

Land, lion and locals: Understanding the distribution of lions and large carnivore human interactions in the Greater Gir Landscape of Saurashtra

SUBMITTED FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY
in
Wildlife Science



FOREST RESEARCH INSTITUTE
DEEMED TO BE UNIVERSITY

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भारतीय वन्यजीव संस्थान
Wildlife Institute of India

Dated: 26-02-2024

DECLARATION

This is to certify that the thesis titled “**Land, lion and locals: Understanding the distribution of lions and large carnivore human interactions in the Greater Gir Landscape of Saurashtra**” submitted by **myself** (Enrolment No 18PHD511, dated 01-03-2019) to Forest Research Institute (FRI), Deemed to be University, Dehradun, for the degree of Doctor of Philosophy in Forestry (Wildlife Science), represents a comprehensive and genuine research conducted under the guidance of Dr. Y.V. Jhala. No segment of the thesis has been utilized to pursue any other academic qualification within the institution or elsewhere. I also declare that the thesis embodies an original work carried out by myself, including field data collection, analysis and writing. This research work appears to advance the understanding of the complex interactions between the large carnivores and humans in the Saurashtra landscape. The doctoral thesis is duly checked for plagiarism using **DrillBit**, an authorized plagiarism detection tool approved by FRI.



Keshab Gogoi

Countersigned:



Y.V. Jhala, PhD

(Supervisor)
Fellow of The Indian National Science Academy
Fellow of the National Academy of Sciences, India
Sr. Professor & Dean (Retd.)
Wildlife Institute of India, Dehradun

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Y.V. Jhala, PhD

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Fellow of The Indian National Science Academy
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Dated: 26th February, 2024

**To,
The Registrar
Forest Research Institute (Deemed to be) University
P.O.: I.P.E., Kaulagarh Road
Dehradun**

Subject: Submission of RAC Meeting Minutes of Mr. Keshab Gogoi (Enrolment No. 18PHD511, Dated: 01.03.2019)

Sir,

Please find attached herewith a copy of RAC Meeting Minutes submitted by **Mr. Mr. Keshab Gogoi (Enrolment No. 18PHD511, Dated: 01.03.2019)** for the pre-thesis submission titled **“Land, lion and locals: Understanding the distribution of lions and large carnivore human interactions in the Greater Gir Landscape of Saurashtra”**.

Thanking you,



Y.V. Jhala, Ph.D.

(Supervisor)

Fellow of The Indian National Science Academy
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Performa of the minutes of meeting of RAC for Pre-thesis submission seminar

- (i) Name of Ph.D. Scholar : Keshab Gogoi
- (ii) Registration Number & date : 18PHD511, Dated: 01.03.2019
- (iii) Date of meeting : 26th December 2023
- (iv) Topic : Land, lion and locals: Understanding the distribution of lions and large carnivore human interactions in the Greater Gir Landscape of Saurashtra
- (v) Institute's name : Wildlife Institute of India, Dehradun
- (vi) Discipline : (as per clause 3.3 of the Ph.D. ordinance)
Forestry (Wildlife Science)
- (vii) Chairman's Name : Dr. Ruchi Badola
Dean (FWS), WII, Dehradun
- (viii) Expert members' names : (1) Sh. Qamar Qureshi, Scientist G
(2) Dr. B. S. Adhikari, Scientist G
(3) Dr. Vishnupriya Kolipakam, Scientist-D
- (ix) Supervisor's name : Y.V. Jhala, Ph.D., Wildlife Institute of India
- (x) Co-Supervisor's name : Nil
- (xi) Head of Division : (Member Secretary)

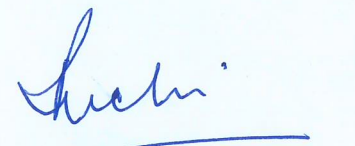
Dr. Samrat Mondol
Scientist E
Nodal Officer
Wildlife Institute of India



(xii) Suggestions: Attached

(in detail must be given)/ recommendation of RAC

Recommended for submission


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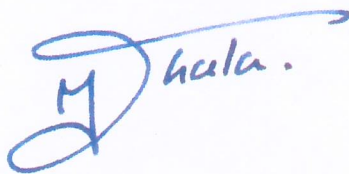
Minutes of pre-thesis defence by Keshab Gogoi on 26th December 2023

Keshab Gogoi's pre-PhD thesis presentation (Enrolment No 18PHD511, dated 01-03-2019) was approved by the RAC members and captivated the audience. His study investigated into the intricate dynamics surrounding human-lion-leopard interactions within the Saurashtra landscape. Through rigorous socio-economic surveys, Gogoi sought to unravel the underlying causes and driving forces behind these conflicts. His research shed light on the perplexing wonder of local communities coexisting with lions despite facing conflicts. Furthermore, Gogoi's thesis meticulously examined the availability and spatial distribution of suitable habitats for Asiatic lions, both within Gujarat and across their historical range in India. Additionally, he delineated movement corridors essential for maintaining connectivity among lion metapopulations within the Saurashtra landscape. By addressing these critical aspects, Gogoi's thesis significantly advances our understanding of the intricate balance required for conserving large carnivores in landscapes dominated by human presence—a pressing global conservation challenge of the present time.

There were no major suggestions or recommendations on Keshab Gogoi's pre-thesis defence apart from the following:

1. Dr Jhala, his PhD supervisor, suggested adding the names of the villages and the number of different land use types in each of the villages along the least-cost pathways of the lion movement corridors.

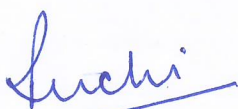
Signatures of the Members of the RAC, including Supervisor and Member Secretary



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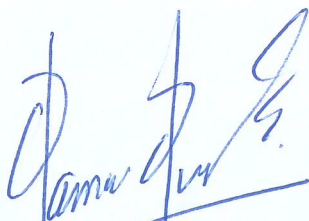
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Dated: 26-02-2024

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This is to certify that the thesis titled “**Land, lion and locals: Understanding the distribution of lions and large carnivore human interactions in the Greater Gir Landscape of Saurashtra**” submitted by **Mr. Mr. Keshab Gogoi (Enrolment No 18PHD511, dated 01-03-2019)** to Forest Research Institute (FRI), Deemed to be University, Dehradun, for the degree of Doctor of Philosophy in Forestry (Wildlife Science), represents a comprehensive and genuine research conducted under my guidance. The doctoral thesis underwent thorough scrutiny using **DrillBit**, an authorized plagiarism detection tool approved by FRI. The analysis revealed a 2 % similarity report, affirming the originality of Mr. Gogoi's work. Importantly, no segment of the thesis has been utilized to pursue any other academic qualification within the institution or elsewhere. It is affirmed that the thesis satisfactorily fulfils all the criteria stipulated by the ordinances governing the award of a PhD. Degree by FRI (Deemed to be University), Dehradun.



Y.V. Jhala, PhD

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Throughout my career journey as a wildlife biologist and during my Ph.D., the influence of Dr. Jhala has far surpassed that of a mere supervisor. To me, he embodies the epitome of good governance, ethics, patience, and compassion—an inspiration and a paragon of humanity. His leadership, akin to the noble lion reigning over his domain, has steered the institute with remarkable efficiency, mediating conflicts and overseeing research endeavours with an unwavering dedication to scientific integrity. Under his mentorship, I have had the privilege to witness firsthand the delicate balance he maintains between politics, administration, and the pursuit of knowledge—a feat unparalleled in my experience. I am deeply privileged to have learned and grown under his guidance. I fondly recall Dr. Jhala's boundless enthusiasm for the natural world, evident during our field visits and discussions

amidst the breathtaking landscapes of Gir and in the Wildlife Institute of India, Dehradun. Our long road trips, filled with academic discussions and exploration, are imprinted vividly in my memory. Time spent on his farm provided solace from the rigours of work life, fostering a sense of peace that greatly influenced my endeavours in the Gir Forests. It was beneath the shade of the banyan tree on his farm that I completed my first publication on Asiatic lions—a momentous occasion that symbolizes the countless collaborative efforts we shared, from crafting manuscripts to debating ideas for my Ph.D. thesis. Reflecting on those times fills me with a sense of nostalgia and gratitude for being part of his extraordinary world. The arrival of Bapu, with his enthusiasm and humbleness, always filled me with excitement and renewed motivation. The evenings spent on the terrace, watching the sun set behind Andhania Palace, hold a special place in my heart—a testament to the profound joy and contentment his presence brought. My gratitude to Dr. Jhala knows no bounds for accepting me as his Ph.D. student. Though some of our planned research endeavours on Asiatic Lions faced obstacles, I remain hopeful that we will accomplish them in the near future. When I was at the lowest point of my life, inhuman brutalities in my personal and professional life made me stand between life and death; you kept holding my hand and gave me the hope to see the day and live life anew. I extend my heartfelt thanks to Dhanajay bhai and Harshini for their encouragement and support during our time in the Gir Forests. I wish them both a bright and fulfilling journey ahead and hope to reunite with them in Gir again.

I express my gratitude to my immediate seniors of the Asiatic Lion project, Dr Kausik Banerjee, Dr Stotra Chakrabarti, and junior colleague Doli Borah, for their unwavering support and assistance during our fieldwork endeavours. The time we spent in the field was undeniably memorable, filled with laughter and enjoyment. I will forever cherish those adventurous journeys through the lush greenery of the Gir forests during the monsoon season, navigating the slippery forest roads in our trusty old 4x4 green Thar and Gypsy, all while tracking lions

amidst brown leafless forests under the scorching sun above during the unbearable summer and sharing our symbolic "singdana black tea" breakfasts. Each one of you has played a significant role in shaping my academic career and personal growth, and for that, I am truly grateful. Special thanks to former researcher Doli Borah for her invaluable contributions to field data collection and project management. I hope that our joint publication on the Sociality of Female Asiatic lions will see the light of day soon, as it holds some very interesting undiscovered mysteries of the subspecies which need to be revealed to the world. I extend my appreciation to Rutu Prajapati for her assistance in curating and translating data from Gujarati to English.

I am deeply indebted to our field assistants—Osman, Hamal, Sameer, Iqbal, Ismail, Late Guga, Bhola, Bhupat, Kanti, Mannu, and Hanif—for their unwavering dedication and hard work. You all are the epitome of excellence in your field, serving not just as field assistants but also as mentors who imparted invaluable skills and experiences to me. I vividly remember the excitement I felt when Bhiku bhai, Ismail bhai, Hamal bhai, and Sameer guided me close to the lions on foot, capturing some of the first-ever vibrissae photographs. The way you communicated with the lions seemed like an exchange of emotions and thoughts, a unique connection built on trust and mutual respect. It is an experience I will forever cherish. Spending countless hours with the lions, facing challenges, and pushing our limits every day has been an unforgettable journey. I have entrusted my life to you on numerous occasions, and I know that I can always rely on you until my last breath. While you may hold the title of field assistants, in my heart, you are akin to my blood brothers. Together, we have navigated through daring and perilous encounters with the lions, sharing moments of laughter and joy amidst the adversities. This is the life of a lion tracker in the Gir Forests—a life filled with wonder and adventure that I will forever hold dear in my heart.

I extend my heartfelt gratitude to all the trackers of the Gir forests for their invaluable help and unwavering support during my time in the landscape. Your dedication, kindness, and

fearlessness exemplify the true spirit of conservationism as you tirelessly devote yourselves to protecting the lions and preserving their natural habitat. Your passion and commitment to working with these majestic creatures are truly commendable, and your contributions to wildlife conservation are immeasurable. I would like to express my special thanks to Nirmal Vala, Murad bhai, Sagar bhai, Ibrahim bhai, and Mohammad bhai for their invaluable assistance and for generously sharing their day-to-day experiences with me. Your insights and guidance have been invaluable in enhancing my understanding of the intricacies of life in the Gir forests. I am also deeply grateful to Mahindra Bhai and Bhailu Bhai for their warm hospitality and unwavering support throughout my time in Saurashtra. Your kindness and generosity have made my stay in the region all the more memorable and enjoyable.

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I extend my sincere appreciation to my seniors and colleagues at the Wildlife Institute of India, including Dr. Ujjwal Kumar, Neha didi, Ninad, Dipak, Neeraj bhaiya, and the entire Tiger cell, for their unwavering assistance and support throughout various stages of my professional journey. I am also grateful to Dipak for his selfless assistance and unwavering support since our days in MSc. I wish you all continued success and happiness, and I am deeply thankful for your invaluable friendship.

My journey in wildlife sciences owes everything to the unwavering support of my family. To my beloved father, whose early years were dedicated to serving our country, and whose retirement was devoted to fostering our education and career aspirations, I owe an immeasurable debt of gratitude. Your selfless sacrifices and boundless dedication have been the cornerstone of my success. May every child be blessed with parents as humble and supportive as you both. Despite the challenges, you never once burdened us with your own difficulties, a fact that still brings tears to my eyes. The joy of presenting my first fellowship earnings to you, a saree to Maa and a shirt to Deuta remains one of my happiest memories. I am equally grateful to my brother and sister, whose unwavering support has been a source of strength throughout my career. You are truly wonderful, kind-hearted siblings, and I wish such blessings upon every individual. You have contributed greatly to your personal sacrifices and selfless support in my education. From spending our early adulthood together in shared apartments, constant fights over cooking and cleanliness, to the limitless joy of laughing, you

both made my life no less than a heavenly abode. I fondly reminisce about those times and wish that we could still be together, sharing our lives indefinitely.

Executive Summary

1. Introduction:

Lions hold profound cultural significance for many human societies, both within India and globally. Evidence from cave paintings, fossil records, and ancient Indian texts suggests their possible presence on the subcontinent since antiquity and the exact time of its colonisation in the subcontinent is debatable. Mentions of lions in the Rig-Veda, dating back 3000 to 4000 years, indicate their significance in ancient Indian culture. However, in later years, the Artharva-Veda, dating 2500 to 3000 years old, replaces lions with tigers. In the past century, lions once roamed extensively across India, from the Indo-Gangetic plains to Bengal and southward along the Narmada riverbank. Despite popular belief that lions were confined to the northern bank of the Narmada river, historical hunting records indicate their presence on the southern bank as well. Unfortunately, indiscriminate hunting and habitat destruction led to the decline of lions, confining them to a single panmictic population in the Gir Forests of the Saurashtra peninsula. Despite claims by some conservationists depicting Asiatic lions as alien species from Africa, historical records and recent genetic studies refute this notion. Presently, about 40% of the Asiatic lion population resides outside protected areas, amidst human-dominated landscapes. The lion's range spans across 7 districts, covering more than 30,000 km² of the Saurashtra region of Gujarat state, including Junagadh, Gir Somnath, Amreli, and Bhavnagar, as well as parts of Porbandar, Botad, Rajkot, and Surendra Nagar. This region falls under the semi-arid biogeographic zone 4B of Gujarat Rajputana Biotic province and lies within the Afro tropical realm. Constant interactions with humans occur in this shared landscape, with refuge patches being small and lions traversing through various human land-use types to move between patches. Therefore, research questions and hypotheses for my PhD have been formulated as follows:

Question 1: Where are the suitable habitats for Asiatic lions within Saurashtra and across the historical distribution range in the Indian subcontinent?

Hypothesis: Grasslands, shrubs, and deciduous forest patches with minimal human impact distributed across the historic ranges of lions shall serve as suitable habitats.

Question 2: What are the available habitat corridors connecting existing lion populations in the landscape of Saurashtra?

Hypothesis: Lions will predominantly use broken terrain and forest patches as stepping stones, optimizing their movement to minimize contact with humans.

Question 3: What is the spatio-temporal pattern of attacks by lions and leopards on livestock and humans in the Greater Gir Landscape of Saurashtra?

Hypothesis: Attacks on both livestock and humans will be more frequent in areas proximate to suitable wildlife habitats and where wild prey density is low.

Question 4: How are the perceptions of locals towards the conservation of these large carnivores shaped by the temporal extent of land-sharing and conflict?

Hypothesis: People with less temporal experience of living with lions (land-sharing) and high levels of conflict shall hold more negative perceptions towards lions.

2. Habitat Suitability

Currently, Asiatic lions inhabit extensive agropastoral landscapes in Saurashtra, predominantly under private land ownership. Balancing development with conservation emerges as a crucial strategy for effectively managing conflicts and ensuring the long-term survival of lions. Furthermore, the lower genetic heterogeneity among Asiatic lions increases their susceptibility to extinction from catastrophic events. The recent Canine Distemper virus outbreak has already claimed the lives of many lions in the landscape. Therefore, it becomes imperative to identify suitable habitats to establish separate lion populations away from Gir Protected Areas (PAs) and safeguard the remaining forest patches, ensuring the persistence of the lion population.

To achieve this, I utilized current lion locations and historic hunting records to develop three habitat suitability models. These models aim to identify available habitat patches within Gujarat and across the lion's historic range in India. Additionally, a comparative analysis was conducted between past and current scenarios based on hunting locations. Through this comprehensive approach, I identified a total of 22 protected areas across India's historic distribution range where habitats suitable for lions exist. Within Gujarat, two clusters of suitable habitats were pinpointed: Barda Wildlife Sanctuary in Porbandar district and Jessor-Balaram Ambaji wildlife sanctuaries in Banaskantha district.

This strategic identification of suitable habitats not only facilitates the creation of separate lion populations but also contributes to the conservation of remaining forest patches. By ensuring

the long-term persistence of lion populations outside Gir PAs, we can mitigate the risk of extinction posed by catastrophic events and enhance the overall resilience of the species.

3. Corridor connectivity among lion metapopulation

Apart from the Gir Protected Areas, Asiatic lions inhabit various coastal forest patches in Mangrol, Veraval, Kodinar, Mahua, and Rajula-Jafrabad areas. They also reside in Girnar Wildlife Sanctuary (WLS) and within human-dominated landscapes across Amreli, Junagadh, and Bhavnagar districts (Mitiyala WLS), as well as along the Shetrunji river, Hipavadli, Palitana, and Shihor. However, the presence of extensive townships, linear infrastructure, and urban development has led to the fragmentation of lion populations. This fragmentation restricts the efficient exchange of individuals across the matrix of multi-use human-dominated landscapes. Historical corridors that once connected hills, forests, and lion habitats, including protected and un-classed forests, have largely succumbed to agriculture and human settlements.

To address this pressing issue, it is crucial to identify and conserve existing habitat corridors that connect these lion patches. Failure to do so could exacerbate reproductive isolation, leading to genetic bottlenecks and reduced genetic diversity within lion populations. To tackle this challenge effectively, I utilized Circuitscape theory to model connectivity among habitat patches in the Saurashtra landscape at a scale of 1km². Additionally, I employed least-cost pathway tools to determine the shortest pathways with the least total costs. My analysis revealed varying levels of permeability among different lion habitats. For instance, the permeability between the coastal forests of Veraval-Sutrapada and Rajula with Gir PA was found to be high. Similarly, coastal patches around Mahua taluka exhibited high permeability with forest patches around Palitana. However, the permeability between Girnar and Gir Forest was moderate, indicating the need for interventions to maintain suitable lion movement. In the eastern part of the Gir protected area, there is notable connectivity between Mitiyala Wildlife Sanctuary and Gir, as well as other habitat patches along the Shetrunjay river. By prioritizing the identification and conservation of these critical habitat corridors, we can enhance connectivity among lion populations, mitigate the risk of genetic isolation, and safeguard the long-term survival of Asiatic lions in the Saurashtra landscape.

4. Conflict Dynamics and Human-Carnivore Interactions

The Saurashtra landscape harbours approximately 700 adult lions across its expansive 30,000 km² expanse, with around 40% of the population residing outside the protected confines of the Gir Sanctuary. Sharing this habitat are leopards, compounding the complexities of coexistence. Given the scarcity of wild prey in such areas, lions and leopards frequently resort to preying on livestock and, on rare occasions, may pose a threat to humans. Mitigating these conflicts hinges upon proactive measures and a thorough understanding of the underlying dynamics.

To shed light on these interactions, I delved into compensation claim records for livestock and human attacks by lions and leopards spanning from 2012 to 2017. This dataset encompassed vital details including owner names, village locations, livestock types, and incident timestamps. Field visits augmented this data, providing insights into attack locations, predator numbers, and timing.

Leveraging machine learning algorithms, particularly Species Distribution Modelling, I identified key contributing factors. A total of 11,901 claims for lion-induced livestock losses and 4,465 for leopard-induced losses were documented. The frequency of compensation claims exhibited a linear increase over the years for both lion and leopard attacks. During this period, 125 lion attacks on humans were recorded, resulting in 8 fatalities, alongside 391 leopard attacks, with 41 proving lethal. Notably, 519 villages experienced human-carnivore encounters.

Predictive model outputs of Maxent, demonstrated robust predictions (AUC > 80%) for attacks on both humans and livestock. Livestock predation frequency by lions emerged as the most influential factor, explaining 48% of variability. Furthermore, lion-human conflict risk was heightened in areas with low lion density within the multi-use agro-pastoral landscape. Conversely, attacks were most prevalent in or around lion-show hotspots, tapering away from such areas and declining around forest perimeters. Leopard attacks, on the other hand, were influenced by various factors, including elevational profiles, average annual NDVI, human population density, distance to forest patches, and drain density. As anticipated, the probability of attacks on humans increased with greater cover and drainage density, while diminishing with distance from forest patches and elevation. Understanding these nuances is critical for planning targeted strategies to mitigate human-wildlife conflict and foster harmonious coexistence in the Saurashtra landscape.

5. Community Perceptions and Coexistence Mechanisms

As the populations of both large carnivores and humans increase within the Saurashtra landscape, the enduring acceptance of lions among locals raises pertinent questions about their long-term coexistence. To grasp the intricacies of this relationship in its socio-ecological dimensions, a comprehensive scientific understanding is imperative. The tangible and intangible factors, ranging from benefit sharing to losses incurred from wildlife damage, profoundly influence people's attitudes and perceptions. Identifying the underlying factors fostering coexistence is paramount despite conflicts with these apex predators. Unveiling existing systems of harmony, such as those observed among the lions of Gir and local communities, holds the key to reimagining carnivore conservation beyond protected areas in the Anthropocene era. Employing socio-economic surveys, I researched the mechanisms underpinning lion-human coexistence in the shared landscape. I tried to elucidate the relevant insights through careful questionnaire design based on prior reconnaissance and knowledge.

Contrary to expectations, individuals from villages with high to moderate conflict exhibited a more positive attitude towards lions compared to those with moderate and no conflict. Notably, pastoralists displayed the highest levels of negative sentiments towards these apex predators. Upon investigating deeper into attitudes, admiration for lions were mostly due to perceived attributes of nobility, charisma, the sense of pride associated with their presence and economic benefits of sharing the landscape with lions was significant. Conversely, economic losses due to livestock predation and perceived threats to human safety were cited as reasons for dislike. Economic considerations emerged as pivotal in shaping community perceptions towards lions, influencing both positive and negative attitudes. The best model that explains the odds of liking lion in the landscape is characterized by economic status of a person, educational status, temporal extent of land-sharing, distance to lion-show hotspots and conflict frequency, $R^2=0.40$. People used better livestock corralling facilities in areas with long exposure of lion colonisation compared to areas where lions have colonised recently. Similarly in such areas higher proportion of the respondents also practiced mixed herding of livestock.

List of figures:

Figure 1.1: (A) Past and present distribution of lions, (B) Genetic divergence of lion populations

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Chapter I

Chapter I:

I. Introduction and literature review:

A. Asiatic lion: its origin and a brief description in Indian history and culture

Lions have great significance to Indian culture and religion (Divyabhanusinh, 2005; Geer, 2019). Since ancient times, they have been symbolized as icons of power and royalty. Ancient rulers often used lion motifs to showcase their authority and power in India and worldwide (Divyabhanusinh, 2005; Geoghegan, 2021). In Hindu mythology, the lion is associated with various deities symbolizing strength, courage, guardianship and protection (Patel and Binjola, 2021). The lion's significance is not limited to Hinduism but also extends to other religions, such as Jainism and Buddhism, where the lion is recognized as a symbol of spiritual power and enlightenment (Ven. Jampa Choskyi, 1988). Besides, the origin of the Asiatic lion is as intriguing as its cultural significance to human societies worldwide. Various scientists across the globe have put forward many postulates and hypotheses about the origin and diversification of Asiatic lions. Genetic studies have been a powerful tool for demystifying the past for many species including the unknown histories of ourselves. One such recent study revealed that Asiatic lions are believed to have originated from an older East African refuge dispersal event some 118,000 BP (95% CI 28,000 to 208,000 BP) (Antunes et al., 2008) and colonization of Asia started sometime around 21,000 BP (Barnett et al., 2014). However, the genetic closeness of Asiatic lions to the Northern, West and Central African lions as compared to Southern and East African lions, (Bertola et al., 2011) results another alternative explanation that after a Pleistocene extinction event in Western and Central Africa, recolonization occurred from a *refugia* in the Middle East and the maternal lineage of Gir lion was found to be nested within the clade formed by Northern, Western and Central African lions (Barnett et al., 2014). The debate is on, especially after the recognition of two distinct subspecies of lions as *Panthera*

leo leo consisting of lions from India, Central and West Africa and *Panthera leo melanochaita* comprised of lions from Eastern and Southern Africa by the IUCN cat specialist group (Kitchener et al., 2017). The whole-genome sequence of lions across its current distribution range has delineated the existing lions into four major clads i.e. West & Central Africa, India, East Africa, and Southern Africa, wherein the Gir lions were observed to form a distinct clade from the African lions (Figure 1.1) (Bertola et al., 2022; Manuel et al., 2020).

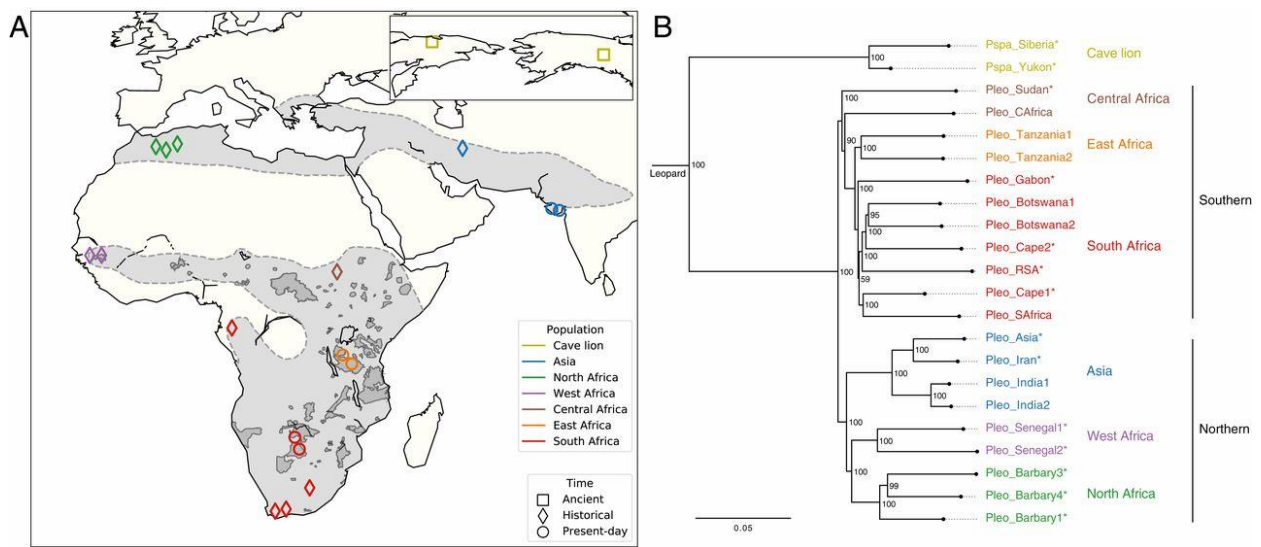


Figure 2.1: (A) Past and present distribution of lions, (B) Genetic divergence of lion populations (Manuel et al., 2020)

Various archeological and fossil evidences give us rough idea about the earliest presence of lions in the subcontinent. The fossil record of Sri Lanka suggest that both tigers and lions might have colonized the subcontinent as early as the late quaternary period, but which probably got extinct due to change in vegetation structure and climatic conditions and hunting by early humans in later times (Manamendra-Arachchi et al., 2005). The Neolithic/Chalcolithic cave painting of lions in the Bhimbetka rock shelters which dates back to 30,000–100,000 years BP (Badam and Sathe, 1991) further supports the fossil records of Sri Lanka and hints at the

earliest possible presence of lions in the subcontinent. The proto-Indian inscriptions were often depicted with emblems, various animals, plants and scenes, that gives us snapshots of biodiversity of those times. In the Indus valley civilization animals like tigers, elephants and rhinoceros could be widely seen in seals, pottery and terracotta images however there are rare representation of lions (Divyabhanusinh, 2005) apart from a two-faced lion like figurine that was recovered in the Indus valley site (Iyer, 1977) and lion terracotta art recovered at Mehrgarh near Bolan pass (Pakistan) (Divyabhanusinh, 2005). Similarly the representation of tigers could be widely seen in the archaeological discoveries from the Harappan period, except a “lion handle” that was excavated in Taxila (Pakistan) date backs to the late Harappan period (~ 2500 BP) (Divyabhanusinh, 2005). The lions as a symbol of both power and godliness to fierce beast has been well depicted in the ancient Buddhist texts and Hindu holy book “Vedas”, that represents a deep-rooted cultural connection of the inhabitants with the beast since ancient times. In the Rig-Veda (3000 to 4000 years old) there are several mentions of lions (at least on 15 occasions) (Jhala et al., 2019), and no mention of tigers (Zide and Zvelebil, 1976). However in the later years lion is replaced by tigers in the Artharva-Veda (2500-3000 years old) (Zide and Zvelebil, 1976). It is evident that the familiarity and representation of ancient Indian/Hindu literature increased with the advent of Aryans into the subcontinent (Jhala et al., 2019). Singh 2007 speculates that the lions entered into India through the western passes of Hind Kush mountains around 2600-3500 years ago. Subsequently by the time Jainism and Buddhism evolved depiction of lions could be widely seen in various literatures. The Buddhist religious text depicts many animals various religious symbolization. Among different Buddhist gods of directions lions is often connected with the north, east and south (Zide and Zvelebil, 1976). Ancient Jain literature depicts the lion as the symbol of the 24th *Jain tirthakar Mahaveer* (spiritual leader) (~ 2,600 BP), whereas the contemporary Buddhist texts depict Gautam Buddha (son of Sakya chieftain, born around ~2500 BP) as *Sakyasimha* after achieving

enlightenment (Jhala et al., 2019). In the times of Puranas (~1000 – 1,500 BP) and the great epics of Ramayana and Mahabharata the lion is often depicted as incarnation of Lord Vishnu as “Narasimha” (half lion half human) and vahana (carrier) of Goddess Durga. In the medieval Indian history lions were used to symbolize the royal status of kings and kingdoms (Divyabhanusinh, 2005) as well as a subject of political interest (Ranjitsinh, 2014). The charisma and symbolism of lion’s supremacy continued to influence the human psyche in modern era. Lion was the national animal of independent India until tiger was designated as the national animal in 1973 (Rangarajan, 2013). “Bharatmata” (mother India) riding a lion is often used to symbolized the modern independent India (Newell, 2011). The national emblem of India is also depicted lions *i.e.* four lions standing back-to-back, within a Persepolitan style, adopted from the Ashoka pillar (3rd century BCE). Even, the recent “make-in-India” icon adopted by the Government of India for encouraging local entrepreneurship is a logo of Asiatic lion made from mechanized parts.

However, the history of lion in India is not as glorious as it seems from the above descriptions. Once they ranged from Persia to eastern India but are now restricted to a single population in the Gir-Saurashtra region of the state of Gujarat, Western India. Indiscriminate hunting and habitat destruction are believed to be the main cause of their extirpation from rest of India (Divyabhanusinh, 2005). Lions were often considered as better sport than the tiger by the colonial hunters (Mundy, 1832). It was after the conquest of Haryana by the British in 1809, when the expeditionary force and officers came in continuous encounter with lions in the state, the Imperial Government officially declared the presence of free ranging lions in India (Kazmi, 2021). Aftermath of this discovery the British unleashed rampant extermination of lions across much of north and central India. The scale of the killing can be well understood by a note from one of the first military stations in a place called “Hansi” in Haryana, about the hunting of lions around one camp among many such camps in the state of Haryana (Figure 2), within a period

of one year (Kazmi, 2021), which states as follows, “*Hansi, June 18, 1811. – The lions are still very plentiful here; yet we have now killed in all, forty-three; besides tigers, and two leopards*” (Anon, 1810). This note also mentions the first ever evidence of Tiger and Lions sharing the same landscape in the Indian subcontinent during the recent past (Kazmi, 2021). There are several mentions of the co-occurrence of tiger and lions in the travel diary of Maria Nugent, the wife of Sir George Nugent, the Commander-in-Chief of India between 1811–1813 (Kazmi, 2021). The elimination of “dangerous beasts” was a policy innovation, taken up first at a local level and then in a more concerted, coordinated manner at a pan-Indian level in the 1870s (Rangarajan, 2013). By 1880s they were restricted as a single free-ranging population in and around the Barda hills, Alech hills, Mitiyala, Girnar and Gir forests in the Saurashtra peninsula of Gujarat, western India (Dalvi, 1969). By the first decade of the 19th century lions were considered as exceptionally rare trophy among the colonial hunters and the number is believed to be as low as 16 (sixteen) individuals surviving in the Gir Forests of Kathiawar (Wilson, 1921). In the book “Fauna of British India” by Blanford (1888) it is mentioned that apart from the Gir Forests in Kathiawar lions were also present in forests of Rajasthan’s Southern Jodhpur, Udaipur and common in Mount Abu. While few lions were also reported to be present in the jungles of Lalitpur, Uttar Pradesh. There are records of lion hunting in Gwalior, Kota, Goona in the year 1873, Sheorajpur near Prayagraj (Old name Allahabad) in the year 1864 and a male with full grown mane was shot near the 80th railways milestone from Prayagraj to Jabbalpur in the year 1866. There is record of lion hunt within 40 miles of Kot Diji, Sind currently in Pakistan in the year 1810, as well as in the Khandesh region (North Western part of Maharashtra) and eastward as far as Rewah and Palamau. It is mentioned in the book “Deadly wild beasts of India” that 25 rupees were offered as bounty for lions in Kotah (Fayrer, 1889). Further fragmentation of forested patches and irreversible loss of habitat connectivity due to agricultural expansion and grazing needs in the region finally restricted lions to the 1,883km²

of the Gir forests (Divyabhanusinh, 2005). The timely protection measures taken by the erstwhile Nawabs of Junagadh, (the largest princely state in the Kathiawar peninsula) the lions remained safe in the forests of Gir. There are various depictions of lion hunting in India by the kings and colonial rulers in form of art and stories (Figure 1.2, 1.3, 1.4 & 1.5).

Figure 1.2: A pencil sketch of lion hunt around the village of Pewur (near Jind) in Haryana (Mundy 1832)



At the onset of the twentieth century, when efforts to protect them gathered force, the lions became far more of a threat to human life than ever before (Rangarajan, 2013). There was a serious and prolonged drought in the region from 1899–1901. It was so severe that Junagadh State had to set up 157 relief works in its territory (Srivastava and Srivastava 1996). It is still remembered as the terrible '*Chappanyo Kal*' ('*Chappan*' means fifty-six in Gujarati). There were huge mortalities of both wildlife and domestic livestock due to the scarcity of food and lion attacks on herds of goats, cows buffaloes as well as on humans became commonplace well beyond the forest (Rangarajan, 2013). After 1904, this ceased altogether, and lion–human relations took a turn for the better. The rulers of Junagadh compensated losses of livestock, and also fiercely asserted that all lions, even those in other neighboring princely states, were their patrimony (Divyabhanusinh, 2005). Another tragic escalation of lion–human confrontations occurred during the drought of 1987–88. From 1978 to 1991 there were on average two deaths a year due to lions, however as mentioned by Rangarajan (2013), the levels of attacks rose dramatically to forty attacks during the above-mentioned drought period.

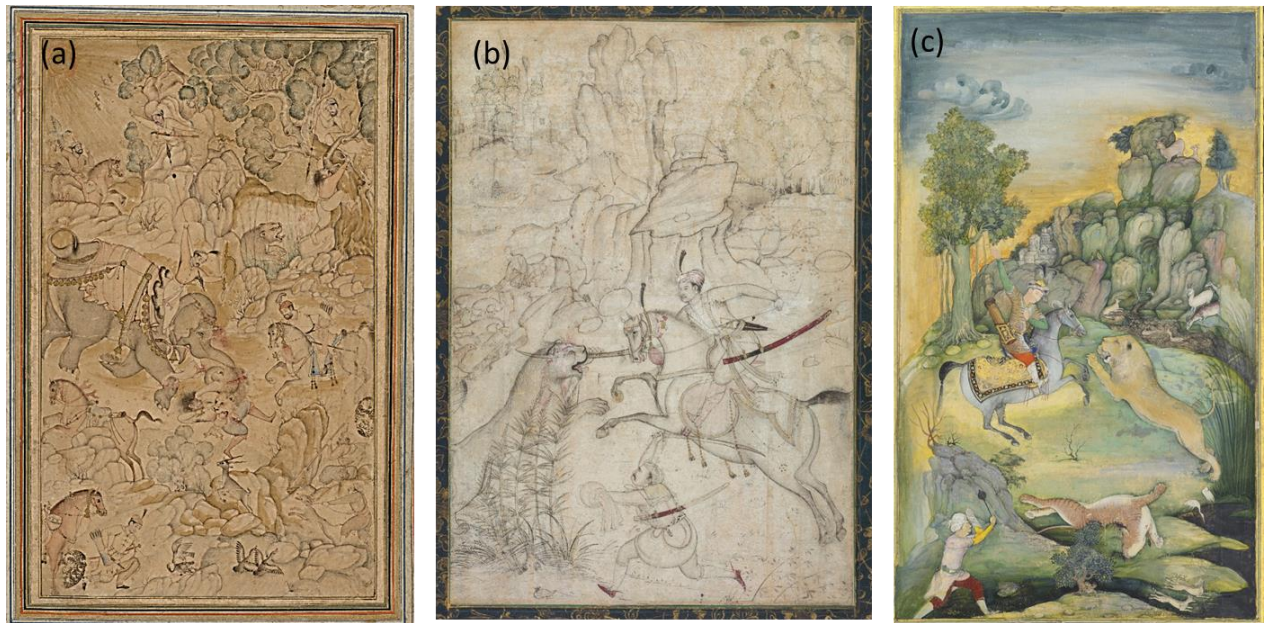


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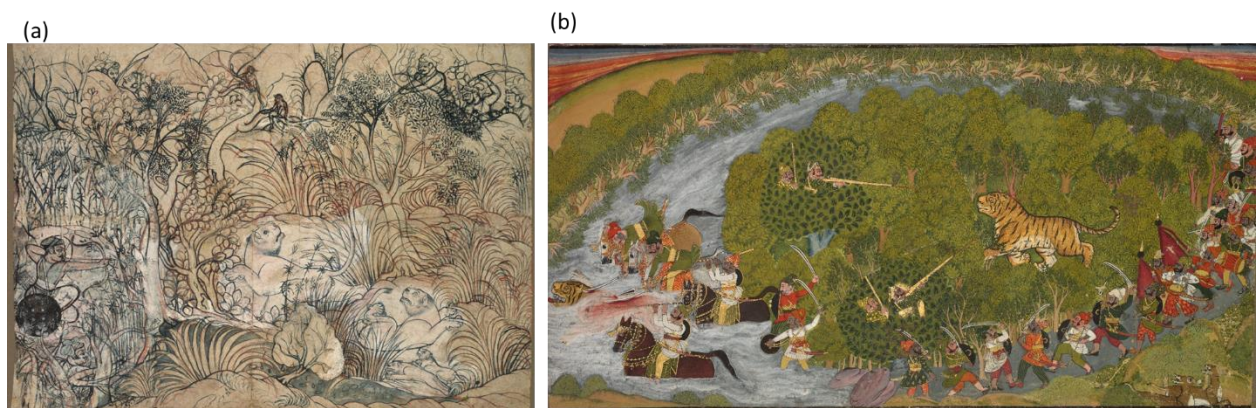


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The numbers of Asiatic lions were as low as 50 during the early 19th century (Cadell, 1935). From mid 1900s, lions started to move out occasionally in the adjoining forests of Gir and started appearing in Mitiyala hills in the dominion of the erstwhile princely state of Bhavnagar from 1917 and they were last reported in 1968 census from this area. Lions were frequently seen in small numbers in Girnar hills adjoining Junagadh till 1963 (Singh, 2007). After the enforcement of complete ban on lion shooting in 1955 by the Government of India, declaration of Gir forests as Gir Wildlife Sanctuary in 1965 and subsequent protection and habitat manipulations by the state-run Gujarat Forest Department (GFD); the lion population has shown a steady increase (Singh and Kamboj, 1996). Within the past two decades, lions have dispersed from the Gir Protected Area into agropastoral landscape of the surrounding districts of Junagadh, Amreli and Bhavnagar covering more than 13,000 km² of multi used human-dominated landscapes (Singh, 2017) and presently their number has increased to more than 700 individuals in the wild (Gujarat Forest Department, 2020).

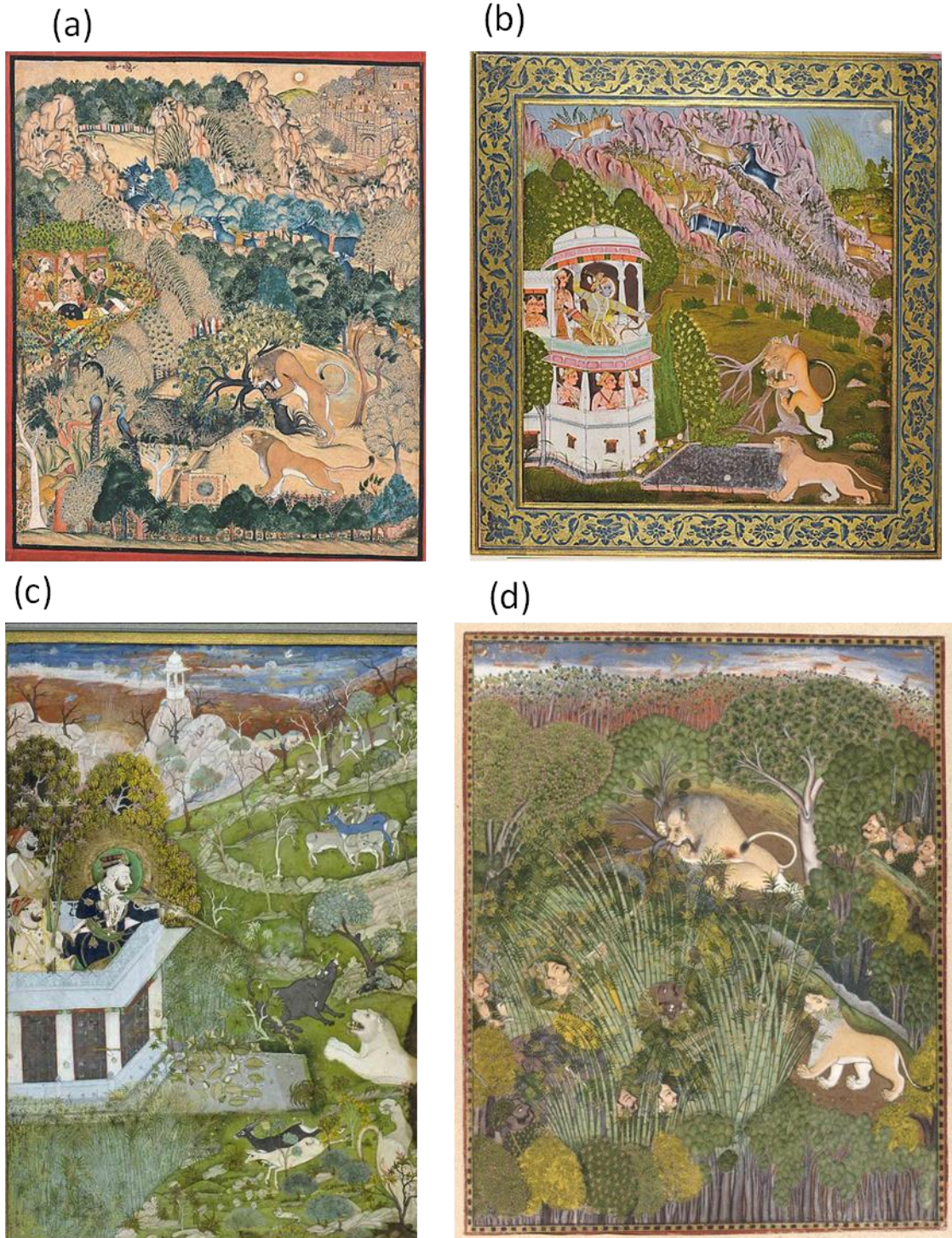


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B. Ecology:

There are drastic morphological differences and behavioural plasticity among the subpopulation of the species across its distribution range. The Asiatic lions in the Saurashtra landscape are smaller in size and have very scanty mane compared to its African cousins. Asiatic lions have a prominent belly fold which is rare in case of African lions. There are two infra-orbital foramina in the skull of Asiatic lion while there is only one in case of African lions. There is social plasticity among the populations of lion from Serengeti and Gir forests of India, mostly due to the difference in resource availability and habitat characteristics of the two ecosystems (Chakrabarti & Jhala, 2017; Jhala et al., 2019). Here a pride is formed by females and their dependent cubs while males form coalitions of two to four individuals and defends a territory that encompasses several female groups. Lions in Serengeti and Ngorongoro, are reported to be egalitarian (Packer & Pusey, 1982), while in Gir pronounced dominance hierarchies have been observed within coalitions of male lions (Chakrabarti & Jhala, 2017) and female prides (Borah 2019). A distinct feeding order and higher mating access of the dominant males were observed among the coalition partners, demonstrating the presence of a hierarchical system (Chakrabarti & Jhala, 2017) as well as it is observed that dominant females have high priority in accessing a kill or carcass (Borah 2019). Mostly the older females hold the top ranks in the hierarchy and younger females holds the bottom ranks in the hierarchy (Borah 2019). The home-ranges of lions outside the Gir PAs are almost three times larger than the home-ranges within the Gir PAs, mostly due to the differences in resource availability. The average size of home-range core area of Gir lion was estimated to be 166 (SE 40) km². The average size of male core area is 214 (SE 43), higher than average breeding female core area *i.e.* 85 (SE 17). Average core area size of territorial males within Gir PA (Gir and Girnar) is 87 (SE 18) km² was smaller compared to the males residing outside the Gir PAs *i.e.* 334 (SE 110) km². Similarly, the average size of core area of breeding females outside the Gir PAs is 88 (SE 45)

km² larger than the average core area size of breeding females within the Gir PAs i.e. 60 (SE 28) km² (Banerjee, 2012).

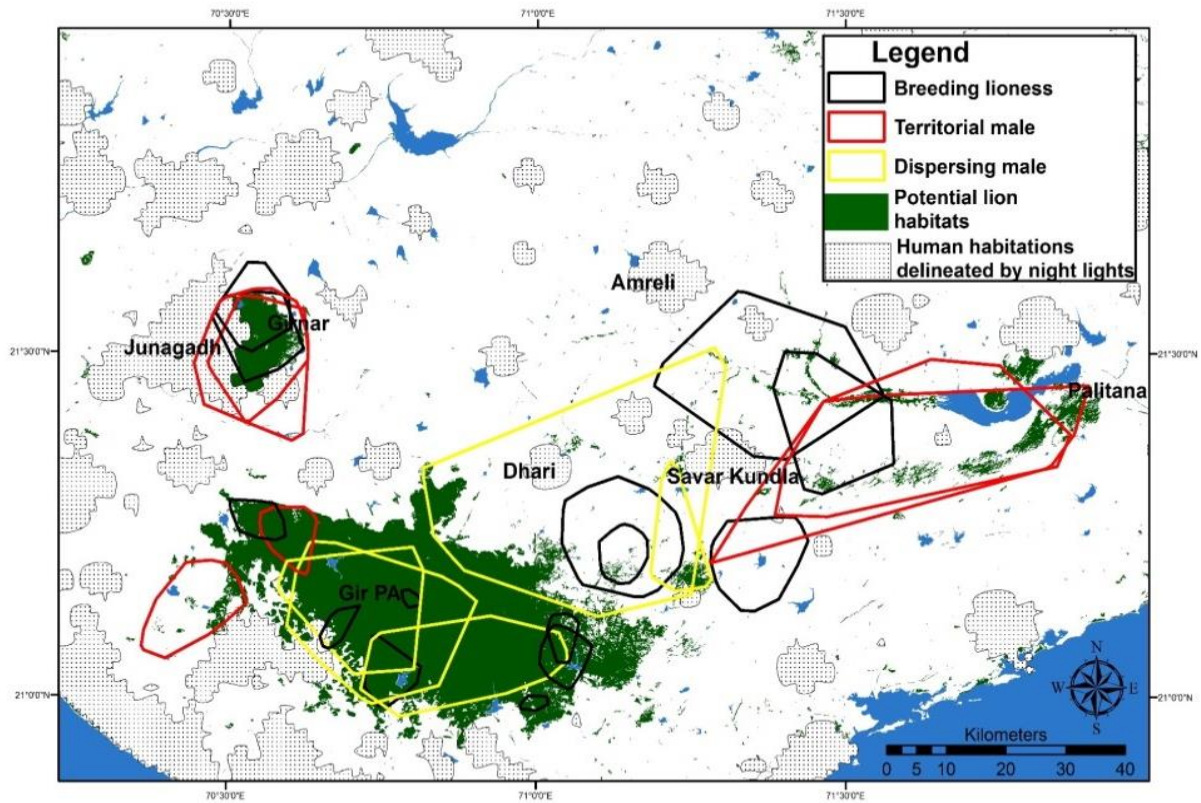


Figure 1.6: 95% MCP home-range (km²) of Asiatic lions (n=28) in the multi-used agro-pastoral landscape of Saurashtra, Gujarat. (Source: (Banerjee, 2012)).

II. Research questions and problem statements:

Problem statement I:

The Asiatic lions have been expanding both in geographic range and number since last few decades (Banerjee and Jhala, 2012; Gogoi et al., 2020; Jhala et al., 2019; Ram et al., 2023; Singh and Gibson, 2011), occupying habitats of their historic range within the Saurashtra peninsula. They have reached the carrying capacity within the Gir Protected Areas and now occupying surrounding areas among the multi-used human dominated landscape (Jhala et al., 2019; Singh, 2017). However, due to the increasing human population density there is high demand for development and land-use change. As a result the surrounding areas of Gir Protected area are highly modified for human use and remaining habitat patches among the human dominated landscape once suitable for the lions are reducing fast (Basu, 2013; Jhala et al., 2012; Singh, 2017). Therefore, its important to identify the remaining suitable habitats where lions were once present historically to safeguard them from further destructions and whether natural dispersal of the lions possible to these areas or human aided dispersal to these areas would be necessary in future. The current population of Asiatic lions are distributed across >30,000 km² of multi-used human dominated landscape of the Saurashtra peninsula characterized by agricultural lands, privately owned hillock and forest patches, protected grasslands interspersed among human habitations, urban centers and linear infrastructures like roads and railway lines. Moreover, the single panmictic population Asiatic lion is small and have less genetic heterogeneity, highly susceptible to extinction risk due to any catastrophic event. Therefore, mapping the distribution and availability of suitable habitats for lions can help to prioritize areas of management importance and identify habitats or protected areas for reintroduction of the species to create separate populations that could minimize the risk of extinction and ensure long-term survivability of the species in the sub-continent. Various protected areas have already been identified within Gujarat and across the historical

distribution range of lions within India to create subpopulations as a measure to safeguard this only surviving wild population of the Asiatic lions from extinction due to catastrophic events. The following two questions in my thesis is trying to address this issue pertaining to the long-term conservation of the endangered Asiatic lions in India.

Question 1: Where are the suitable habitats for Asiatic lions withing Saurashtra and across the historical distribution range in the Indian subcontinent?

Hypothesis: Grasslands, shrubs and deciduous forest patches with less human impact distributed across the historic ranges of lion shall serve as suitable habitats for lions.

Problem statement II:

Currently, Gir lion populations are distributed in six satellite pockets of human dominated landscape with the Protected Area of Gir being the ‘source’ (GEC ENVIS, 2015). The multi-used human dominated matrix and habitat patches suitable for lions in the landscape are under tremendous pressures of development induced habitat fragmentations. As a result, most of the lion satellite patches in the landscape are slowly becoming analogous to small islands in a vast sea of ‘lion hostile’ land use (Basu, 2013). Which could potentially lead to reproductive isolation, resulting genetic bottleneck and lower genetic diversity. Therefore, it is imperative to delineate their functional corridors to prevent further degradation of these habitats due to human activities.

Question 2: What are the available habitat corridors connecting the existing lion populations in the landscape of Saurashtra?

Hypothesis: Lions will mostly use broken terrain, forest patches as stepping stones and optimize their movement to reduce contact with humans.

Problem statement III:

The population of Asiatic lion is on a rise (Bauer et al., 2015; Singh, 2017), presently estimated over 674 individuals spanning over more than 30,000 km² outside protected areas (GEC ENVIS, 2015). Concurrent with a 19.17 % rate of human population growth (Human census report 2011) in Gujarat state there has also been a significant increase in the population of Asiatic lions outside (GEC ENVIS, 2015). About 30% of the total population is known to be located outside the protected area (GEC ENVIS, 2015). Due to the natural paucity of wild prey in such landscapes, lions often predate upon livestock (Inskip and Zimmermann, 2009). Moreover, outside the protected areas Asiatic lions are also dependent on scavenging dead livestock (Banerjee, 2012). Large carnivores habituated to anthropogenic food sources are known to modify their daily behaviour (Ayres et al., 1986; Matthews et al., 2006) and lose fear of human beings (Massé et al., 2014). This change in behaviour escalates the conflicts with humans (Herrero et al., 2011). Therefore, delineating the pattern and processes of these conflicts can be useful to formulate effective management interventions for the long-term conservation of the species in the landscape.

Question 3: What is the spatio-temporal pattern of attacks by lion and leopard on livestock and humans in the Greater Gir Landscape of Saurashtra?

Hypothesis: Attacks on both livestock and humans will be higher in areas proximate to suitable wildlife habitats and where wild prey density is low.

Problem statement IV:

Current conservation ideology recognizes that participation or active involvement of local communities is crucial to make conservation efforts successful (Robinson and Sasu, 2013). Human-wildlife conflict in this context presents a challenge for protected areas, particularly, when conflict impacts the quality of life for local people (Bajracharya et al., 2006). Such negative interactions with humans not only result in loss of property and live but also creates anti-conservation sentiment amongst the locals (Woodroffe et al., 2005). Hence, these factors often increase opposition and weaken support of the locals towards conservation. People are more likely to tolerate risks that are undertaken voluntarily rather than enforced upon them (Starr, 1969, Skogen et al., 2008). Religious beliefs and cultural importance have undoubtedly played a significant role in India towards losses to wildlife conflicts but such values are changing fast and wildlife managers need innovative mechanisms for conflict resolution (Sukumar, 1994). Therefore, understanding the sentiments and perceptions of the people is of utmost important to formulate effective management goals.

Question 4: How the perceptions of locals towards the conservation of these large carnivores are shaped by the temporal extent of land-sharing and conflict?

Hypothesis: People with less temporal experience of living with lions (land-sharing) and high magnitude of conflict shall have higher negative perceptions towards lions.

III. Objectives

The following objectives were formulated to address the above-mentioned questions:

1. To assess the availability of suitable habitats for lions within current and historic distribution ranges across the country.
2. To delineate the available habitat corridors among lion satellite habitats in the Saurashtra Landscape.
3. To map and assess the spatio-temporal patterns of livestock predation by lion and leopards in the landscape.
4. To assess the perception of the locals towards conservation of lions in the landscape.

IV. Study area:

The study area covers 7 districts, encompassing more than 30,000 km² of the Saurashtra region of Gujarat state, namely Junagadh, Gir Somnath, Amrely and Bhavnagar, as well as parts of Porbandar, Botad, Rajkot and Surendranagar (Figure 7). The region falls under the semi-arid biogeographic zone 4B (Champion and Seth 1968) of Gujarat Rajputana Biotic province (Rodgers and Panwar 1988) and lies within the Afro tropical realm (Singh and Kamboj 1996). The area experiences three distinct seasons. The winter extends in Gir from December to March (average minimum temperature 9⁰C.) followed by a hot dry summer (average maximum temperature 42⁰C), which lasts until mid-June. The monsoon starts in June and continues till September and is followed by a dry post monsoon season till mid-December. The south-westerly winds from Arabian Sea brings rain during the monsoons between June and September. The average rainfall in the west is 1000 mm and eastern part of the PA is approximately 800 mm (Khan et al. 1996). The landscape is characterized by broken topography, small drainage systems, Government and privately-owned wastelands, fallow lands and is predominantly agricultural with seasonal crops, fruit orchards (mango and coconut) and coastal forests. The protected forests of Gir is the largest contiguous habitat for Asiatic lion (1883 km²) in the region. The vegetation of Gir has been classified into three broad categories namely: moist mixed vegetation, thorn forests and hill forests. Major vegetation includes Teak (*Tectona grandis*), *Zizyphus spp.*, *Acacia spp.*, *Butea monosperma*, *Anogeisus spp.*, and *Boswellia serrata* (Qureshi and Shah, 2004). Historically the ecological boundary of Gir encompassed about half of the Saurashtra peninsula (Divyabhanusinh, 2005). However, due to increased cultivation and developmental activities Gir forest has shrunk to almost the legal boundaries of the protected forest areas. Between 1872 and 1969 there was a reduction in 87% of forest cover outside the sanctuary area as reported by Joslin in 1973, mostly owing to cultivation. This decline further continued under the commercial exploitation of forest

resources and increasing demand for cultivation land by the expansion of human settlement. In 1920 a small portion of Gir forest (Devalia Block in the south-western boundary of the Gir PA) was declared as a lion sanctuary by the erstwhile Nawab of Junagadh. After independence, the Government of Gujarat constituted the Gir Wildlife Sanctuary in 1965, and later it was expanded in 1974 to the present size of the PA. Subsequently, a tract of land nearly 150 km² was declared as a National Park in 1975 and was enlarged to its present size in 1978.

The major urban centres fall within the study area are Junagadh, Gir Somnath, Veraval, Sutrapada, Jafrabad, Mahua, Rajula, Savarkundla, Dhari, Visavadar, Amreli, Shihor, Palitana, Gondal, Jetpur, Jasdhan, Botad, Talaja, Doraji, Upleta, Ranavav, Kutiyana, Keshod, Manavadar, Vanthali, Una and Porbandar. Three National highways NH 8B, NH 8E and NH 8D are passing through Saurashtra connecting Gondal, Upleta, Kutiyana, Ranavav, Porbandar, Rajkot, Bamanbore by NH 8B; Vanthali, Jetpur, Junagadh, Somnath, Keshod, Veeraval connecting by NH 8D and Kodinar, Una, Bhavnagar, Somnath, Mahuva connecting by NH 8E (Gujarat Infrastructure Development Board, 2006). There are several state highways interspersing through the region. The intensive network of railways in the region is another linear infrastructure cutting through the habitats of Asiatic lion. Besides there are 10 major commercial ports for cargo transportation to various regions of the country and abroad in the coastal habitats of Saurashtra (Gujarat Infrastructure Development Board, 2006).

The major wild animals within the Gir protected area and its peripheral habitats constitutes about 32 species of mammals, 26 species of reptiles and over 300 species of birds (Divyabhanusinh, 2005; Meena and Kumar, 2012). Along with the majestic Asiatic lion other carnivorous species found 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 ungulates include chital, sambar (*Rusa*

unicolor), nilgai, wildpig (*Sus scrofa*), four horned antelope (*Tetracerus quadricornis*), and chinkara (*Gazella gazella*) (Singh and Kamboj 1996). Within the Gir Protected Area Chital is the most abundant wild ungulate with a density of $56.1 \pm 8.3/\text{km}^2$ (Jhala et al. 2016). Besides, the human dominated landscape has several cattle camps (Gaushalas and Panjrapoles) housing thousands of ill and abandoned cattle and lions obtained a substantial part of their diet by scavenging the carcasses (Banerjee et al., 2013).

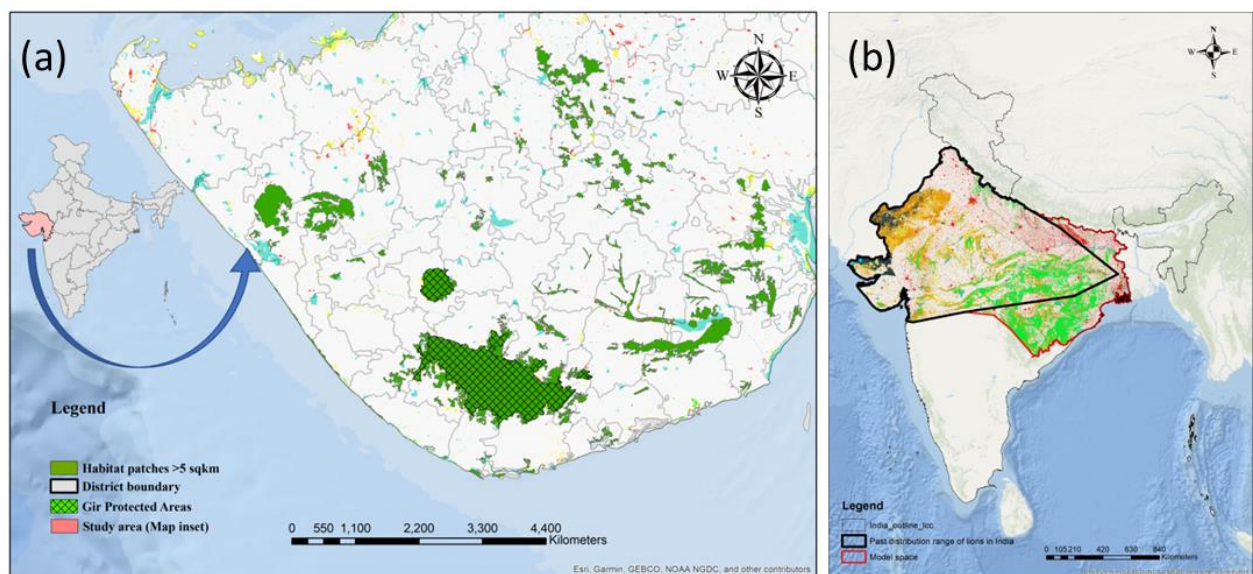


Figure 1.7: The study landscapes. (a) Gir Protected areas and habitat patches are highlighted in the Saurashtra landscape of Gujarat. (b) historic distribution range of lions in India

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Chapter II

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Chapter II: Spatial Distribution of suitable habitats for Asiatic lions.

Objective 1: To assess the availability of suitable habitats for lions within current and historic distribution range across India.

Introduction:

Large carnivores are threatened globally (Ripple et al., 2014; Terraube et al., 2020; Wolf and Ripple, 2018). In the last few decades, numbers and range of many large carnivores have reduced primarily due to human persecution, habitat loss and fragmentation (Cardillo et al., 2004; Wolf and Ripple, 2018, 2016). Historically about 96% of the global land mass was occupied by large carnivores at present they only occupy just about 34% (Wolf and Ripple, 2017). Large carnivores like tigers, lions, cheetahs, red wolves, Ethiopian wolves and African wild dogs have lost more than 90% of their former global ranges (Wolf and Ripple, 2017). Such species that have experienced population size and range reductions are at high risk of extinction (Ceballos and Ehrlich, 2002). Nevertheless, in last few decades various rewilding efforts have been put forward to recover the carnivore populations worldwide (Wolf and Ripple, 2018) and conservation practices proved to achieve some success in the recovery of large carnivores in few parts of the globe, *i.e.* Black bears in North America and grey wolf, brown bear, wolverine and lynx in Europe (Chapron et al., 2014; Cimatti et al., 2021; Mech, 1995). In India, the conservation of Gir lions (*Panthera leo leo*) illustrates one such success story and showcases the commitments and efficacies of India's conservation governance in protecting an endangered large carnivore (Divyabhanusinh, 2005; Singh and Gibson, 2011). Conservation of such recovering carnivores is challenging in modern times where the natural dispersion of these animals into the multi-used human-dominated landscapes results in conflict with humans and development goals. In such landscapes availability of suitable habitats is rare and due to the

constraints in movement by various human land-use practices, these animals are forced to utilize suboptimal habitats often closer to human habitation (Tucker et al., 2018). There is also an urgent need to establish a separate population of the Asiatic lions to ensure the long-term survival of the species as the Gir lions currently thriving as a single panmictic population and have very low genetic heterozygosity (Bertola et al., 2022) and stochastic events like disease epidemics that have prevailed in the Gir lions resulting in mass mortality due to canine distemper in last few years (Mourya et al., 2019). Hence it is a necessity to identify the available suitable habitats of Asiatic lions within their historic range so that separate populations of the species can be established by reintroduction and to facilitate their natural dispersion at a local scale.

