jungle cat, and 0.05 kg for domestic cat), multiple carcasses were offered in single trial to ensure adequate biomass for whole scat production and avoid starvation of carnivores. For lions, small-medium carcasses (<75 kg) were offered to single animals and large carcasses (>100 kg) to a group of animals to mimic their feeding ecology. Carcasses were kept in enclosures till

carnivores stoppedfeeding for $\geq$ 24 hours to imitate wild conditions, after which unconsumed portions were accurately weighed and removed. 3) Collectable scats (solid faeces with high persistence rate and detectability in field; Floyd et al. 1978) were collected in paper bags twice daily to prevent trampling, till no more scats were produced for 48 hours. Scats were cleaned with soft brush and weighed fresh, thereafter sun-dried for 96 hours, oven-dried at 70°C for 24 hours (Jethva and Jhala 2004), and weighed dry. Non-collectable scats (loose/viscous feces unlikely to persist long enough for field collection; Floyd et al. 1978) were counted twice daily and removed from enclosures, wherefrom a few representative samples were dried and weighed.

Desiccation experiment

To compute biomass consumed by carnivores, we subtracted unconsumed prey weights from offered carcass weights. However, carnivores feed on carcasses for varied durations, exposing the unconsumed prey parts to prolonged moisture loss that should be accounted for while computing biomass consumption (Jethva and Jhala 2004). We estimated moisture loss from mammalian (goat and buffalo) and bird (chicken) carcasses by exposing freshly dressed body parts that were usually not consumed by carnivores to ambient conditions mimicking trial durations. Chicken, goat, and buffalo carcasses were exposed for 48, 72, and 120 hours, respectively. Desiccating carcasses were weighed after every 24 hours, and the proportion of initial weight remaining was modeled on exposure time. Based on exploratory analysis (scatter plots) and model-fit diagnostics (R^2 and residual plots), we fitted linear regression to data on chicken carcass and quadratic regression to pooled data of goat and buffalo carcasses as they showed similar desiccation rates. Based on these models, we corrected for moisture loss in weights of carcass remains, and estimated fresh weights consumed by carnivores.

Carnivore-specific biomass models

To develop carnivore-specific biomass models, we regressed prey biomass consumed per collectable scat (Y) on prey weight (X). We expected an asymptotic trend of biomass consumed per collectable scat along prey weight gradient (Wachter et al. 2012). We tested this hypothesis by fitting three mechanistic models that represent different biological processes of how predators feed:

1) Linear model: $Y = b_0 + b_1X$; where b_0 (intercept) allows some faecal excretion of body waste when no biomass is consumed, and b_1 (slope) represents the constant rate of increase of biomass consumed per scat with prey weight. This model follows the conventional approach used by Floyd et al. (1978); Ackerman et al. (1984) and others.

2) Nonlinear 2-parameter exponential model: $Y = b_1 - b_1 exp^{-b_2 X}$, where b_1 (asymptote) represents maximum consumable biomass per collectable scat, and b_2 (slope) represents shape of the curve. This model passes through origin (hereafter, constrained model) assuming no fecal excretion without consumption, and reaches an abrupt asymptote. This model was used by Wachter et al. (2012) and is appropriate for cheetahs which get very limited feeding time due to kleptoparasitism by larger carnivores and consume highly digestible prey matter from moderate-large carcasses within single feeding bout (Hayward et al. 2006), resulting in abrupt saturation of biomass consumed per scat with prey weight.

3) Nonlinear 3-parameter exponential model: $Y = b_1 - b_2\ exp^{-b_3\ X}$, where b_1 (asymptote) represents maximum consumable biomass per collectable scat, b_2 represents the difference between maximum and minimum consumed biomass per collectable scat, and b_3 (slope) represents shape of the curve. This model (hereafter, unconstrained model) approximates Mistcherlisch's growth function with diminishing returns (Stern and Bresler 1983), akin to consumption in most carnivores that feed on carcasses through several bouts, wherein one would expect gradual saturation of biomass consumed per scat with prey weight.

We ranked models using Akaike Information Criterion corrected for sample size (AICc), computed from residual sum of squares (Burnham and Anderson 2002), and assessed their goodness-of-fit using R^2 statistic and residual diagnostics.

Prey digestibility

We estimated prey digestibility (*D*) following Jethva and Jhala (2004) as:

*D = (Dry prey weight consumed - Total dry scat weight)*100 / Dry prey weight consumed*;
assuming moisture content of carnivore diet to be 70% (Robbins 1983). Prey digestibility for each carnivore was modeled on prey weight following similar routine as mentioned above.

Generalized biomass model

We postulated that biomass models should be similar among obligate carnivores after accounting for their body size effects (allometry) if prey digestibility is similar between them. To test this prediction, we pool data from feeding trials on all the study carnivores and developed generalized models of a) prey digestibility and b) biomass consumed per scat by accounting for differences in predator and prey weights. We tested the three mechanistic models explained above (linear, constrained and unconstrained) on the generalized models of digestibility and biomass (Crawley 2007). For the generalized digestibility model we regressed percent digestibility (y axis) against prey weight divided by predator weight (x-axis). Similarly for the generalizid biomass model we regressed the pooled data from all study carnivores on biomass consumed per collectable scat divided by predator weight (y-axis) versus prey weight divided by predator weight (x-axis). If allometry primarily explained differences in prey digestibility and consumption per scat between these carnivores, then accounting for body weight differences through our generalized models would sufficiently explain the observed data, with no additional variation (pattern) in residual distributions between carnivores. We examined this premise by regressing the model residuals on scaled prey weight, carnivore species and their interaction. Expecting model residuals to be independent of carnivores apart from being randomly distributed (around mean zero) against scaled prey weight, we tested if parameter estimates of the residual regressions (main and interactive effects of each carnivore species) equaled zero. Additionally, we linearized the asymptotic patterns of prey biomass consumed per collectable scat against prey weight for study carnivores by using their natural-log transformed data and fitted them with linear models (hereafter log-linear biomass models). If our hypothesis of allometric equivalence held true then log-linear carnivore-specific biomass models would exhibit similar slopes across carnivores but differ only in their intercepts. A log-linear model fitted to data of biomass consumed per scat scaled to predator weight from all study felids should account of individual model differences in intercepts while having the same slope as that of individual predator models.

For these analyses, average carnivore weights were obtained from published literature (Prater 1971; Mukherjee and Groves 2007), except for domestic cats for which mean weight of study animals was used as literature reported large size variability. For all computations, mean

prey weight (when more than one carcass was offered in a trial) and mean consumption to scat production (when more than one carnivore fed on carcass in a single trial) were used.

Net digestible biomass

To assess how digestibility and utilization of different prey sizes further constrain optimal foraging in carnivores, we computed biomass consumed and digested from carcass scaled to carnivore's weight, and plotted it against scaled prey weight. Based on exploratory analysis and model fit diagnostics, we fitted a nonlinear 2-parameter exponential model to data pooled across the study felids.

Model applications

Finally, by applying our biomass models to published diet studies on large felids, we refined current understanding of two important aspects of carnivore ecology and conservation.

1) *Diet profiles of large felids*

As iconic top terrestrial predators, tigers steer much research and many conservation programs. Diet studies on this felid have extensively used Ackerman et al. (1984) model to estimate relative biomass contribution of prey species. To assess the ensuing bias, we reanalyzed published information on prey incidence in scats using our generalized biomass model. Although biomass models require whole scat equivalence of prey incidence to compute consumption (Angerbjorn et al. 1999), most studies have erroneously used frequency of occurrence of prey in scats (for e.g. Sankar and Johnsingh 2002; Biswas and Sankar 2002; Harihar et al. 2011). To minimize the resulting error in computing biomass consumption when single scats can have multiple prey, we selected 10 studies that reported single prey in ≥60% scats from across the tiger distribution range in Indian subcontinent (Schaller 1967; Sunquist 1981; Sankar and Johnsingh 2002; Biswas and Sankar 2002; Bagchi et al. 2003; Andheria et al. 2007; Ramesh et al. 2009; Sankar et al. 2010; Harihar et al. 2011; Selvan 2013). For each of these studies, we computed bias in diet composition as percentage change between estimates using Ackerman et al. (1984) model and reanalyzed estimates (using models developed herein) of biomass consumption of common prey. We estimated prey-specific mean bias across studies along with 95% confidence intervals by pooling uncertainties of Ackerman's and our models using delta-variance method.

Similarly, we reanalyzed published diet of leopard (Mondal et al. 2011) and Asiatic lion (Banerjee et al. 2013) using carnivore-specific and generalized biomass models, and compared the results with published estimates.

2) Revisiting livestock predation by lions

We demonstrated the implication of our study on important conservation issues like human-carnivore conflict by reanalyzing data on livestock predation by lions in Gir forests of India (Banerjee et al. 2013). We used data from Banerjee et al. (2013) on whole scat equivalents of prey and computed biomass consumed of each prey using the lion specific biomass model developed herein. We subsequently compare our estimated consumption with the published results of Banerjee et al. (2013) that used Ackerman et al. (1984) model to estimate prey consumption. Based on our reanalyzed results we recomputed the annual economic loss incurred by the local forest dwelling *Maldhari* community due to livestock depredation by lions, following the same approach as Banerjee et al. (2013).

We conducted all data processing using MS Excel and analyses using program R v15 (R Core Team 2013) and SPSS v 16 (SPSS Inc.).

Table 11.1: Prey species and biomass offered, biomass consumed, and scats (collectable and non-collectable) produced in 68 feeding trials on lion, leopard, jungle cat and domestic cat.

Predator	Prey (no.)	Scientific name	Mean prey wt. (kg)	CS (NCS)	CS /no. of pred & prey	BC /no. of pred & prey	BC /CS
Lion	Rabbit (2)	*Oryctolagus sp.*	1.8	4 (0)	2.0	1.54	0.77
	Rabbit (2)		2.4	4 (1)	2.0	2.04	1.02
	Chicken (2)	*Gallus sp.*	2.6	4 (0)	2.0	2.61	1.31
	Chicken (1)		3.8	3 (1)	3.0	3.80	1.27
	Chicken (1)		4.5	2 (1)	2.0	4.45	2.23
	Goat (1)	*Capra hircus*	6.6	5 (0)	5.0	5.91	1.18
	Goat (1)		8.5	5 (0)	5.0	6.48	1.30
	Goat (1)		10.5	4 (0)	4.0	9.01	2.25
	Lamb (1)	*Ovis aries*	10.5	4 (0)	4.0	9.54	2.39
	Sheep (1)		28.6	6 (1)	6.0	16.37	2.73
	Sheep (1)		31.0	6 (1)	6.0	19.35	3.22
	Goat (1)		26.9	6 (1)	6.0	14.90	2.48
	Goat (1)		30.1	5 (1)	5.0	16.38	3.28
	Goat (1)		33.2	7 (1)	7.0	20.13	2.88
	Chital (1)	*Axis axis*	42.3	7 (0)	7.0	22.29	3.18
	Buffalo (1)	*Bubalus bubalus*	74.0	10 (0)	10.0	36.92	3.69
	Buffalo (1)		114.0	10 (2)	5.0	19.00	3.80*****
	Nilgai (1)	*Boselaphus tragocamelus*	131.0	10 (0)	5.0	19.85	3.97*****
	Buffalo (1)		319.0	20 (3)	6.7	30.01	4.50******
Leopard	Chicken (2)		1.7	5 (0)	2.5	1.66	0.66
	Chicken (2)		2.0	6 (1)	3.0	1.96	0.65
	Rabbit (1)		2.5	4 (0)	4.0	2.28	0.57
	Goat (1)		6.7	5 (1)	5.0	4.87	0.97
	Goat (1)		6.7	5 (1)	5.0	6.30	1.26
	Goat (1)		7.5	4 (0)	4.0	6.18	1.54
	Sheep (1)		7.8	6 (0)	6.0	6.67	1.11
	Goat (1)		17.3	8 (0)	10.0	10.53	1.05
	Sheep (1)		20.2	4 (3)	5.0	6.29	1.26
	Sheep (1)		27.3	8 (1)	9.0	13.49	1.50
	Chital (1)		30.7	8 (0)	8.0	16.54	2.07
	Buffalo (1)		44.0	9 (1)	9.0	18.91	2.10
	Buffalo (1) Buffalo (1)		74.0 151.0	15 (1) 9 (2)	15.0 9.0	30.95 19.86	2.06 2.21
Jungle cat	Rat (2)	*Rattus rattus.*	0.1	4 (0)	2.0	0.08	0.04
	Rat (2)		0.1	5 (0)	2.5	0.11	0.04
	White Rats (2)	*Rattus norvegicus*	0.2	5 (0)	2.5	0.15	0.06
	Pigeon (1)	*Columba sp.*	0.3	4 (0)	4.0	0.26	0.06
	Pigeon (1)		0.3	3 (0)	3.0	0.29	0.10
	Pigeon (1)		0.3	4 (0)	4.0	0.31	0.08
	Dove (1)	*Streptopelia chinensis*	0.1	3 (0)	3.0	0.141	0.047
	Guinea Pig (1)	*Cavia sp*	0.7	7 (0)	7.0	0.63	0.09
	Guinea Pig (1)		0.8	7 (0)	7.0	0.67	0.10
	Rabbit (1)		0.8	7 (0)	7.0	0.67	0.10
	Rabbit (1)		1.6	12 (0)	12.0	1.36	0.11
	Chicken (1)		2.3	5 (0)	5.0	0.63	0.13
	Chicken (1)		2.3	10 (0)	10.0	1.44	0.14
	Guinea Fowl (1)	*Numida sp.*	1.2	9 (0)	9.0	1.082	0.12
	Guinea Fowl (1)		1.3	8 (0)	8.0	1.156	0.14
	Goat (1) Goat (1) Goat (1) Goat (1)		3.5 5.6 7.4 10.1	10 (0 7 (0) 7 (0) 9 (0)	10.0 7.0 7.0 9.0	1.42 1.21 1.12 1.43	0.14 0.17 0.16
Domestic cat	House gecko (4)	*Hemidactylus sp.*	0.01	2 (0)	2.0	0.013	0.02

Predator	Prey (no.)	Scientific name	Mean prey wt. (kg)	CS (NCS)	CS /no. of pred & prey	BC /no. of pred & prey	BC /CS
	Dove (1)		0.15	3 (0)	3.0	0.141	0.047
	Chicken (1)		2.21	10 (0)	10.0	0.927	0.13
	Chicken (1)		0.94	7 (0)	7.0	3.80	1.27
	Guinea pig (1)		0.55	5 (0)	5.0	0.491	0.09
	Guinea pig (1)		0.55	4 (0)	4.0	0.44	0.11
	Rabbit (1)		1.38	8 (0)	8.0	1.102	0.14
	Rabbit (1)		2.22	12 (0)	12.0	1.78	0.15
	Pigeon (1)		0.25	4 (0)	4.0	0.241	0.06
	Pigeon (1)		0.30	3 (0)	6.0	0.275	0.09
	Squirrel (1)	*Funambulus pennantii*	0.10	3 (0)	3.0	0.096	0.032
	Rat (1)		0.12	2 (0)	2.0	0.116	0.058
	White rat(2)		0.17	5 (0)	2.5	0.166	0.07
	Goat (1) Goat (1) Goat (1)		4.51 7.18 9.89	16 (0) 8 (0) 7 (0)	16.0 8.0 7.0	2.5 1.48 1.13	0.155 0.18 0.16

Each row indicates a feeding trial on singular predator unless marked as * or ** (indicating two or three individuals respectively).Collectable scat [CS], non-collectable scat [NCS], predator [pred], biomass consumed [BC].

Results

Desiccation experiments

Proportion of initial weight of carcasses remaining in successive days (*PW*) was explained by a linear model for birds:

$PW = 1.005(0.140_{SE}) - 0.181(0.010_{SE})\ day$

(R^2=0.99, p<0.05);

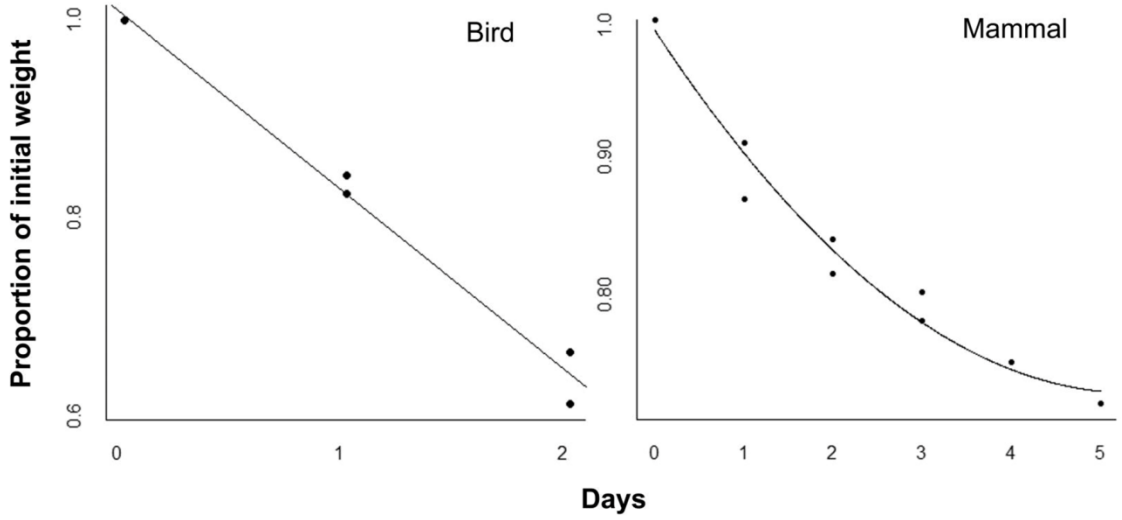
and a quadratic model for mammals:

$PW = 0.992(0.010_{SE}) - 0.098(0.010_{SE})\ day + 0.009(0.002_{SE})day^2$

(R^2=0.97, p<0.05).

Thus, with increasing days and declining moisture content of carcasses, desiccation rates reduced linearly for birds whose carcasses were exposed for shorter durations, and curvilinearly for mammals whose carcasses were exposed for longer durations, mimicking trial conditions (**Figure 11.1**).

Fig. 11.1: Models for computing weight loss from carcasses due to desiccation. Models explained how exposed bird and mammalian carcasses decreased in weights with progressive days in the desiccation experiments. Proportion of initial weight remaining in successive days (PW) was given by: $PW = 1.005(0.140_{SE}) - 0.181(0.010_{SE})day$ (for birds) and $PW = 0.992(0.010_{SE}) - 0.098(0.010_{SE})day + 0.009(0.002_{SE})day^2$ (for mammals)



Carnivore-specific biomass models

In feeding trials, 90-100% of scats produced by carnivores were collectable (collectable/total scats = 122/135 for lion, 97/107 for leopard, 126/126 for jungle cat and 90/90 for domestic cat, **Table 11.1**). Biomass consumed per collectable scat (kg) ranged between 0.77-4.50 for lion, 0.66-2.21 for leopard, 0.04-0.17 for jungle cat, and 0.02-0.18 for domestic cat (**Table 11.1**). Prey biomass consumed per collectable scat initially increased but levelled off beyond certain prey weights that varied between carnivores (100 kg [lion], 50 kg [leopard], 4 kg [jungle cat] and 3.5 kg [domestic cat]). These patterns were best explained by 3-parameter exponential models (**Figure 11.2 a left panel, Table 11.2a**).

Table 11.2: Model selection statistics and parameter estimates of the best model relating biomass consumed /collectable scat to prey-weight for: a) individual carnivores using data from 68 feeding trials, b) individual carnivores using natural-log transformed data scaled to carnivore weight, c) all four carnivores by pooling their scaled data.

a)

Predator	Model	n	K	Ak.wt	ΔAICc	AICc	RSS	R^2	b_1 (SE)	b_2 (SE)	b_3 (SE)
Lion (130 kg)	**Unconstrained**	**19**	**3**	**0.995**	**0**	**23.79**	**2.198**	**0.90**	**4.105** (0.227)	**3.116** (0.260)	**0.032** (0.007)
	Constrained	19	2	0.005	10.51	34.31	4.539	0.79			
	Linear	19	2	0.000	26.03	49.82	10.266	0.54			
Leopard (65 kg)	**Unconstrained**	**14**	**3**	**0.985**	**0**	**-5.43**	**0.229**	**0.95**	**2.171** (0.101)	**1.671** (0.120)	**0.056** (0.011)
	Constrained	14	2	0.015	8.42	2.99	0.558	0.87			
	Linear	14	2	0.000	25.79	20.36	1.926	0.55			
Jungle cat (5kg)	**Unconstrained**	**19**	**3**	**0.995**	**0**	**-104.03**	**0.002**	**0.92**	**0.158** (0.007)	**0.118** (0.009)	**0.881** (0.117)
	Constrained	19	2	0.005	10.69	-93.34	0.005	0.83			
	Linear	19	2	0.001	27.88	-76.15	0.013	0.56			
Domestic cat (4.5 kg)	**Unconstrained**	**16**	**3**	**0.894**	**0**	**-88.58**	**0.002**	**0.95**	**0.161** (0.006)	**0.134** (0.008)	**1.550** (0.276)
	Constrained	16	2	0.106	4.28	-84.30	0.003	0.91			
	Linear	16	2	0.000	32.52	-56.06	0.017	0.55			

b)

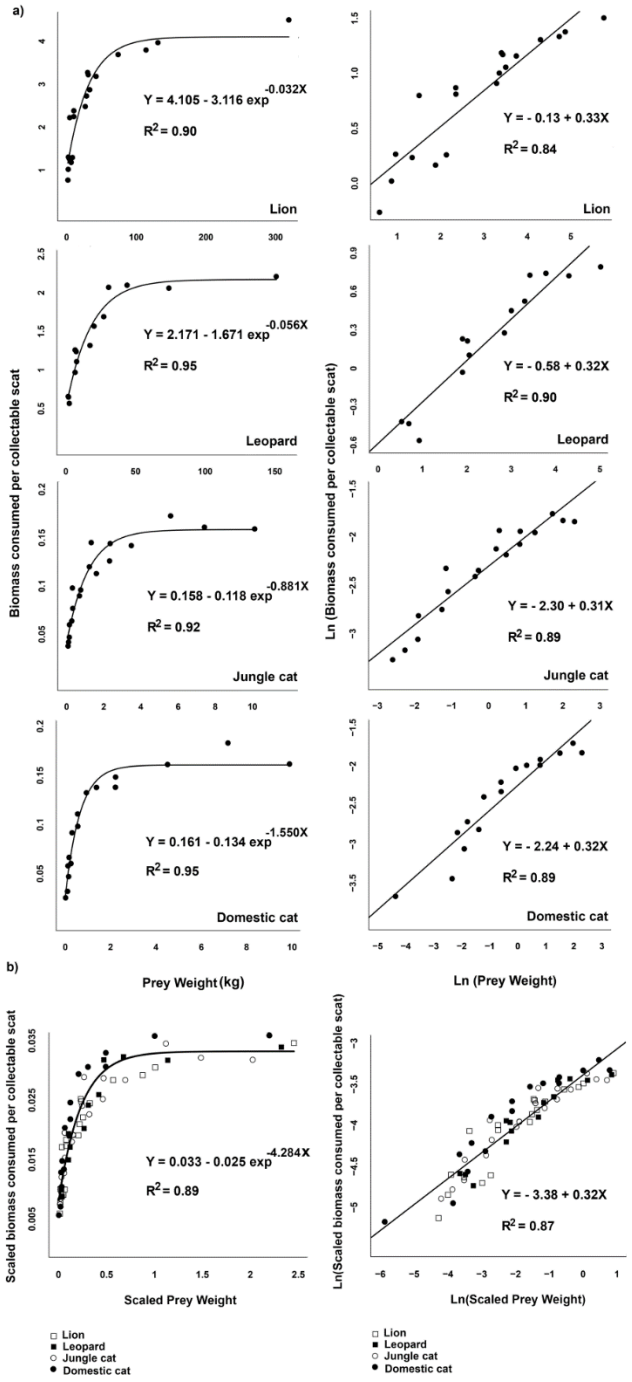
Predator	**Model**	**n**	**K**	**R^2**	**Intercept (SE)**	**Slope (SE)**
Lion (130 kg)						
	Log-Linear	19	2	0.84	-3.41 (0.08)	0.33 (0.03)
Leopard (65 kg)						
	Log-Linear	14	2	0.90	-3.41 (0.06)	0.32 (0.03)
Jungle cat (5kg)						
	Log-Linear	19	2	0.89	-3.42 (0.06)	0.31 (0.02)
Domestic cat (4.5 kg)						
	Log-Linear	16	2	0.89	-3.27 (0.08)	0.32 (0.03)

c)

Predator	**Model**	**n**	**K**	**Ak.wt**	**ΔAICc**	**AICc**	**RSS**	**R^2**	**b_1 (SE)**	**b_2 (SE)**	**b_3 (SE)**
All tropical felids	**Unconstrained**	**68**	**3**	**1**	**0**	**-589.31**	**0.0006**	**0.89**	**0.033** (0.001)	**0.025** (0.001)	**4.284** (0.507)
	Constrained	68	2	0	35.56	-553.75	0.0010	0.81			
	Linear	68	2	0	95.52	-493.79	0.0025	0.55			

Feeding trials [n], Number of parameters [K], Akaike weight [Ak.wt], Akaike Information Criterion corrected for sample size [AICc], Residual Sum of Squares [RSS], parameters: mean$\pm$SE [b_x(SE)]

Figure 11.2: a. Left panel: carnivore-specific biomass models developed by regressing biomass consumed per collectable scat (Y axis) with prey weight (X axis) obtained from feeding trial data on lion (n=19), leopard (n=14), jungle cat (n=19) and domestic cat (n=16); and Right Panel: Natural-log transformed values of X and Y to indicate similar trends (identical slopes and parallel lines) but different scales (varying intercepts) of consumption to defecation across study carnivores.
b. Left panel: generalized biomass model for tropical felids developed by regressing biomass consumed per collectable scat / predator weight (Y axis, scaled biomass consumed per collectable scat) with prey weight/predator weight (X axis, scaled prey weight) using data from 68 feeding trials on lion, leopard, jungle cat and domestic cat (left panel); and Right panel: Natural-log transformed data from feeding trials scaled by predator weight.



Prey digestibility

Percentage of consumed prey digested by carnivores (D) increased asymptotically with prey weight across carnivores. Patterns of digestibility against scaled prey weight (X) were best described by the 3-parameter exponential model (**Figure 11.3a, Table 11.2a**), and were found similar across study carnivores as parameter estimates of residual regressions were not significantly different from zero. The generalized prey digestibility model was:

$D = 92.03 - 23.3exp^{-2.6X}$

(R^2=0.78)

This showed that prey digestibility initially increased but leveled off beyond prey weight equal to predator weight across carnivores.