Asiatic lions that once ranged from Persia to Palamau in eastern India were almost driven to extinction by indiscriminate hunting and habitat loss (Joslin 1973). A single population of fewer than 50 lions persisted in the Gir forests of Gujarat by the late 1890s (Divyabhanusinh, 2005). With timely and stringent protection offered by the Nawabs of Junagadh and subsequently by the Gujarat Forest Department (GFD), Gir lions have increased to the current population of over 700 with an annual rate of about 6% during the past decades. About 50% of the Asiatic lion population has dispersed beyond the PA boundary to cover >30,000 km² of the human-dominated landscape of Saurashtra. Gir lions are continuously expanding their range and colonizing new areas (Meena and Kumar, 2012); while the movement corridors and habitat patches suitable for lions in Saurashtra are under tremendous pressures of development induced habitat fragmentation. With lions occupying vast tract of agropastoral 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. Therefore, identifying the suitable habitats and corridors are important to conserve the remaining forest patches and

movement of lions in the landscape, which will ensure the long-term persistence of the lion population in these human dominated landscape.

Organisms do not occur randomly in space (Wuellner, 2009), their distribution is governed by the interactions of various biotic and abiotic factors at different spatial scales (Krebs, 2001). Therefore, persistence of an organism in a geographical space depends on whether ecological conditions match with the niche space of the species. Availability of adequate food resources, interspecific competition, habitat quality and anthropogenic pressure are some of the important factors that affects the distribution and density of wild animals. Carnivores in this regard are more susceptible to anthropogenic changes due to their K selected life history, large space requirement and direct conflict with human interests and life (Woodroffe, 2000). In last few decades effective conservation management of large carnivores has led to the recovery of many endangered large carnivores in human dominated landscapes of Europe (Chapron et al., 2014), North America (Bangs *et al.* 2001) and Asia (Singh & Gibson 2011). However, these conservation success story comes with unique challenges of whether there is sufficiently large and functional areas left for the establishment of viable populations in the multiuse human dominated landscapes (Packer et al., 2013) and managing these species at larger geographical scale to minimize the negative interaction of human and large carnivores to a tolerable level so as to maintain a balance of coexistence between the two (Carter and Linnell, 2016).

About 2,680 years ago (1081-4279 BP), the Kathiawar peninsula was separated from the mainland India by rising sea level (Driscoll et al., 2002; Gupta, 1972) causing the first genetic bottleneck that isolated the founders of the present Asiatic lion population in Saurashtra leading them to inbreed for several generations (O'Brien, 2003). A second bottleneck happened at the onset of the nineteenth century when lions became restricted to the Gir forests and their numbers declined to around 50 individuals due to hunting and habitat loss (Kinnear, 1920;

Pocock, 1930). Studies on allozyme and microsatellite indicate that there is very less genetic heterozygosity among the Asiatic lion population, attributed to an isolated inbred population with a small founder base (O'Brien, 2003). Moreover, inbred carnivore populations restricted to single sites (such as Asiatic lions) face a variety of extinction threats from genetic and environmental stochastic factors. Catastrophes such as an epidemic, an unexpected decline in prey, natural calamities or retaliatory killings could result in the extinction of a threatened species when it is restricted to a single site (Soulé, 1987). It is worth recording that an epidemic caused by Canine Distemper Virus (CDV) emerged abruptly in the lion population of the Serengeti National Park, Tanzania in early 1994 resulting in fatal neurological disease characterized by grand mal seizures and myoclonus; the lions that died had encephalitis and pneumonia (Roelke Parker et al., 1996). Recent outbreak of Babesiosis and CDV in Gir has already resulted into mortality of at least more than 60 lions during past two years. As the world is currently witnessing the rapid spread of corona virus during COVID outbreak, any epidemic may also prove fatal for the lions especially when containment is not possible due to feral animal vectors in a landscape that remains in close proximity for disease transmission. This necessitates urgency for establishing a geographically distant population. Therefore, several key protected areas within the Gujarat state and across India have been identified as potential sites for lion reintroduction (Figure 2.1). Assessing the suitability and corridors between the identified protected forest is hence necessary to enhance our understanding of much needed management intervention to safeguard and improve the remaining habitat and its connectivity for the long-term survival of the endangered lions in the multiuse human dominated landscape.

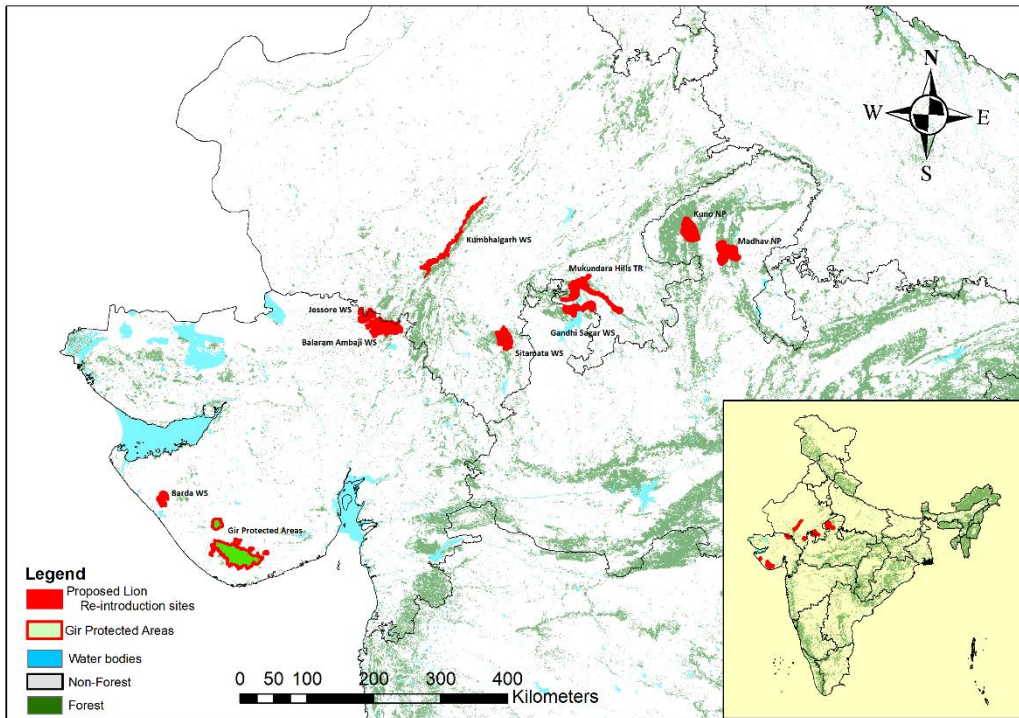


Figure 2.1: Protected areas (red) that can have the potential for lion reintroduction

Methods:

Species Distribution Models based on Extant Lion Locations in Saurashtra:

Twenty-seven lions ranging between approximately 2.5 and 12 years, from different prides across the Saurashtra landscape were radio-collared. The radio collared lions were tracked and monitored on a fixed schedule to cover all time periods of the day either by a four-wheel drive vehicle or on foot, using a 3-element Yagi antenna (AF Antronics Inc., Urbana, Illinois, USA) and a hand-held receiver (HABIT receiver model HR 2600 and Vectronics GPS Plus Handheld Terminal Unit). Lions were also individually identified and monitored across the Gir landscape, based on their unique vibrissae patterns and additional body marks, which resulted into more than 23000 detections. We maintained individual profiles based on repeated sightings in the database program LION (Jhala et al. 2005). These non-collared lions were regularly located across the landscape for quantifying lion abundance, demographic parameters, conflict and predation. Therefore, individually identified lions had a good opportunity of being sampled.

All the occurrence points were spatially thinned to 1 km and duplicate occurrence points were removed before processing in the Maxent programming platform (Phillips et al. 2006). The long-term ecological study on lion's habitat use in the human dominated landscape reveals that the minimum patch size needed for breeding lioness in the human dominated landscape is >4 km² in size (Jhala et al., 2019). Therefore, we mapped all the habitat patches that are more than 4 km² in size outside the protected area boundary from Google Earth imagery and subsequently ground validated these patches through field visits. Ecogeographical covariates of "Drainage density", "Distance to urban setup", "Normalized Difference Vegetation Index (NDVI)", "Distance to water sources", "Elevation" and "Distance to habitat patches" were used to model the habitat suitability for Asiatic lions in the Greater Gir Landscape. These variables were

scaled to 1 km² for the analysis. Maximum Entropy Modeling in software MAXENT (Phillips et al. 2006) was used to model the habitat suitability for lions.

Model 1: Pan India assessment of suitable habitats using current occurrence data from Saurashtra

Covariate layers with a spatial coverage of the entire known historic geographic range of the Asiatic lions within India were used and current occurrence locations of lions were used from the Saurashtra region. A random 20% of the occurrence locations were used for testing the output for model accuracy and performance. I used logistic outputs with auto features for the estimation of probability distribution of the habitat suitability. With 10000 background points I used the random seed option for the selection of background points in each of the replicate runs.

Model 2: Assessment of suitable habitats within Gujarat using current occurrence data from Saurashtra

The spatial extent of model spaces for this analysis was restricted only for the state of Gujarat and used the same covariate layers use in the above model but clipped to the state of Gujarat. Same as the above model a random 20% of the occurrence locations were used for testing the output for model accuracy and performance. I used logistic outputs with auto features for the estimation of probability distribution of the habitat suitability. With 10000 background points I used the random seed option for the selection of background points in each of the replicate runs.

Species Distribution Models based on Historical Occurrence Data:

Model 3: Assessment of suitable habitats using historic hunting locations

I used historic locations of recorded lion hunting within India to predict the probable historic distribution of suitable habitats for lions in India. I reviewed >230 literatures on hunting of wild animals in India by the British colonial officials and Indian rulers to extract information on lion hunts. Records where a precise information on area or locality of the lion hunts were mentioned were further processed for geotagging. Out of the 441 records of lions hunts withing Indian subcontinent I could geotag 259 records after removing duplicates and unconfirmed places (Table S1). The geotagged locations of lion hunts were then used as presence points to predict the historic distribution of suitable habitats of lions within India by using maximum entropy modeling in software Maxent (Phillips, 2017). I hypothesized that areas with low human density with open forests, grassland and shrubland habitats with moderate precipitation will have higher suitability for lions in the historic past (Table S2).

Spatial variables that explain the historic eco-geographic condition of the region were used from various sources (Table S2) and used as covariates in the maxent models. To address the possibility of spatial bias or errors in the historic localities of the lion hunts I used the covariates at a coarse scale of 10 km² in the maxent models. Only one occurrence location was used in the models if locations were closer than 1 km to each other. A random 20% of the occurrence locations were used for testing the output for model accuracy and performance. I used logistic output with auto features for the estimation of probability distribution of the habitat suitability. I used the random seed option for the selection of 10000 background points for each of the 100 bootstrap replicate runs. Current environmental and eco-geographical raster layers were then used to predict the historically modelled relationships to present day scenario.

Results:

Models based on Extant Lion Locations

Total of 1910 presence locations of lions were used for modeling the suitable habitats of the Asiatic lions within the historic distribution range of India and within the state of Gujarat. The Area Under the Curve (AUC) of the Receiver Operator Curve (ROC) and omission/commission analysis with 100 bootstrap runs and with 20% test data showed that both the models assessing the suitable habitats within the historic distribution range of India and within the state of Gujarat had good fit (AUC 0.92, TSS 0.89 and AUC 0.92, TSS 0.88 respectively). The parsimony of the best models was well explained by the lower AIC values compared to other candidate models in both the models (Table 1, 2). The high values of True Skill Statistics (TSS) further support the accuracy of the best fit models (Table 1, 2). Habitat suitability across the historic range estimated based on present occurrence data was best explained by annual mean precipitation (% contribution 64.6), distance to forest (% contribution 14.2), elevation (% contribution 12.7), human modification index (% contribution 3.7), annual mean temperature (% contribution 3.1), land use land cover (% contribution 1.4) and pre monsoon NDVI (% contribution 0.1) (Figure 2.2). We observed that the probability of habitat suitability for lions increases with increasing mean annual temperature up to around 27⁰ C and then reduces sharply (Figure 2.2 c). Annual mean precipitation was observed to have the highest contribution in explaining the variability of the data by the model (contribution 64.6%). Areas with mean annual rainfall between 500-800 mm were observed to be highly suitable for the Asiatic lions (Figure 2.2 d). Habitat suitability decreases gradually in areas that are more than 20-25 kms away from forested patches (contribution 14.2%) (Figure 2.2 e). Similarly, the

suitability values were observed to decrease as the elevation profile of the areas were more than 200m (Figure 2.2 f). Areas with low to moderate human impacts were observed to be suitable for the Asiatic lions but decreases after certain limits (Figure 2.2 g). Evergreen forest tracts mostly represented by the riverine habitats, shrub and scrub lands and deciduous forest tracts were observed to have positive influence on habitat suitability for lions across historic distribution range within India (Figure 2.2 h).

The habitat suitability model for Asiatic lions within Gujarat predicted based on current occurrence data was best explained by mean temperature of the warmest month (contribution 46.1%), elevation (contribution 27.4%), annual mean precipitation (contribution 16.3%), distance to forest (contribution 9.5%), and pre-monsoon NDVI (contribution 0.6%). It was observed that the probability of habitat suitability for the Asiatic lions was highest between the annual mean rainfall of 500-800mm and then gradually decreases as the rainfall increases (Figure 2.4 c). The mean temperature of the warmest months had the highest contribution in the model having 46.1 % contribution explaining the variabilities (Figure 2.4 d). The most suitable areas of lions were observed to have the highest temperature of the warmest month of the year not exceed about 38⁰C, beyond which there is an sharp decline in the suitability values for lions (Figure 2.4 d). Areas closer to forested habitats were observed to have higher suitability value and gradually declined away from such habitats (Figure 2.4 e). Areas that had an elevational profile between 100-300 within Gujarat were observed to have higher suitability values for lions and a gradual decrease in suitability beyond that (Figure 2.4 f).

Results of models based on Historical occurrence of lions

The model used to predict the historical suitable habitats based on hunting locations of lions and subsequently projected to present day scenarios had a reasonable fit with AUC 0.78 and TSS 0.37. The most parsimonious model differed by a AIC value of 26 from the next

competing model (Table 2.3). The best model predicting the historical suitable habitats for lions within India was explained by annual mean precipitation (contribution 63%), land use land cover (contribution 18%), mean temperature of the warmest month (contribution 6.4%), elevation (contribution 6.3%) and human population density (contribution 4.3%). In accordance with our a priori hypothesis we observed that areas with very low human density have higher suitability values for lions but slowly decreases as the human density increases with huge variabilities (Figure 2.6 c). Similarly, in Forested habitats, grasslands and scrublands were observed to have higher contribution among all other categories of land use in the model depicting the high suitability of these land use categories for the Asiatic lions in the historic past (Figure 2.6 d). Suitability values were observed to increase with increasing rainfall up to about 500 mm mean annual rainfall and then gradually decrease with increasing rainfall (Figure 2.6 e). Areas with mean temperature of the warmest month upto 34⁰C were observed to be suitable for lions and suitability values sharply reduced after the temperature exceeds more than ~41⁰ C (Figure 2.6 f). Suitability values were observed to decrease gradually but with wide variability in areas with elevational profile more than 200 m from mean sea level (Figure 2.6 g).

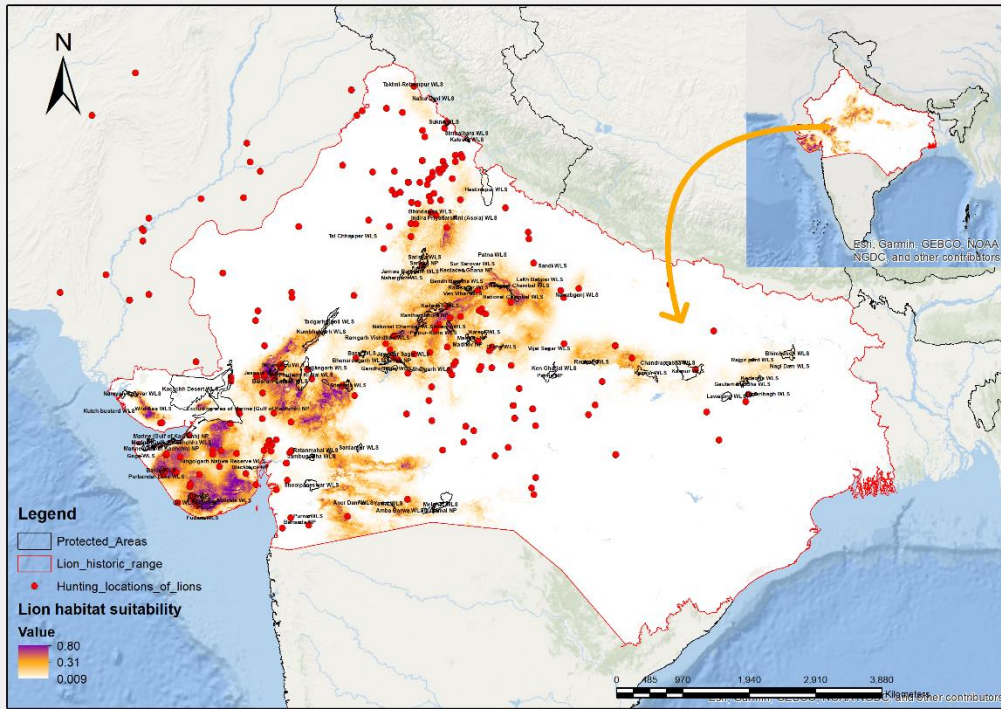


Figure 2.2: MaxEnt probability modeled from historical hunting records of lions and historical ecogeographical variables to predict current suitable habitats for Asiatic lions within the historical range in India using current ecogeographical covariates.

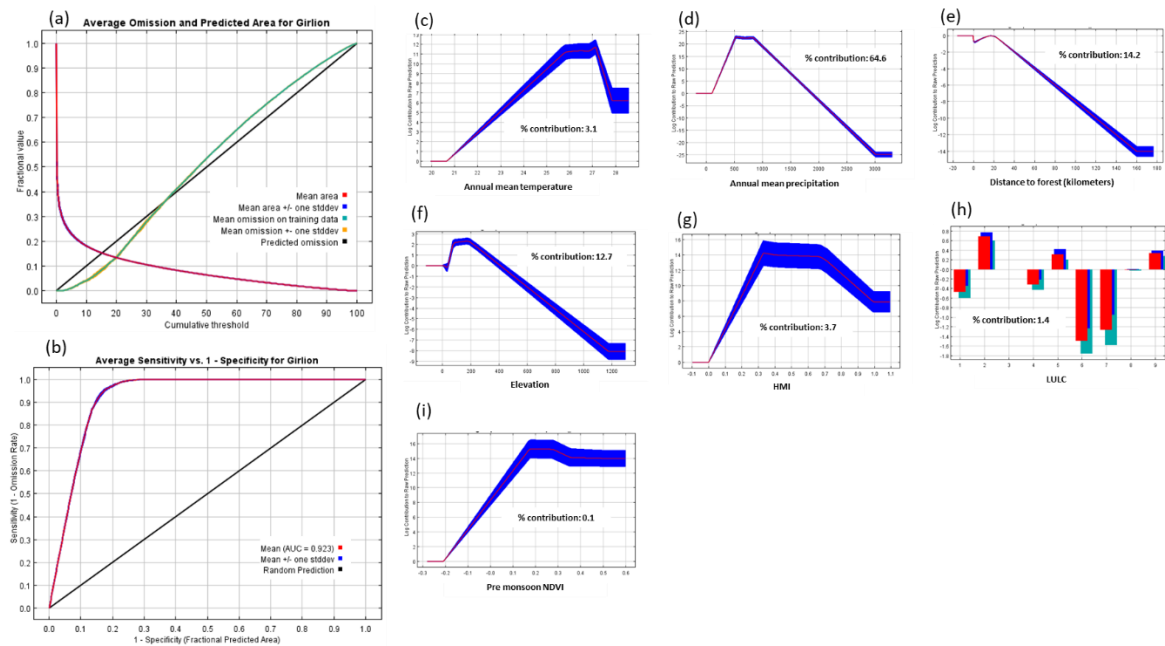


Figure 2.3: (a) Receiver operator curve for assessing MaxEnt model fit for habitat suitability of the Asiatic lions at a pan India level within the historic distribution range, (b) Omission/Commission analysis for model accuracy. Response curves obtained from the 100-bootstrap runs, where (c) annual mean temperature, (d) annual precipitation, (e) distance to forest in km, (f) elevation (g) human modification index, (h) land use land cover and (i) pre-monsoon NDVI (Normalized Difference Vegetation Index)

Here, PremonNDVI= Average NDVI (Normalise Difference in Vegetation Index) for the month of April, May and June; AMT= Average annual mean temperature; AMP= Average annual mean precipitation; DistForest= Euclidean distance to forest patches (In meters); Elevation= elevation (in meters); Rugg= Ruggedness; HMI= Human modification index; LULC= Land use land cover (classified as 1= water, 2= Evergreen Forest, 3. Flooded vegetation, 4= Agriculture, 5= shrub-scrub, 6= Built-up areas, 7= Bare ground, 8= Grasslands, 9= Deciduous forests); NL= Nightlight.

Table 2.1: Model selection table of MAXENT models used to predict the suitable habitats for lions within historic range of India using the current distribution of lions as presence and present day eco-geographic variables as predictors.

Here, PremonNDVI= Average NDVI (Normalise Difference in Vegetation Index) for the month of April, May and June; AMT= Average annual mean temperature; AMP= Average annual mean precipitation; DistForest= Euclidean distance to forest patches (In meters); Elevation= elevation (in meters); Rugg= Ruggedness; HMI= Human modification index; LULC= Land use land cover (classified as 1= water, 2= Evergreen Forest, 3. Flooded vegetation, 4= Agriculture, 5= shrub-scrub, 6= Built-up areas, 7= Bare ground, 8= Grasslands, 9= Deciduous forests); NL= Nightlight.

Sl No	Model	Training	Test	TSS	Kappa	AIC	AIC
	Lion	AUC	AUC			score	diff
<i>Univariate responses of habitat characteristics</i>							
1	PremonNDVI	0.61	0.61	0.22	0.16	55032.81	9420.81
2	AMT	0.73	0.73	0.39	0.26	53263.69	7651.69
3	AMP	0.91	0.91	0.74	0.42	49445.46	3833.46
4	DistForest	0.67	0.67	0.27	0.17	53817.06	8205.05
4	Elevation	0.76	0.76	0.42	0.26	53071.51	7459.50
5	Rugg	0.67	0.66	0.26	0.15	54149.85	8537.85
<i>Univariate responses of anthropogenic factors</i>							
6	HMI	0.68	0.68	0.30	0.19	53683.46	8071.46
7	LULC	0.61	0.60	0.21	0.12	54512.44	8900.44
8	NL	0.63	0.62	0.16	0.11	54224.52	8612.52
<i>Habitat mixed model</i>							
9	PremonNDVI+AMP+AMT+Elevation+ DistForest	0.92	0.92	0.90	0.46	46182.87	570.86
<i>Anthropogenic factors mixed model</i>							
10	HMI + LULC	0.69	0.70	0.35	0.24	53543.58	7931.57
<i>Mixed model of habitat+anthropogenic factors</i>							
11	PremonNDVI+AMP+AMT+DF+HMI	0.92	0.92	0.87	0.45	45736.55	124.55
12	PremonNDVI+AMP+AMT+DF+HMI+LULC	0.92	0.92	0.89	0.46	45612.00	0.00

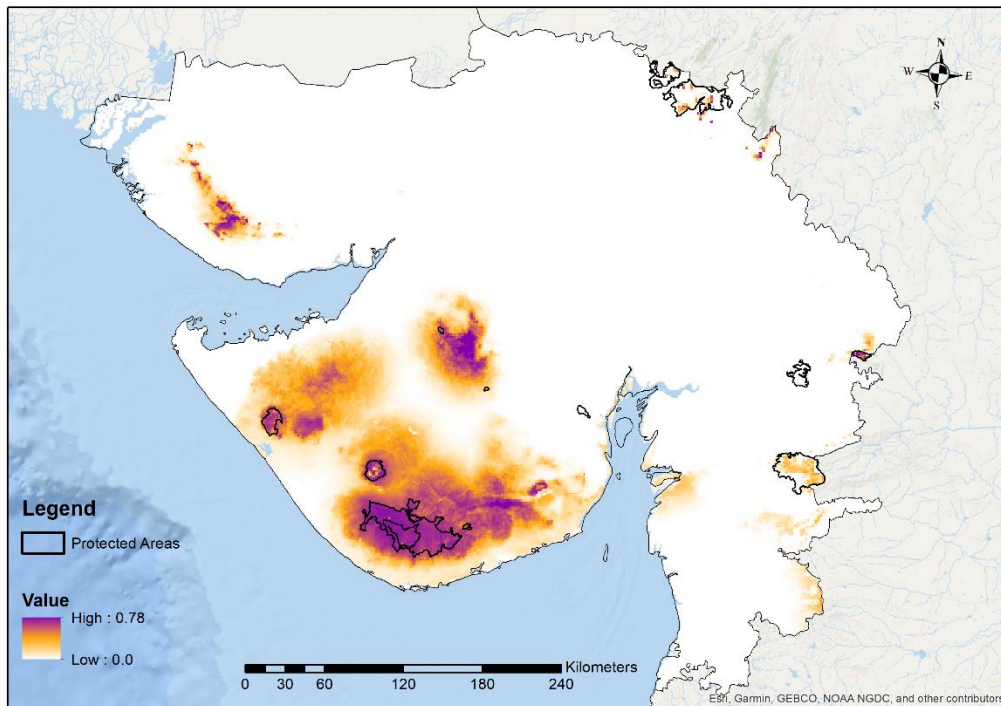


Figure 2.4: Suitable habitats for the Asiatic lions within Gujarat

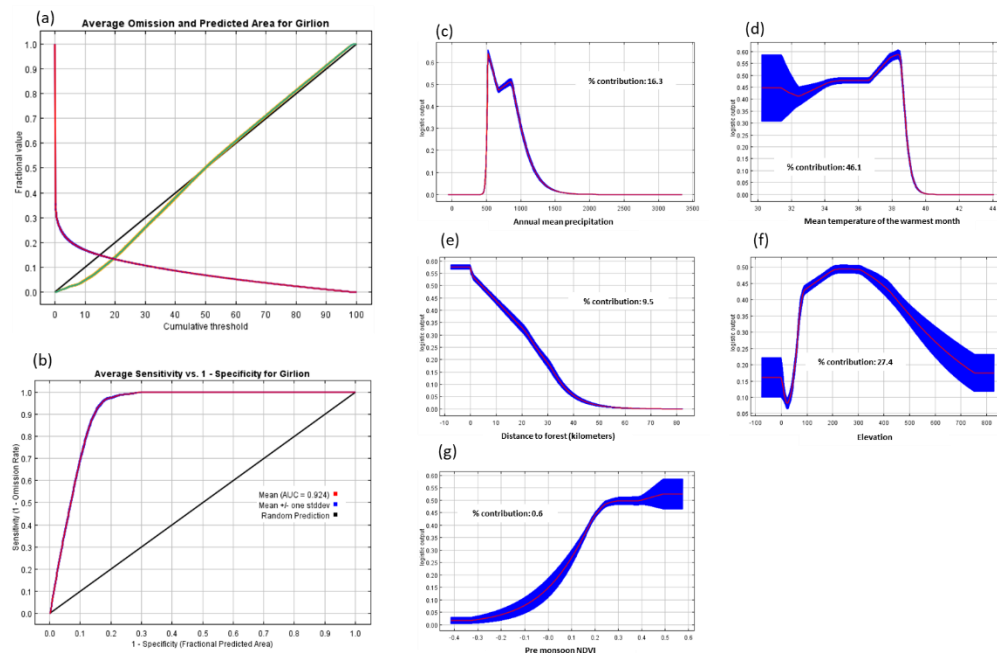


Figure 2.5: (a) Omission/Commission analysis for model accuracy, (b) Receiver operator curve for assessing MaxEnt model fit for habitat suitability of the Asiatic lions within Gujarat. Response curves of lion occurrence probability to covariates obtained from the 100-bootstrap runs, where (c) annual

mean precipitation, (d) mean temperature of the warmest month, (e) distance to forest in km, (f) elevation in m (g) pre-monsoon NDVI (Normalized Difference Vegetation Index).

Here, PremonNDVI= Average NDVI (Normalise Difference in Vegetation Index) for the month of April, May and June; AMT= Average annual mean temperature; AMP= Average annual mean precipitation; DistForest= Euclidean distance to forest patches (In meters); Elevation= elevation (in meters); Rugg= Ruggedness; HMI= Human modification index; LULC= Land use land cover (classified as 1= water, 2= Evergreen Forest, 3. Flooded vegetation, 4= Agriculture, 5= shrub-scrub, 6= Built-up areas, 7= Bare ground, 8= Grasslands, 9= Deciduous forests); NL= Nightlight.

Table 2.2: Model selection, and explanatory power of predictor variables used in MAXENT models to estimate suitable habitats for lions within the state of Gujarat.

SI No	Model	Training	Test	TSS	Kappa	AIC	AIC
	Lion	AUC	AUC			score	diff
<i>Univariate responses of habitat characteristics</i>							
1	PremonNDVI	0.68	0.68	0.30	0.20	45135.43	7462.10
2	AMT	0.79	0.79	0.38	0.21	44091.95	6418.62
3	MTWM	0.88	0.87	0.60	0.37	41883.86	4210.53
4	AMP	0.77	0.77	0.45	0.31	43971.96	6298.63
5	DistForest	0.73	0.72	0.35	0.19	44835.26	7161.93
6	Rugg	0.82	0.81	0.52	0.29	43396.83	5723.50
7	Elevation	0.83	0.83	0.52	0.33	43327.66	5654.33
<i>Univariate responses of anthropogenic factors</i>							
8	HMI	0.69	0.69	0.32	0.22	44871.49	7198.16
9	LULC	0.70	0.70	0.29	0.16	45142.66	7469.33
10	NL	0.59	0.59	0.16	0.11	45867.55	8194.22
<i>Habitat mixed model</i>							
11	AMP_ATWM_PreMonNDVI_Elevation_Difrst	0.92	0.92	0.87	0.45	37684.77	11.44
<i>Anthropogenic factors mixed model</i>							
12	DistFrst+ HMI	0.80	0.80	0.53	0.31	43436.70	5763.37
<i>Mixed model of habitat+anthropogenic factors</i>							
13	AMP_ATWM_PreMonNDVI_Elevation_Difrst_HMI	0.92	0.92	0.88	0.46	37673.33	0.00

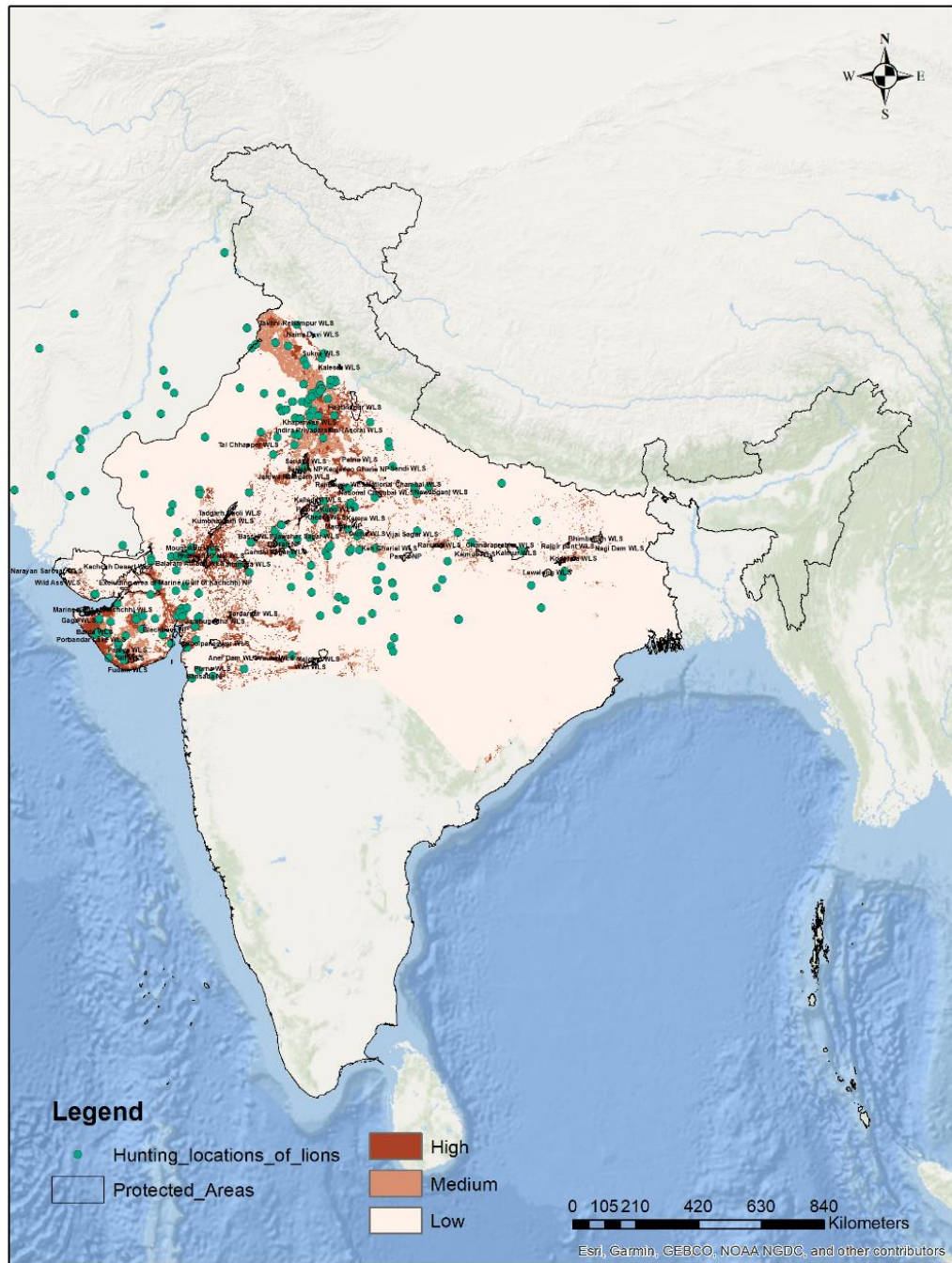


Figure 2.6: Historical model projected to current covariates for estimating suitable habitats for lions in recent times within the historic range.

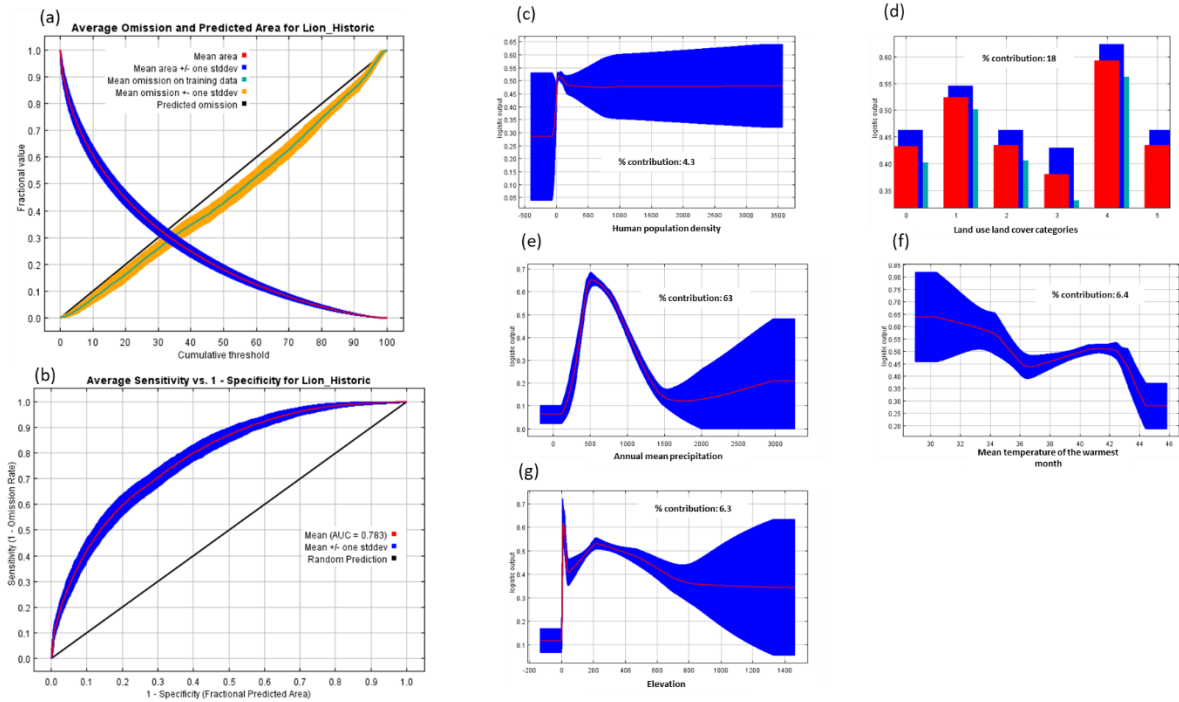


Figure 2.7: (a) Omission/Commission analysis for model accuracy, (b) Receiver operator curve for assessing MaxEnt model fit for habitat suitability of the Asiatic lions within the historic distribution range of India projected to present scenario based on hunting records and past eco-geographic predictor variables. Response curves obtained from the 100-bootstrap run, where (c) human population density, (d) land use land cover category, (e) annual mean precipitation, (f) mean temperature of the warmest month (g) elevation

Table 2.3: Model selection table of MAXENT models used to predict the suitable habitats for lions within the historic distribution range of India based on past hunting records and past eco-geographic variables that was projected to present day scenarios using current eco-geographic predictor variables.

Here, AMT= Average annual mean temperature; MTWM= Maximum temperature of the warmest month; MTWQ= Mean Temperature of the warmest quarter; AMP= Average annual mean precipitation; DistForest= Euclidean distance to forest patches (In meters); Elevation= elevation (in meters); Rugg= Ruggedness; HMI= Human modification index; LULC= Land use land cover (classified as 1= Cropland, 2= Forest, 3= Grassland, 4= Human habitations, 5= shrub-scrub, 6= Bare ground, 7= Water.

SI No	Model	Training	Test	TSS	Kappa	AIC	AIC
	(Lion Human)	AUC	AUC			score	diff
<i>Univariate responses of habitat characteristics</i>							
1	AMT	0.55	0.53	0.12	0.07	5814.84	161.62
2	MTWM	0.57	0.50	0.02	0.02	5786.45	133.23
3	MTWQ	0.59	0.62	0.30	0.18	5785.45	132.23
4	AMP	0.73	0.69	0.44	0.27	5680.98	27.76
5	Elevation	0.62	0.59	0.19	0.11	5783.99	130.77
<i>Univariate responses of anthropogenic factors</i>							
6	LULC	0.58	0.56	0.20	0.13	5764.81	111.59
7	HPopD	0.55	0.53	0.06	0.05	5830.12	176.90
<i>Habitat mixed model</i>							
8	AMP+ MTWM +Elevation	0.76	0.70	0.30	0.17	5696.36	43.14
<i>Anthropogenic factors mixed model</i>							
9	HPopD + LULC	0.66	0.62	0.26	0.15	5753.45	100.23
<i>Mixed model of habitat+anthropogenic factors</i>							
10	HPopD + LULC+ AMP+MTWM+Elevation	0.78	0.75	0.37	0.21	5653.22	0.00
11	HPopD+LULC+AMT+Elevation	0.70	0.69	0.11	0.07	5753.96	100.74
12	HPopD+LULC+AMP+Elevation	0.78	0.76	0.21	0.13	5679.42	26.20
13	HPopD+LULC+Elevation	0.68	0.68	0.20	0.12	5766.74	113.52

Discussions:

Identifying suitable habitats for the endangered Asiatic lions to create separate populations away from the existing lion populations in the Saurashtra region is important to safeguard the species from catastrophic events like disease and environmental hazards, that might threaten and possibly can cause extinction of the only surviving wild population of the Asiatic lions. In the year 2018 and 2019 lions suffered canine distemper virus outbreak that resulted in the deaths of many individuals and prides (Mourya et al., 2019). Therefore, I believe that this study is timely, important and would help the management authorities and the policy makers to decide about the future of the Asiatic lion conservation in India. Since Gujarat has been reluctant to give lions outside of the state (Kausik, 2016), I provide several habitat options within Gujarat as well as in entire India so that conservation requirement is not compromised. Although the lions in the Saurashtra region extensively use the human dominated landscapes outside of the Gir Protected areas, whether the same is possible in other part of the country is questionable. Nevertheless, these habitats will serve as important habitat corridors between the protected forests. In this study I have identified all the protected areas that were of sufficient size that could potentially hold a viable population of lions (that can hold about 16-20 individuals of breeding lionesses (Banerjee et al., 2010)) (Table S3).

All the three models {i.e. (i) pan India assessment of suitable habitats using current occurrence data from Saurashtra (model 1), (ii) assessment of suitable habitats within Gujarat using current occurrence locations of lions from the Saurashtra region (model 2) and (iii) assessment of suitable habitats using historic hunting locations (model 3)} have similar prediction of the suitable habitats available within Gujarat. Based on the estimated threshold value of 0.25 of the best model with 100 bootstrap runs, I considered areas having equal or higher values of predicted probability as suitable for lions for model 1 and identified the protected area that have suitable habitats for the Asiatic lions.

In the north all the three models have predicted Jesore Sloth Bear Sanctuary and Balaram Ambaji wildlife sanctuary to have suitable habitats for the Asiatic lions. However, it would be difficult for lions to naturally colonise these areas since there are no stepping stone habitats patches or corridors that could connect these areas with the existing population of lions in Saurashtra. In the hunting records these areas were often mentioned to have good lions population and several documentation of lions hunts (Blanford, 1888; Divyabhanusinh, 2005, Kinner 1920). Towards the eastern border of Gujarat State the Shoopaneswar Wildlife Sanctuary and Ratanmahal Wildlife Sanctuary in Vasdodara district were observed to have suitable habitats for the Asiatic lions. There are also records of lions being seen and hunted in the adjacent areas to these protected forests in the past (Burton 1933, Forbes 1813).

One of the proposed lion reintroduction sites the Barda Wildlife Sanctuary along with the Alech hills and adjoining forested areas in the Jamnagar district were observed to be highly suitable for the Asiatic lions. The Barda wildlife Sanctuary was surveyed for the potential of lion reintroduction by Wildlife Institute of India and a report had been submitted to the Gujarat Forest Department. Where we have clearly explained the challenges and needed management interventions to make it suitable for the reintroduction of lions. In that report all the socio-cultural and eco-geographical aspects that need to be addressed before any reintroduction have been discussed thoroughly (Jhala et al., 2014). Excluding the difficult terrains (i.e. slopes more than 30⁰) it was estimated that about 175 km² of potential habitats could be available for lions in Barda that can hold upto 26 lions (Jhala et al., 2014). In this analysis I found that about 167 km² area within Barda Wildlife Sanctuary have suitable habitats for lions (Table S3).

The huge extent of grassland habitats (*Vidis*) which are under the revenue department and some under the private ownership in the Chotila taluka of Surendra Nagar district were also found to be suitable for the Asiatic lions. In the year 2019 two subadult male lions also visited this area (<https://timesofindia.indiatimes.com/city/ahmedabad/pride-of-gujarat->

hunting-for-new-habitats-2-lions-seen-near-chotila/articleshow/7213489) and previously there are many instances of lions visiting and being resident in the Hingolgarh Wildlife Sanctuary (about 7 km²) that have good prey base and are connected to these grassland habitats. A lioness was known to reach Hingolgarh and Umeth grasslands in 2015 and there are many instances of small groups of lions visiting Kunal and catchment area of Kalubhar River in 2015, that created the juncture of Amreli, Botad and Rajkot districts (Singh, 2017). The grassland areas of Chotila extends upto the the Rampara Wildlife Sanctuary in the Morbi district and Hingolgarh Wildlife Sanctuary in the Jasdan Taluka, but there are many major and minor road networks that causes hindrance in free movements of wild animals. Also, there is a new airport coming up in Hisar and the areas towards the north of the Rajkot Ahmedabad highway upto the Rampara Vidi is highly industrialized. Since lions have already been using this landscape and existing corridors are already functional, therefore if lions were to live and use this landscape, appropriate mitigation measures need to be incorporated in the planning phase of such development projects.

The forest patches along river Shatrunjay and Palitana hill ranges in the districts of Amreli and Bhavnagar have been already colonized by lions and these habitat patches are the lifeline of lions in the human dominated landscape. According to the official census these areas hold about 80 lions (Gujarat Forest Department, 2020). These habitats are mostly *Prosopis juliflora* thickets along the river network of Shetrunjay and its tributaries, that have both private and government ownership. Lions also use the cattle grazing areas (Gausar) owned by the communities to take refuge and breed. Besides the protected grassland habitats in the Savarkundla taluka serves as an important habitat for the lions to thrive in the human dominated landscape. These areas are rich in nilgai and wild pig population. The landscape also holds a significant amount of unowned cattle population that serves as important food source for the lions in such areas. As well as lions utilize dead livestock that are being dumped outside the

village peripheries and know to often visit such areas at night and take refuse in small patches of forested habitats among the agricultural field during the day (Banerjee, 2012).

The coastal forest patches of Mangrol, Veraval, Sutrapada, Una, Rajula-Jafrabad and Mahuva were also found to be suitable to Asiatic lions and lions have already colonized these forest patches in the last decade. The official census reported to have > 50 lions in these areas, as well as about 37 lions in the coast of Bhavnagar district (Gujarat Forest Department, 2020). These coastal areas are also having high density of human settlements and highly industrialized. Due to rapid urbanization and land use changes these suitable habitat patches however is vulnerable to anthropogenic alteration, therefore management authorities should emphasize in protecting these habitats for the long-term conservation of Asiatic lions in the human dominated landscape of Saurashtra.

At a pan-India level, there are 3 protected areas in Gujarat (other than the Gir protected forests), 12 in the state of Rajasthan, 3 in Madhya Pradesh, and one in the state of Uttar Pradesh that were observed to have suitable habitats for the Asiatic lions. However, the level of protection, their size, status of prey and competing predators (such as Tigers) and human influence and acceptance of local communities need to be considered before planning any translocations (Table S3). Among which the complex of Kumbhalgadh Wildlife Sanctuaries; the complex of Darah/Mukundra Hills Tiger Reserve, Gandhisagar Wildlife Sanctuaries (Madhya Pradesh), Bhensrodgarh WLS and Jawahar Sagar WLS; the Kuno Wildlife Sanctuary (Madhya Pradesh), the Madhav National Park (Madhya Pradesh), the Sitamata Wildlife Sanctuary (Rajasthan), the Jessore-Balaram Ambaji wildlife sanctuary complex (Gujarat) and the Barda Wildlife Sanctuary complex have been already proposed for the reintroduction of the Asiatic lions.

Besides the peril of having all the eggs in one basket, lions will soon reach biological and social carrying capacity in Saurashtra. Surplus lions will become problematic to manage, as it is evident that the current coexistence between the local communities and the lions are at a very delicate balance and the intensity of conflict with lions in the landscape is increasing over the years with increasing number and extent of lions in the landscape (Chapter 4 and 5). With the current rate of their population increase (~6% per annum (Ram et al., 2023)) very soon surplus populations will either need to be translocated or contracepted. My analysis will assist the Government of Gujarat and Government of India in planning and prioritizing sites for the translocation and reintroduction of Asiatic lions that will be required for their conservation and management.

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Appendix:

Table S1: List of hunting records of Asiatic lions in India with description of areas and source of the information.

Sl No	Time Period	Current Locality	Number	Reference
1	2 nd May 1942	40 miles North of west of Dizful	1	JBNHS, Vol 44, p 467
2	1857 or 1857	Dumoh district, MP	1	
3	1837	Saugardh, MP	1	Dr. Spry, Modern India (book)
4	1834	Rhylee, Damoh District, MP	1	Dr. Spry, Modern India (book)
5	1856	Saugardh, MP		Dr. Spry, Modern India (book)
6	1857 to 1864	Seonee, MP		Dr. Spry, Modern India (book)
7	1847	Dumoh district, MP	1	Sterndale 1884, Natural history of Indian mammals
8	1837 (?)	Hisar, Haryana		Modern India, by Dr, Spry 1837
9	Mid 1800	Haryana		Times of India, Handbook of Hindustan, . R. ABERIGH-MACKAY, 1875
10	Mid 1800	Gwalior		Times of India, Handbook of Hindustan, . R. ABERIGH-MACKAY, 1875
11	Mid 1800	Sagar		Times of India, Handbook of Hindustan, . R. ABERIGH-MACKAY, 1875
12	1855	About 7-8 miles from Ilav (Elav) towards Bharuch, bamboo mixed forest.	1	Perils and pleasure of a hunters life
13	1855	Near Bharuch towards Baroda.	1	Perils and pleasure of a hunters life
14	1830	Kuree, 1830 April	4	The oriental Sporting Magazine, Vol 2, 1873

15	Mid 1800	Lahore, Goojeranw ala, Gujarat, Bhimbur		Newall 1887, Highlands of India
16	1862	Five miles from Gwalior	5	Newall 1887, Highlands of India, page 416
17	Ancient note			Newall 1887, Highlands of India, page 431
18	Mid 1800	Near Rajkot	1	Newall 1887, Highlands of India, page 445
19	Mid 1800	Gir		Newall 1887, Highlands of India, page 445
20	1887	Kutch		Newall 1887, Highlands of India, page 445
21	Mid 1800	Kathiawar, Cheetah in Manikwara	80	Newall 1887, Highlands of India, page 445
22	Mid 1803	Near Rajkot	1	Newall 1887, Highlands of India, page 446
23	1887 (?)	Bundelkha nd, Jhansi and Gwalior		
24	1781	Ghod, North of Persia, where lion was known to be abundant		Oriental field sports, Vol2, Thomas Williamson 1808
25	1770-1844	North India, from Madras		Young cadet, Mrs Hofland 1831
26	1824	Oudh (Awadh)		Seeley 1826, Wonders of Elora
27	1826	Oudh (Awadh)& Rohilcund		Through the upper provinces of India, Rginal Heber 1826
28	1826	Saharanpur, Loodhiana, West of Ganges towards North of Rohilcund, Moradbad, Rampoor		Through the upper provinces of India, Rginal Heber 1826
29	Late 18th century	Rohtas & surroundin g districts, Bihar	—	Pennant 1798, pp. 185–186

30	Early 19th century	Dinajpur district, B'desh	–	Thornton 1854a, p. 173
31	Early 19th century	Dinajpur district, B'desh	1	Hamilton 1828, p. 515
32	Prior to 1810*	Patna district, Bihar*	–	Divyabhanusinh 2008, p. 118
33	Early 19th century*	Ramgarh, Hazaribagh & surrounding districts*	–	Thornton 1854b, pp. 279–281
34	Early 19th century*	Ranchi, Gumla & surrounding districts*	–	Bradshaw 1864b, pp. 286–287
35	1814	Khundra village, Garwah district, Jharkhand	–	Ball 1881, pp. 3–4
36	1814	Patna district, Bihar	1	Ball 1886, pp. 723–758
37	1823	Jharkhand*	4	Anon. 1829, pp. 7–8
38	1833	Calcutta district, West Bengal*	1	Anon. 1833, p. 420
39	1834	Bihar	–	Joslin 1973, pp. 242–249
40	Before 1845	Jharkhand*	1	Anon. 1845a, pp. 16–18
41	Before 1845	Jharkhand*	1	Anon. 1845a, pp. 16–18
42	Before 1845	Jharkhand*	5	Anon. 1845a, pp. 16–18
43	Before 1845	Jharkhand*	12	Anon. 1845a, pp. 16–18
44	Late 18th	Bhauwapar, Gorakhpur district	1	Martin 1838, p. 501

45	Early 19th century	Bareilly district, U.P.	–	Bradshaw 1864a, pp. 145–146.
46	Prior to 1810*	Kanpur district, U.P.*	1	Divyabhanusinh 2008, p. 118
47	1824	Moradabad district, U.P.	–	Heber 1829, pp. 380–381
48	1824	Rampur district, U.P.	–	Heber 1829, pp. 380–381
49	1824	Saharanpur district, U.P.	–	Heber 1829, pp. 380–381
50	1825	Awadh region (Lucknow, Ayodhya, Kanpur, Allahabad & Mirzapur divns), U.P.	–	Seeley 1825, p. 401
51	1825–40	Etawah district, U.P.*	–	Lassen 1840, p. 660.
52	1827	Meerut district, U.P.	9	Hayward 1864, pp. 263–265
53	1828	Meerut district, U.P.	–	Archer 1833, p. 375
54	1830s (before 1833)*	Fatehgarh, Farrukhabad and surrounding districts*	1	Quondam 1833, pp. 557–559
55	1833	Saharanpur district, U.P.	10	Quondam 1833, pp. 557–559
56	1836	Rampur district, U.P.	1	Anon. 1836, p. 407
57	1850s*	Banda district, U.P.	–	Thornhill 1899, p. 310

58	1850	Jhansi and surrounding districts, U.P.	5	Anon. 1850, p. 482
59	1851	Jhansi district, U.P.	2	Zoophilus 1857, pp. 1–7
60	1853	Prayagraj district, U.P.	1	Sinha 1990, p. 10
61	1860–63*	Shivrajpur, Fatehpur district, U.P.	2	Blanford 1868, pp. 189–200
62	1864	Shivrajpur, Fatehpur district, U.P.	1	Blanford 1868, pp. 189–200
63	1864*	Bara village, Prayagraj district, U.P.	1	Balfour 1885, pp. 719–720.
64	1865	Ashoknagar & Lalitpur districts, U.P.*	–	Junior 1865, pp. 558–559
65	Late 19th century*	Prayagraj district, U.P.	1	Divyabhanusinh 2008, p. 229.
66	1867	Jhansi & surrounding districts*	–	Joslin 1973, pp. 242–249.
67	1871	Lalitpur district, U.P.	–	Joslin 1973, pp. 242–249
68	Mid-18th century	Punjab province, Pak; Punjab & Haryana states	–	Forbes 1813, p. 90
69	Late 18th century	Derawar, Bahawalpur district, Punjab province, Pak.	–	Roberts 1997, p. 222

70	Late 18th century	Bahawalpur, Bahawalnagar, and Rahim Yar Khan districts, Punjab, Pak	–	Farooq et al. 2005
71	Late 18th to Early 19th century	Ferozpur district, Punjab, Pak	–	Anon. 1845b, p. 205
72	Late 18th to Early 19th century	Kot Sabzal, Rahim Yar Khan district, Punjab province, Pak	–	Anon. 1845b, p. 205
73	Late 18th to Early 19th century*	Moga district, Punjab	–	Schnitzler & Hermann 2019
74	Late 18th to Early 19th century	Rohri, Sukkur district, Sindh, Pak	–	Anon. 1845b, p. 205
75	Late 18th to Early 19th century	Sakhar, Killa Saifullah district, Balochistan province, Pak	–	Hughes 1874, p. 667
76	Late 18th to Early 19th century	Shikarpur district, Sindh province, Pak	–	Hughes 1874, p. 667
77	Late 18th to Early 19th century*	Sanghar district, Sindh	–	Schnitzler & Hermann 2019
78	Late 18th to Early 19th century	Sukkur district, Sindh province, Pak	–	Anon. 1845b, p. 205

79	Early 19th century	Hoshiarpur district, Punjab	–	Newall 1887, p. 253
80	Early 19th century	Sirhind, Fatehgarh Sahib district, Punjab	–	Hume 1854, p. 192
81	1800	Rahim Yar Khan, Bawahalpur, & Bawahalnagar districts, Punjab province, Pak*	–	Mitra 2005, pp. 46–47
82	1810	Kot Diji, Khairpur district, Sindh province, Pak	1	Pottinger 1816, p. 357
83	1813	Ludhiana & surrounding district, Punjab	1	Kazmi 2021; Anon. 1813
84	Before 1816	Las Bela district, Balochistan province, Pak*	–	Pottinger 1816, p. 22
85	1820	Patiala and surrounding districts, Punjab	–	Lloyd 1840, pp. 71–72
86	1824	Ludhiana district, Punjab	–	Heber 1829, pp. 380–381
87	1828	Manchar lake, Dadu district, Sindh province, Pak	–	Pottinger 1816, p. 357

88	1830	Kurree, Tharparkar district, Sindh province, Pak	4	S.E.R. 1830, pp. 5–6
89	1830s	Lahore district, Punjab province, Pak	–	Divyabhanusinh 2008, p. 122
90	1830s*	Punjab & Sindh, Provinces, Pak*	–	Lassen 1840, p. 660
91	1834	Punjab	–	Joslin 1973, pp. 242–249
92	1835	Lahore district, Punjab province, Pak	–	Lowrie 1842, p. 153
93	1836	Multan district, Punjab province, Pak	3	Vigne 1840, pp. 13–14
94	1842	Lodhran district, Punjab province, Pak	–	Orlich and Lloyd 1845, p. 144.
95	1842	Mamdot, Punjab, India	–	Orlich and Lloyd 1845, p. 154–155.
96	1842	Sindh	1	Rangarajan 2013.
97	1845	Sindh province, Pak	1	Joslin 1973, pp. 242–249
98	1848	Sindh province, Pak	1	Balfour 1858, pp. 218–222
99	Late 19th century	Sirohi, Tharparkar district, Sindh, Pak.	4	Watson 1899, pp. 97–99
100	Late 18th century	Alnia, Kota district	–	Divyabhanusinh 2008, p. 108–109

101	Late 18th to Early 19th century*	Bagpura, Udaipur district	–	Schnitzler and Hermann 2019
102	Early 19th century*	Regions of Barmer, Jodhpur & Nagaur*	–	Boileau 1837, p. 170
103	Early 19th century*	Bikaner, Bikaner district	–	Tod 1832, p. 204
104	Early 19th century*	Bundi & Kota districts	–	Tod 1832, p. 468
105	Early 19th century*	Bundi, Kota and surrounding districts*	100	Tod 1832, p. 503
106	Early 19th century*	Chittaur fort, Chittaurgarh district	–	Tod 1832, p. 757
107	Early 19th century*	Drainage of river Luni*	–	Boileau 1837, p. 120
108	Early 19th century*	Jaipur & surrounding districts*	–	Irvine 1841, p. 24
109	Early 19th century*	Jodhpur district	–	Pease 1913, p. 110
110	Early 19th century*	Karnagarh, Pratapgarh district	–	Cuvier 1827, pp. 364–365
111	Early 19th century*	Kota district	–	Pease 1913, p. 110
112	Early 19th century*	Lalpur, Jhunjhunu district	–	Pease 1913, p. 110
113	Early 19th century*	Pratapgarh district	3	Cuvier 1827, pp. 364–365
114	Early 19th century*	Udaipur district	–	Pease 1913, p. 110
115	Early 19th century*	Sirohi district	–	Pease 1913, p. 110
116	Early 19th century*	Southwestern	–	Irvine 1841, pp. 19–20

		Rajasthan *		
117	Early 19th century	Hanuman garh & Sri Ganganag ar districts*	1	Archer 1833, p. 375
118	Early 19th century*	Western borders of Thar desert*	–	Tod 1884, p. 365
119	1820s	Bikaner and surroundin g districts	4	Medwin 1834, pp. 259–264
120	1820s*	Churu and Hanuman garh districts	–	Royle 1839, p. 6
121	1825–40	Karauli district*	–	Lassen 1840, p. 660.
122	1828	Churu and Hanuman garh districts	–	Archer 1833, p. 375
123	1828–33	Eastern Rajasthan	2	Collector 1832, p. 331–332
124	1833	Eastern Rajasthan	6	Clarke, 1833
125	1834	Sekhawati *	1	Burton 1833, pp. 268–281
126	Mid-19th century*	Ajmer and surroundin g districts*	–	Late Customs Officer 1874, p. 95
127	Mid-19th century*	Region surroundin g Barmer and Luni	–	Rice 1884, p. 218
128	Mid-19th century*	Jaisalmer and surroundin g districts	–	Thornton 1854a, p. 276
129	Mid-19th century*	Drainage of river Luni*	–	Thornton 1858, p. 456
130	Mid-19th century*	Mukundar a hills	–	Hunter 1886, pp. 303–304

131	Mid-19th century*	Sirohi district	1	Saltoun 1883, pp. 226–229
132	1840s	Eastern Rajasthan	–	Torrens 1851, p. 37
133	1847	Damoh district	1	Burton 1933, pp. 268–281
134	1847	Kota district	–	Joslin 1973, pp. 242–249
135	1847	Shahabad, Baran district	1	Zoophilus 1857, pp. 1–7
136	1860s*	Kota district	–	Blanford 1888–91, pp. 56–58
137	1860s*	Sirohi district	–	Blanford 1888–91, pp. 56–58
138	1860s	Western Madhya Pradesh	–	J.B. 1862, p. 27
139	1862	Borders of eastern Rajasthan or Madhya Pradesh	2	J.B. 1862, p. 27
140	1863	Kota district	–	Joslin 1973, pp. 242–249
141	1866	Kota and surrounding districts*	10	Divyabhanusinh 2008, p. 122
142	1866	Kota and surrounding districts*	9	Blanford 1868, pp. 189–200
143	1866	Kota and surrounding districts*	9	Joslin 1973, pp. 242–249
144	1866	Kota and surrounding districts*	10	Blanford 1868, pp. 189–200
145	Late 19th century*	Sirohi district	1	Eastwick 1883, p. 137
146	1867	Baran district*	–	King 1868, pp. 198–200
147	1867	Bundi and surrounding districts*	–	King 1868, pp. 198–200

148	1867	Gole village, Barmer district	4	King 1868, pp. 198–200
149	1867	Baran, Jhalawar, Kota, Bundi and Chittorgarh districts*	–	King 1868, pp. 198–200
150	1867	Jodhpur and surrounding districts*	–	King 1868, pp. 198–200
151	1867	Kota district	–	Joslin 1973, pp. 242–249
152	1867	Kota and surrounding districts*	–	King 1868, pp. 198–200
153	1867	Sirohi district	1	King 1868, pp. 198–200
154	1867	Sirohi and surrounding districts	–	Joslin 1973, pp. 242–249
155	1872	Jalore district	4	Kinnear 1920, pp. 33–39
156	1872	Sirohi district	1	Kinnear 1920, pp. 33–39
157	1873	Jodhpur, Jodhpur district	1	Thompson 1932, p. 127
158	Early 1880s*	Sirohi district	–	Blanford 1888–91, pp. 56–58
159	Early 1880s*	Udaipur district	–	Blanford 1888–91, pp. 56–58
160	1891	Jodhpur district	–	Joslin 1973, pp. 242–249
161	1891	Sirohi district	–	Joslin 1973, pp. 242–249
162	1891	Udaipur district	–	Joslin 1973, pp. 242–249
163	Late 18th century*	Gwalior & surrounding districts	–	Pennant 1798, pp. 185–186

164	Late 18th to Early 19th century*	Chichli, Sehore district	–	Schnitzler & Hermann 2019
165	19th century*	Northwestern Madhya Pradesh*	1	Divyabhanusinh 2008, p. 228
166	Early 19th century	Bhopal, Raisen & Sihore districts*	–	Sherer 1824, pp. 305–307
167	Early 19th century	Bhopal, Raisen & Sihore districts*	1	Sherer 1824, pp. 305–307
168	Early 19th century	Northwestern Madhya Pradesh*	26	Fenton 1924
169	Early 19th century*	Guna district	–	Pease 1913, p. 110
170	Early 19th century	Gwalior district	–	Egerton 1852, pp. 135–136
171	Early 19th century*	Gwalior district	–	Pease 1913, p. 110
172	Early 19th century*	Sagar district	1	Burton 1933, pp. 268–281
173	1807	Chanderi, Ashoknagar district	–	Tod 1829, p. 138
174	Before 1821	Northwestern Madhya Pradesh*	3	Griffith 1821, pp. 28–29
175	1827	Baghwara, Sagar District*	1	Jami Jehan Numa 1827
176	1832	Guna & Sagar districts*	26	Fenton 1909, pp. 4–15
177	1825–40	Bhind district*	–	Lassen 1840, p. 660
178	1825–40	Dholpur district	–	Lassen 1840, p. 660
179	1825–40	Sheopur district*	–	Lassen 1840, p. 660
180	1834	Tendukheda,	1	Burton 1933, pp. 268–281

		Damoh district		
181	1834	Rehli, Sagar district	1	Sterndale 1884, pp. 159–161
182	Mid-19th century*	Agar Malwa, Guna & Rajgarh districts*	350	Anon. 1868, p. 774
183	Mid-19th century*	Guna district	2	Paris Universal Exhibition of 1867, pp. 297
184	Mid-19th century	Gwalior district	2	Jerdon 1867, pp. 91–92
185	Mid-19th century	Guna district	–	Thapar et al. 2013, p. 144
186	Mid-19th century*	Northwestern Madhya Pradesh*	1	Paris Universal Exhibition of 1867, pp. 292
187	Mid-19th century	Amarkantak, Madhya Pradesh	–	Buckle & Rousselet 1876, p. 393
188	Mid-19th century	Piparwani, Narsinghpur district	–	Thornton 1858, p. 970
189	century	Rewa district*	1	Burton 1933, pp. 268–281
190	Mid-19th	Valley of river Sone,	–	Newall 1887, pp. 455–450
191	1837	Sagar district	1	Sterndale 1884, pp. 159–161
192	1837	Sagar district	1	Joslin 1973, pp. 242–249
193	1837	Sagar district	1	Sterndale 1884, pp. 159–161
194	1840s	Kala Bag, Shivpuri & Ashoknagar districts	–	Sleeman 1849, p. 249
195	1845	Gwalior district	1	Joslin 1973, pp. 242–245
196	1847–48	Damoh district	1	Sterndale 1884, pp. 159–161

197	1847	Rehli, Sagar district	1	Burton 1933
198	1847–48	Rehli, Sagar district	1	Joslin 1973, pp. 242–249
199	1847	Umri, Guna district	1	Zoophilus 1857, pp. 1–7
200	1851	Narwar, Raisen district	2	A Looker On, 1851, pp. 172-173
201	1851	Sagar district	1	Forsyth 1871, p. 28
202	1851	Sagar district	1	Balfour 1885, pp. 719–720
203	1851	Sagar district	1	Joslin 1973, pp. 242–249
204	1856	Sagar district	–	Sterndale 1884, pp. 159–161
205	1857–58	Northwest ern Madhya Pradesh*	250	Kinnear 1920, pp. 33–39
206	1859	Guna	6	Lyttelton 2017
207	Late 1850s*	Sagar district	2	Jerdon 1864, pp. 91–92
208	1860s	Guna district	2	Thapar et al. 2013, p. 144
209	1862	Guna district	6	Thompson 1932, p. 127
210	1862	Gwalior district	5	Newall 1887, p. 416
211	1863	Patalgarh, Sheopur district	8	Kinnear 1920, pp. 33–39
212	1864	Sagar district	1	Joslin 1973, pp. 242–249
213	1865	Ashoknag ar & Lalitpur districts*	–	Junior 1865, pp. 558–559
214	1865	Gwalior district	3	Kinnear 1920, pp. 33–39
215	1865	Gwalior district	3	Junior 1865, pp. 558–559
216	1865	Gwalior district	3	Joslin 1973, pp. 242–249

217	Late 19th century	Lalitpur & Tikamgarh districts	–	Knowles 1889, p. 226
218	Mid-19th century	Ratanpur, Sagar district	–	Rangarajan 1996, p. 153
219	Mid-19th century	Shahgarh, Sagar district	–	Rangarajan 1996, p. 153
220	1860–62	Northwestern Madhya Pradesh*	11	Anon. 1863, p. 765
221	1862	Guna district	8	Anon. 1862, p. 579
222	1867	Guna district	1	King 1868, pp. 198–200
223	1867	Guna district	7	King 1868, pp. 198–200
224	1867	Guna district	1	King 1868, pp. 198–200
225	1867	Guna district	3	Joslin 1973, pp. 242–249
226	1867	Guna district	3	Kinnear 1920, pp. 33–39
227	1867	Gwalior district	–	Joslin 1973, pp. 242–249
228	1867	Sheopur district	2	Thackeray 1916, p. 169
229	1867	Sheopur & Shivpuri districts*	3	King 1868, pp. 198–200
230	1872	Guna district	1	Kinnear 1920, pp. 33–39
231	1872	Guna district	2	Gerard 1903, pp. 133–134
232	1873	Guna district	1	Blanford 1888–91, pp. 56–58
233	1873	Guna district	1	Kinnear 1920, pp. 33–39
234	1873	Guna and surrounding districts*	1	Joslin 1973, pp. 242–249
235	1884	Northwestern Madhya Pradesh*	1	Burton 1933, pp. 268–281

236	Late 18th century	Nardak, Karnal & Kaithal districts		Gazetteer of Karnal 1883, p. 13
237	Late 18th century	Bhiwani & Hisar districts, Haryana		Archer 1833, p. 374.
238	Early 19th century*	Assandh, Karnal district, Haryana		Long 1839, pp. 28–36
239	Early 19th century*	Balsaman d, Hisar district, Haryana	–	Hamilton 1820, p. 525
240	Early 19th century	Delhi	–	Bengal Civilian, 1843, p. 145
241	Early 19th century	Delhi & surrounding areas	–	Shore 1837, p. 69
242	Early 19th century	Fatehabad, Fatehabad, Haryana	–	Hamilton 1820, p. 525
243	Early 19th century	Haryana	–	Elphinstone 1815, p. 4
244	Early 19th century	Haryana	–	Burton 1933, pp. 268–281
245	Early 19th century	Hisar district, Haryana	13	Bengal Civilian 1844, pp. 169–174
246	Early 19th century	Hisar district, Haryana	13	Bengal Civilian 1844, pp. 169–174
247	Early 19th century	Hisar & surrounding	–	Bengal Civilian 1844, pp. 169–174
248	Early 19th century	Jhajjar district, Haryana*	1	Chaudhuri et al. 2018
249	Early 19th century	Jind district, Haryana	1	O’Flanagan 1873, pp. 160–161
250	Early 19th century	Karnal district, Haryana	1	Shoberl 1834, pp. 99–100
251	Early 19th century	B/W Nilokheri	–	Gazetteer of Karnal, 1883, pp. 12–14

		& Haryana*		
252	Early 19th century	Panipat district,	–	Thornton 1854b, pp. 76–80
253	Early 19th century	Pewar village, Jheend district, Haryana	1	Kazmi 2021; Fogarty 1867
254	1809	Delhi	2	Kazmi 2021
255	1810	Bhiwani & Hisar districts, Haryana	2	Anon. 1810, pp. 1376–1377
256	1810	Hisar district, Haryana	1	Anon. 1810, pp. 1376–1377
257	1810–14*	Haryana & surrounding areas*	–	Anon. 1816b, pp. 172–186
258	1810–14*	Karnal district, Haryana	1	Anon. 1816b, pp. 172–186
259	1811	Bhiwani & Hisar districts, Haryana	43	Anon. 1813
260	1812	Bhiwani district, Haryana	6	Nugent 1839, pp. 8–32
261	1812	Bhiwani & Hisar districts, Haryana	1	Nugent 1839, pp. 8–32
262	1812	Jind district, Haryana	7	Nugent 1839, pp. 8–32
263	1812	Jind district, Haryana	8	Nugent 1839, pp. 8–32
264	1812	Jind district, Haryana	1	Nugent 1839, pp. 8–32
265	1812	Kalwa village, Jind district, Haryana	4	Nugent 1839, pp. 8–32

266	1812	Munak, Karnal district, Haryana	–	Nugent 1839, pp. 8–32
267	1812	Safidon, Jind district, Haryana	1	Nugent 1839, pp. 8–32
268	1812	Safidon, Jind district, Haryana	1	Nugent 1839, pp. 8–32
269	1814	Rohtak, Rohtak district, Haryana	1	Ultimo 1814, p. 352
270	1814	Rohtak, Rohtak district, Haryana	1	Williams 1814; Kazmi 2021
271	1814	Rohtak, Rohtak district, Haryana	5	Williams 1814; Kazmi 2021
272	1814	Rohtak, Rohtak district, Haryana	4	Williams 1814; Kazmi 2021
273	1815	Bahadurgh, Jhajjar Haryana	–	Marchioness of Bute 1858; Kazmi 2021
274	1815	Dholera, Mahendragarh Haryana	2	Marchioness of Bute 1858; Kazmi 2021
275	1815	Bhiwani district, Haryana	2	Marchioness of Bute 1858, pp. 301–310
276	1815	Bhiwani & Hisar	9	Moira 1815
277	1815	Jind district, Haryana	1	Marchioness of Bute, 1858, pp. 289.
278	1818	Sirsa district, Haryana	–	Anon. 1818, p. 552
279	1818	Sanghi, Rohtak district, Haryana	3	Egan 1822, pp. 36–42

280	1819–25	Pinjore, Panchkula, Haryana	–	Moorcroft & Trebeck, 1841, p. 35
281	1820s*	Hisar & surrounding areas Haryana	**	Price 1829, pp. 91–93
282	1820s*	Hisar and Sirsa districts	–	Royle 1839, p. 64
283	1820s*	Hisar and neighbouring areas Haryana	45	Skinner 1832, p. 168
284	1820s	Punjab & Haryana,	84	Divyabhanusinh 2008, p. 122
285	1822	Bhiwani	13	Comyn 1822; Kazmi 2021
286	1823	Hisar district, Haryana	2	Anon. 1823, pp. 281–283
287	1823	Hisar district, Haryana	–	Anon. 1823, pp. 281–283
288	1825	Delhi	1	Elliot 1831, p. 88
289	1828	Hisar and Sirsa districts	–	Archer 1833, p. 375
290	1828	Hisar and Sirsa districts	–	Royle 1839, p. 64
291	1828	Kaithal district, Haryana	1	Mundy 1858, pp. 158–161
292	1828	Karnal district, Haryana	5	Anon. 1827, p. 374
293	1828	Sirsa district, Haryana	–	Mrs Cotton 1871, p. 492
294	1827–57	Mahendragarh district, Haryana	–	Anon. 1858, p. 724
295	Early 1850s	Gharaunda, Karnal district, Haryana	–	Anon. 1852, p. 3
296	1857–58	Delhi	50	Kinnear 1920, pp. 33–39

297	Late 18th century	Nardak, Karnal & Kaithal districts	–	Gazetteer of Karnal 1883, p. 13
298	1780	Anand district	1	Forbes 1813, pp. 91–95
299	1780	Dholka, Ahmedabad	–	Gazetteer of the Bombay
300	1781	Anand & Kheda district* near Gulf of Khambhat	–	Presidency: Ahmedabad 1879, p. 25
301	1781	Anand & Kheda district*	4	Forbes 1813, pp. 91–95
302	1781	Anand & Kheda district*	4	Joslin 1973, pp. 242–249
303	Early 19th century	Deesa, Banaskantha	1	Eastwick 1849, p. 3
304	Early 19th century	Gir forests	1	Burton 1933, pp. 268–281
305	Early 19th century	Gir forests	–	Burton 1933, pp. 268–281
306	Early 19th century	Mount Girnar, Junagadh	–	Mrs Postans 1844, p. 156
307	Early 19th	Gujarat	1	Asiatic Journal 1837, pp. 19–21
308	Early 19th	Gujarat	1	Burton 1933, pp. 268–281
309	Early 19th	Khirasara, Rajkot	2	Goldsmid 1881, p. 38
310	1812	Kheda, Kheda district	5	Anon. 1812, pp. 458–459
311	1813	Eastern Gujarat	5	Anon. 1813, p. 491
312	1813	Anand & Kheda district*	1	Joslin 1973, pp. 242–249
313	1816	Vadodara district	2	Anon. 1816a, pp. 228–229
314	1820	Rann of Kutch, Kutch	–	Joslin 1973, pp. 242–249

315	1828	Deesa, Banaskant ha	1	E.L. 1828
316	1828	Deesa, Banaskant ha	6	E.L. 1828
317	1828	Deesa, Banaskant ha	1	E.L. 1828
318	1829	Gir forests	–	Joslin 1973, pp. 242–249
319	1830s	Ahmedaba d,	–	Blanford 1888–91, pp. 56–58
320	1828–33	Dholka, Ahmedaba d	2	Bushman (1873)
321	1828–33	Gujarat	1	Burton 1933, pp. 268–281
322	1828	Benap village, Kutch	1	E.L. 1828
323	1828	Kutch district	7	E.L. 1828
324	1830s*	Bharuch & Vadodara	1	Burton 1933, pp. 268–281
325	1830s	Deesa, Banaskant ha	1	Andersson & Lloyd 1873, pp. 173–191
326	1830s	Gujarat	–	Burton 1933, pp. 268–281
327	1830s*	Ranpur, Botad district	–	Smee 1835, pp. 165–174
328	Late 1820s– Early 1830s	Ahmedaba d,	–	Smee 1835, pp. 165–174
329	Late 1820s–	Boru village, Ahmedaba d district	–	Smee 1835, pp. 165–174
330	Late 1820s–	Golana village, Ahmedaba d & Anand	–	Smee 1835, pp. 165–174
331	Late 1820s–	Northern Gujarat &	–	Smee 1835, pp. 165–174
332	Late 1820s–	Kasva village, Mehsana	–	Smee 1835, pp. 165–174
333	Late 1820s–	Kutch district	–	Smee 1835, pp. 165–174

334	1830	Gujarat	11	Smee 1835, pp. 165–174
335	1831	Dholka, Ahmedabad	2	Bushman (1873)
336	1831	Kathiawar Peninsula	1	A Looker On 1831, pp. 176-179
337	1831	Patan district	4	Khandesee 1831, pp. 193–195
338	1831	Rajkot district	2	Anon. 1831, pp. 99–100.
339	1831	Rajkot district	4	Andersson & Lloyd 1873, pp. 173–191
340	1832	Ahmedabad district	–	Joslin 1973, pp. 242–249
341	1832	Banas river, Northern Gujarat	1	Divyabhanusinh, 2008, pp. 228–234.
342	1832	Kutch district	–	Joslin 1973, pp. 242–249
343	1832–33	Rajkot district	–	Joslin 1973, pp. 242–249
344	1832	Patan district	4	Anon. 1832, pp. 184–185
345	1832	Vadodara district	1	Joslin 1973, pp. 242–249
346	1832	Vadodara district	2	Burton 1933, pp. 268–281
347	Mid-19th	Beraja village, Kutch	–	Gazetteer of the Bombay Presidency: Kathiawar, 1884, p. 578
348	Mid-19th	Deesa, Banaskantha	1	Saltoun 1883, pp. 229–235
349	Mid-19th	Deesa, Banaskantha	1	Saltoun 1883, pp. 235–238
350	Mid-19th	Deesa, Banaskantha	2	Saltoun 1883, pp. 238–239
351	Mid-19th	Deesa, Banaskantha	3	Balfour 1885, pp. 719–720
352	Mid-19th	Deesa, Banaskantha	2	Balfour 1885, pp. 719–720
353	Mid-19th	Gir forests	2	Balfour 1885, pp. 719–720
354	Mid-19th	Gir forests	14	Rice 1884, pp. 136–145

355	Mid-19th	Gir forests	1	Rice 1884, pp. 62–63
356	Mid-19th	Gir forests	1	Rice 1884, pp. 136–145
357	Mid-19th	Gir forests	300	Rice 1884, p. 144
358	Mid-19th	Gir forests	2	Newall 1887, pp. 448–450
359	Mid-19th	Gujarat	4	Andersson & Lloyd 1873, pp. 173–191
360	Mid-19th	Gujarat	1	Andersson & Lloyd 1873, pp. 173–191
361	Mid-19th	Gujarat	1	Balfour 1858, pp. 218–222
362	Mid-19th	Gujarat	4	Rangarajan 2013
363	Mid-19th	Kathiawar Peninsula	80	Newall 1887, p. 445
364	Mid-19th	Kathiawar Peninsula	2	Newall 1887, p. 448
365	Mid-19th	Kathiawar Peninsula	2	Newall 1866, pp. 201–202
366	Mid-19th	Rajkot district	1	Newall 1887, p. 446
367	Mid-19th	Rajkot district	–	Balfour 1885, pp. 719–720
368	Mid-19th	Vadodara district	1	Herne 1855, pp. 211–212
369	Mid-19th	Sabarmati river	–	Rangarajan 2013
370	Mid-19th	Vadodara district	–	Herne 1855, p. 210
371	1834	Jamnagar district	1	Gazetteer of the Bombay Presidency: Kathiawar, 1884, p. 578
372	1835	Zinzuwada, Kutch	1	Balfour 1885, pp. 719–720
373	1837	Gujarat	2	Anon. 1837, p. 17–28
374	1838	Near Datar Jamiyalshah Dargah, Junagadh city,	1	Mrs Postans 1839, pp. 145–148
375	1838	Datar hill, Junagadh	4	Mrs Postans 1839, pp. 145–148
376	1838	Kathiawar Peninsula	13	Balfour 1858, pp. 218–222
377	1838	Kathiawar Peninsula	14	Thapar et al. 2013, p. 144
378	1840	Ghogha (Bhavnagar district), &	18	Hall 1848, pp. 25–29

		Khokhra (Ahmedabad district)		
379	1840s*	Gujarat	8	Burton 1933, pp. 268–281
380	1840s	Gujarat	2	Balfour 1858, pp. 218–222
381	1840s	Kathiawar Peninsula	50	Balfour 1858, pp. 218–222
382	1840	Kathiawar Peninsula	1	Balfour 1858, pp. 218–222
383	1840–41	Kathiawar Peninsula	20	Balfour 1858, pp. 218–222
384	1841	Gujarat	8	Burton 1933, pp. 268–281
385	1843	Vadala, Kutch district	1	Gazetteer of the Bombay Presidency: Kathiawar, 1884, p. 578
386	1844	Kathiawar Peninsula	1	Balfour 1858, pp. 218–222
387	1847	Deesa, Banaskantha	1	Bristles 1847, pp. 51–52
388	1850s	Gir forests	1	Divyabhanusinh 2008, pp. 228–234
389	1850s	Sihor, Bhavnagar	1	Gazetteer of the Bombay Presidency: Kathiawar, 1884, p. 386
390	1851	Balambha, Jamnagar	1	Gazetteer of the Bombay Presidency: Kathiawar, 1884, p. 386
391	1851	Jamnagar district	4	Gazetteer of the Bombay Presidency: Kathiawar, 1884, p. 386
392	1853	Gujarat	2	Burton 1933, pp. 268–281
393	1853	Jamnagar district	3	Gazetteer of the Bombay Presidency: Kathiawar, 1884, p. 386
394	1855	Rajkot district	3	Anon. 1855, p. 326
395	1856	Jamnagar district	1	Gazetteer of the Bombay Presidency: Kathiawar, 1884, p. 386
396	1857	Jamnagar district	2	Gazetteer of the Bombay Presidency: Kathiawar, 1884, p. 386
397	1858	Porbandar district	1	Gazetteer of the Bombay Presidency: Kathiawar, 1884, p. 386
398	1860s	Gir forests	4	Divyabhanusinh 2008, p. 137

399	1862	Deesa, Banaskant ha	–	Joslin 1973, pp. 242–249
400	1864	Deesa, Banaskant ha	1	Kinnear 1920, pp. 33–39
401	Late 19th	Deesa, Banaskant ha	1	St. Clair 1899
402	Late 19th	Deesa, Banaskant ha	1	St. Clair 1897
403	Late 19th	Gujarat	3	Burton 1933, pp. 268–281
404	Late 19th	Gujarat	1	Burton 1933, pp. 268–281
405	Late 19th	Gujarat	2	Burton 1933, pp. 268–281
406	Late 19th	Kathiawar Peninsula	4	Markham 1874, p. 206
407	1867	Ahmedaba d district	–	Joslin 1973, pp. 242–249
408	1867	Deesa, Banaskant ha	–	Joslin 1973, pp. 242–249
409	1868	Alech hills, Jamnagar	–	Joslin 1973, pp. 242–249
410	1868	Barda hills, Porbandar district	–	Joslin 1973, pp. 242–249
411	1868	Chorwad, Junagadh district	–	Joslin 1973, pp. 242–249
412	1868	Chotila, Surendran agar district	–	Joslin 1973, pp. 242–249
413	1868	Deesa, Banaskant ha district	–	Joslin 1973, pp. 242–249
414	1868	Dhank, Rajkot district	–	Joslin 1973, pp. 242–249
415	1868	Dhrangad hra, Surendran agar district	–	Joslin 1973, pp. 242–249

416	1868	Jasdan, Rajkot district	–	Joslin 1973, pp. 242–249
417	1870s	Kathiawar	16	Rangarajan 2013
418	1870s	Gir forests	5	Divyabhanusinh 2008, p. 137
419	1870s*	Kathiawar Peninsula	6	Gazetteer of the Bombay Presidency: Kathiawar 1884, p. 100
420	1870s*	Kathiawar Peninsula	2	Gazetteer of the Bombay Presidency: Kathiawar 1884, p. 100
421	1870	Kathiawar Peninsula	2	Anon. 1870 pp. 1069–1077
422	1872	Gir forests	5	E.A.B. 1876
423	1874	Kathiawar Peninsula	3	Anon. 1874, pp. 72-73
424	1876	Gir forests	4	E.A.B. 1876
425	1878	Deesa, Banaskant ha district	1	Joslin 1973, pp. 242–249
426	1884	Porbandar district	3	Divyabhanusinh 2008, p. 137
427	1886	Gir forests	2	Anon. 1886, p. 28
428	1888	Gujarat	4	Joslin 1973, pp. 242–249
429	1890	Gir forests	1	Divyabhanusinh 2008, pp. 228–234
430	1893	Gir forests	1	Divyabhanusinh 2008, pp. 228–234
431	1895	Gir forests	2	Divyabhanusinh 2008, pp. 228–234
432	1895	Gir forests	1	Divyabhanusinh 2008, pp. 228–234
433	1900	Gir forests	1	Divyabhanusinh 2008, pp. 228–234
434	1900	Gir forests	1	Divyabhanusinh 2008, pp. 228–234
435	Early 19th century*	Burhanpur , Madhya Pradesh	–	Egerton 1852, p. 193
436	1828–33	Valsad & Navsari districts	4	Bushman (1873)
437	1830	Dhule district, Maharash tra	–	S.E.R. 1830, p. 44

438	1831	Umra, Surat district	2	G.O.K. 1831, p. 200
439	Mid-19th century	Amarkant ak, Madhya Pradesh	–	Newall 1887, pp. 450–455
440	Mid-19th century	Bharuch & Surat districts*	1	Herne 1855, pp. 201–204
441	1857–64	Seoni & Chindwar a districts	–	Sterndale 1884, pp. 159–161

Table S2: Covariate layers used for the habitat suitability models and their sources.

Spatial Data	A priori hypothesis	Satellite/Sensor	Original Resolution	Source	Reference
Nightlight Intensity	Indexing urbanization. We hypothesised that conflict with lions would be maximum in rural and semi-urban conditions. Lions would avoid urban centres and livestock as well as human encounters would be low within Protected Areas.	(VIIRS) Day/Night Band (DNB)	~ 500m	https://eogdata.mines.edu/nighttime_light/annual/v20/2020/	(Elvidge et al., 2021)
Distance to Forest Patches	Forest patches are daytime refuges for lions from which they venture out into the human landscapes to forage. Therefore, conflict would likely be higher in the proximity of PA's.			Wildlife Database Cell, Wildlife Institute of India and Project Tiger Directorate	
Digital Elevation Model	Lions were found to use broken terrain and riverbeds to move	Cartosat-1	~30m	https://bhuvan-app3.nrsc.gov.in/data/download/index.php#	

Ruggedness	across the human dominated landscape. Therefore, elevation and drainage density were used as covariates in the model.			Wildlife Database cell, Wildlife Institute of India and Project Tiger Directorate	
Human Population Density (Current)	We hypothesized that low and moderate human density areas will have high suitability compared to high human density areas that represents the urban centres in the landscape.		~1 km	https://sedac.ciesin.columbia.edu/data/set/gpw-v4-population-density-rev11/data-download	(CIESIN, 2018)
Normalized Difference Vegetation Index, NDVI	Surrogates for vegetation cover in the human dominated landscape. Such areas act as refuse patches for lions. And we hypothesise that conflict magnitude will increase with increasing green cover in the landscape.	MODIS	250m	National Aeronautics and Space Administration	Didan et al. 2015
Land use land cover	Hypothesised that lions will use deciduous forest patches, scrub-shrublands and grasslands more and avoid built up areas.	ESRI	10 m	ArcMAP living Atlas	https://livingatlases.arcgis.com/landcover/
Present day bio climatic variables	We hypothesised that areas with moderate rainfall and moderate temperature will have higher suitability values		30 s	https://www.worldclim.org	https://www.worldclim.org

	for the Asiatic lions				
Human Modification Index			1 km	SEDAC	https://sedac.ciesin.columbia.edu/data/set/lulc-human-modification-terrestrial-systems
Histoic Land use land cover (year 1800)	Hypothesised that lions will use deciduous forest patches, scrub-shrublands and grasslands more and avoid built up areas.		10 sqkm	SEDAC (Ellis, E. C., K. Klein Goldewijk, S. Siebert, D. Lightman, and N. Ramankutty. 2010. Anthropogenic transformation of the biomes, 1700 to 2000. <i>Global Ecology and Biogeography</i> 19 (5):589-606)	Ellis at al. 2010 (ecotope.org)
Past bioclimatic data	We hypothesised that areas with moderate rainfall and moderate temperture will have higher suitability values for the Asiatic lions		30 s	https://www.worldclim.org/data/worldclim21.html	https://www.worldclim.org/data/worldclim21.html
Historic human population data (year 1800)	We hypothesized that low and moderate human density areas will have high suitability for lions compared to high human density areas that represents the urban centres in the historic past.		10 sqkm	SEDAC (Ellis, E. C., K. Klein Goldewijk, S. Siebert, D. Lightman, and N. Ramankutty. 2010. Anthropogenic transformation of the biomes, 1700 to 2000. <i>Global Ecology and Biogeography</i> 19 (5):589-606)	Ellis at al. 2010 (ecotope.org)

Table S3: A detailed account on the protected areas that have suitable habitats within the historic distribution range of the Asiatic lions in India.

Sl No	Protected Area Name	State	Size of Protected Area (km ²)	Total_area_suitable (km ²)	Percent_area_Suitable
1	Gir WLS and National Park	Gujarat	1883	1843.457	97.92
2	Balaram Ambaji WLS	Gujarat	712.883	431	60.46
3	Kailadevi WLS	Rajasthan	757.187	418	55.20
4	Palpur-Kuno WLS	Madhya Pradesh	333.715	308	92.29
5	Sitamata WLS	Rajasthan	403.459	248	61.47
6	Ramgarh Vishdhari WLS	Rajasthan	283.691	240	84.60
7	Kumbhalgarh WLS	Rajasthan	871.671	233	26.73
8	Phulwari Ki Nal WLS	Rajasthan	1770.18	229	12.94
9	Ranthambhore NP	Rajasthan	362.764	224	61.75
10	Jessore WLS	Gujarat	224.76	191	84.98
11	Barda WLS	Gujarat	182.184	167	91.67
12	Sariska WLS	Rajasthan	629.062	117	18.60
13	Mount Abu WLS	Rajasthan	351.167	95	27.05
14	Darrah NP	Rajasthan	318.717	85	26.67
15	Wild Ass WLS	Gujarat	5252.39	37	0.70
16	Madhav NP	Madhya Pradesh	279.849	27	9.65
17	Kaimur WLS	Uttar Pradesh	677.386	22	3.25
18	Sariska NP	Rajasthan	217.158	18	8.29
19	Tadgarh Raoli WLS	Rajasthan	420.026	17	4.05
20	Kheoni WLS	Madhya Pradesh	331.578	16	4.83
21	Rampura Vidi WLS	Gujarat	13.9307	14	100.50
22	Ratanmahal WLS	Gujarat	52.6397	13	24.70

Chapter III

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Chapter III: Corridor connectivity among lion metapopulation

Objective 2: To delineate the available habitat corridors among lion satellite habitats in the Saurashtra Landscape.

Introduction:

The increased isolation of animal populations due to habitat alteration and fragmentation, primarily by anthropogenic activities, has posed severe threats to the conservation of threatened species worldwide (Crooks & Soulé 1999). Fragmented habitats are often unsuitable for maintaining viable animal populations (Bond 2003). Especially large carnivores need large areas that are relatively forested (Noss et al. 1996) and, due to their unique life history strategies, are vulnerable to these challenges (Woodroffe, 2000; Madhusudan and Karanth, 2002). Due to successful conservation efforts, many carnivore populations have also exceeded the carrying capacity of the protected areas and spilled over to the nearby human-dominated landscapes, colonizing small forested habitats and the agro-pastoral regions amidst human habitations (Jhala et al. 2019; Rio-Maior et al. 2019), following a source-sink dynamics (Hanski 1997; Walters 2001). However, movement between human-dominated landscapes is complex for large carnivores, often resulting in conflict, mortalities, and further isolation into small satellite populations, mostly in suboptimum habitats (Mueller et al. 2018). Such isolated populations of endangered species are prone to extinction due to catastrophic events (Dennis et al. 1991; Kohlmann et al. 2005). According to the metapopulation theory, if the colonization rate of individuals through immigration from other habitats exceeds the extinction rate in such areas, the species can survive (Hanski 1997). However, the frequency of individual exchange between populations depends on the landscape

physiognomy, composition (Pulliam et al. 1992), and connectivity (Taylor et al. 1999). Linear habitat patches, embedded in a dissimilar matrix that connects the source and sink populations, are vital in facilitating animal movements and are termed habitat corridors (Beier & Noss 1998). The distance between habitat patches, quality of the corridors, number of connections, permeability to animal movements, and species biology influence an individual's ability to disperse through such corridors (Gustafson & Gardner 1996; Walters 2001; Mariela et al. 2019).

In developing countries like India, where the average human density per km² is 481 individuals ("India Population" 2023) and natural habitats are rapidly altered for development, many large carnivore species have occupied suboptimum habitats among human habitations. There is hardly any sizeable contiguous tract of forest left unfragmented. India's protected area network is mostly isolated amidst the ocean of human-dominated landscape. In such a situation, the isolated populations of wild animals could be conserved by safeguarding the habitat patches that serve as corridors of animal movement between the protected areas.

The Asiatic lions in the Saurashtra landscape of Gujarat are currently distributed in more than 30,000 km², i.e., almost 15 times larger than the Gir Protected Areas. The lions outside the protected area's boundaries have established small satellite populations and use a wide range of habitat patches of different sizes amidst human habitations (Singh 2017). Although the conservation of the Asiatic lion is considered a success story of present times, now the challenge is to provide adequate space and manage the increasing lion populations. At present, besides Gir, lions permanently exist in the coastal forest patches of Mangrol, Veraval, Kodinar, Mahua, and Rajula-Jafrabad area; Girnar WLS and human-dominated landscape of Amreli, Junagadh, and Bhavnagar districts (Mitiyala WLS, Savarkundla along the river Shetrunji, Hipavadli, Palitana, Shihor. Recently, two sub-adult lions have also visited the grassland habitats of Chotila and Rajkot (Khakhariya & Kausik 2019). However, large

townships and urban developments separate many of these lion populations, restricting the efficient exchange of individuals through the matrix of multi-use human-dominated landscapes. The earlier existent of corridors connecting hills, forests, and the lion's habitat in the form of protected and un-classed forests have almost been transformed into agriculture and human settlements (Johnsingh et al. 1998). Railway lines, highways, and expressways have been widened and are now filled with high traffic and speeding vehicles, making it difficult for animals to cross them safely. A large tract of grazing pastures and wastelands used by wildlife and livestock have been transformed into other uses (Basu 2013). Therefore, identification and conservation of existing habitat corridors connecting these patches are essential to maintain the dispersal of individuals amongst these satellite populations; otherwise, it could potentially lead to further reproductive isolation of the already inbred population, resulting in genetic bottleneck and lower genetic diversity.

Earlier studies on the same landscape have identified corridors for lions between the Gir Protected Area and Girnar Hills. We have also observed lions fitted with radio transmitters using these corridors to move between the protected areas. However, the corridors between the other satellite habitats and the source population have yet to be modeled. With the increasing urbanization and other development activities, it is essential to identify the remaining habitat corridors for the movement of lions in the human-dominated landscape and take proper measures of protection based on scientific findings.

Method:

I have used the Circuitscape tool (Mcrae et al. 2008) to model the connectivity among the habitat patches in the Saurashtra landscape at a scale of 1km². This tool is widely used in landscape ecology to assess the connectivity of habitat patches and understand the movement of organisms across landscapes. It utilizes circuit theory to simulate how organisms move through landscapes, considering the resistance or permeability of different land features (Pope et al. 1998). Here, a landscape is considered a conductive surface, wherein resistances are derived from the landscape features, and current flow represents the movement potential of species between habitat patches or nodes. Resistance surfaces are generated by assigning resistance values to different land cover types based on prior knowledge of habitat use by the targeted species. These values reflect the ease or difficulty of movement for a particular species across different terrain/habitat types. For example, natural barriers or urban areas may have higher resistance values, while corridors or suitable habitats may have lower resistance values. Each pixel in the resistance surface is assigned a resistance value based upon land cover type as described above. The resistance value represents the relative effort required for a given species to traverse a pixel on the map, and the map of resistance values is used to derive all the possible pathways for modeling the electrical current flow from one point or region to another (Dixo et al. 2009).

I considered habitat patches more than 4 km² in size as nodes or the habitat patches that need to be connected. As it was observed that the minimum habitat size requirement for breeding females is ~4 km² in the human-dominated landscape (Banerjee 2012). The resistance layer was prepared by inverting the habitat suitability raster (1-habitat suitability) that was rescaled between 1-to-100-pixel values. Given different resistance values (from 0 to 100) to the land-use land cover (LULC) categories based on the prior information on lion habitat use from the long-term monitoring of radio-collared lions in the landscape (Table ...). Both the

raster was than mosaiced to produce the final resistance layers for the models. The areas with higher permeability/current flow between nodes (habitat patches) indicated the suitability of the landscape matrix as corridors. I used the program Linkage Mapper (McRae & Kavanagh 2011) to model the Least Cost Pathways between pairs of adjacent PAs based on the same resistance and habitat patch/nodes layers used for the Circuitscape program.

Table 3.1: Land-use categories and assigned resistance values

Layer		Resistance value
Habitat Suitability		(1- Habitat suitability)
Roads	Absent	0
	Dart roads	10
	State Highways	40
	National Highways	60
	Expressways	80
Railways	Absent	0
	Present	50
LULC	Forest	0
	Degraded	2
	Scrub	0
	Barren	2
	Water	50
	Agriculture	5
Human settlement	Rural village	40
	Semi Urban Villages	50
	Urban Villages	70
	Townships	90
	Major Cities	100

Result:

We observed that the eastern part of the landscape has high permeability for lion movement between habitats. The western part of the landscape is less permeable to lion movement, and only habitat patches available outside the Gir Protected Area are the Barda and Alech hill ranges (Figure 3.1). The corridor between Girnar and Gir Protected area that is characterized by riverine forests and agricultural fields juxtaposed with grassland patches, shows some degree of permeability for lion movement (Cluster A, Figure 3.3). There is a high degree of permeability between the source population, i.e., Gir Protected Area, Mitiyala Wildlife Sanctuary, the grass-shrub mixed patches of the Shatrunjay-Palitana landscape, to the coastal forests around Veraval, to the coastal forests of Una and Rajula. We observed higher current flow between the habitat patches of Palitana with Mahuva and other habitat patches in the district of Bhavnagar. The connectivity between the Gir Wildlife Sanctuary and proposed lion reintroduction site the Barda Wildlife Sanctuary is very weak (Cluster G, Figure 3.3). However the connectivity/current flow between the habitat patches towards the north part of the landscape in the district of Rajkot and Chotila have high connectivity (Cluster F, Figure 3.3).

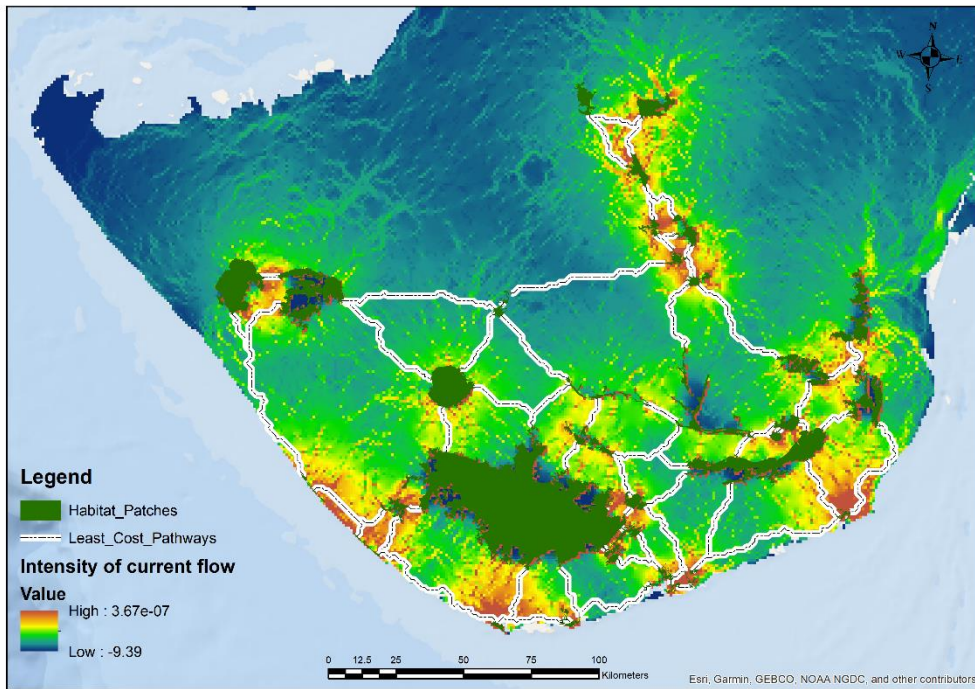
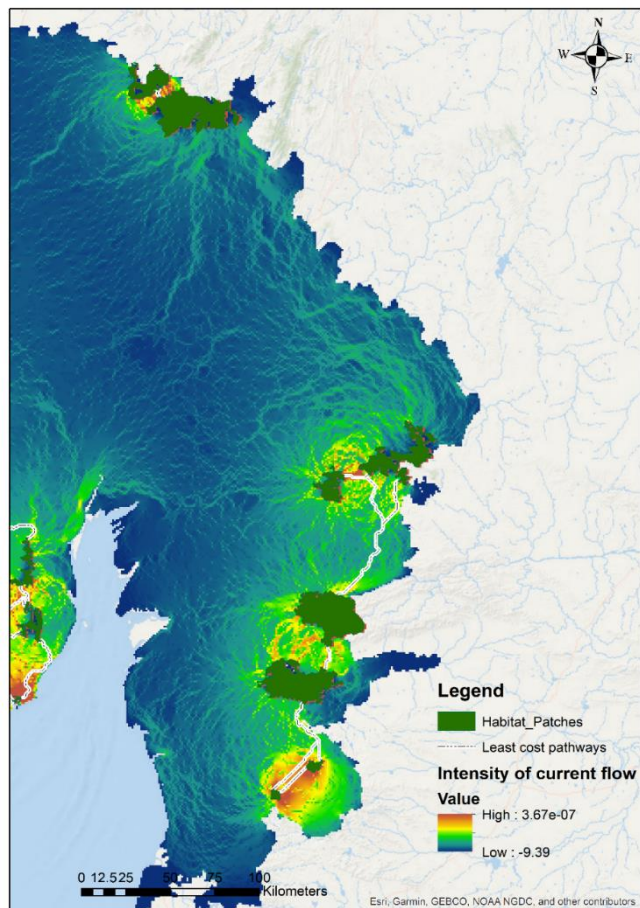


Figure 3.1: Corridors and least cost pathways of lion movement in the Saurashtra Landscape.

Figure 3.2: Corridors and least cost pathways of lion movement in the South-Eastern part of Gujarat State.



Although it is biologically impossible for the lions to naturally disperse into the protected areas of Jessore-Balarama Ambaji wildlife sanctuary (cluster J, Figure 3.3) and the complex of Dang Wildlife Sanctuaries (cluster I, Figure 3.3) in the Southernmost part of Gujarat, I have also accessed the connectivity among these complex (Figure 3.2, 3.3) of wildlife sanctuaries where lions were historically known to occur.

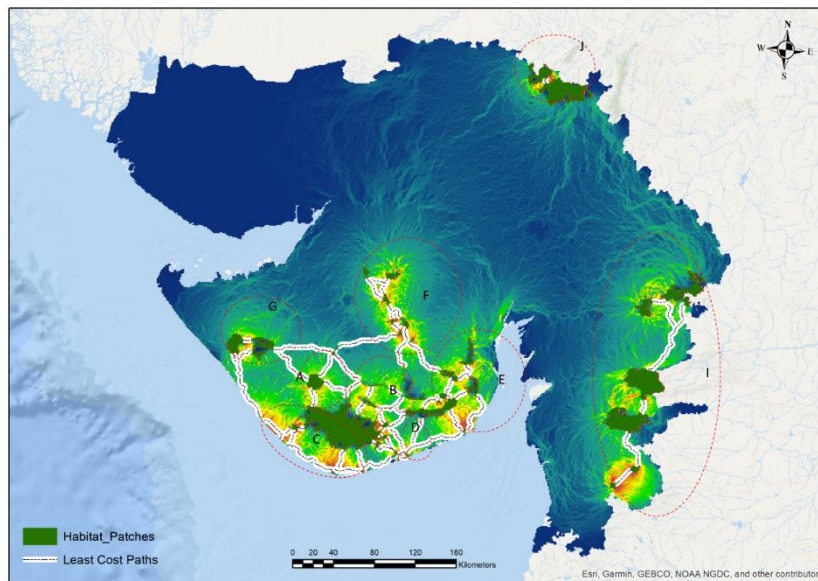


Figure 3.3: Least path corridors and intensity of current flow between habitat patches in the state of Gujarat, categorized into different habitat clusters.

About 6 major corridors are linking the Gir Protected Areas and other lion habitats (grassland habitats in Palitana) with the coastal forests. Among which the corridors connecting Gir with Veraval and Sutrapada facilitates the movement of lions from the western part of Gir Forests to the coast. The mosaic of dry river beds, orchards and *Prosopis* patches connecting the Gir Forests with the coastal forests of Una serves another important corridor connecting these habitats for lion movement (cluster C, Figure 3.3). Similarly riverine habitats, protected

and unprotected grassland patches between the coastal habitats of Rajula-Jafrabad serves as another important corridor for the lions to move between these areas (Cluster D, Figure 3.3). Similarly the mosaic of riverine forests, agricultural fields and other grasslands patches between the coastal forests of Mahua and Palitana Hill ranges facilitates the movement of lions between these habitats (Cluster E, Figure 3.3). A good intensity of current flow can also be seen among the Forested patches of Shihor and Talaja (Cluster E, Figure 3.3). Towards north of Gir Protected area the habitat patches of Hingolghadh Wildlife Sanctuary, protected and unprotected grasslands patches in the district of Surendernagar and Rajkot are connected by various riverine patches and other small grassland patches that acts as stepping stones (Cluster F, Figure 3.3).

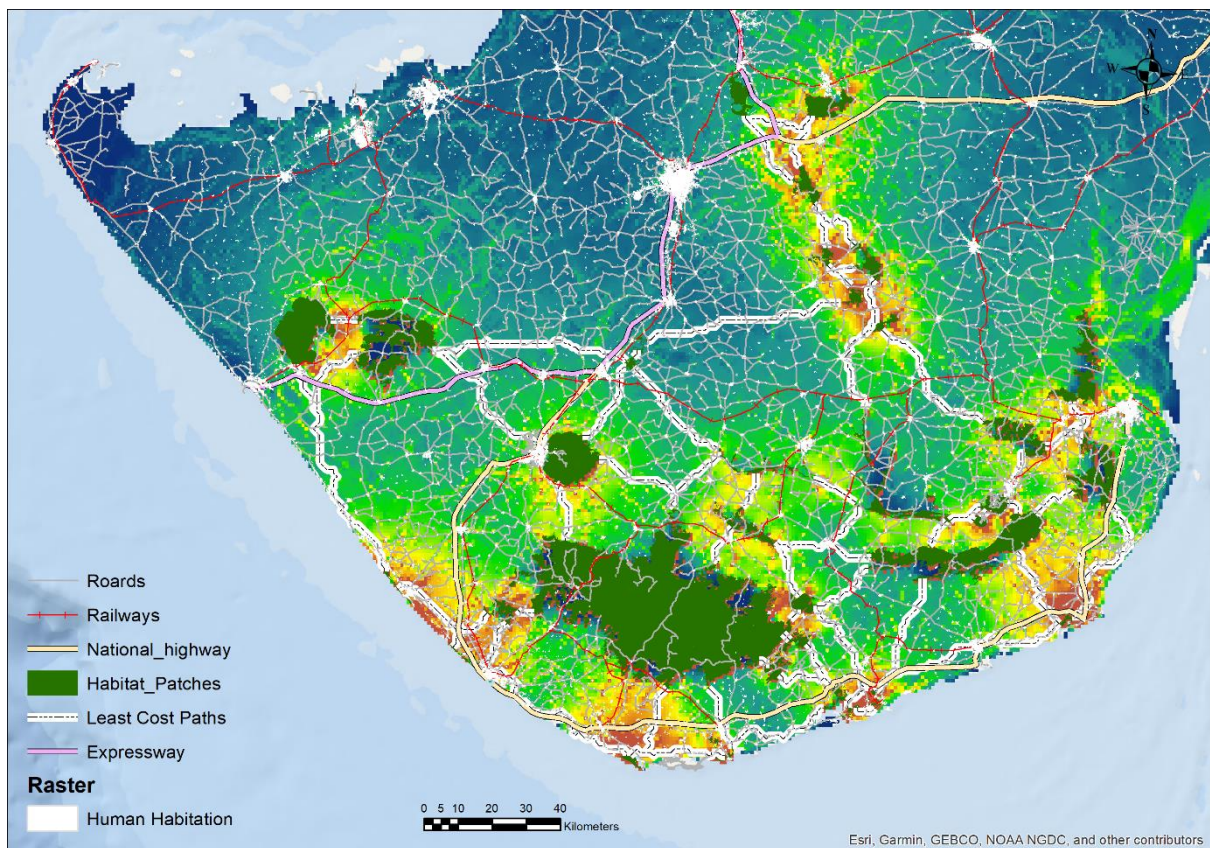


Figure 3.4: Current flow map and least cost pathways overlaid with road and railways networks in the Saurashtra landscape.

Discussion:

The long-term survival of the Asiatic lions in the human dominated Saurashtra landscape is highly dependent on the sustenance of the habitat corridors connecting the satellite lion populations. However, due to rapid development in the landscape and increased human population density the land-use patterns changing rapidly (Basu 2013). In this chapter I therefore attempted to identify the available habitat corridors connecting the major lion habitats in the landscape based on our long-term data on monitoring lions in the landscape and using robust statistical tools.

We identified four major corridors that connect the lion population of the Gir Protected areas and the Palitana hill ranges to the lion populations along the coastal forests of the landscape. The mosaic of agricultural fields, riverine forests and grassland habitats that connect the Western part of Gir Protected areas with the coastal forests of Veraval and Sutrapada serves as an important corridor maintaining the movement of lions between these habitats. This corridor is known to be widely used by the lions (Ram et al. 2023a). The coastal habitats of Veraval also connects with the coastal *Prosopis* patches of Gir Somnath, Sutrapada and Chorvad where about more than 20 lions are known to exist (Gujarat Forest Department 2020). Similarly, the coastal habitats of Kodinar are connected with the Jamwala-Babaria areas of the Gir Wildlife Sanctuary (Cluster C, Figure 3.3), while Jafrabad and Rajula are connected by various riverine forest patches, small grasslands and agricultural fields with Gir through the areas of Khambha (Cluster D, Figure 3.3), forming two major corridors. Although the coastal forests of Mahua, which hosts about 67 lions (Gujarat Forest Department 2020) are not directly connected to the Gir Wildlife Sanctuary but have good connection with the Savarkundla-Palitana Hill ranges where about 98 lions are known to reside (Gujarat Forest Department 2020). The coastal areas of the landscape have about 7 busiest sea ports connected by highways and railway lines. These areas witnesses some of the heaviest vehicular traffic due to the

transport of goods from these ports. There are many cases of lion mortalities along the railway lines and highways connecting these coastal habitats (Figure 3.4) (Ram et al. 2023a). The coastal areas of this landscape due to its proximity to the oceanic trade routes also harbors many big industries and mines. In past few decades due to such economic importance of this coast the natural habitats are rapidly altered for human use.

The rugged terrain, protected and unprotected grassland patches, riverine habitats and mosaic of agricultural landscape form another important link that facilitates the movement of lions between the Girnar Wildlife Sanctuary to Gir protected area. In the past a radio collared adult male lion from the Girnar Wildlife Sanctuary had crossed this matrix and reached the western part of the Gir Protected Area (Banerjee 2012). Although the closest aerial distance between Gir and Girnar is around 20 km there are 4 major road and a railway network traversing through this landscape. Roads have wide range of both direct and indirect ecological impacts on wilderness areas (Forman and Alexander 1998, Trombulak and Frissel 2000, Iuell et al. 2003). Such linear infrastructures constrain free movement of wild animals and impact on the spatial distribution-densities of species (Clarke et al. 1998, Alexander and Waters 2000, Lodge 2000, Yale Conroy and Mills 2001, Proctor 2003, Bjurlin and Cypher 2003, McDonald and St.Clair 2004, Shepard et al. 2008) by decreasing colonization rate and increase on the extinction rate (Mader 1984). Linear infrastructures like road and railways among animal habitats also intensifies animal–vehicle collisions (Bjurlin and Cypher 2003). Moreover, the landscape is fast transforming and remaining wilderness areas are being converted into other land-use types (agricultural field, development etc.) that possess a serious threat to the conservation of this important corridor (Basu 2013).

Riverine ecosystems can function as essential pathways for the movement and survival of large carnivores within environments heavily impacted by human activities (Paolino et al. 2018). Riverine corridors can provide continuous pathways that connect various habitats

among human dominated landscapes where large carnivores as well as other wild animals can utilize the landscape features to avoid direct contact with human by concealing themselves. Riverine habitats also serves as critical resource of water for both large carnivores and their prey. The presence of riverine habitats ensures that these animals have access to water, contributing to their survival in human modified landscapes. Riverbanks and associated riparian zones provide suitable refuge sites for large carnivores. The vegetation along rivers can offer cover for hunting and protection from human disturbances. This diversity of habitats within the riverine corridor enhances the overall suitability of the landscape for large carnivore's movement.

The riverine habitats along river Shetrunji and its tributaries serves as one of the major corridor for the lions to move between satellite populations (sinks) in the human dominated landscape and these river networks also connects the satellite lion habitats with the source population in the Gir forests. There are breeding populations of lions in areas around Lilia, Krankach, Savarkundla-Palitana hill ranges, which constitutes around 98 individuals according to the official estimates of lions numbers in the landscape (Gujarat Forest Department 2020). Lions mostly use the prosopis patches along the rivers as day time refuge and come out into the villages, agricultural field in search of feral cattle, dumped livestock carcasses, wild pig or nilgai during the night (Jhala et al. 2019). The land along the Shetrunji that have good prosopis cover have both government and private ownership. Therefore, one major challenge to conserve these important habitats for the lions are to control the destruction of such habitats for other land use types. However, due to improved irrigation and agricultural practices privately owned riverine prosopis patches are often removed for cultivation of cash crops. People also burn the prosopis wood to produce char-coal, which have great demand in local markets. These riverine habitats also hold some number of chital, abundant wildpigs and Nilgai, that constitutes a good prey base for the lions in these areas.

There are regular movement of lions between Gir Protected Area and Mitiyala Wildlife Sanctuary, which is about 5-6 kms aerial distance apart (Banerjee 2012; Ram et al. 2023b). The matrix in between is mostly composed of agricultural fields, grasslands patches and few semi-urban human settlements. A state highway connecting the coastal areas with the major urban centers of the state in the north and many other village road network is traversing through the landscape.

The proposed lion reintroduction site Barda Wildlife Sanctuary is about 192 km² of size and situated at 15 kilometer north-east of Porbandar and at an aerial distance of 60kms from the Gir Wildlife Sanctuary. Many state highways, national highways and railway lines traversed through this landscape. There are various small and big townships forming the matrix along with industrial complexes. The permeability of this matrix for lions is very low and natural dispersal of lions between Gir and Barda WS is precarious. Nevertheless there are good connectivity of coastal habitats upto the Porbandar district where lions are recorded to travel in the recent past (“Lion scare on beach near Porbandar | Rajkot News - Times of India” 2020). In the year 2014 the Wildlife Institute of India has conducted a scientific assessment of this landscape to understand the potential for lion translocation (Jhala et al. 2014) and found that after required habitat improvements Barda Wildlife Sanctuary have a carrying capacity of 26-35 lions (Jhala et al. 2014). At present due to two large towns (Ranavav and Adityana) bordering Barda sanctuary human caused disturbances are higher in the west and southern boundaries of the sanctuary.

In recent time two male lions were observed to travel upto the Chotila taluka in the Surendernagar district of Gujarat (Ram et al. 2023a). There are good grassland habitats under both government and private ownership. Major wild prey for lions includes Nilgai, wild pig and chinkara. The landscape is also interspersed with many water reservoirs that ensures year-round water availability. However, the areas are intensively used for grazing, mining and other

human activities. Although the exact movement path of the two lions were unknown, it is suspected that they might have travelled somewhere from the Lilia-Krankach area through Hingolgadh Wildlife Sanctuary to the Chotila grasslands. We also observed high permeability of this corridor (Figure 3.1, 3.3). Both of these lions were radio collared in Chotila to understand their movements and observed that they reached the Girnar Wildlife Sanctuary using various riverine habitats and grassland patches (Ram et al. 2023a), that further supports the functionality of the corridors (Figure 3.5). These habitat patches are well connected by grasslands and scrub patches up to the Rampara Wildlife Sanctuary in the Morbi District. However, the Porbandar-Ahmedabad expressway is traversing through and is a major barrier obstructing the movement of wild animals. The landscape on the north of this highway is also highly altered due to various industrial setups and mines.

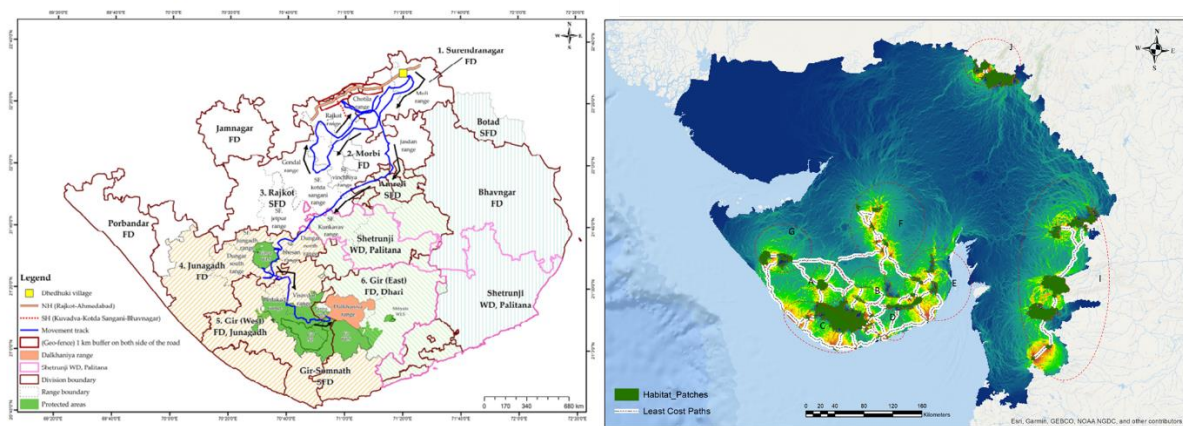


Figure 3.5: (a) movement pathways of the radio collared male coalition from Chotila to Girnar WS and to Gir (Source Ram et al. 2023a). (b) permeability of the landscape for lion movement (current flow) and least-cost corridors.

I did not assess the connectivity with the Banni grasslands in the Kutch district since historically lions were not observed to present there. There are many records of lions sighting and hunting by the British colonial officers and Indian Royals in and around the Jessore-

Balaram Ambaji wildlife sanctuary complex and these habitats are observed to be still suitable for the lions (Chapter 2 of this thesis). However, natural dispersal of lions to these areas from the source population in Gir Wildlife Sanctuary is not possible and the landscape in between is very less permeable for movement. Similarly, the forest in the Vadodara and Bharuch were also well known to be inhabited by lions in the past (Divyabhanusinh 2005). Although there is good connectivity among these habitat patches. There is no direct connection of these habitats with the source population in Gir WS.

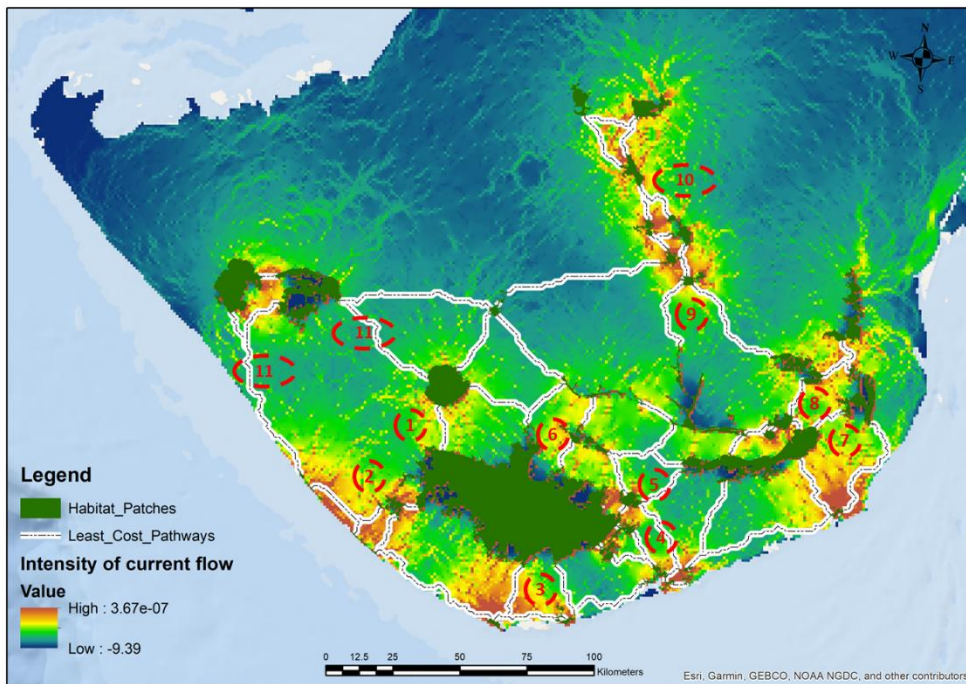


Figure 3.6: Major movement corridors in the Saurashtra landscape.

In this chapter, I have delineated 11 primary corridors (clusters) for lion movement across the Saurashtra landscape (refer to Figure 3.6). Detailed descriptions regarding the number of villages, land-use categories, and proposed mitigation structures are provided in the attached appendix at the conclusion of this chapter.

Periodic supplements of individuals, either through natural dispersal or human-facilitated introduction, are the only way to conserve patchily distributed endangered wild large carnivores with small population sizes, where the rate of extinction is balanced by the speed of immigration (Hanski 1999; Fryxell 2001; Lee & Bolger 2017). Manual introductions of wild animals are costly and require long-term commitments with funding support and political willingness. Nevertheless, it is the only alternative to natural dispersal when individuals' natural movement between populations is impossible. On the other hand, Habitat corridors are essential to conserve populations spatially structured in a landscape. Therefore, conserving the habitats that connect the isolated patches of animal populations is critical to ensure individuals exchange between populations that help maintain the genetic diversity and long-term sustenance of small isolated populations through immigration (Vila et al. 2003). The remaining habitat corridors connecting the satellite lion populations in the Saurashtra landscape needs urgent protection to stop them from further degradation due to human activities and land-use change. Moreover, the ongoing economic activities, particularly limestone extraction by cement manufacturers, may pose significant challenges to the suitability of this area as a movement corridor for lions as the local community members during our informal discussions revealed that the frequency of visits by lions has reduced due to the intensive mining activities in areas which were once used by the lions to disperse to the coastal forests.

To address these concerns, there are a few possible mitigation measures we can explore:

- (a) *Zoning and Buffer Areas*: Establishing no-mining zones or buffer areas around key wildlife habitats and corridors could help minimize the direct impact of mining activities on lion movements.
- (b) *Rehabilitation and Restoration*: Post-mining land rehabilitation efforts could focus on restoring degraded areas, which may support future wildlife use of these regions.

(c) *Alternative Corridors*: It may be worth identifying and assessing alternative movement corridors that avoid high-impact industrial areas, ensuring safe passage for lions between habitats.

(d) *Collaborative Solutions*: One way forward could be to engage with local stakeholders, including cement manufacturers, to develop environmentally friendly mining practices or even support wildlife conservation efforts.

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<http://doi.wiley.com/10.1111/j.1469-1795.2000.tb00241.x>.

Appendix:

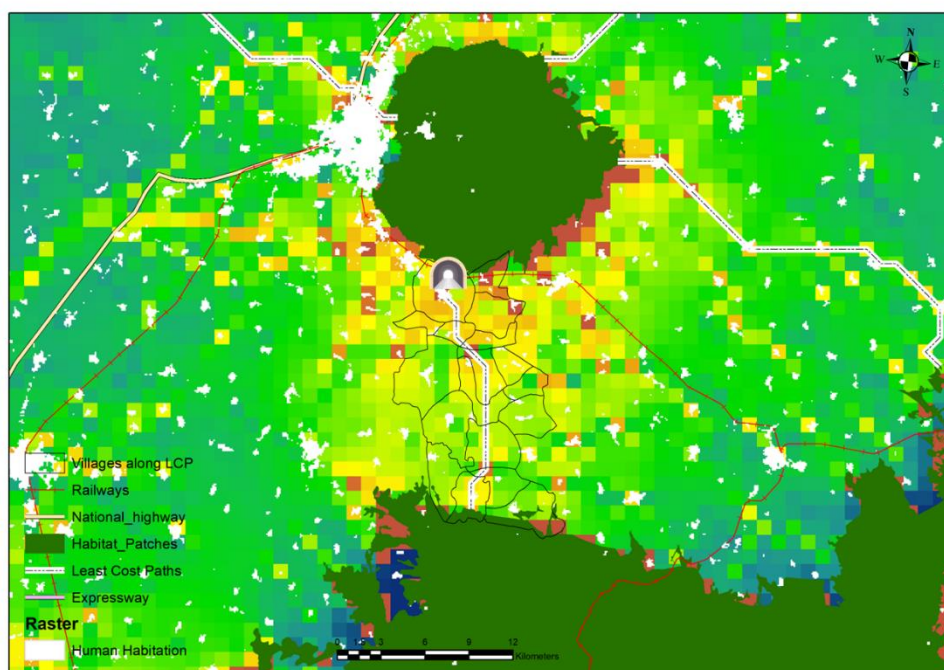
1. Gir-Girnar Corridor:

The Gir-Girnar wildlife corridor stands as a vital ecological bridge, linking the Gir National Park and Wildlife Sanctuary and the Girnar Wildlife Sanctuary. This corridor plays a pivotal role as a lifeline for the movement of the endangered Asiatic lions between these two significant habitats. Over recent times and in preceding decades, there have been numerous documented instances of lions utilizing this corridor to traverse between Gir WS and Girnar WS.

Functioning as a conduit for the natural dispersal of lions, the Gir-Girnar wildlife corridor facilitates crucial exchanges of genetic material, aids in the movement of individuals seeking new territories, and grants access to essential resources. These elements are paramount for maintaining robust lion populations and preserving genetic diversity within these protected areas.

However, despite its critical importance, the Gir-Girnar wildlife corridor encounters various challenges. Habitat fragmentation resulting from human activities such as agriculture, grazing, and infrastructure development poses a substantial threat to its integrity. The presence of a railway line and several state highways traversing this landscape further compounds the issue. Encroachments, road construction, and urbanization exacerbate fragmentation, impeding the free movement of lions and other wildlife species.

Preserving the Gir-Girnar wildlife corridor is imperative not solely for safeguarding the region's abundant biodiversity but also for securing the future of iconic species like the Asiatic lion. Additionally, it is essential for maintaining the ecological health and resilience of the entire landscape. Through the protection of this vital ecological linkage, we can contribute significantly to the conservation of Gujarat's natural heritage for generations to come.