Figure 11.3: a. Digestibility of prey for tropical felids based on 68 feeding trials on lion, leopard, jungle cat and domestic cat. The Y axis is (dry prey weight consumed – total dry scat weight) / dry prey weight consumed, expressed as a percentage and the X axis is prey weight/predator weight; b. Net digestible biomass obtained from prey. The Y axis is net digestible biomass per predator weight and X axis is prey weight/predator weight

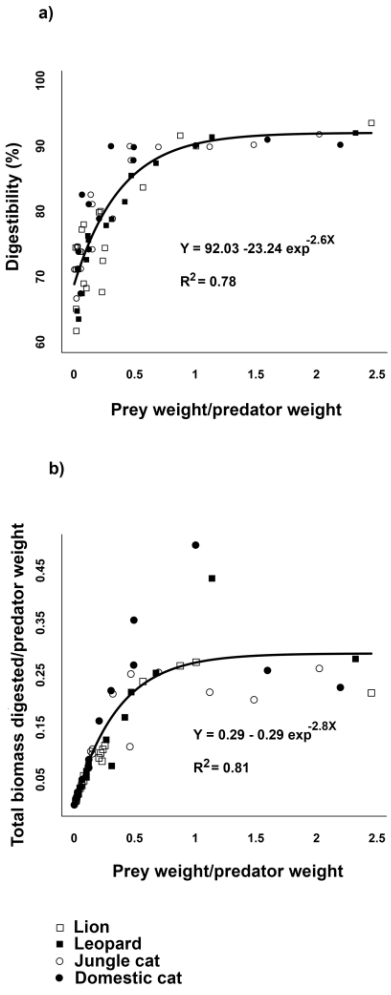


Table 11.3: Model selection statistics and parameter estimates of the best model relating: a) Prey digestibility to prey weight scaled to predator weight from feeding trial data on lion, leopard, jungle cat and domestic cat and b) Net digestible biomass to prey weight for all four carnivores by pooling data scaled to predator weight

a)

Predator	Model	n	K	Ak.wt	ΔAICc	AICc	R^2	b_1 (SE)	b_2 (SE)	b_3 (SE)
All tropical felids	**Unconstrained**	**64**	**3**	**1**	**0**	**370.36**	**0.78**	**92.03** (1.56)	**23.34** (1.65)	**-2.6** (0.51)
	Linear	64	2	0	43.91	414.27	0.56			

b)

Predator	Model	n	K	Ak.wt	ΔAICc	AICc	R^2	b_1 (SE)	b_2 (SE)
All tropical felids	**Constrained**	**64**	**2**	**0.7**	**0**	**-197.38**	**0.81**	**0.29** (0.17)	**2.80** (0.41)
	Unconstrained	64	3	0.3	1.63	-195.75	0.81		
	Linear	64	2	0	64.6	-132.78	0.48		

Feeding trials [n], Number of parameters [K], Akaike weight [Ak.wt], Akaike Information Criterion corrected for sample size [AICc], parameters: mean±SE [b_x(SE)]

Generalized biomass model

Biomass consumed per collectable scat when scaled to carnivore weights (*Y*) showed similar asymptotic patterns against scaled prey weight (*X*) across the study felids. There was no inter-carnivore variability in these patterns as indicated by zero values of parameter estimates of the residual regressions. Also, log-linear biomass models exhibited identical slopes between carnivores but had parallel intercepts (**Figure 11.2a right panel**), but when scaled to carnivore weight had no difference in intercepts (**Table 11.1 b**). This further indicated that carnivore specific biomass models differed in scales equivalent to the body size differences between carnivores. Subsequently, we developed a generalized biomass model applicable for all tropical felids:

$Y = 0.033 - 0.025exp^{-4.284X}$

($R^2 = 0.89$).

This indicated an allometric equivalence of biomass models among obligate carnivores (**Figure 11.2b, Table 11.2c**).

Net digestible biomass

Prey biomass digested when scaled to carnivore weights (E) increased asymptotically with scaled prey weight (X) (**Figure 11.3b**), leveling off at prey size roughly equal to the predator size:

$E = 0.291 - 0.291exp^{-2.803X}$

($R^2 = 0.81$).

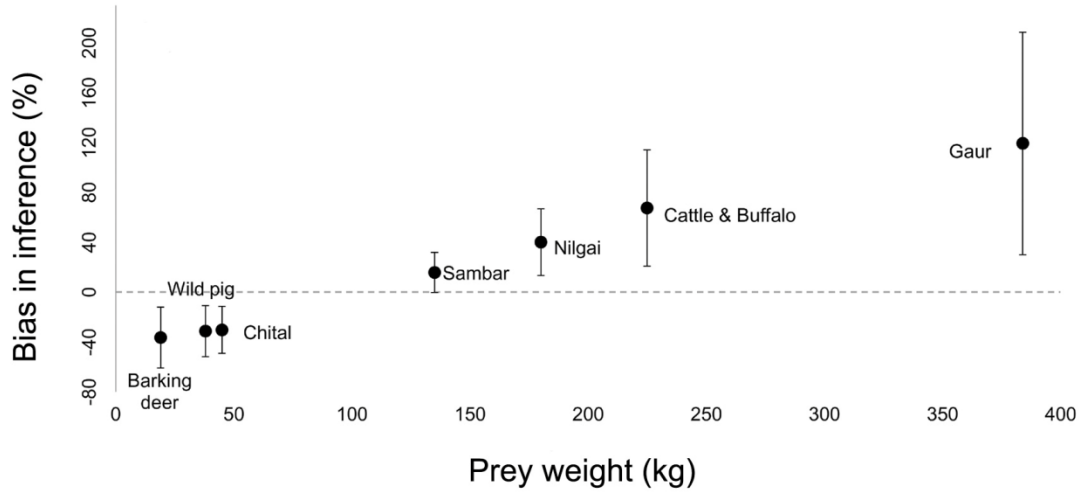
Percent prey carcass utilization declined exponentially with prey size. The combination of asymptotic digestibility and declining carcass utilization with increasing prey size suggests that gains from hunting in terms of net digestible biomass reach a ceiling at prey to predator weight ratio of one (**Figure 11.3b**).

Application of biomass models

Reanalysis of tiger diets using the generalized biomass model showed strong bias-trend in prey contribution estimated using Ackerman et al. (1984) model (**Figure 11.4**). Consumption of relatively small prey like barking deer *Muntiacus muntjac*, wild pig *Sus scrofa* and chital *Axis axis* were underestimated by 30-35%, while relatively large prey like domestic livestock and gaur *Bos gaurus* were overestimated by 70-120% in published studies.

Application of carnivore-specific biomass models to select studies on lion and leopard revealed higher contribution of small and medium size prey (20-50 kg) but lower contribution of large prey (>100 kg) in their diet than was previously estimated. In case of leopard, chital contributed 25% (contrary to earlier estimate of 15%) of total biomass intake (**Figure 11.5a**), while nilgai *Boselaphus tragocamelus* contributed 10% (contrary to earlier estimate of 20%). Similar trend was observed in lions as well, where chital contributed 40% (contrary to earlier estimate of ~30%), while domestic buffalo *Bubalus bubalus* contributed only 15% (contrary to earlier estimate of 25%) of total biomass intake (**Figure 11.5b**). Results were identical between carnivore-specific and generalized biomass models (**Figures 11.5a and b**). Additionally, economic loss from lion depredation on livestock was over-estimated by 32 % in Banerjee et al. (2013) due to the use of an inappropriate biomass model.

Figure 11.4: Percentage bias in relative biomass consumption of common prey species of tiger in 10 published studies. Published data on prey occurrence in scats were reanalysed using generalized biomass model and the ensuing bias associated with using Ackerman et al. (1984) model was computed as the percentage difference between published and reanalysed estimates of prey consumption. Error bars represent pooled 95% CIs of two models.

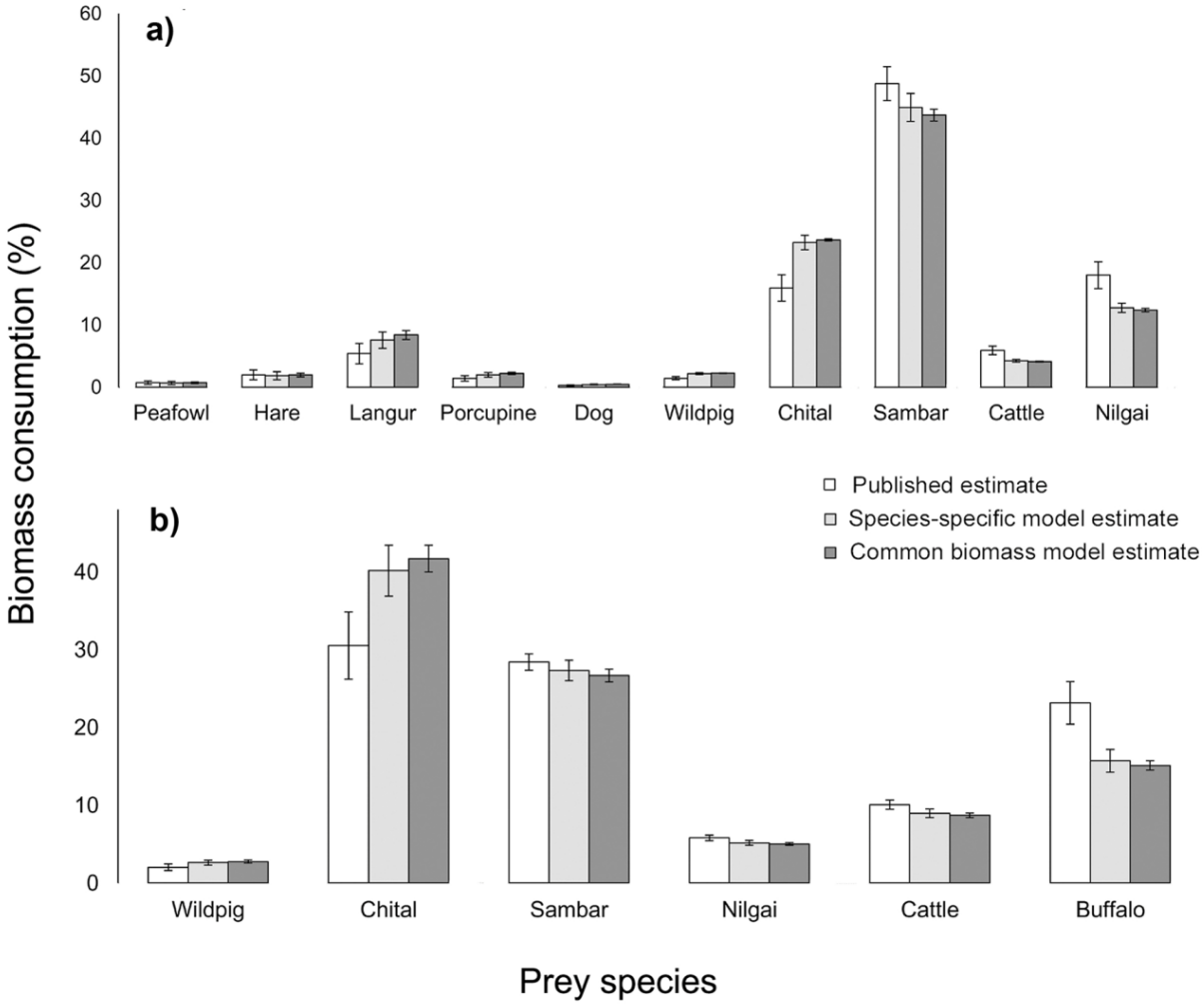


Reviewed studies: Schaller 1967; Sunquist 1981; Sankar and Johnsingh 2002; Biswas and Sankar 2002; Bagchi et al. 2003; Andheria et al. 2007; Ramesh et al. 2009; Sankar et al. 2010; Harihar et al. 2011; Selvan 2013 (unpublished).

Discussions

Owing to the relevance of carnivore diets on key ecological and management issues, around 15,000 studies based on scat analysis have been published in last two decades with annual publication rates increasing exponentially by 10% (https://scholar.google.co.in). The critical source of error in these studies stems from an important link - conversion of prey occurrence in scats to biomass consumed. Earlier attempts to establish this link through feeding trials and biomass models have focused on specific predators and used limited range of prey weights, thereby documenting only the linear component of this relationship. Our study unifies this link across obligate carnivores on the fundamental premise of allometry (Earle 1987; Carbone et al. 1999) that governs prey consumption, digestibility, and utilization - the key factors determining biomass models. Biomass consumed to excrete a collectable scat increased asymptotically with prey weight for study carnivores, best explained by unconstrained non-linear model. This corroborates the findings of Wachter et al. (2012) that consumption to defecation pattern is influenced by multiple factors in addition to discrepancy in surface area to volume ratio between prey sizes.

Figure 11.5: Comparison between published (using Ackerman et al. 1984 model) and present (using carnivore-specific and generalized biomass model) estimates of prey biomass consumption by a) leopard and b) Asiatic lion. Relative contribution (biomass) of prey species to lion and leopard diet were estimated using carnivore specific and generalized biomass models developed in this study and compared with recently published estimates which used Ackerman et al. 1984 model. Error bars represent 95% CIs of individual models.



These additional factors are: a) selective feeding, b) physiological constraints of gut fill and food passage rate, and c) environmental factors in tropics leading to higher decomposition, which limits available feeding time at large prey sizes. We observed that small carcasses were almost entirely consumed excluding few bony remains and feathers. But for large carcasses, carnivores selectively fed on highly digestible flesh, leaving much of the carcasses unconsumed. Proportional utilization of carcass reduced with increase in prey size, as intake declined and

carcass decomposition rate increased progressively with time. Because of selective feeding on highly digestible body parts from large prey, the differences in digestibility between prey sizes diminish towards the upper limit of prey size range. Responses of prey digestibility were found to be similar across carnivores when prey weights were scaled by predator weights, indicating a common mechanism of consumption to defecation among obligate carnivores.

The generalized biomass model represents the underlying mechanism of allometric equivalence among predators. Relationships between predator and prey weights have been documented earlier (Earle 1987; Carbone et al. 1999) with large carnivores predating on large prey. To generalize models of consumption and digestibility across different predator sizes and their prey, we account for this size variation by dividing prey weight by their predator weight. We show that accounting for body size differences in predator and prey is sufficient to explain the variability in consumption and digestibility between obligate tropical carnivores. Thus, our generalized model can potentially be used to estimate prey biomass consumption from prey incidence in scats for tropical carnivore-prey systems. However, we advocate caution against applying this model indiscriminately, especially to characterize diet of omnivorous species (e.g., canids and ursids) as they may differ from our study animals in the mechanism of consumption to defecation. This model may not be applicable for temperate predator-prey systems as well since temperate conditions reduce carcass decomposition rates, allowing carnivores to utilize greater proportions of carcasses over longer durations (Haynes 1982). This study was done under captive and controlled environment since obtaining data required for these experiments from free-ranging animals was not feasible. All of our study animals were wild caught and were capable of feeding on whole carcasses. We tried to mimic natural conditions to the best possible by inducing starve-feed cycles as obsererved in the wild and by housing our study animals in large enclosures. However, the activity of our study animals and the presence of competitors and scavengers would likely differ from free-ranging conditions. We do account for social feeding in lions by offering prey >75 kg to a group of lions. Consumption at single bouts in our study lions was comparable to that observed in free ranging conditions (Schaller 1972; Joslin 1973). We believe that our experiment depicts a maximum consumption scenario as competition, kleptoparasitism and scavenging would likely reduce consumption in wild conditions.

Although earlier studies (Floyd et al. 1978; Baker et al. 1993) reported discrepancies of their linear biomass model-fits at large prey sizes, subsequently these issues were overlooked and only linear models were used for computing biomass consumption from scats. We demonstrate how linear models limited in their prey size range and applied indiscriminately across systems have led to biases and misinterpretation of carnivore feeding ecology. Application of biomass models developed herein to published literature on diet of tropical big cats revealed significant difference in prey contribution estimates. These studies have consistently overestimated relatively large prey while underestimating small and medium prey in the carnivores' diets. Reanalysing these data using biomass models developed herein, show that medium prey like chital constitute the bulk of the diet of all large carnivores, acting as the key prey for sustaining large carnivore populations in tropical forests of India. Our study has wide implications on understanding human-carnivore conflict as depredation of large domestic livestock would likely be lower in reality than reported in literature. As an example, economic loss due to livestock depredation by Asiatic lions was estimated to be 32% lower than what was recently published (Banerjee et al. 2013), further reducing the cost of living with lions for local communities.

We also highlight some problems with the published reporting of big cat diets, foremost being: a) the use of frequency of occurrence of prey in scats instead of their whole scat equivalence for estimating consumption through biomass models; and b) lack of standardized prey weights that hinders collation/comparison of carnivore prey preference across studies. While the first can cause significant errors in estimating biomass consumption and should be corrected (Angerbjorn et al. 1999), the second can be circumvented by taking the average weight of an individual in a population to be $3/4^{th}$ of the adult female weight (Hayward et al. 2007a).

Current notions on optimally foraging predators suggest that predators should maximize the size of the prey that they can safely subdue (MacArthur and Pianka 1966; Charnov 1976; Sunquist and Sunquist 1989; Mukherjee and Heithaus 2013). The costs to predation were considered to be search and handling time of prey and potential risks of injury to the predator. We show that prey- utilization and digestibility act as additional constraints to an optimally foraging predator. Our results indicate that efficiency of predation would be highest when a carnivore hunts prey roughly equal to its own body weight. Beyond this weight, there are diminishing benefits to

predators due to the constraints of gut fill, asymptotic digestibility, and decreasing carcass utilization owing to decomposition in tropical systems. Since handling costs and risk of injuries usually increase with prey size, we postulate that tropical felids would tend to gain more by predating on prey roughly equal to or less than their own sizes and not from larger prey as was believed earlier. The inferences of this study provide an enhanced understanding of *what and how much carnivores consume and factors likely governing their choice of diet* which are essential for their conservation and management.

CHAPTER XII

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

Introduction

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

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

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

At the onset of the nineteenth century, Asiatic lions (*Panthera leo persica*) became restricted to the Gir forests of western India and their numbers declined to around 50 individuals due to hunting and habitat loss (Kinnear 1920; Fenton 1924). However, owing to the timely and stringent protection by the Rulers of Junagadh and subsequently during the post-independence by the State-run forest department; Gir lions have increased to about 400 and dispersed into a large tract of agro-pastoral landscape adjoining the Gir forests embodying a global conservation success story (Singh and Gibson 2011; Banerjee and Jhala 2012).

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

Methodology

*Maldhari*s and the study area

Gir PA is subjected to biotic pressure from 50 *Maldhari* settlements (*Ness*es) and 14 forest settlement villages (human population of 4,500; nearly 23,440 livestock) inside the PA boundary. There are 97 peripheral villages with a human population of approximately 150,000 and a livestock population of 94,600 within one km of the PA. The villagers use the PA for livestock grazing and other minor forest produces (Singh and Kamboj 1996; Singh and Gibson 2011). Each *Maldhari* family rears about 20-100 regionally famous indigenous breed of livestock, primarily Jafrabadi breed of buffalo (*Bubalus bubalis*) and Gir breed of cattle (*Bos indicus*). Often one or two camels (*Camelus dromidarius*) are kept for carrying fuel wood and fodder. The sale of dairy products has always been the mainstay of *Maldhari*s' traditional economy (Varma 2009). Our study concentrated in the eastern part of Gir PA that is dotted with *ness* sites and has good lion density. The study area covered the livestock grazing areas of a cluster of six *ness*es namely Asundrali, Dodhi, Gudjinjva, Khajuri, Leriya and Mindha **(Figure 12.1)**.

Lion density estimation

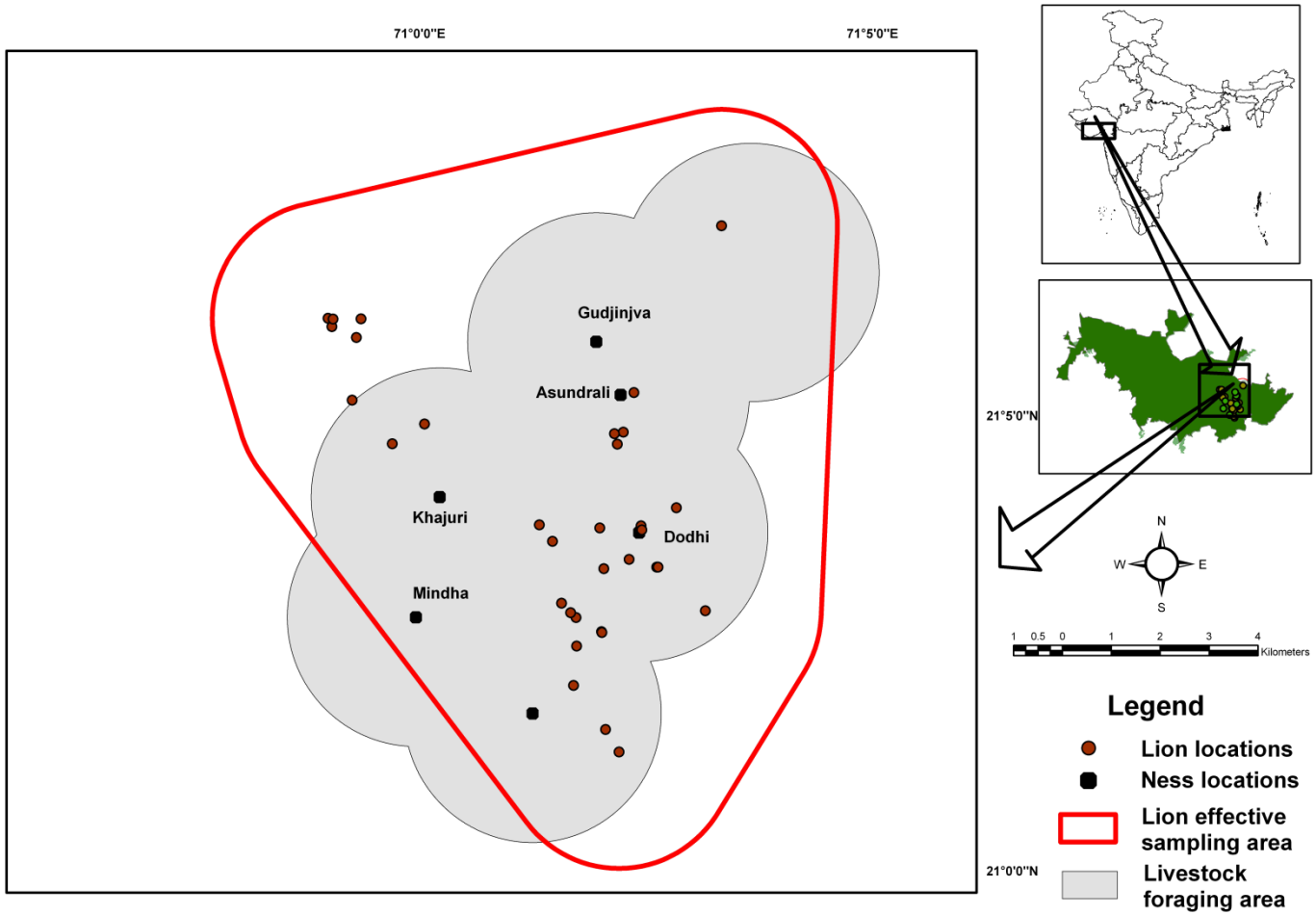
Lion population was estimated using closed-population mark-recapture (Pollock et al. 1990). We used cues, including tracks, roars and alert behavior of prey to locate lions. The entire study area of eastern Gir PA was systematically searched by vehicle and on foot within a period of 3-4 days which represented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

width estimated by half of the mean maximum distance moved (½ MMDM) by recaptured lions (Karanth and Nichols 1998; Banerjee et al. 2010; **Figure 12.1**).

Livestock population and density

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

Figure 12.1: Study site within the Gir forests showing locations of different study *Nesses* buffered by average livestock foraging area, lion capture points and effective lion trapping area. The maps inset show the location of the Gir PA in India and the study site within the eastern part of the Gir forests.



Lion diet

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

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

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

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

On an average 75% of the biomass of each carcass/kill was observed to be utilized by the predators (Chellam 1993). We estimated livestock's' contribution to lion's diet from lion numbers in the study area obtained from lion density multiplied by daily intake requirement (7.3 kg/day, Joslin 1973) per lion, scat analysis and continuous monitoring of radio-collared lions in the study area.

Livestock depredation pattern

Data on livestock depredation was obtained by forming a network of informants with appropriate incentives in all six *ness*es where all events of livestock predation and death were reported within a few hours by mobile-phone to our research team. Each predation site was visited within 24 hours to collect information on the time of day of each attack, the number, species and age-sex-productivity class of livestock killed, approximate weight of the predated individual, name of the owner and the identity of the predator.

Livestock that died due to natural causes were generally dumped at specific sites outside the *ness*es. We recorded scavenging events by large carnivores which were identified based on direct sightings, vocalization and signs. Owners of dead/predated livestock were interviewed to evaluate the market price of the livestock and whether they had filed a claim for the Government Compensation Scheme for livestock depredation or not. The compensation claims were cross validated from the Forest Department's records.

The monetary value of livestock was assigned in accordance with average prevalent market rate **(Table 12.1)**. We compared this with the present compensation scheme provided by the Gujarat State Forest Department **(Table 12.1)** and the proportion of predation events claimed for compensation from the Government to estimate the offset of the capital loss incurred by the *Maldhari*s due to livestock predation.

Lion carrying capacity

In order to understand the relative significance of wild ungulates and *Maldhari* livestock in maintaining lion density in the study area, we used a regression model (Hayward et al. 2007a) that related prey biomass and lion density to estimate the ecological carrying capacity of the eastern Gir for lions. There are several approaches to indirectly predict carnivore density at a site; but studies have shown that it can be obtained more reliably by regressing against prey biomass (Carbone and Gittleman 2002). The carnivore density derived from this relationship only works as long as no other mechanisms besides prey availability limit a carnivore population. We used prey biomass for predicting lion carrying capacity in the study area as other major top-down limiting factors like trophy hunting and incidence of epizootics (Kissui and Packer 2004; Whitman et al. 2007) were not prevalent in Gir (Pathak et al. 2002). The model (Hayward et al. 2007a) based on lions' preferred prey species was more suited when lions occur sympatric with other carnivores like leopards. The equation was $y = -2.158 + 0.377x$ ($r^2 = 0.71$, $n = 23$) where y is the $\log_{10}$ of lion density and x is the $\log_{10}$ of preferred prey biomass (Hayward et al. 2007a). We deduced prey biomass of different species by multiplying their densities (Dave 2008, Dave and Jhala 2011) with their respective unit weights. Since all the livestock units were not available for lion predation, we therefore assessed the lion carrying capacity for three different scenarios; i) no livestock biomass (depicting a situation where there were no *Maldhari* livestock inside the Gir forest), ii) 100% livestock biomass available and iii) 24% (based on the information on feeding events and predation we considered all carcasses of dead livestock and a proportion of dry females, sub- adults and calves that foraged within the forest to be available to lions; this proportion was about 24% of the total livestock population). This enabled us to examine the relative importance of different levels of livestock biomass in sustaining lion population in the study site of eastern Gir sanctuary.

Table 12.1: Average monetary values (Indian Rupees ₹.; 1 US$ ~ ₹. 50) for various age-sex-productivity categories of livestock (buffalo and cattle) used for analysis. The values in parentheses show the compensations amounts paid by the state forest department for the respective livestock classes to offset economic loss due to predation by carnivores in and around the Gir Protected Area (after Singh 2007).