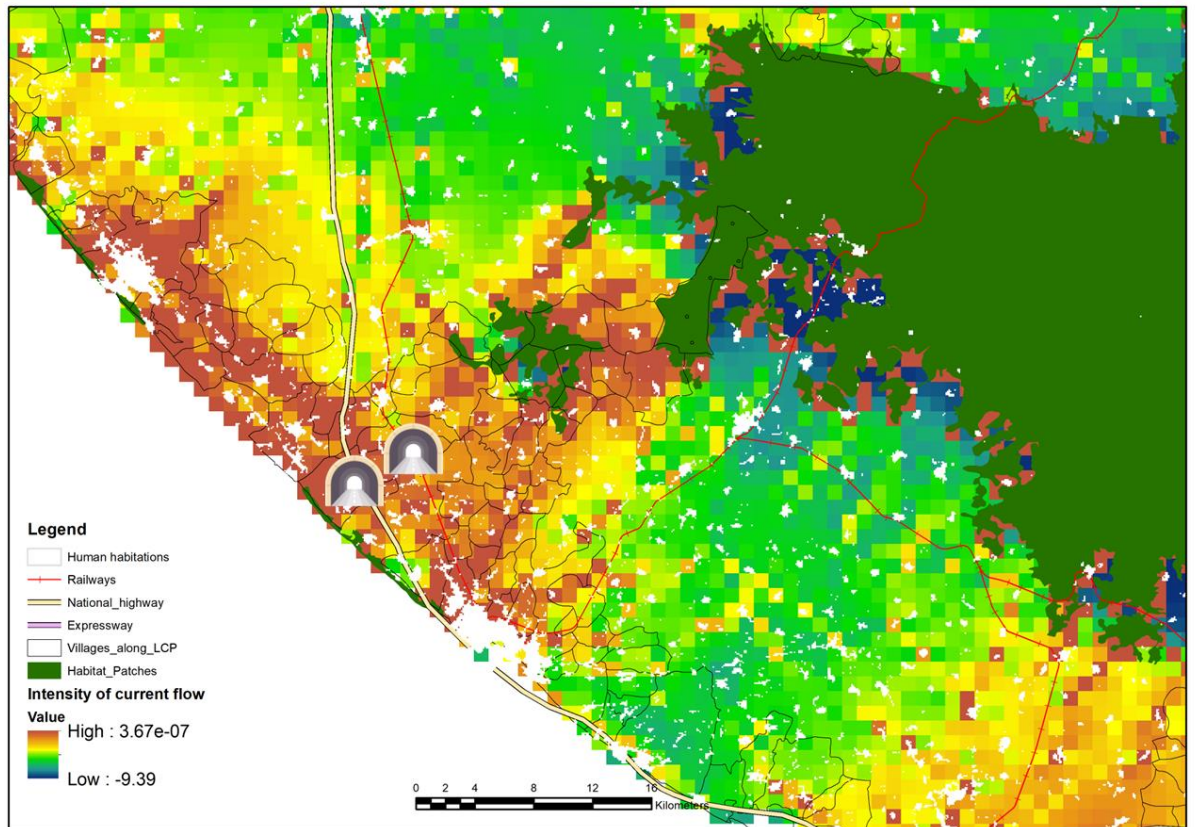
Suggested underpass for movement of lion and other wild animals

Table S3.1: List villages with major landuse categories along the least cost pathways connecting the Girnar Wildlife Sanctuary with Gir Protected Area. Here: Area in km², length in km

Village Name	District	Area	Rail_lengt	CROPLANDS	FOREST	GRASSLANDS	HUMAN_HABI	SCRUBLAND	BARE_GROUN	WATER	Road_lengt	Drain_leng
Toraniya	Junagadh	5.0743	2.372	4.17	0.62	0	0.24	0.05	0	0.03	1.481	2.365
Khadiya	Junagadh	14.0256	90	11.53	1.58	0	0.81	0.03	0	0.15	0.21	4.185
Anandpur	Junagadh	2.67136	0	2.48	0	0.01	0.12	0	0	0.03	0.767	0.517
Mevasa Khadiya	Junagadh	3.08077	0	2.73	0	0.02	0.2	0	0	0.11	0.214	1.104
Bagdu	Junagadh	16.3681	0	15.42	0.02	0.03	0.61	0	0	0.3	2.891	0.934
Jamka	Junagadh	11.4835	0	10.94	0	0	0.53	0	0	0	1.115	2.563
Jambala	Junagadh	10.2501	0	9.96	0	0	0.22	0.03	0	0.07	0.067	3.97
Liliya	Junagadh	6.21929	0	5.93	0	0	0.14	0.15	0	0	0.742	2.933
Limadhra	Junagadh	11.3048	0	10.68	0	0.24	0.36	0	0	0	4.33	0.28
Badalpur	Junagadh	4.12479	0	3.06	0	0.15	0.31	0	0.08	0.53	0	1.362
Prabhatpur	Junagadh	6.48208	0	5.92	0.08	0.06	0.1	0.01	0	0.37	0	2.288
Sankhdavadar	Junagadh	3.99639	0	1.36	0	0.04	0.1	0	0.56	1.94	0	0.519
Shobhavadia Gir	Junagadh	7.68602	0	7.16	0	0	0.42	0	0	0.08	0	0.69
Chorvadi	Junagadh	8.00448	0	7.74	0	0	0.26	0	0	0	0.793	0
Nani Khodiyar	Junagadh	8.47339	0	7.54	0	0.28	0.31	0.38	0	0	1.756	0
Itali	Junagadh	7.09976	0	6.63	0	0.21	0.19	0.04	0	0	2.943	0
Rameshvar	Junagadh	3.61063	0	3.49	0	0	0.07	0	0	0	0	0
Semrala	Junagadh	6.17688	0	5.97	0	0	0.2	0	0	0	0	0

2. Gir Veraval-Sutrapada corridor:

This is another functional corridor connecting the Gir forests with the coastal forests of Veraval and Sutrapada. This corridor is frequently used by lions and that connects with other coastal forest patches upto Porbandar towards the west and upto Kodinar in the east.



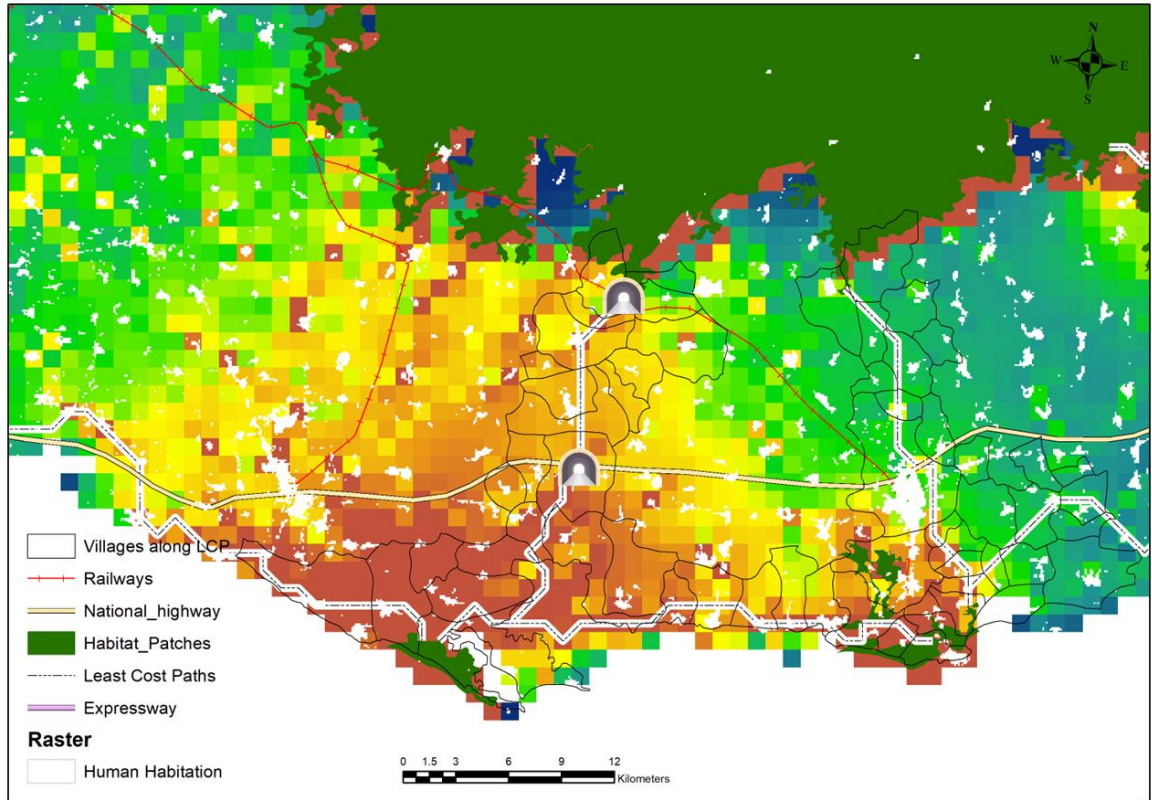
Suggested underpass for movement of lion and other wild animals

Table S3.2: List villages with major landuse categories along the least cost pathways connecting the Veraval-Sutrapada coastal forests with Gir Protected Area. Here: Area in km², length in km

Village Name	DISTRICT	Area	Rail_lengt	CROPLANDS	FOREST	GRASSLANDS	HUMAN_HABI	SCRUBLAND	BARE_GROUN	WATER	Road_lengt	Drain_leng
Visanvel	Junagadh	9.35	0.05	4.84	3.72	0.01	0.63	0.00	0.00	0.27	1.33	3.05
Sukhpur	Junagadh	5.50	1.44	3.44	1.54	0.00	0.29	0.00	0.00	0.15	0.07	1.45
Ladudi -Gir	Junagadh	11.04	0.00	9.26	0.21	1.09	0.38	0.12	0.01	0.03	3.90	3.94
Kadaya	Junagadh	9.52	0.00	8.13	0.15	0.98	0.22	0.01	0.04	0.01	0.82	2.70
Bakula Dhanej	Junagadh	16.89	0.00	12.85	1.20	0.68	0.40	1.61	0.00	0.14	5.46	6.04
Dhanej Moti	Junagadh	5.04	0.00	4.43	0.00	0.30	0.24	0.02	0.00	0.03	0.63	1.94
Khorasa Gir	Junagadh	20.98	0.00	18.84	0.41	0.68	0.93	0.06	0.00	0.10	5.41	1.51
Samdhiyala	Junagadh	4.38	0.00	3.77	0.08	0.06	0.30	0.00	0.00	0.16	0.53	0.12
Chhapri	Junagadh	5.07	0.00	4.55	0.05	0.27	0.10	0.01	0.00	0.13	0.32	1.81
Achhidra	Junagadh	5.38	0.00	4.94	0.00	0.00	0.41	0.00	0.00	0.00	1.01	1.73
Januda	Junagadh	4.75	0.00	4.14	0.43	0.01	0.18	0.00	0.00	0.00	1.60	0.10
Kherali	Junagadh	2.86	0.00	2.80	0.00	0.00	0.07	0.00	0.00	0.00	0.87	1.95
Simar	Junagadh	5.95	0.00	3.79	1.09	0.02	0.80	0.00	0.00	0.26	2.00	1.18
Vadodra Dodiya	Junagadh	15.85	0.00	12.00	0.63	0.14	0.75	0.04	0.17	2.13	0.86	0.37
Dari	Junagadh	12.10	0.00	9.03	1.37	0.00	1.61	0.00	0.00	0.07	1.05	2.38
Shantipura	Junagadh	5.44	1.31	4.78	0.06	0.02	0.35	0.00	0.05	0.19	3.78	0.00
Chhatroda	Junagadh	3.25	1.51	1.84	1.24	0.00	0.12	0.00	0.00	0.00	2.21	0.00
Babra	Junagadh	16.67	0.00	9.85	0.62	1.84	0.31	4.02	0.00	0.00	4.12	0.00
Dhrabavad	Junagadh	6.48	0.00	6.14	0.00	0.01	0.23	0.11	0.00	0.00	2.58	0.00
Jangar	Junagadh	7.72	0.00	6.38	0.00	0.63	0.18	0.52	0.00	0.00	2.13	0.00
Chuldi	Junagadh	12.18	0.00	8.27	0.34	1.39	0.27	1.91	0.00	0.00	3.45	0.00
Patla	Junagadh	2.65	0.00	1.93	0.00	0.36	0.24	0.11	0.00	0.00	1.49	0.00
Lachhadi	Junagadh	4.43	0.00	3.64	0.00	0.13	0.19	0.30	0.00	0.15	1.01	0.00
Barula	Junagadh	7.03	0.00	6.65	0.00	0.15	0.25	0.00	0.00	0.00	3.72	0.00
Pipalva	Junagadh	2.68	0.00	2.30	0.02	0.12	0.27	0.00	0.00	0.00	0.56	0.00
Chorvad	Junagadh	19.76	0.00	6.02	9.60	0.07	3.20	0.04	0.05	0.75	1.20	0.00
Danderi	Junagadh	4.37	0.00	4.13	0.00	0.00	0.23	0.00	0.00	0.00	0.41	0.00
Paldi	Junagadh	5.85	0.00	5.60	0.13	0.00	0.11	0.00	0.00	0.00	1.76	0.00
Deda	Junagadh	2.85	0.00	2.75	0.04	0.00	0.05	0.00	0.00	0.00	1.87	0.00
Vavdi Adri	Junagadh	7.24	0.00	6.29	0.33	0.00	0.60	0.00	0.00	0.00	0.54	0.00
Chamoda	Junagadh	5.99	0.00	5.11	0.59	0.00	0.27	0.00	0.00	0.00	0.25	0.00
Dabhor	Junagadh	3.30	0.00	2.55	0.75	0.00	0.00	0.00	0.00	0.00	2.44	0.00

3. Gir Kodinar Corridor:

This is another important functional corridor connecting the Gir forests with the coastal forests of Kodinar. There is frequent movement of lions through the mosaic of villages and agricultural patches. Two major mitigation structures required to be installed to facilitate the movement of lions.



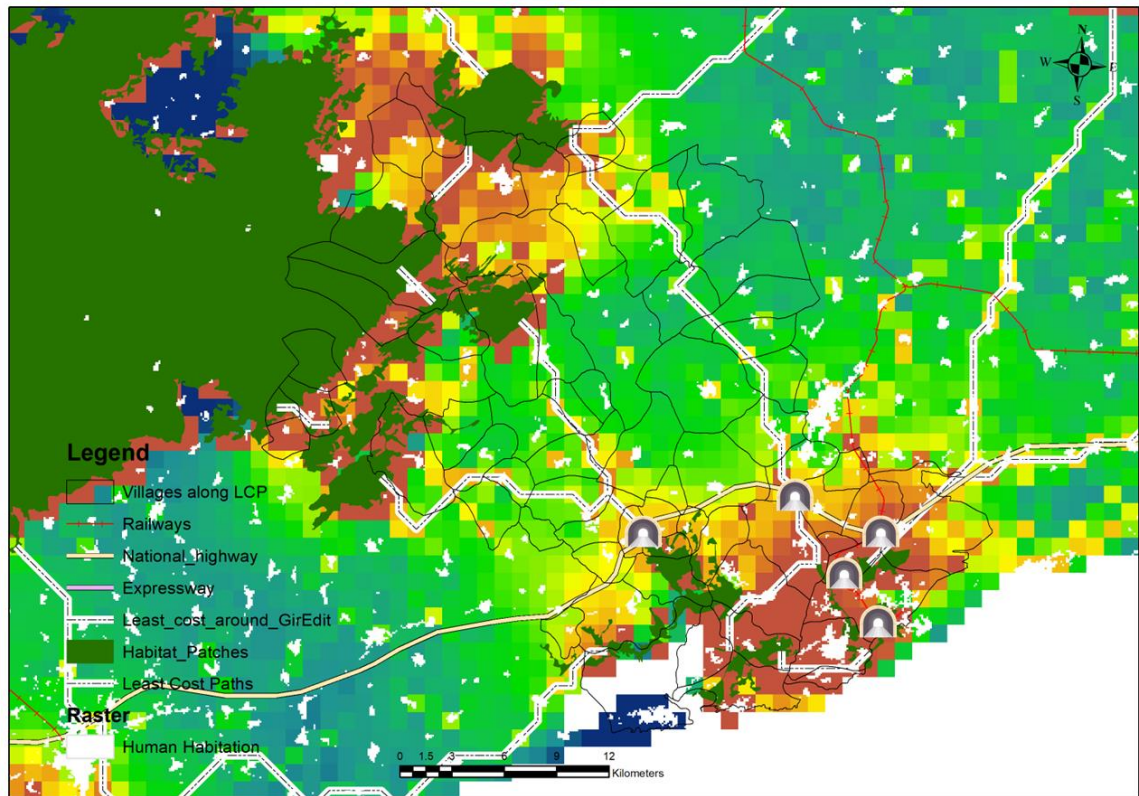
Suggested underpass for movement of lion and other wild animals

Table S3.3: List villages with major land-use categories along the least cost pathways connecting the coastal forests along the Kodinar with Gir Protected Area. Here: Area in km², length in km

NAME	DISTRICT	Area (Sq km)	Rail_lengt	TOTAL_AREA	CROPLANDS	FOREST	GRASSLANDS	HUMAN_HABI	SCRUBLAND	BARE_GROUN	WATER	Road_lengt	Drain_leng
Alidar	Junagadh	13.54	0	0.25	12.76	0	0.03	0.72	0	0	0.01	2.816	2.222
Bodidar	Junagadh	12.28	0	0.47	11.97	0	0.02	0.3	0	0	0.01	1.693	1.337
Sonpura	Junagadh	7.98	0	0.29	7.18	0	0	0.79	0	0	0	2.567	2.758
Dolasa	Junagadh	17.44	0	0.65	16.11	0	0	1.17	0	0	0.14	4.172	4.929
Velva	Junagadh	4.43	0	0.38	4.09	0	0	0.32	0	0	0	0.019	0.401
Panch Pipalva	Junagadh	4.92	0	1.01	2.46	0.01	1.24	0.51	0.6	0	0.05	2.286	2.284
Chikhli	Junagadh	14.94	0	1.52	12.02	0.03	1.79	0.47	0.21	0.01	0.35	1.037	0.879
Velan	Junagadh	23.53	0	4.62	9.59	2.17	3.12	0.89	1.41	3.46	2.82	7.098	2.653
Umedpara	Junagadh	6.47	1.223	1.3	5.88	0	0.32	0.17	0.12	0	0	0	1.882
Sanvav	Junagadh	15.38	1.659	1.14	14.36	0	0.39	0.56	0.06	0	0	0	3.598
Jhankhiya	Junagadh	3.82	0	0.77	3.01	0.04	0.31	0	0.47	0	0	0	0.726
Velakot	Junagadh	5.66	0	0.29	5.47	0	0	0.19	0	0	0	0	0.029
Kob	Junagadh	15.27	0	1.45	14.28	0	0.02	0.75	0.01	0	0.3	0	0.897
Pichhvi	Junagadh	10.74	0.635	3.92	4.58	0.39	1.64	0.28	2.35	0.16	1.38	1.689	0
Pichhva	Junagadh	3.59	0.306	0	3.56	0	0	0.05	0	0	0.01	1.709	0
Bodva	Junagadh	2.67	0	0	2.52	0	0	0.16	0	0	0	0.138	0
Advi	Junagadh	6.16	0	0.27	5.66	0	0	0.48	0	0	0	0.961	0
Kaj	Junagadh	12.54	0	0.38	10.99	0	0.36	0.68	0.02	0.39	0.05	2.999	0
Jhanjhariya	Junagadh	3.98	0	0.57	3.93	0	0	0.04	0	0	0.02	0	0
Nanavada	Junagadh	6.97	0	1.75	4.69	0	0.9	0.35	0.01	0.71	0.33	0	0
Bhingran	Junagadh	4.51	0	0	4.07	0	0.01	0.3	0.12	0	0.01	0	0

4. Gir Rajula Corridor:

This corridor is frequently used by lions. There many reports of lion mortality in the linear infrastructures (railways and the national highway) passing through this corridor (Ram et al. 2023). Therefore constructing mitigation structure to reduce collision with the train and vehicles are very crucial for the safe movement of lions.



Suggested underpass for movement of lion and other wild animals

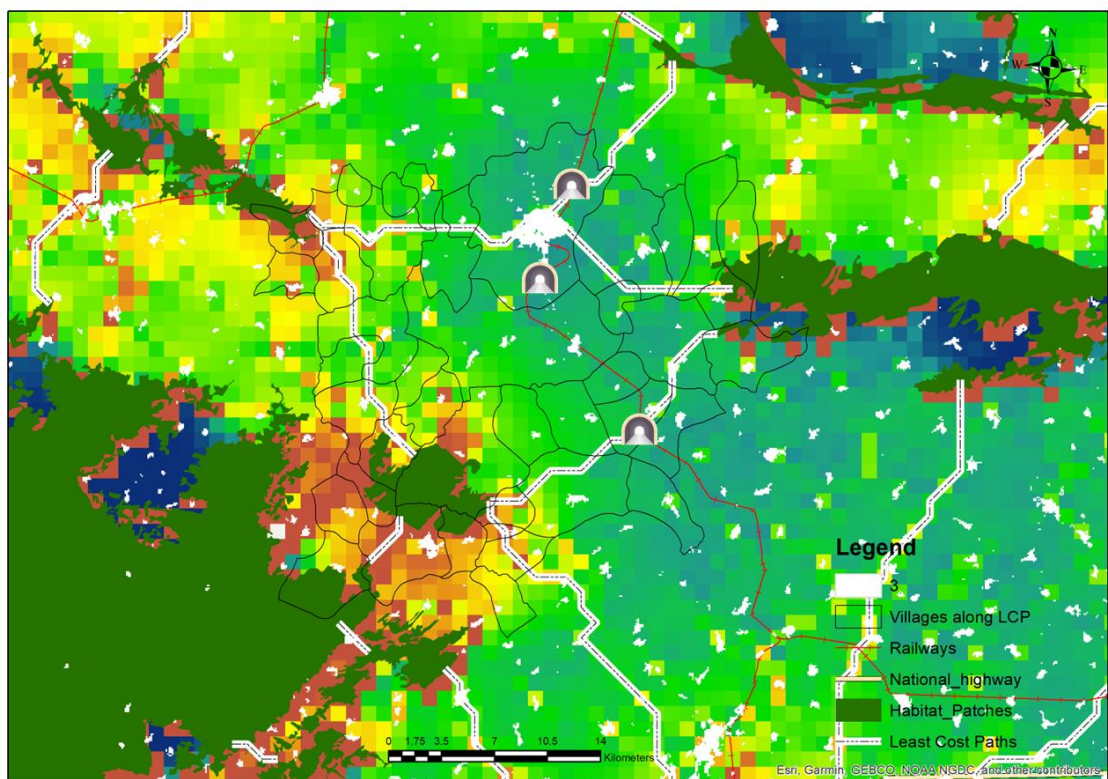
Table S3.4: List villages with major land-use categories along the least cost pathways connecting the coastal forest patches of Rajula with Gir Protected Area. Here: Area in km², length in km

NAME	DISTRICT	Area	Rail_lengt	CROPLANDS	FOREST	GRASSLANDS	HUMAN_HABI	SCRUBLAND	BARE_GROUN	WATER	Road_lengt	Drain_lengt
Bherai	Amreli	24.74	0.12	11.15	0.00	1.07	1.08	1.79	3.27	6.35	0.78	0.76
Uchaiya	Amreli	5.31	3.69	3.91	0.02	0.00	0.18	1.04	0.00	0.17	0.28	1.54
Rampara No-2	Amreli	20.23	2.39	12.28	0.18	0.73	3.24	2.36	0.44	1.02	1.75	3.99
Dedan	Amreli	12.58	0.00	11.71	0.00	0.01	0.56	0.33	0.00	0.00	4.92	0.47
Borala	Amreli	15.96	0.00	4.77	0.90	1.04	0.21	9.00	0.00	0.00	2.75	1.49
Kotdi	Amreli	25.63	0.00	24.67	0.00	0.29	0.69	0.00	0.00	0.05	2.35	4.96
Kantala	Amreli	8.43	0.00	1.33	2.08	0.11	0.08	4.50	0.00	0.33	1.32	1.79
Jivapar	Amreli	4.46	0.00	4.03	0.00	0.03	0.39	0.00	0.00	0.00	1.03	1.22
Trakuda	Amreli	10.41	0.00	9.70	0.00	0.15	0.56	0.00	0.00	0.00	2.70	1.78
Dhundhavana	Amreli	6.36	0.00	4.44	0.00	0.07	0.18	1.66	0.00	0.00	2.45	2.50
Vangadhara	Amreli	10.09	0.00	9.27	0.00	0.13	0.20	0.00	0.00	0.49	1.49	3.39
Gorana	Amreli	3.94	0.00	3.48	0.00	0.02	0.18	0.00	0.00	0.20	1.25	0.38
Jamka	Amreli	18.71	0.00	15.32	0.01	0.32	0.44	2.55	0.00	0.05	2.02	2.60
Ningala No-2	Amreli	7.89	0.00	6.30	0.00	0.05	0.31	1.26	0.00	0.00	1.88	1.86
Bhundani	Amreli	8.07	0.00	6.66	0.00	0.23	0.34	0.00	0.02	0.78	1.37	0.72
Salva	Amreli	4.47	0.00	4.31	0.00	0.00	0.15	0.00	0.00	0.00	0.27	1.33
Fachariya	Amreli	4.61	0.00	4.43	0.00	0.03	0.18	0.00	0.00	0.00	1.20	1.35
Barman Mota	Amreli	10.60	0.00	8.97	0.00	0.58	0.32	0.30	0.15	0.26	2.94	2.44
Lor	Amreli	8.00	0.00	7.02	0.00	0.21	0.19	0.24	0.00	0.32	2.58	4.01
Barman Nana	Amreli	7.15	0.00	6.66	0.00	0.11	0.39	0.01	0.00	0.00	0.10	1.64
Lothpur	Amreli	16.22	0.00	15.51	0.00	0.02	0.52	0.00	0.00	0.06	0.12	4.42
Bhatvadar	Amreli	2.84	0.00	2.68	0.00	0.00	0.15	0.00	0.00	0.00	0.07	1.40
Lunsapur	Amreli	18.54	0.00	16.07	0.04	0.16	1.80	0.27	0.10	0.14	3.13	0.33
Chotra	Amreli	5.44	0.00	5.07	0.11	0.00	0.26	0.00	0.00	0.04	2.34	2.50
Mithapur	Amreli	9.75	0.00	9.49	0.00	0.01	0.02	0.25	0.00	0.00	2.48	1.32
Nageshri	Amreli	16.99	0.00	15.33	0.28	0.00	0.75	0.60	0.00	0.00	0.66	2.71

Jafrabad	Amreli	27.49	0.00	5.90	0.04	1.87	2.18	3.08	8.98	5.49	0.08	0.05
Vandh	Amreli	9.78	0.00	6.30	0.17	0.56	0.33	1.71	0.68	0.04	2.00	0.65
Mitiyala	Amreli	9.25	0.00	4.59	0.02	0.44	0.53	1.09	1.43	1.18	0.27	1.50
Babarkot	Amreli	12.00	0.00	2.49	0.46	2.82	0.69	3.27	1.93	0.30	0.35	0.34
Pipalava	Amreli	20.81	0.00	10.65	0.18	0.81	0.29	8.41	0.04	0.37	0.00	3.81
Munjiyasar	Amreli	4.98	0.00	4.88	0.00	0.00	0.11	0.00	0.00	0.02	0.00	0.15
Bhachadar	Amreli	8.90	3.88	8.46	0.00	0.00	0.37	0.00	0.00	0.02	0.71	0.00
Khadadhar	Amreli	19.90	0.00	7.64	0.47	1.05	0.37	10.40	0.00	0.00	3.52	0.00
Raningpara	Amreli	23.82	0.00	13.08	0.00	2.15	0.29	8.28	0.00	0.00	3.26	0.00
Katar	Amreli	16.05	0.00	13.96	0.00	0.76	0.39	0.85	0.00	0.07	3.45	0.00
Barpatoli	Amreli	18.60	0.00	17.84	0.00	0.01	0.68	0.00	0.00	0.03	4.43	0.00
Sarovarda	Amreli	3.13	0.00	3.06	0.00	0.01	0.08	0.00	0.00	0.00	0.84	0.00
Kanthariya Koli	Amreli	3.95	0.00	3.76	0.00	0.09	0.11	0.00	0.00	0.00	2.52	0.00
Kanthariya Khalsa	Amreli	3.66	0.00	3.43	0.00	0.06	0.17	0.00	0.00	0.00	0.29	0.00
Pati Mansa (Nana)	Amreli	7.75	0.00	7.53	0.00	0.10	0.02	0.11	0.00	0.00	2.29	0.00
Pichhadi	Amreli	3.31	0.00	3.29	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00
Balanivav	Amreli	3.33	0.00	2.74	0.00	0.14	0.07	0.30	0.05	0.03	1.67	0.00
Mota Mansa	Amreli	7.62	0.00	6.58	0.00	0.04	0.51	0.49	0.00	0.00	2.13	0.00
Kovaya	Amreli	11.23	0.00	5.05	0.23	0.77	2.85	1.84	0.30	0.15	3.18	0.00
Bhankodar	Amreli	3.05	0.00	1.75	0.00	0.65	0.46	0.22	0.00	0.01	1.27	0.00
Varahsvarup	Amreli	1.24	0.00	0.68	0.00	0.11	0.11	0.26	0.03	0.00	0.24	0.00
Nava Malaknes	Amreli	10.68	0.00	7.45	0.00	1.15	0.17	1.91	0.00	0.00	0.00	0.00
Pachapachiya	Amreli	2.64	0.00	1.06	0.00	0.27	0.00	1.33	0.00	0.00	0.00	0.00
Vad	Amreli	7.65	0.00	6.48	0.51	0.24	0.37	0.00	0.00	0.05	0.00	0.00
Dharano Nes	Amreli	1.85	0.00	1.84	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00

5. Gir Mitiyala Palitana corridor:

The corridor linking the Gir forests with Mitiyala and the Palitana hill ranges serves as a vital pathway for the significant dispersion of lions into areas dominated by humans. Stretching seamlessly into the Bhavnagar District, the hill ranges create an uninterrupted expanse of grasslands and deciduous forests, providing a sanctuary for lions away from the Gir region. We propose the implementation of three mitigation structures: one situated between the villages of Goradka and Luvara, and two positioned on the northern and southern outskirts of the Savakundla township. These structures aim to address the issue of lion crossings over the railway line. By strategically placing these structures, we intend to minimize the risk of encounters between lions and trains, thereby enhancing the safety of lions.



Suggested underpass for movement of lion and other wild animals

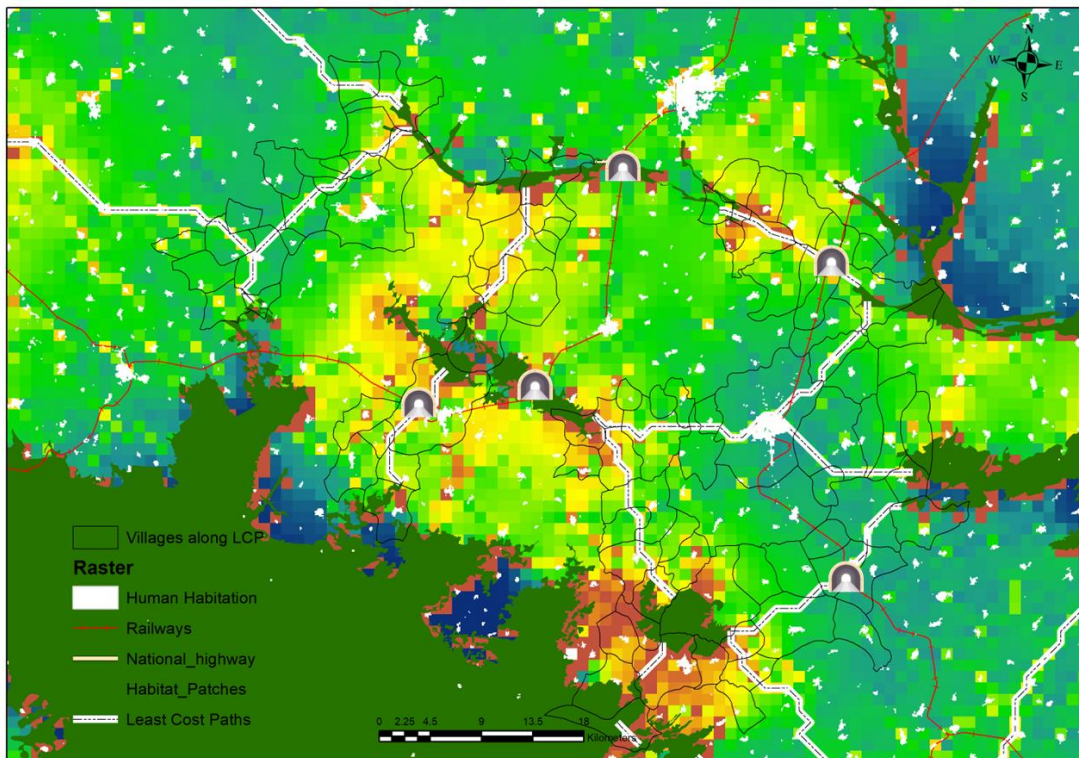
Table S3.5: List villages with major land-use categories along the least cost pathways connecting the Mitiyala WS and Palitana hill ranges with Gir Protected Area. Here: Area in km², length in km

NAME	DISTRICT	Area	Rail_lengt	CROPLANDS	FOREST	GRASSLANDS	HUMAN_HABI	SCRUBLAND	BARE_GROUN	WATER	Road_lengt	Drain_lengt
Savarkundla	Amreli	75.843	7.254	65.52	0.02	1.51	7.78	0.83	0.01	0.14	0.166	2.3
Ramgadh	Amreli	9.86779	0.019	9.76	0	0	0.1	0	0	0	2.813	0.761
Luvara	Amreli	13.7154	3.293	13.29	0	0.01	0.41	0	0	0.01	3.37	0.042
Goradka	Amreli	15.1896	2.668	14.62	0	0	0.56	0	0	0	0.053	1.697
Pithvadi	Amreli	20.353	0	18.97	0.14	0.38	0.68	0	0.02	0.1	1.944	1.67
Senjal	Amreli	14.5929	0	10.84	0.45	1.58	0.17	1.52	0	0.06	3.788	1.41
Mota Zinzuda	Amreli	36.1402	0	32.54	0	2.03	0.89	0.42	0	0.17	5.843	2.502
Vavdi	Amreli	4.52956	0	4.46	0	0	0.11	0	0	0	2.018	0.181
Dhargani	Amreli	23.1748	0	20.35	1.47	0.43	0.56	0.23	0	0.14	2.36	4.924
Samadhiyala Mota	Amreli	22.1866	0	21.69	0.05	0.03	0.51	0	0	0.01	3.444	2.801
Jabal	Amreli	16.6595	0	15.45	0	0.24	0.37	0	0	0.64	0.084	4.904
Mitiyala	Amreli	40.9001	0	16.86	0.59	1.98	0.45	20.79	0.01	0.28	1.308	1.223
Ingorala	Amreli	16.3749	0	13.82	0.1	1.81	0.43	0.03	0	0.12	0.119	3.237
Ambardi	Amreli	30.9257	0	27.92	0	0.43	0.81	0.07	0	1.71	0.047	1.047
Dolti	Amreli	14.4712	0	13.59	0	0.12	0.59	0	0	0.19	0.272	7.524
Khambha	Amreli	26.2897	0	20.51	0.07	0.62	1.38	3.61	0	0.15	1.351	5.533
Dadhiyali	Amreli	9.40313	0	6.37	0.01	0	0.24	2.75	0	0	2.238	3.134
Giniya	Amreli	2.04723	0	1.76	0	0	0.28	0	0	0	2.082	2.254
Khodiyana	Amreli	9.97974	0	9.39	0	0.34	0.25	0	0	0.01	2.689	2.5
Ditla	Amreli	6.06801	0	5.53	0.13	0.14	0.24	0	0	0	0	2.965
Kanatalav	Amreli	6.03633	0	5.89	0	0	0.18	0	0	0	0	3.403
Kaner	Amreli	5.26478	0	5.01	0	0.03	0.18	0.03	0	0.01	0	0.516
Hathasani	Amreli	15.0751	0	13.42	0.08	0.44	0.25	0	0.03	0.78	0	3.064
Lakhpadar	Amreli	14.9888	0	13.29	0.06	0.77	0.29	0.06	0.17	0.34	0	1.588
Nagadhra	Amreli	8.36888	0	7.32	0.06	0.25	0.41	0	0.02	0.35	0	1.976
Kotda	Amreli	7.77936	0	7.59	0	0.01	0.16	0	0	0	0	1.375

Pipalava	Amreli	20.8098	0	10.65	0.18	0.81	0.29	8.41	0.04	0.37	0	3.812
Nana Zinzuda	Amreli	11.5497	0	11.12	0	0.19	0.24	0	0	0	1.952	0
Bhenkra	Amreli	9.9501	0	6.47	0	1.37	0.23	1.76	0.01	0.13	3.827	0
Vijayanagar	Amreli	6.83585	0	4.82	0.01	0.31	0.13	1.54	0	0	1.787	0
Gadhakda	Amreli	28.3816	0	26.82	0	0.28	0.79	0.5	0	0	2.586	0
Likhala	Amreli	19.9336	0	17.29	0	1.58	0.41	0.47	0	0.16	2.604	0
Anida	Amreli	9.84834	0	9.29	0	0.31	0.2	0	0	0	1.88	0
Vankiya	Amreli	12.2108	0	11.33	0	0.56	0.23	0.12	0	0	4.49	0
Abhrampara	Amreli	14.6438	0	13.19	0	0.84	0.2	0.38	0	0.06	1.249	0
Bhad	Amreli	12.6262	0	6.93	0	2.68	0.22	2.75	0	0	4.618	0
Nanudi	Amreli	8.11811	0	2.92	0.1	1.6	0.17	3.34	0	0	3.192	0
Bagoya	Amreli	6.83277	0	6.39	0	0	0	0.38	0	0.05	0.389	0
Kodiya	Amreli	8.9376	0	8.09	0	0.05	0.18	0.6	0	0	0.587	0
Khambhaliya	Amreli	4.88942	0	4.88	0	0	0.03	0	0	0	0	0
Vaghvadi	Amreli	10.0274	0	6.81	0	1.33	0.13	1.68	0	0.05	0	0
Umariya	Amreli	11.3951	0	9.21	0	1.33	0.29	0.54	0	0	0	0

6. Gir Shetrunji corridor:

The Shetrunji river corridor serves as the lifeline for lion movements within the human-dominated landscape, extending all the way to the Palitana Hill Ranges in the Bhavnagar district. Encompassing a vast network of prosopis thickets along its banks, the Shetrunji river and its tributaries offer crucial refuge and cover for lions as they navigate through areas heavily influenced by human activity. In light of this, we propose the construction of four mitigation structures to facilitate the safe passage of lions across the busy railway lines that traverse this landscape.



Suggested underpass for movement of lion and other wild animals

Table S3.6: List villages with major land-use categories along the least cost pathways connecting the Shetrunji riverine forest patches with Gir Protected Area. Here: Area in km², length in km

NAME	DISTRICT	Area	CROPLANDS	FOREST	GRASSLANDS	HUMAN_HABI	SCRUBLAND	BARE_GROUN	WATER	Road_lengt	Drain_leng	Rail_lengt
Lonka	Amreli	4.17	3.75	0	0	0.09	0.36	0	0	0.743	0.357	0.106
Khadkala	Amreli	13.31	12.52	0	0.01	0.33	0.37	0	0.09	0.26	2.291	0.398
Bhuva	Amreli	14.89	14.46	0	0	0.41	0	0	0	4.594	0.92	0.517
Savarkundla	Amreli	75.84	65.52	0.02	1.51	7.78	0.83	0.01	0.14	0.166	2.3	7.254
Dhari	Amreli	50.01	32.5	0.07	4.6	4.11	3.26	1.19	4.28	0.085	0.931	1.102
Ramgadh	Amreli	9.87	9.76	0	0	0.1	0	0	0	2.813	0.761	0.019
Luvava	Amreli	13.72	13.29	0	0.01	0.41	0	0	0.01	3.37	0.042	3.293
Goradka	Amreli	15.19	14.62	0	0	0.56	0	0	0	0.053	1.697	2.668
Vaghaniya Juna	Amreli	23.89	22.25	0	0	0.66	0.83	0	0.15	0.161	2.011	0
Pithadiya	Amreli	13.07	12.48	0	0	0.47	0.11	0	0.09	4.686	2.047	0
Hadala	Amreli	15.12	14.6	0	0	0.41	0	0	0.08	4.06	4.287	0
Khari	Amreli	10.72	10.16	0	0	0.25	0.15	0	0.2	4.261	1.628	0
Babapur	Amreli	17.52	13.43	0.56	0.02	0.41	2.84	0.01	0.23	4.952	1.251	0
Amba	Amreli	16.95	16.08	0	0.03	0.47	0.16	0	0.24	0.223	0.141	0
Timbla	Amreli	17.57	15.75	0.07	0.03	0.19	1.39	0	0.07	1.878	0.85	0
Bagasara	Amreli	42.66	38.06	0.03	0.22	3.79	0	0.18	0.43	1.852	0.16	0
Gokharvala Mota	Amreli	6.22	5.72	0.02	0.17	0.24	0.02	0	0.04	0.363	2.804	0
Taravda	Amreli	7.71	7.18	0	0.24	0.18	0	0	0.14	0.649	1.655	0
Munjiasar Mota	Amreli	14.36	11.53	0	0.02	0.57	0	0.07	2.2	3.703	3.866	0
Chandgadh	Amreli	15.08	11.63	0.11	0.08	0.21	2.4	0	0.54	1.474	2.511	0
Lapaliya	Amreli	4.91	4.66	0	0	0.25	0	0	0	0.06	1.1	0
Lonki	Amreli	6.30	6.05	0	0	0.12	0.02	0	0.11	1.076	2.024	0
Sarambhda	Amreli	22.18	21.49	0	0.07	0.66	0	0.02	0	1.005	5.028	0
Jira	Amreli	22.10	21.31	0.05	0.03	0.44	0.17	0	0.09	1.304	1.158	0
Borala	Amreli	6.41	6.18	0.01	0.02	0.04	0.12	0	0.01	1.493	1.612	0

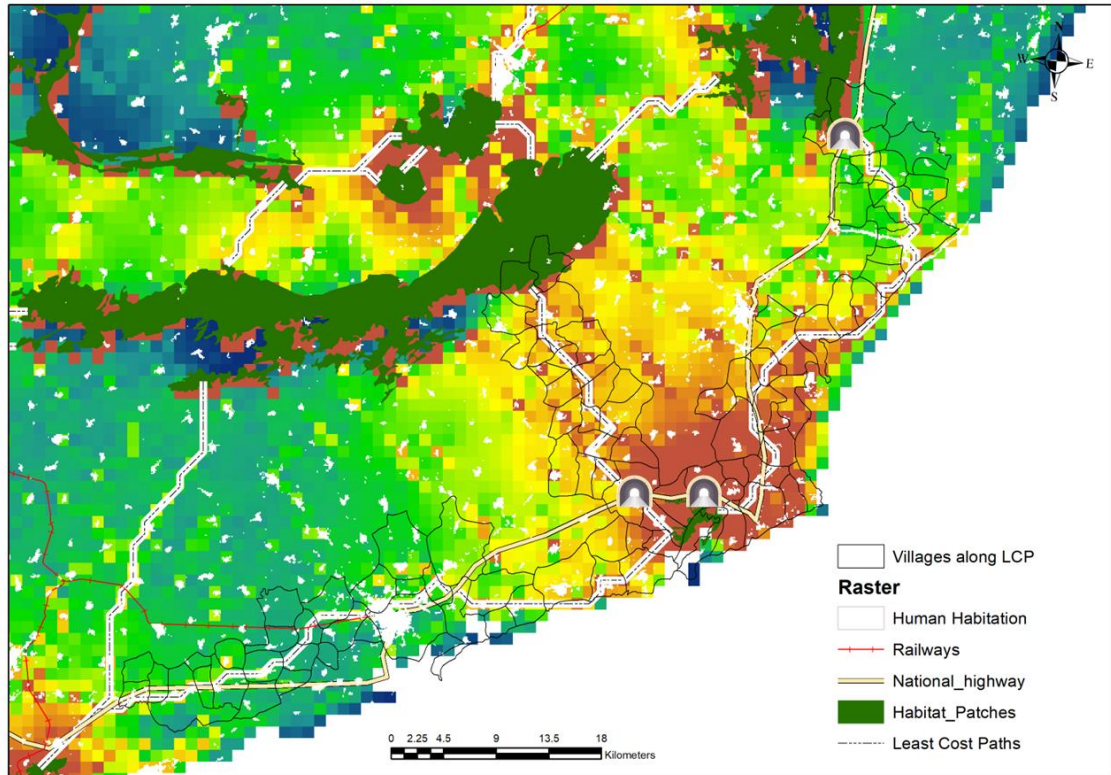
Juna Savar	Amreli	25.84	22.19	0.18	0.06	0.45	2.43	0	0.55	3.163	3.748	0
Kerala	Amreli	18.06	13.91	0.08	0	0.25	3.82	0	0.04	2.948	0.34	0
Halariya	Amreli	12.81	11.18	0.07	0.67	0.43	0.31	0.14	0	1.08	0.587	0
Gopalgram	Amreli	16.90	16.53	0	0	0.38	0	0	0	4.135	0.078	0
Padargadh	Amreli	10.93	9.89	0.04	0.21	0.05	0.65	0.1	0	1.956	2.326	0
Jhanjhesar	Junagadh	10.88	9.25	0.01	0.89	0.17	0	0.01	0.58	0.71	4.215	0
Kadaya	Amreli	5.25	4.79	0	0.3	0.16	0.01	0	0	2.115	1.484	0
Amrutvel	Amreli	12.57	12.06	0	0	0.3	0.24	0	0	1.074	1.212	0
Ambardi	Amreli	20.65	11.73	0.68	2.31	0.23	5.66	0.02	0.03	0.295	6.139	0
Moldi	Amreli	15.76	15.04	0	0	0.41	0.31	0	0	1.532	0.19	0
Pithvadi	Amreli	20.35	18.97	0.14	0.38	0.68	0	0.02	0.1	1.944	1.67	0
Senjal	Amreli	14.59	10.84	0.45	1.58	0.17	1.52	0	0.06	3.788	1.41	0
Mota Zinzuda	Amreli	36.14	32.54	0	2.03	0.89	0.42	0	0.17	5.843	2.502	0
Vavdi	Amreli	4.53	4.46	0	0	0.11	0	0	0	2.018	0.181	0
Dhargani	Amreli	23.17	20.35	1.47	0.43	0.56	0.23	0	0.14	2.36	4.924	0
Malshika	Amreli	12.68	12.08	0	0.19	0.38	0	0	0	0.063	2.598	0
Kubda	Amreli	9.78	9.48	0	0.05	0.29	0	0	0.03	2.834	1.095	0
Samadhiyala Mota	Amreli	22.19	21.69	0.05	0.03	0.51	0	0	0.01	3.444	2.801	0
Govindpur	Amreli	16.97	12.16	0.18	0.64	0.43	3.42	0	0.1	0.133	5.601	0
Jabal	Amreli	16.66	15.45	0	0.24	0.37	0	0	0.64	0.084	4.904	0
Mitiyala	Amreli	40.90	16.86	0.59	1.98	0.45	20.79	0.01	0.28	1.308	1.223	0
Ingorala	Amreli	16.37	13.82	0.1	1.81	0.43	0.03	0	0.12	0.119	3.237	0
Ambardi	Amreli	30.93	27.92	0	0.43	0.81	0.07	0	1.71	0.047	1.047	0
Dolti	Amreli	14.47	13.59	0	0.12	0.59	0	0	0.19	0.272	7.524	0
Khambha	Amreli	26.29	20.51	0.07	0.62	1.38	3.61	0	0.15	1.351	5.533	0
Dadhiyali	Amreli	9.40	6.37	0.01	0	0.24	2.75	0	0	2.238	3.134	0
Khodiyana	Amreli	9.98	9.39	0	0.34	0.25	0	0	0.01	2.689	2.5	0
Gokharvala Nana	Amreli	2.33	2.26	0	0.04	0.02	0	0	0.03	0	1.777	0
Hadmatiya Nana	Junagadh	7.63	7.05	0	0.18	0.39	0	0	0.05	0	0.584	0
Dittla	Amreli	6.07	5.53	0.13	0.14	0.24	0	0	0	0	2.965	0

Kanatalav	Amreli	6.04	5.89	0	0	0.18	0	0	0	0	3.403	0
Kaner	Amreli	5.26	5.01	0	0.03	0.18	0.03	0	0.01	0	0.516	0
Hathasani	Amreli	15.08	13.42	0.08	0.44	0.25	0	0.03	0.78	0	3.064	0
Lakhapadar	Amreli	14.99	13.29	0.06	0.77	0.29	0.06	0.17	0.34	0	1.588	0
Nagadhra	Amreli	8.37	7.32	0.06	0.25	0.41	0	0.02	0.35	0	1.976	0
Gigasan	Amreli	16.64	15.68	0	0.38	0.54	0	0	0.01	0	0.982	0
Kotda	Amreli	7.78	7.59	0	0.01	0.16	0	0	0	0	1.375	0
Pipalava	Amreli	20.81	10.65	0.18	0.81	0.29	8.41	0.04	0.37	0	3.812	0
Bhensvadi	Amreli	7.12	6.21	0	0	0.21	0.66	0	0.01	2.038	0	2.731
Devaliya	Amreli	11.32	10.97	0	0	0.33	0	0	0	1.566	0	0
Kankot Mota	Amreli	12.00	11.65	0	0	0.32	0.03	0	0	1.999	0	0
Haliyad Juni	Amreli	13.07	12.31	0	0.01	0.58	0	0	0.2	0.734	0	0
Deri Pipaliya	Amreli	11.44	11.1	0	0	0.33	0	0	0	1.38	0	0
Medi	Amreli	3.10	3.02	0	0	0.02	0	0	0	1.005	0	0
Manekvada	Amreli	6.70	6.21	0	0.19	0.29	0	0	0.01	1.535	0	0
Mandavda Nana	Amreli	2.80	2.7	0	0	0.1	0	0	0	0.88	0	0
Pindakhai Nani	Junagadh	12.14	11.38	0	0.52	0.21	0	0	0	2.049	0	0
Bhalgam	Junagadh	18.92	18.09	0	0.22	0.6	0	0	0	3.675	0	0
Rafala	Amreli	3.12	2.87	0	0	0.18	0	0	0.06	1.022	0	0
Hulariya	Amreli	3.24	3.12	0	0.05	0.03	0.01	0	0	0.427	0	0
Jambuda	Junagadh	12.83	12.19	0	0.31	0.3	0	0	0	3.565	0	0
Nana Zinzuda	Amreli	11.55	11.12	0	0.19	0.24	0	0	0	1.952	0	0
Bhenkra	Amreli	9.95	6.47	0	1.37	0.23	1.76	0.01	0.13	3.827	0	0
Vijayanagar	Amreli	6.84	4.82	0.01	0.31	0.13	1.54	0	0	1.787	0	0
Gadhakda	Amreli	28.38	26.82	0	0.28	0.79	0.5	0	0	2.586	0	0
Likhala	Amreli	19.93	17.29	0	1.58	0.41	0.47	0	0.16	2.604	0	0
Anida	Amreli	9.85	9.29	0	0.31	0.2	0	0	0	1.88	0	0
Vankiya	Amreli	12.21	11.33	0	0.56	0.23	0.12	0	0	4.49	0	0
Abhrampara	Amreli	14.64	13.19	0	0.84	0.2	0.38	0	0.06	1.249	0	0
Bhad	Amreli	12.63	6.93	0	2.68	0.22	2.75	0	0	4.618	0	0

Nanudi	Amreli	8.12	2.92	0.1	1.6	0.17	3.34	0	0	3.192	0	0
Kodiya	Amreli	8.94	8.09	0	0.05	0.18	0.6	0	0	0.587	0	0
Khadadhar	Amreli	19.90	7.64	0.47	1.05	0.37	10.4	0	0	3.521	0	0
Pipaliya Nava	Amreli	2.62	2.61	0	0	0	0	0	0	0	0	0
Adpur	Amreli	3.36	3.27	0	0	0.06	0	0	0	0	0	0
Khambhaliya	Amreli	4.89	4.88	0	0	0.03	0	0	0	0	0	0
Vaghvadi	Amreli	10.03	6.81	0	1.33	0.13	1.68	0	0.05	0	0	0
Umariya	Amreli	11.40	9.21	0	1.33	0.29	0.54	0	0	0	0	0

7. Palitana Mahua corridor:

The direct migration of lions from Gir to the coastal forests in the Mahua taluka and beyond presents challenges; nevertheless, lions have been observed to traverse into these coastal woodlands from the Palitana Hill Ranges. Through our research, we have pinpointed these crucial corridors and identified the least-cost paths that link these habitats. To ensure the safe passage of lions across the landscape intersected by busy railway lines and the national highways, we propose the implementation of three significant mitigation structures.



Suggested underpass for movement of lion and other wild animals

Table S3.7: List villages with major land-use categories along the least cost pathways connecting the coastal forest patches of Mahua with Gir Protected Area. Here: Area in km², length in km

NAME	DISTRICT	Area	CROPLANDS	FOREST	GRASSLANDS	HUMAN_HABI	SCRUBLAND	BARE_GROUN	WATER	Road_lengt	Drain_leng	Rail_lengt
Bhanvad	Bhavnagar	10.9116	9.76	0	0	1.16	0	0	0	0.388	2.986	1.159
Mahuva	Bhavnagar	25.9875	12.29	3.25	0.6	9.11	0.31	0.2	0.23	0.976	0.161	2.292
Kukad	Bhavnagar	11.4722	10.93	0	0.27	0.27	0	0	0.03	2.88	3.81	0
Rajpara No.2	Bhavnagar	10.0439	8.27	0	0.25	0.75	0.79	0	0.01	3.869	1.431	0
Navagam(Nana)	Bhavnagar	6.4356	6.18	0	0.08	0.12	0	0	0.04	1.759	0.161	0
Bhankhal	Bhavnagar	8.33718	7.25	0	0.64	0.47	0	0	0.03	1.909	3.603	0
Alang	Bhavnagar	15.827	12.48	0.25	0.44	2.63	0	0	0.02	1.242	3.548	0
Kalmodar	Bhavnagar	10.5609	5.2	0	2.6	0.14	2.65	0	0	4.37	2.886	0
Ralgon	Bhavnagar	12.9284	12.27	0	0	0.62	0	0	0	1.054	3.461	0
Tarsara	Bhavnagar	11.7421	9.81	0	0.64	0.71	0.39	0.01	0.2	4.417	2.133	0
Bagdana	Bhavnagar	9.90512	8.61	0	0.23	1.01	0	0	0	0.1	2.859	0
Dakana	Bhavnagar	11.9717	10.31	0	0.89	0.41	0	0	0.35	4.694	2.199	0
Dudana	Bhavnagar	3.76715	3.55	0	0	0.23	0	0	0	1.662	2.462	0
Dharai	Bhavnagar	5.79232	5.2	0	0.03	0.59	0	0	0.03	2.387	0.912	0
Borla	Bhavnagar	3.61053	3.47	0	0.02	0.11	0	0	0.03	0.208	1.176	0
Samadhiyala No.3	Bhavnagar	3.73057	3.43	0	0.03	0.09	0	0.12	0.06	1.529	1.165	0
Khardi	Bhavnagar	5.29927	5.01	0	0.08	0.03	0	0.09	0.07	0.126	1.2	0
Padargadh	Bhavnagar	7.12835	6.98	0	0	0.2	0	0	0	0.123	0.945	0
Gundarana	Bhavnagar	6.14301	5.49	0	0.17	0.25	0	0.17	0.08	1.463	1.009	0
Mahadevpara	Bhavnagar	5.86898	5.51	0	0	0.3	0.03	0	0.05	0.393	0.943	0
Vavadi	Bhavnagar	7.2685	6.5	0	0	0.76	0	0	0	1.578	2.845	0
Unchdi	Bhavnagar	16.2846	15.36	0	0	0.67	0.11	0	0.09	1.242	3.275	0
Nichadi	Bhavnagar	2.58829	2.32	0	0.02	0.25	0	0	0	1.143	1.351	0
Bhaguda	Bhavnagar	6.76178	5.79	0	0.19	0.69	0.11	0	0	0.265	0.694	0
Bordi	Bhavnagar	3.49649	3.08	0	0	0.37	0	0	0	0.703	1.8	0
Ambla	Bhavnagar	8.50485	6.14	0	0.61	0.49	0.62	0.16	0.47	0.223	1.327	0

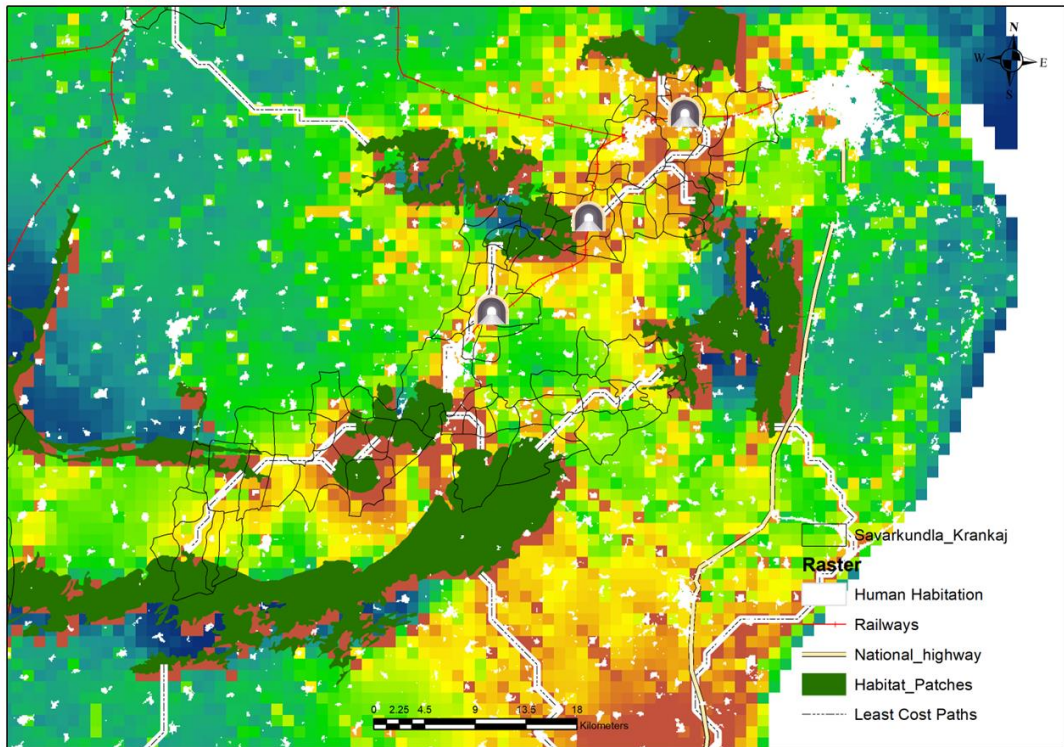
Moti Jagdhar	Bhavnagar	7.26351	6.35	0	0.03	0.85	0	0	0.04	2.379	1.004	0
Longdi	Bhavnagar	11.1869	10.29	0	0.08	0.75	0	0.05	0.04	0.038	1.23	0
Vejodari	Bhavnagar	8.94419	8.32	0	0	0.56	0	0	0.04	0.438	3.872	0
Lilvan	Bhavnagar	4.72509	4.28	0	0	0.41	0	0	0	0.944	1.166	0
Datha	Bhavnagar	16.8786	15.87	0	0.09	0.88	0	0	0.03	2.291	4.088	0
Valar	Bhavnagar	10.8166	10.45	0.06	0.01	0.17	0.06	0	0.05	0.279	4.885	0
Talli	Bhavnagar	6.95907	5.94	0.03	0.08	0.42	0.51	0	0	0.063	1.08	0
Methla	Bhavnagar	8.50043	4.47	1.4	0.71	0.34	0.59	0.08	0.96	0.392	0.583	0
Bhadrod	Bhavnagar	26.0713	24.05	0	0	1.79	0.27	0	0.03	1.761	0.602	0
Katakda	Bhavnagar	9.54739	9.11	0	0	0.25	0.2	0	0	1.356	0.946	0
Bhatakda	Bhavnagar	3.9524	3.79	0	0	0.12	0	0	0	0.618	0.132	0
Talgajarada	Bhavnagar	19.5028	18.04	0	0.03	1.44	0	0	0	1.793	6.327	0
Bambhor	Bhavnagar	4.826	4.52	0	0.1	0.09	0	0	0.1	2.084	2.255	0
Vadli	Bhavnagar	5.116	4.72	0	0.02	0.35	0	0	0	0.363	0.672	0
Sathara	Bhavnagar	14.2114	13.65	0	0	0.56	0	0	0.01	5.857	4.245	0
Nesvad	Bhavnagar	9.97213	6.41	0.04	0.06	3.3	0	0	0.19	0.794	2.035	0
Vagnagar	Bhavnagar	14.8491	8.09	0.34	0.88	0.7	0.1	2.54	2.17	1.137	0.581	0
Umaniyavadar	Bhavnagar	3.09269	2.65	0	0	0.42	0	0	0	1.787	0.368	0
Dantardi	Amreli	9.86793	9.24	0	0	0.48	0.15	0	0.01	0.109	4.07	0
Padhiyarka	Bhavnagar	4.53802	3.69	0	0	0.18	0.66	0	0	0.111	1.731	0
Visaliya	Amreli	4.4699	4.38	0	0.05	0.06	0	0.01	0	1.33	0.212	0
Kathivadar	Amreli	20.0542	8.87	0.12	1.55	0.79	0.41	4.68	3.55	0.079	1.263	0
Majadar	Amreli	4.88645	4.88	0	0.01	0	0	0	0	0.144	3.584	0
Mota Jadra	Bhavnagar	8.31635	7.48	0	0	0.88	0	0	0	0	2.995	3.111
Chaniyala	Bhavnagar	4.6639	4.44	0	0.09	0.05	0	0	0.09	0	2.31	0
Lilivav	Bhavnagar	5.05101	4.44	0	0.12	0.27	0	0	0.24	0	1.796	0
Kodiya	Bhavnagar	10.3671	9.9	0	0.05	0.28	0	0.06	0.02	0	1.166	0
Kumbhariya	Bhavnagar	3.5222	2.9	0	0.07	0.17	0	0.29	0.1	0	2.522	0
Nani Jagdhar	Bhavnagar	5.6514	4.74	0	0.51	0.29	0.1	0	0.01	0	2.069	0
Rabhda	Amreli	5.53139	5.24	0	0	0.3	0	0	0	0	3.567	0

Nesdi No -1	Amreli	2.21627	2.13	0	0	0.09	0	0	0	0	1.078	0
Samadhiyala No-1	Amreli	8.17172	5.46	0	0.96	0.32	0.69	0.41	0.33	0	4.3	0
Tanasa	Bhavnagar	19.2672	14.16	0	0.16	0.66	4.34	0	0	2.979	0	0
Goriyali	Bhavnagar	8.0539	6.82	0	0.11	0.21	0.88	0	0	1.35	0	0
Trapaj	Bhavnagar	10.7953	10.33	0	0.17	0.16	0	0	0.07	3.322	0	0
Kathava	Bhavnagar	4.07586	4.02	0	0	0.01	0	0	0	1.343	0	0
Bharapara	Bhavnagar	3.7342	3.53	0	0.07	0.15	0	0	0	1.419	0	0
Kotiya	Bhavnagar	9.7581	3.07	0.07	3.63	0.09	2.59	0	0.3	3.334	0	0
Mathavda	Bhavnagar	7.73864	4.77	0	1	0.45	1.21	0.1	0.19	3.008	0	0
Padari(Gohil)	Bhavnagar	9.46907	8.55	0	0.02	0.63	0.21	0	0.07	2.543	0	0
Chopada	Bhavnagar	7.96934	7.48	0	0.07	0.31	0	0.01	0.06	3.406	0	0
Sakhvadar	Bhavnagar	6.61823	6.02	0	0.13	0.41	0	0.01	0.01	1.022	0	0
Fulsar	Bhavnagar	7.63409	6.82	0	0.02	0.07	0.75	0	0	3.299	0	0
Khandhera	Bhavnagar	9.96908	7.69	0	0.99	0.24	0.24	0.53	0.28	0.321	0	0
Kundali	Bhavnagar	5.19225	5.21	0	0	0	0	0	0	1.491	0	0
Borda	Bhavnagar	10.6352	9.71	0	0	0.92	0	0	0.01	5.697	0	0
Vataliya	Bhavnagar	8.461021	7.76	0	0	0.35	0.38	0	0	2.118	0	0
Pithalpur	Bhavnagar	6.67021	6.07	0	0.01	0.41	0.2	0	0.01	3.359	0	0
Gadhula	Bhavnagar	5.15847	2.18	0.03	1.14	0.48	0.02	0.01	1.29	0.914	0	0
Kerala	Bhavnagar	3.91671	3.9	0	0	0	0	0	0	0.402	0	0
Nava Rajpara	Bhavnagar	5.44047	4.9	0	0.23	0.28	0.01	0.01	0	1.633	0	0
Pratapara	Bhavnagar	4.04801	3.45	0	0	0.59	0	0	0	2.223	0	0
Zanzmer	Bhavnagar	14.4556	12.5	0.06	0.49	1.21	0.07	0.01	0.13	0.965	0	0
Madhuvan	Bhavnagar	8.09998	6.75	0.23	0.3	0.55	0.21	0	0.05	0.416	0	0
Kalsar	Bhavnagar	18.0674	16.23	0.01	0.06	1.82	0	0	0	4.574	0	0
Uncha Kotda	Bhavnagar	13.011	9.99	0.34	0.57	1.13	0.06	0.29	0.65	1.501	0	0
Dayal	Bhavnagar	8.2058	7.08	0	0.18	0.95	0	0	0	3.008	0	0
Naip	Bhavnagar	8.341641	7.66	0	0	0.64	0	0	0	3.256	0	0
Nikol	Bhavnagar	5.07477	3.02	0	0.55	0.19	0.24	0.8	0.29	1.128	0	0
Maliya	Bhavnagar	3.2129	2.78	0	0	0.41	0	0	0	1.508	0	0

Dudhala No.1	Bhavnagar	3.06301	2.98	0	0	0.05	0	0	0	1.091	0	0
Madhiya	Bhavnagar	5.89145	5.64	0	0	0.23	0	0	0	2.462	0	0
Jholapar	Amreli	5.06701	5.09	0	0	0	0	0	0	2.046	0	0
Pipavav	Amreli	4.62412	3.54	0	0.22	0.76	0	0.1	0.02	2.505	0	0
Bildi	Bhavnagar	6.11858	5.73	0	0	0.45	0	0	0	0	0	2.592
Sankhadasar No.2	Bhavnagar	5.5928	2.65	0	0.4	0.23	2.36	0	0	0	0	0
Dundas	Bhavnagar	9.83266	9.42	0	0.04	0.31	0	0	0	0	0	0

8. Palitana Bhavnagar Corridor:

Significant connectivity exists between the forest patches of Palitana and the Bhavnagar district. Through our research, we have meticulously identified the existing corridors that link these vital habitat patches. Additionally, we have pinpointed key locations where the construction of mitigation structures is warranted, aiming to enhance and facilitate the movement of lions within this interconnected landscape.



Suggested underpass for movement of lion and other wild animals

Table S3.8: List villages with major land-use categories along the least cost pathways connecting the coastal forest patches of Bhavnagar district with the Palitana Hill ranges. Here: Area in km², length in km

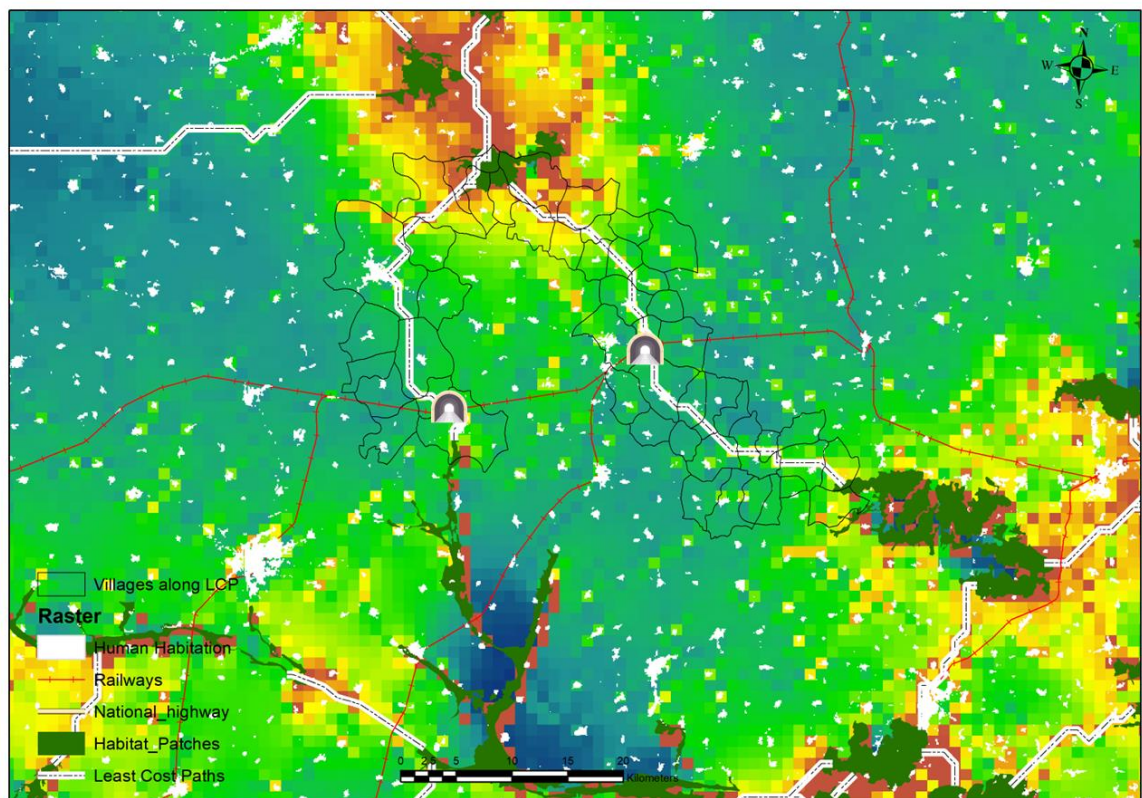
NAME	DISTRICT	Area	CROPLANDS	FOREST	GRASSLANDS	HUMAN_HABI	SCRUBLAND	BARE_GROUN	WATER	Road_lengt	Drain_leng	Rail_lengt
Dhasa Vishi	Bhavnagar	19.76	16.98	0	0.16	2.18	0	0	0.41	2.367	3.475	3.24
Vartej	Bhavnagar	23.62	17.22	0.01	1.03	4.4	0.81	0	0.14	1.112	4.861	0.944
Khakhariya	Bhavnagar	3.23	3.02	0	0	0.18	0	0	0	0.424	1.046	1.095
Sihor	Bhavnagar	29.24	11.01	1.81	4.68	6.48	5.11	0	0.07	0.045	4.481	1.021
Rajpara (Khodiyar)	Bhavnagar	9.84	5.48	0.02	2.01	0.9	1	0.04	0.42	2.478	2.876	0.554
Mahadevpara	Bhavnagar	4.66	2.86	0	1.09	0.02	0.03	0.08	0.59	0.828	0.262	0.851
Randola	Bhavnagar	11.17	10.86	0	0	0.36	0	0	0.01	0.602	1.66	2.124
Sagapara	Bhavnagar	3.71	3.51	0	0.11	0.07	0	0	0	0.083	0.464	0.546
Palitana	Bhavnagar	40.57	17.47	0.03	2.62	7.2	12.87	0	0.36	0.972	4.54	0.88
Patana	Bhavnagar	13.22	11.89	0	0.05	0.68	0.01	0	0.62	1.075	2.717	0
Bhojpura	Bhavnagar	6.73	6.11	0.05	0	0.59	0.01	0	0	3.185	3.16	0
Vadiya	Bhavnagar	4.10	3.59	0	0.01	0.48	0	0	0	1.614	0.753	0
Juna Jaliya	Bhavnagar	6.64	2.77	0.01	2.96	0.11	0.71	0.05	0.06	0.775	2.268	0
Bhadli	Bhavnagar	10.00	6.84	0	2.57	0.18	0.41	0.01	0.02	1.643	0.583	0
Sar	Bhavnagar	4.60	2.96	0	0.77	0.17	0.24	0	0.42	1.73	2.367	0
Kajavadar	Bhavnagar	7.98	7.25	0	0.28	0.42	0	0	0	2.952	2.256	0
Mokhadaka	Bhavnagar	7.00	6.77	0	0	0.18	0.07	0	0.01	1.672	1.477	0
Bharatimba	Bhavnagar	6.00	5.56	0	0	0.46	0	0	0	0.304	0.957	0
Malpara	Bhavnagar	2.96	2.55	0	0	0.4	0	0	0	2.654	0.16	0
Moti Rajasthali	Bhavnagar	5.60	4.97	0	0	0.62	0	0	0.02	0.07	0.56	0
Varal	Bhavnagar	29.10	24.18	0	3.02	1.03	0.89	0	0	6.389	1.216	0
Mandavda	Bhavnagar	8.16	5.82	0	0.2	0.19	0	0.96	1.02	0.518	3.296	0
Bakhalka	Bhavnagar	9.73	7.46	0	0.88	0.33	0.66	0	0.42	0.206	1.716	0
Anida(Lakhavad)	Bhavnagar	5.68	5.3	0	0.06	0.3	0	0	0	0.164	1.733	0
Bhutiya	Bhavnagar	5.72	4.29	0	0.56	0.9	0	0.02	0	1.162	2.769	0
Pingali	Bhavnagar	14.25	13.12	0	0.15	0.6	0	0	0.4	4.282	4.318	0

Lakhavad	Bhavnagar	5.40	4.83	0	0.07	0.34	0	0	0.14	1.656	0.243	0
Nani Rajasthali	Bhavnagar	23.01	7.74	0.02	6.67	0.8	7.3	0.03	0.43	3.1	0.579	0
Satapada	Bhavnagar	14.55	13.72	0	0.02	0.43	0	0.05	0.4	0.494	0.337	0
Samadhiyala	Bhavnagar	11.96	11.51	0	0	0.37	0	0	0.07	3.515	2.02	0
Jaliya(Manaji)	Bhavnagar	5.66	5.17	0	0	0.42	0	0	0.06	0.266	0.835	0
Vadal	Bhavnagar	26.73	4.88	0	5.29	0.28	8.56	1.68	6	5.568	5.576	0
Hathsani	Bhavnagar	14.40	8.77	0.05	0.16	0.18	2.61	1.44	1.16	0.25	2.897	0
Ranigam	Bhavnagar	19.51	16.09	0.06	0.11	0.59	2.4	0	0.28	3.51	0.75	0
Piparadi	Amreli	6.86	4.42	0	0	0.2	2.03	0	0.14	1.668	0.25	0
Chok	Bhavnagar	15.43	1.82	0.19	1.01	0.12	6.25	3.95	2.06	2.25	0.976	0
Depla	Bhavnagar	11.83	10.98	0	0.01	0.22	0.38	0	0.24	2.589	0.834	0
Kantrodi	Amreli	19.30	9.54	0	4.93	0.59	4.21	0	0	2.792	0.209	0
Shampara	Bhavnagar	4.87	4.63	0	0	0.27	0	0	0	0	1.334	0.004
Khijadiya	Bhavnagar	7.33	6.7	0	0.01	0.14	0.17	0	0.32	0	0.961	0
Khijadiya(Mokhadaka)	Bhavnagar	2.85	2.61	0	0	0	0.21	0	0	0	0.864	0
Thorali	Bhavnagar	5.62	4.81	0	0.22	0.27	0	0	0.31	0	2.406	0
Ranparda (Chok)	Bhavnagar	10.00	9.57	0	0	0	0	0.1	0.31	0	0.889	0
Mandva	Bhavnagar	17.77	17	0	0.15	0.49	0	0	0.05	5.289	0	5.26
Bhandariya	Bhavnagar	5.26	4.92	0	0	0.33	0	0	0.07	0.022	0	0.674
Kanad	Bhavnagar	17.93	12.4	0	3.34	0.2	2	0	0	3.362	0	4.743
Khari	Bhavnagar	4.66	3.97	0	0.4	0.31	0	0	0	1.872	0	0.998
Virpur (Palitana)	Bhavnagar	3.70	2.45	0	0.02	1.19	0	0	0	2.004	0	2.575
Sodvadra	Bhavnagar	7.23	6.13	0	0.81	0.22	0.03	0.06	0.01	3.351	0	0
Dhrupka	Bhavnagar	4.71	3.13	0	1.17	0.17	0.19	0	0	0.305	0	0
Khambha	Bhavnagar	6.24	5.59	0	0.46	0.19	0.06	0	0	0.892	0	0
Sakhvadar	Bhavnagar	6.49	5.96	0	0.14	0.38	0	0	0.01	0.468	0	0
Nava Jaliya	Bhavnagar	5.82	3.62	0	1.6	0.11	0.44	0	0	1.627	0	0
Kumbhan	Bhavnagar	11.18	8.41	0	1.11	0.37	1.27	0	0.05	2.522	0	0
Rabarika	Bhavnagar	6.38	4.99	0	1.08	0.2	0	0	0.03	1.481	0	0
Juna Sarod	Bhavnagar	4.01	1.4	0	0.99	0.16	1.43	0	0.01	1.855	0	0

Todi	Bhavnagar	4.97	0.97	0	2.24	0.04	1.7	0	0.03	0.701	0	0
Nava Sroda	Bhavnagar	2.92	2.67	0	0.11	0.12	0.02	0	0	1.761	0	0
Sarkadia (Tana)	Bhavnagar	8.20	7.61	0	0.07	0.46	0.06	0	0.02	1.943	0	0
Luvarvav	Bhavnagar	4.70	3.57	0	0.06	1.08	0	0	0.04	0.497	0	0
Dedarada	Bhavnagar	10.14	9.7	0	0	0.42	0	0	0	2.834	0	0
Sonpari	Bhavnagar	4.44	1.96	0	1.63	0.32	0.27	0.01	0.27	1.806	0	0
Nani Mandavali	Bhavnagar	4.80	4.27	0	0.47	0.05	0.02	0	0	0.327	0	0
Kanjarada	Bhavnagar	5.56	4.93	0	0.42	0.13	0.11	0	0.02	1.513	0	0
Nani Paniyali	Bhavnagar	5.51	2.22	0	0.66	0.32	0.02	1.39	0.91	2.3	0	0
Nana Garajiya	Bhavnagar	3.94	1.29	0	1.97	0.25	0.39	0	0.01	0.025	0	0
Jaliya(Amaraji)	Bhavnagar	11.87	7.53	0.01	0.89	0.38	3.07	0	0.02	0.886	0	0
Rohishala	Bhavnagar	11.19	2.59	0	0.72	0.31	5.62	1.37	0.6	2.603	0	0
Gandhol	Bhavnagar	5.94	2.03	0	0.14	0.04	3.75	0	0	0.94	0	0
Hipavadli	Amreli	7.27	7.11	0	0	0.19	0	0	0	0.303	0	0
Pa	Bhavnagar	11.04	8.57	0	1.09	0.23	1.13	0	0	1.954	0	0
Zadkala	Amreli	7.22	4.63	0	1.88	0.24	0.5	0	0	1.224	0	0
Kedariya	Amreli	5.55	3.75	0	1	0.04	0.76	0	0	1.514	0	0
Thorali	Bhavnagar	3.72	0.55	0	1.62	0	0.19	0.67	0.71	0	0	0
Mota Garajiya	Bhavnagar	2.45	0.9	0	1.15	0	0.18	0.03	0.18	0	0	0

9. Shetrunji Hingolghad Corridor:

These corridors serve as vital connections between the extended tributaries of the Shetrunji river and the northern part of the Saurashtra landscape, traversing through a diverse terrain of riverine forest patches, agricultural landscapes, and small forested hillocks and grassland patches. The forested areas along the tributaries of the Shetrunjay create a highly permeable corridor, facilitating the movement of lions into the forests of Hingolghad Wildlife Sanctuary and adjacent areas. In the past few decades, many lions have been observed to visit the Hingolghad WS and adjacent areas.



Suggested underpass for movement of lion and other wild animals

Table S3.9: List villages with major land-use categories along the least cost pathways connecting the riverine forests patches of the human-dominated landscape in the Amreli and Bhavnagar district with the Hingolghadh Wildlife Sanctuary in Jasdand District. Here: Area in km², length in km

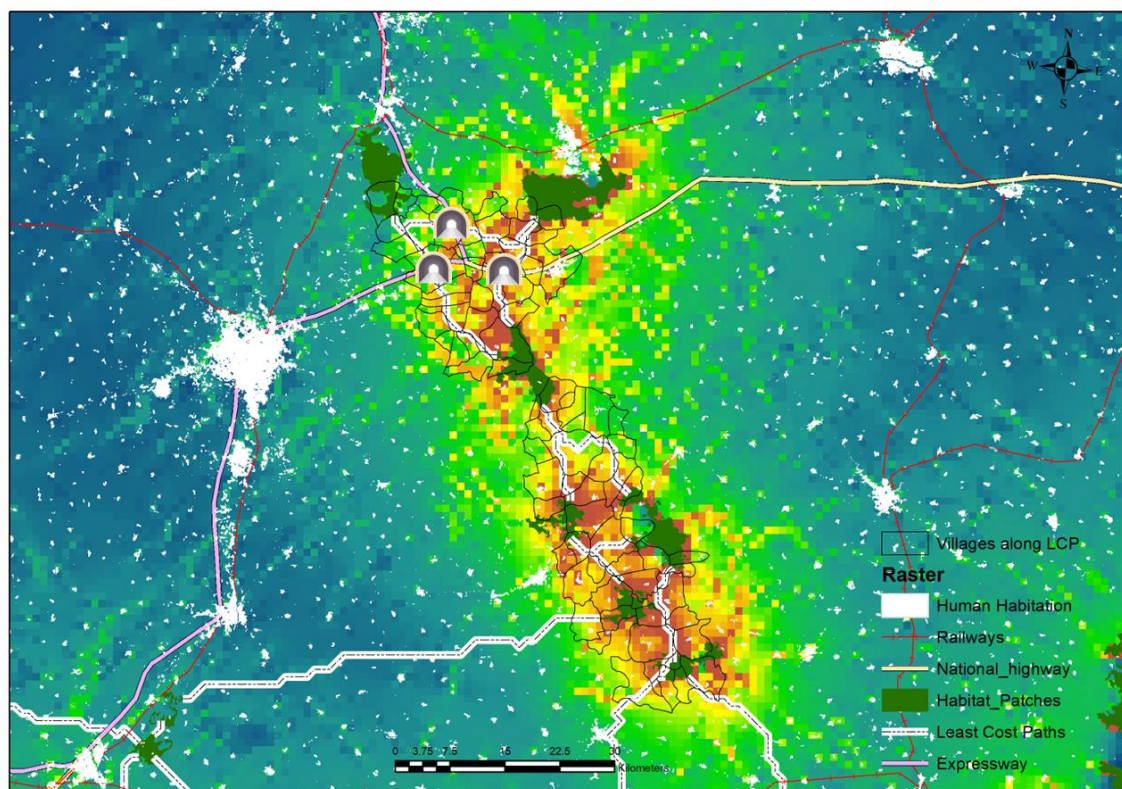
NAME	DISTRICT	Area	CROPLANDS	FOREST	GRASSLANDS	HUMAN_HABI	SCRUBLAND	BARE_GROUN	WATER	Road_lengt	Drain_leng	Rail_lengt
Dhasa Vishi	Bhavnagar	19.76	16.98	0	0.16	2.18	0	0	0.41	2.367	3.475	3.24
Kanchardi	Amreli	12.31	11.43	0	0.01	0.78	0	0	0.04	1.549	0.4	0.089
Harsurpur	Amreli	14.18	13.36	0	0	0.39	0.02	0	0.34	4.776	2.423	0.856
Keriya	Amreli	7.09	5.96	0	0	0.08	0.69	0	0.37	2.361	1.742	1.604
Lathi	Amreli	35.38	31.69	0	0.15	2.55	0.05	0	0.89	2.736	5.698	0.984
Jarakhiya	Amreli	14.87	14.08	0	0	0.57	0	0	0.26	3.238	0.087	1.658
Kundal Nani	Amreli	22.51	11.5	1.45	4.77	0.25	4.17	0	0.31	1.323	0.189	0
Kariyana	Amreli	29.32	24.63	0	1.65	0.86	0	0.21	1.95	4.654	5.316	0
Moti Kundal	Bhavnagar	16.34	13.72	0	1.98	0.31	0.1	0	0.25	2.333	4.065	0
Gundala	Bhavnagar	21.00	20.45	0	0.05	0.4	0	0	0.07	0.038	5.036	0
Limbadiya	Bhavnagar	13.04	10.4	0.09	2.21	0.23	0.08	0	0.04	0.051	3.575	0
Padvadar	Bhavnagar	8.50	7.98	0	0.28	0.25	0	0	0	4.255	0.131	0
Ingorala	Bhavnagar	5.35	4.93	0	0.05	0.21	0	0	0.17	1.206	1.855	0
Babra	Amreli	60.15	51.38	0	2.53	4.76	0	0.14	1.34	3.618	2.59	0
Khakhariya	Amreli	15.80	14.62	0.01	0.82	0.34	0	0	0.08	2.452	3.576	0
Malpara	Bhavnagar	6.62	4.66	0	0.02	0.33	0	0.03	1.57	2.112	3.531	0
Patana	Bhavnagar	13.22	11.89	0	0.05	0.68	0.01	0	0.62	1.075	2.717	0
Galkotdi	Amreli	17.04	16.31	0	0.2	0.49	0	0	0.06	2.074	1.691	0
Vandaliya	Amreli	18.75	17.91	0	0	0.48	0	0	0.3	1.537	4.349	0
Shekhipariya	Amreli	26.13	24.89	0	0	0.58	0.2	0	0.46	3.645	1.204	0
Jalalpur	Bhavnagar	20.70	19.58	0	0.17	0.89	0	0	0.08	0.988	0.313	0
Mota Umarda	Bhavnagar	9.19	8.53	0	0.26	0.29	0	0	0.07	2.754	2.326	0
Nana Umarda	Bhavnagar	11.95	11.49	0	0.05	0.31	0	0	0.11	3.923	1.606	0
Punjapar	Amreli	8.68	8.57	0	0	0.01	0	0	0.13	2.269	2.565	0
Hadmatiya	Bhavnagar	13.30	8.61	0	0.8	0.29	0.02	0.28	3.32	0.449	0.181	0
Dhrufania	Amreli	9.23	7.93	0	0.11	0.3	0	0.08	0.81	3.695	1.91	0

Suvagadh	Amreli	6.95	6.8	0	0	0.11	0	0	0.07	2.746	1.691	0
Thonda	Bhavnagar	4.36	3.93	0	0.04	0.23	0	0	0.19	0.06	2.171	0
Zariya	Bhavnagar	11.39	10.49	0	0.6	0.31	0.05	0	0.01	1.304	1.204	0
Vikaliya	Bhavnagar	13.78	12.52	0	0.33	0.52	0	0	0.42	0.12	1.317	0
Piparadi	Bhavnagar	13.33	11.9	0	0.52	0.56	0	0	0.26	0.395	2.733	0
Mandvi	Bhavnagar	13.91	11.98	0	1.19	0.61	0	0.08	0.06	1.953	4.446	0
Bhamariya	Bhavnagar	13.14	12.17	0	0.43	0.4	0	0.04	0.05	3.595	0.906	0
Kharadi	Bhavnagar	5.95	5.82	0	0	0.14	0	0	0.02	0.766	0.135	0
Manpur	Bhavnagar	8.25	7.9	0	0.11	0.21	0	0	0.01	0.273	0.746	0
Sitapar	Bhavnagar	9.08	8.46	0	0.18	0.33	0	0	0.15	0	3.078	0
Ghogha Samdi	Bhavnagar	8.73	7.67	0.21	0	0.26	0.08	0	0.52	0	2.646	0
Pipardi	Bhavnagar	8.13	7.78	0	0	0.27	0	0	0.05	0	1.419	0
Khijadiya	Bhavnagar	7.33	6.7	0	0.01	0.14	0.17	0	0.32	0	0.961	0
Gangavada	Bhavnagar	6.82	3.84	0	0.32	0	0	0.15	2.54	0	2.186	0
Mandva	Bhavnagar	17.77	17	0	0.15	0.49	0	0	0.05	5.289	0	5.26
Bhandariya	Bhavnagar	5.26	4.92	0	0	0.33	0	0	0.07	0.022	0	0.674
Ishvariya	Amreli	11.54	6.67	0.57	2.44	0.12	1.75	0	0	2.116	0	0
Sirvaniya	Amreli	8.10	4.98	0.77	1.5	0.12	0.64	0	0.13	0.336	0	0
Kidi	Amreli	10.58	7.34	0.03	2.07	0.23	0.82	0	0.08	2.247	0	0
Bhutiya	Bhavnagar	9.25	8.88	0	0.02	0.3	0	0	0	2.32	0	0
Sarkadiya (Songadh)	Bhavnagar	3.64	3.53	0	0	0.11	0	0	0	0.273	0	0
Sarvedi	Bhavnagar	13.08	11.69	0.01	1.06	0.22	0.11	0	0	1.373	0	0

10: Hingolgadh to Rampara Wildlife Sanctuary:

The connectivity of habitats between Hingolgadh Wildlife Sanctuary (WS) and the expansive grassland plateaus in the Chotila Taluka of Surendernagar District makes the landscape highly permeable for the movement of lions. These grassland habitats, under both private and government ownership, support a rich diversity of wildlife, including wild prey such as Nilgai, Chinkara, and wild pigs. However, the landscape faces significant human pressure, primarily due to extensive grazing by domestic livestock. Furthermore, numerous small and large mines observed during field surveys contribute to the landscape's challenges.

Towards the north of the Ahmedabad-Rajkot National Highway, the landscape undergoes a stark transition, becoming highly industrialized. The proliferation of small and large industries throughout the area has led to habitat fragmentation and disturbance. Despite forest connectivity extending up to Rampara Vidi in the Morbi district, the landscape's high level of human activity severely limits permeability for wildlife movement



Suggested underpass for movement of lion and other wild animals

Table S3.10: List villages with major land-use categories along the least cost pathways connecting forest patches in and around Hingolghadh WS with the grasslands of Chotila in Surendranagar District and Rmapara WS in the Morbi District. Here: Area in km², length in km

NAME	DISTRICT	Area	CROPLANDS	FOREST	GRASSLANDS	HUMAN_HABI	SCRUBLAND	BARE_GROUN	WATER	Road_lengt	Drain_lengt	Rail_lengt
Gundakhada	Rajkot	8.08	7.55	0	0.35	0.12	0.09	0	0.05	3.408	2.228	0
Tarakiya	Rajkot	8.08	4.22	0	1.62	0.08	2.02	0	0.09	1.639	0.068	0
Holmadh	Rajkot	5.60	2.72	0	2.63	0.09	0.06	0.01	0.08	0.972	1.455	0
Mesariya	Rajkot	17.38	8.56	0.05	3.65	0.46	4.38	0	0.22	1.158	0.516	0
Chotila	Surendranagar	29.66	19.59	0	4.72	4.35	0.9	0	0.04	2.519	1.765	0
Bhalgam	Rajkot	7.66	4.33	0	1.41	0.44	0.29	0.02	1.16	1.951	2.932	0
Bamanbore	Surendranagar	17.36	5.79	1.39	5.48	0.95	3.71	0	0.06	2.782	3.857	0
Nani Moldi	Surendranagar	14.36	11.92	0.05	0.37	0.72	0.33	0	1	5.167	4.727	0
Navagam (Bamanbor	Surendranagar	6.28	4.15	0	1.2	0.28	0.62	0	0.02	1.913	0.952	0
Hirasar	Rajkot	8.76	5.16	0	1.39	0.87	1.32	0	0.01	2.479	0.563	0
Garida	Surendranagar	11.70	3.12	0.01	5.04	0.25	2.94	0	0.36	1.576	1.992	0
Doshalighuna	Surendranagar	8.70	2.1	0.11	4.02	0.12	2.15	0	0.19	0.365	1.923	0
Pipaliya (Bamanbo	Surendranagar	10.07	4.99	0	3.45	0.11	1.47	0	0.05	1.388	0.312	0
Chiroda (Rajpara)	Surendranagar	14.59	4.66	0.26	4.67	0.18	4.52	0	0.32	3.435	1.977	0
Rajpara (Chobari)	Surendranagar	27.11	7.37	0.49	12.64	0.22	6.42	0	0	2.9	1.574	0
Rampara (Rajpara)	Surendranagar	5.73	3.02	0.17	1.51	0.09	0.86	0	0.09	1.296	3.854	0
Kabran	Surendranagar	9.66	2.87	0.15	2.1	0.08	4.46	0	0	0.971	0.847	0
Dhedhuki	Rajkot	10.71	10.13	0	0.37	0.1	0	0	0.04	0.776	0.902	0
Chhasiya	Rajkot	20.85	18.62	0	1.58	0.62	0	0	0.12	3.796	3.073	0
Mota Hadmatiya	Rajkot	7.44	7.18	0	0.09	0.15	0	0	0.03	0.075	3.529	0
Dhokalva	Surendranagar	33.81	26.24	0	5.97	0.5	0.82	0	0.27	2.352	4.011	0
Dharaie	Surendranagar	14.73	12.2	0	1.6	0.32	0.18	0	0.37	2.11	0.645	0
Parewala	Rajkot	10.14	9.29	0	0.61	0.19	0	0	0	2.725	2.659	0
Kalasar	Rajkot	24.88	21.04	0	1.94	0.41	0.17	0.01	1.3	7.24	3.138	0
Som Pipaliya	Rajkot	12.34	9.6	0	2.08	0.35	0.25	0	0.05	5.957	2.535	0
Gadhadiya (Jas)	Rajkot	8.45	6.9	0	0.68	0.33	0	0.05	0.48	2.519	0.014	0

Madhavipur	Rajkot	6.57	6.39	0	0	0.13	0	0	0.01	0.314	2.402	0
Shivrajpur	Rajkot	21.54	19.54	0	1.18	0.72	0.01	0	0	1.292	4.98	0
Somalpar	Rajkot	5.31	3.02	0	1.49	0.22	0.45	0	0.15	0.37	2.145	0
Vadod	Rajkot	14.86	12.9	0	1.35	0.19	0.38	0	0.04	4.505	0.862	0
Ambardi	Rajkot	21.26	17	0.01	2.16	0.56	0.54	0	0.99	2.846	2.599	0
Navagam	Rajkot	3.03	2.61	0	0.16	0.2	0	0	0.03	1.468	0.118	0
Vankiya	Amreli	16.03	10.81	0	3.81	0.19	0.93	0	0.33	0.816	0.981	0
Itariya	Bhavnagar	19.16	15.97	0.39	1.67	0.28	0.82	0	0.04	0.231	4.836	0
Khambhala	Amreli	28.56	21.41	0	3.65	0.42	0.37	0.02	2.67	3.848	6.183	0
Kundal Nani	Amreli	22.51	11.5	1.45	4.77	0.25	4.17	0	0.31	1.323	0.189	0
Kariyana	Amreli	29.32	24.63	0	1.65	0.86	0	0.21	1.95	4.654	5.316	0
Jalsika	Rajkot	8.45	4.7	0.45	2.75	0.22	0.16	0.01	0.14	0	1.253	0
Vasundra	Rajkot	18.75	7.09	1.5	6.07	0.57	3.02	0.03	0.44	0	1.803	0
Rupavati	Rajkot	10.78	1.52	0.46	2.56	0.01	0.94	0.94	4.37	0	1.671	0
Jepur	Rajkot	13.32	5.93	0.02	2.7	0.23	1.7	0.13	2.59	0	1.65	0
Gundala	Surendranagar	4.39	2.48	0.13	1.29	0	0.48	0	0	0	1.315	0
Kherdi	Surendranagar	12.18	9.98	0.03	0.84	0.3	0.46	0	0.58	0	0.628	0
Loma Kotadi	Surendranagar	2.61	1.04	0	1.35	0.02	0.14	0	0.1	0	0.014	0
Mevasa (Bamanbore	Surendranagar	12.81	6.6	0.02	4.4	0.16	1.55	0	0.07	0	4.87	0
Shekhaliya	Surendranagar	4.56	2.79	0	1.13	0.09	0.4	0	0.19	0	2.849	0
Khatadi	Surendranagar	8.21	6.25	0.03	1.44	0.15	0.18	0	0.11	0	1.022	0
Dakvadla	Surendranagar	12.85	6.77	0	2.14	0.14	3.14	0	0.68	0	0.052	0
Dadli	Rajkot	9.32	8.58	0	0.38	0.21	0.13	0	0	0	0.47	0
Garida	Rajkot	12.82	7.27	0.04	3.31	0.25	1.5	0.1	0.32	2.772	0	0
Rangpar	Rajkot	10.78	5.17	0	3.62	0.45	1.43	0	0.07	1.044	0	0
Jalida	Rajkot	14.76	7.5	0.97	3.68	0.6	2.06	0	0.02	3.61	0	0
Chanpa	Surendranagar	8.38	6.78	0	1.1	0.29	0	0	0.17	2.282	0	0
Moti Moldi	Surendranagar	10.78	7.47	0.11	1.47	0.6	0.83	0	0.27	1.001	0	0
Zinzuda	Surendranagar	9.86	6.8	0.01	1.53	0.23	1.25	0	0.07	0.179	0	0
Chobari	Surendranagar	14.95	8.64	0	4.29	0.28	1.73	0	0	5.25	0	0

Parabdi	Surendranagar	7.06	5.88	0	1.07	0.09	0	0	0.01	1.129	0	0
Ajmer	Rajkot	4.79	4.08	0	0.3	0.38	0	0	0.06	0.175	0	0
Devpara (Anandpur	Surendranagar	7.02	6.39	0	0.47	0.14	0	0	0	2.002	0	0
Golida	Surendranagar	8.73	8.45	0	0.17	0.13	0	0	0	2.101	0	0
Gundala (Jas)	Rajkot	8.44	7.62	0	0.5	0.3	0	0	0.05	0.286	0	0
Kamlapur	Rajkot	22.27	20.41	0	1.1	0.75	0	0	0.03	1.725	0	0
Hingolgadh	Rajkot	9.38	4.6	0.33	2.59	0.2	1.64	0	0.02	1.632	0	0
Madava	Rajkot	6.90	6.28	0	0.43	0.19	0	0	0	0.565	0	0
Khadkana	Rajkot	6.20	5.56	0	0.58	0.02	0	0	0.04	0.776	0	0
Kaduka	Rajkot	13.77	12.71	0	0.58	0.45	0.05	0	0.07	1.026	0	0
Lalavadar	Rajkot	3.58	2.67	0.04	0.08	0.23	0.54	0	0.01	1.961	0	0
Lilapur	Rajkot	22.73	19.05	0.03	2.25	0.5	0.91	0	0.03	4.82	0	0
Hadmatiya khanda	Rajkot	10.29	7.38	0	2.42	0.33	0.17	0	0.01	2.956	0	0
Bandhali	Rajkot	7.69	5.14	0	1.96	0.25	0.29	0	0.03	1.35	0	0
Godladhar	Rajkot	11.41	10.66	0	0.54	0.25	0	0	0	0.693	0	0
Lalka	Amreli	18.33	15.13	0	2.41	0.24	0.55	0	0.02	2.229	0	0
Gadhala	Rajkot	9.61	9.35	0	0.1	0.19	0	0	0.02	3.346	0	0
Gokhlana	Rajkot	18.19	17.29	0	0.32	0.44	0	0	0.15	3.993	0	0
Ishvariya	Amreli	11.54	6.67	0.57	2.44	0.12	1.75	0	0	2.116	0	0
Sirvaniya	Amreli	8.10	4.98	0.77	1.5	0.12	0.64	0	0.13	0.336	0	0
Kidi	Amreli	10.58	7.34	0.03	2.07	0.23	0.82	0	0.08	2.247	0	0
Ghiyavad	Rajkot	17.68	5.76	3.56	5.3	0.02	2.78	0	0.25	0	0	0
Rampara (Rajavad)	Surendranagar	10.15	3.87	0.01	2.16	0	4.14	0	0	0	0	0
Naliyeri	Surendranagar	10.20	3.12	0	5.11	0.04	1.93	0	0.01	0	0	0
Pajvali	Surendranagar	6.47	5.45	0	0.81	0.15	0.09	0	0	0	0	0
Janivadla	Surendranagar	8.91	3.57	0.05	3.63	0.18	1.5	0	0.01	0	0	0
Kalasar	Surendranagar	12.50	8.57	0	2.18	0.1	1.62	0	0.02	0	0	0
Sakhpar	Surendranagar	3.10	2.1	0	0.38	0	0.6	0	0	0	0	0
Fulzar	Rajkot	11.60	9.18	0	2.06	0.26	0	0	0.11	0	0	0
Kansloliya	Rajkot	9.28	6.48	0	2.03	0.12	0.62	0	0.04	0	0	0

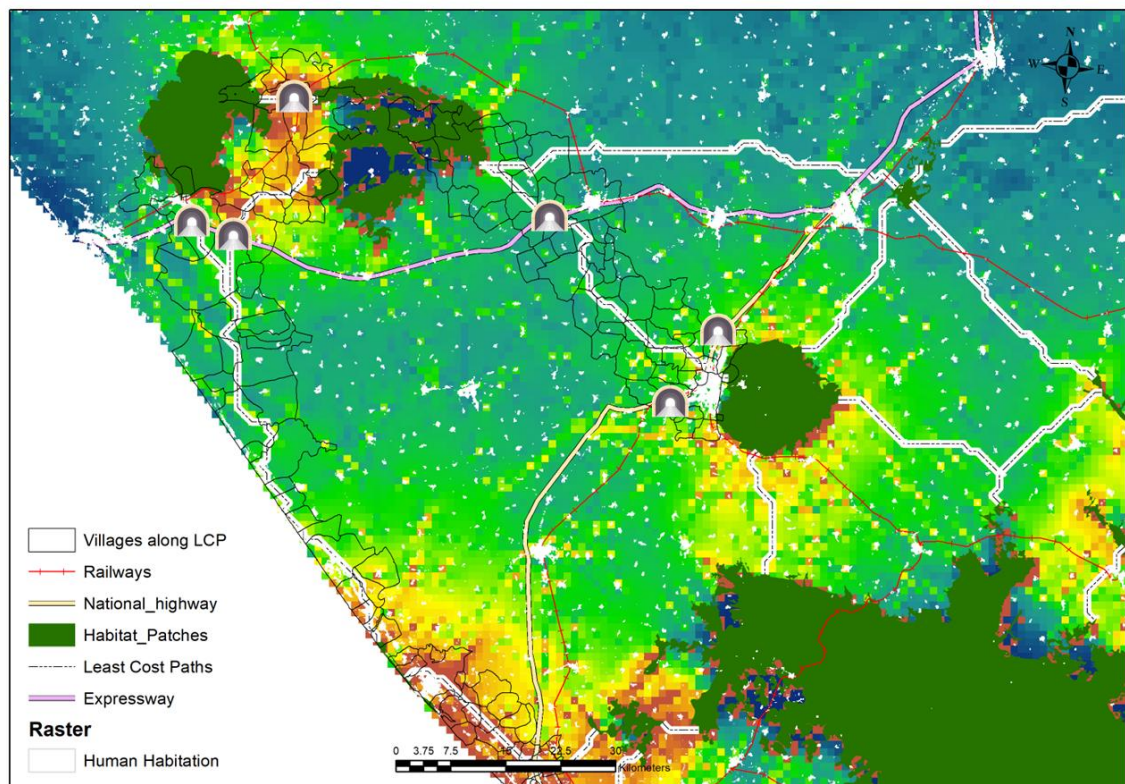
11. Gir Barda corridor:

The Barda Wildlife Sanctuary, once a historical habitat for the Asiatic lion, has recently witnessed the return of these majestic creatures, as they naturally disperse from the Gir Protected areas (Ram et al., 2024). It has also been earmarked as a potential reintroduction site for the endangered Asiatic lions. Through our research, we have identified two potential corridors that connect the Gir forests with Barda Wildlife Sanctuary: one traversing through coastal forest patches and another navigating through multi-use human-modified landscapes.

The Gir and Barda wildlife corridor serves as a vital ecological link, bridging two significant wildlife sanctuaries in the Indian state of Gujarat. This corridor is indispensable for the movement of wildlife, particularly the Asiatic lion, between these critical conservation areas.

Nevertheless, the corridor confronts numerous challenges, including habitat fragmentation caused by human activities such as agriculture, grazing, and infrastructure development. Encroachments, road construction, and industrialization further threaten the integrity of the corridor, impeding the free movement of wildlife.

Preserving the Gir and Barda wildlife corridor is imperative not only for safeguarding the region's rich biodiversity but also for securing the future of the Asiatic lion and ensuring the ecological health and resilience of the entire landscape.



Suggested underpass for movement of lion and other wild animals

Table S3.11: List villages with major land-use categories along the least cost pathways connecting Gir WS and Barda WS. Here: Area in km², length in km

Corridor	NAME	DISTRICT	Area	CROPLANDS	FOREST	GRASSLANDS	HUMAN_HABI	SCRUBLAND	BARE_GROUN	WATER	Road_lengt	Drain_lengt	Rail_lengt
Through the coast	Katkola	Jamnagar	26.74	24.22	0	1.56	0.48	0.38	0	0.12	3.922	4.372	0.122
Through the coast	Kalyanpar	Jamnagar	8.84	8.56	0	0	0.3	0	0	0	1.546	2.217	2.699
Through the coast	Jasapar	Jamnagar	10.37	9.42	0	0.48	0.29	0.07	0	0.1	0.456	0.565	0.065
Through the coast	Vansjaliya	Jamnagar	15.51	14.84	0	0	0.47	0	0	0.19	2.246	5.784	1.156
Through the coast	Tarsai	Jamnagar	27.36	19.06	0.09	4.32	0.31	3.1	0.04	0.43	2.288	2.282	0.204
Through the coast	Devda	Porbandar	26.29	16.53	0.21	4.08	0.67	4.67	0	0.16	3.012	0.4	0.041
Through the coast	Bordi	Porbandar	9.82	6.87	0	1.12	0.25	1.59	0	0.01	1.548	0.851	1.258
Through the coast	Aadityana	Porbandar	29.83	16.25	0.64	3.21	2.7	5.5	1.13	0.45	3.209	2.502	0.522
Through the coast	Ranavav	Porbandar	46.14	33.12	0.28	1.2	6.65	3.86	0.19	0.69	2.608	4.014	1.613
Through the coast	Gadu	Junagadh	4.01	2.55	0.33	0	1.05	0	0	0.05	1.938	0.37	3.139
Through the coast	Visanvel	Junagadh	9.35	4.84	3.72	0.01	0.63	0	0	0.27	1.333	3.048	0.045
Through the coast	Sukhpur	Junagadh	5.50	3.44	1.54	0	0.29	0	0	0.15	0.068	1.449	1.438
Through the coast	Kapurdi Nes	Jamnagar	14.59	3.65	0	6.65	0.27	3.73	0	0.25	0.066	0.921	0
Through the coast	Satapar	Jamnagar	30.20	17.03	1.73	3.51	0.94	5.53	0.18	1.31	0.086	3.045	0
Through the coast	Jambusar	Jamnagar	10.12	7.31	0	1.98	0.07	0.66	0	0.13	0.41	1.817	0
Through the coast	Ramnagar	Porbandar	14.35	11.16	0	2.17	0.2	0.79	0	0.01	1.186	1.667	0
Through the coast	Khirsara	Porbandar	5.71	5.15	0	0.19	0.31	0	0.05	0.03	0.866	1.88	0
Through the coast	Dolatgadh	Porbandar	5.65	5.42	0	0.01	0.09	0.03	0.04	0.03	1.367	2.363	0
Through the coast	Daiyar	Porbandar	8.72	8.08	0	0.22	0.24	0.1	0.02	0.05	2.347	0.116	0
Through the coast	Bhod	Porbandar	20.08	12.9	2.35	0.81	0.86	2.08	0.65	0.44	0.065	0.04	0
Through the coast	Vadwala-Rana	Porbandar	24.08	19.84	0.41	1.25	0.84	1.61	0.02	0.17	0.027	3.69	0
Through the coast	Pipaliya	Porbandar	15.89	8.93	0.34	1.36	0.58	1.19	3.35	0.25	0.992	0.753	0
Through the coast	Mokal	Porbandar	74.01	29.8	0.93	8.28	0.7	3.78	30.07	0.51	3.089	6.559	0
Through the coast	Bapodar	Porbandar	13.99	13.41	0	0.01	0.45	0.01	0	0.05	3.998	4.536	0
Through the coast	Padardi	Porbandar	19.56	12.77	0.13	3.59	0.51	2.31	0.13	0.08	0.035	2.609	0
Through the coast	Keshod (Lushala)	Porbandar	19.42	2.94	0	6.59	0	1.69	8.17	0	6.795	2.532	0
Through the coast	Erada	Porbandar	16.69	14.29	0	0.59	0.19	1.55	0	0.1	0.296	7.544	0
Through the coast	Delodar	Porbandar	8.45	8.09	0	0	0.16	0.17	0	0.05	0.088	0.436	0

Through the coast	Bhad	Porbandar	39.15	36.91	0	0.01	0.71	0.98	0.01	0.53	0.333	6.809	0
Through the coast	Garej	Porbandar	35.03	30.79	0	0.26	0.46	3.01	0.2	0.28	1.418	6.547	0
Through the coast	Chikasa	Porbandar	9.71	8.87	0	0.23	0.08	0.31	0.06	0.2	0.962	1.467	0
Through the coast	Navi Bandar	Porbandar	8.60	4.5	0.13	0.58	0.52	1.01	0.24	1.58	0.343	0.897	0
Through the coast	Ratiya	Porbandar	37.56	25.15	0.57	2.32	2.01	4.96	1.74	0.76	6.242	0.897	0
Through the coast	Balej	Porbandar	45.88	42.43	0.44	0.09	2.02	0.61	0	0.28	3.637	1.674	0
Through the coast	Chingariya	Porbandar	9.30	7.78	0.52	0	0.98	0.01	0.01	0	3	2.992	0
Through the coast	Pata	Porbandar	11.58	10.31	0.3	0.02	0.92	0	0	0	1.261	1.558	0
Through the coast	Madhavpur	Porbandar	36.84	29.49	0.86	0.18	6.07	0.02	0.11	0.1	5.335	1.697	0
Through the coast	Mekhadi	Junagadh	19.30	18.52	0	0	0.81	0	0	0.01	1.305	0.702	0
Through the coast	Shil	Junagadh	10.45	6.61	1.12	0.1	1.81	0.11	0.16	0.55	3.2	4.567	0
Through the coast	Shepa	Junagadh	14.74	13.51	0.8	0	0.49	0	0	0	2.011	0.461	0
Through the coast	Husenabad	Junagadh	4.57	2.52	1.98	0	0.02	0	0	0.07	1.424	2.091	0
Through the coast	Budhecha	Junagadh	11.76	11.03	0.33	0	0.38	0	0	0	3.084	4.228	0
Through the coast	Sheriyaj	Junagadh	11.00	4.24	4.74	0.06	0.66	0.23	0.04	1.01	3.17	1.166	0
Through the coast	Ghumli	Junagadh	7.82	7.4	0.01	0	0.42	0	0	0	1.246	0.685	0
Through the coast	Gotana	Junagadh	7.87	7.51	0.06	0	0.31	0	0	0	2.065	0.985	0
Through the coast	Langodra	Junagadh	6.28	2.5	3.5	0	0.15	0	0	0.06	0.046	2.849	0
Through the coast	Kukasvada	Junagadh	13.80	6.16	6.47	0.02	1.07	0	0.09	0.05	0.01	0.952	0
Through the coast	Simar	Junagadh	5.95	3.79	1.09	0.02	0.8	0	0	0.26	2	1.18	0
Through the coast	Vadodra Dodiya	Junagadh	15.85	12	0.63	0.14	0.75	0.04	0.17	2.13	0.864	0.371	0
Through the coast	Valotra	Porbandar	9.09	8.32	0	0.03	0.28	0.2	0	0.26	0	1.768	0
Through the coast	Khodada	Junagadh	7.04	3.71	2.45	0	0.33	0.01	0	0.54	0	0.127	0
Through the coast	Aniali	Porbandar	13.01	9.78	0	1.52	0.44	1.06	0	0.19	4.132	0	0
Through the coast	Gosa	Porbandar	34.41	29.75	0.05	2.61	1.29	0.46	0.21	0.02	5.074	0	0
Through the coast	Mitrالا	Porbandar	6.76	6.43	0	0	0.24	0	0	0.05	0.845	0	0
Through the coast	Rajpar	Porbandar	10.74	9.58	0	0.56	0.13	0.47	0	0.03	1.746	0	0
Through the coast	Untada	Porbandar	6.36	5.45	0.07	0.01	0.74	0	0	0.06	2.247	0	0
Through the coast	Mocha	Porbandar	6.89	6.03	0.4	0.03	0.42	0	0.01	0	2.157	0	0
Through the coast	Gorsar	Porbandar	9.33	7.43	0.75	0	1.11	0	0.01	0.01	2.85	0	0

Through the coast	Ajak	Junagadh	8.79	8.45	0	0	0.31	0	0	0	0.576	0	0
Through the coast	Antroli	Junagadh	11.69	7.71	1.91	0.05	1.99	0.02	0.03	0	3.846	0	0
Through the coast	Divasa	Junagadh	6.45	4.65	0.62	0.01	1.13	0	0.05	0	2.081	0	0
Through the coast	Sangavada	Junagadh	3.68	2.49	0.76	0	0.37	0	0.06	0	0.982	0	0
Through the coast	Mangrol	Junagadh	36.87	13.94	14.28	0.05	8.34	0.22	0	0	4.483	0	0
Through the coast	Mankhetra	Junagadh	2.88	2.63	0.19	0	0.08	0	0	0	0.467	0	0
Through the coast	Rahij	Junagadh	6.30	5.37	0.03	0	0.9	0.01	0	0	1.967	0	0
Through the coast	Maktupur	Junagadh	6.62	5.12	0.68	0.02	0.8	0	0	0	1.703	0	0
Through the coast	Kotda Nava	Junagadh	2.42	1.38	0.92	0	0.12	0	0	0	1.222	0	0
Through the coast	Shapur	Junagadh	4.11	1.58	1.46	0	1.01	0.01	0	0.01	2.076	0	0
Through the coast	Arena	Junagadh	5.81	1.53	3.59	0	0.73	0	0	0	3.372	0	0
Through the coast	Kanek	Junagadh	6.22	2.99	2.99	0	0.18	0	0	0	0.995	0	0
Through the coast	Chorvad	Junagadh	19.76	6.02	9.6	0.07	3.2	0.04	0.05	0.75	1.204	0	0
Through the coast	Dhoria Nes	Porbandar	8.02	0	0.17	2.4	0	5.44	0	0	0	0	0
Through Junagadh	Saragvada	Junagadh	8.09	0.001355	6.52	0	0	1.46	0	0	110	0.943	0.949
Through Junagadh	Khamdhrol (Part)	Junagadh	4.54	0.000579	2.17	0.07	0	2.28	0	0	20	0.057	2.615
Through Junagadh	Junagadh	Junagadh	20.60	0.001277	3.25	0.84	0.17	15.83	0.26	0.06	60	0.227	0.999
Through Junagadh	Dhank	Rajkot	72.86	0	47.4	1.54	3.88	1.19	18.64	0.01	280	1.714	1.645
Through Junagadh	Rabarika	Rajkot	5.62	0	4.57	0	0.18	0.15	0	0.33	340	2.956	0.469
Through Junagadh	Gadhethal	Rajkot	6.75	0	5.59	0	0.4	0.14	0	0.17	480	4.016	2.117
Through Junagadh	Nagvadar	Rajkot	10.52	0	9.25	0	0.52	0.53	0	0	220	3.027	2.817
Through Junagadh	Isra	Rajkot	7.31	0	6.19	0.29	0.02	0.6	0	0	250	0.025	2.813
Through Junagadh	Nilakha	Rajkot	16.16	0	15.51	0.05	0.05	0.37	0	0	130	1.013	2.038
Through Junagadh	Hadfodi	Rajkot	6.73	0	5.54	0.25	0.02	0.25	0	0	650	0.942	0.646
Through Junagadh	Samadhiyala	Rajkot	10.40	0	9.66	0	0	0.34	0	0	440	1.527	2.712
Through Junagadh	Talgana	Rajkot	10.18	0	9.09	0.03	0	0.32	0	0	740	3.02	2.848
Through Junagadh	Majevedi	Junagadh	21.15	0	19.87	0	0	0.81	0	0	470	1.055	4.357
Through Junagadh	Patrapasar	Junagadh	10.64	0	9.81	0.33	0	0.28	0	0	240	1.092	2.523
Through Junagadh	Ambaliya	Junagadh	8.66	0	8.28	0.01	0	0.19	0	0	150	0.772	4.8
Through Junagadh	Galiyavada	Junagadh	7.06	0	6.53	0.01	0	0.49	0	0	20	2.092	1.436

Through Junagadh	Virpur	Junagadh	3.78	0	3.6	0.01	0	0.08	0	0	60	0.7	2.842
Through Junagadh	Dolatpara(Part)	Junagadh	6.62	0	1.18	2.3	0	3.06	0.07	0	30	1.14	1.074
Through Junagadh	Dhandhusar	Junagadh	23.46	0	19.68	2.24	0.05	0.93	0	0	560	2.582	0.082
Through Junagadh	Rajpara	Rajkot	5.02	0	2.6	0	0.08	0	0	0.24	2090	0	2.101
Through Junagadh	Mekhatimbi	Rajkot	9.53	0	8.59	0	0.21	0.4	0	0	320	0	0.449
Through Junagadh	Taliyadhar	Junagadh	4.32	0	3.65	0.35	0	0.14	0	0	210	0	1.135
Through Junagadh	Bhavnath	Junagadh	3.96	0	0	3.45	0	0	0.55	0	0	0	0.351
Through Junagadh	Gadha	Rajkot	1.77	0	1.77	0	0	0	0	0	0	1.093	0
Through Junagadh	Kathrota	Rajkot	7.23	0	6.81	0	0	0.3	0	0	20	2.894	0
Through Junagadh	Patanvav	Rajkot	27.87	0	25.38	0.18	0.48	0.6	1.27	0	0	6.488	0
Through Junagadh	Nani Marad	Rajkot	5.10	0	5.06	0	0	0	0	0	0	1.734	0
Through Junagadh	Chichod	Rajkot	7.24	0	4.72	0.33	0.94	0.04	1.24	0	0	2.822	0
Through Junagadh	Vadodar	Rajkot	22.62	0	22.28	0	0	0.34	0	0	30	4.088	0
Through Junagadh	Velariya	Rajkot	7.56	0	7.05	0	0.27	0.19	0.02	0	20	0.221	0
Through Junagadh	Kalana	Rajkot	17.49	0	15.08	0.07	1.17	0.42	0.79	0	10	2.459	0
Through Junagadh	Bhader	Rajkot	13.56	0	13.01	0	0	0.46	0	0	30	0.34	0
Through Junagadh	Rupavati	Junagadh	5.70	0	5.49	0	0	0.16	0	0	40	0.589	0
Through Junagadh	Vadhavi	Junagadh	7.92	0	7.51	0	0	0.45	0	0	0	0.23	0
Through Junagadh	Khalilpur	Junagadh	4.06	0	3.89	0	0	0.16	0	0	10	0.505	0
Through Junagadh	Joshiपुरa	Junagadh	3.04	0	0.95	0	0	2.14	0	0	0	0.052	0
Through Junagadh	Jhanjharda	Junagadh	5.26	0	3.71	0	0.01	1.41	0	0	50	2.699	0
Through Junagadh	Murakhada	Rajkot	2.11	0	2.01	0	0	0.14	0	0	10	0	0
Through Junagadh	Varjang Jalia	Rajkot	11.37	0	11.25	0	0	0.06	0	0	0	0	0

Chapter IV

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Chapter IV: Conflict Dynamics and Human-Carnivore Interactions

Objective 3: To map and assess the Spatiotemporal patterns of livestock predation by lions and leopards in the landscape.

Introduction:

Managing successful recoveries of carnivore populations exceeding the carrying capacity of protected areas is one of the biggest global conservation challenges of current times (Hayward *et al.* 2007). Although large carnivore populations thriving outside of protected areas are rare but do exist in Europe (Chapron *et al.*, 2014), North America (Bangs *et al.* 2001) and Asia (Singh & Gibson 2011). The concomitant rise in human appropriation of natural resources with increasing human population around carnivore habitats inevitably intensifies negative interactions amongst human and large carnivores (Graham *et al.* 2005). For lions (*Panthera leo*), in particular, high-profile debate surrounds the issue of whether they can be conserved effectively outside protected areas (Packer *et al.* 2013, Stephens 2015). Whereas, in India, the Asiatic lion population is increasing (Bauer *et al.*, 2015, Singh 2017), presently estimated over 700 individuals (Gujarat Forest Department, 2020) spanning over more than 30,000 km² outside protected areas (Ram *et al.*, 2023). Concurrent with a 19.17 % rate of human population growth (Human census report 2011) in Gujarat state there has also been a 6% annual increase in the population of Asiatic lions (Ram *et al.*, 2023). More than 40% of the total population is known to be located outside the protected area (Gujarat Forest Department, 2020). Due to the natural paucity of wild prey in such landscapes, lions often predate upon livestock (Inskip and Zimmermann, 2009). In Saurashtra, outside the protected areas Asiatic lions are also dependent on scavenging dead livestock (Banerjee, 2012). Large carnivores habituated to anthropogenic food sources are known to modify their behaviour (Ayres *et al.*, 1986; Matthews *et al.*, 2006)

and lose fear of human beings (Massé et al., 2014). This change in behaviour escalates conflicts with humans (Herrero et al. 2011). Such negative interactions with humans not only results in loss of property and live but also creates anti conservation sentiment amongst the locals (Woodroffe et al., 2005). Religious beliefs and cultural importance have undoubtedly played a significant role in India towards losses to wildlife conflicts but such values are changing fast and wildlife managers need innovative mechanisms for conflict resolution (Sukumar, 1994).

Leopard: another large carnivore in the shared landscape:

Conservation of large carnivores in modern times represent unique challenges, i.e. reconciling the needs of human development with the needs of wildlife in socio-political landscapes (Barua et al., 2013). The protected areas represent a tiny share of about 14% for the wildlife amongst the vast extent of human dominated landscapes worldwide (UNEP, 2013). Large carnivores due to their extensive range, unique ecology and social dynamics inhabit areas that extend beyond these boundaries, drawing them into conflict with people (Woodroffe & Frank, 2005, Inskip & Zimmermann, 2009). Livestock in these habitats are often vulnerable to predation due to inadequate anti-predator responses diminished by domestication (Bagchi and Mishra, 2006). Leopards in this context are highly likely to be involved in conflicts due to their adaptability to thrive in various ecological condition and close proximity to humans (Daniel 1996, Hayward et al. 2006). They are one of the most widely distributed large carnivores in India. Leopards are known to prey on dogs, cows, goats, other domestic species and even in humans on areas with low density of wild prey (Marker & Sivamani, 2009). On the other hand, people have converted natural habitats into sugarcane fields or other cultivational purpose where the climate and soil are ideal to meet the demands of the increasing population. These agricultural areas provide shelter and cover for the leopard outside protected forests (Athreya & Belsare 2007). There is higher probability of occurrence of conflict in such areas.

The effectiveness of conflict mitigation strategies are highly influenced by the ability to take proactive measures to counter negative interactions. Forecasting the spatial probabilities of conflicts based on available spatial information on conflict occurrence would be a good measure to formulate effective mitigation strategies. Therefore, in this chapter I tried to disseminate the spatiotemporal patterns of attacks on human and livestock predation by lions and leopards and the eco-geographical, factors governing the conflicts in the in the Saurashtra landscape.

Method:

Data collection:

Data on livestock predation:

The study was carried out in >30,000 km² covering 29 talukas of five districts (counties) of Saurashtra peninsula of Gujarat State, in western India. The landscape includes the protected areas of Gir (Gir Wildlife Sanctuary, Gir National Park, Girnar Wildlife Sanctuary, Pania Wildlife Sanctuary and Mitiyala Wildlife Sanctuary), vidis (protected grasslands), coastal forests and the human dominated part of the landscape constituted by towns, villages, and agro-pastoral-industrial areas. The Gujarat Forest department pays compensation for livestock predation and for injury or death to humans by carnivores (Jhala et al 2019). Records registered as compensation claims for attack on livestock and human by lions were collected from the respective forest divisions and ranges from 2012 to 2017. The data included name of the owners, village, taluka, district, forest division, type of livestock killed, predator involved and date (and in some cases time) of each incident. Field visits were conducted in villages where information was partially available and recent conflict sites to obtain details of location, number of predators, and time of the event.

Machine learning algorithms for Species Distribution Modelling (SDM) have been widely used to disintegrate complex occurrence-environment interactions or species habitat relationships and predict current/future distribution of occurrence in a robust way (Elith et al., 2010; Merow et al., 2013; Thuiller et al., 2016; Guisan et al., 2017). The ability of SDMs to explain the appropriate amount of complexity influences the predictive accuracy of the models (Merow et al., 2014; Thuiller et al., 2009). However, given the number of different techniques available for SDMs it is often difficult to select the most appropriate models (Elith et al. 2006, Heikkinen et al. 2006). We used Maximum Entropy Models in Maxent software (Phillips and Dudík, 2008), which has been a method of choice due to its predictive accuracy, easy user interface, and ecological interpretation (Merow et al., 2013).

Analytical method:

Data preparation and exploratory analysis:

We translated the recorded information from the local language Gujarati to English, and subsequently arranged the data into analysable format by using Microsoft Excel (Microsoft Inc 2016) and geo-referenced each data point to the level of villages by using ArcMap 10.5 (ESRI). Village shapefiles were obtained from Survey of India database (surveyofindia.gov.in). Prior to analysis information was checked for duplicate records and arranged according to the year of incidents to analyse temporal trends in conflict intensity. We used base R (R core Team 2013) to analyse basic diagnostics plots. We used linear regression to estimate the trends in conflict intensity across the years. Density of conflict per year was estimated by dividing the total number of incidences by the total number of villages that experienced conflict in a given year. We used dodged bar graphs to plot the different categories of livestock predated by lions across the years and simple bar graphs to plot the seasonal difference and District wise magnitude of attacks on human and livestock by lion.

Economics of livestock predation:

Though Gujarat Forest Department has a prompt and efficient compensation scheme for mitigating human large carnivore conflict, it however doesn't fully cover the actual market price of the livestock (Supplementary table..). We compiled the number of compensation claims for livestock killed by lions in Saurashtra and computed the compensation amount that would have been paid by the Gujarat Forest Department as per the official rates. We calculated the economic loss by subtracting the compensation amount from the market price of the livestock. We used linear models to see the yearly trend of economic loss due to livestock predation by lions in base R.

Spatial prediction of conflict risk:

Maxent uses known occurrence locations and creates a relationship with user defined spatial covariates and randomly generated background points to predict the probability of presence across the modeled space (Merow et al., 2013). The idea of generating background points or pseudo-absences are not to attempt to guess absence locations, but rather characterize the environment of the study region (Hijmans and Elith, 2011; Phillips et al., 2009). For the analysis, we randomly split the presence locations into 80% for training the models and rest 20% to test the model performance. Linear, quadratic, product, threshold and hinge feature type approaches available in MaxEnt were used for building the relationships between ecogeographical covariates and lion attack locations. Jackknife analysis was used to estimate the importance of various variables in the models. Regularization multiplier was set to default value of 1 and 5 bootstrap runs were used. We evaluated model performance by using the scores of a threshold-independent measure (i) area under receiver operating characteristics (AUC of ROC) (Hanley and McNeil, 1982) as well as threshold dependent measure (ii) true skill

statistics (TSS) (Allouche et al., 2006), which is the sum of sensitivity and specificity minus one and the value of TSS ranges from -1 to +1, values above zero indicates a better model performance than random chances. For better computation of model uncertainty, we used 100 bootstraps simulations for the best models.

The distribution and density of animals are governed by underlying processes that operate at varying ecological scales and are highly dynamic across different taxa (Coreau and Martin, 2007). Therefore, the choices of variable scales in ecological modelling have great influence over the outcomes (Weins 1989). SDMs are known to be robust to positional errors (Graham et al. 2008), however they depend on the amount of spatial autocorrelation among predictor variables (Osborne and Leitão 2009; Naimi et al. 2011). If nearby locations of species occurrence points have similar environmental characteristics, positional inaccuracy will have less impact on predictive performance of models (Osborne & Leitão, 2009). In our case, the average size of our study villages was 10 km² (SE 0.16) with median ~8 km². Therefore, we selected a spatial scale of 10 km² for the predictor variables and used the centroid of the villages as conflict locations for the Maxent analysis.

We used spatial covariate layers depicting anthropogenic influence and ecogeographical characteristics to model the probability of conflicts. Outside the Gir Protected Areas there are few large protected forest patches available for the lions in the human dominated landscape. Scrub patches along rivers, hillocks and unused lands under public/private ownership and village owned cattle grazing areas along with government owned grasslands (*vidis*) serves as major refuse areas for lions in the human dominated landscape (Jhala et al 2019). From the long-term monitoring of lions through radio telemetry it was found that such habitat patches > 4 km² are vital for breeding lioness outside the PA. Therefore, digitised all habitat patches (>4 km²) from google earth and ground validated them. We subsequently computed Euclidean distance using distance tool in ArcMap 10.5 (ESRI) of each

10 km² grid from such habitat patches as a covariate layer in the MaxEnt model. We used density of lions in different habitat patches (Gujarat Forest Department, 2020) and created a weighted density matrix by using Kernel Density Estimation tool in ArcMap 10.5 (ESRI) and used as a covariate in the model. We used Nightlight intensity and human density as a surrogate for urbanization and annual average NDVI as surrogate for vegetation cover. The topography varies greatly with multiple hill ranges, dams, rivers and streams crisscrossing both wilderness areas and human habitations. Lions were found to use broken terrain and riverbeds to move across the human dominated landscape (Banerjee, 2012). The landscape is also intercepted by networks of linear infrastructures of road and railways. Therefore, we used the spatial layers of “elevation”, “ruggedness” derived from digital elevation models and we estimated “density of drainage” and “density of linear infrastructure” by using “line density” tool in ArcMap 10.5 (ESRI). The Saurashtra peninsula of Gujarat State has a very high livestock density which constitutes a major proportion of lion’s diet in the landscape (Banerjee et al. 2013). Therefore, we used spatial densities of livestock as a covariate in the models.