	Male calf	**Female calf**	**Juvenile male**	**Juvenile female**	**Sub-adult male**	**Sub-adult female**	**Milk yielding adult female**	**Dry productive adult female**	**Non-productive adult female**	**Adult male**	**Non-productive adult male**
Buffalo	800 (1,100)	1,000 (1,500)	1,200 (1,100)	2,500 (1,500)	3,500 (3,500)	4,000 (2,100)	15,000 (8,000)	10,000 (2,100)	4,000 (1,100)	5,000 (3,500)	3,000 (1,100)
Cattle	500 (1,100)	800 (1,100)	500 (1,100)	1,200 (1,100)	2,000 (3,500)	3,500 (2,100)	8,000 (6,000)	5,000 (1,100)	1000 (1,100)	8,000 (6,000)	500 (1,100)

Cost of lion predation on *Maldhari*s' livestock husbandry

We compared the livestock rearing costs by a *Maldhari* herder living within Gir with a livestock herder living outside the forest. *Maldhari* livestock within Gir obtain most of their forage requirements from the forest free of cost, while a major proportion of the fodder for livestock outside the PA needed to be purchased. Occasional predation by lions is the cost of rearing livestock in the Gir forests. We developed a deterministic economic model **(Table 12.4)** where we hypothesized that all other costs and profits being equal between the forest dwelling *Maldhari*s and pastoralists living outside, it would be economically profitable for the *Maldhari*s 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 12.4)**.

Hypothetically this component of cost (b) would occur if there was a deficit between market rates and government compensation paid for different livestock classes predated by lions. We calculated the lost opportunity cost as the amount of income that a *Maldhari* would have made from the predated livestock based on its life expectancy and productivity **(Table 12.4)**. We modeled two scenarios of *Maldhari*-lion economics; i) with the current state-run predation compensation scheme and ii) without any such compensation scheme to understand the efficacy of the predation compensation scheme in permitting lion-*Maldhari* co-existence inside the Gir forests and its implications for the larger lion-occupied agro-pastoral landscape as well.

Results

Lion density

We obtained 36 sightings of 20 individual lions (three adult males, 10 adult females and seven sub-adults). Plot of cumulative number of unique lions against lion sightings reached an asymptote suggesting adequacy of sampling. The model selection procedure of program CAPTURE selected the model incorporating time variation and individual heterogeneity ($M_{th,}$ scored at 1). Program CloseTest supported population closure (χ^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 ½ 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.

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 *ness*es overlapped i.e. these areas were used by livestock from more than one *ness*es. 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 *ness*es 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 12.2)**. 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.

Lion diet

Frequency of occurrence of all prey items in scats reached an asymptote after sampling over 130 scats; so the sample size of 165 scats was deemed sufficient. Most (97.6%) lion scat contained a single prey type, while 2.4% of the scats had two prey items. Wild ungulates comprising chital,

sambar, nilgai and wild pig together accounted for 76.4% of all prey occurrences, while domestic livestock (buffalo 13.7% and cattle 7.8%) contributed the rest **(Table 12.2)**. 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 12.3)**.

Livestock depredation pattern

We recorded a total 308 livestock mortality from the six *ness*es 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 12.4)**. Average age of livestock predated by lions was estimated at 4 (SE 0.2) years. Of the 118 events of natural death of livestock, 46.6% were scavenged by lions, mostly adult female buffalo carcasses (27.2%) reflecting a higher availability of this livestock category in the study area.

Figure 12.2: Average seasonal livestock holding of *Maldhari* family within the Gir forest (error bars are standard errors).

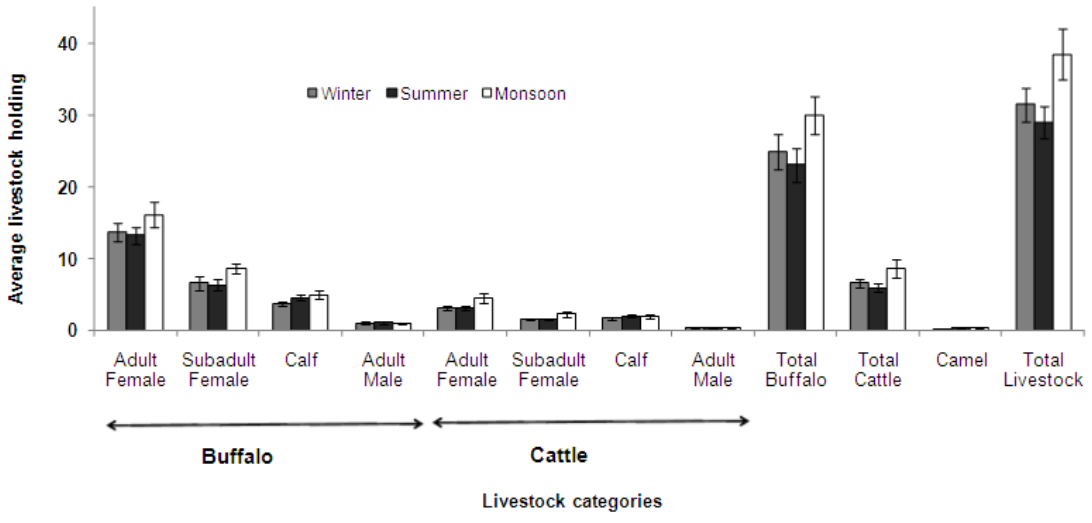


Figure 12.3: Food preference of lions in the Gir forests, India based on Jacob's index (Jacob 1974). Program SCATMAN (Hines and Link 1994) suggests that at 10% CV * Chital ($p < 0.001$), sambar ($p < 0.001$), nilgai ($p < 0.05$) and wild pig ($p < 0.001$) were found to be positively selected while **buffaloes ($p < 0.001$) were underused in proportion to their availabilities. Cattle ($p = 0.33$) were utilized in proportion to their availabilities.

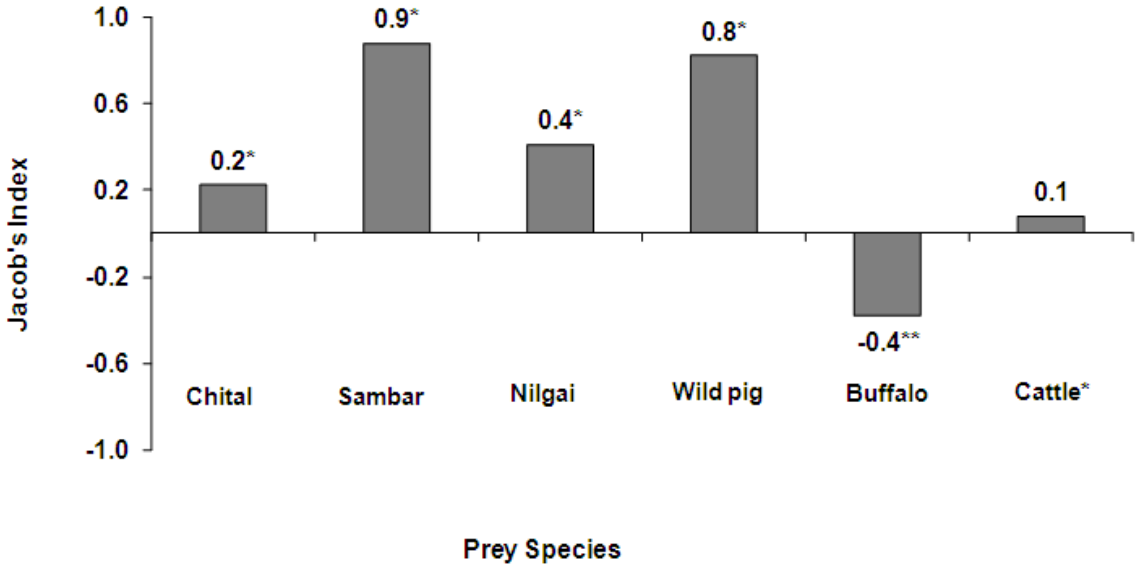


Figure 12.4: Livestock utilization by lions in the Gir East Sanctuary, India showing percent contribution of different livestock classes in livestock feeding events documented by continuous monitoring on radio-collared lions.

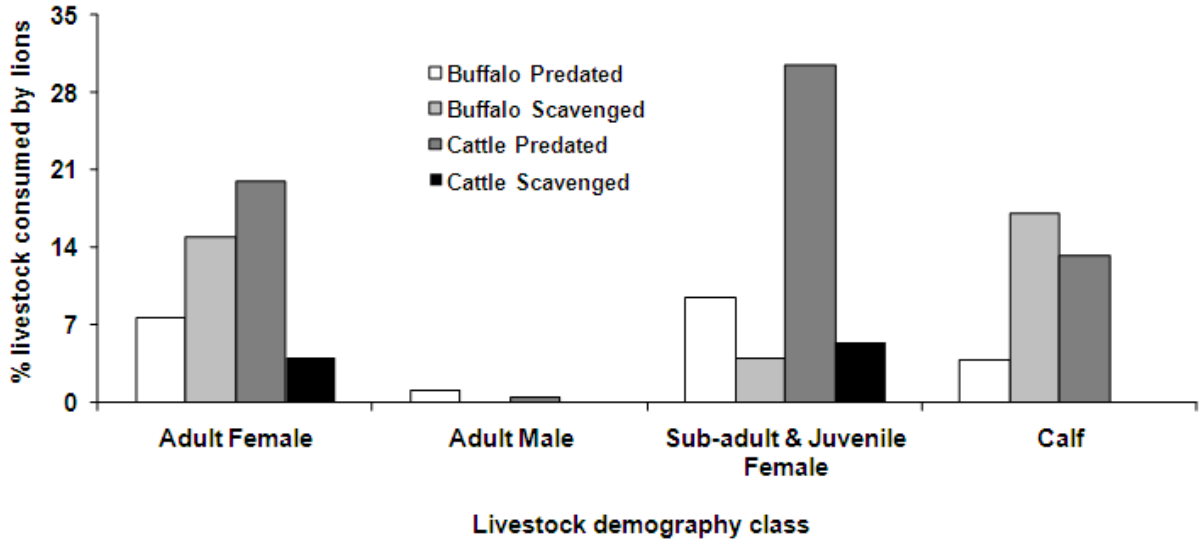


Table 12.2: Prey species composition in Asiatic lion *Panthera leo persica* scats (n = 165) and their relative biomass contribution to lion diet in eastern part of the Gir forests, India. Where x and y are related through the equation y = 1.98 + 0.035 x (Ackerman et al. 1984).

Prey Items	Body Weight (kg), (x)	Total Number of Scats	Observed Frequency of Occurrence [F] (95% CI)*	Relative Occurrence (as %)	Collectable scats/kill (y)	% Biomass Consumed (95% CI)
Chital	42	72.5	44 (37 - 51.8)	45	3.5	28.9 (24.3 – 34.1)
Sambar	119	40	24.4 (17.9 – 30.6)	24.9	6.2	28.3 (20.9 – 35.7)
Nilgai	136	7.5	4.6 (1.8 - 8.5)	4.7	8.3	7.2 (2.8 – 13.4)
Wild pig	28	5.5	3.4 (1.6 - 6.8)	3.4	2.9	1.9 (0.8 – 3.8)
Buffalo	204	22.5	13.7 (8.6 - 19.1)	13.9	9.1	23.6 (14.8 – 33)
Cattle	136	13	7.8 (3.7 - 11.7)	8.1	6.7	10.1 (4.7 – 14.9)

* 95% CIs obtained by 1,000 bootstrapped replicates

The 180 lion kills recorded involved 151 successful hunt events [average killed/hunt 1.2 (SD 0.5)]. The number of livestock killed per successful hunt was weakly correlated with the number of lions reported by the herders (Spearman rank correlation r_s= 0.15, p = 0.03). Of the successful lion attack events on livestock, only 13% occurred within the *ness* when lions jumped into the fenced *ness* and killed livestock while 87% occurred in forests when livestock were out grazing. We did not record any leopard attack on grazing herds. In 68 events of lion attacks on grazing herds the herders could affirm the gender of the lions making the kills. Female lions with dependent cubs were responsible for 54.4% of the attacks; single male or male coalitions were responsible for 19.1% of the attacks and mixed groups of lions made 26.4% of the kills. Lionesses in the study area were found to raid livestock in proportion to the prevailing adult sex ratio in the population (χ^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) [χ^2 = 29.5, df = 2, p < 0.0001]. But during monsoon, most predation events (44%) occurred during late afternoon or evening (χ^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 (χ^2 = 6.5, df = 2, p = 0.04), with 45% occurring in summer, followed by 30% in monsoon and 25% in winter.

A crude estimate of total intake requirement of the lion population in the study area was about 124,733 kg for the study period of 28 months. Livestock were found to be contributing about 31,582 kg (25.3 %) of biomass to the lion's diet. Inter-feeding interval of lions estimated by the continuous monitoring was 3.5 (SE 0.7) days with an average associated lion group size during feeding being 3.5 (SE 0.8). Telemetry data showed that livestock composed 42% of lions' feeding events (16% from predation and 26% was from scavenging on livestock carcasses). Wild ungulates were found to compose the remainder 58% of lions' feeding events (47% predated and 11% appropriated from leopard kills or other lion kills).

Lion carrying capacity

Under the assumption of 100% availability of livestock biomass to lion predation, the lion carrying capacity was estimated to be 22 (95% CI 20-25) lions/100 km^2 while with no

availability of livestock, the carrying capacity was 12 (95% CI 9-15) lions/100km^2. Lion carrying capacity with 24% of livestock population available for lions were 16 (95% CI 13-18) lions/100km^2 **(Table 12.3)**.

Economics of lion predation

Annual fodder cost for maintaining 100 livestock was estimated to be ₹. 1,460,000 [1US$ ~ ₹. 50]. For forest-dwelling *Maldhari* this resource is available free of cost. Average cost of livestock units predated by lion was ₹. 4,018 ± 278 SE. *Maldhari*s 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 *Maldhari*s 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 *Maldhari*s 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 12.4)**. Cost saving (additional profit) by *Maldhari*s 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 12.4)**.

Discussions

We found that presently *Maldhari* and lions co-exist in a win-win state where lions get a considerable part of their food from *Maldhari* livestock and *Maldhari*s profit substantially by free access to forest resources. Average annual financial loss/*Maldhari* household due to livestock predation by lions after offsetting by the compensation was minimal (₹. 2,038) and was only 5% of the average *per capita* income for Gujarat province and 7% of the national average during the fiscal year 2005-06 (Ministry of Finance, Government of India 2009). With free grazing rights and at current rate of compensation, additional profits of a *Maldhari* family residing inside Gir approximately amount to a person's annual minimal wage (231 man-day

wages). Current government compensation scheme, though small in comparison to the value of free resources, was important as it provided a *Maldhari* family an additional monthly monetary

Table 12.3: 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 12.4: 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)*[(5x20x200) + 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)*[(5x20x200) + 845]* 0.28	378,212 (359,535 – 396,889)
F	Guarding cost for *Maldhari* (Assuming that outside herder will need half the herders than a *Maldhari* in lion habitat)	1 person extra for a herd of 25 therefore for 100 LS the cost is of 4 persons@ ₹. 142[§] /day for a year	207,320
G	Total revenue loss to *Maldhari* by lion predation & extra guard cost when **Govt.**	B+D+F	355,626 (353,979 – 357,275)

	compensation is availed for lion predation		
H	Total revenue loss to *Maldhari* 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 *Maldhari* 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.

advantage of 21 man-day wages to a no-compensation scenario **(Table 12.4)**. We did not, however, consider the additional benefits *Maldhari*s 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 *Maldhari*s 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 *Maldhari*s (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 *Maldhari*s (Mukherjee and Borad 2004). Livestock has always been an important part of lion's diet in Gir ranging between 83 to 25% (Joslin 1973; Sinha 1987; Chellam 1993; Meena et al. 2011). We studied livestock depredation pattern by lions with a combination of methods *viz*., scat analysis, predation pattern and feeding events of the radio-collared lions in order to address inherent limitations of each method and estimated biomass contribution by domestic livestock in lions' diet to range between 25 to 42% within eastern Gir PA. Past long-term research from Africa have shown that prey availability and density govern lion demography like cub survival and dispersal rates (Schaller 1972; Van Orsdol et al. 1985). The current study suggested that the carrying capacity of lions modeled with available biomass of dead livestock and livestock classes vulnerable to lion predation (24%) was almost similar with the current lion density estimated in the study area (15 lions/100 km^2). However, when we considered a hypothetical situation where there were no *Maldhari* settlements in the study area and therefore no availability of livestock biomass for lions, the predicted lion carrying capacity went down (12 lions/100 km^2), 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 *ness*es 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), and also depend on their attachment to livestock (Vittersø et al. 1998). Gir *Maldhari*s did not view lions as a threat to their lives (Raval 1991) and there was no lion attack on humans within our study area during past two decades. Moreover, unproductive cattle (such as males and poor condition calves, aged, and dying cattle) were mostly targeted by lion predation. The average cost of such unproductive cattle was ₹. 3,425 and at times, it was not profitable to maintain them by stall-feeding. We believe that retaliatory killing of lions is not prevalent in Gir due to low economic losses, *Maldhari*s' cultural ethics, combined with strict legal enforcement by the Gir Park management. But traditional value systems of the *Maldhari*s are rapidly changing under the influence of globalization and free markets (Sinha et al. 2004). Younger generations are less tolerant to even small monitory losses which older generations considered as fait-accompli. We anticipate that such changes in attitudes and values are likely to result in a change of *Maldhari*s' harmonious coexistence with lions. A similar transition has happened with the pastoral Masai community in the eastern Africa within the past two decades (Homewood et al. 2009; McCabe et al. 2010). With this change in values, comes complacency towards professional lion poachers by local communities. This was probably the case when 8- 10 lions were poached for their body parts in the recent past in Gir (Singh 2007; Fair 2009) and elsewhere in India in the case of tigers, *Panthera tigris* (Check 2006; Gopal et al. 2010). Reparative measures such as compensation programs become important herein, mitigating conflicts by offsetting monetary costs to local communities (Agarwala et al. 2010). The success of Asiatic lion conservation is partly attributable to the early policies (1930s) of the erstwhile Junagadh Nawabs (Gee 1964) and later to the state run Gujarat Forest Department in implementing compensation schemes for livestock predation (Singh 2007). In order to reflect the current market value of the livestock, the compensation rate is usually revised at an interval of every 6-8 years (Singh 2007). We found that the current compensation scheme substantially minimized lion-*Maldhari* conflicts by lowering the latter's capital loss by 64% and allowing them to make an additional monthly monetary profit of 51 man-day wages/family in comparison

to a non-compensation scenario. We believe that this had a positive role in shaping *Maldhari*s' perceptions about their personal losses and thus acts as an important factor promoting their coexistence with lions. A similar pattern has been observed among the Masai community residing around the Mbirkani Ranch, Kenya where individuals receiving compensation from a local NGO showed a lower propensity to kill lions and were found to bear more positive attitude towards conservation (Hazzah et al. 2009; Maclennan et al. 2009). The current compensation scheme in Gir addresses *Maldhari*s' 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.

*Maldhari*s 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 herdsmen (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* herdsmen orient their herds with cattle leading, buffaloes in the middle and juvenile animals trailing. We speculate that the current traditional mechanism of warding off lion predation by corralling livestock at night and having a mixed grazing herd composition being always accompanied by expert herdsmen minimized the risks and economic losses to lion predation. In Gir since livestock are reared only for dairy products and are not consumed by *Maldhari*s (Raval 1991) there is a large cohort of old and weak cattle in which natural mortality is high and these carcasses are available to lions for scavenging.

We conclude that the underlying economics of *Maldhari* livelihood securities, their religious sentiments, ecological benefits enjoyed by pastoralists living in lion habitats and strict legal protection regime for lions in the Gir forests (Raval 1991; Singh and Kamboj 1996; Pathak

et al. 2002) are all needed as recipe for lion-*Maldhari* co-existence. Indefinite increase in human and livestock population within the Gir forests would upset this balance by altering the forest composition or even population dynamics of wild prey (Owen-Smith 2002) and would thus be detrimental for the conservation objective of the Protected Area. Presently lions are dispersing out of the Gir PA and have already occupied about 20,000 km^2 of agro-pastoral landscape (Singh and Gibson 2011, Banerjee and Jhala 2012; Meena and Kumar 2012). The current study suggests that lions outside the PA depend substantially on livestock (see chapter 10 for more details), thereby increasing the chances of human-lion conflict in the region. In the agro-pastoral landscapes, there are no free economic benefits for the communities. Government compensation scheme therefore becomes extremely crucial for maintaining the goodwill of the communities towards lion conservation. Compensation cannot 'buy' an individual's tolerance of carnivores (Naughton-Treves et al. 2003) but does ameliorate hostility.

Due to high human densities and demand for land most human free inviolate protected areas in India and elsewhere are too small to hold viable populations of large carnivores for the long-term (Narain et al. 2005). Coexistence with humans therefore becomes essential if large carnivores were to be conserved for the long-term. Considering the case of Asiatic lions, only about 7% of the adult lion population resides in the human-free Gir National Park, 49% of adult lion population resides in the Gir sanctuary (with *Maldhari* settlements) while 44% of the adult lion population resides in the human-dominated agro-pastoral landscape of Saurashtra (Gujarat Forest Department 2010; Jhala et al. 2011a). A similar situation exists with most tiger populations in India as well (Jhala et al. 2011b). Such scenarios are common to several developing countries and activities like paying compensation should be considered as ecosystem maintenance costs that need to be paid to the local communities by Global societies or Governments for the continued survival of large carnivores within landscapes of conflict to promote coexistence. This would foster greater tolerance by local communities towards lion conservation in the Gir landscape and for other large carnivores elsewhere. We see no end to this or similar programs worldwide and believe that they form an integral component of coexistence and an important component of conserving viable populations of large carnivores.

CHAPTER XIII

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

Introduction

Caughley and Sinclair (1994) suggested that the first step of conflict management should be the identification of the real damage and actual level of conflict. Although in some cases losses might not be economically significant at a regional scale, for the affected household, they could be damaging (Mishra 1997) or at least perceived to be so. Therefore understanding the economic strain of conflict on local peoples' livelihoods and their attitudes towards conservation are central to the successful conflict mitigation. People who endure conflict and feel they are ineffective in ameliorating the problem are likely to be more inclined to retaliate (Mills and Hofer 1998). Public attitudes are generally believed to be most positive in areas where carnivores are absent (Zimmermann et al. 2001) or in areas with an unbroken carnivore-human coexistence (Boitani 1995). But while attitudes might be favorable in a large portion of today's urban population, locally the old conflicts still might exist with marginalized communities like farmers and pastorals strongly opposed to carnivore recovery. They are the groups most directly affected, and they are afraid of damage to livestock and game, increased costs and working efforts, foreign involvement and new restrictions (Kaczensky 2003). In the absence of large carnivores, locals have often abandoned traditional herding methods and may have lost the knowledge about the predators themselves. The re-appearance of large carnivores, therefore, may result in locally high damage levels (Kaczensky 1999) and/or a high level of fear among local residents (Zimmermann et al. 2001). In addition, with the perceived social pressure to act in a certain way, this may result in a highly negative attitude across a whole region. Even though the actual financial losses might be small, the recoveries of large carnivores are seen as threats to the traditional lifestyle and often highlight a gap between urban and rural people in modern society (Breitenmoser 1998).

Zimmermann et al. (2001) found that the proportion of people with negative attitudes continues to increase to its maximum with the arrival of large carnivores, and then decreases with experience of living with large carnivores over time. Similarly, they found that the proportion of people afraid of large carnivores was relatively high during initial phase of

carnivore arrival but also decreased with experience. It appears that people can learn to coexist with large carnivores and change their views. This could have been attributed to the human fear psychology (bio-phobic or bio-philic) and peoples' concern about their own safety and health (Røskaft et al. 2003). However; ethical, cultural and traditional values and beliefs of the communities towards wildlife and particular species as well as political representation of the species could be the most important socio-ecological factors governing such perceptions and thereby could be a significant driver in shaping human-wildlife conflicts (Mishra 1997, Naughton-Treves et al. 2003).

Gir PA has a legacy of harmonious co-existence of lions and other wildlife species along with its traditional pastoral communities (*Maldhari*s) in spite of livestock depredation by lions and leopards (Singh and Kamboj 1996; Divyabhanusinh 2005). There is a state run compensation scheme for livestock depredation which is being revised periodically in reflectance with market values (Singh 2007). Additionally, these communities being at the centre of the forests enjoy free access to many forest resources and are economically benefited at the prevailing Compensation Scheme. These act as the economic driver behind *Maldhari*-lion co-existence (Banerjee et al. 2013). But this equation of coexistence may not hold true in the vast unprotected agro-pastoral landscape outside the Gir PA where lion conservation is not a prime land-use objective and communities get compensation but do not have any access to other free forest resources. A farmer outside the Gir might have economic gains in having lions as a control to crop damage by killing agricultural pests (wild ungulates) but a pastoral with hardly any access to the forest resources and often ignorant about the government compensation schemes might hold hostility towards lions. Livestock constitutes majority of lions' diet in the larger landscape (Chapter 10). Although lions mostly scavenged on carcasses and mostly predated on unproductive cattle but local communities might perceive otherwise. Local tolerance towards lion populations is determined by several factors but we hypothesize that these would primarily be economics of damage and perception of threat. The prediction that follows this hypothesis is that lion populations that obtain most of their food by scavenging, predation on unproductive livestock, and wild prey, would be tolerated or even encouraged by local communities while others persecuted.

The future of survival and conservation of lions in the Gir landscape will depend significantly on how local communities outside the Gir PA perceive lions and react accordingly

(tolerance *versus* hostility; see Conover 2002). Currently park management and conservation communities may be elated by the success story of the Gir lions (Lenin 2011; Singh and Gibson 2011) but we feel that this should not preclude the foresightedness in planning based on realistic future projections of conservation risks and management challenges. It is therefore imperative to have an unbiased understanding of the local communities' perception towards lion conservation in the human-dominated landscape and timely adopt the current policies to suit the challenges. This effectively checks public repercussions even before they sprout. In this chapter we assess the local communities' perception towards lion conservation and government compensation scheme in the agro-pastoral Gir landscape. This component of the study would highlight the conservation perception at different socio-economic level and would be useful to identify the social carrying capacity for lions in the landscape. This understanding would be the necessary ingredient in the recipe for future persistence of lion population in the larger landscape.

Methodology

Field method: A closed and open ended structured questionnaire (Bath 1987; Bernard 1995) was administered to 680 respondents (272 from Junagadh district, 238 from Amreli district and 170 from Bhavnagar district) from 254 villages of the Gir landscape (84 villages of Junagadh, 138 villages of Amreli and 32 villages of Bhavnagar; **Figure 13.1**) 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 conservation 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 13.1)**. The first section primarily dealt with the demographic details (age, gender, caste, education level, etc.), awareness of the interviewee regarding animal species present in and around the villages and a visual assessment of the economic condition of the interviewee. The second part dealt with

socio-economic questions pertaining land holding, livestock owned and occupation. The final section comprised of questions pertaining attitudes and perception of the respondents towards lions and government compensation scheme paid for livestock predation. The initial questions were related to simple demographic information. This helped to ease the respondents into the interview session. If the respondent did not understand any given question, it was repeated and elaborated till it became clear that the respondent had understood it, and only then was the response noted down.