People also avail economic benefits through by showing lions to tourist around their villages or private land and bait lions with dead or live livestock. Baiting of wild animals are considered as punishable offence by the Wildlife Protection Act of India 1972. However, such practices although illegal are difficult to control and are spread across many localities within the lion’s distribution range and an exorbitant amount of revenue generation associated with it through tourism. We mapped, these lion show locations by interviewing villagers across the landscape and generated a distance matrix by using Euclidean distance tool in ArcMap 10.5 (ESRI).

Results:

Total of 11,901 claims for 14,099 (SE 0.01) livestock predated by lion were recorded, which belonged to 1092 villages between the year 2012-2017. At the same time there were 4,465 (SE 25.90) cases of compensation claims for livestock killed by leopards. The district of Amreli had highest claims of livestock predation by lions followed by Junagadh, Gir Somnath and Bhavnagar (Figure 4.1). However, in case of leopard predation Junagadh district had the highest number of cases followed by Amreli, Gir Somnath and Bhavnagar (Figure 4.1). There were 1026 (SE 0.02) (8.64 %) and 10875 (SE 0.02) (91.38 %) recorded claims of livestock killed by lion inside and outside the Gir PA respectively (Figure 4.2). In contrast there were 33 (SE 0.11) and 4431 (SE 0.02) incidences of livestock predation by leopards inside and outside the PA respectively. We observed that there were higher representation of compensation claims for cattle followed by goat-sheep and buffalo (Figure 4.3). There were more incidences of livestock predation by lions during monsoon (July, August, September, October) and winter (November, December, January, February) compared to summer (March, April, May, June) months (Figure 4.4). For leopards we did not observe any seasonal difference in livestock predation pattern (Figure 4.4).

The number of compensation claims for livestock killed by lions showed a linear increase ($R^2 = 0.86$, $p = 0.01$) across the years with an increment of around 150 claims per year (Figure 4.5). The number of villages that experienced livestock predation by lions showed an increasing trend as well (Figure 4.6). The cumulative number of villages that reported predation by lion was also observed to increase linearly ($R^2 = 0.97$, $p = 0.01$), with an addition of over 110 new villages each year (Figure 4.7). Density of conflict, indexed through number of incidences of livestock predation divided by the number of villages showed an increasing trend ($R^2 = 0.73$, $p = 0.06$) (Figure 4.8b) over the years.

In case of leopard an increasing trend of number of compensation claims for livestock predation was observed ($R^2 = 0.86$, $p=0.01$) (Figure 4.9). Although, there was no significant increase in the number of villages that registered predation on livestock by leopards (Figure 4.10), the cumulative number of villages that reported leopard predation showed a linear increase ($R^2 = 0.98$) (Figure 4.11). This also indicates an expanding leopard population in the landscape. However, intensity of conflict, indexed by number of conflict incidences divided by the number conflict villages did not show any significant trend for leopard predation ($R^2=0.005$) (Figure 4.8). This is indicative of a stable per unit area magnitude of conflict during the study period for leopard.

There were 125 reports of attacks on humans by lion during the same time frame, out of which 8 resulted in the death of the victims. 391 cases of attack by leopard on humans were recorded, out of which 41 were lethal. A total of 519 villages were observed to have experienced attacks on humans by these carnivores. The district of Amreli reported highest incidents of attacks on human by lion followed by Junagadh and Gir-Somanth (Figure 4.1a). There were no records of attack on humans by lions inside the Gir PA during the study (Figure 4.2a). The yearly trend of attacks on human by lion and leopard didn't show any significant trend (Figure 4.12). We observed seasonal difference in magnitude of attacks on human by both lion and leopard. Comparatively there were more incidences of conflict during summer, followed by winter and monsoon (Figure 4.13). Intensity/density of conflict was almost stabilized with no significant trend detected for both lion and leopards (Figure 4.8 a).

The economic evaluation of livestock predation by lion showed significant deficit in the amount paid as compensation and the actual market price of the livestock. A yearly increment of more than 54 lakhs rupees per year ($R^2=0.87$, $p= 0.02$) incurred as a monetary loss due to predation on livestock by lions in the landscape (Figure 4.14).

The Maxent outputs of attacks by lion on both human and livestock had overall good predictions (Table 1; Figure 4.15 & 174). The Area Under the Curve (AUC) of the Receiver Operator Curve (ROC) and omission/commission analysis with 100 bootstrap runs and with 20% test data showed that both livestock-lion conflict and human-lion conflict models had good fit (AUC 0.83 (SE..) and AUC 0.92 (SE..) respectively) and predictive ability (Figure 4.15 & 4.17). The parsimony of the best models was well explained by the lower AIC values compared to other candidate models in both the cases (Table 1). The higher True Skill Statistics (TSS) further support the accuracy of the best fit models (Table 1). The lion-livestock conflict was best explained by Distance to lion-show hotspots, lion density, livestock density, distance to forest and average NDVI. As we hypothesized the predicted probability of livestock predation risk was highest closer to lion-show hotspots with maximum probability of livestock predation up to about 15 kms around such areas and gradually declines afterwards. Lion-show hotspots also had the highest contribution (69.2%) in explaining the variability in the model. The second most contributing factor was density of lion (23.8%), it was observed that low lion density areas that signifies the multi-used human dominated landscape outside the Gir PA had higher probability of livestock predation compared to high lion density areas i.e. the Gir PAs. Livestock predation probability was observed to increase with increasing livestock density (contributed 4.5%) and was highest in areas with low livestock density in the landscape and gradually declines as livestock density becomes high. Livestock predation risk was highest in or around forest edges and declined away from forest patches (distance to forest) with a contribution of 1.4% in the model. Livestock predation risk was highest in areas with an average value of moderately dense vegetation and gradually decreased towards both open and dense vegetations (Figure 4.16 & 4.18).

The best model that explains the spatial risk of lion attacks on humans was included frequency of livestock predation by lion in a village, distance to lion-show hotspots, distance

from forest, and human population density. Livestock predation frequency by lions had the highest contribution in the model explaining about 48% variability. We observed that the risk of attack on humans by lion increases with increasing livestock predation frequency in a village. Similar to livestock-predation models, risk of lion-human conflict was high in low lion density areas (Lion Density contributed 21.6 %) that are within the multi-used agro-pastoral landscape outside the Gir PA. We observed that attacks on humans by lion was highest in or around the lion-show hotspots (17.1 % contribution) and gradually declines away from such areas. Risk of lion-human conflict was high around forest edges and declined away from forest patches. The risk of lion-human conflict was high in low human density areas and gradually declined with increasing human population density (2.3 % contribution) in the landscape (Figure 4.17& 4.18).

There were 391 incidences of attack by leopard on humans, out of which 41 were lethal. A total of 519 villages were observed to have experienced attacks on humans by these carnivores. Although not significant, attacks on human by both lion and leopard showed a moderate increasing trend over the years (Figure 4.12). We observed seasonal difference in magnitude of attacks on human by leopard. Comparatively there were more incidences of conflict during summer, followed by winter and monsoon (Figure 4.13). Intensity/density of conflict was almost stabilized with no significant trend detected for both lion and leopards (Figure 4.8).

The economic evaluation of livestock predation by lion and leopard showed significant deficit in the amount paid as compensation and the actual market value of the livestock. A yearly increment of more than 10 lakhs rupees per year ($R^2=0.74$, $p= 0.06$) incurred in addition to the actual monetary loss (Figure 4.14), which was more than 4,557.00 lakhs of rupees for lion predation.

The maxent output for predicting the spatial risk of attacks on human and livestock by leopard showed a good fitting and predictive accuracy (Figure 4.19a and 4.20a). The Area Under the Curve (AUC) of the Receiver Operator Curve (ROC) and omission/commission analysis with 100 bootstrap runs and with 20% test data showed that both human-leopard conflict and livestock-leopard conflict models had good fit (AUC 0.83 (SE 0.03) and AUC 0.73 (SE 0.02) respectively) and predictive ability (Figure 4.19 & 4.21). The parsimony of the best models was well explained by the lower AIC values compared to other candidate models in both the cases (Table 4.2). The higher True Skill Statistics (TSS) further support the accuracy of the best fit models (Table 4.2). Attacks on human by leopards was best explained by elevational profile of the landscape (24.4% contribution explaining the variability of the predicted model), followed by average annual NDVI (24.3%) , human population density (22.7%), distance to forest patches (19.3%) and drain density (9.3%). As hypothesized, we observed that with increasing cover (Figure 4.19c) and drainage density (Figure 4.19e) the probability of attacks on humans increased. In contrary, increasing distance from forest patched (Figure 4.19d) and elevation (Figure 4.19f) in the landscape the probability of attacks on humans decreased. However, attacks on humans were observed to increase with increasing livestock density and then exponentially decrease as the density increases beyond 100 livestock per square kilometers (Figure 4.19g).

The lion-livestock conflict was best explained by average NDVI, distance to forest, drainage density, human population density and livestock density. Drainage density had the highest contribution (37%) explaining the probability of livestock predation by leopards in the landscape followed by average annual NDVI (25.3%), livestock density (18.1 %), distance to forest (15.8%) and human density (3.9%). As hypothesized the intensity of livestock predation gradually reduced away from forest patches (Figure 4.21d) and increased as the density of

drainage density started increasing in the landscape (Figure 4.21f). Livestock predation frequency was observed to increase with increasing livestock density in the landscape but after reaching about 100 livestock in a square kilometer the intensity of predation gradually decreased (Figure 4.21g). Livestock predation was observed to increase with the increasing average green cover in the landscape (Figure 4.21c) and started decreasing with increasing human density and slowly stabilizes after a certain limit (Figure 4.21g).

Figure 4.1: District wise livestock predation by Lion and leopards

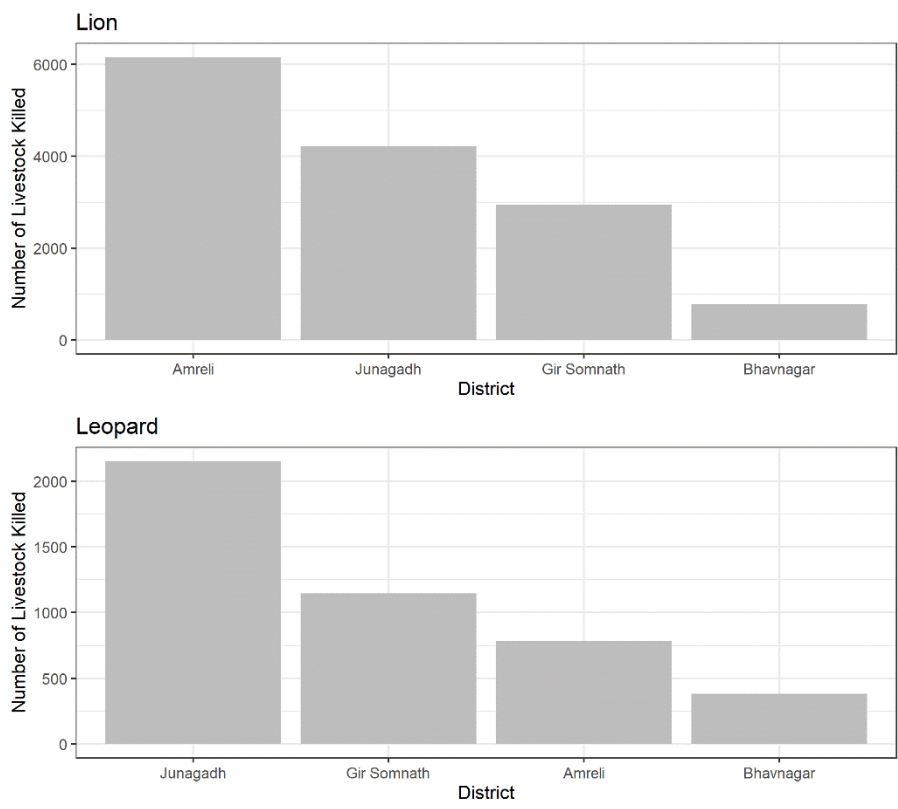


Figure 4.2: Difference in magnitude of livestock predation by lion and leopards inside and outside the Protected Areas

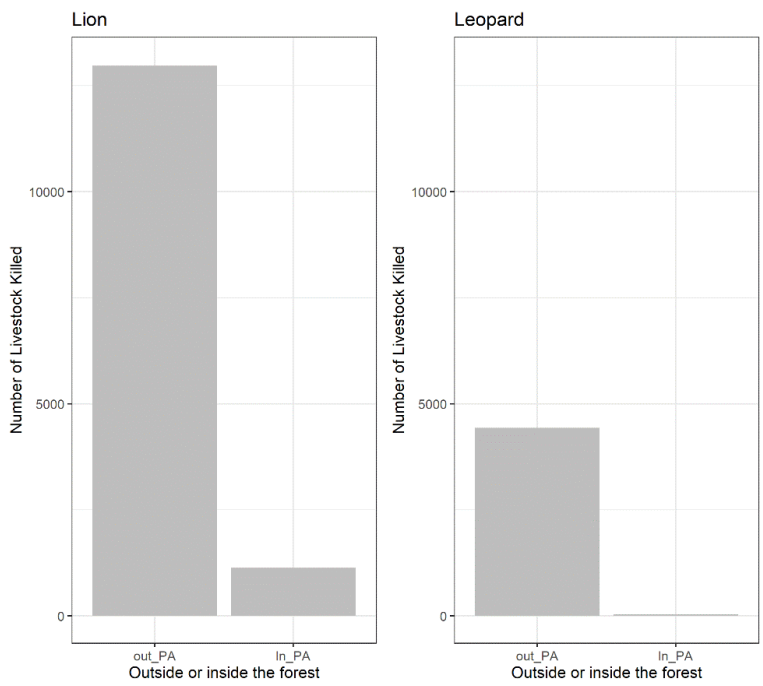


Figure 4.3: Magnitude of different livestock categories predated by lion and leopard

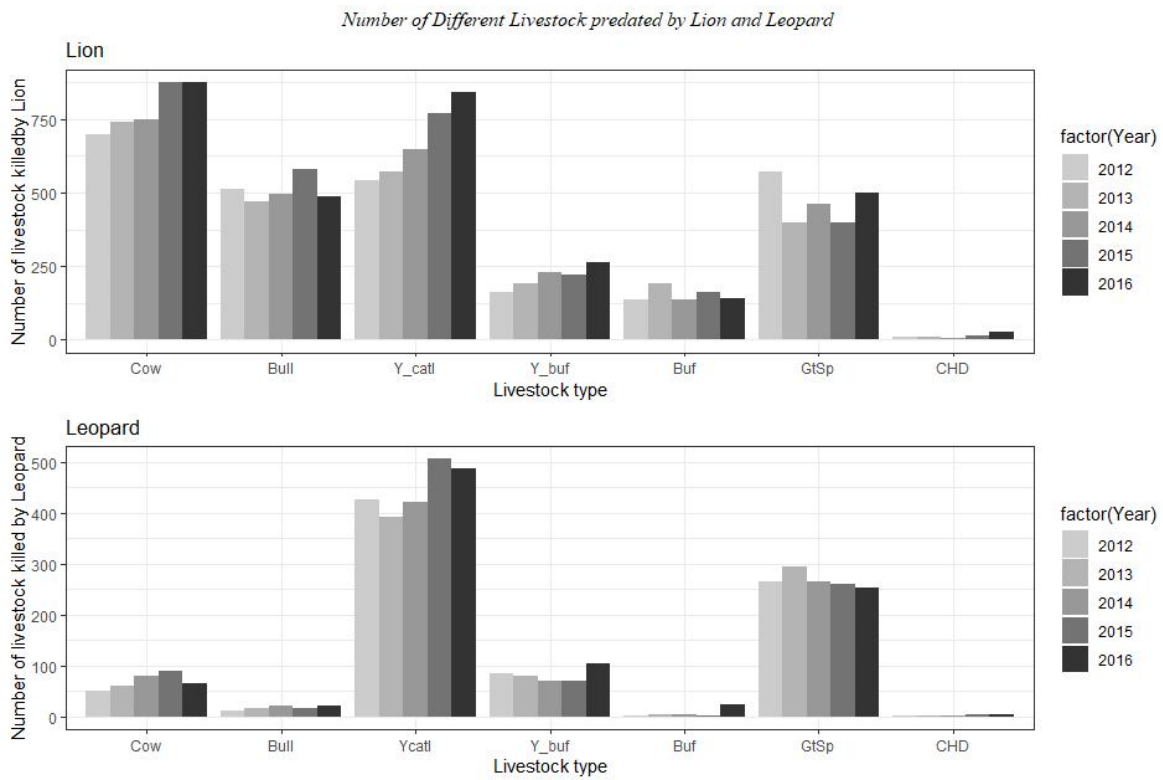


Figure 4.4: Seasonal magnitude of livestock predation and attacks on human by (a) lion and (b) leopard in Saurashtra

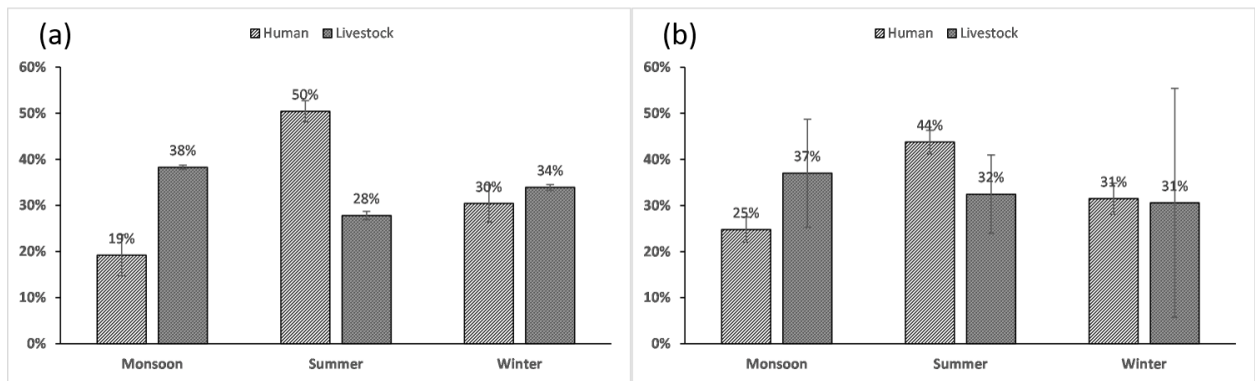


Figure 4.5: Yearly trend of livestock killed by lions

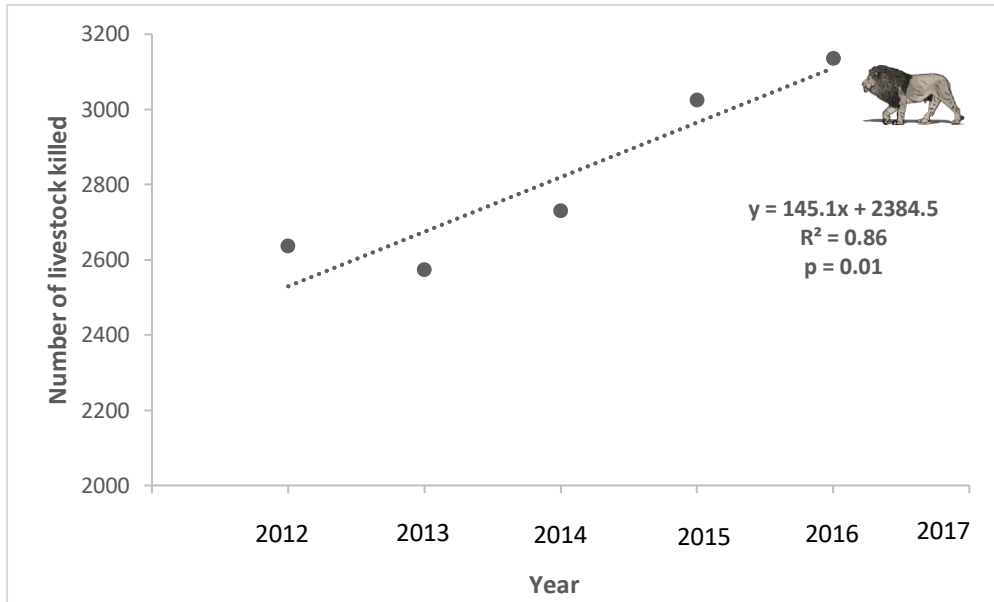


Figure 4.6: Graph showing the total number of villages under predation by lion

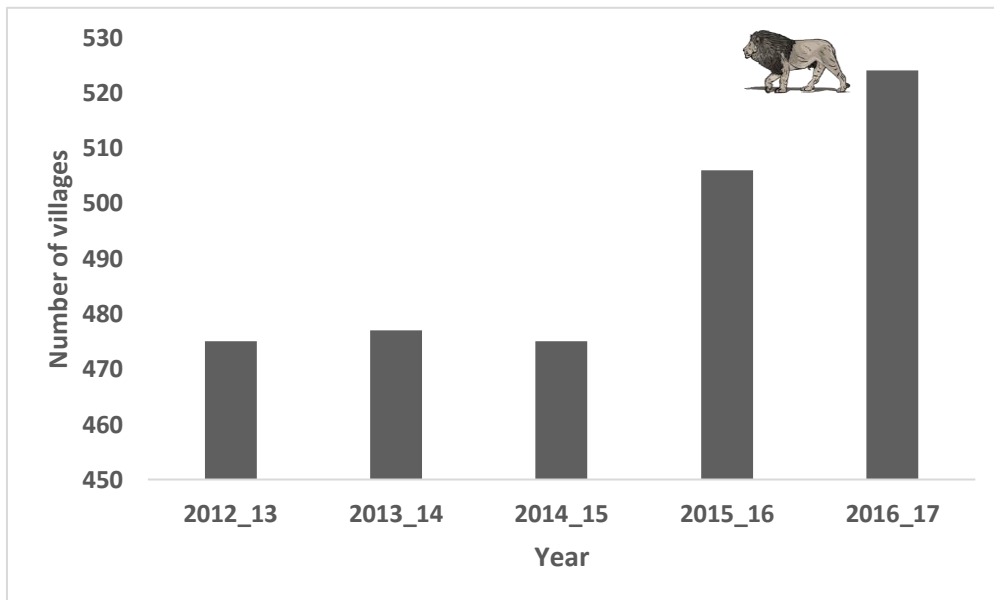


Figure 4.7: Cumulative number of villages experienced livestock predation by lion

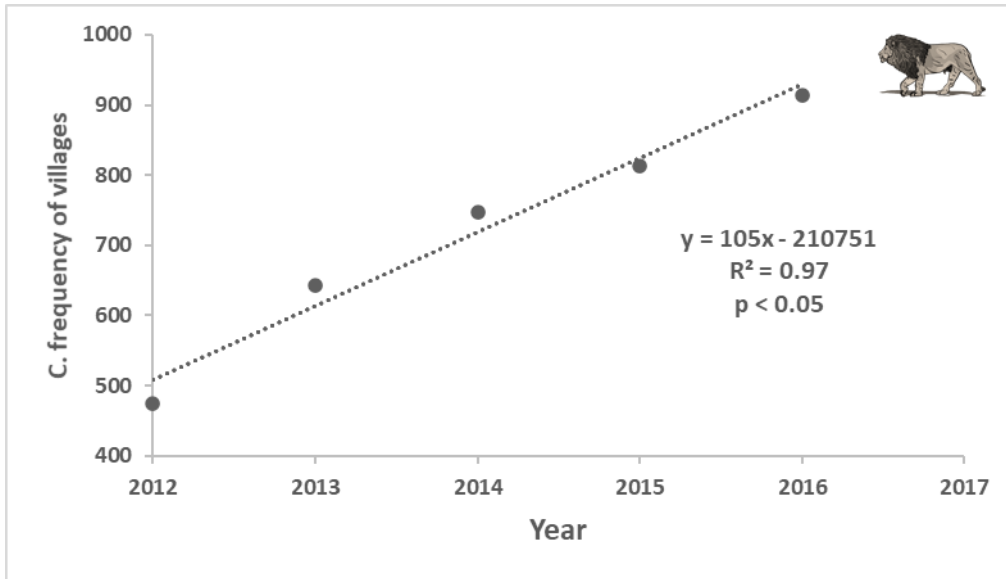


Figure 4.8: Intensity of livestock predation and attacks on human by lion and leopard

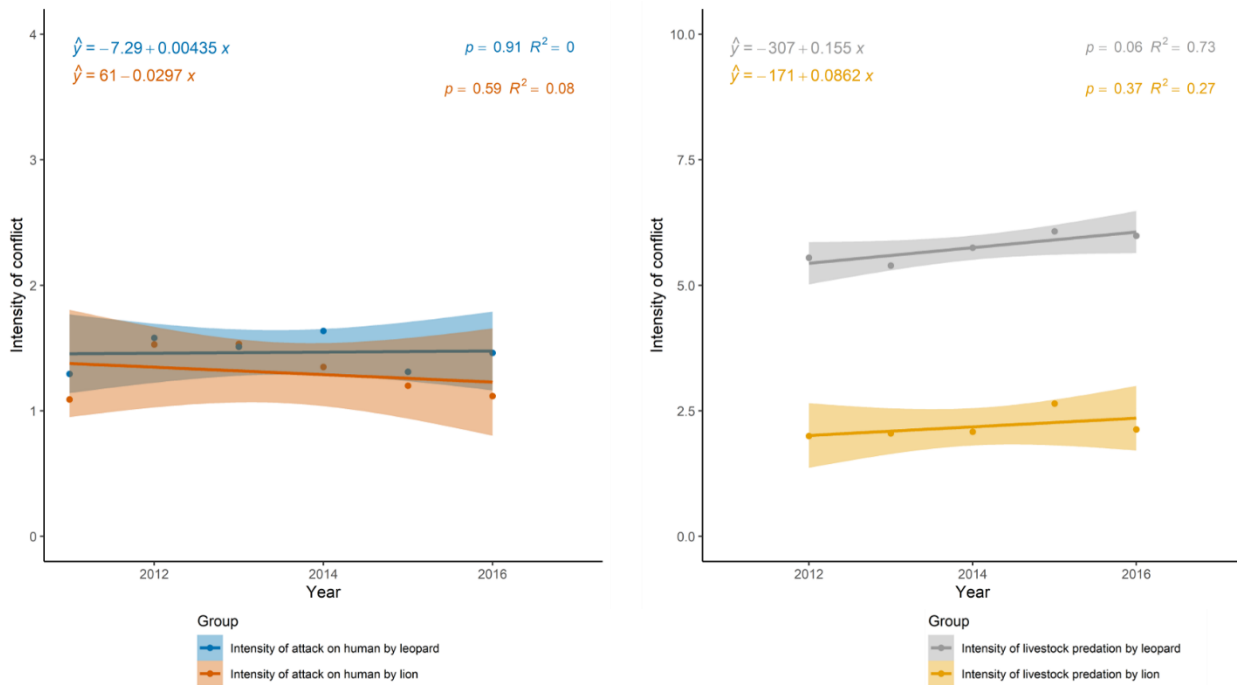


Figure 4.9: Yearly trend of livestock killed by leopard

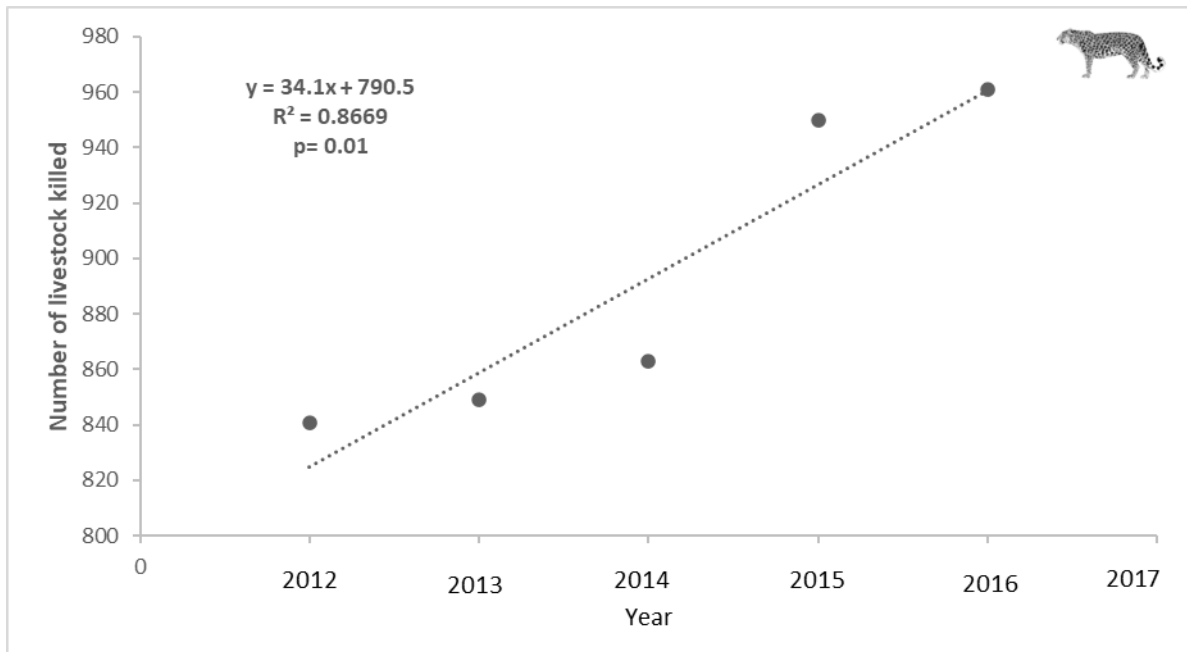


Figure 4.10: Graph showing the total number of villages under predation by leopard

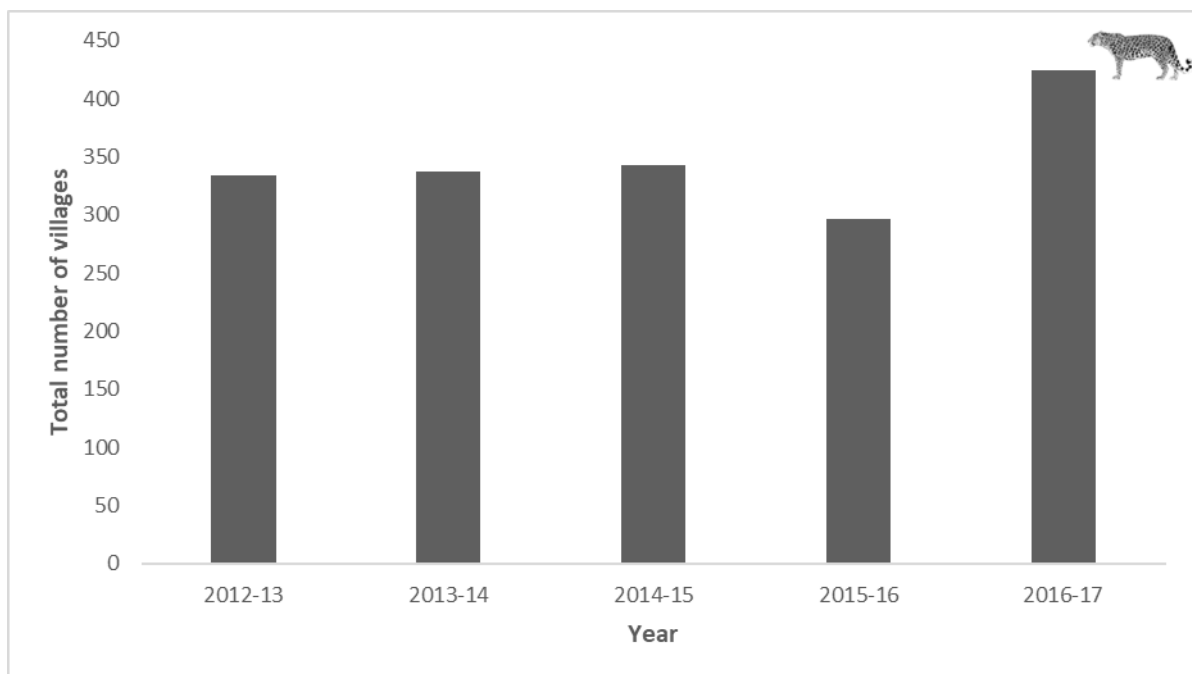


Figure 4.11: Cumulative number of villages experienced livestock predation by leopard

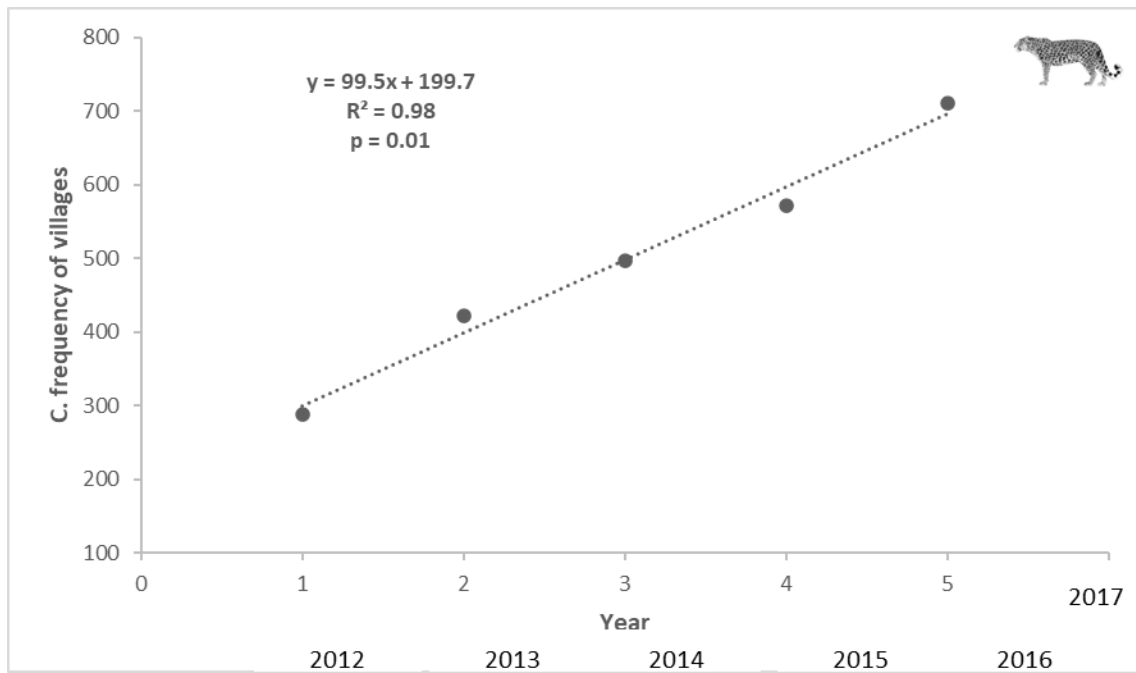


Figure 4.12: Yearly trend of attacks on human by lion and leopard

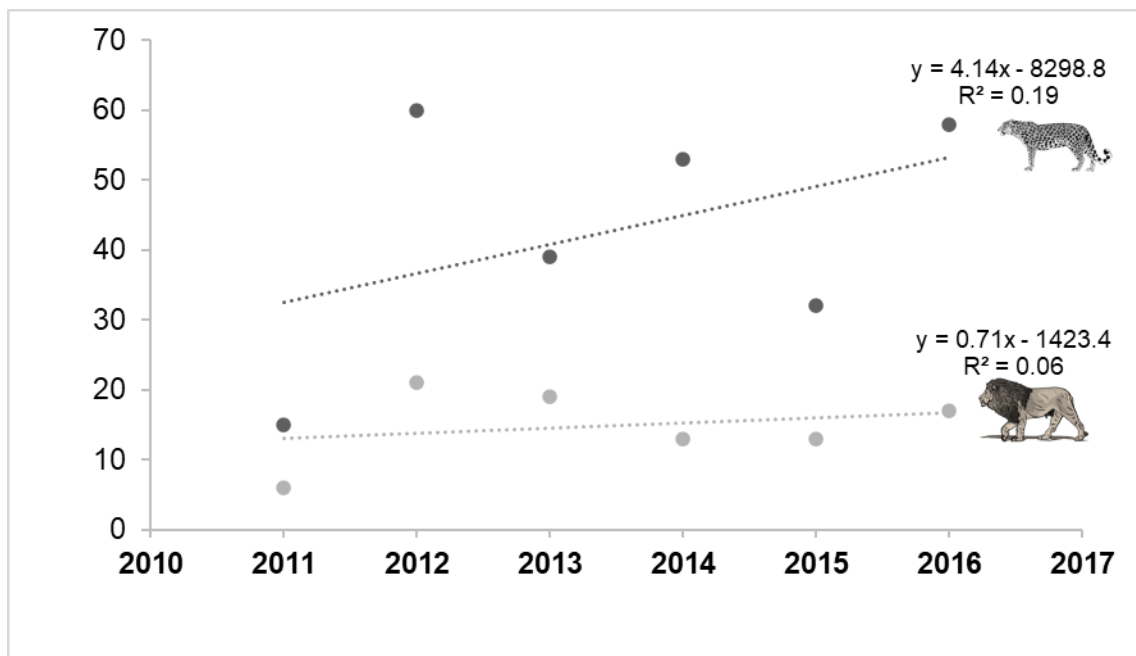


Figure 4.13: Seasonal pattern of attacks on human by lion and leopard

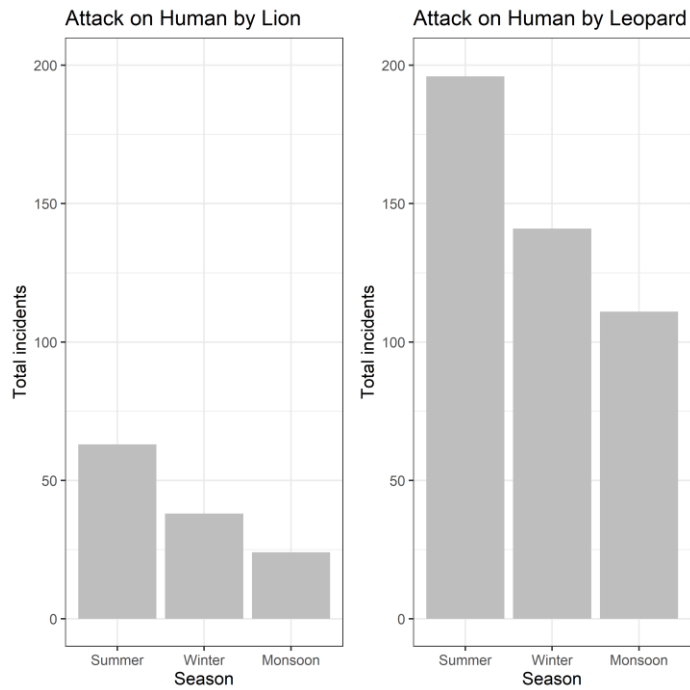


Figure 4.140: Differences between the compensation and actual market price of livestock

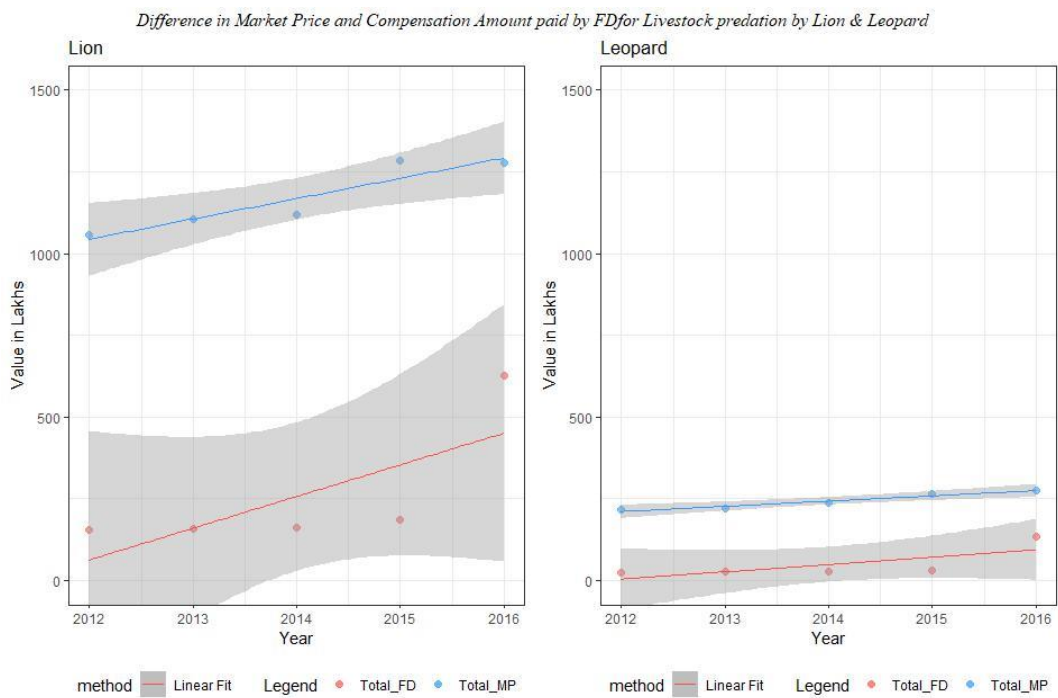


Figure 4.15: (a) Receiver operator curve for assessing model fit for livestock predation by lion, (b) Omission/Commission analysis for model accuracy of maxent models. Response curves obtained from the 100-bootstrap run, where (c) Distance to lion show hot-spots, (d) Lion density per 100 km², (e) Livestock density, (f) Average NDVI and (g) Distance to forest patches.

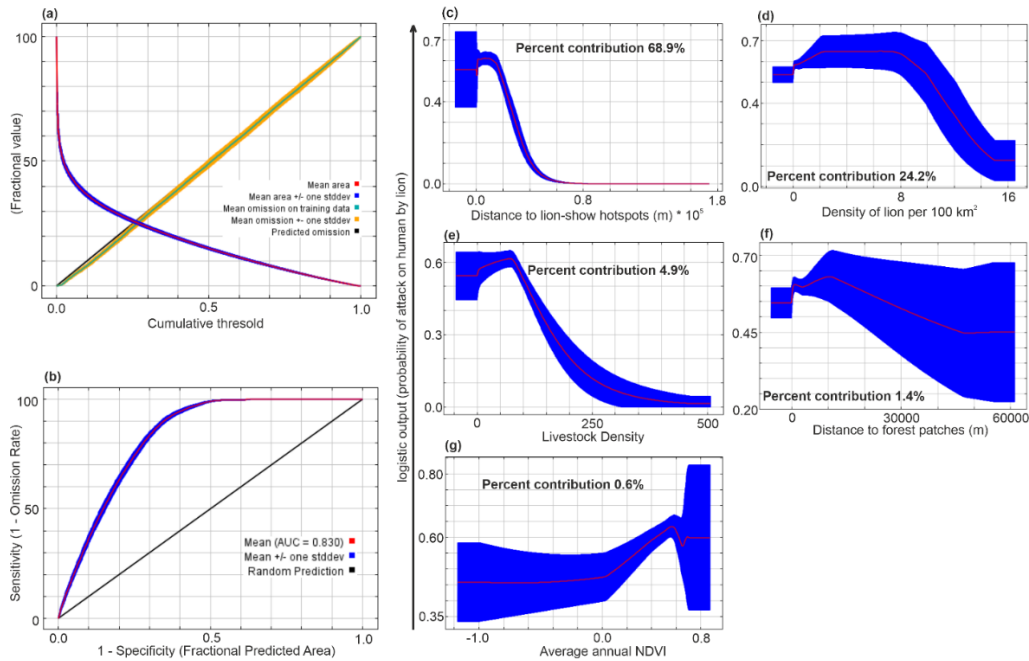


Figure 4.16: The probability risk map of livestock predation by lion in the Saurashtra landscape

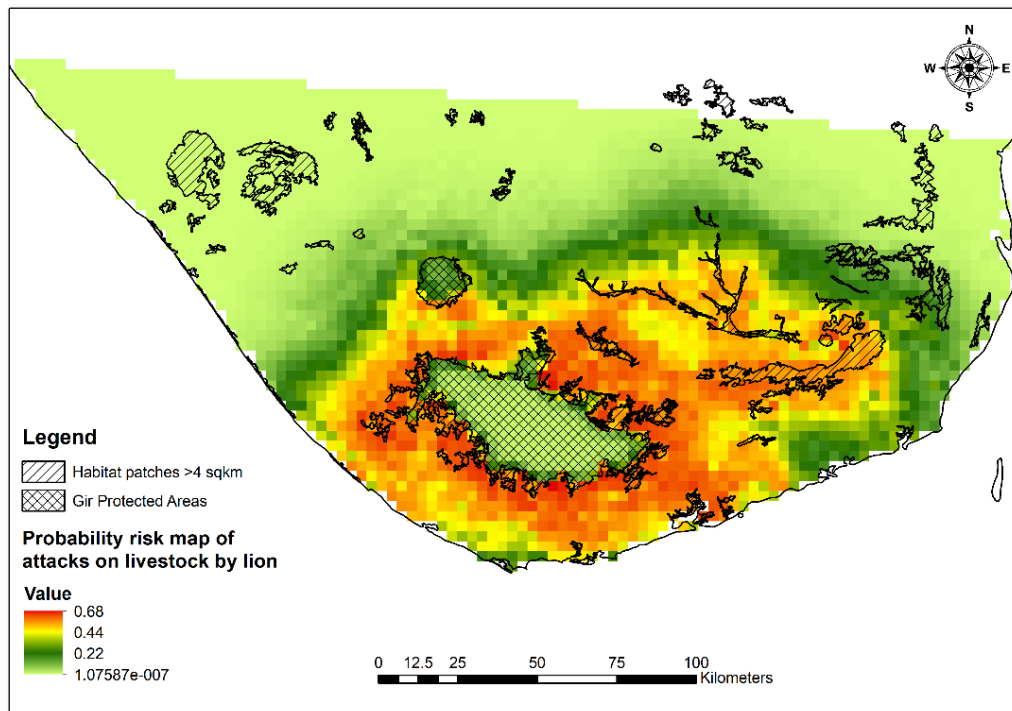


Figure 4.17: (a) Receiver operator curve for assessing model fit for attacks on human by lion, (b) Omission/Commission analysis for model accuracy of maxent models. Response curves obtained from the 100-bootstrap run where (c) Livestock predation frequency in a village, (d) Distance to lion-show hot-spots, (e) Lion density, (f) Distance to forest and (g) Human population density.

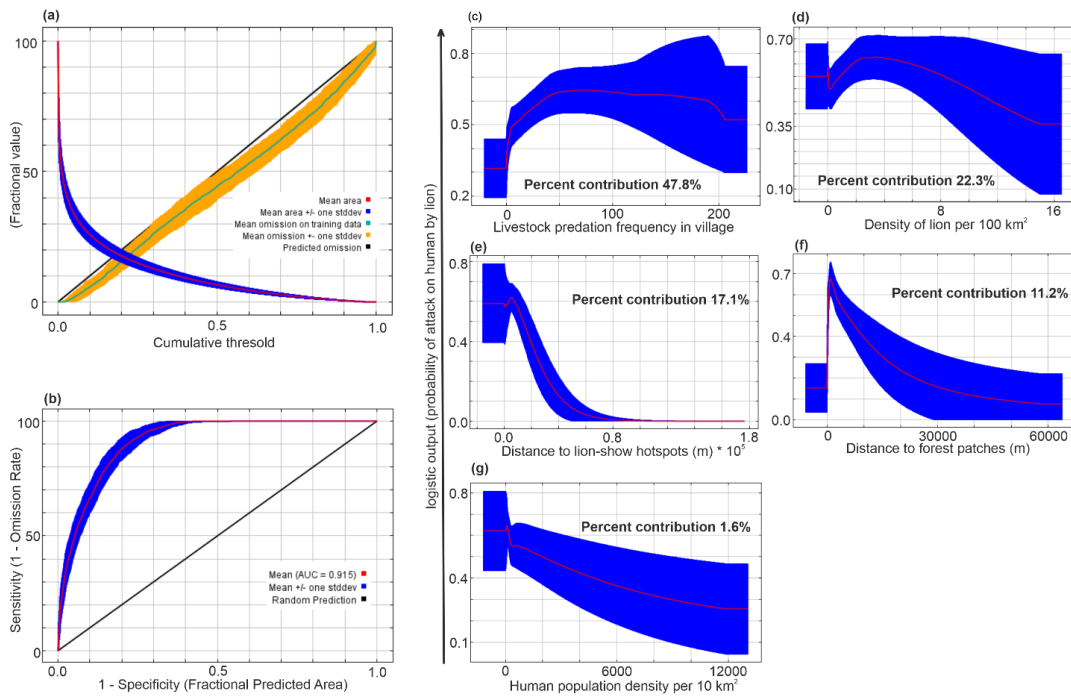


Figure 4.18: The probability risk map of attacks on human by lion in the Saurashtra landscape

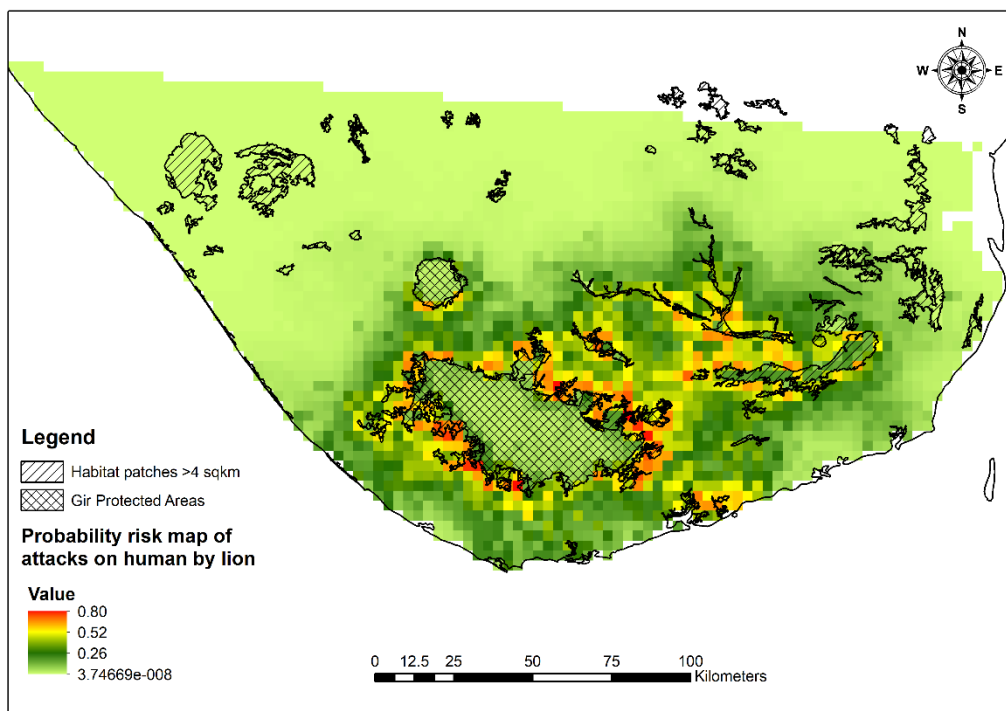


Table 4.1: Covariates of the maxent model and model selection scores. Here, AUC = area under the curve; TSS = true skill statistics and AIC = Akaike information criterion. The best models were selected based on higher AUC, TSS, Kappa and lowest AIC values. Best models (represented in bold letters) are most parsimonious and ecologically meaningful.

Sl No	Model (Lion Livestock)	Training AUC	Test AUC	TSS	Kappa	AIC score	AIC diff	Model (Lion Human)	Training AUC	Test AUC	TSS	Kappa	AIC score	AIC diff	
<i>Univariate responses of habitat characteristics</i>								<i>Univariate responses of habitat characteristics</i>							
1	AvNDVI	0.6	0.59	0.15	0.1	13789.97	1227.94	AvNDVI	0.58	0.52	0.11	0.06	1089.35	104.33	
2	Dforest	0.63	0.61	0.18	0.18	13854.15	1292.12	Dforest	0.75	0.72	0.39	0.23	1075.42	90.39	
3	DrainD	0.54	0.532	0.04	0.02	14058.63	1496.6	DrainD	0.58	0.61	0.19	0.11	1114.47	129.44	
4	Elev	0.56	0.54	0.08	0.06	14022.99	1460.96	Elev	0.62	0.6	0.12	0.09	1114.56	129.53	
5	LionD	0.74	0.74	0.4	0.25	13511.73	949.7	LionD	0.8	0.85	0.53	0.33	1041.67	56.64	
6	Rugg	0.58	0.59	0.1	0.07	13989.3	1427.27	Rugg	0.57	0.52	0.04	0.03	1135.11	150.08	
7	-							LivePF	0.83	0.79	0.57	0.33	1027.9	42.87	
<i>Univariate responses of anthropogenic factors</i>								<i>Univariate responses of anthropogenic factors</i>							
8	DlionSHP	0.79	0.78	0.51	0.3141	12957.94	395.91	DlionSHP	0.83	0.83	0.54	0.32	1010.81	25.78	
9	HpopD	0.6	0.59	0.15	0.11	13949.95	1387.92	HpopD	0.64	0.64	0.19	0.13	1116.19	131.16	
10	LinInf	0.53	0.5	0.04	0.02	14051.01	1488.98	LinInf	0.58	0.53	0.02	0.02	1123.47	138.44	
11	LiveD	0.63	0.64	0.21	0.13	13934.38	1372.35	LiveD	0.69	0.73	0.2	0.14	1098.83	113.81	
12	NL	0.58	0.55	0.05	0.03	13958.52	1396.49	NL	0.59	0.55	0.06	0.06	1111.61	126.59	
<i>Habitat mixed model</i>								<i>Habitat mixed model</i>							

13	AvNDVI + DrainD + Elev + LionD + Rugg + Dforest	0.79	0.76	0.45	0.27	13071.64	509.61	AvNDVI + DrainD + Elev + LionD + Rugg + Dforest	0.87	0.88	0.53	0.3	1052.26	67.23	
<i>Anthropogenic factors mixed model</i>								<i>Anthropogenic factors mixed model</i>							
14	DlionSHP + HpopD + LinInf + NL+ LiveD	0.82	0.81	0.54	0.32	12746.44	184.41	DlionSHP + HpopD + LinInf + NL+ LiveD	0.89	0.88	0.58	0.34	1028.81	43.78	
<i>Mixed model of habitat+anthropogenic factors</i>								<i>Mixed model of habitat+anthropogenic factors</i>							
15	AvNDVI + DrainD + Elev + HpopD + LinInf + NL + Rugg	0.71	0.68	0.27	0.18	13550.57	988.54	DlionSHP + LiveD + LionD + Dforest + AvNDVI	0.9	0.85	0.58	0.33	990.28	5.26	
16	DlionSHP + LiveD + LionD + Dforest + AvNDVI	0.83	0.82	0.55	0.33	12562.03	0	LivePF + LiveD + LionD + Dforest + HpopD	0.92	0.89	0.65	0.35	1030.53	45.5	
17	-							LivePF + LiveD + LionD + Dforest	0.91	0.91	0.68	0.38	985.03	0	

Figure 4.19: (a) Receiver operator curve for assessing model fit for attacks on human by leopard, (b) Omission/Commission analysis for model accuracy of maxent models. Response curves obtained from the 100-bootstrap run where (c) Average annual NDVI, (d) Distance to forest, (e) Drain density, (f) Elevation and (g) Human population density per 10km².

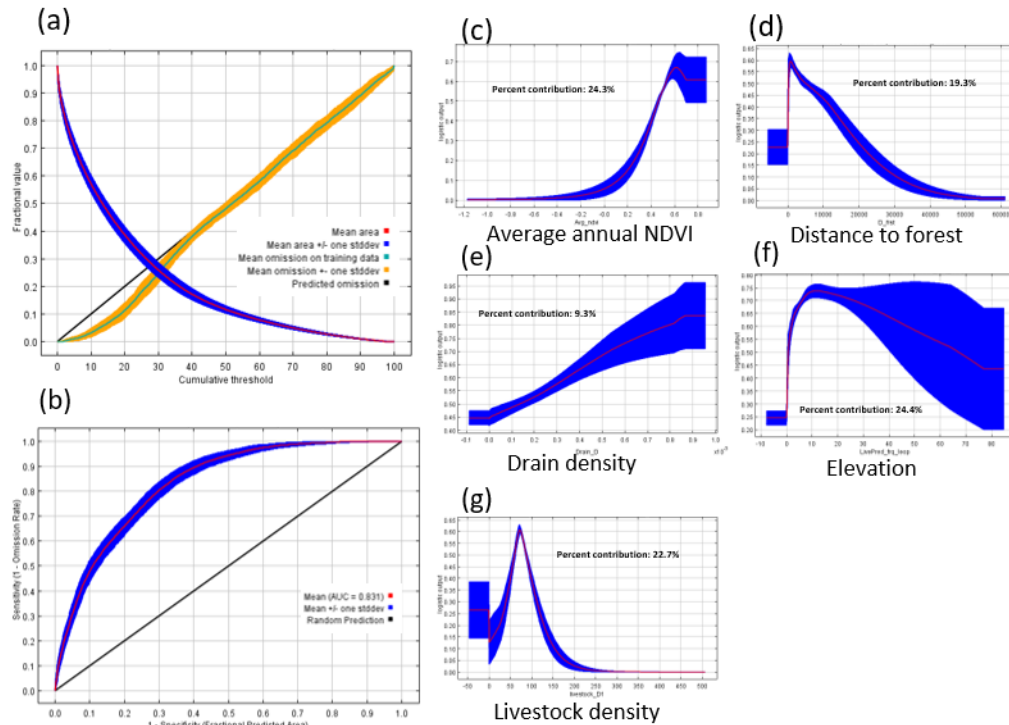


Figure 4.20: The probability risk map of attacks on human by leopard in the Saurashtra landscape

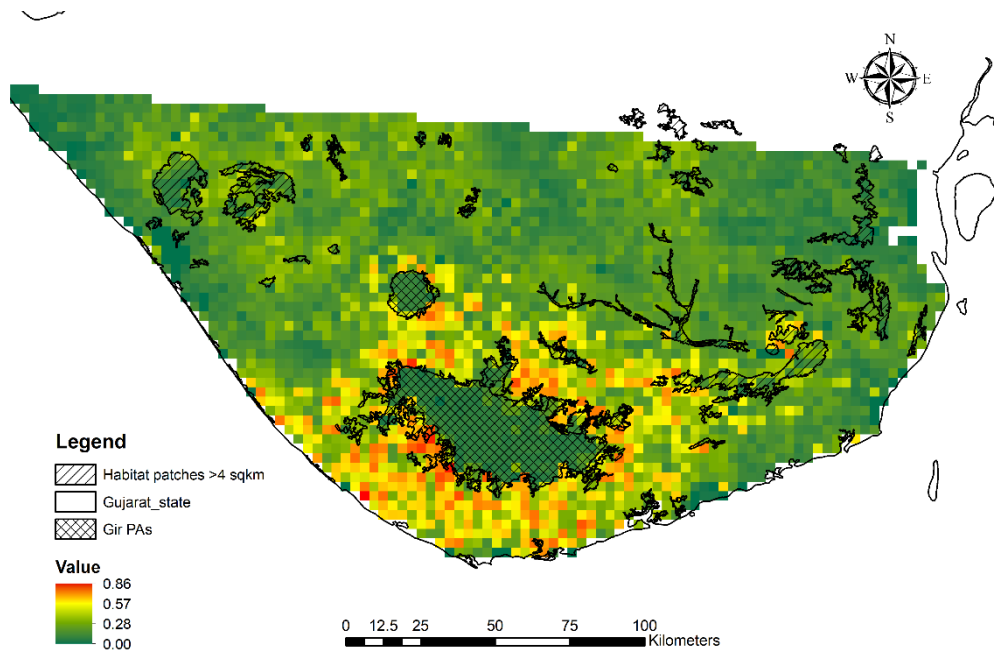


Figure 4.21: (a) Receiver operator curve for assessing model fit for attacks on livestock by leopard, (b) Omission/Commission analysis for model accuracy of maxent models. Response curves obtained from the 100-bootstrap run where (c) Average annual NDVI, (d) Distance to forest, (e) Drain density, (f) Human population density per 10km² and (g) Livestock density.

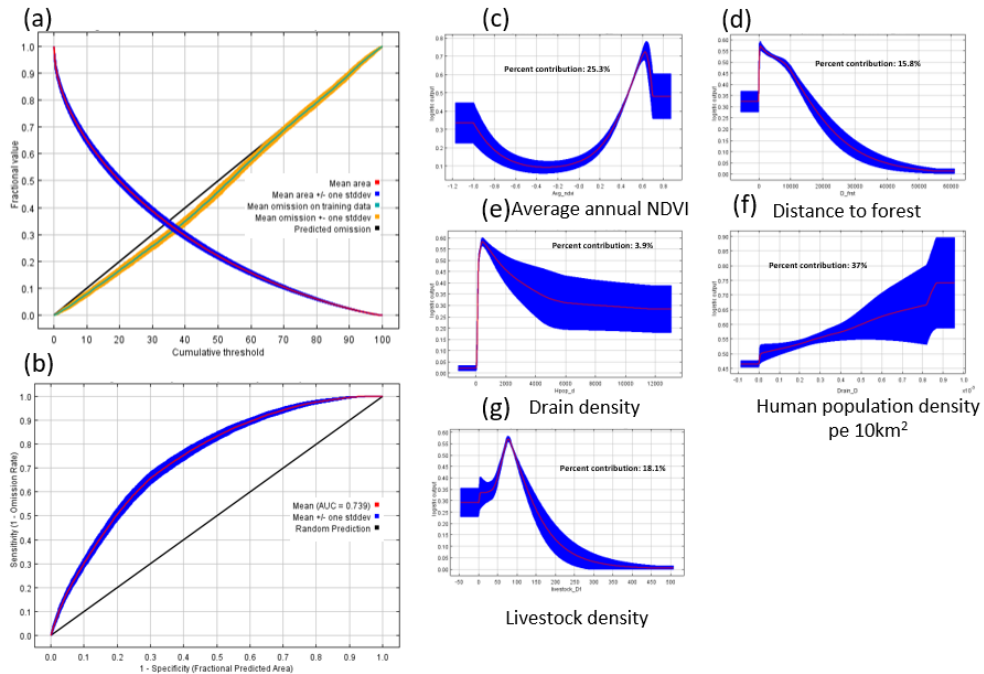


Figure 4.22: The probability risk map of attacks on livestock by leopard in the Saurashtra landscape

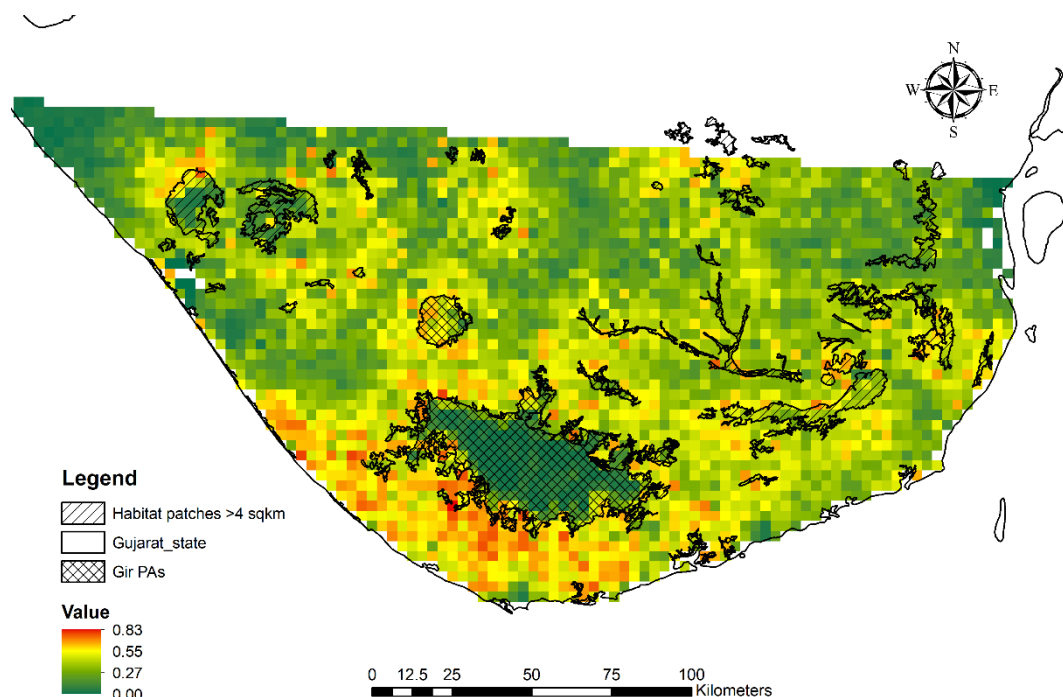


Table 4.2: Covariates of the maxent model explaining the probability of attacks on human and livestock by leopards and model selection scores. Here, AUC = area under the curve; TSS = true skill statistics and AIC = Akaike information criterion. The best models were selected based on higher AUC, TSS, Kappa and lowest AIC values. Best models (represented in bold letters) are most parsimonious and ecologically meaningful.