Although the questionnaire had a provision for gender but we could not interview women sufficiently (n = 4) and excluded them from our dataset.

Analytical method: Responses from the questionnaire survey were analyzed to arrive at economic well being index, primary source of livelihood in the area and the attitudes and perceptions of people towards lion.

Economic well-being index: To make it possible to compare data among different respondents, it was important to get all the answer categories into a uniform system. Therefore, the responses were at first put into categories explained in details in **Table 13.1**. Each question was then assigned a score. Total score for all the questions was calculated and then an average score was calculated to indicate the economic well being of the people. The combined weighted scores were then graphically represented for a better visual interpretation.

Source of livelihood: The livelihood sources of the people were categorized into major four groups- agriculture, pastoralism, agro-pastoralism (we assumed the person holding land along with at least eight livestock unit as an agro-pastoralist) and others (service, business and daily wage labor). Service includes all private and government jobs where the respondent is getting paid by his/her employer while business includes a variety of self-entrepreneur employments like shop-keeping, motor garage, priest, blacksmith, potter etc.

Attitudes and perceptions of people towards lion conservation: Attitudes and perceptions of people towards lions were examined by considering both—effect of lions on people's lives and the effect of the people's lifestyles on lions. Answers to different questions were once again scored generally with the more 'negative attitudes' getting lower scores while more 'positive attitudes' getting the higher scores.

All data analysis was done with SPSS version 19.0 (SPSS Inc., Chicago, USA). A test was considered significant at $P < 0.05$ level and were two tailed. Responses were either on

continuous scale (e.g. land holding, herd size etc.), or categorical form (e.g. major future threats to lions, like to have lions in the neighborhood etc.) later converted into proportion of positive response in different categories. To characterize the socio-economy and demography of the landscape, we reported mean and 95% confidence intervals of these variables. The differences in attitudes towards lions among various demographic groups were analyzed using chi-square analysis (Zar 2010).

We divided our dataset into two categories; i) attitude and perception towards lion conservation (like to have lions or not; section C of **Table 13.1**) and ii) perception about the government compensation provided for livestock depredation (section D of **Table 13.1**). To explore the interrelatedness of socioeconomic variables for both the data sets (i and ii), we used Spearman's rank correlation coefficients (Zar 2010) to check for redundancy in the socio-economic variables and selected only one for further statistical analysis when two or more variables significantly correlated with each other. We performed generalized linear models (GLM; McCullagh and Nelder 1989) with a linear scale response to investigate local people's liking for having lions in neighborhood in future and efficacy of government compensation scheme for livestock predation (is the compensation appropriate in monetary term). We constructed *a priori* candidate models representing factors behind local people's attitudes toward lions and the Government compensation scheme for livestock predation. Given the available data and knowledge of the study landscape, we constructed each candidate model based on the plausibility of *a priori* hypothesis (Burnham and Anderson 2002). We used information–theoretic approach to select between candidate models (Kullback and Leibler 1951); either selecting the one with the smallest 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.

Table 13.1: 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 cloth of the respondent	1-5 scale where 1 = torn cloth, 5 = excellent cloth
Visual assessment of the ornaments (bangles, ear rings, wrist watches etc.) of the respondent	1-5 scale where 1 = no ornament, 5 = costly ornaments
Visual assessment of the housing of the respondent	1-5 scale where 1 = thatch, 2 = *kutcha*/semi-*pucca* tinned/cement sheet roof, 3 = *kutcha*/semi-*pucca* mud baked tiles roof, 4= *pucca* mud baked tiles roof, 5 = concrete
Economic status	Rated in a 1-3 scale where 1 = very poor, 2 = well off and 3 = effluent
Section B: Occupation	
Pastoralist	If yes, holding pattern of buffaloes, cattle, shoat (sheep + goat) and others (camel, pig, horse, donkey etc.)
Farmer	If yes, land holding (in *bighas*) 1 *bigha* = approx 2,327 m^2
	Is the land irrigated/non-irrigated/*vidi* (*gauchar*) 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 & 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 and Daniel 2003)
Awareness of risk in having lions in the neighborhood ***Table 8.3.1 Contd.***	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

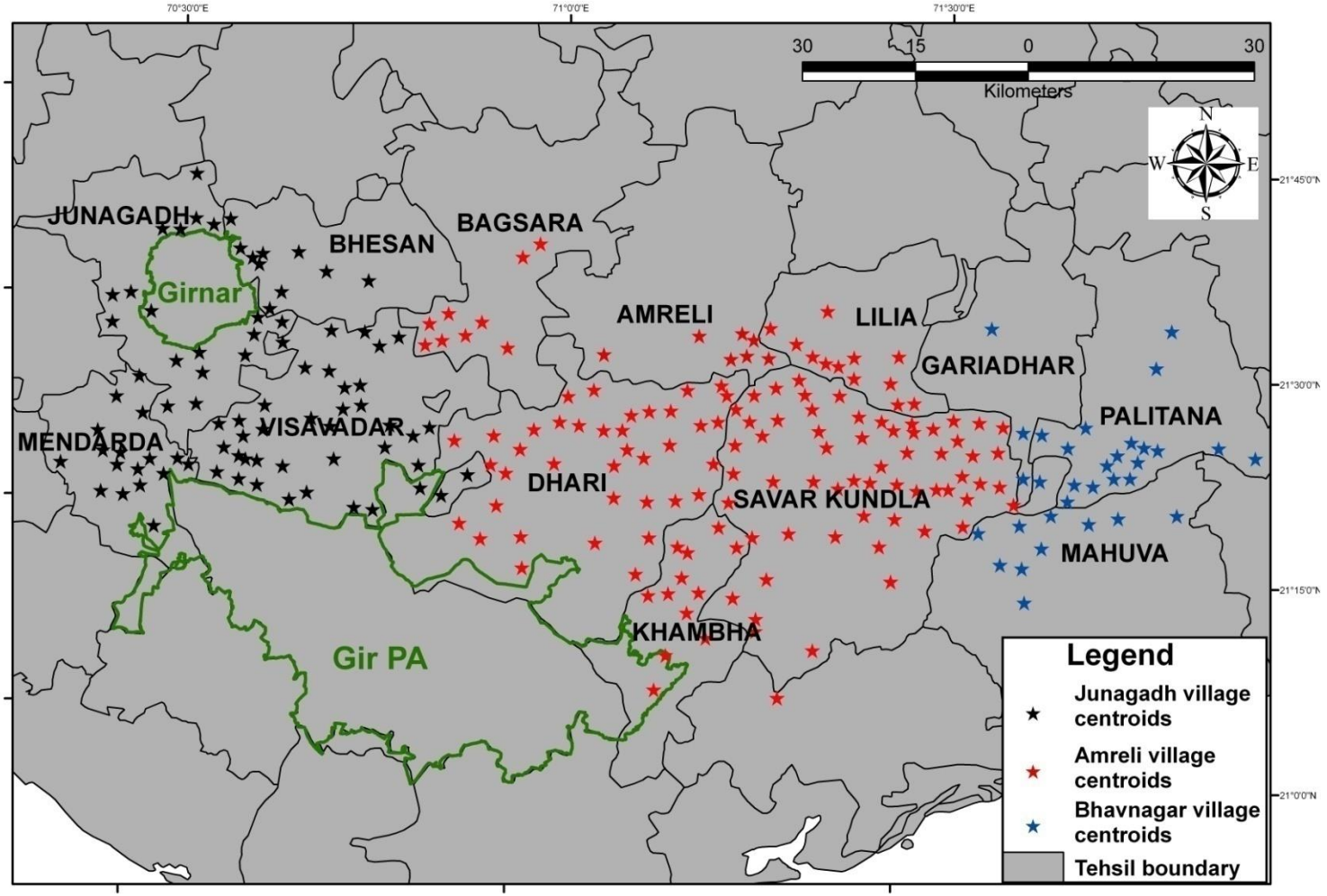
	or livestock = 1
Since when lions started living in the vicinity?	0-3 scale where 0 = no idea, 1= < 5 yrs, 2 = 5-10 yrs and 3 = > 10 yrs
How did lions reach in your area?	0-2 scale where 0 = no idea, 1 = natural dispersal and 2 = left over by the forest department
Would you like lions to continue to 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

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 13.2**). 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) *bigha*s. 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 13.3**). 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 13.2)**.

Figure 13.1: Gir landscape showing centroids of villages (n = 254) sampled for studying local people's attitudes toward lion conservation. *Tehsil* names and boundaries of the Gir PA and Girnar are shown. Village centroids of three districts are marked separately.



Majority (56%) of the respondents were of view that lions living in their surroundings for more than 10 years **(Figure 13.3)** with more elderly people saying this compared to the younger groups (χ^2 = 8.7, df = 4, p = 0.06). We found no difference of this view among different economic status (χ^2 = 4.1, df = 4, p = 0.39) or among different occupation (χ^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 (χ^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 (χ^2 = 252.4, df = 12, p < 0.001; **Figure 13.3**).

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 13.4)**. 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 (χ^2 = 43.1, df = 4, p < 0.001; **Figure 13.4**). We found no significant differences in the respondents' view about how lions reached in their locality among different age-groups (χ^2 = 5.5, df = 4, p = 0.24), among different economic status (χ^2 = 2.7, df = 4, p = 0.60) or among people of different occupations (χ^2 = 5.7, df = 6, p = 0.44). Less educated people viewed lions to be left over by the forest department (χ^2 = 106.1, df = 12, p < 0.001).

Table 13.2: 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 13.3: 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 = *Hyeana hyeana*, Chital = *Axis axis*, Sambar = *Rusa unicolor*, Blackbuck = *Antilope cervicapra*, Jackal = *Canis aureus*, Wolf = *Canis lupus pallipes*, Hare = *Lepus nigricollis*, Mongoose = *Herpestes edwardsii*, Porcupine = Hystrix indica, Peafowl = *Pavo cristatus*.

Figure 13.2: Awareness of risks of 680 respondents from 254 villages in the eastern landscape to question on having lions in the vicinity of their villages.

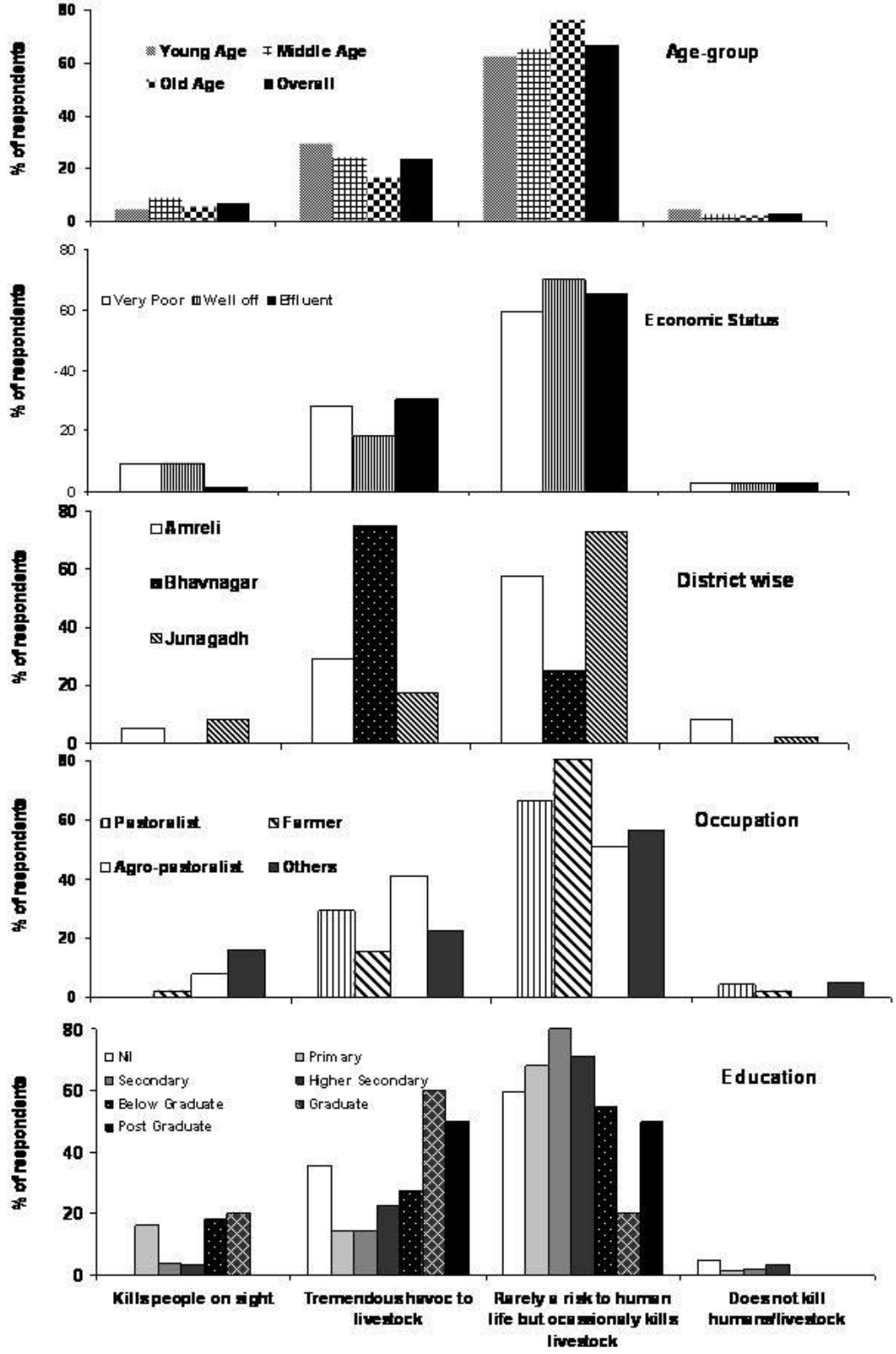


Figure 13.3: Views of 680 respondents from 254 villages in the eastern landscape to question on when lions started to live in their vicinity.

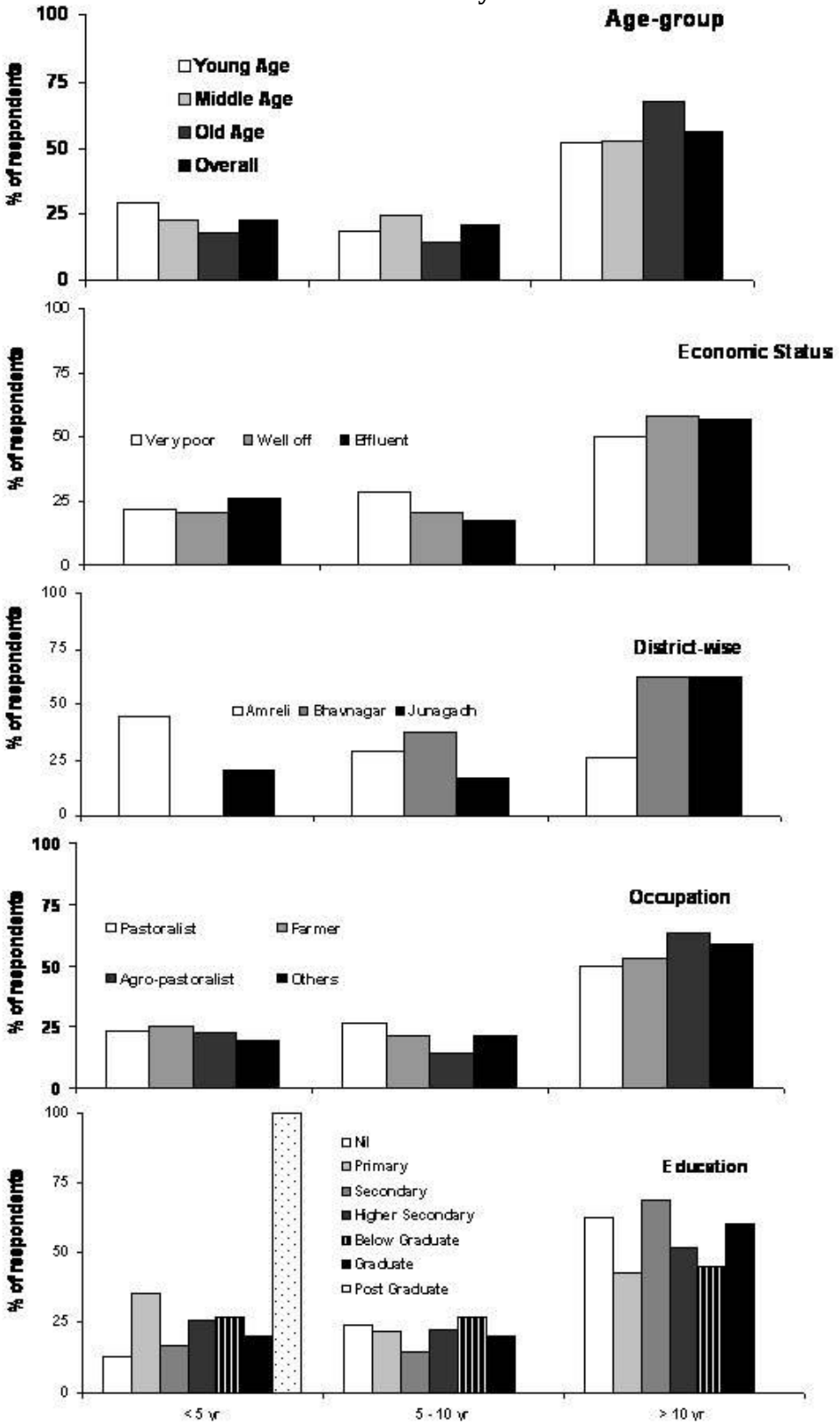
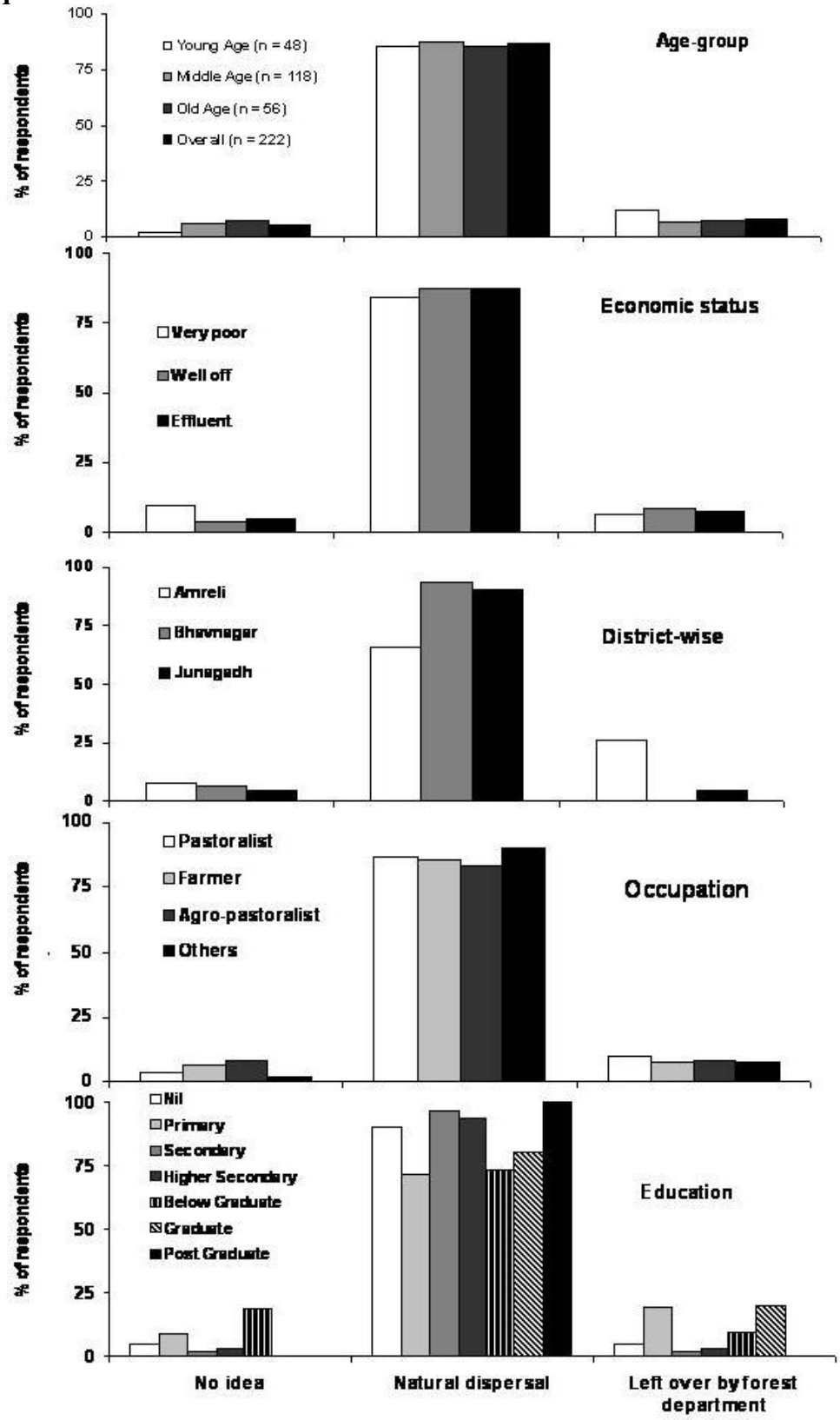


Figure 13.4: Views of 680 respondents from 254 villages in the eastern landscape to question on how did lions reach in their localities.



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 (χ^2 = 6.5, df = 2, p = 0.03; **Figure 13.5**). Respondents from Junagadh district were more unwilling to have lions in future (33%) compared to those from Bhavnagar (6%) and Amreli (18%) districts (χ^2 = 23.7, df = 2, p < 0.001; **Figure 13.5)**. Respondents of lower economic status were more unwilling (47%) to have lions in future than well offs (28%) and effluents (21%) [χ^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%) [χ^2 = 13.1, df = 3, p = 0.004]. More educated respondents were more willing to 'like to have lions in future' (χ^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 13.6]**.

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 13.7)**. 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 (χ^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 (χ^2 = 80.8, df = 12, p < 0.001; **Figure 13.7**). Pastoralists (17%) and agro-pastoralists (31%) wanted lions to be released back to the Gir PA while majority of the farmers (21%) opined that no intervention was needed for lion conservation (χ^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 activites (χ^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 (χ^2 = 538.1, df = 36, p < 0.001; **Figure 13.7**).

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 depratment for the local people would be helpful to gain more public participation in lion conservation (χ^2 = 25.6, df = 10, p = 0.004; **Figure 13.8**). 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 (χ^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 13.8)** 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 (χ^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 effluent respondents (32% each) wanted more employment generation with the forest department (χ^2 = 64.6, df = 10, p < 0.001; **Figure 13.8**). 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 (χ^2 = 487, df = 20, p < 0.001; **Figure 13.8**).

Figure 13.5: 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.

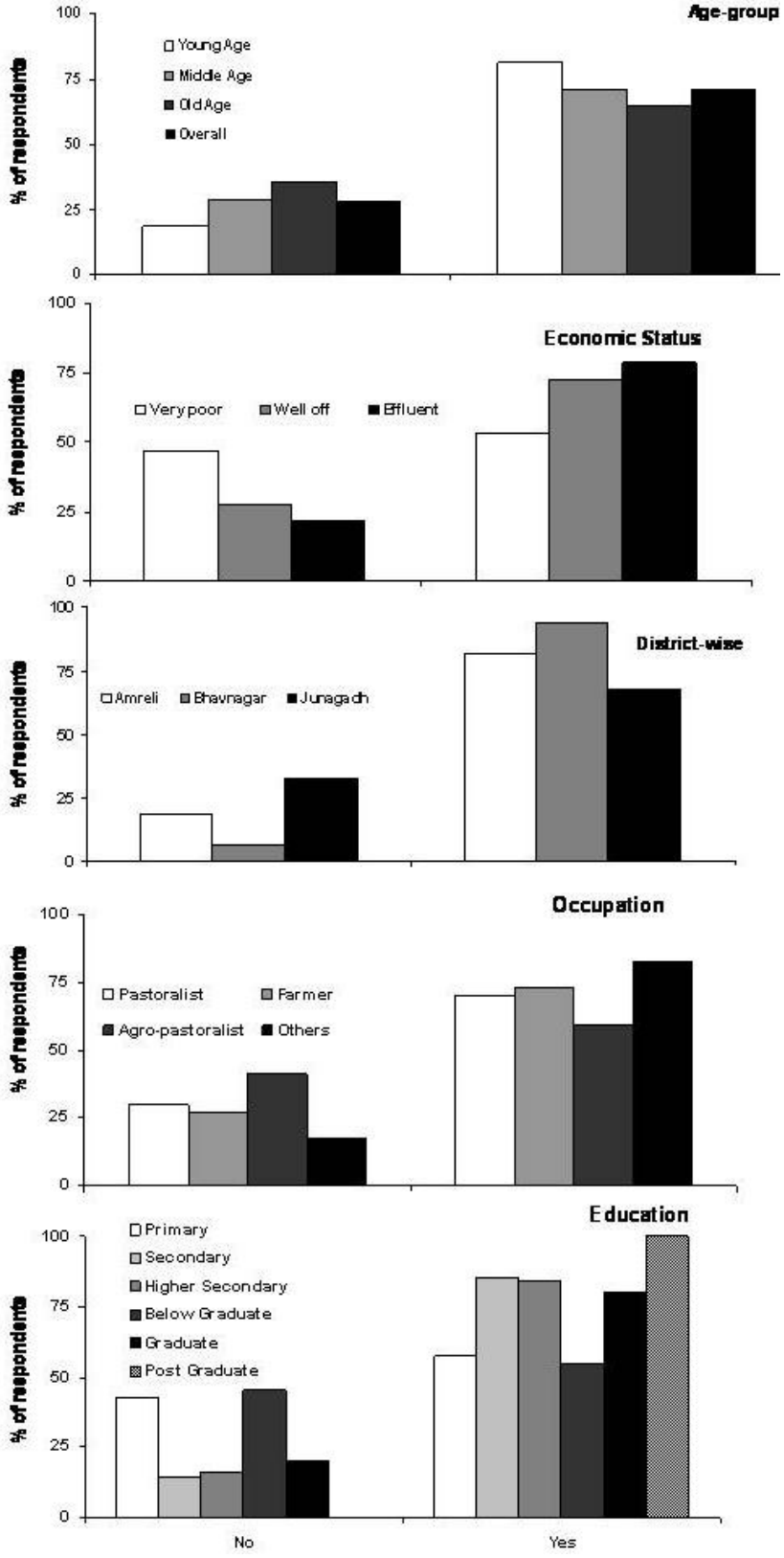


Figure 13.6: Views of 680 respondents from 254 villages in the eastern landscape to question on the reasons behind their liking/disliking lions to continue to live in their neighborhoods.

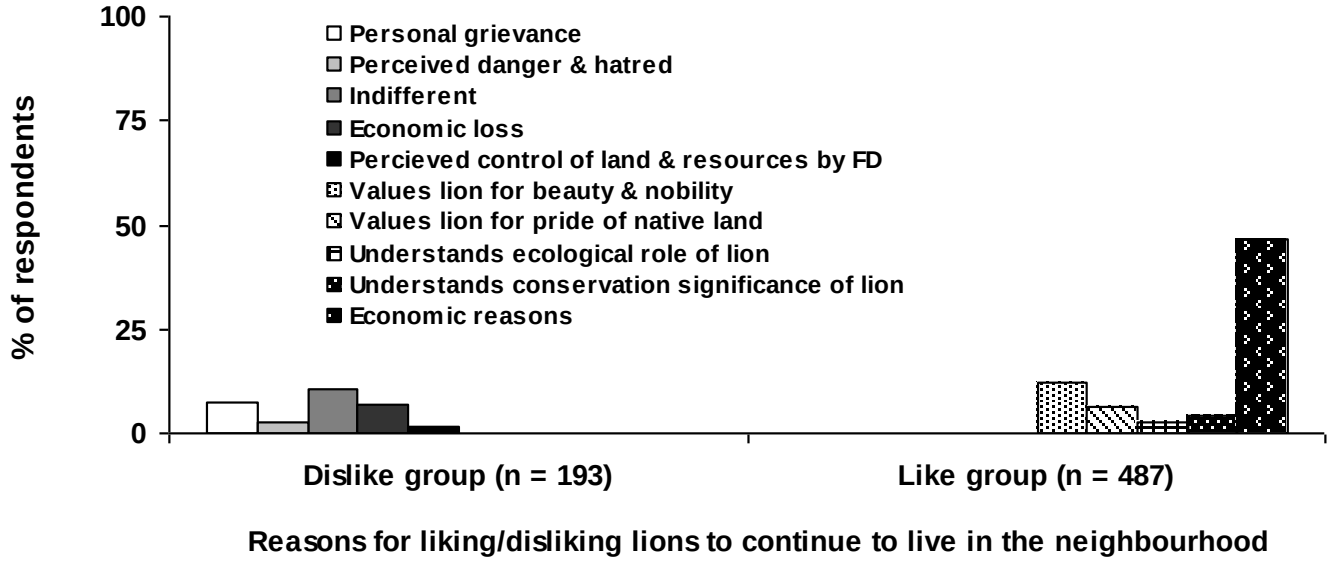


Figure 13.7: Views of 680 respondents from 254 villages in the eastern landscape to question on their recommendations for future lion conservation.

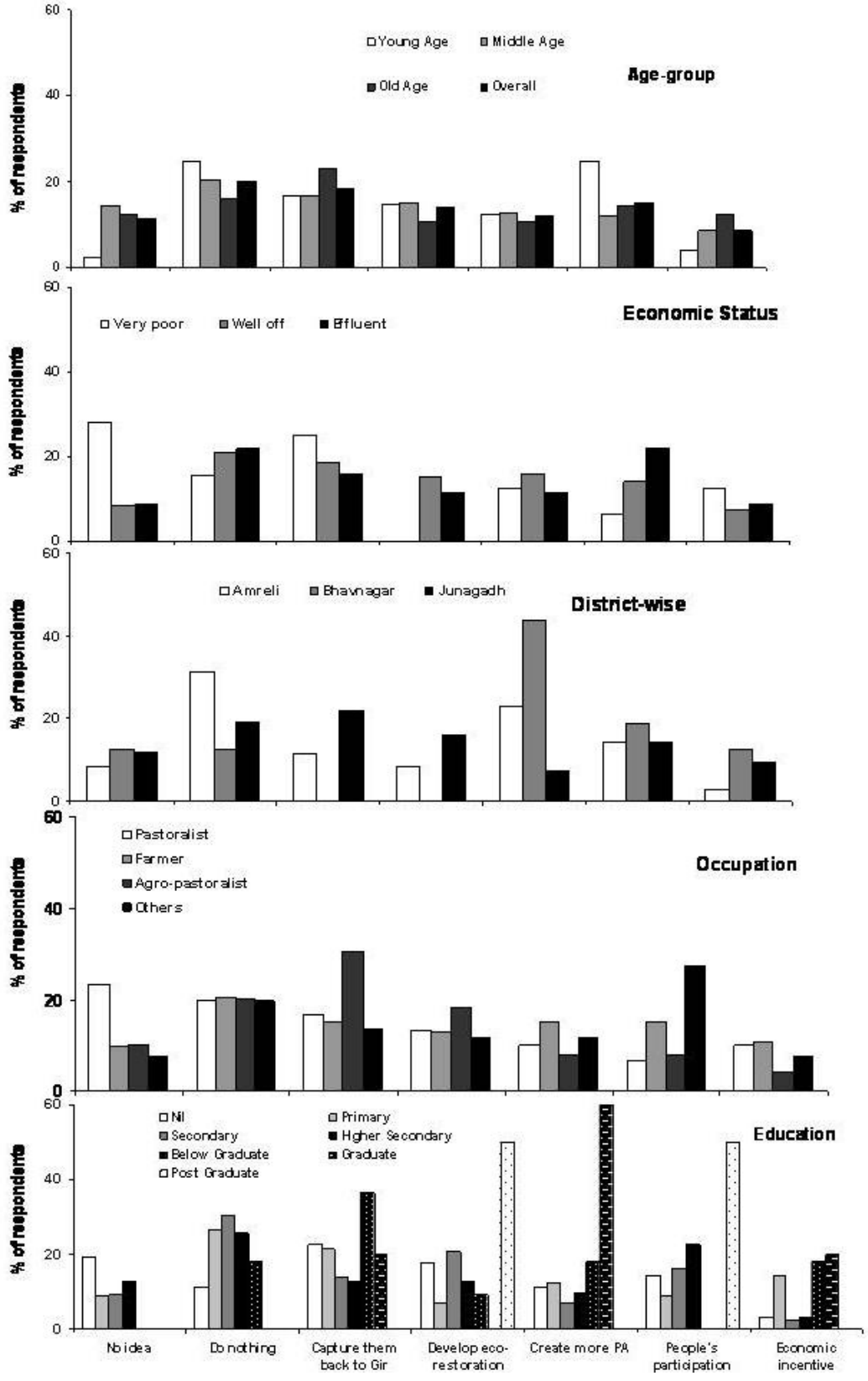
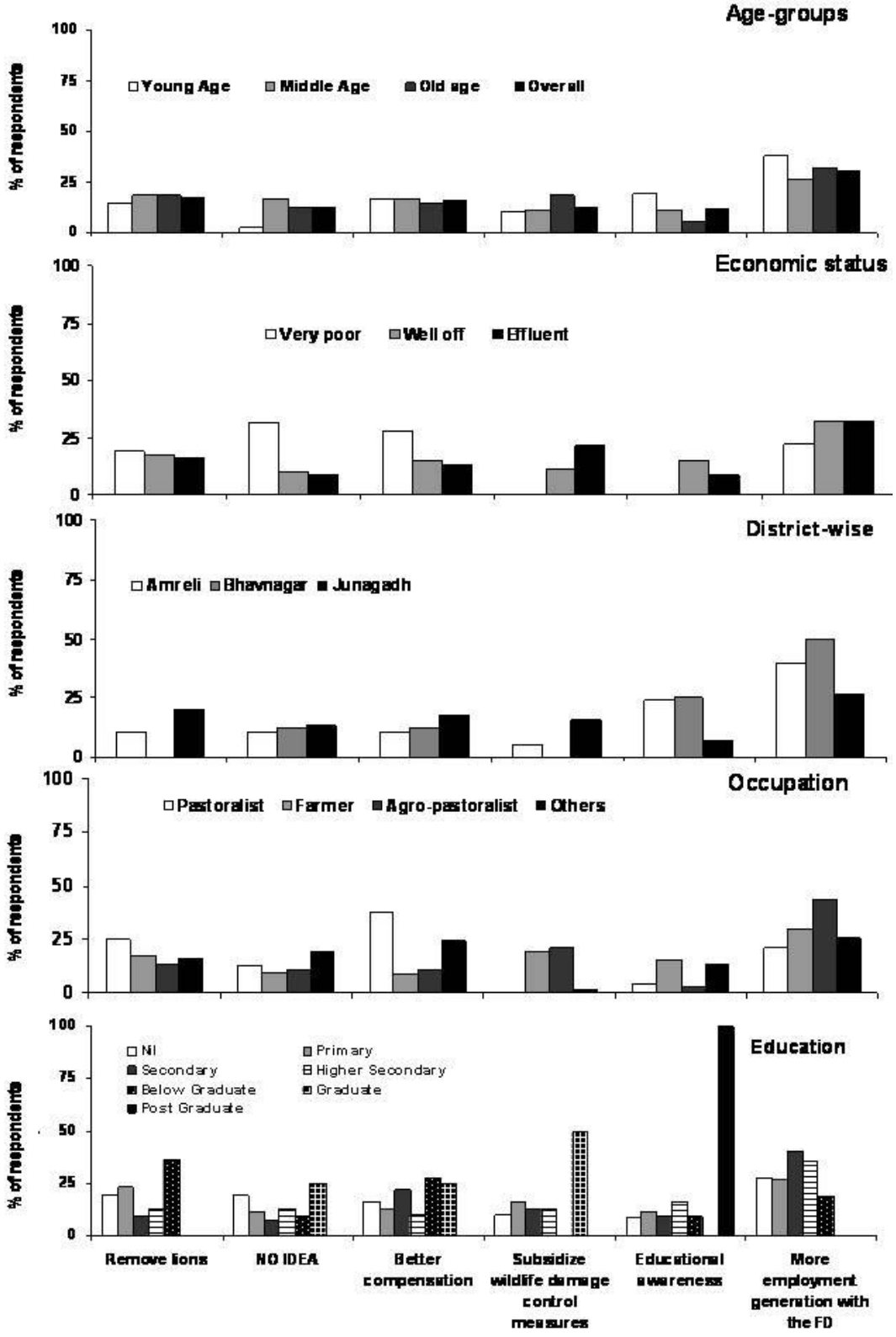


Figure 13.8: Views of 680 respondents from 254 villages in the eastern landscape to question on their recommendations gaining more public support for lion conservation.



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 13.9)**. 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 (χ^2 = 11.6, df = 2, p = 0.002; **Figure 13.9**). Young aged respondents were more unaware (31%) of the scheme compared to middle aged (18%) and old aged (14%) respondents (χ^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 effluent (81%) economic status (χ^2 = 6.8, df = 20, p = 0.03). All of the pastoralists interviewed were aware of the compensation scheme for livestock depredation **(Figure 13.9)** while agro-pastoralists were more aware (92%) of the scheme compared to farmers (81%) and people engaged in other professions (63%; χ^2 = 57.2, df = 3, p < 0.001). More educated respondents were less aware of the compensation scheme (χ^2 = 61.1, df = 6, p < 0.001; **Figure 13.9)**.

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%) [χ^2 = 15.1, df = 4, p = 0.004; **Figure 13.10**]. Seventy four percent respondents form Junagadh district informed that the scheme was not financially appropriate compared to 40% respondents from Bhavnagar and 47% respondents from Amreli districts (χ^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%) [χ^2 = 55.1, df = 6, p < 0.001; **Figure 13.10**]. We found no difference among respondents with various economic status regarding their views on the appropriateness of the compensation scheme in terms of money (χ^2 = 4.6, df = 4, p = 0.32). However, respondents from various education levels opined differently on their views on compensation scheme (χ^2 = 209.3, df = 12, p < 0.001).

Figure 13.9: 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.

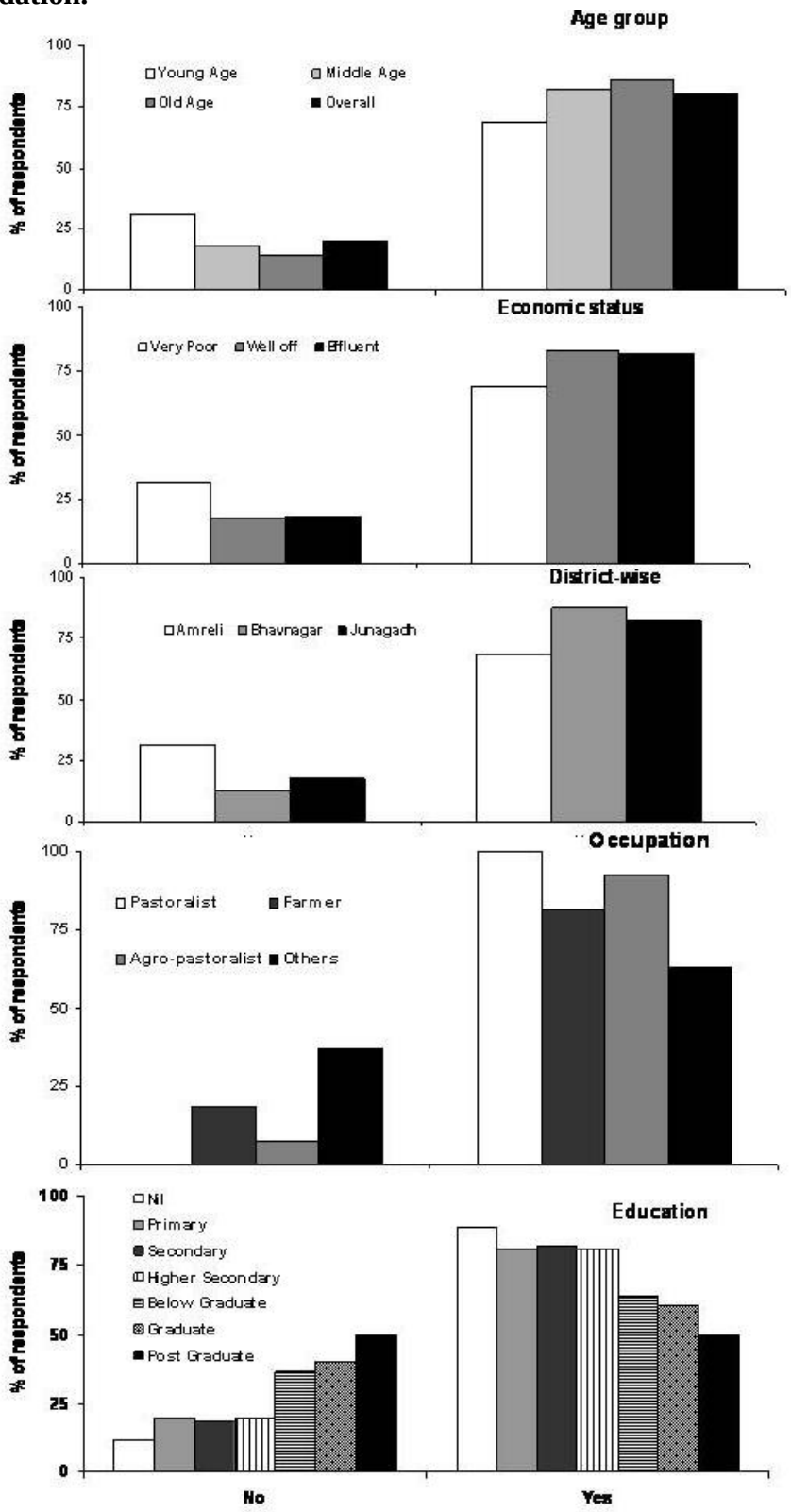
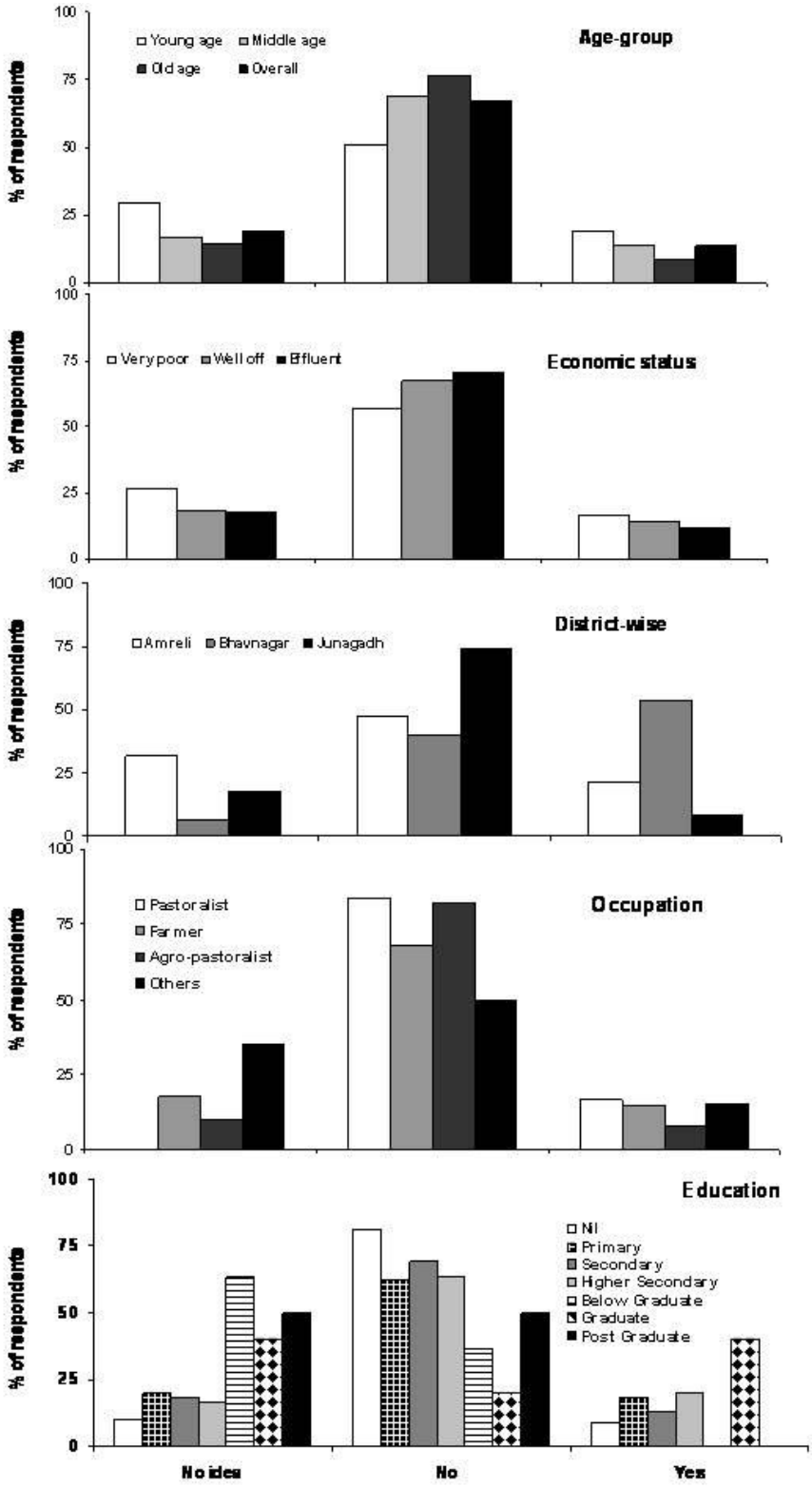


Figure 13.10: Views of 680 respondents from 254 villages in the eastern landscape to question on financial appropriateness of the Government compensation scheme for livestock predation.



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 13.11**). 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 13.11**). We did not find any significant difference in the respondents' view about the promptness of the scheme among various economic status ($\chi^2 = 7.8$, df = 4, $p = 0.09$). Respondents of different education levels informed in a mixed way with more ill-literate people considering the scheme 'not prompt and systematic' in comparison to the higher educated respondents ($\chi^2 = 238.9$, df = 12, $p < 0.001$).

False claim (claiming compensation from the Government against the kills of feral cattle) was not a major problem (74% of the overall respondents opined). However, middle aged (9%) respondents considered this as a problem more than those of young age (2%) and old age (4%; $\chi^2 = 16.4$, df = 4, $p = 0.002$; **Figure 13.12**). 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 13.12**). 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 13.12**). 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 13.11: 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.

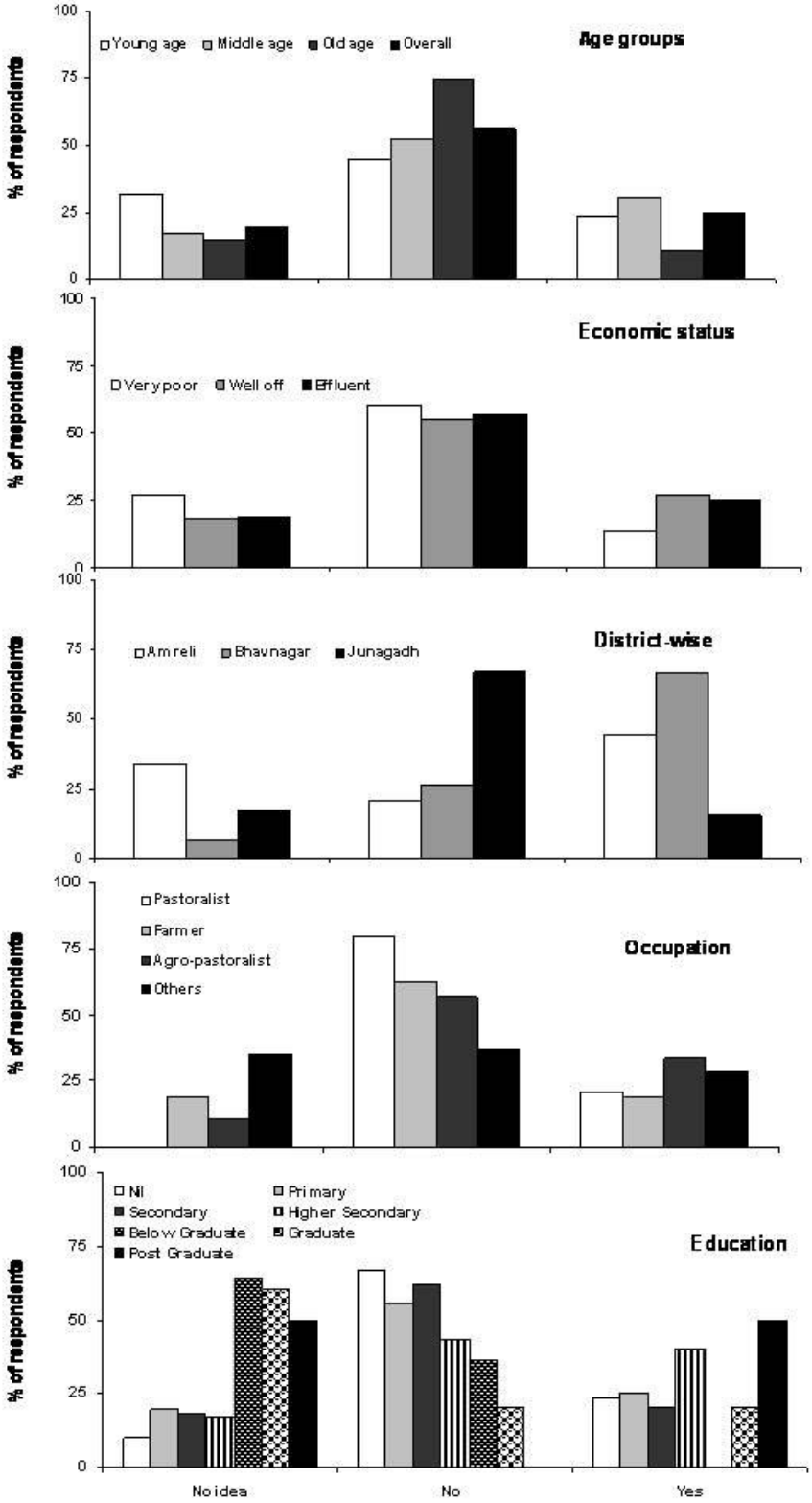
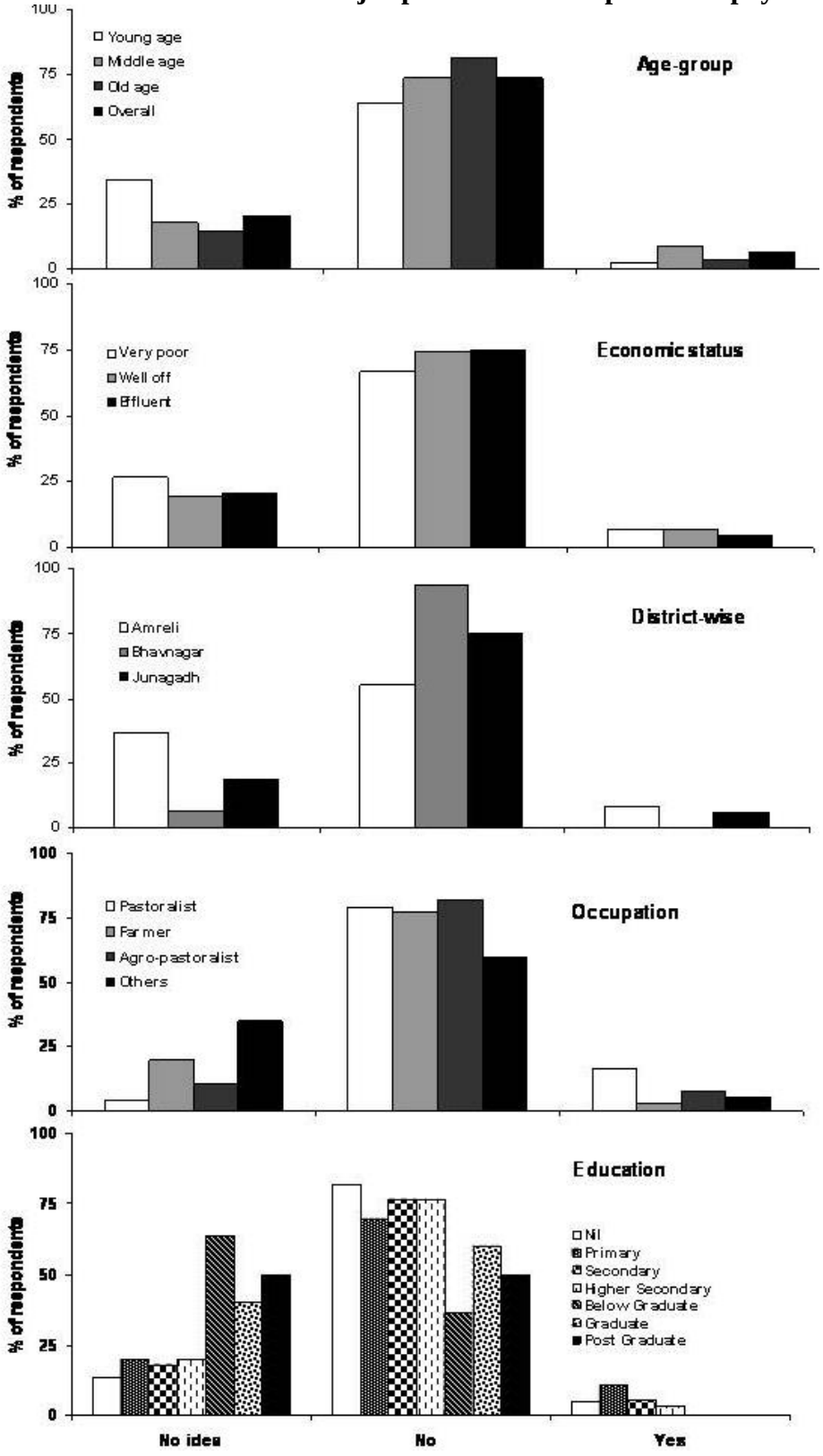
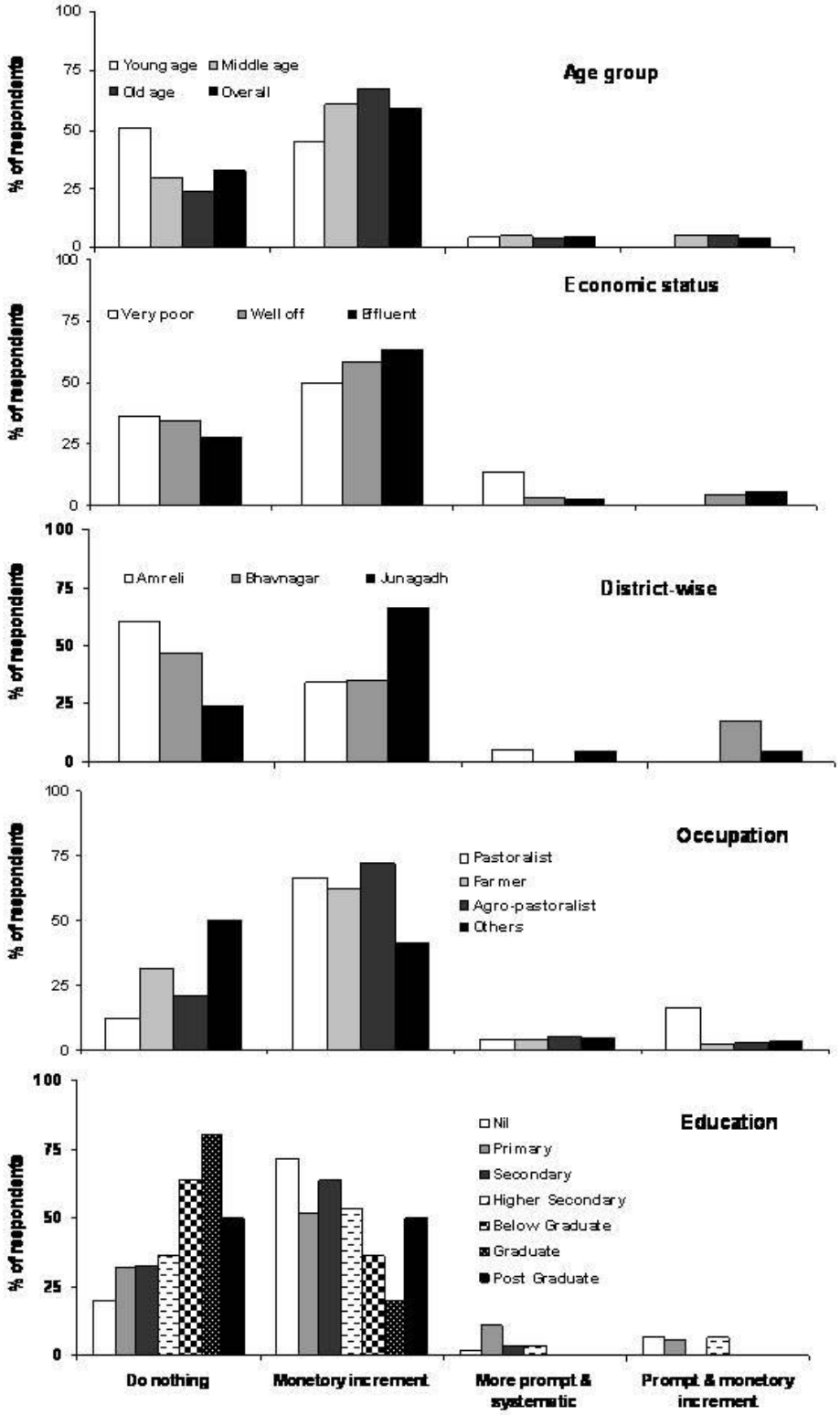