Model No	Model (Leopard_Livestock)	Training AUC	Test AUC	TSS	Kappa	AIC score	AIC diff	Model (Leopard Human)	Training AUC	Test AUC	TSS	Kappa	AIC score	AIC diff	
Univariate responses of habitat characteristics								Univariate responses of habitat characteristics							
1	Avg_NDVI	0.62	0.64	0.37	0.23	10292.52	263.84	Av_NDVI	0.65	0.66	0.18	0.03	3261.72	155.70	
2	Dist_forest	0.61	0.60	0.25	0.19	10358.61	329.94	Dist_forest	0.64	0.60	0.14	0.04	3260.87	154.85	
3	Drain_Density	0.55	0.53	-0.03	-0.02	10430.88	402.20	Drain_density	0.55	0.57	0.08	0.03	3301.66	195.64	
4	Elevation	0.56	0.54	0.04	0.02	10427.17	398.50	Elevation	0.58	0.57	0.10	0.03	3299.04	193.02	
5	Rugg	0.59	0.57	-0.49	-0.45	10415.80	387.13	Rugg	0.65	0.65	0.22	0.05	3284.29	178.27	
6								Live_pred_mag	0.73	0.74	0.46	0.18	3167.99	61.97	
Univariate responses of anthropogenic factors								Univariate responses of anthropogenic factors							
7	Human_pop_Density	0.62	0.63	0.15	0.10	10304.17	275.49	Humanpop_density	0.61	0.57	0.08	0.02	3277.63	171.62	
8	Linear_infra	0.53	0.52	0.06	0.03	10426.59	397.91	Linear_infra	0.56	0.55	0.05	0.01	3311.35	205.34	
9	Livestock_density	0.63	0.61	0.10	0.07	10326.10	297.43	Livestock_density	0.68	0.67	0.30	0.08	3249.02	143.00	
10	NL	0.60	0.59	0.15	0.09	10325.06	296.38	NL	0.59	0.61	0.11	0.02	3282.31	176.29	
Habitat mixed model								Habitat mixed model							
11	Avndvi_DrainD_elev_Dforest	0.71	0.71	0.35	0.21	10142.06	113.38	Avndvi_Dforest_DrainD_Elev_LpVill	0.81	0.80	0.35	0.21	3167.34	61.32	
Anthropogenic factors mixed model								Anthropogenic factors mixed model							

12	Hpop_Lninfra_liveD	0.70	0.69	0.23	0.14	10199.12	170.44	HP_LinINfra_NL_LiveD	0.77	0.75	0.43	0.26	3230.01	123.99
	Mixed model of habitat+anthropogenic factors							Mixed model of habitat+anthropogenic factors						
13	AvNDVI_Dforest_DrainD_HPD_liveD	0.74	0.72	0.27	0.16	10028.68	0.00	Avndvi_Dforest_DrainD_LiveD_LpVill	0.83	0.80	0.52	0.30	3106.02	0.00
14	AvNDVI_DFrst_DrainD_HpopD_LinInfra_LivestockD	0.74	0.72	0.31	0.19	10041.51	12.83	Avndvi_Dforest_DrainD_LiveD	0.80	0.75	0.43	0.26	3210.88	104.86
15								Avndvi_Dforest_DrainD_Elevation_Humanpop_density	0.78	0.76	0.44	0.26	3176.60	70.59

Discussion:

This study provides an in-depth understanding of the pattern and processes of attacks by lions and leopards on human and livestock at a spatio-temporal scales and governing factors of these conflicts in the Saurashtra landscape. Here, lion and leopards predate on livestock and occasionally attack humans. I have attempted to identify the governing factors of such incidents and produce a spatial map of the probable hotspots of human lion/leopard conflict in the landscape that might help the management authorities to formulate effect conflict mitigation strategies.

In Saurashtra, lions are expanding their range and increasing in abundance as shown by an increasing trend in the cumulative number of villages experiencing attacks as well as an increase in the number of livestock being predated per village. The higher incidences of livestock predation in the districts of Amreli followed by Junagadh, Gir Somnath and Bhavnagar correlates with the abundance of lions in these districts (Supplementary figure 7; Gujarat Forest Department, 2020). Buffalos are the most priced of all livestock and therefore enjoy better husbandry practices like stall feeding by concentrates, always accompanied by human herders when taken out to graze, kept in secure *bomas* after dark, and buffalos also retain collective anti-predatory social defense behaviour (Banerjee et al., 2013) these traits makes them least vulnerable to lion attacks compared to cattle, goat and sheep (Supplementary figure 2). Though attacks on livestock were similar across seasons (Figure 3), there was a minor peak during the monsoon. Most of the farming in the landscape is rain dependent, and during the monsoon the standing crop offers good cover to lions which probably increases their hunting efficiency of livestock.

Saberwal et al. in 1993 reported an average annual frequency of 14.8 attacks on human by lions. Between 1978 to 1991 when the lion population was less than 250 individuals and primarily restricted to the Gir National Park, Gir Wildlife Sanctuary and it's immediate vicinity,

82% of the attacks were observed to have occurred in the agro-pastoral landscape outside of the Gir Protected Areas (Saberwal et al. in 1993). Currently, the geographic extent and population of lions have increased substantially and we report about 25 incidences/annum of attacks on humans by lions where about 89.6% of the attacks were outside PAs. This is suggestive that either lions living within Protected Areas have ample prey and avoid humans and/or humans that have a long history of living with lions know how to avoid being attacked by lions. Although the cumulative frequency of villages reporting attacks on human by lion was increasing over the years, we did not observe any significant trend in the intensity and frequency of attacks on human by lions during the study. Most attacks on humans were accidental or provoked, rarely did lions consider humans a prey. Lion's close association with humans since the historic times in the Saurashtra landscape has possibly evolved a culture amongst lions to avoid confrontation with humans, as evident in many other wild animals (Gruber et al., 2019; Struller et al., 2022; Whitehead et al., 2004). Simultaneously, abundant livestock availability either as carcasses or live animals are sufficient to sustain lions outside the forest have forged unique behavioural traits that allow lions to live in close proximity with humans. Our long-term radio telemetry study revealed that the probability of translating a human-lion encounter into a negative interaction was about 1 in 10000 (Jhala et al., 2016). Lions in the human dominated landscape become active at times when human activity is lowest, but in summers when temperatures are extremely hot during the day, human activity often extends well into the night and there is high spatio-temporal overlap of lions and humans and therefore there is a peak in attacks on humans in this season. Even though the number of attacks on humans were few, these evoke a huge negative reaction from the public and the press (Express News Service, 2019; Kausik, 2022; Republicworld.com, 2021; The Times of India, 2021; The Wire Staff, 2021; Venkataraman, 2018).

The yearly economic loss due to livestock predation by lion has an increasing trend. The current compensation scheme although periodically revised is usually never on par with market rates and does not account for loss opportunity costs (Bannerjee et al 2013). Thus, lion predation on livestock does affect local livelihoods.

The best MaxEnt model had a good fit (Table 4.1) and identified large area of potential risk of livestock predation by lions in the Saurashtra landscape. Matrixes between lion refuge patches have high probability of livestock predation (Figure 4.16). The coastal areas of Veraval, Sutrapada, Una, Rajula and Mahua are predicted as high-risk areas. Proximity to lion-shows explained the maximum spatial variation in livestock depredation (68.9%). These high-risk hotspots extend up to about 20 kms from *lion show* locations (Figure 4.15 c). Lions were usually provided livestock carcasses or as live bait to attract and localise them for tourist viewing (Singh, 2017). Such practices of baiting lions artificially inflate densities around such areas (Gogoi et al., 2020; Saberwal et al., 1994) and larger prides were observed in the vicinity of lion shows (Gogoi et al., 2020). Carnivores dependent on human subsidised food and baiting are known to loose fear of humans (Beckmann and Berger, 2003; Dunkley and Cattet, 2003) which escalates conflict (Massé et al., 2014; Saberwal et al., 1994). Saberwal et al. (1994) have observed an increase in frequency of attacks on human by lions around lion-show areas during the drought period of 1987-88 around Gir PA. Attacks on livestock were negatively correlated with lion density (Figure 4.15 d), since low lion density was found in the human dominated landscape outside of the Protected Areas which abounded with livestock, while having fewer wild prey compared to areas of high lion density within the Protected Areas that had fewer livestock and abundant wild prey (Gogoi et al., 2020). Spatial relationship between livestock attacks and distance to forest patches (which serve as day refuges for lions in human landscapes) and areas of thick canopy (NDVI) both conformed to our initial hypotheses but with a large variation (Figure 4.15f.)

The best model explaining spatial attacks on humans by lions in the Saurashtra landscape has a good fit (Table 4.1, Figure 4.17h) and predictive ability. Areas prone to attack on livestock also registered higher attacks on humans by lions. Ecotones of Protected Areas and forest patches with agro-pastoral landscapes were more prone to lion attacks on humans (Figure 4.18), these areas were characterized by medium to low lion densities (2-4 lions per 100km²; compared to the Protected Areas, 6-15 individuals /100 km², Jhala et al., 2019). It is in these ecotone habitats that lion-human encounters are maximum. Our data suggests that attacks on humans were high in the proximity of areas where “lion shows” were conducted. Lions are baited to localise (Singh, 2017) and tourists pay exorbitant amount of money where they are guaranteed of seeing the lions in action (killing livestock, at night, on foot, night photographing etc.) (Jhala et al., 2019). This practice of luring and retaining lions by artificial feeding increases local lion densities (Gogoi et al., 2020) and due to positive reinforcement of food lions often lose fear of humans resulting in higher number of attacks (Beckmann and Berger, 2003; Massé et al., 2014). Saberwal et al. (1993) reported similar patterns around Gir where most of the lion attacks on humans were around such baiting sites.

The extent of livestock predation by leopard across the Greater Gir Landscape of Saurashtra was found to be skewed. The Western and Coastal belt of the landscape had higher extent of livestock predation which towards the eastern side have very disjunct distribution. This is likely a function of habitat favourable to support higher leopard densities in the western and coastal zone as horticulture and orchards, mostly contributed by sugarcane which provides good cover and breeding ground for the large carnivore. High predation was recorded from villages bordering the protected areas and in the coastal region. The district of Junagadh experienced the highest magnitude of livestock predation by leopards followed by Gir Somnath, Amreli and Bhavnagar (Figure 4.1). There were more records of livestock predation by leopards outside the Gir protected areas compared to inside (Figure 4.2), this is simply an

artifact of low livestock density inside the protected areas. As per the ecology of leopards, where they mostly prefer small to medium body sized prey, in case of livestock predation as well we observed a similar pattern of livestock selection which were smaller in body size and were observed to predate more on young cattle followed by goat and sheep (Figure 4.3). There was high magnitude of livestock predation incidents during monsoon followed by post-monsoon and pre-monsoon (Figure 4.4 b) because of the increased vegetation cover during monsoon, which gives more concealment to the leopards and less visibility for the livestock, similar with post-monsoon seasons where the vegetation of the landscape still remains close compared to the openness of the pre-monsoon seasons. Intensity of conflict, indexed through number of conflicts/number of villages did not show any trend ($R^2= 0.27$, $p= 0.37$) (Figure 4.8), which indicates towards an stable per unit are density of conflicts in the study area. However, the number of livestock killed by leopard showed an increasing trend between 2012 to 2016, with an predation increament of more than 34 livestock per year in the landscape ($R^2= 0.86$, $p= 0.01$) (Figure 4.9). The number of villages experienced livestock predation by leopards didn't show any significant trend over the years (Figure 4.10). However I obseved an increasing trend of the cumulative number of villages experienced livestock predation by leopards (Figure 4.117). This could be a result of slow growing but spatially expanding population of leopards in the landscape.

The best model predicting the probability of attacks on humans by leopards explains that, with increasing elevation the probability of attacks on humans by leopards are decreasing (Figure 4.19 f), which represents the hilly and rugged areas in the human dominated landscape of Saurashtra that naturally has low human density and human activities. Probability of attacks on both human and livestock showed an increasing trend in areas with high average annual NDVI. These areas represent the riverine habitats, prosopis patches that remain green through the year, distributed along the rivers and coastal belt of the Saurashtra region. The orchards and sugarcane fields around the Gir protected forests and along the coast provides good breeding ground for the leopards in the human dominated landscape and also elevates interactions with humans (Dahya et al., 2021; Vijayan and Pati, 2002). The peak in the probability of attacks on both human and livestock between 50-100 livestock per km² represents the small villages with low density of livestock mostly along the forest patches. As hypothesized the probability of attacks on both human and livestock decreased away from the forest patches (Figure 4.19d) because leopards use such forest patches as day time refuge and venture into human habitations, therefore nearby areas to such patched experience more conflict with leopards than the areas far away from such patches. Leopards are known to use rugged terrains to avoid its competitors and in the human dominated landscape they are also known to use broken terrains, and drainage systems to move between habitat patches. Therefore, we observed a sharp linear increase in the probability of attacks on both human and livestock by leopards as the density of drainages increased in the landscape (Figure 4.19e). However, with increasing human density in the landscape the probability of attacks on livestock reduces that represents the urbanization gradient in the landscape.

The conflict between human and large carnivores in shared landscape is unavoidable but with proper management strategies magnitude of these negative interactions can be reduced. It is also important to mention that complementing compensation records with sample surveys would provide a more accurate picture of livestock losses and conflict incidents. However, it was observed that in 250 interviews 95% of the pastoralists who lost their livestock to lions actually claimed and received compensation, so these records were quite reliable. These statistics with more detailed explanations are now accepted for publication in the *Journal of Conservation Biology* (Conservation Biology 24-228.R2) also included the accepted version of the MS as an appendix to the updated thesis. Additionally assessing the effectiveness of compensation schemes to inform policy recommendations and understanding the broader context of livestock deaths, including those caused by species other than lions and leopards, as well as factors like disease, drought, and extreme climate events, is crucial for developing a holistic approach to conflict mitigation. Incorporating this data could indeed provide valuable insights into local animal husbandry practices, livestock management, and the broader vulnerabilities faced by communities, especially in relation to climatic impacts. While my PhD research primarily focused on predator-related depredation, I recognize the importance of exploring these additional factors and highlight a valuable direction for further research.

Such evaluations could indeed help improve community satisfaction with the schemes and potentially enhance reporting and mitigation efforts. Few salient point that would be appropriate for the Saurashtra regions would be as follows:

1. Regular scientific monitoring of the spatiotemporal patterns of the conflict hotspots in the landscape.
2. Awareness campaigning about the behaviour, habitat use, ecology of the large carnivores and measures need to take upon seeing these carnivores in the human dominated landscape should be a regular effort across the landscape.

3. Rapid action teams should be established across the key areas of the landscape for fast-track action on conflict situations.
4. Create platform for knowledge exchange on better livestock rearing practice between the Maldharies (Pastoralists) living inside Gir Protected Areas and the community members from the human dominated areas to safeguard livestock from leopards and lions.
5. Guidelines for the farmers and daily wages farm workers hired from other states and areas to work in the landscape to minimize their interaction in the farmlands.
6. Effective dumping of livestock and other animal waste.
7. Installation of machans in farmlands to avoid the large carnivores while guarding crops at night.

Chapter V

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Chapter V: Locals in the conservation of large carnivores:

Objective 4: To assess the perception of the locals towards conservation of lions in the landscape.

Objective 5: To model the manifestation of current co-existence scenarios of lion and human in the Greater Gir Landscape.

Introduction:

Current conservation ideology suggests that local community participation or active involvement is crucial to successful conservation efforts (Robinson and Sasu, 2013). However, protected areas impose significant social impacts on rural people, including displacement from land, restricted access to natural and cultural resources and increased threats from damage-causing animals (Hill, 2004, West et al., 2006, Anthony and Szabo, 2011). In addition, where the balance of benefit-sharing systems for local people has not occurred, relations between management authorities and surrounding communities have become increasingly stressed (Dickman, 2009). Human-wildlife conflict presents a challenge for protected areas, particularly when conflict impacts the quality of life for local people, especially in areas that lack suitable compensation (Bajracharya et al., 2006). These factors increase opposition and weaken support for conservation efforts. People are more likely to tolerate risks that are undertaken voluntarily rather than enforced upon them (Starr, 1969, Skogen et al., 2008). Religious beliefs and cultural importance have undoubtedly played a significant role in India towards maintaining a balance amidst conflicts but such values are changing fast and wildlife managers need innovative mechanisms for conflict resolution.

Global conservation scientists have been increasingly emphasizing on improving co-

adaptation measures, which is believed to be the key driving force of coexistence between humans and large carnivores in such habitats (Carter and Linnell, 2016). People and animals are likely to be less hostile to each other when the mutual benefit of living together exceeds the cost (Jacobsen et al., 2021).

The Asiatic lions exemplify a rare scenario where their recovery has created opportunities for lions and humans to mutually adapt to each other's presence and coexist. In the human-dominated landscape of Saurashtra neighbouring the Gir forests, Asiatic lions have increased in numbers and extent (Figure 1). Presently claimed to be over 674 individuals with an annual growth rate of ~6% (since 2015), the lion population spans over 30,000 km² (36% increase in geographic range between 2015 to 2020) of multi-use human dominated landscape (Gujarat Forest Department 2015). Nearly 85% of the lion population shares its habitat with humans (Gujarat Forest Department 2020). In most of such shared habitats, wild prey availability is poor and lions rely on anthropogenic food subsidies i.e. livestock, either through scavenging or predation. Local communities in this landscape predominantly do not consume beef owing to religious and cultural sentiments, while dairy farming constitutes a major form of livelihood in the region. Unproductive cattle are not slaughtered, instead are often disowned by their owners and live as strays. Such strays (as well as owned cattle) die frequently of old age in the landscape, and are dumped at specific locations (*hadda-khodis*) at the outskirts of villages. These dumpsites create a carrion bonanza that subsidizes the survival of large carnivores in these human modified habitats (Jhala et al. 2019). Radio-telemetry and scat analysis data show that livestock constitutes 71% of lion diet in this landscape, out of which carcass-scavenging contributes to 65% of the biomass (Banerjee, 2012; Jhala et al. 2019). Predation on livestock is relatively low, however an expanding and increasing lion population challenges the status-quo.

While living with a large carnivore is no easy feat, the endemism of free-ranging Asiatic lions to this area attracts a large number of domestic and international tourists, creating a vibrant ecotourism industry. Lion tourism is controlled by the Gujarat Forest Department, and occurs only within a restricted section of the Gir Protected Area. Such tourism is contingent upon the checks and balances imposed by the Forest Department under the Wildlife Protection Act (1972); lion safaris are only allowed on vehicles and during the day. However, tourists often fancy viewing lions on foot, and at night during lion peak activity hours. Local communities often harness this opportunity and conduct *lion shows* on local private lands by baiting lions with livestock (Singh, 2017) where enforcement of legal, ethical, and safety norms is difficult. Such activities can be prosecuted under the Wildlife Protection Act (1972) evoking strict penalties and imprisonment. However, law enforcement across a large landscape especially on private lands is often difficult and *lion shows* are conducted clandestinely, creating avenues for local communities to accrue economic benefits from living with lions. Such supplementary feeding, while beneficial to both lions (food) and humans (money) in the short term can become counter-productive in the long run because it may cause physiological changes in the provisioned lions (Robbins et al., 2004), increase vulnerability to zoonotic diseases (Miller et al., 2003; Becker et al., 2015), alter behaviour (Barocas et al., 2018), increase local density (Kirby et al., 2017; Gogoi et al., 2020), change population dynamics (Gray et al., 2004) and provisioned individuals may lose fear of humans (Gray et al., 2004; Herrero, 2018) resulting in higher conflicts (Matthews et al., 2003; Massé et al., 2014; Kirby et al., 2017). However, perception of local communities can be directly moulded through these short-term tangible economic benefits, and such ecosystem services provided by a large carnivore can often support coexistence. Furthermore, intangible values reflecting the prevalent socio-cultural norms of local communities coupled with past lived experiences of encountering carnivores can nuance the resultant attitudes of people.

Maldharis (pastoralist) living inside the Gir Protected occasionally lose their livestock to lions and leopards, however with the free access to fodder & grazing inside the forest along with compensation from the forest department for livestock predation by the carnivores, they are 76% more benefited than the Maldhari's living outside the PA (Banerjee et al., 2013). Lions mostly preyed on unproductive livestock (males and poor condition calves, aged, and dying cattle). Moreover, due to religious sentiments and cultural beliefs livestock is not consumed in the landscape and dead livestock are often dumped in "haddakhodi". Which serves as free and easily accessible for the lions. Therefore, there is a conducive amalgamation of socio-cultural sentiments of locals and behaviour of lions resulting in a win-win situation for both the carnivore and humans living with them. Although currently the lion density outside the PA is low i.e. just 2 (SE 0.1) per 100 km² (Banerjee, 2012) the population of lion is increasing both in number and geographic extent over the years (Singh and Nala, 2018; Gujarat Forest Department, 2020). As a result the conflict in the human dominated landscape has been on rise (Meena et al., 2014; Jhala et al., 2019). So far majority of the in the agro-pastoral landscape outside the Gir PA observed to have positive attitude towards lions (Meena et al., 2014). However, with the increasing population of both the large carnivores and human population in the landscape the long-term persistence of conducive attitude of locals towards lions is questionable and need thorough scientific understanding of their interaction in both socio-ecological dimensions. Both tangible and intangible factors of benefit sharing or loss due to damages by wildlife are found to play important role in shaping the attitude and perception of people (Jacobsen et al., 2021). Despite conflicts with the large carnivores the factors that are promoting the coexistence of lions with the local communities are needed to be understood. While there is no silver bullet for the resolution of human-carnivore conflict, understanding already existing systems of

coexistence like the lions of Gir and local communities can be the key to reimagining carnivore conservation outside of protected areas in the Anthropocene.

Method:

Ethics Statement:

The study was carried out with permission from the office of the Chief Wildlife Warden, Gujarat State and Ministry of Environment and Forests, Government of India under the provisions of the Wildlife (Protection) Act, 1972, Government of India. Prior to the interviews a verbal consent of the respondents were asked and only proceeded with the interview if the respondents agreed. The study was approved by the Training, Research, and Academic Council of the Wildlife Institute of India which considers the merit of the science, conservation implications, and ethics of the study.

Data collection:

Addressing human-wildlife conflicts requires interdisciplinary understanding of the socio-ecological components of the system (Pooley et al. 2017; Carter et al. 2017; Struebig et al. 2018). The social and ecological systems always interact at a spatial scale that determines the interactions between human and the wild animals (Lischka et al. 2018). Therefore, it is often emphasized to integrate both socio-ecological factors to understand human-wildlife interactions (Dickman 2010; Zimmermann et al. 2020). We followed a theoretical framework described by (Lischka et al. 2018) to understand the socio ecological system of interactions that is promoting co-existence between lions and humans in the Saurashtra landscape. Where, we integrate the spatial magnitudes of conflicts (Chapter 4) with attitudes of local community through socio-economic surveys to understand the manifestation of co-existence at a spatiotemporal scale. We tried to assess the factors that promote or inhibit the psychological

mechanism of tolerance towards lions in the landscape. Tolerance is considered to be a major governing factor of human actions towards the carnivores that directly or indirectly influences the density and distribution of the carnivores and hence interactions with humans (Bruskotter & Wilson 2014).

Based on prior knowledge and reconnaissance survey we designed our questionnaire for the social survey interviews. Before the interviews consent from the respondents about the survey was obtained and if agreed we proceeded with the interviews. All the person interviewed for the survey were above 18 years. We conducted household interviews with predefined questions that addresses the general demography of the respondents, economic status, occupation, education qualification, awareness of wildlife in the vicinity of their village including presence of large carnivores and status of crop damage by herbivores. If the respondents were aware of lion presence, we further asked them the temporal experience of land-sharing with lions indexed through the approximate year of colonization by lion and leopard around the village, experience of encounter and livestock predation, whether satisfied with the compensation amount, whether they like the carnivores and reasons behind liking or disliking. We stratified the villages into (a) high, (b) moderate and (c) no conflict villages based on the frequency of lion predation events. We sampled villages from each of these strata for our survey questionnaire at random to get a full representation of respondents exposed to different magnitudes of conflict with lions across the landscape. A randomly selected household was our unit of sampling from which an adult member was approached for consent to engage with us in answering our questionnaire. This person was explained in brief regarding the study we were conducting, and subsequent to his/her consent was asked the following questions (Table 5.S1). Number of household were selected randomly that ranged from one to twenty one per village and every subsequent households were selected by generating a random number between five to ten with the help of a smartphone to maintain

the randomness of the process (Table S 5.1).

Analytical method:

We categorized the social survey responses into high conflict, moderate conflict and no conflict villages based on the frequency of incidences to see whether the magnitude of conflict have any influence on the perception of locals towards conserving lions in their backyard. We hypothesized that there will be high proportion of negative sentiments in villages having higher conflict compared to moderate and no conflict villages. We also hypothesized that pastoralists would have higher negative sentiments towards lions compared to people from other occupational background. We further investigated on the reasons behind liking and disliking of lion. Among the group that liked lions we asked them to elaborate why they liked lions by choosing from the following reasons (a) for the noble and charismatic qualities of lions, (b) religious and cultural values of lions, (c) lions were considered important for the ecosystem, (d) lions provided economic gain and (e) others (which were open ended, and included reasons besides those listed above). Among the group that disliked lions we asked them to elaborate and choose the reason for their dislike from (a) due to the aggressive nature of lion, (b) lions perceived as dangerous to humans, (c) lions caused economic loss through livestock predation, (d) unreasonable interference by wildlife managers with community affairs due to the presence of lions and (e) others (which were open ended, and included reasons other than those listed above). We used logistic regression to understand the influence of various socio-ecological factors on shaping the attitude of people towards lions (Objective 5) at a binomial scale of “0 (dislike lion) and “1” (like lion). Before the analysis we categorized the age of the respondents into “18-30 years old” as (1), “31-50 years old” as (2) and “>50 years old” as (3); educational status into “no education” as

(1), “primary education” as (2), “high school” as (3) and “graduates or above” as (4); economic status into “poor” as (1), “well off” as (2) and “wealthy” as (3); colonization time of lion into “no lion” as (1), “0.1-5 years” as (2), “5-15 years” as (3), “15-30 years” as (4), “30-50 years” as (5) and “>50 years” as (6). We used the magnitude of livestock predation as a covariate in the model and hypothesized that villages with high livestock predation frequency will also have higher risk of attacks on humans. We used distance to lion habitats and distance to lion-show hotspots as covariates in the model. Magnitude of livestock predation, distance to lion habitat and distance to lion-show hotspots were log transformed to get a better linear fit in the model (Zar, 2014). Best model was selected based on lowest AIC value (Akaike, 1974).

Results:

Contrary to our hypothesis, we observed that people belonging to high and moderate conflict villages had more positive attitude towards lions compared to villages with no lion conflict (Figure 5.1). Among people with different occupational background pastoralists had the highest negative sentiments towards lions (Figure 5.2). When we further examined the reasons for people liking or disliking lion, we found that people liked lions for its perceived qualities of nobility and charisma, feeling of pride in having lions in their area, and due to economic benefits derived from lions (Figure 5.3a). The reasons for not liking lions were due to the economic loss incurred from lion predation on livestock as well as perceived threat to human lives (Figure 5.3b). For both responses of liking and disliking lions, economic reasons were found to be playing a major role in shaping the perception of local communities towards lions.

The best model that explains the odds of liking lion in the landscape is characterized by economic status of a person, educational status, temporal extent of land-sharing, distance

to lion-show hotspots and conflict frequency, $R^2= 0.40$ (Table 5.2). The logistic model has an overall classification accuracy of 80 %, wherein about 83 % dislike (0) and 78 % like (1) categories were correctly classified (Table S 5.2; Figure S 5.2). Variables that best explained the odds of liking lions were economic and educational status of a person, experience of living with lions, distance to lion show hotspots and conflict frequency, $R^2= 0.40$ (Table 5.2). The logistic model had an overall classification accuracy of 80%, wherein about 83 % dislike (0) and 78 % like (1) categories were correctly classified (Table S 5.2; Figure S 5.3) by the best model. In contradiction to our a priori hypothesis, we observed that the probability of liking lion increases with increasing frequency of conflict in a village where the odds of liking lions increased by a factor of 1.94 with each increasing conflict category (Table 5.2). However, the probability of liking lion decreases with distance from lion shows, where the odds of liking lions decrease by 0.66 with each km distance. As per our a priori predictions the probability of liking lions was found to be significantly higher with increasing economic and educational status of a person and the temporal extent of land sharing with lions (Table 5.2).

Figure 5.1: Bar plots showing the percentage of liking or disliking for lions by the respondent in villages categorized into high, moderate and no conflict.

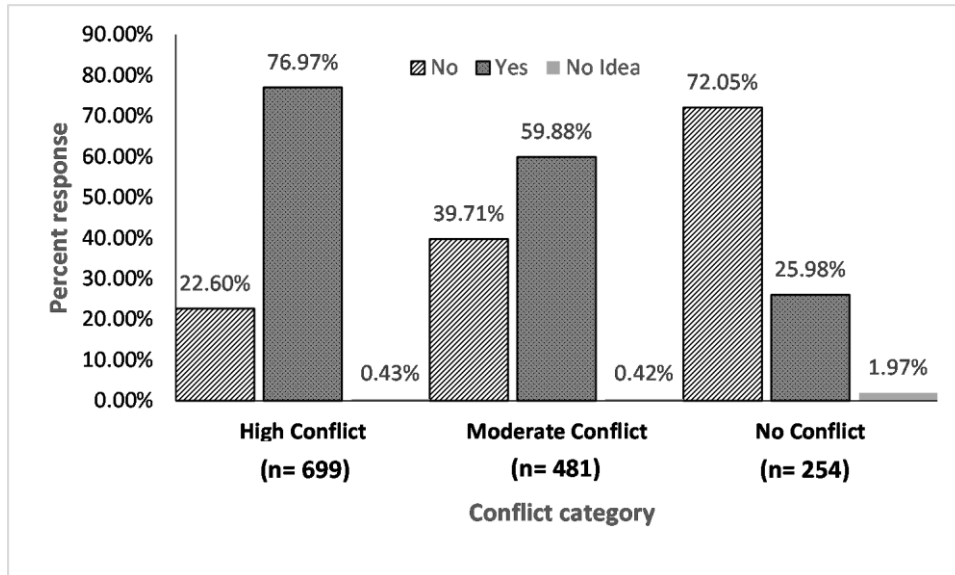


Figure 5.2: Bar plot showing the percentage of liking and disliking by respondents of different occupational background.

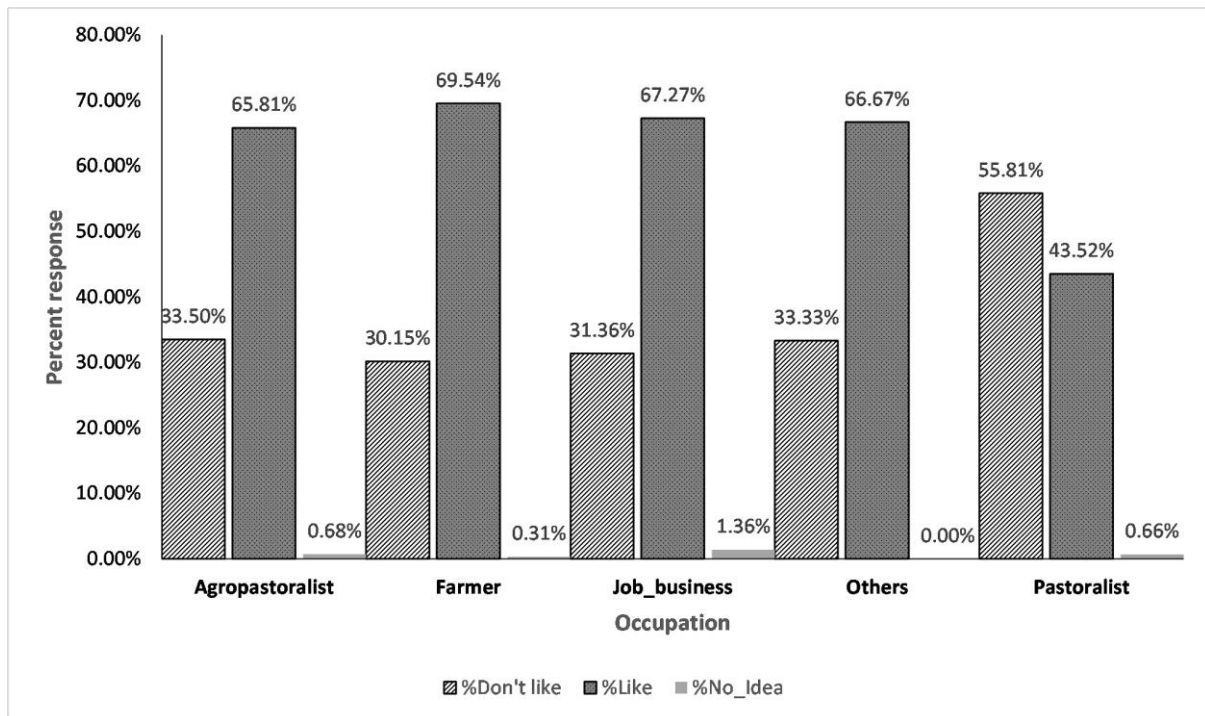
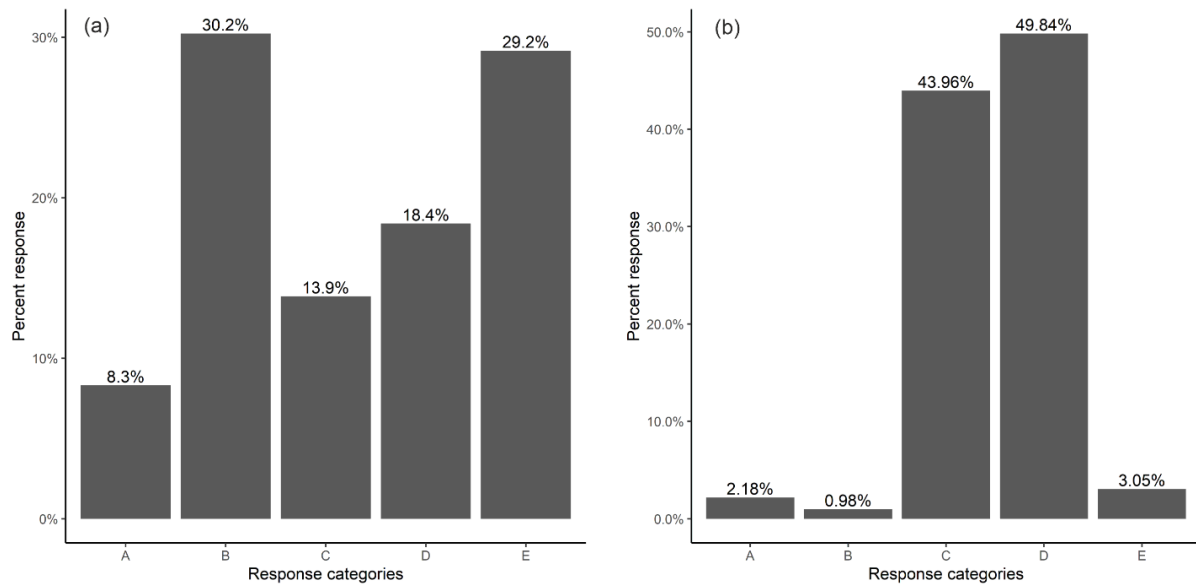


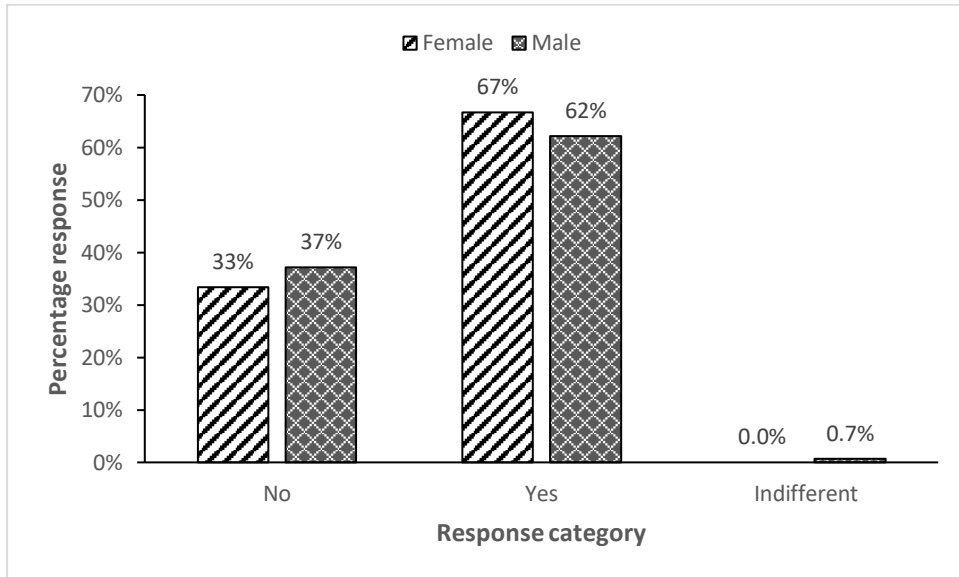
Figure 5.3: The bar plots represent the percentage of response in each category of (a) reasons of liking lions (A- Other, B- Pride and nobility, C- Religio-cultural importance, D- Good for environment, E- Economic gain, pest control) and (b) reasons of disliking lions (A- Other, B- Aggressive, C- Danger to human life, D- Economic loss, livestock predation, E- Problem with forest department).



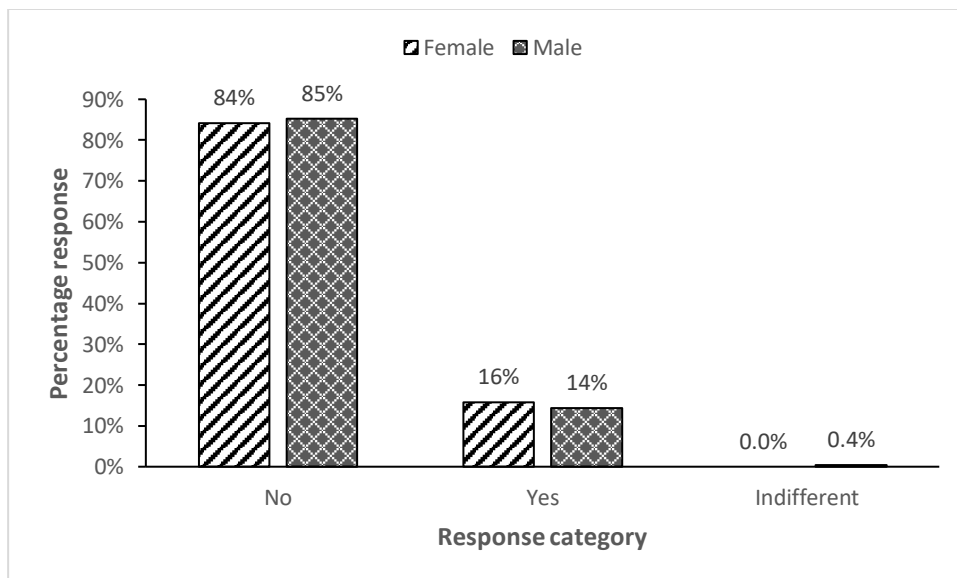
We didn't observe any significant difference in the percent responses of male and female respondents towards their liking or disliking of lions (Fig 5.4a). About 67% of the females interviewed expressed their liking for lions and 33% expressed disliking for lions. About 62% of the total male respondents expressed their liking for lions while 37% expressed their disliking for lions. While for leopards' higher proportion of the respondents of both the genders expressed disliking compared to lions. Almost equal proportion of male (85 %) and female (84%) respondents expressed their disliking for leopards, while only 14 % male and 16% of female respondents expressed their liking for leopards.

Figure 5.4: Gender wise (male, female) percentage of respondents expressed liking and disliking towards (a) lion and (b) leopard

(a) Lion



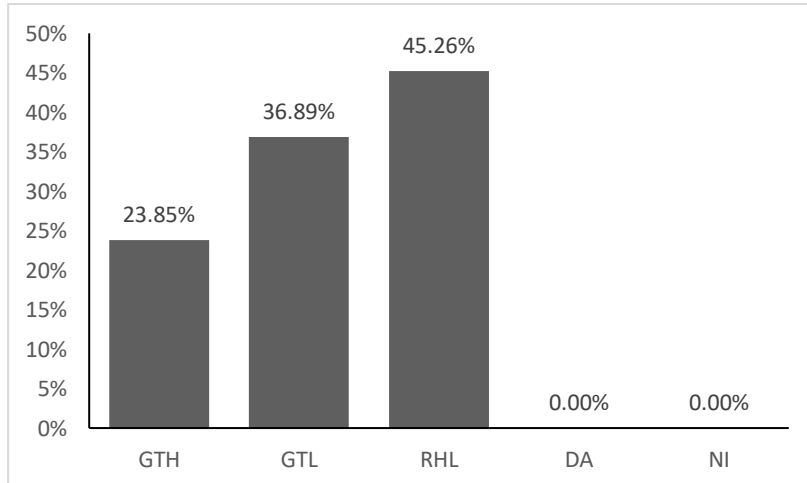
(b) Leopard



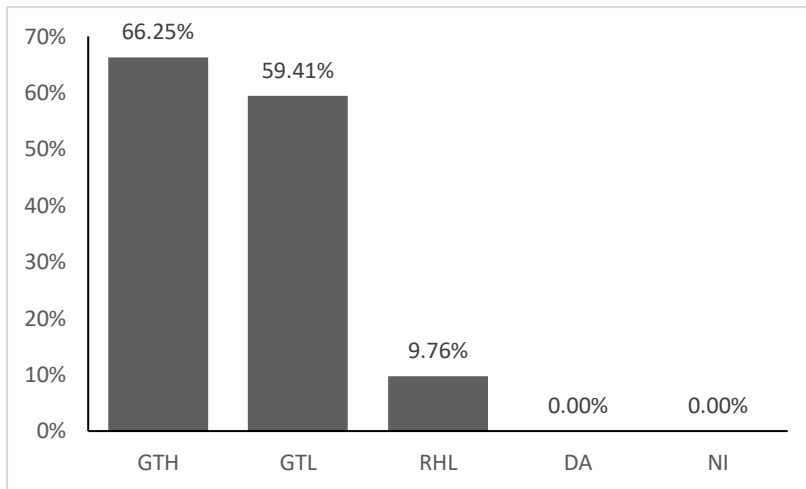
Among the perceived threat of lions and leopard higher percentage of respondents expressed that lion “rarely attack human and livestock” (45.26%) however about 36.89% of the respondents expressed lions as “greater threats to livestock” and about 23.85% respondents perceived lion as “greater threat to human life” (Figure 5.5 a). However, the responses were exact opposite towards leopards. 66.25% of the respondents said that leopards are “great threat to human life”, 59.41% respondents expressed leopards to be “great threat to livestock and 9.76% respondents said that leopards “rarely attacks human and livestock” (Figure 5.5 b).

Figure 5.5: Perception of respondents towards lion and leopard categorized into different classes. Here *GTH*: *Great Threat to human*, *GTL*: *Great threat to livestock*, *RHL*: *Rarely attack human and livestock*, *DA*: *Don't attack human and livestock*, *NI*: *No idea*.

(a) Perception about lion



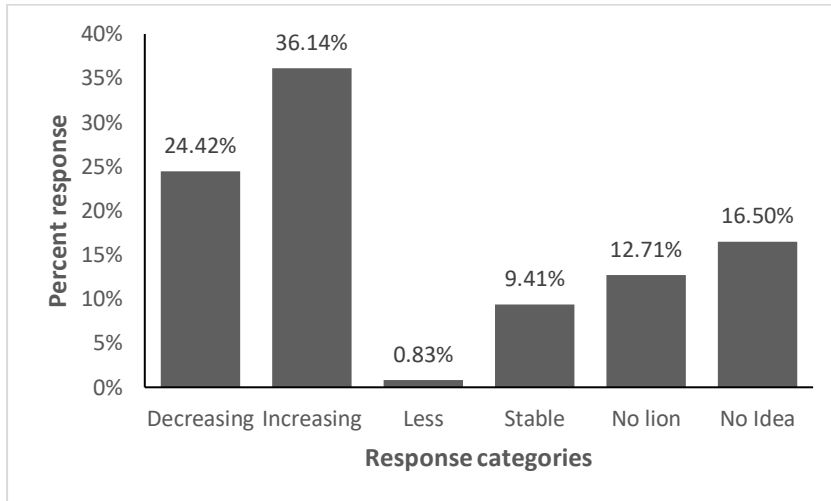
(b) Perception about leopard



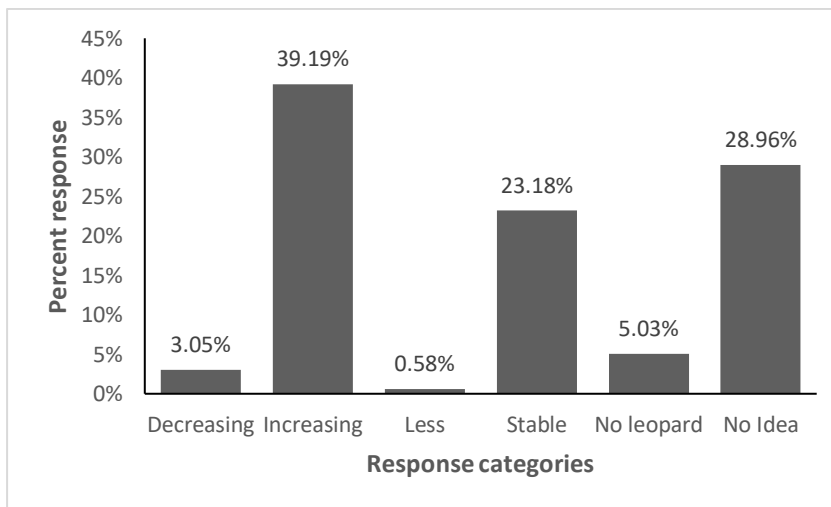
About 36.14% of respondents believe that number of lions are increasing in the landscape whereas 24.42% respondents believed to be decreasing. About 12.71% of the respondents either belonged to areas with no lions or they believe to have no lions in their vicinity. 9.41% of the total respondents believed the lion population to be stable over the years. About 0.83% believed that lions rarely visit their vicinity and about 16.50% said that they have no idea about the population trend of lions in their vicinity (Figure 5.6a). Similarly, a significant percentage of the respondents said that population of leopards are increasing in the landscape (39.19%) and only 3.05% of the respondents said that population of leopards are decreasing. About 0.83% of the respondents said that leopards rarely visit their village vicinity and 23.18% of the respondents said that population of leopards are stable. Whereas, 16.50% of the respondents had no idea about the population trend of leopards in their vicinity (Figure 5.6b).

Figure 5.6: Perception of the respondents about the trend of number of (a) lion and (b) leopard number in neighborhood.

(a) Perception on lion number



(b) Perception on leopard number

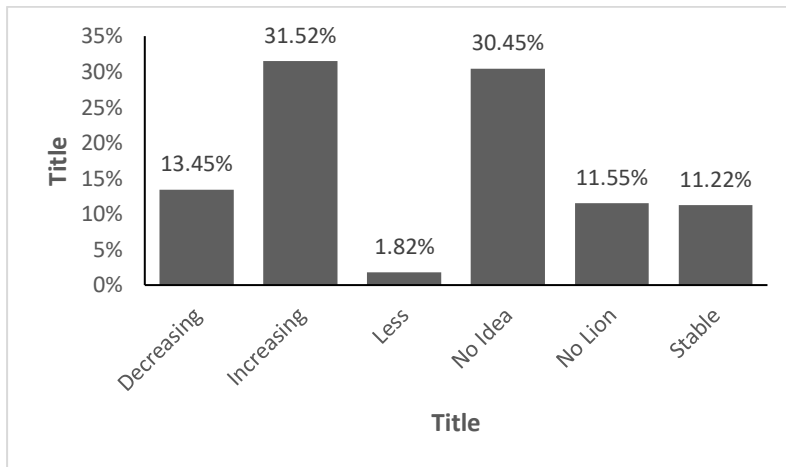


About 36% of the respondents expressed an increasing number of lions in their neighborhood. While about 24.42% of the respondents also expressed a declining trend of lions in their neighborhood. About 19.41% respondent said that lion population is stable around their neighborhood. And about 12.71% of responded that there are no lions in their neighborhood (Figure 5.6a). Similarly, majority of the respondents ~39% said that population of leopard is

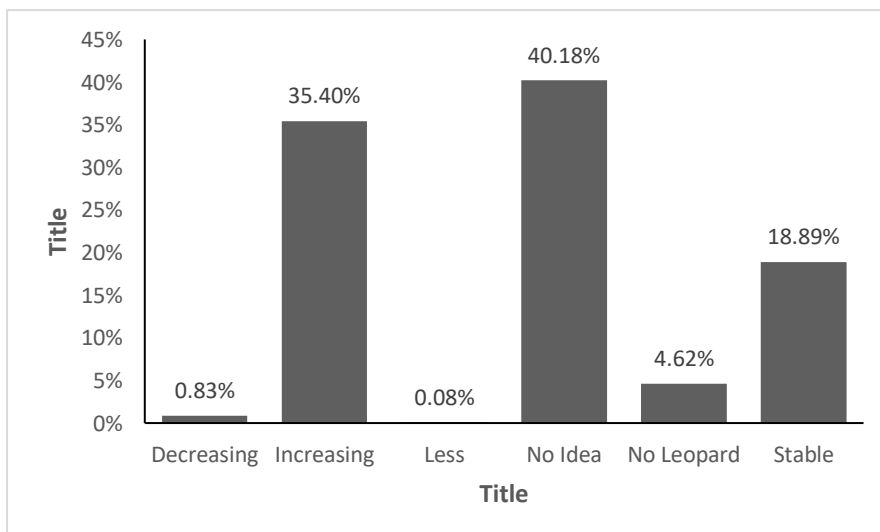
increasing around their neighborhood. About 23% said that leopard population is stable and only 3% said that their population is decreasing. And about 5% respondents said that there are no leopards in their neighborhood (Figure 5.6b).

Figure 5.7: Perception of respondent about the trend of conflict with (a) lion and (b) leopards around their neighborhood

(a) Perception on lion conflict



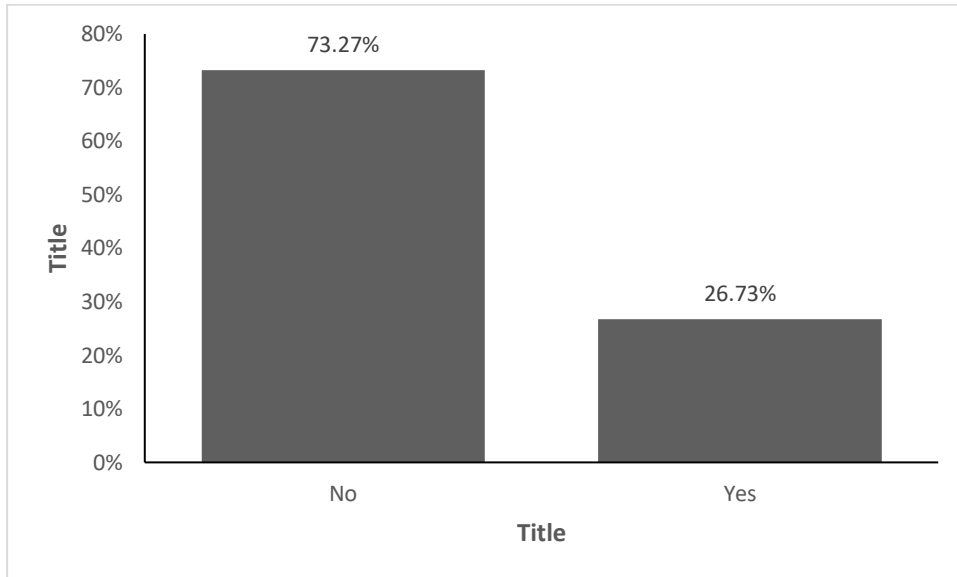
(b) Perception on leopard conflict



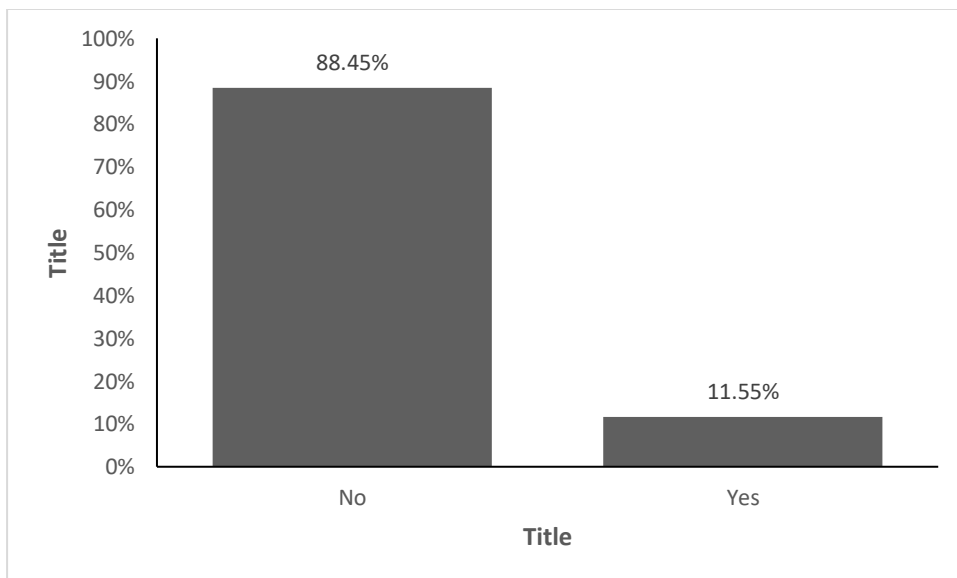
About 31% of respondents expressed their awareness of increasing conflict in their neighborhood while ~13% said that conflict with lion is decreasing. While ~ 30% of the respondents were not aware of the trend of conflict with lions in the neighborhood. About 11% of the respondents feel that the conflicts with lion is stable (Figure 7a). While ~35% respondents said that conflict with leopards is increasing and a very few respondents believes that it is decreasing around their neighborhood (~0.83). Majority respondents were unaware of the trends in the conflict situation with leopards (~ 40%) and about 19% of the respondents believe the conflicts with leopards are stable around their neighborhood (Figure 5.7b).

Figure 5.8: Percentage of respondents experienced livestock predation by (a) lion and (b) leopard

(a) Experience of predation by lion



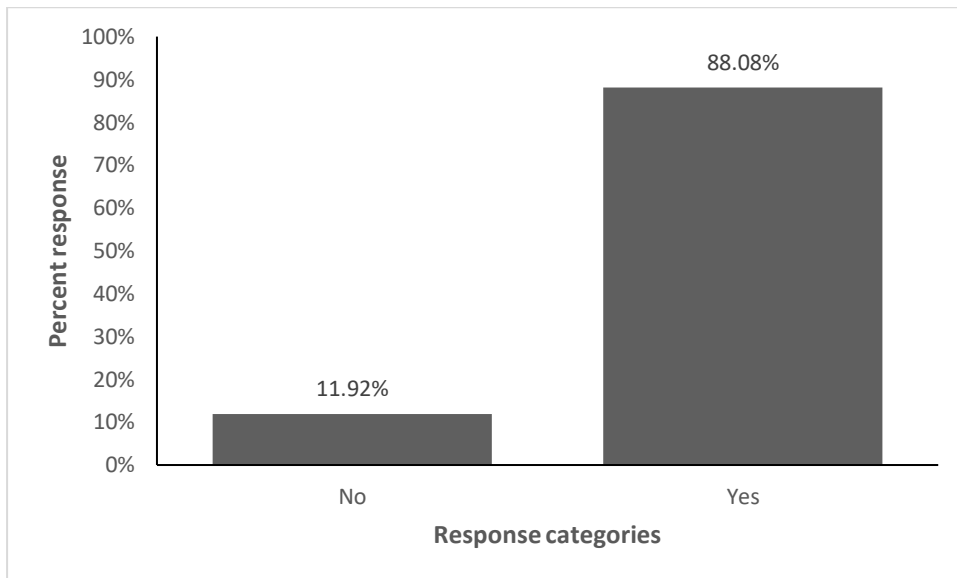
(a) Experience of predation by leopard



Among the respondent's majority have not experienced livestock predation of attacks on their family members by lion and leopards (73% and 88% respectively) and only 26.73%

and 11.55% of the respondents experienced conflict with lion and leopards respectively (Figure 5.8).

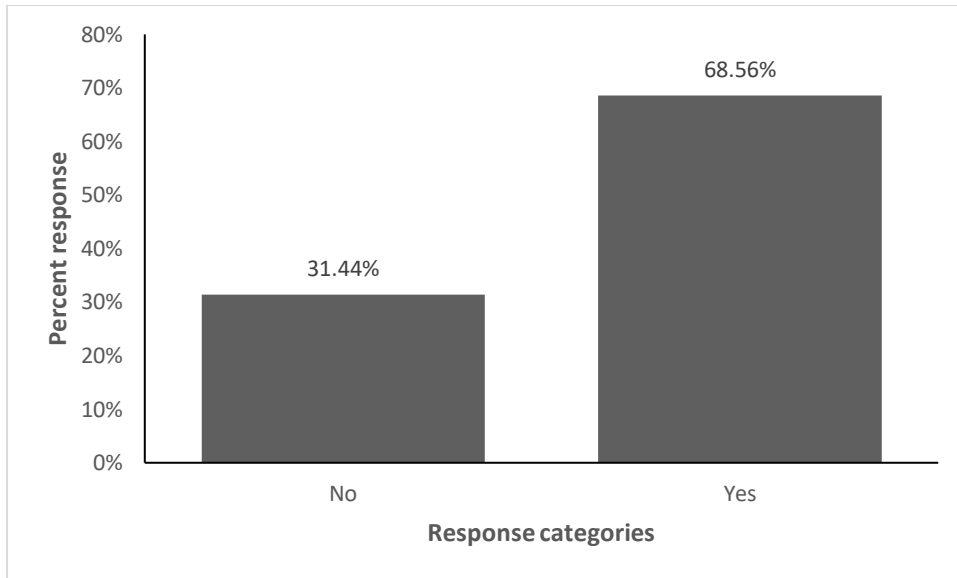
Figure 5.9: Proportion of people applied for compensation when livestock predated by lion and leopard.



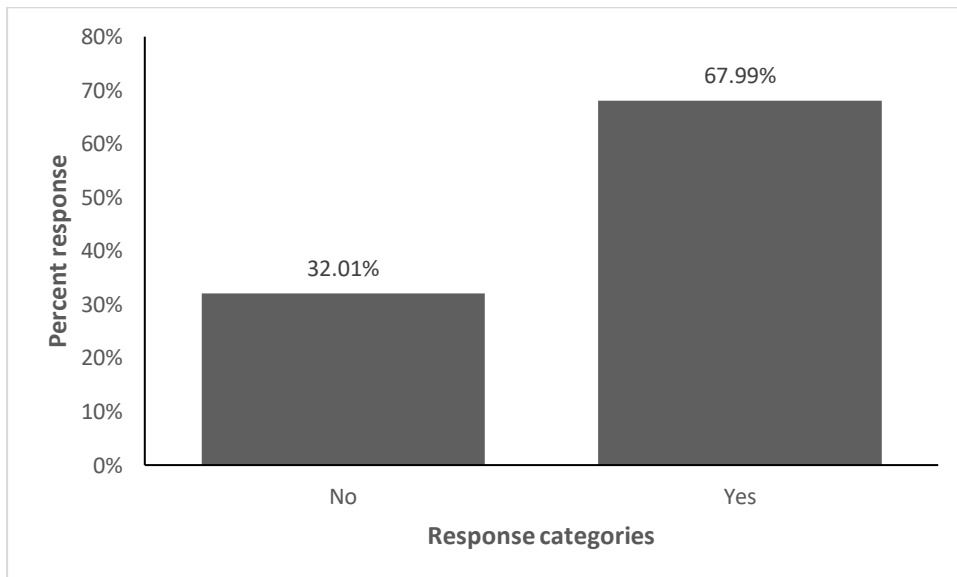
Graph (Figure 5.9) showing the proportion of respondents that have applied for monetary compensation from the forest department when their livestock are being killed or attacked by lions and leopards. About 88.08% of the respondents applied for compensation when their livestock were killed or attacked by the large carnivores while 11.92% of the respondents didn't apply for compensations.

Figure 5.10: Proportion of the respondents encountered lion and leopard in last 1 year

(a) Encounter lion



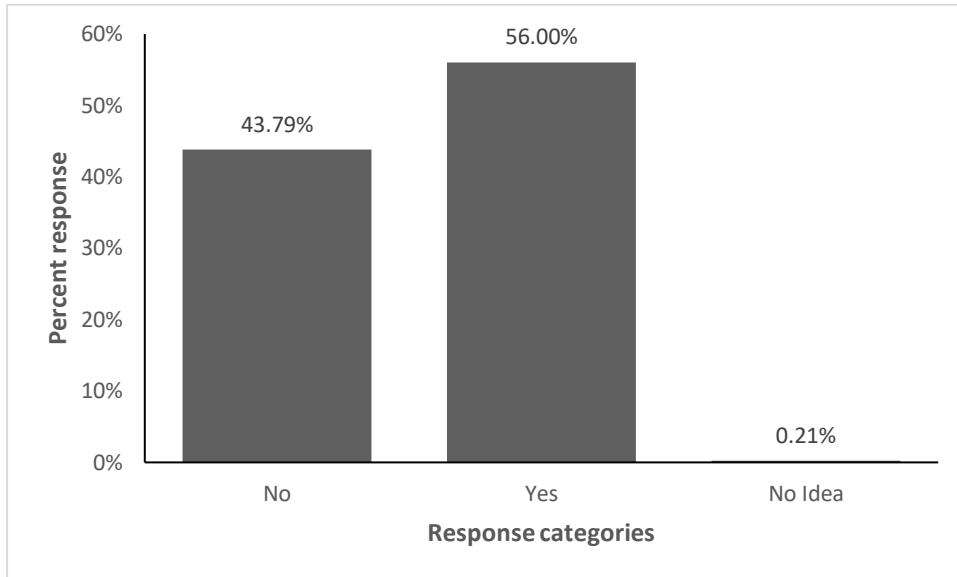
(b) Encounter leopard



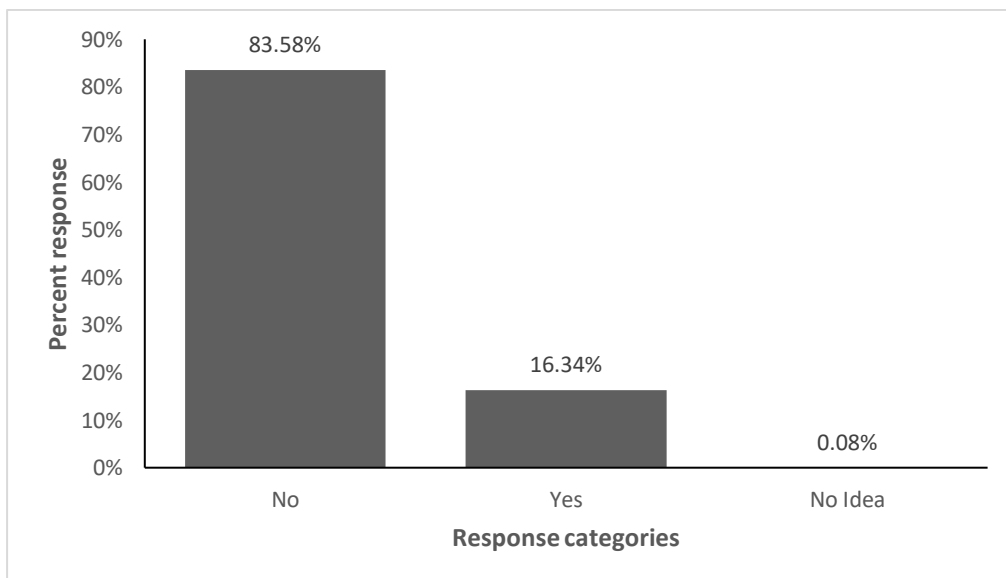
When asked about the experience of encounters with lions and leopards 68.56 % (Figure 5.10a) and 67.99% (Figure 5.10b) respondents said that they have encountered lion and leopards in the previous year.