Figure 13.12: Views of 680 respondents from 254 villages in the eastern landscape to question on if false claims are major problems in compensation payments.



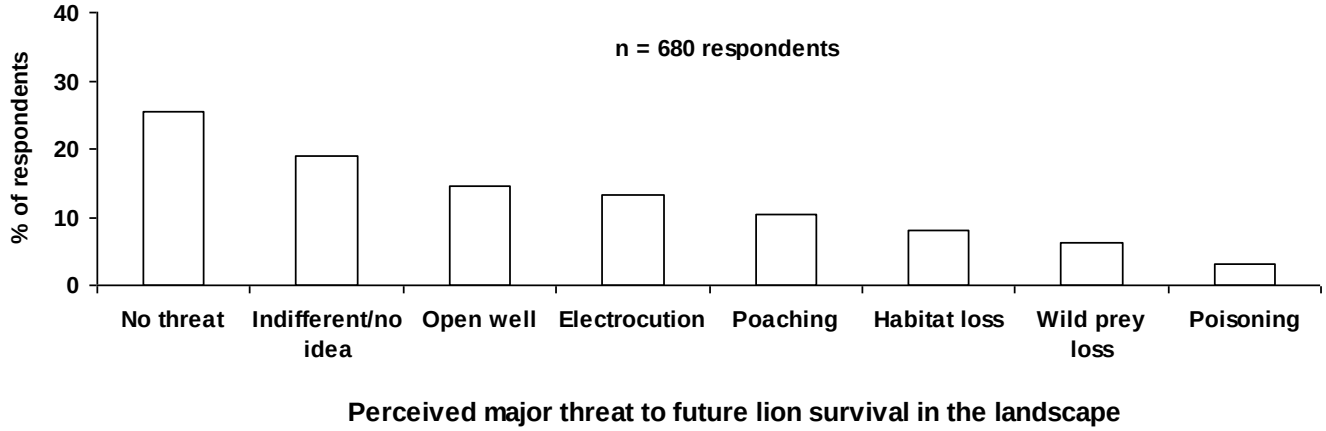
Monetary increment in the Government compensation to better it was the suggested measure by majority (59%) of the respondents. Old aged respondents wanted this more (67%) than young aged (45%) and middle aged (61%) respondents (χ^2 = 21.5, df = 12, p = 0.001; **Figure 13.13**). Majority (47%) of the 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 (χ^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 (χ^2 = 18.2, df = 6, p = 0.001; **Figure 13.13**). Agro-pastoralists (72%) wanted monetary increment in the scheme more than respondents from any other occupation (χ^2 = 59.8, df = 9, p < 0.0001). We found a significant difference in respondents' suggestion in improving the compensation scheme among different education levels with ill-literate respondents wanting the monetary increment more than higher educated groups (χ^2 = 147.2, df = 15, p < 0.0001; **Figure 13.13**).

Figure 13.13: 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 13.15**). 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 (χ^2 = 29.4, df = 7, $p < 0.001$).

Figure 13.15: 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 13.4)**. 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 13.4: Spearman rank correlation plot showing correlation coefficients between respondents' attitudes towards lion conservation in the Gir landscape and different socio-economic variables.

	LVL	AG	OC	ES	ED	ARL	LLV	HLR	RHL	RSL	PS	CS	CAM	CPS	CFC	IP	SIC	PMT
LVL	1																	
AG	-0.13	1																
OC	0.12	-0.10	1															
ES	0.13		-0.19	1														
ED	0.13	-0.30	0.19	0.25	1													
ARL	0.30		-0.21			1												
LLV		0.11					1											
HLR							-0.16	1										
RHL	0.82		0.12	0.16		0.21			1									
RSL	0.23			0.14	0.1			0.19	0.16	1								
PS	0.65	-0.09		0.12	0.10	0.19			0.55	0.45	1							
CS	0.15	0.14	-0.24	0.08	-0.20	0.20	0.33		0.16	0.13	0.13	1						
CAM		-0.19	0.15	-0.09	0.19	-0.12	-0.17	0.15	-0.07			-0.54	1					
CPS	0.09	-0.19	0.23		0.12	-0.13	-0.28	0.13	0.07	-0.13		-0.27	0.33	1				
CFC	-0.13	-0.10	0.13		0.09	-0.22	-0.26		-0.18		-0.13	-0.70	0.35	0.22	1			
IP	-0.17			.076	0.11	-0.14			-0.16		-0.10	-0.38		-0.14	0.37	1		
SIC		0.19	-0.20		-0.21	0.13	0.18					0.65	-0.68	-0.42	-0.44	-0.20	1	
PMT	0.22		-0.09	0.09		0.22		0.18	0.18			0.10	-0.14		-0.11			1

Only significant correlation coefficients ($p < 0.05$) have been reported. Variable abbreviations: *LVL= Like to have lions, AG = Age group, OC = Occupation, ES = Economics status, ED = Education, ARL = Awareness of risks in having lions in neighborhood, LLV = Since when lions started living in vicinity, HLR = How did lions reach, RHL = Reasons to have lions to continue to live in neighborhood, RSL = Recommendations in saving lions in the landscape, PS = What can be done to gain more public support, CS = Aware about the Government compensation scheme for livestock depredation, CAM = Is the compensation scheme appropriate in monetary terms? CPS = Is the compensation scheme prompt and systematic? CFC = Are false claims major problems in compensation, IP = Is irregularity a major problem in compensation payment? SIC = Suggestions to improve compensation scheme, PMT = Perceived major future threat for lions in the landscape.*

Respondents' attitudes towards lions in the Gir landscape

We selected the best model among a set of six *a priori* candidate models constructed to predict people's attitudes towards lions in the landscape **(Table 13.5)**. Model with the lowest AIC value was considered to be the best approximating model in the set of candidate models considered.

Table 13.5: 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 13.5)**. **Table 13.6** shows the parameter estimates for the best model (Model number 1, **Table 13.5**). 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 13.6)**. 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 13.6: 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 & 2; **Table 13.7**) 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 13.8**.

Table 13.7: 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 13.8)**. 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 13.8: 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

Discussion

Human ecology is concerned with how humans adapt to a changing environment (Catton 1987). Environmental change is often manifested as conflicts over the meaning and use of natural resources. One central issue in resource management is how the various interest groups perceive the environment, which values and beliefs do they attach to the environment, and how do diverse environmental beliefs affect the position different actors take in conflict situations? Successful resource management is becoming increasingly dependent upon knowledge about how conflicts are constructed, and this entails identifying attitudes and beliefs held by various interest groups.

An ''attitude is the product of a person's perception of how good or bad the outcome associated with a certain behaviour is'' (Beedell and Rehman 1999). An optimal output can arise when all known costs and benefits are evaluated. Of course, different individuals can perceive the costs and benefits differently, and this is influenced by various factors. This perception then produces the 'best' attitude for the person and directs the appropriate response towards a subject or an object. An advantage of an already formed attitude is that it allows one to make a rapid decision about which behaviour to adopt. The decision is rapid because only the outcome of the evaluation and not all the steps that led to it has to be remembered.

People's attitudes toward large carnivores across the world are polarized with different demographic and socio-economic groups (Kellert 1996). Pastoralists, the elderly, people with less education, communities less involved in recreational activities (tourism), and rural inhabitants often express negative attitudes toward large carnivores, while younger, better educated, and urban people express more positive attitudes toward this species (Kellert 1985, 1991; Dahle 1987; Bjerke et al. 1998). Attitudes towards large carnivores seem to be related to what experience respondents have had with them. Acceptance is high as long as the carnivores are far away from where people live, or if the chance of re-establishment is very low (e.g. in towns).When carnivores come closer, acceptance decreases, and negative attitudes come to a peak when the carnivores actually first arrive. As experience with carnivores increases over time, negative attitudes decrease. After carnivores have become established, fewer people have negative attitudes than at the starting point (Zimmermann et al. 2001).

The current study has revealed a mixed pattern in local attitudes towards lion conservation in the Gir landscape. Respondents hold a diversity of attitudes toward lions that are both positive and negative. Majority of the respondents were aware of the presence of large mammals surrounding their villages **(Table 13.3)**. 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 13.5 and 13.7)**; 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 13.4)** 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 effluent people **(Figure 13.5)**. Poor people being less educated are unaware of their rights and various ongoing government schemes **(Table 13.4 and Figure 13.9)** compared to the effluents 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 effluent people. Interestingly poor respondents wanted the compensation scheme to be 'more prompt and systematic' while effluents wanted monetary increment **(Figure 13.13)**. 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 13.4** suggests that respondents' education level was negatively correlated with age and positively correlated with economic status and views about like to have lions in the neighborhood. As reported by Bath (1987) in a survey about perceptions towards wolves, there was a relationship between knowledge of the species and perceptions. The low educational levels of the older generation and lower income groups in the Gir landscape is likely to have influenced their attitudes about lions by lowering their awareness about their conservation rights and various government run schemes (like the compensation program for livestock depredation) to elicit more public support in lion conservation.

People have always been concerned about their own health and safety, and they have evolved both positive and negative responses to large carnivores. Self reported fear has played an important role in the conservation many large carnivores, especially in the Scandinavian countries (Røskaft et al. 2003). The current study also identifies such risk perceptions as one of the main factors shaping people's attitudes toward lions in the Gir landscape. For example, a respondent considering lions as threats to humans was 77% more unwilling to have lions (P = 0.13) in comparison with a respondent thinking that lions 'neither kill humans nor livestock'. Similarly, a respondent with the view that lions killed livestock was 29% less willing (P = 0.63) to continue to live with lions in future. Many wildlife managers, until recently, underestimate significance of these fears and psychology shaping them. It is more important to gain a better understanding of attitudes to carnivores and explore the behavioral and cultural factors influencing them. This is especially relevant in the Gir landscape where lions are being conserved in multiple land-use landscapes with high human density.

Studies on different continents under diverse social and economic circumstances have concluded that depredation on livestock is an important cause of human intolerance for large carnivores, frequently leading to their extirpation (Karanth and Chellam 2009). Studies in East Africa provide similar evidence that African lion populations are declining due to rapid habitat loss and inter-specific conflicts over resources in areas where pastoralism persists (Frank 1998; Ikanda and Packer 2008; Maclennan et al. 2009). A majority of India's protected areas have livestock-related conflicts (Kothari et al. 1989). For example, tigers are also in conflict with pastoralists as 10–12% of their diet consists of domestic livestock in many parts of India (Biswas and Sankar 2002; Bagchi et al. 2003). The problem is more severe in the Himalayas where local pastorals experience livestock depredation problems by snow leopards (Bagchi and Mishra 2006). Pastoral communities react differently to this conflict depending on their religious beliefs, customs, cultures, perceptions of economic losses (Goldman et al. 2010). In India although people resent having large carnivores in their pastures, they do not actively persecute them as in other parts of Central Asia (Mishra and Fitzherbert 2004). The current study highlights this wherein we found a pattern of people's attitudes strongly polarized with occupation. Economic reasons were found to be one of significant factors shaping people's attitudes about future lion conservation (r_s = 0.82; **Table 13.4)**. 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 13.2)** and more unwilling to continue to live with lions in future than the latter **(Figure 13.5)**.

From the Mongolian steppe to the ranches of Montana, the link between stock losses and carnivore persecution has prompted reparatory measures such as livestock compensation schemes with the general intention of mitigating this conflict (Montag and Patterson 2001). Conserving large carnivores in close juxtaposition with humans often involves costs to local people. It is increasingly clear that to promote coexistence in wildlife habitats where local people live, there is a need not only to evaluate and offset the costs but to make wildlife conservation more beneficial for local people (Prins et al. 2000). Unless there are tangible economic returns, local communities are unwilling and often unable to adopt conservation-friendly practices. Incentive programs like compensation cannot ‘buy’ an individual’s tolerance of carnivores (Naughton-Treves et al. 2003) but does ameliorate hostility. Gir has a long history of compensation program for livestock depredation since the time of erstwhile local rulers (Nawabs) in pre-independence era (Gee 1964) which has been continued by the Gujarat Forest Department during the post-independence period (Singh 2007). Banerjee et al. 2013 clearly showed that the Government compensation scheme has a significant role in shaping legendary lion-*Maldhari* coexistence within the Gir PA by ensuring livelihood securities for the latter. The fulcrum of coexistence however is delicately balanced by the free grazing rights of *Maldhari*s within the Gir PA. In the larger landscape pastorals hardly had any access to forest resources and expectedly expressed their antagonism toward the compensation scheme. Majority of the respondents in the Gir landscape expressed their discontent over the monetary values and promptness of payment of the compensation scheme and called for enhancing the payment amount and making it more systematic and timely. Incorporation of lost opportunity cost by the communities in the compensation scheme has been highlighted in the Banerjee et al. 2013. We, however, did not include the travel cost by the local communities in getting compensations (like time invested and travel to forest office for lodging the complaints, pursuing the case and getting

the payment cheque). These when considered further diminish the financial impact of the compensation amount in offsetting the pastorals' loss due to livestock predation. Gujarat government regularly revises this scheme in accordance with the market prices. The scheme seems to have improved over the years as the people's awareness about the prevailing compensation scheme has increased in compared to a previous study (Saberwal et al. 1994). Moreover, the younger generation who were more recently exposed to lions has a better opinion of it. Also communities who were less directly impacted by compensation like the farmers and people engaged in other services had a better opinion than pastoralists and agro-pastoralists. Respondents of Amreli district were more unaware of the compensation scheme in comparison with those from Junagadh and Bhavnagar. This is likely due to the higher education level among the respondents in Amreli district. More educated people in the landscape were found to engage themselves in other services than traditional pastoralism and farming. Job in diamond industry is one of the commonest sources of income for respondents in Amreli district and being a non-impacted group they showed less awareness about the compensation scheme. In the agro-pastoral landscapes, in the absence of any free economic benefits for the communities, the Government compensation scheme becomes extremely crucial for maintaining the goodwill of the communities towards lion conservation. Recognizing the role of compensation policies in providing instant financial relief, the procedural framework of the current system in Gir could be more streamlined and provisions of onsite payments with active involvement of local non-governmental organizations like that prevailing in Corbett Tiger Reserve, India (WWF-India 2007) could also be adopted. Incorporating lost opportunity cost in the compensation and revising compensation amounts every three years would offset economic losses incurred by the local people in the process of livestock predation by lions and other predators and foster their greater tolerance towards conservation (Banerjee et al. 2013).

Lion density (2/100 km^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 (Banerjee and Jhala 2012). Moreover, lack of such compensation also compel local farmers to guard their crops even at nights and this increases the likelihood of lion attacks on humans in the landscape (Banerjee 2012). We, therefore, advocate that introduction of a compensation scheme for crop damage in the landscape would significantly diminish local farmers' antagonism toward wild ungulates and assist in promoting greater tolerance for lions and other carnivores in the landscape. Alternatively, wildlife damage control measures (like pulsating electric fences; Chauhan 2006) could be subsidized to ensure better tolerance of agricultural communities.

The study also evidently highlights a spatial pattern in the local people's attitudes. Bhavnagar district was found to be more lion friendly while Junagadh the least. People in Junagadh district has an uninterrupted history of staying with lions while it is only in recent time that lions dispersed in the agro-pastoral landscape of Bhavnagar and Amreli districts (Pathak et al. 2002; Divyabhanusinh 2005; Singh 2007). Residents of Junagadh district were more aware of lions and the compensation scheme than those of Amreli and Bhavnagar owing to their experiences. However, Junagadh houses major part of the Gir PA and has a higher lion density often resulting into more lion attacks on humans than Amreli and Bhavnagar districts (Banerjee 2012). Longer history of tolerating conflicts with lions and other carnivores might have made respondents of Junagadh comparatively more hostile than people from Amreli or Bhavnagar districts. Moreover, most part of our study area within Junagadh district (Mendarda, Talala, Visavadar, Junagadh and Bhesan talukas) was densely populated and had intensive farming thereby escalating conflicts with lions and other carnivores. On the contrary, our study area within Bhavnagar and Amreli districts (upper and lower Shetrunjee basins, vast agro-pastoral tracts of Chalala, Khambha, Savarkundla, Dhari, Amreli, Palitana, Talaja, Sihor, Mahuva and Gariadhar talukas) was typically pastoral, comparatively less populated and predominantly characterized by broken terrain with sparse agricultural cover, private and government owned grasslands (*vidi*s), *Prosopis juliflora* thickets and drainage networks. Most of the cattle camps (*gaushala*s and *panjrapole*s) of Kathiawar region are also concentrated in this part of the landscape due to impact of Jainism. Therefore, despite lions' use of human-dominated landscape they chiefly depend on low priced unproductive and feral cattle (see chapter 9 for more details). We anticipate that all these together make Bhavnagar and Amreli more 'lion friendly' than

Junagadh. Thus the study contradicts notion that longer exposure to carnivores enhances local people's tolerances. It rather emphasizes the importance of livelihood securities and economics of coexistence as major ingredient in shaping human tolerance in the Gir landscape.

Although majority of the respondents believe that lions do not have any major future threat in the landscape, a substantial proportion, however, opine human-causes as the main future threat for lions. This might be driven by their old experiences. Currently Gujarat forest department has an ongoing project of constructing parapet around the open farm wells and with the covering of about 17,000 wells in past three years (Meena and Kumar 2012) such threat is likely to get diminished in future. About 10% of the respondents pointed out poaching as a probable threat to lion survival and we attribute this to their remembrance of three incidents of poaching that happened in Gir landscape in March-April 2007 (Fair 2009). Due to high price of lion body parts in international markets especially in China (Check 2006), the possibilities of such incident cannot be overruled and respondents' opinions probably reflect this. With the rapid change of the land-use pattern, livelihood diversification and local communities' traditional custodian roles of nature getting fast eroded by western utilitarian values, such perceived animosity, although small, might even lead to complacency with the professional poaching gangs that happened in Gir in 2007 (Fair 2009) and elsewhere in India (Narain et al. 2005; Gopal et al. 2010). Gir PA is likely to be lion unabated stronghold in future owing to the strong protection regime of the forest department. However, we believe that law enforcement alone cannot secure lion survival in the Gir landscape. A broader rural support base has to be generated. In the human-dominated landscape where conservation is not a major land-use objective, understanding the nature and costs of human-lion conflicts through combined assessment of both actual and perceived dimensions of the problem therefore becomes imperative. The findings of the present study have the significant implications herein as it highlights the perceived conflict which could be used to project the threshold of social tolerances for lions in future. The increasing investments in conventional 'solutions' to human-wildlife conflicts such as culling problem animal cannot be adopted in Indian scenario because of legal prohibitions (Karanth and Gopal 2005). Instead, mitigation of lion-human conflict in the Gir landscape bags pragmatic approaches based on ecology based policy framework with a harmonious amalgamation of state's land, tourism and rural development policies. This could be done by targeting appropriate stakeholders through awareness campaigns. Currently the Gujarat Forest Department has an 'Education

Camp' program aiming younger generation only. But this should be made available even to the poorer and backward sectors of the society so as to disseminate the ideas about the conservation benefits even to the lowest stratum of the society. Compensation amount paid to the pastoralists should be enhanced by incorporating lost opportunity cost, streamlined and revised regularly. A compensation for crop damage should be thought upon. Gujarat forest department often argues the complexities in identifying the extent of crop damage as a deterrent of introducing such scheme (Meena and Kumar 2012). 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.

CHAPTER XIV

ASSESSMENT OF BARDA LANDSCAPE FOR POTENTIAL OF LION REINTRODUCTION

Introduction

Last free-ranging population of approximately 500 Asiatic lions *Panthera leo persica* are found in the 20,000 km^2 of the Gir landscape in Gujarat, western India (Gujarat Forest Department 2015). Carnivore populations restricted to single sites face a variety of extinction threats from genetic and stochastic environmental factors (Gilpin and Soulé 1986). Catastrophes such as an epidemic, an unexpected decline in prey, natural calamities or retaliatory killings could result in their extinction when they are restricted to single populations. The reality of this threat was brought home when a canine distemper epidemic played havoc with one of the largest lion populations in the Serengeti ecosystem of East Africa. The outbreak of canine distemper in the lions of the Serengeti National Park, Tanzania, in 1994 killed an estimated 33% of the population (Roelke-Parker et al. 1996). The lion population in the 40,000 km^2 Serengeti-Mara ecosystem is large, with about 3,000 individuals (Bauer and Van der Merwe 2004). If an epidemic of this scale were to affect the lions in the Gir ecosystem, it may severely deplete the population and endanger the species further. The establishment of a second free-ranging population of Gir lions would therefore help to insure against this.

Reintroduction of Asiatic lions to an alternative site to ensure their long-term viability therefore became a major conservation agenda in post-independent India since late-1950s. Failure of the first attempt of the Asiatic lion reintroduction in India (Chandraprabha Wildlife Sanctuary of Uttar Pradesh) in 1960s has been unanimously ascribed to the lack of an *a priori* scientific study on lion prey base, habitat requirements, local people's attitude and a post-release monitoring program (Negi 1969). In early 1990's Wildlife biologists selected Kuno WLS in Madhya Pradesh as a potential reintroduction site (Chellam et al. 1995). As per the Supreme Court's judgment protocols for lion reintroduction in Kuno WLS are being actively pursued by MoEF&CC, Gujarat FD, Madhya Pradesh FD and Wildlife Institute of India (WII). *In-situ* lion conservation would benefit from as many free ranging populations as possible. In this light Barda Wildlife Sanctuary (Barda WLS) situated in the western part of Saurashtra was selected as an alternative site for reintroduction of Asiatic lions by the Gujarat forest department owing to its

eco-climatic and human community resemblance with many parts of the Gir landscape (Joslin 1985; Singh 2007). Accordingly, 192.3 km^2 area of Barda hill was declared as a wildlife sanctuary on 12th February 1979 (*vide* Gujarat Government Gazette notification no. GHKH-21/79-WLP-1079/82068-P-2) and a management plan for ten years was written in 2002 which was revised recently.

Several factors influence success or failure of a carnivore reintroduction. Amongst them a reliable and unbiased *a-priori* assessment of habitat parameters, prey population, co-predator population, current land-use pattern, livelihood issues and local people's attitude towards carnivores is essential for planning carnivore reintroductions (IUCN/SSC 2013). WII was mandated by the Gujarat forest department to undertake the current study that aims at obtaining the above information so as to assess Barda Wildlife Sanctuary for its preparedness of reintroduction of free ranging Asiatic lions. The specific sub-objectives addressed during the study were:

a) *Assessment of the status and distribution of co-predators*
b) *Assessment of status and distribution of prey species*
c) *Quantifying human impacts in the sanctuary*
d) *Quantifying local people's attitudes towards lion reintroduction in Barda and,*
e) *Identifying potential habitat corridor between Gir PA and Barda Wildlife Sanctuary permitting regular lion movements between these two PAs and*
f) *Develop an appropriate strategy for reintroduction*

Methodology

To achieve these objectives, we surveyed Barda Wildlife Sanctuary and its surroundings between October 2013 and March 2014. Sampling grids of 2×2 km^2 dimensions were overlaid on the study area using a handheld GPS unit. We used conventional and spatially explicit capture-recapture (SECR) framework (Otis et al. 1978; Borchers and Efford 2008; Efford et al. 2009) based on camera traps (1,856 trap nights) for abundance estimation of leopards and occupancy of other carnivores (Jhala et al. 2013). Distance sampling based on line-transects (n = 27; 50 km walk) was used to estimate prey abundance in Barda (Buckland et al. 2004). We carried out a total head count of livestock units in 542 *Maldhari* households of 29 *nesses* within Barda sanctuary and interviewed *Maldharis* to understand livestock husbandry practices (Banerjee et al.

2013). We collected information pertaining to forest and natural resource extraction by *Maldhari*s, livestock pressure, and general anthropogenic factors due to the presence of people in and around Barda sanctuary on each transect, at every 400 m on 15 m radii plots (n = 130 plots; Jhala et al. 2013). We used Ecological Niche Factor analysis (Hirzel et al. 2002) based on lion locations obtained through telemetry in Gir to model lion habitat. The probability of lion habitat use was then used as a cost surface using circuit theory and program Circuitscape to delineate movement corridors between Barda WLS and Gir lion populations (McRae and Beier 2007; McRae et al. 2008; McRae and Shah 2009). We interviewed 90 respondents from 23 human settlements (18 *Maldhari nes*ses within Barda and 5 peripheral villages) using a closed and open ended structured questionnaire to quantify the socio-economic conditions of the local people, occupational patterns in the area and the attitudes and support of local communities towards lion reintroduction.

Salient findings of the present study relevant for planning lion reintroduction:

Barda sanctuary is currently having high anthropogenic pressure. Human caused disturbances are higher in the west and southern boundaries of the sanctuary owing to the presence of two large towns (Ranavav and Adityana) bordering Barda sanctuary (**Figure 14.1**).

Current wild prey density in Barda is very low with nilgai (0.3 ± SE 0.02 km^{-2}) and wild pig (3.4 ± SE 2.8 km^{-2}) constituting the major prey and is inadequate for sustaining even a small lion population (**Table 14.1**). Since Barda WLS is similar in terms of eco-climate and vegetation communities to eastern part of Gir PA, we believe that given adequate protection and removal of human pressures, wild ungulate populations in Barda WLS can build up to levels observed in eastern Gir PA. To facilitate recovery of wild prey populations we recommend: 1) continued and intensified restocking program of wild prey (chital and sambar) after disease checks; 2) strict protection against prey poaching by regular patrolling and law enforcement and 3) reduction of the livestock population from Barda by incentive driven voluntary relocation of *Maldhari*s so as to reduce competition for wild prey species. Reduction of livestock from Gir PA has resulted in a dramatic increase in the prey population of the PA and a similar response is expected in Barda WLS as well.

Figure 14.1: Map showing gradients of anthropogenic pressures operating in Barda WLS.

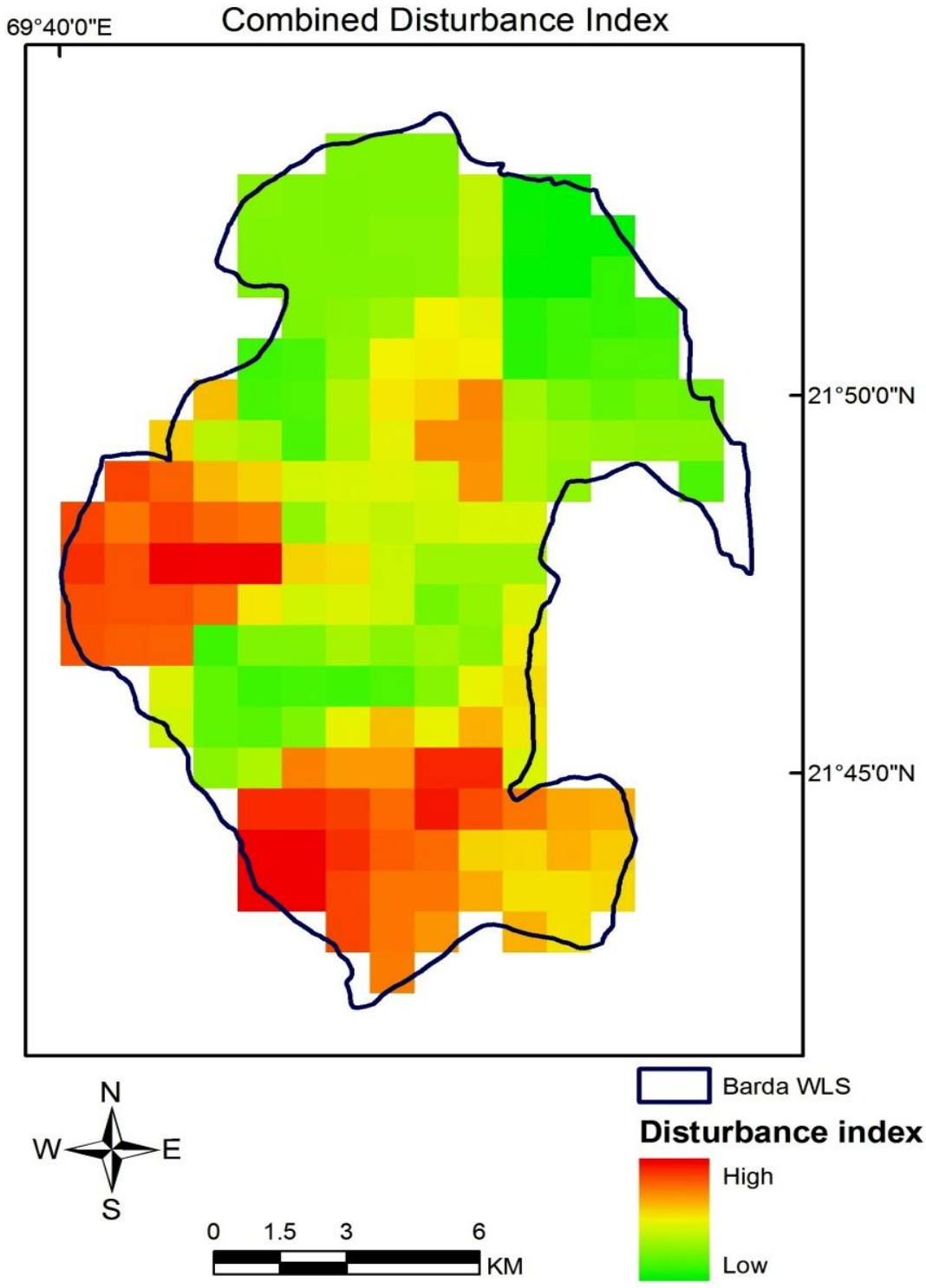


Table 14.1: Estimates of density and available biomass of prey species in Barda WLS. Figures within parentheses represent standard errors. Unit weight of different species was taken from Banerjee (2012). ESW (62 m ± SE 4.4) was taken from Dave (2008). Standard errors on ESW and group size were pooled using delta variance method (Seber 1982) for each prey species.

Prey species	Weight (kg)	Numbers detected	Density (/km^2)	Encounter Rate (/km^1)	Biomass density (kg/km^2)
Nilgai*	**136**	**2**	**0.3 (0.02)**	**0.04 (0.02)**	**40.8**
Wild pig*	**28**	**23**	**3.43 (2.8)**	**0.43 (0.3)**	**96.04**
Domestic livestock (cattle and buffalo)*	**170**	**288**	**42.9 (7.8)**	**5.3 (1.6)**	**7,293**
Camel*	**520**	**25**	**3.73 (0.71)**	**0.46 (0.14)**	**1,939.6**
Goat	37	2	0.3 (0.02)	0.04 (0.02)	11.1
Peafowl	4	64	9.6 (1.9)	1.2(0.42)	38.4
Hare	2.1	14	2.1 (0.15)	0.26 (0.09)	4.41

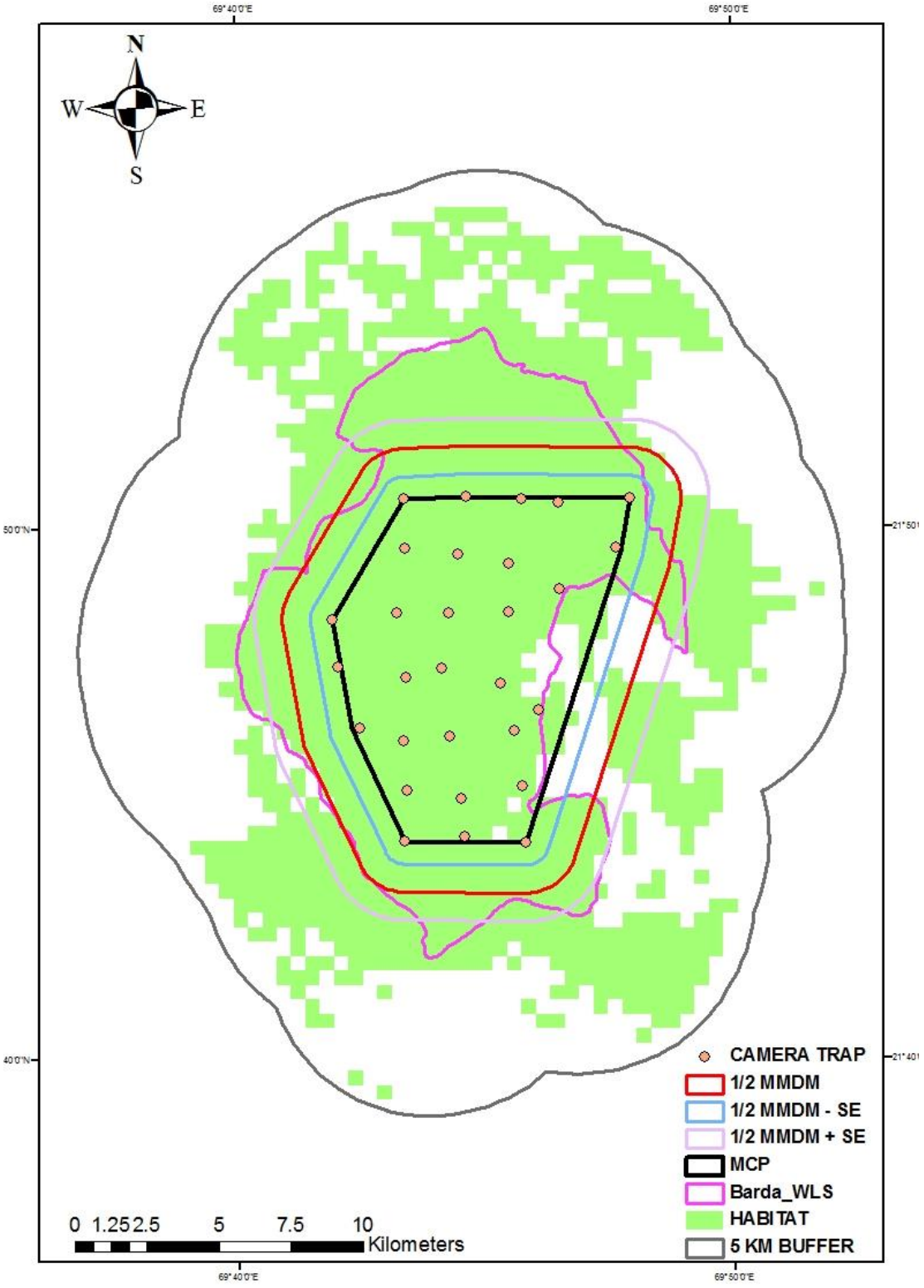
Species in bold letters indicate principal prey for lions

The combined effect of multiple predators on shared prey is often additive, and may produce a top-down mode of population regulation of prey and may adversely influence each other through exploitative competition. Currently, leopards (with a density of 8/100 km^2) are the apex predator in Barda ecosystem (**Figure 14.2**). However, with release of lions in Barda, it is more likely that leopards will be 'displaced' in the peripheries since the 'best' habitats of Barda would be colonized by lions. Lack of sufficient wild prey in Barda is also likely to compel leopards (and sometimes lions as well once they reach a higher density) to predate livestock from the peripheral villages and escalate conflicts. A good livestock depredation compensation scheme and high wild prey densities within Barda WLS are required to minimize the potentially adverse effects of lion reintroduction on local communities and prevent retaliations and hostility.

Currently, Barda has a high density of domestic livestock (43 ± SE 8 km^{-2}) which creates opportunity for conflicts with lions and leopards. Moreover, with a lower livestock holding per capita by the *Maldhari*s in Barda (12 ± SE 0.3) in comparison to Gir (33 ± SE 3), repercussions of livestock depredation to a *Maldhari* family in Barda WLS would be much higher. Gujarat forest department should address this by introducing an appropriate government compensation scheme for livestock predation in the Barda landscape to foster and promote better tolerance of

the local communities to lions. The ingredients for a successful compensation scheme would be a) fair

Figure 14.2: Barda Wildlife Sanctuary with a 5 km buffer showing camera trap locations and potential leopard habitats used for computing leopard density in the region.



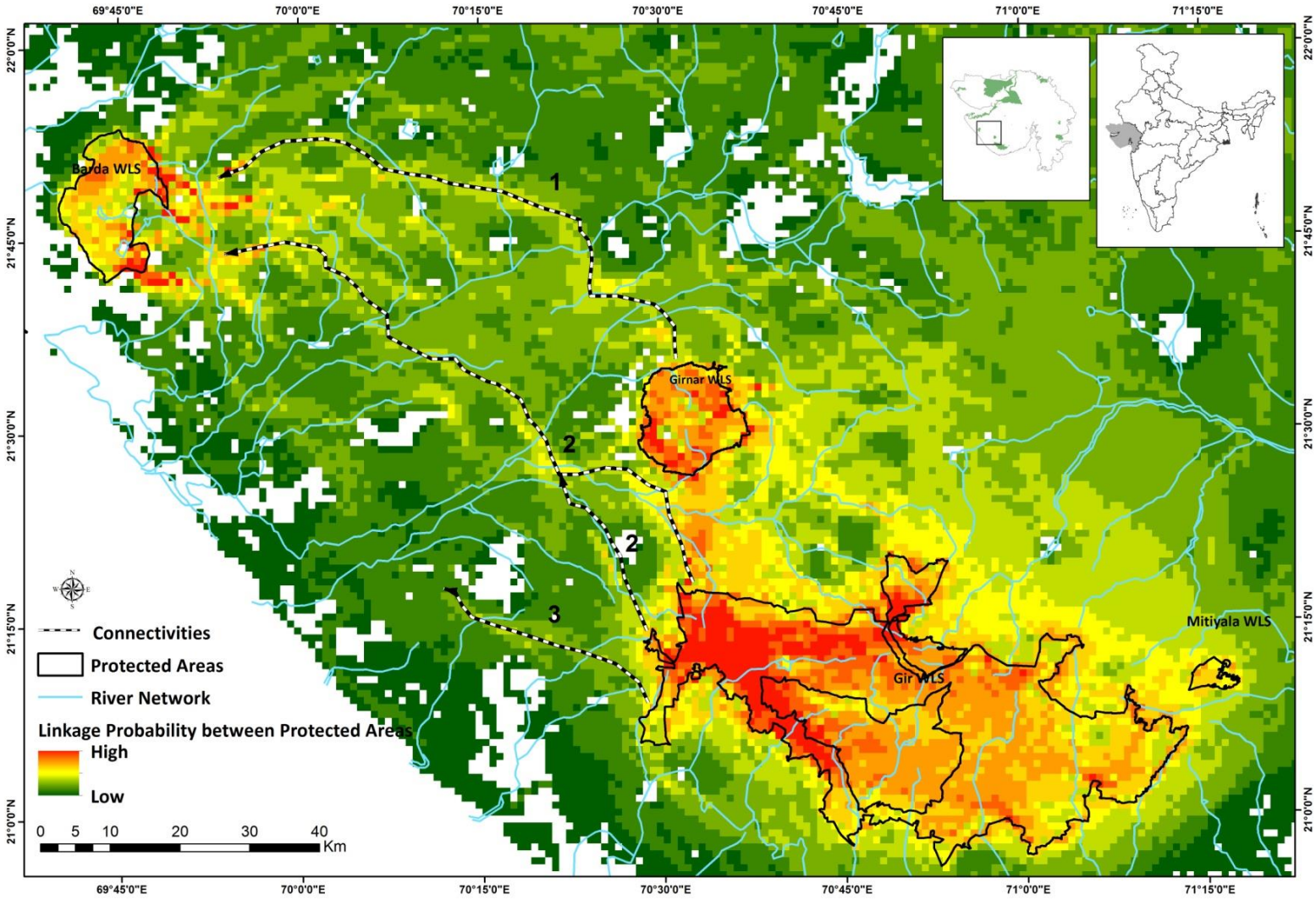
market price for *capital loss*, b) inclusion of lost *opportunity cost* while computing the compensation, c) prompt payment (50% on detection of kill and 50% after 7 days of the predation event), the full payment should be made after the carnivore has stopped feeding on the carcass so as to ensure that retaliation in the form of poisoning etc. is minimized.

The human dominated habitat matrix between Gir PA and Barda WLS is less permeable to lion movement in comparison to the habitat matrix between Girnar WLS and Gir PA. The habitat corridors between Barda WLS and lion populations of Gir PA and Girnar WLS are less likely to be conducive for lion movement across them due to more human pressures and several intervening linear infrastructures like State and National Highways (**Figure 14.3**). Therefore, lions are unlikely to disperse across this corridor; even if some movement occurs, it would be rare and of a few lions which would not be sufficient for a demographically viable natural recolonization. The corridor landscape requires major restorative inputs through policy and management by strategically declaring eco-sensitive zones, mitigation of linear infrastructures with appropriate under and over passes at specific locations and eco-restorative measures to facilitate lion movement. Specific village lands that form the corridor habitat are identified for policy and management inputs.

We found that 98% of Barda *Maldhari*s were willing to resettle outside Barda. Such willingness for 'voluntary resettlement' is a bonus for wildlife managers and maximum effort should be made to secure a large inviolate area for wildlife within Barda WLS by incentivized, voluntary relocation. Being a largely illiterate community, Barda *Maldhari*s are increasingly realizing how the lack of education is hindering their ability to adapt to an increasingly monetary economy. Also the remoteness and hostile terrain of Barda WLS is an impediment for the forest dwellers from accessing better markets and to diversify their livelihood options. Moreover, current attitudes of the local communities toward lion reintroduction are largely positive. Gujarat forest department should take advantage of this situation before the human perceptions alter adversely. Development of infrastructure like roads, electricity, solar lights, etc., within the Barda WLS should not be done as it would compromise the motivation for resettlement of forest communities. **A fair and incentive driven *Maldhari* resettlement plan should be immediately initiated to relocate *Maldhari* settlements as a whole outside Barda**. Settlements (*nesses*) should be targeted as a unit, relocation of individual families would not serve the conservation

objective and would result in loss of conservation investment if part *ness*es are resettled. Simultaneously, the first batch of lions could be reintroduced inside Barda along with introduction of a compensation scheme for livestock depredation. This would assist in a slow and gradual introduction of local communities' experience of living with lions.

Figure 14.3: Probable connectivity map within the landscape of Greater Gir and Barda WLS.



Synthesis and strategies of lion reintroduction in Barda (already communicated to GFD through a technical report Jhala et al. 2014a)

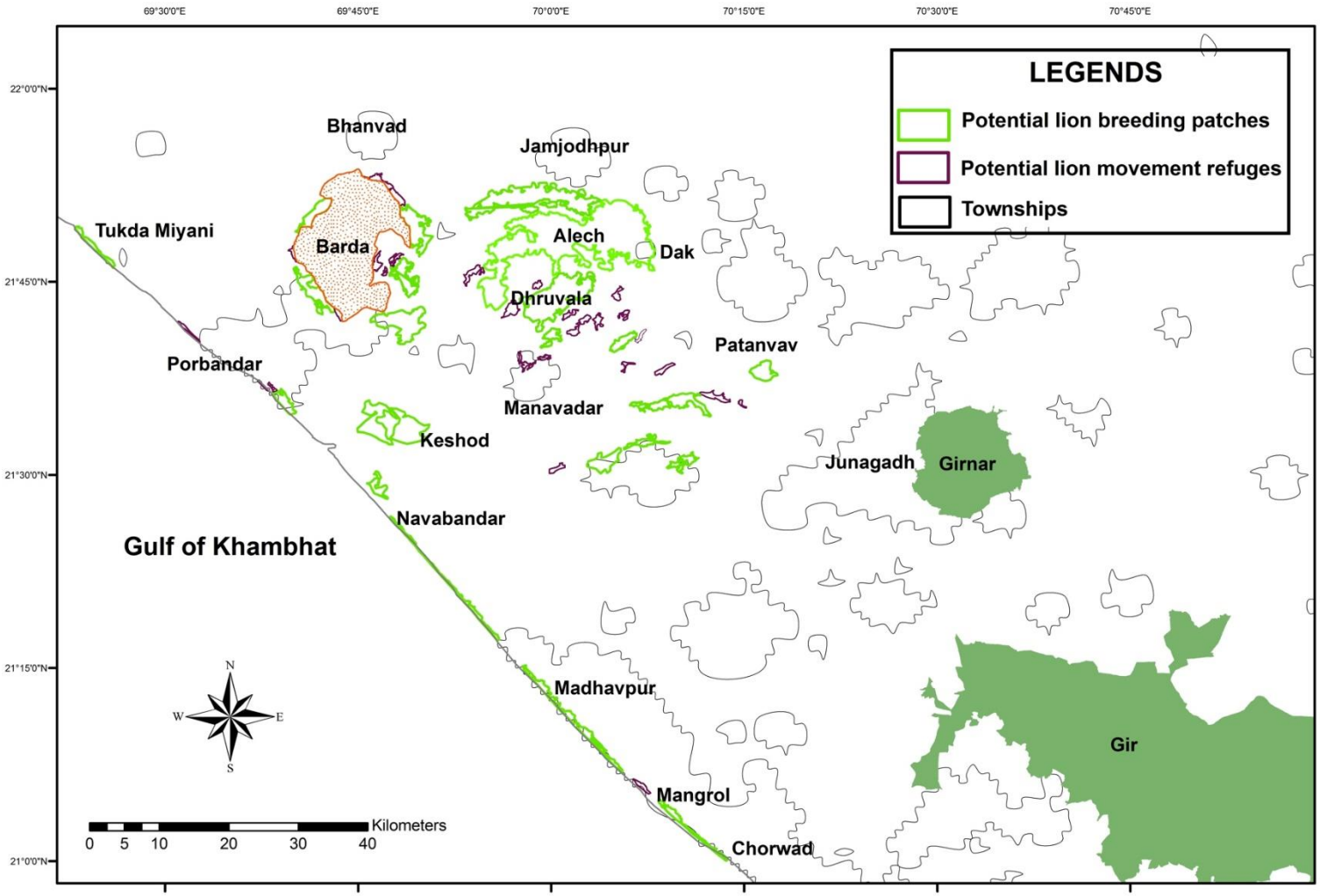
Based on our findings, we advocate some necessary strategies and actions needed to be addressed by the Gujarat forest department required for success of the reintroduction program.

Lion carrying capacity in Barda: We used information on lion habitat use and prey availability from Gir eastern sanctuary and Girnar (due to eco-climatic similarity with Barda) to estimate the potential lion carrying capacity in Barda. We excluded areas of Barda with a slope > 30% based on lion density in the eastern Gir sanctuary, we estimated carrying capacity of Barda wildlife sanctuary to be 26 lions. Due to small sized Barda wildlife sanctuary and large area requirements of lions, we also identified habitat refuge patches in the Barda landscape (410 km^2) essential for supporting breeding lion nuclei in future. These patches were characterized by broken terrain, drainage network, grasslands (*vidi*s), scrublands, coastal forests and *wastelands*. We calculated the combined capacity these patches based on estimates of lion densities in the agro-pastoral eastern Gir landscape and found that an additional 12 lions can be supported. Combining both the agro-pastoral part of the landscape and Barda sanctuary; we estimate that **at best the Barda landscape can support between 26 - 35 lions after restorative inputs.**

Habitat patches > 4 km^2 need to be legally protected and recommend them to be considered for community reserves while smaller habitat patches need to be made 'eco-sensitive' so as to promote landscape scale lion conservation without compromising on traditional livelihood needs (Figure 14.4).

Prioritization of reintroduction objective: The primary aim of the lion translocation in Barda is to establish another separate free ranging population of the species initially and subsequently to promote the natural colonization of lions in the western part of the Saurashtra landscape with a connectivity with the source Gir population. First of all Gujarat forest department needs to explicitly decide this and should maneuver their conservation action plans accordingly. Barda landscape is too small to sustain a self-sustaining free ranging populations of lions (which requires about 80 – 100 lions) and therefore needs to be managed as a metapopulation of the greater Gir

Figure 14.4: Barda landscape (Barda WLS and Alech hills) showing potential habitat patches that could sustain breeding and serve as day refuges for lions.



landscape. However, if the objective is to use Barda as a security against disease caused epidemics and natural calamities in Gir, then the natural movement corridors between Barda and Gir landscape is not desirable. Barda population then needs to be artificially managed as a separate metapopulation with supplementation and exchange of individuals from Gir artificially after appropriate health checks. Alternatively, if Barda is desired to be a metapopulation of Gir to enhance long-term viability of lions then it would be judicious for the government to allocate and spend funds for restoring habitat corridors between Barda and Gir. In this case, the long-term viability of lions in the Saurashtra landscape is enhanced by adding Barda to the existing metapopulation structure of the Gir lions. **Considering the current corridor connectivity to be extremely tenuous and the extensive investments, policy changes and management interventions required to restore the viable corridors, the first alternative (maintaining Barda lion population artificially as a metapopulation of Gir) seems to be more practical and desirable for lion conservation.**

Summarizing the ideal scenario of lion reintroduction:

- Make Barda habitats (initially about 120 km^2) suitable for lion reintroduction by resettling *Maldhari*s and building up natural prey base through continued prey restocking.
- Soft release of few lions (one male, two females and dependent juveniles) into wild concurrent with activities listed above. This would expose the local communities to few numbers of lions and gradually enhance their experience and confidence of staying in proximity with lions. The second batch of lions should be released only after all the *ness*es are removed from the sanctuary and a disturbance free core area is secured.
- Strong protection against prey poaching and human-caused lion deaths should be enforced. Conflicts with pastoral communities should be addressed by introducing a livestock predation compensation while crop damage of local farmers by wild ungulates should be compensated by introducing crop damage compensation and/or subsidizing crop damage mitigation measures and insurance of crops.

Success of Barda reintroduction within a span of 5 years should be judged by the following indicators: 1) establishment of a population of more than 15 lions (50% carrying capacity) that are breeding naturally with a good recruitment rate, 2) resettlement of *ness*es from inside Barda sanctuary, 3) building up of natural prey within Barda sanctuary to over 10

wild prey per km^2 and 4) landscape scale conservation through legislation (declaring community reserves and eco-sensitive areas) and eco-restoration. On the other hand, the project could b considered to be a failure if 1) an inviolate space of about 200 km^2 in and around Barda WLS is not established within 5 years, 2) failure of securing lion habitats in Barda landscape by declaring them as conservation reserves and/or eco-sensitive zones, 3) wild prey population occurring at a density of < 5 per km^2 after 5 years, 4) lions with less than 8 breeding individuals after 5 years with no natural births and high mortality (>70%) of reintroduced lions due to human-induced causes. If these occur then the project needs to be rolled back and reconsidered in terms of policy and alternative strategies.

Carnivore reintroduction is an appropriate conservation strategy to restore the integrity of ecosystems. It is a rapidly growing science which, if carried out accurately, has the potential to be a valuable component of the conservationist's toolkit. However, many pitfalls exist that can result in the total or partial failure of a reintroduction program and can potentially waste valuable and limited resources. This study aimed to guide the reintroduction program of the Asiatic lions in Barda landscape based on best available information and pro-active management.

CHAPTER XV

LEOPARD ABUNDANCE IN GIRNAR WILDLIFE SANCTUARY

Introduction

Human–carnivore conflicts are particularly frequent in India because human population densities are high and several species of potentially dangerous large mammals live outside protected areas (Seidensticker and Lumpkin 1991; Karanth and Madhusudan 2002). Elephants and other herbivores damage crops and property, and carnivores prey on livestock (Treves and Karanth 2003; Sillero-Zubiri et al. 2007). Most species of large carnivores in India are known to attack and kill people (e.g., Saberwal et al. 1994; Jhala and Sharma 1997; Karanth and Gopal 2005). The largest number of attacks on humans by large cats are perpetrated by leopards (*Panthera pardus fusca*) (Goyal et al. 2000; Athreya et al. 2004).

Leopards are also widely distributed in India in both protected areas and human-dominated landscapes. They can persist near human settlements by feeding on livestock and domestic dogs (Goyal et al. 2000). The high tolerance of the people to the presence of large, wild, and potentially dangerous animals (Karanth and Gopal 2005) makes it possible for species such as leopards to come close to human settlements to prey on domestic animals. Human-leopard conflict is a complex issue influenced by political and social attitudes, the biology of the species, and management action. Effective management of conflict will have to strike a balance between minimizing serious conflict (attacks on people) and the long-term conservation of the leopard species. Although the leopard is commoner and more resilient than other large cat species that occur in India, it is poached in the largest numbers to meet the demand of the illegal wildlife trade (Mondol et al. 2015).

In the past decades, many Indian states have reported an increase in leopard population outside the forested areas based on increased attacks on humans and demanded resources to cope with the problem (Athreya et al. 2007). However, in absence of reliable abundance estimates, most of these claims were turned down. Density of biological populations is the most vital parameter in ecological research, and is commonly used in conservation monitoring and management decisions. Because of low numbers (since they occur at the trophic apex, see Schaller 1967), poor detectability (due to their elusive nature) and movements over large areas,

obtaining reliable information on population status and trends of big cats is problematic and often costly (Smallwood and Fitzhugh 1995). Amongst all large carnivores, the leopard (*Panthera pardus*) has the reputation of being the least studied despite being the most abundant (Hamilton 1976). Most studies on leopards have been done in Africa (Hamilton 1976; Bertram 1982; Bailey 1993). In India, sparse information on leopards comes from studies that have actually focussed on tigers (Sunquist 1981; Karanth and Sunquist 1995, 2000; Jhala et al. 2011c) or lions (Chellam 1993; Jhala 2004). More recently some studies have been focussed exclusively on leopards (Chauhan et al. 2005; Edgaonkar 2008; Sankar et al. 2008; Harihar et al. 2009; Kalle et al. 2011; Mondal et al. 2012).

Girnar forests in Gujarat provides with an excellent semi-urban setup to study leopard abundance. Girnar WLS comprises of a circular forested patch surrounding Girnar hills (the highest in the Kutch-Saurashtra region). Majority of the WLS has hilly steep terrains providing excellent respites for leopards. Under intense pressures of urbanization, industrialization and agricultural expansion, Girnar has become an isolated forest patch surrounded by high human densities (including Junagadh city) in all sides. Girnar is an important pilgrimage site of all religions, Hindus, Jains and Muslims, leading to influx of devotees throughout the year, with numbers reaching upto 10 lakh during major religious events. The current study, mandated by the CWLW Gujarat state as an additional research work, therefore, aimed at estimating leopard abundance in Girnar. Till date the population estimation of leopards in Gujarat has been done based on "Pugmarks" at all instances (Singh 2007). This study incorporates camera trapping in a mark recapture framework for the first time in the state, aiming to provide more reliable estimates (Basu 2012).

Methodology

Photographic capture-recapture analysis (Karanth 1995; Karanth and Nichols 1998) was used to estimate the abundance of leopards in Girnar Wildlife Sanctuary in between March and May 2012. Sampling grids of 2.235×2.235 km^2 dimensions were overlaid on the study area using ArcMAP v9.3, and were realized on ground using a handheld GPS unit (GARMIN GPS 72). To intensify sampling, the study area was divided into the northern (21°33'51.8'' to 21°31'25.6'') and southern (21°31'25.6'' to 21°26'34.1'') blocks. Camera trapping was carried out for 26 days in each block, with a total effort of 884 trap nights (442 trap nights in each block). Each day was

considered as one occasion. To increase the photographic rate (i.e., capture probability) of leopards, camera trap locations were chosen based on reconnaissance of the area (Jhala et al. 2013) and a minimum of one camera pair was installed at the best potential site within each grid to have a systematic camera coverage over the entire study area.

Flank of each leopard photographed was compared to every other leopard photograph obtained (of the same flank). Each leopard was identified with the rosette patterns on its flanks, limbs and forequarters. When match in a pattern was found between two photographs, the identity was confirmed after verifying the rosette patterns of different parts. Pattern recognition software Wild-ID ver 1.0 (Bolger et al. 2011) was also used to confirm identification. Each individual leopard identified was assigned with a unique identification code (e.g., L1, L2, L3, L4…).

Once all the leopard pictures were identified to unique individuals, capture histories (Pollock et al. 1990) were developed for each individual leopard using each day as a sampling occasion. Closed population capture-recapture framework has been used to estimate the population parameters of leopards in this study (Pollock et al. 1990). 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.

Leopard density 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 leopards added to the polygon (Karanth and Nichols 1998; Parmenter et al. 2003). Non leopard habitats like water bodies were removed from the ETA using habitat masking in ArcMap 9.3.

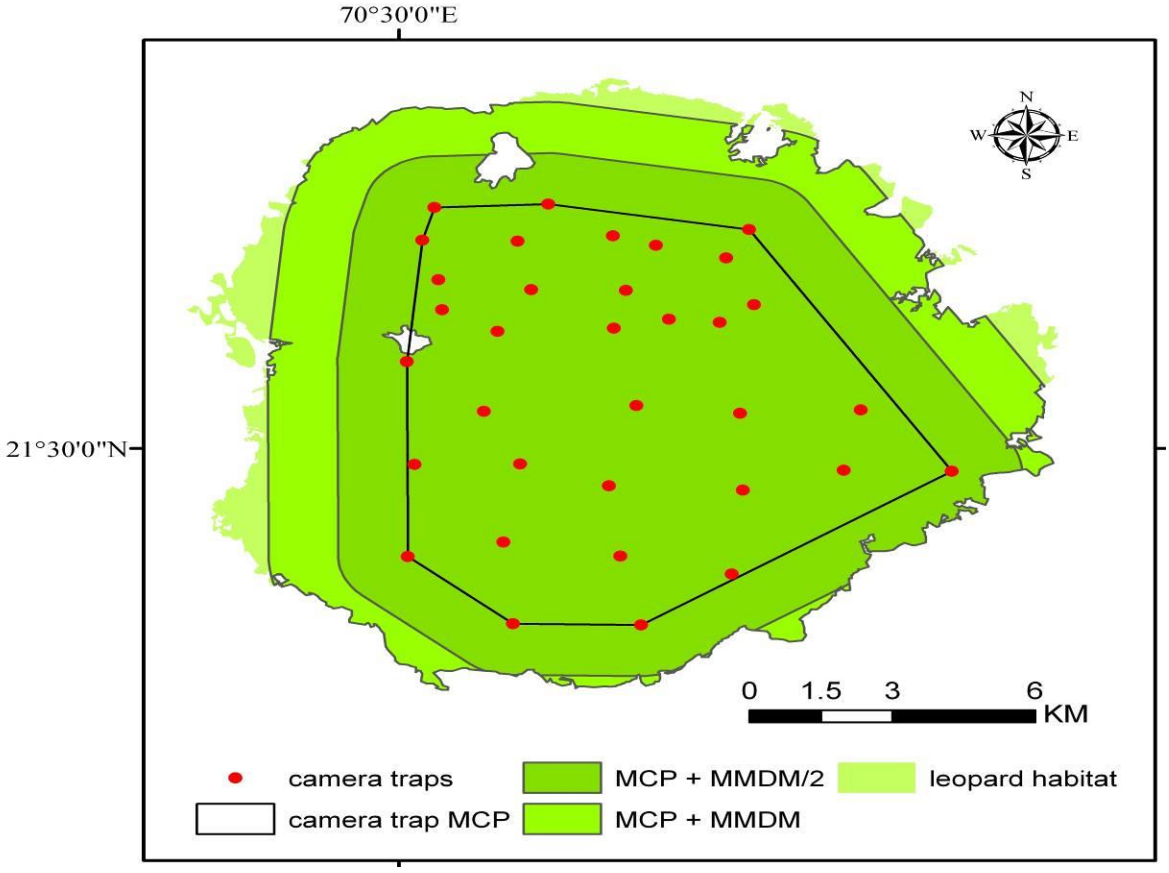
We also used spatially explicit capture recapture models in program Density (Borchers and Efford 2008; Efford et al. 2009) to deduce leopard density in Girnar. The need for a buffer around the trapping area is not required in this method as the density is estimated in a spatially explicit framework. The distribution of individuals is modelled by a homogeneous Poisson process. The detection function (half normal, hazard rate or negative exponential) was selected

based on the lowest Akaike Information Criterion (AICc) value (Burnham and Anderson 2002), and fitted to the distance between the home range centre and the trap.

Results

A total number of 222 pictures of leopards were obtained during the study period. A total of 26 individual leopards were identified. Camera trapping was carried out in an area of 87.6 km^2 (MCP; **Figure 15.1**). The cumulative number of individual leopards photographed plotted against sampling occasions to check the adequacy of sampling showed that capture of new individual plateaued after 18 days of sampling, while rate of obtaining leopard photographs remained constant across the study period (R^2=0.96, P<0.01)

Figure 15.1: Camera trap locations and the effective trapping area for estimating leopard density.



Model selection criterion was highest for the behavioural heterogeneity model (M_b). This model estimated leopard capture probability ($\widehat{P}$) at 0.086 (SE 0.03), recapture probability ($\widehat{C}$)

at 0.14 (SE 0.02), and abundance at ($\widehat{N}$) at 28 (SE 2.89) adult individuals. The mean maximum distance moved by leopards between successive recaptures (MMDM) was estimated at 2,867-m. Removing unsuitable habitat areas within and outside the Sanctuary, the effective trapping area was estimated at 197.74 km^2 using MMDM and 153.63 km^2 using MMDM/2 buffer widths. The population abundance ($\widehat{N}$) obtained from program CAPTURE was used to estimate density of leopards using the afore-computed effective trapping areas (**Table 15.1**).

The maximum likelihood spatially explicit capture recapture density was estimated using M_b Zippin estimator and Hazard rate detection function. Density was estimated at 17.17 (SE 3.48) leopards / 100 km^2.

The MLSECR density when extrapolated to suitable leopard habitat in and around the Sanctuary area of 189.62 km^2, yielded a total population of 33 (SE 7) individual leopards.

Table 15.1: Population and density estimates of leopards in Girnar Wildlife Sanctuary, Gujarat in 2012.

Parameters	Values
Trapnights	26
M_{t+1}	28 (SE 2.9)
Density (per 100 km^2)	20.1 (SE 3.5)
½ MMDM (meter)	1,434 (SE 199)
MLSECR Density	17.17 (SE 3.48)

Discussions

An extensive spatial and temporal distribution, complemented with secretive life, low detectability, low density, and wide ranging behaviour, have made population estimation of carnivores extremely difficult (Sharma et al. 2005). Several analytical advances, combined with technologically sophisticated methods for studying the ecology of cryptic and elusive animals have evolved with time. However recent developments in capture-recapture technique (Otis et al. 1978; Pollock et al. 1990; Nichols 1992; White et al. 1996) have helped us to overcome this problem to a great extent. More recently developed spatially explicit capture-recapture models (Bayesian inference- Royle et al. 2009; Spatially explicit maximum likelihood- Borchers and Efford 2008) provide us with more reliable population estimates which are of great importance

for biologists and conservationists. Capture-mark-recapture using camera traps has been found to be useful (Karanth 1995), and is a worldwide accepted methodology now. Camera trapping is believed to provide us more reliable estimates of species distribution and abundance and their spatial variations. Camera trapping for species with individually identifiable coat patterns has proven to be one of the most successful non intrusive techniques to study their population dynamics (Silveira et al. 2003).

This study involved camera trapping for leopards for the first time in the state of Gujarat, India. Prior to this, population estimation of leopards in the state was based on pugmark technique (Panwar 1979) in all instances. The working plan of the region reported a total number of 40 leopards within the Sanctuary in the year 2005 (Parmar 2005).

To check the adequacy of this study the graph plotted for the cumulative number of individual leopards photo-captured against the occasions, reached an asymptote after ~24 days of sampling. Later a minor fluctuation was noticed in the asymptote curve. Hence, 25 to 30 days' trapping effort is recommended for subsequent studies. The present study revealed an abundance of 28 (SE 2.89) individual adult leopards in 96.5 km^2 of the Girnar Wildlife Sanctuary. Although the mean capture probability was lower than the recapture probability, their 95% confidence intervals were overlapping (0.05 – 0.15 for capture probability and 0.11 – 0.17 for recapture probability). Thus, recapture probability tended to be higher than the capture probability (trap happy) but not with certainty. This may be due to the application of olfactory lures and dynamic positioning of the camera traps to circumvent leopards' camera shyness.

Population density is considered to be ecologically much more significant than abundance. It allows direct comparisons of population status between different areas. The calculation of the effective area of sampling is a noteworthy issue in estimating densities. Usually there is no concrete measurement of the home range of individuals used in the estimation. Since the animals are mobile, and the same individual can be active both inside and outside the camera trapping area, it is recommended to consider an additional buffer width around the area enclosed by the camera traps (MCP or Minimum Convex Polygon) to obtain the Effective Trapping Area (ETA). Usually half of the mean maximum distance moved (half-MMDM) by individuals is estimated using the distance between different cameras that capture the same individuals, and is used as a buffer width around the MCP to obtain the ETA for density estimation, recommended by Wilson and Anderson (1985). However, a study on jaguars

using radio-telemetry revealed that densities obtained from full MMDM are much closer to densities based on actual movement rates than MMDM/2 (Soisalo and Cavalcanti 2006). But there is still not enough data available for movement in leopards to command a shift to full MMDM from MMDM/2. Also with an increase in the area due to incorporation of the buffer, it is likely to include habitat that is unsuitable for the species. Hence, spatially explicit models are much more preferred in obtaining reliable population estimates. Here no buffer width is required around the camera trapping area as density estimation takes place in a spatially explicit framework. Moreover, with the incorporation of habitat mask, the density can be estimated in suitable species habitat. Hence, Maximum Likelihood Spatially Explicit Capture Recapture (MLSECR) was used was used to estimate density of leopards in the study. However, density estimates were also carried out using MMDM and MMDM/2 buffer for comparison with previous classical studies conducted elsewhere. The MLSECR density when extrapolated to the Sanctuary area (180 km^2), it yielded a total population of 31 (SE 6) individuals. The MMDM/2 density extrapolated to the habitat Sanctuary area estimated 34 (SE 3) individuals, which was similar to the estimates of 40 leopards given by the Forest Department (Parmar 2005; Karn and Sahu 2014).

Similar studies using camera trapping have been carried out in some parts of India, namely, Sariska Tiger Reserve, Rajasthan; Satpura National Park, Madhya Pradesh; Rajaji National Park, Uttarakhand; and Mudumalai Tiger Reserve, Tamil Nadu (**Table 15.2**). Comparison with these studies reveals a very high density of leopard population in Girnar Wildlife Sanctuary, Gujarat, ranking just after Mudumalai Tiger Reserve in India. There might be several factors, both natural and anthropogenic playing an additive role to harbour such a high leopard density in the study area.

Table 15.2: Densities of leopards in different landscapes of India.

Study site	MMDM/2 Density (#/100 km^2) SE	Author
Girnar (2012)	18.88 ± 1.97	This study
Sariska TR, Rajasthan (2007)	10.7 ± 1.8	Mondal et al.
Satpura TR, Madhya Pradesh (2007)	7 ± 2.1 – 10 ± 5.1	Edgaonkar
Sariska TR, Rajasthan (2008)	7 ± 0.2	Sankar et al.
Rajaji NP, Uttarakhand (2009)	14.99 ± 6.9	Harihar et al.
Sariska TR, Rajasthan (2010)	3.1 ± 0.4	Mondal et al.
Mudumalai TR, Tamil Nadu (2011)	28.91 ± 7.22	Kalle et al.

Knowledge about the distribution and abundance of a species are essential for the formulation of conservation strategies. While some species are considered to be habitat generalists, others are specialists. The leopard is a wide ranging large carnivore that is less susceptible to disturbances, is a habitat generalist, and can survive on a wide range of prey species. In areas where wild prey population is low, leopards are known to survive on domestic dogs and rodents (Sunquist and Sunquist 2002). Nevertheless, continuous monitoring of predator population based on robust methodology as employed in this study assumes critical importance for both management and scientific reasons. Given the high density of leopards in an area which is not only bordered with human settlements, but also with active human interference within the sanctuary, it is very likely that leopards come in close contact with humans.

This high density leopard population lives in proximity of a high density human population and their associated domestic animals like dogs. The leopards likely use dogs and small livestock to sustain such high densities. It is surprising that despite such high carnivore and human densities, magnitude of conflict between the two is low (Karn and Sahu 2014). However, the Girnar Management should explicitly address how to deal with problem leopards in a timely manner to prevent backlash from the people and permit the existing delicate coexistence. Thus, this study is an important one as far as framing management practices are concerned.

Analysing this study from a research point of view can also be fruitful as it provides baseline data for the ecological studies of leopards in such a high density area. Moreover, it can be very interesting to analyse the food habits of leopards in such a semi-urban setup, and assessing the viability of the population. A telemetry study can also be carried out to determine

the ranging and dependence of leopards on urban food resources to develop strategies that will enable management to take precautionary actions to minimize conflicts in future scenarios. Another interesting aspect is how changes in lion population affect the ecology of leopards in this area across spatial and temporal scales.

ACADEMIC ACHIEVEMENTS (2006 – 2016)

Peer-reviewed publications:

- Jhala, Y. V., Mukherjee, S., Shah, N., Chauhan, K.S., Dave, C.V., Meena, V. and Banerjee, K. 2009. Home range and habitat preference of female lions (Panthera leo persica) in Gir forests, India. Biodiversity and Conservation 18: 3383–3394.

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- Dave, C. and Jhala, Y.V. 2011. Is competition with livestock detrimental for native wild ungulates? - A case study of chital (Axis axis) in Gir forest, India. Journal of Tropical Ecology 27: 239-247.

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International Conference Proceedings:

- Basu, P., Jhala, Y.V., Qureshi, Q. 2012. Habitat fragmentation displeasing metapopulation dynamics of the Asiatic lions: importance of maintaining functionality of corridors in a highly fragmented landscape. Conference Proceeding of Geomatrix 12, 2012.

- Basu, P., Jhala, Y.V., Qureshi, Q. 2012. Assessment of the future of potential dispersal corridors of Asiatic Lions (Panthera leo persica) across the agro-pastoral landscape between Gir and Girnar Wildlife Sanctuary. Conference Proceeding of India Geospatial Forum, 2012.

Doctoral and Masters Theses: Four doctoral theses and three M.Sc theses completed; one PhD thesis ongoing

- Meena, V. 2008. Reproductive strategy and behaviour of male Asiatic lions. **PhD thesis** submitted to Forest Research Institute University, Dehradun, India, 179 pp.

- Dave, C. 2008. Ecology of chital (Axis axis) in Gir. **PhD thesis** submitted to Saurashtra University, Rajkot, India, 262 pp.

- Banerjee, K. 2012. Ranging patterns, habitat use and food habits of the satellite lion populations (Panthera leo persica) in Gujarat, India. **PhD thesis** submitted to Forest Research Institute University, Dehradun, India, xxxv + 400 pp.

- Basu, A. 2012. Abundance estimation of leopards (Panthera pardus) in Girnar wildlife sanctuary, Gujarat. **Masters thesis** submitted to Forest Research Institute Deemed University, Dehradun, India, 49 pp.

- Basu, P. 2013. Assessment of landscape pattern for modelling habitat suitability for Lions and Prey species in Gir protected area, Gujarat. **PhD thesis** submitted to Forest Research Institute University, Dehradun. India, pp xxi + 267.

- Chakrabarti, S. 2013. Computing biomass consumption from prey occurrences in scats of tropical felids. **Masters thesis** submitted to Saurashtra University, Rajkot, India, iv + 57 pp.

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- Jhala, Y., Chellam, R., Pathak, B., Qureshi, Q., Meena, V., Chauhan, K., Dave, C., Banerjee, K. and Basu, P. 2012. Ecology of Lion in the Agro-pastoral Greater Gir Landscape—Phase I. Technical Report, Wildlife Institute of India, Dehra Dun, India, pp xiv + 382. TR-2012/004.

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- Jhala, Y.V., Banerjee, K., & Basu, P. 2014. Ecology of Lion in agro-pastoral Gir landscape, Gujarat - Final Project Report. Technical Report, Wildlife Institute of India, Dehra Dun, India, pp xvi + 374. TR-2014/006.

Besides, there have been eight International and twenty National Conference and symposia presentations and four popular articles published based on the research findings of this project. The project has received good press coverage, nationally and internationally.

Wildlife Instituite of India's (WII) research history in Gir dates back to early 1980s (Sinha 1985; Khan 1993; Chellam 1993; Sharma 1995; Jhala 2004; Meena 2008; Dave 2008; Banerjee and Jhala 2012; Banerjee 2012; Jhala et al. 2012, Basu 2013; Chakrabarti 2013; Gogoi 2015). In fact, the project is one of the only long term research undertakings in India. This project has been providing crucial information on the dynamics of ecosystems which short term projects cannot provide. Over the years, WII has addressed many ecological questions pertaining to the successful conservation of the Gir lions and maintenance of the ecosystem functionality. Need-based specific objectives were also addressed. WII's research priorities also kept on changing as demanded by the emerging management challenges. Long-term aspects addressed by this project include a) abundance estimation of lions and their population trends, b) abundance estimation of ungulates and their population trends, c) habitat and ranging patterns of lions. Followings are some salient achievements of the project :

- Understanding land tenure system, ranging and habitat use/preference of lions through radio-telemetry and continuous observations
- Population estimation and trends of lions in and around Gir PA
- Demographic parameters of Asiatic lions
- Delineation of habitat corridors for lions in Saurashtra and declaration of Gir-Girnar corridor as an eco-sensitive zone
- Assessment of leopards in Girnar WLS
- Assessment of Barda WLS as a probable site for lion re-introduction and development of the action plan
- Understanding the drivers of lion-Maldhari co-existence in Gir
- Understanding of lion-human conflict in and round Gir PA
- Assessment of lion prey populations at regular intervals with a thorough understanding of trends in their population

Over the years, WII's research recommendations were incorporated in the management and long-term conservation of Asiatic lion in Gir and became intricate part of the policy

documents (Singh and Kamboj 1996; Pathak et al. 2002; Meena and Kumar 2012; Karn and Sahu 2014; Mathur et al. 2015). However, there are many more evolving conservation challenges in the Saurashtra landscape which need to be addressed urgently. For example-

- Continuous monitoring of lion population, predators, prey and their habitats to keep a track on their performances and decide on the need of ameliorating measures, if needed.
- On one hand, Gir lions are continuously expanding their ranges and colonizing newer areas (Ranjitsinh 2014); while on the other hand the movement corridors and habitat patches suitable for lions in Saurashtra are under tremendous pressures of development induced habitat fragmentations. The traditional land use patterns in Saurashtra is changing at an unprecedented rate due to agricultural intensifications, sedentarization of pastoralism, privatization of land tenures and urban sprawl driven by socio-economic and political pressures. As a result, most of the lion satellite patches in Saurashtra are slowly becoming analogous to small islands in a vast sea of 'lion hostile' land use (Banerjee 2012; Basu 2013). In an economic progressive state like Gujarat where conservation is not a major land-use objective; likelihood of such habitat fragmentations gets escalated with increasing Government priorities for human developments and economic growths. This becomes a serious challenge for conservation management of a large carnivore like Gir lions.
- With lions occupying vast tract of agro-pastoral Saurashtra landscape where land ownership is predominantly private; a balance between development and conservation could probably be the best strategy for the managers in managing conflicts and ensuring long-term lion conservation. At the current rate of expanding human populations and other competing land-use forms in the region; there is neither any scope for the Gujarat Forest Department to increase the area of the Gir PA; nor to create any new 'inviolate area' for lion conservation. Pragmatic conservation approaches such as creating 'Conservation Reserves', declaring 'Eco-sensitive Zones' and legally protecting them without compromising with the local livelihoods should be embraced to safeguard lion habitat patches and movement corridors in a human-dominated Saurashtra landscape. However, delineations of movement corridors and habitat patches conducive for future lion conservation should be based on scientific knowledge in the absence of which educated guesses are often used and can have detrimental

impacts on their future persistence (Beier and Noss 2008). Such scientific approach has already been executed by the Gujarat Forest Department by delineating the lion movement corridor between Gir PA and Girnar Sanctuary and protecting a part of that landscape as an 'Eco-sensitive Zone' based on radio telemetry data on lions and subsequent scientific model based inferences (Jhala et al. 2012; Karn and Sahu 2014). However, there are many more potential lion movement corridors between 1) Gir PA and eastern landscape, 2) Gir PA and coastal forests, 3) Girnar and eastern landscape and 4) Gir landscape and recently lion recolonized areas of Saurashtra, which should be urgently identified and protected before they are lost to unplanned development. Prioritising critical refuge/breeding patches and movement corridors for lions brings in harmony between developmental goals and effective lion conservation.

- Despite lions occupying human dominated landscapes of Saurashtra, their dependence on productive livestock for diet is minimal (Banerjee 2012). Nevertheless, there are instances of livestock raiding by lions. Such incidents, if not managed timely, may upset the current balance of human-lion coexistence in Saurashtra (Banerjee et al. 2013).
- Mitigating human–lion conflicts, therefore, requires identifying the landscape features that reduces livestock accessibility and risk of death. The mere presence of prey on the landscape (availability) is not sufficient to guarantee predator hunting success. Factors such as prey antipredator behavior and predator hunting tactics influence the locations where predators can successfully capture prey (accessibility). When selecting hunting sites, many large carnivores prioritize prey catchability as much as or more than prey abundance (Hopcraft et al. 2005). Thus, identifying high-risk areas (predation hotspots) requires distinguishing between areas where prey are available versus accessible to carnivores (Miller et al. 2015).

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