Figure 5.11: Proportion of respondents expressed their willingness and unwillingness to continue to live with lion and leopard in the neighborhood.

(a) Can you continue to live with lions in the neighborhood?



(b) Can you continue to live with leopards in the neighborhood?

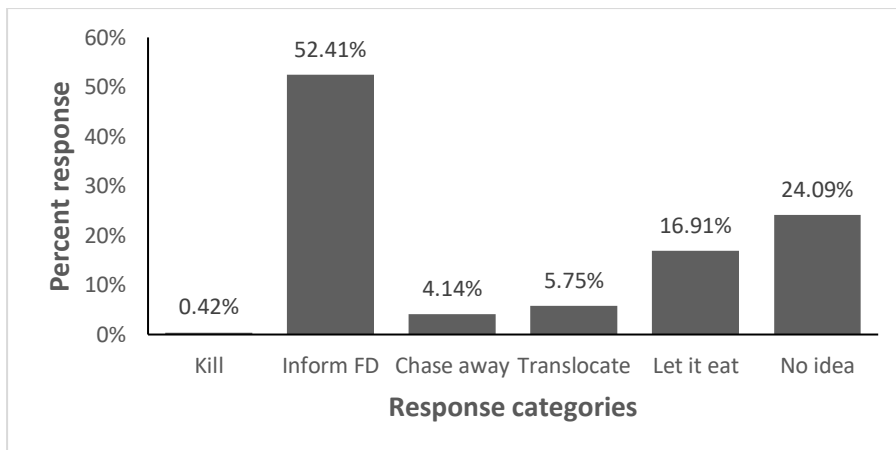


High percentage of respondents expressed their willingness to continue to live with lions in their neighborhood (56%) (Figure 5.11a) compared to only 16.34% of the

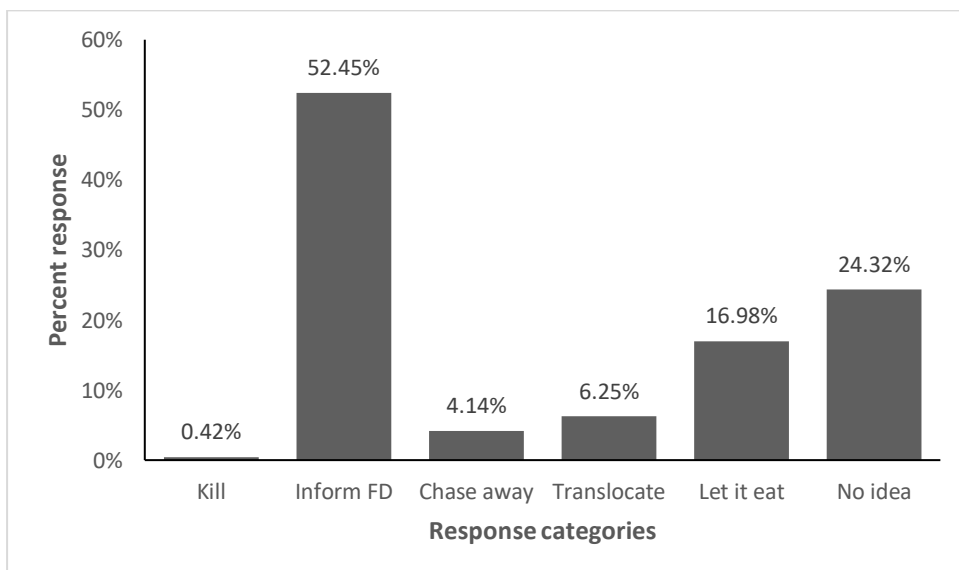
respondents who wish to continue living with leopards in their neighborhood (Figure 5.11b). A majority of the respondents expressed their unwillingness to continue to live with leopards in the neighborhood (83.58%) (Figure 5.11b) while only 43.79% of the respondents expressed their unwillingness to continue living with lions in their neighborhood (Figure 5.11a).

Figure 5.12: Responses of people when they were asked “What should you do when lion and leopard attack livestock?”

(a) Lion



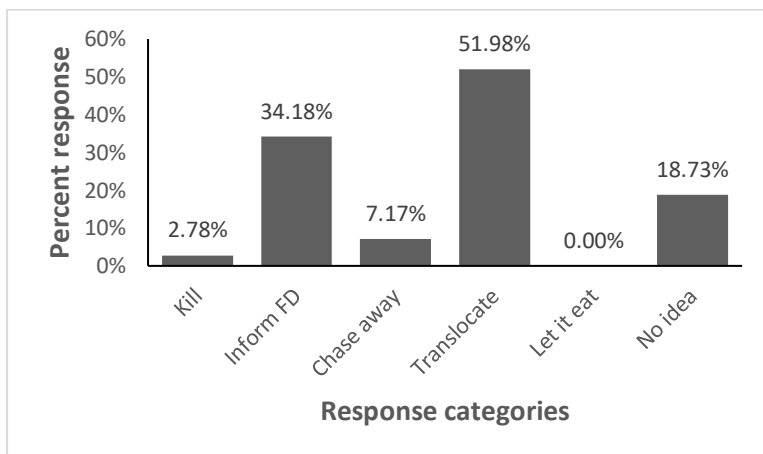
(b) Leopard



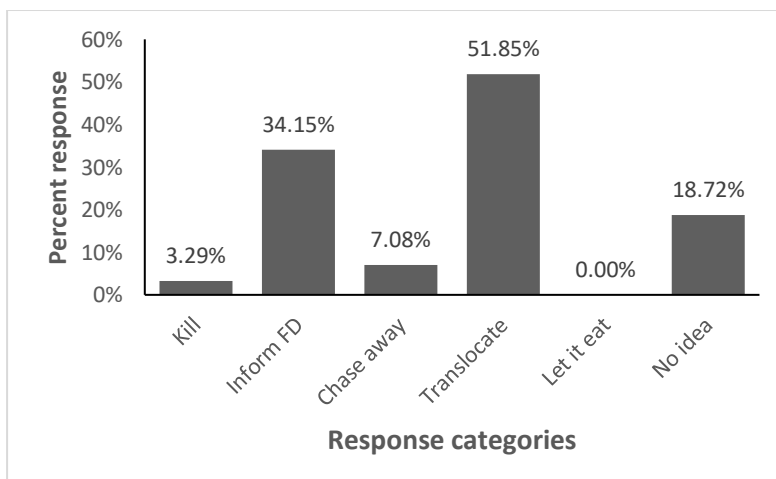
In both cases of attack on livestock by lion and leopards, majority respondents (52.41% and 52.45% respectively) said that they should inform forest department about the incident as a first-hand measure. 16.91% and 16.98% respondents expressed that they should allow the lion and leopards to eat their livestock once it is being killed respectively. While 4.14 % of the respondent in both cases said that they should chase away the carnivores if their livestock are being attacked by either lion or leopards.

Figure 5.13: Responses of people when they were asked “What should you do when lion and leopard attack people?”

(a) Lion

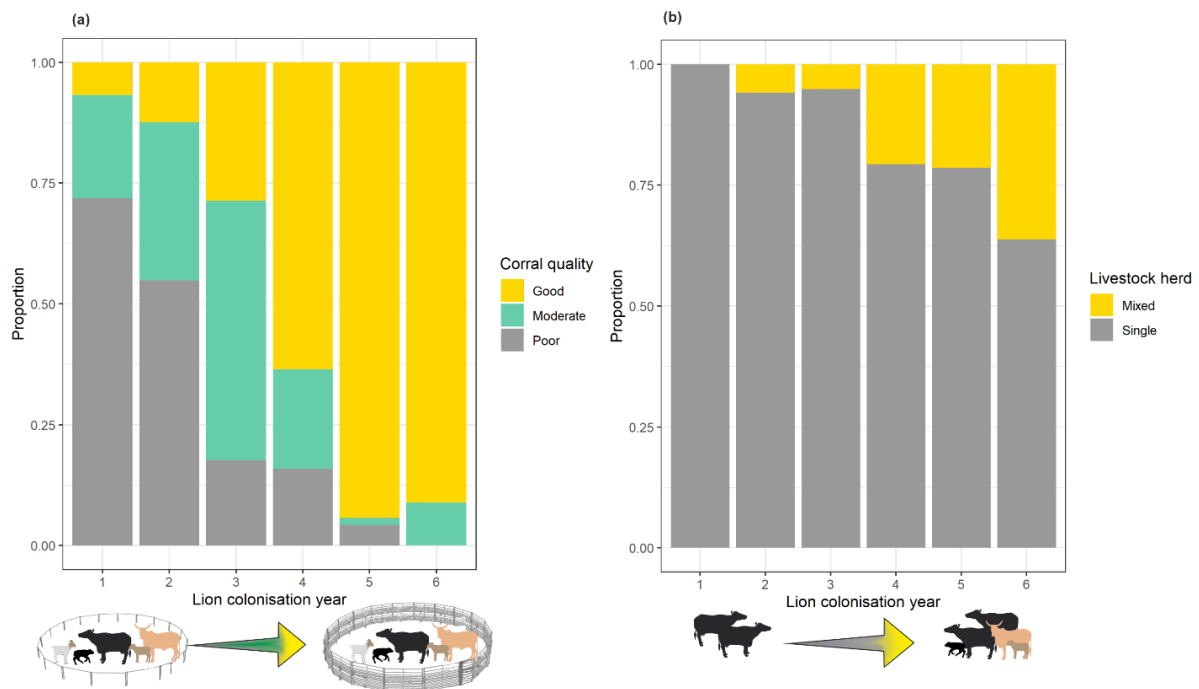


(b) Leopard



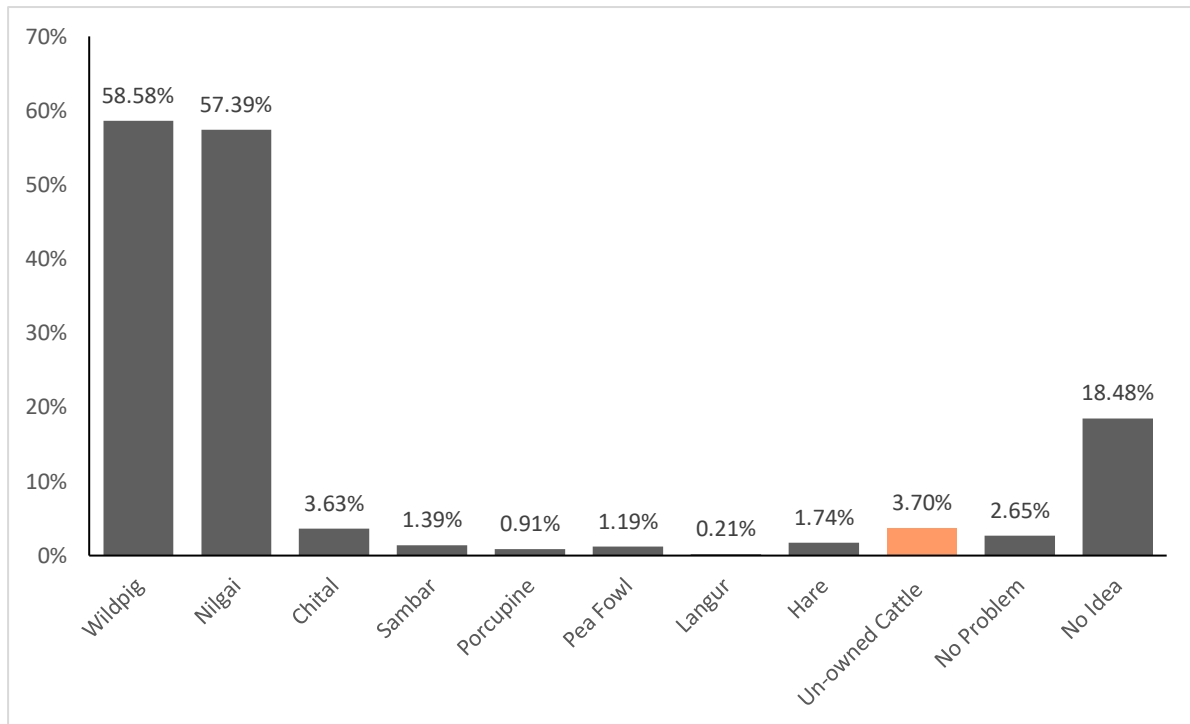
In contrast to the previous responses against livestock predation, high proportion of the respondent expressed that lions and leopards need to be translocated as the first-hand action when attack people and inform the forest department (Figure 5.13 a and b).

Figure 5.14: Livestock husbandry practices in relation to the duration of exposure to living with lions. (a) Quality of night corralling facilities for livestock and (b) livestock herd composition taken out for foraging. The x-axis represents duration of exposure to living with lions; 1= *no exposure*; 2 ≤ 5 years; 3 = 5-15 years; 4 = 15-30 years; 5 = n 30-50 years and 6 = >50 years.



People used better livestock corralling facilities in areas with long exposure of lion colonisation compared to areas where lions have colonised recently (Figure 5.14a). Similarly in such areas higher proportion of the respondents also practiced mixed herding of livestock (Figure 5.14b).

Figure 5.15: Proportion of the respondents experienced crop raiding by different herbivores.



Along with livestock predation by lion and leopards the communities in the Saurashtra landscape also experience conflicts with herbivores. Wild pig is having the highest responses (58.58%) of being the most frequent crop raider in the landscape followed by Nilgai (57.39%). There was very low representation of crop raiding incidences by the other wild herbivores as reported by the respondents. People mentioned about crop raiding by chital (3.63%) followed by hare (1.74%) (Figure 5.15).

Table 5.2: (a) Model selection statistics for logistic regression models that explain the probability of having a positive attitude towards lions by people in the Saurashtra landscape. Here, “Econ_state” = Economic State; “Edu_category” = Education category; “Lion_CY” = Lion colonisation year; “D_lionshowHP” = Distance to lion-show hotspots; “Conflict_F” = Conflict frequency; “Age_cat” = Age category; “D_lionhab” = Distance to lion habitats.

Sl	Model	AIC	AIC_diff
1	Econ_state+ Edu_category+ Lion_CY+ D_lionshowHP+ Conflict_F	1252.6	0
2	Age_cat+ Econ_state+ Edu_category+ Lion_CY + D_lionhab+ D_lionshowHP+ Conflict_F	1257.1	4.5
3	Edu_category+ Lion_CY+ D_lionshowHP+ Conflict_F	1258.4	5.8
4	Econ_state+ Edu_category+ Lion_CY+ D_lionhab+Conflict_F	1264.2	11.6
5	Age_cat+ Econ_state+ Edu_category+ Lion_CY+ D_lionhab+ Conflict_F	1266.8	14.2
6	Econ_state+ Edu_category+ Lion_CY	1287.9	35.3

(b) Coefficients of the best model representing the individual contribution of each predictor variables explaining the variabilities in the odds of liking lions by the respondents.

Sl	Independent	Regression	Wald	Wald	Odds	Probability

No	variables	Coefficient	Z value	P value	Ratio	Estimates
1	Intercept	-1.52 (SE 0.64)	-2.37	0.02	0.22	0.18
2	Conflict_F	0.66 (SE 0.15)	4.49	<0.01	1.94	0.66
3	log_D_lionshow	-0.41 (SE 0.12)	-3.42	<0.01	0.66	0.40
4	(Econ_state=2)	0.33 (SE 0.18)	1.85	0.06	1.38	0.58
	(Econ_state=3)	0.97 (SE 0.32)	3.04	<0.01	2.64	0.73
5	(Edu_category=2)	0.43 (SE 0.35)	1.25	0.21	1.54	0.61
	(Edu_category=3)	0.98 (SE 0.38)	2.60	0.01	2.66	0.73
	(Edu_category=4)	1.45 (SE 0.46)	3.17	0.00	4.28	0.81
6	(Lion_CY=2)	0.29 (SE 0.29)	0.98	0.33	1.33	0.57
	(Lion_CY=3)	0.78 (SE 0.31)	2.55	0.01	2.19	0.69
	(Lion_CY=4)	2.68 (SE 0.38)	7.00	<0.01	14.68	0.94
	(Lion_CY=5)	2.79 (SE 0.41)	6.77	<0.01	16.34	0.94
	(Lion_CY=6)	3.19 (SE 0.32)	9.89	<0.01	24.38	0.96

Discussion:

This study provides a detailed understanding of the socio-economic factors resulting in the intriguing co-existence of lions and humans in the Saurashtra landscape of India. Despite livestock predation and occasional attacks on humans, it was surprising to find that majority of the local communities having strong positive attitudes towards lions in their neighborhood. It was observed that the economic status of a person was one of the major driving factors of such positive attitudes (Table 5.2). Economically sound people rarely need to deal with lions at a personal level and thus have the latitude of liking their presence in the neighborhood, while livestock herders and agricultural laborers, the most economically impoverished strata in the society confront lions on a daily basis and likely have a more pragmatic attitude (Figure 5.2). People in this landscape believe that presence of lions in their agricultural fields deter crop raiding wild herbivores thereby increasing agricultural yield. However, I do not have quantitative data to substantiate this claim. Legitimate ecotourism associated with lions (operated through the Gujarat Forest Department) provides livelihood opportunities (employment in resorts, shops, 4WD vehicles for rent, employment by Park Management, etc.) and economic benefits to communities living in and near the township of Sasan from where the Forest Department allows access to the Gir Protected Area tourism zone. Pastoral communities living inside the Gir Protected Area reap about 76% more profits compared to equivalent pastoralists living outside the Gir PA, by having free excess to forest resources and grazing (Banerjee et al., 2013). However, people living with lions outside the Gir PA in villages distant from such regularised tourism centres don't get these benefits legitimately. These communities often resort to lion shows (H.S. Singh, 2017). From our observations, it seems that compensation is often claimed in these villages for livestock that are offered as bait to lions for these lion shows. This illegal practice of lion shows seems to be thus subsidized with public funds. However, the concept of generating revenue associated

with lions appears to be an important factor in shaping human-lion coexistence. This might explain why contrary to our expectations, people living in high lion conflict areas had more positive attitudes towards lions than people from areas with no to moderate levels of conflict (Figure 5.1; Table 5.2 a & b). I suggest that while formulating policy and management strategies, it would be beneficial to ensure that local communities continue to profit from ecotourism opportunities associated with lions while simultaneously addressing the negative impacts of baiting, dangerous night tourism, and illegitimate claims for livestock predation (Jhala et al., 2019). While legitimizing community-based lion tourism on community lands the government needs to ensure a mechanism by which revenues earned are somewhat equitably shared amongst all strata of the society, the current illegality of such activity allows antisocial elements in the society to monopolise the profits.

A positive influence of formal education on people's attitude towards lions was observed (Table 5.2 a & b), akin to studies on carnivores elsewhere (Caruso and Pérez, 2013). This provides optimistic opportunities to enhance social carrying capacity of local communities towards lions by education and sensitization campaigns. Furthermore, people who have lived for several generations with lions tend to be more positively aligned to having them in their neighbourhoods, and are less fearful of encountering them (Table 5.2). Communities with a longer duration of living with lions have adopted husbandry practices that reduces economic losses to lions (Figure 5.14) and reduced activities at night when lions were most active (Banerjee, 2012). Our results show that communities adapt their lifestyles and have more positive attitudes towards lions the longer they were exposed to lions in their neighbourhood. In addition, many local communities showed strong religious and cultural sentiments of symbolising lions as a vehicle of Goddess Durga, "noble animal" and "pride of their native land", invigorated by the religious and mythological symbolism of the lion (Bhaty, 2020; Kak, 2019) coupled with the historic endemism of Asiatic lions only to this

place on the planet (Figure 5.3a). The high proportion of respondent's willingness to continue live with lions also represents that the lions in Saurashtra have not yet reached the social carrying capacity.

Exploring the reasons for negative attitudes towards lions, it was observed that economic loss due to lion predation and perceived threat to human life played a major role shaping the attitude (Figure 5.3b). As expected, among the people that disliked lions, high proportion were pastoralists because their livelihoods were affected the most from lion depredation as well as their economic constraints aggravated such losses (Figure 5.2). Though lions fed mostly on cattle carrion in this landscape (Banerjee et al., 2013), and livestock predation was compensated by the government, pastoralists still suffered losses borne out of the disparity among market rates of livestock and compensation amounts, added with the lost opportunity costs (Banerjee et al., 2013).

Overall, there were high negative attitude towards leopards across the landscape compared to lions. While only 23.85% of the respondent believed that lions rarely attack livestock or human, about 66.25% believes that leopards are great threat to human life (Figure 5.5). Since historic times leopards are known to predate on humans and humans have naturally developed a fear for the animals mostly due to the reputation of being frequent man eaters across its distribution ranges (Corbett, 1945; Marker and Sivamani, 2009) and probably due to the past negative experiences of the respondents with the species, which is considered to be a major driving factors of creating negative sentiments towards carnivores (Bencin et al., 2016; Crown and Doubleday, 2017). Moreover, the higher proportion of respondent's unwillingness to live with leopards represents the already surpassed social carrying capacity of leopards in the study landscape.

Majority of the respondents reported that both the population of lion and leopards are increasing in the landscape (Figure 5.6 a & b). While 24.42% respondents also mentioned that the population of lions are decreasing in their neighborhood compared to only 3.05% respondents having similar thoughts for leopards. This could be either because the surroundings of the respondents are becoming unsuitable for lions or corridors are being destroyed for the colonization of lions from the source populations. Very similar pattern could also be observed when the respondents were asked whether the conflicts with lion and leopards are increasing or decreasing (Figure 5.7). Although only 26.73 % and 11.55% of the respondents experienced livestock predation by lions and leopards respectively (Figure 5.8), majority of the respondents had encountered lion and leopards during last one year since the interview was conducted (Figure 5.10).

Communities' awareness and support is an important factor for conserving large carnivores in human dominated landscapes. Supporting the management authorities in mitigation measures and adapting themselves to live with the carnivores are appreciated as good measures of creating a conducive environment for large carnivore conservation in human dominated landscapes (Carter and Linnell, 2016; Meena and Macdonald, 2023). Various measures of adaptations by the communities were observed to be acquired in order to live with the large carnivores in Saurashtra. Among which the perception about the importance of pro-active information sharing about conflict with management authorities (Figure 5.12 a, b and 13 a, b) that helps in quick resolution of conflict situations. However, it was also observed that respondents had a very strong perception on translocating the problematic animals from their areas if involved in attack or killing of humans (Figure 5.12) compared to livestock predation (Figure 5.13), as well comparatively high percentage of respondents also believe in lethal control of problematic animals. It was also observed that people having long exposure to live with lions also provided better corralling facilities to

their livestock to minimize predation by lions compared to areas where lions have colonized in recent times and areas with no lions (Figure 5.14a). People also practiced mixed herding in order to minimize predation lost to lions by keeping low-cost livestock with the highly priced buffalo (Figure 5.14b).

Besides livestock predation and attacks on human by lion and leopards people in the Saurashtra landscape also experience crop raiding by herbivores (Figure 5.15). Majority of the respondents reported to have experienced crop damage by wildpig and nilgai. However, in few villages people also reported to experience livestock predation by unowned cattle. These are mostly the unproductive individuals people disowned. Due to the total ban of cattle slaughter in the state and mechanized agricultural facilities male cattle which doesn't have much contribution to the local economy are often disowned. Lions predate on such unowned cattle in the human dominated landscape but there is no scientific quantification of the population of such unowned cattle so far and well as the predation intensity on such animals by lions.

The current model of human-lion in the Saurashtra landscape of India is thus borne out of the fine play of coadaptation between humans and lions, coupled with strict law enforcement by both the federal and state governments, the prevalent socio-cultural and economic predispositions of local communities. As expected, coexistence with a formidable predator is variable and nuanced, and sustaining this delicate balance where the benefits to both parties outweigh the costs of sharing space would require reimagining conservation paradigms to include land-sharing and participatory approaches instead of just relying on conventional land-sparing strategies (Srivathsa et al., 2023). From the results I recommend the following strategies that can potentially safeguard this balance:

1. Livestock depredation compensation scheme should be revised regularly to maintain parity with market values, and also include lost opportunity costs (Banerjee et al., 2013). This will directly ameliorate economic losses to communities in this landscape.
2. Identified problem/conflict lions should be efficiently removed following guidelines mentioned for removal of conflict tigers (NTCA, 2013). While removal of animals from an endangered population is contentious, fostering good-will for conservation among local communities is of paramount importance and should take precedence.
3. Dialogues should be sought out with local communities to develop pragmatic ways to institutionalize and regulate community-based ecotourism of lions which prevents the ill-effects of baiting while also sustaining the economic incentives of living with lions, the latter being crucial for this coexistence to work (Jhala et al., 2019).
4. Educational and awareness campaigns should be developed in partnership with school curricula, researchers, managers, and local communities to enhance social carrying capacity of the people. Sensitization programs should be undertaken regularly in areas with recent recolonization of lions so as to educate local communities about ways to live with lions and lifestyle changes required to avoid negative lion interactions.
5. Risk hotspots identified in the landscape should be monitored proactively, with certain lion prides in these sensitive areas fitted with radio-collars that have virtual-geo-fencing with early warning signals to pre-emptively mitigate potential conflict (Khorozyan and Waltert, 2021; Weise et al., 2019).
6. Under the Indian Wildlife Protection Act of 1972, there is provision for declaring areas as “community reserves”. This will allow legal frameworks to be established, addressing concerns and outlining specific guidelines for community based tourisms. These guidelines may include provisions for permitting economic benefits and ensuring equitable sharing of

economic benefits with amongst all sections of the society local communities, thus fostering a sense of ownership and incentivizing conservation efforts among the residents.

The lions of Saurashtra are not an isolated case of sharing space with a large carnivore, India abounds with such examples of coexistence, the urban leopards of Mumbai (Athreya et al., 2016; Braczkowski et al., 2018), tigers on the outskirts of the city of Bhopal (Saxena, 2023), leopards of Jawai-Beda (Dutta Gupta et al., 2021) and sloth bears of Mt. Abu (Patel et al., 2022; Philip et al., 2021) amongst others. Each situation has its unique features that permits coexistence yet some commonalities are evident; that of human tolerance; adaptive behaviour by both carnivores and humans; and benefits of coexistence outweigh the costs. Governance and conservation management can work towards increasing human tolerance, lifestyle changes required to live alongside carnivores, and create opportunities for economic profits arising from charismatic carnivores to promote land-sharing between carnivores and humans.

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Supplementary materials:

Table S5.1: Details of questions of the social survey. Responses of a few questions were classified into various categories as shown below.

SI No	Questions	0	1	2	3	4	5	6
1	Gender	-	Male	Female				
2	Age	-	18-30	30-50	>50			
3	Education	-	No formal education	< Class 10	Class 10-12	> Class 12		
4	Economic Status (Income per month, in INR)	-	<10000	10000-30000	>30000			
5	Occupation	-	Agro-pastoralist	Farmer	Pastoralist	Job/Business	Others	
6	Perception on Lion	-	Great risk to human	Tremendous havoc to livestock	A rare risk to human life	Rarely kills livestock	Does not kill humans/livestock	No Idea
7	Lion number	-	Increasing	Decreasing	Stable	No Idea		
8	Conflict with lion	-	Increasing	Decreasing	Stable	No Idea		
9	Since when lion started living in vicinity?	-	No lion	<5 years	5-15	15-30	30-50	>50
10	Have you experienced livestock predation?	No	Yes					
11	Corral quality	-	Poor	Medium	Good			
12	Livestock herding practice	Single	Mixed					
13	Did you apply for compensation?	No	Yes					
14	Did you get compensation?	No	Yes					
15	Are you happy with the compensation amount?	No	Yes	No idea				
16	Have you encountered lion in last six months?	No	Yes					
17	Have you encountered lion in at any point of time in life?	No	Yes					

18	Like lion?	No	Yes	No idea				
19	Can you continue living with lions in your neighborhood?	No	Yes	No idea				
20	Reasons of liking lions	Other	Pride and nobility	Religious/cultural importance	Good for environment	Economic gain, pest control		
21	Reasons of disliking lions	Other	Aggressive	Danger to human life	Economic loss, livestock predation	Problem with forest department		
22	What will you do when livestock is attacked by lion?	No Idea	Kill	Inform Forest Department	Chase away	Translocate the lion	Do nothing & let the lion eat	
23	What will you do when human is attacked by lion?	No Idea	Kill	Inform Forest Department	Chase away	Translocate the lion	Do nothing & let the lion eat	
24	Do herbivores raid crop?	No	Yes	No idea				
25	Crop raiding herbivores	Nilgai, Wild pig, Hare, Peafowl, Langur, Chital, Sambar, Porcupine, Unowned Cattle, Others						
26	What do you do to guard crops?							

Table S5.2: The table represents the percent of correct classification in each category “0”

(No) & “1” (Yes).

Like lion	Count	Unique rows (Y and X's)	Y Proportion	Y Prior	R ² (Y vs Pred. Probability)	% Correctly Classified
0 (No)	535	289	0.38	0.5	0.41	82.99
1 (Yes)	886	444	0.62	0.5	0.41	78.10
Total	1421	733				79.94

Appendices

Appendix 1: Certificate of Full Talk presentation at the International Congress for Conservation Biology (ICCB) 2021, Kigali, Rwanda



Appendix 2: Certificate of Full Talk Presentation at the Student Conference on Conservation Science, Cambridge University, United Kingdom in 2024



UNIVERSITY OF
CAMBRIDGE

Department of Zoology

Student Conference on Conservation Science

Department of Zoology, Downing Street,

Cambridge CB2 3EJ

T: 01223 762979

E: sccs@zoo.cam.ac.uk

This is to certify that:

Keshab Gogoi

attended the

Student Conference on Conservation Science

26-28 March 2024

at the University of Cambridge, Downing Street, Cambridge, UK,
and gave a talk titled:

Large carnivores in human dominated landscapes: the delicate balance of co-adaptations between human and the Asiatic lions in the Saurashtra landscape

Claire Davies

Conference Coordinator:



Appendix 3: Poster Presentation at the International Statistical Ecology Conference, Swansea University, Swansea, the United Kingdom (Acceptance letter and picture)



Swansea, 02/06/2024

ISEC 2024 Invitation Letter - Mr. Keshab Gogoi

To: **Mr. Keshab Gogoi**
Wildlife Institute of India
Chandrabani, Dehradun-248001, Uttarakhand, India

Dear Dr Keshab Gogoi,

We are writing to invite you to participate in the International Statistical Ecology Conference (**ISEC 2024**) which will be held at Swansea University (Bay Campus, Swansea, Wales, UK) from 15 to 19 July 2024 and the preconference workshops taking place 13-14 July, organised by our Centre for Biomathematics at Swansea University. Your abstract entitled 'Unveiling Co-Adaptation Mechanisms between Humans and Lions: A Multifaceted Spatiotemporal Modeling Approach' has been peer-reviewed and accepted to be presented at the meeting. We also confirm that we have granted you an ISEC 2024 Widening Participation Bursary of £1200 to cover costs associated with the conference. We look forward to welcoming you at ISEC 2024 in Swansea.

Please feel free to contact me if you need any further information.

Best wishes,

Professor Luca Börger, PhD
Head of Department of Biosciences
Professor of Ecology and Biodiversity, Department of Biosciences
Co-Director, Centre for Biomathematics, Faculty of Sciences and Engineering
Swansea University, Singleton Park, SA2 8PP, UK
Tel. 01792 513112 | email: l.borger@swansea.ac.uk
<http://www.swansea.ac.uk/staff/science/biosciences/borger-l/>



Parc Singleton, Abertawe, SA2 8PP, Cymru, DU • Singleton Park, Swansea, SA2 8PP, Wales, UK
Tel/Ffôn: +44 (0)1792 205678

Appendix 4: Full talk presentation at the International Statistical Ecology Conference, Australia, 2020. Online

eventbrite

Order no. 1365638940

vISEC2020 International Statistical Ecology Conference



Registration (financially disadvantaged)

<http://www.isec2020.org/>, , NSW 2052, Australia

Monday, 22 June 2020 at 6:00 pm - Friday, 26 June 2020 at 9:00 pm (AEST)

Free Order

Order Information

Order no. 1365638940. Ordered by Keshab Gogoi on 11 June 2020 4:24 pm

Name

Keshab Gogoi



13656389401906517064001

Event Information:

Thank you for registering for vISEC2020, the virtual International Statistical Ecology Conference. We will e-mail you directly with further details in the lead-up to the event. We look forward to seeing you in late June!

Please note our refund policy:
if you cancel more than 2 weeks prior to the conference, you will receive a refund of ticket price with less the Eventbrite fee.
if you cancel 2 weeks prior to the conference, you will receive a refund of 50% of ticket price with less the Eventbrite fee.
if you cancel 1 week prior to the conference, you will receive no refund.

Kind regards,
vISEC2020 Local Organising Committee

Registration Information:

It will help us schedule events to know where you are watching from!
Where will you be when you participate in vISEC2020? (eg. Country)
India

From what timezone will you participate? (to the nearest hour)
+5 GMT

Thinking ahead to beyond this conference, can we include you in our mailing list for when we advertised future ISECs?
Yes

I have read and agree to abide by the vISEC2020 Code of Conduct
Yes

Do you organise events?

Start selling in minutes with Eventbrite!
www.eventbrite.com.au

Appendix 5: Field pictures



Keshab conducting a survey



A pastoralist with livestock



A pair of lions in the Pipavav port area



A pride of lions on an agricultural field of village



A lion in a industrial complex



A lioness in the Pipavav port



The field team



A pride with a collared lioness



A lioness with cubs in Pipavav port



A lion crossing a road



Interviewing a pastoralist



A break for tea during field work



Fixing the radio receiver during a field session



Interviewing a pastoralist for a recent predation event



Dr Jhala delivering a field session in Gir



Tracking radio-collared lions in the human-dominated landscape



Some discussions with fellow team mates in Gir



Tracking lion pugmarks on the coastal areas



Crossing a river to reach a conflict site



Discussion with community members about interactions with lion and leopards



Trying to catch a signal of radio collared lion from a vantage point



Tripling on a bike during field session



Some of the moments I spent in Gir was the best in my life, precious and forever valuable



A precious moment with beloved Bapu



Sharing breakfast with fellow teammates in Gir



A part of the team in Gir

Appendix 5: Below is the Accepted copy of the manuscript in the journal of *Conservation Biology*

Deciphering the Enigma of Human-Lion Coexistence in India

Journal:	<i>Conservation Biology</i>
Manuscript ID	24-228.R1
Wiley - Manuscript type:	Contributed Paper
Keywords:	Asiatic Lion, ecosystem services, Gir, human-carnivore interactions, Lion-human conflict, livestock compensation, Community Attitudes, Land-sharing
Abstract:	<p>Asiatic lions have increased in range and abundance in densely populated India, a rare example of coexistence between humans and large carnivores. We attempt to understand the underlying mechanisms, and infer lessons that could help conserve carnivores in multiuse-landscapes, globally. Using data from conflict-compensation records we studied the spatio-temporal trends in human-lion conflict, simultaneously we surveyed local communities across the gradient of conflict to understand their attitudes regarding living with lions. Cumulative number of villages that registered attacks on livestock increased by 105 (9.61%) per-year, suggestive of an expanding lion population. Livestock killed per village increased by 15% per-year, indicative of increasing lion density. However, attacks on humans remained low and showed no trends. Human attacks were spatially correlated with livestock predation, and both were best explained by proximity to community tourism hotspots, lion habitat patches, and areas with high lion density. Intolerance towards lions was best explained by economic losses and fear of lions. Communities that have lived longer with lions had higher odds of tolerating lions and practised livestock-rearing techniques that minimised predation. Despite negative interactions, human-lion coexistence has been achieved in India through a mix of socio-cultural tolerance, enforced legal protection, government compensation, and importantly, mutual adaptation of humans and lions because both benefit from living together - lions from subsidised food and space, while local communities from enhanced livelihoods and bolstering of socio-cultural norms. We propose institutionalizing lion-based ecotourism on community lands that transform a conflict-prone carnivore to an asset, thereby supporting this coexistence for the long-term. Such mechanisms should ideally bestow agency to local people on equitable distribution of generated revenues, thereby directly linking lion conservation to human livelihoods. In the burgeoning Anthropocene, only through such participatory and profitable land-sharing approaches can we best sync the well-being of local communities with sustainable carnivore conservation.</p>

1 **Title:** Deciphering the Enigma of Human-Lion Coexistence in India.
2
3

4 **Keywords:** Asiatic lion, community attitude, ecosystem services, Gir, human-carnivore
5 interactions, land-sharing, livestock compensation, wildlife conflict
6

7 **Abstract:**

8 Asiatic lions have increased in range and abundance in densely populated India, a rare example of
9 coexistence between humans and large carnivores. We attempt to understand the underlying
10 mechanisms, and infer lessons that could help conserve carnivores in multiuse-landscapes,
11 globally. Using data from conflict-compensation records we studied the spatio-temporal trends in
12 human-lion conflict, simultaneously we surveyed local communities across the gradient of conflict
13 to understand their attitudes regarding living with lions. Cumulative number of villages that
14 registered attacks on livestock increased by 105 (9.61%) per-year, suggestive of an expanding lion
15 population. Livestock killed per village increased by 15% per-year, indicative of increasing lion
16 density. However, attacks on humans remained low and showed no trends. Human attacks were
17 spatially correlated with livestock predation, and both were best explained by proximity to
18 *community tourism hotspots*, lion habitat patches, and areas with high lion density. Intolerance
19 towards lions was best explained by economic losses and fear of lions. Communities that have
20 lived longer with lions had higher odds of tolerating lions and practised livestock-rearing
21 techniques that minimised predation. Despite negative interactions, human-lion coexistence has
22 been achieved in India through a mix of socio-cultural tolerance, enforced legal protection,
23 government compensation, and importantly, mutual adaptation of humans and lions because both
24 benefit from living together - lions from subsidised food and space, while local communities from
25 enhanced livelihoods and bolstering of socio-cultural norms. We propose institutionalizing lion-
26 based ecotourism on community lands, that transforms a conflict prone carnivore to an asset,
27 thereby supporting this coexistence for the long-term. Such mechanisms should ideally bestow
28 agency to local people on equitable distribution of generated revenues, thereby directly linking
29 lion conservation to human livelihoods. In the burgeoning Anthropocene, only through such
30 participatory and profitable *land-sharing* approaches can we best sync the well-being of local
31 communities with sustainable carnivore conservation.

32

33 **Introduction:**

34 Current conservation of large carnivores faces unique challenges, typically emanating from
35 the need to reconcile human interests with carnivore ecology (Barua et al. 2013; Braczkowski et
36 al. 2023). While extremely challenging and contentious, conservation practices have helped in the
37 recovery of some carnivore species; often, such recoveries have resulted in populations spilling
38 beyond the boundaries of protected areas (Bangs et al. 2001; Chapron et al. 2014; Jhala et al. 2019,
39 2021). Carnivore populations that have exceeded the carrying capacity of protected habitats and
40 have colonized surrounding human habitations pose a serious challenge resulting from ensuing
41 conflict. However, the realization of such conflicts is nuanced and contingent upon the attitude of
42 local communities, the latter varying substantially across sociocultural landscapes (Jacobsen et al.
43 2021; Braczkowski et al. 2023). While there is no one-size-fits-all solution to human-carnivore
44 conflict, understanding already existing systems of coexistence can be the key to reimagining
45 human-carnivore coexistence in the Anthropocene.

46 Asiatic lions exemplify a rare scenario where their recovery has created opportunities for
47 lions and humans to mutually adapt to each other's presence and coexist. In the human-dominated
48 landscape of Saurashtra neighbouring the Gir forests, lions have increased in numbers and extent
49 (Singh 2017; Ram et al. 2023b). Recent census places the population at approximately 674
50 individuals across the entire distribution range (within and outside the Gir Protected Areas,
51 hereafter Gir PA) of 30,000 km², with an annual growth rate of ~6% and a 36% increase in
52 geographic range between 2015 to 2020 (Gujarat Forest Department 2020; Ram et al. 2023b).
53 Nearly 500 lions share space with ~6.8 million people and their ~3.5 million livestock (PTI 2016;
54 Kachhiapatel et al. 2018; Gujarat Forest Department 2020; Ram et al. 2023b). In majority of such
55 shared habitats, wild prey availability in the form of pigs (*Sus scrofa*) and nilgai (*Boselaphus*
56 *tragocamelus*) is low. Dairy farming constitutes the chief form of livelihood for local communities,
57 however cattle slaughter is culturally a taboo owing to prevalent socio-cultural norms as well as it
58 is legally banned under the Gujarat Animal Preservation (amendment) Bill 2017. Consequently,
59 unproductive cattle are not slaughtered, instead are often abandoned and live as strays or are cared
60 for by religious charities in cattle camps. Such strays as well as owned livestock die frequently in
61 the landscape, and are dumped at specific sites at the outskirts of villages and cattle camps. These
62 dumpsites create a carrion bonanza that subsidizes the survival of large carnivores in these human

63 modified habitats (Jhala et al. 2019). Livestock constitutes a major portion of the lions' diet in this
64 landscape, however most of which is attributed to the consumption of stray livestock and carrion
65 (Banerjee 2012; Jhala et al. 2019; Ram et al. 2023a). Predation on owned livestock is relatively
66 low (Banerjee 2012; Jhala et al. 2019), however an expanding and increasing lion population
67 challenges the status-quo.

68 While living with a large carnivore is challenging, the existence of the only free-ranging
69 Asiatic lion population in this area attracts a large number of domestic and international tourists.
70 Formal lion tourism is regulated by the Gujarat Forest Department, and occurs only within a
71 restricted section of the Gir PA. Certain checks and balances have been imposed by the Forest
72 Department under the Wildlife Protection Act (1972), such as lion safaris are allowed only on
73 vehicles and during the day, with a restricted number of vehicles permitted into the safari circuit.
74 However, there is more demand for viewing lions with fewer restrictions. Local communities often
75 harness this opportunity and conduct lion tourism on private lands, sometimes by baiting lions
76 with livestock (Singh, 2017) and with fewer restrictions on tourist numbers and viewing time. The
77 private ownership of these lands where such tourism occurs, hereafter referred to as *community*
78 *tourism hotspots (CTH)*, coupled with the vastness of the landscape, preclude a complete
79 enforcement of ethical and safety norms, and are therefore considered illegal. Lion tourism on
80 private lands continues clandestinely in the *CTH*, providing direct revenues to local communities
81 from living with lions. These *CTH* also provide substantial supplementary food for lions.
82 Community tourism while beneficial to both lions (food) and humans (money), can become
83 counter-productive in the long run because of potential physiological changes in the provisioned
84 lions (Robbins et al. 2004), increased local density (Kirby et al. 2017; Gogoi et al. 2020), increased
85 vulnerability to zoonotic diseases (Miller et al. 2003; Becker et al. 2015), alteration of behaviour
86 (Barocas et al. 2018), change in population dynamics (Gray et al. 2004) and the loss of fear of
87 humans among provisioned lions (Harris & Herrero 1987; Gray et al. 2004) resulting in higher
88 conflicts (Matthews et al. 2003; Massé et al. 2014; Kirby et al. 2017). Keeping these negative
89 impacts in mind, the Gujarat Forest Department has completely banned any form of private
90 tourism. However, the attitudes of local communities towards sharing the landscape with lions can
91 be directly moulded through these tangible economic benefits, and such monetary services
92 provided by a large carnivore can often support coexistence. Furthermore, intangible values
93 reflecting the prevalent socio-cultural norms of local communities coupled with past lived

94 experiences of encountering carnivores can nuance the resultant attitudes of people (Jacobsen et
95 al. 2021). Past lived experience of sharing space with a large carnivore becomes crucial in the
96 current context because the re-establishment of the lion population across the human dominated
97 landscape, which has grown from dispersing individuals from within the Gir PA, has occurred
98 gradually over the past 30 years (Jhala et al. 2019). This has resulted in a mix of areas – *maldhari*
99 communities living inside the PA with lions for over 150 years, some communities in the
100 neighbourhood of the Gir PA have had lion presence for over three decades, while in others,
101 communities have just started experiencing lions in their vicinity.

102 In sum, this scenario exemplifies a complex and nuanced system with considerable
103 heterogeneity in demography, economic conditions, formal education, occupation, experience of
104 living with lions, and the benefits versus costs accrued from living with lions among local
105 communities. All these factors are expected to contextualize the spatial and social reasons and
106 outcomes of lion conflict – what explains where conflict occurs, how frequently, and how do
107 people react to living with such conflict? We predict that:

- 108
- 109 1. People will be less tolerant towards lions in villages having higher conflict compared to
110 moderate conflict and no conflict villages.
 - 111 2. Globally, there is a general perception that traditional values towards lifeforms are
112 eroding (Pooley et al. 2017) and if that was the case then younger generations in our study
113 area would be less tolerant towards lions than the older demographic.
 - 114 3. We also predict that higher education, better economic status, the duration of experience
115 of living with lions, and proximity to *CTH* (economic incentives) would positively
116 influence tolerance among people.
 - 117 4. Similarly, we expect that compared to other occupations, pastoralists would be less
118 tolerant towards lions because their livelihoods are directly threatened by lions.

119

120 We investigate these predictions using records of monetary compensation paid for attacks
121 by lions on livestock and humans, coupled with surveys of local communities. Our results suggest
122 that human-carnivore coexistence does not necessitate a total absence of negative interactions,
123 instead can be possible through co-adaptation where mutual benefits exceed the costs of living
124 together.

125

126 Methods**127 Ethics Statement**

128 The study was carried out with permission from the office of the Chief Wildlife Warden,
129 Gujarat State and Ministry of Environment and Forests, Government of India under the provisions
130 of the Wildlife (Protection) Act, 1972. Before conducting any surveys, verbal consent was
131 obtained from all respondents, and surveys were conducted only with those who agreed to
132 participate. The study was approved by the Training, Research, and Academic Council of the
133 Wildlife Institute of India which considers the merit of the science, conservation implications, and
134 ethics of the study.

135

136 Study area

137 We conducted the study across the entire range of the lions (~30,000 km²) covering 29
138 talukas of five districts (counties) of the Saurashtra peninsula within the state of Gujarat, in western
139 India (Figure 1). The Saurashtra Peninsula is surrounded by the Arabian sea in the south and west,
140 Gulf of Khambhat in the east and Runn of Kutch in the north. The area is a dry semi-arid landscape
141 traversed by small hillocks and several perennial and seasonal rivers. Four contiguous protected
142 areas are designated for the conservation of lions in this landscape: Gir National Park and Wildlife
143 Sanctuary, Pania Wildlife Sanctuary, Mitiyala Wildlife Sanctuary and Girnar Wildlife Sanctuary.
144 Together they form the Gir PA of ~1800km². The area also includes *vidis* (protected grasslands),
145 coastal forests, while the human dominated part of the landscape is constituted by towns, villages,
146 and agro-pastoral-industrial areas.

147

148 Data collection and processing

149 The Gujarat Forest department pays compensation for livestock predation and for injury or
150 death to humans by carnivores (Jhala et al. 2019). We collected records of compensation from all
151 forest divisions and forest ranges between 2012-2017. The information we used from these records
152 include location of conflict, type of livestock killed, predator involved, and date of each incident.
153 For cases where information was partially available and in case of recent conflicts, we conducted
154 field visits and obtained missing as well as additional information regarding location, number of
155 predators, and time of the event (Jhala et al. 2018). We mapped *CTH* through information from

156 key individuals in the landscape who were conversant with the area, coupled with our long-term
157 experience of working in the landscape, and by surveying villagers. We generated a distance matrix
158 from *CTH* by using the Euclidean distance tool in ArcMap 10.5 (ESRI) and used it as a covariate
159 in our models to explain human-lion conflict.

160

161 **Magnitude and temporal trends of conflict**

162 We translated the recorded information of compensation claims from the local Gujarati
163 language to English, and subsequently curated the data into analysable format using Microsoft
164 Excel (Microsoft Inc 2016), and geo-referenced each data point to the level of villages by using
165 ArcMap 10.5 (ESRI). We obtained village shapefiles from the Survey of India database
166 (surveyofindia.gov.in). Prior to analysis, we cross referenced the data for removing duplicates, and
167 subsequently arranged them chronologically to analyse temporal trends. We used base R (R Core
168 Team 2023) to analyse basic diagnostics plots. We calculated the intensity of livestock predation
169 as the frequency of incidences per village, expressed as an annual rate. We used linear regression
170 to estimate the trends in conflict frequencies across the years. We utilized basic diagnostic plots to
171 illustrate the various categories of livestock preyed by lions over the years, as well as to depict
172 the seasonal patterns and district-wise extent of attacks on both humans and livestock.

173

174 **Economics of livestock predation**

175 Though Gujarat Forest Department has a prompt and efficient compensation scheme for
176 mitigating human carnivore conflict (Appendix S1), it doesn't fully cover the market price of the
177 preyed livestock. We calculated the economic deficit by subtracting the paid compensation
178 amount from the market price of the livestock. We then used linear models to explore yearly trends
179 in this economic deficit, which represents the loss incurred by local communities to lions even
180 after being compensated.

181

182 **Spatial prediction of conflict risk**

183 We used Maximum Entropy Models (MaxEnt) in Maxent software (Phillips & Dudík
184 2008) to model lion-human conflict with ecogeographical covariates (Merow et al. 2013) (refer to
185 Appendix S2 for model details and analysis). For the analysis, we randomly split the conflict
186 locations into two groups, 80% for training the models and rest 20% to test model performance.

187 We used the spatial extent of the conflicts as the model space for selecting the background points
188 in the analysis. In our study, the smallest spatial administrative and management unit for which
189 lion conflict data was cured was that of a village. The average size of villages was 10 km² (SE
190 0.16) with median ~8 km². We thus selected a spatial scale of 10 km² for the predictor variables
191 and used the centroid of the villages as conflict locations for the Maxent analysis. We evaluated
192 model performance by using the scores of a threshold-independent measure (i) area under receiver
193 operating characteristics (AUC of ROC) (Hanley & McNeil 1982) as well as threshold dependent
194 measure (ii) true skill statistics (TSS) (Allouche et al. 2006), which is the sum of sensitivity and
195 specificity minus one, where the value of TSS ranges from -1 to +1; values above zero indicate a
196 better model performance than random chance. For better computation of model uncertainty, we
197 used 100 bootstraps simulations for the best models.

198 We used spatial covariate layers representing anthropogenic influence and ecogeographical
199 characteristics to model the probability of conflict (Appendix S3). We checked for correlations
200 between the spatial covariates using package “ENMTools” (Warren et al. 2021) in R, and we
201 selected only one variable from a pair of variables having a correlation $>\pm 0.6$ in a model based on
202 their ecological relevance (Appendix S4).

203

204 **Attitude of local communities**

205 The socio-psychological dimensions of conflict are predominantly shaped by factors
206 influencing human behaviour (Lawson 2010). Therefore, approaches that provide a better
207 understanding of human behaviour are critical in mitigating human-wildlife conflicts (IUCN
208 2023). Tolerance, a measurable behaviour, is defined as the passive acceptance of wildlife
209 (Bruskotter & Wilson 2014), a measure of positive attitude (Frank et al. 2019) largely governed
210 by the balance of tangible and intangible costs and benefits of coexistence (IUCN 2023). Conflict
211 with wildlife on the other hand is considered a major cause of disrupting the balance of tolerance
212 among communities (Dickman 2010; Redpath et al. 2013). Hence, in addition to the spatial
213 connotations of human-lion conflict, we attempted to model the factors influencing the levels of
214 tolerance among community members across the spatial gradient of human-lion conflicts in the
215 landscape. We attempt to follow the theoretical framework described by (Lischka et al. 2018)
216 wherein we investigate the combined socio-ecological nuances of interactions between lions and
217 humans in the Saurashtra landscape. In this framework, we examined the attitudes of local

218 communities towards lions that manifest into co-existence based on a combination of socio-
219 economic attributes of individuals obtained through questionnaire surveys, aspects of lion ecology,
220 and spatial magnitude of conflict. In doing so, we assessed the factors that promote or inhibit the
221 psychological mechanism of tolerance towards lions in the landscape.

222 We designed the questionnaire for our surveys based on prior knowledge of the area and
223 local communities, coupled with reconnaissance surveys (Appendix 4). We stratified villages
224 based on the magnitude of attacks by lions (MA) into (a) high (> 10 incidences of attacks per year),
225 (b) moderate (< 10 incidences of attacks per year) and (c) no conflict villages (no incidences of
226 attacks by lions during the study period). We randomly sampled villages from each of these strata
227 to get a robust representation of respondents exposed to different levels of conflict. A randomly
228 selected household was our unit of sampling, from which we approached an adult member for
229 consent to participate in our survey. We explained the study objectives to this person, and
230 subsequent to their consent, we surveyed them in Gujarati, their native language. Questionnaires
231 were bilingual, featuring Gujarati translation for each question, designed to preserve the original
232 meaning. All persons surveyed were above the age of 18 years. Our surveys had predefined
233 questions that assessed the general demography of the respondents, economic status, occupation,
234 educational background, attitude that defines tolerance and awareness of wildlife in the vicinity of
235 their village including presence of large carnivores, status of livestock predation, crop damage by
236 herbivores, and government compensation status (Appendix S4). Depending on the size of the
237 village, the number of households that we sampled in each village ranged from 1-20.

238 We categorised the responses to our surveys as tolerant (people who are willing/open to
239 having lions in their neighbourhood), intolerant (people who expressed unwillingness to have lions
240 in the neighbourhood) or indifferent, and further investigated the reasons for such behaviour
241 among communities. Specifically, we asked them to expand on why they either liked or disliked
242 lions by selecting from a set of predefined options (Appendix S4).

243 We used generalised linear mixed effect models (GLME) using *package lme4* (Bates et al.
244 2015) in R (R Core Team 2023) to examine the influence of various socio-ecological and
245 demographic factors on shaping the coexistence of humans. We categorised the responses as “0”
246 for the group that expressed intolerance for lions, (n= 535 and “1” for the group that expressed
247 tolerance for lions, (n = 887), while the group that expressed indifference/indecisiveness in their
248 attitude was excluded from the formal statistical analysis due to a very small sample size (n =12).

249 We used village identity as a random effect in our model to capture village level variations. We
250 first ran univariate fixed effects models and subsequently ran complex models with variables that
251 had significant coefficients. We assessed model fit using AIC (Akaike 1974) and selected the final
252 model having the least AIC value. Details of the model description and covariates can be found in
253 (Appendix S5).

254

255 **Results**

256 **Magnitude and temporal trends of conflict**

257 We analysed a total of 11,901 claims for 14,099 livestock predated by lions from 1092
258 villages between 2012 and 2017. Based on a sample of 292 respondents, we estimated the
259 proportion of livestock predation events that resulted in claims was 95%. The district of Amreli
260 had the highest claims of livestock predation by lions followed by Junagadh, Gir Somnath and
261 Bhavnagar (Appendix S6). Most of the livestock were killed outside of the Protected Area (91.38%
262 of all recorded claims, Appendix S7). Cattle formed the majority of lion kills followed by goat-
263 sheep and buffalo (Appendix S7). There were more incidences of livestock predation by lions
264 during monsoon (July-October) and winter (November-February) compared to summer (March-
265 June), but attacks on humans peaked in the summer (Figure 2).

266 The number of compensation claims for livestock killed by lions showed a linear increase
267 ($R^2 = 0.86$, $P = 0.01$) across the years with an increment of around 145 (5.1%) claims per year
268 (Figure 3a). The number of villages that experienced livestock predation by lions showed an
269 increasing trend with an addition of ~13 villages per year (Figure 3b). The cumulative number of
270 villages that reported predation by lion increased linearly ($R^2 = 0.97$, $P = 0.01$), with an addition of
271 about 105 (9.61%) new villages each year (Figure 3c). Intensity of conflict, indexed through
272 number of incidences of livestock predation in a year divided by the number of villages showed
273 an increasing trend ($R^2 = 0.73$, $P = 0.06$) (Figure 3d) over the years.

274 There were 125 reports of attacks on humans by lions during the same time frame, out of
275 which 8 (6.4%) resulted in death. A total of 78 from 2,208 (3.5%) villages in the entire range of
276 the lions reported attacks on humans. The district of Amreli reported highest incidents of human
277 attacks followed by Junagadh and Gir-Somnath (Appendix S6). About 10.4% of the attacks
278 occurred inside forested areas of the Gir PA while 89.6% were reported from the human dominated
279 areas outside the Gir PA, however the density of attacks (attacks/unit area) on both human and

280 livestock were higher inside the PA (Appendix S8). We did not observe any significant trend in
281 the frequency (Figure 3a) and intensity of attacks on humans by lions over the years (Figure 3d).
282 The total number of villages experiencing human-attacks were also found to be stable, annually
283 (Figure 3b). As expected, the cumulative trend of villages that reported attacks on humans by lions
284 showed an increasing trend (Figure 3c).

285

286 **Economics of livestock predation**

287 The economic evaluation of livestock predation showed a significantly increasing deficit
288 between the amount paid as compensation and the actual market price of the livestock. A yearly
289 increment in monetary loss of 540,00,000 INR (~USD 65000) ($R^2=0.87$, $p= 0.02$) due to lion
290 predation on livestock was recorded for the whole lion range within Saurashtra (Appendix S9).

291

292 **Spatial prediction of conflict risk**

293 The MaxEnt models for both human and livestock conflict had an overall good fit and
294 predictive ability (Appendix S10; Figure 4 and 5). The Area Under the Curve (AUC) of the
295 Receiver Operator Curve (ROC) and omission/commission analysis with 100 bootstrap runs and
296 with 20% test data showed that both livestock predation and human attack models were well
297 explained by the modelled covariates (AUC 0.83 (SE 0.01) and AUC 0.91 (SE 0.02) respectively)
298 with good predictive ability (Figure 4h and 5h). Lion-livestock conflict was best explained by
299 distance to *CTH*, lion density, livestock density, distance to forest and average NDVI (Appendix
300 S10). The predicted probability of livestock predation risk was highest closer to *CTH* with high
301 probability of livestock predation up to 15 km around such areas (Figure 4c). *CTH* also had the
302 highest contribution (68.9%) in explaining the variability in the spatial occurrence of conflict. The
303 second most contributing factor was density of lions (24.2%); it was observed that low lion density
304 areas that signifies the multi-use human dominated landscape outside the Gir PA had higher
305 probability of livestock predation compared to high lion density areas i.e. the Gir PA (Figure 4d).
306 Livestock predation probability was observed to increase with increasing livestock density (that
307 contributed 4.9%) and was highest in areas with moderate livestock density, and gradually declined
308 as livestock density became high (Figure 4e). Livestock predation risk was highest in or around
309 forest edges and declined away from such patches (with a contribution of 1.4% to the model, Figure

310 4f). Vegetation cover (indexed by NDVI) had a positive effect on livestock predation risk, with
311 higher predation in areas with high vegetation cover (Figure 4g).

312 The best model that explained the spatial risk of lion attacks on humans included frequency
313 of livestock predation by lions in a village, distance to *CTH*, distance from forest, and human
314 population density (Appendix S10b). Livestock predation frequency by lions had the highest
315 positive contribution in the model explaining 47.8% variability in the risk of human attacks (Figure
316 5c). Similar to livestock-predation models, risk of attacks on humans was high in low lion density
317 areas (lion density contributed 22.3%) that were within the multi-used landscape outside the Gir
318 PA (Figure 5d). We observed that attacks on humans by lions was highest in and around *CTH*
319 (17.1%) (Figure 5e). Risk of human attacks was high around forest edges and declined away from
320 forest patches (11.2 % contribution, Figure 5f). The risk of human attacks was high in low human
321 density areas and gradually declined with increasing human density (1.6 % contribution) in the
322 landscape (Figure 5g).

323

324 **Attitude of local communities**

325 From surveying a total of 1434 people from 277 villages, we observed that people
326 belonging to high and moderate conflict villages had more positive attitude towards lions
327 compared to villages with no lion conflict (Figure 6). Among people with different occupational
328 background, pastoralists had the highest negative attitudes towards lions (Figure 7). When we
329 further examined the reasons, we found that tolerant people liked lions for perceived qualities of
330 nobility and charisma, feeling of pride in having lions in their area, and due to economic benefits
331 derived from lions (Figure 8a). The reasons for intolerance were economic loss incurred from lion
332 predation as well as the perceived threat to human lives (Figure 8b). In both the cases, economic
333 reasons were found to play a major role in shaping the attitudes of local communities.

334 Variables that best explained the odds of tolerating lions were economic status of a person,
335 duration of experience of living with lions, occupation, distance to *CTH* and conflict magnitude,
336 (Table 1). We observed that the probability of tolerating lions increased with increasing magnitude
337 of conflict in a village, where the odds of tolerating lions increased with increasing conflict (Table
338 1). Tolerance towards lions significantly decreased with distance from *CTH*. The odds of tolerating
339 lions were found to be significantly higher with increasing economic status of a person, and the
340 temporal extent of land sharing with lions (Table 1). Individuals from varying occupations

341 displayed significant differences in their tolerance towards lions. Pastoralists had the most negative
342 attitude to lion presence (Table 1).

343 Communities who have been living with lions for longer periods used better livestock
344 corralling practices compared to areas where lions have recently colonised (Figure 9a). Similarly,
345 in such areas higher proportion of the respondents also practiced mixed herding of livestock
346 (Figure 9b). Men were more likely to be tolerant towards lions compared to women, but this
347 coefficient was barely significant (Appendix S11). The odds of being tolerant towards lions
348 increased with increasing education level of the respondents, but this relationship was not
349 statistically significant and education level did not feature in the best model (Appendix S11b, Table
350 1).

351

352 **Discussion**

353 Our study, by combining lion spatial ecology with socio-cultural-economic nuances of
354 local communities in a model framework, provides crucial insights into the delicate balance that
355 promotes coexistence between an endangered large carnivore and humans, and has far reaching
356 implications for human-wildlife management worldwide. Through our study, we provide a deeper
357 understanding of the magnitude and trends in interactions between humans and lions, and the
358 factors resulting in their intriguing co-existence in India. In India, lions are expanding in range and
359 numbers, evident from the increasing trend in the cumulative number of villages experiencing
360 attacks as well as the number of livestock being predated per village (Figure 3b, 3c). Cattle, goat
361 and sheep were among the most predated livestock, while buffaloes were attacked the least
362 (Appendix S7). Buffaloes are the most prized and consequently are subjected to premium rearing
363 and grazing practices such as stall feeding, shepherding during grazing, and strict corralling at
364 night. These practices coupled with their inherent anti-predatory social defence strategies
365 (Banerjee et al. 2013) make them the least vulnerable to lion attacks compared to cattle, goat, and
366 sheep (Appendix S7).

367 Though attacks on livestock were similar across seasons (Figure 3), we found a minor
368 peak during the monsoon/wet season. This could be because of the irrigational pattern in this semi-
369 arid landscape where majority of the farming is rain dependent, and during the monsoon the
370 standing crop likely offers good cover to lions to ambush livestock.

371 Lion-attacks on humans have been historically low in this region. Between 1978 to 1991
372 when the lion population was <250 and primarily restricted to the Gir PA, Saberwal et al. (1993)
373 reported an average annual frequency of 14.8 attacks on humans. Currently, the geographic extent
374 and population of lions have increased substantially and our results show an annual frequency of
375 ~25 attacks on humans with ~90% of the attacks occurring outside the PAs. The PAs have a
376 relatively high density of lions (Gogoi et al. 2020) and a low density of humans and livestock
377 (Banerjee et al. 2013), compared to the landscape outside the PA. Besides, lions within Gir PA
378 live alongside local communities who have been coexisting with them for ~200 years, and have
379 consequently honed their practices of avoiding lion attacks effectively (Divyabhanusinh 2005).
380 However, recolonization of the human-dominated landscape outside the PAs by lions is relatively
381 recent and an on-going phenomenon, thereby creating interaction zones between lions and
382 predator-naïve human communities. Lion dispersal to these erstwhile unoccupied habitats create
383 novel interactions, potentially increasing aggressive encounters and conflict. Although the
384 cumulative frequency of villages reporting human-attacks increased over the years (Figure 3c), we
385 did not find any significant trend in the intensity (Figure 3d) and frequency of such attacks (Figure
386 3b). Our long-term radio telemetry study in this landscape estimated that the probability of a
387 human-lion encounter (proximity between the two being <30m) translating into a negative
388 interaction was about 1 in 10000 (Jhala et al., 2016; Jhala et al. 2019). Lions were observed to
389 avoid periods of high human activity, and use hedgerows between farmlands and small patches of
390 vegetation as day time refuges to rest in close proximity to settlements, working farmers, and their
391 livestock for several hours without detection or aggression (Jhala et al., 2016; Jhala et al. 2019).
392 In contrast, more than 4 attacks per month (double the frequency than in India) on humans by lions
393 have been reported in similar human dominated landscapes of Tanzania (Packer et al. 2005). While
394 there was no significant trend in human attacks by lions (Figure 3b), we observed a slight peak in
395 the summers (Figure 2). During summer, human activity often extends into the cooler nights
396 because diurnal temperatures are extremely high (43°C), which causes high spatiotemporal overlap
397 with lions, possibly creating a peak of attacks in this season. However, most attacks on humans
398 were found to be accidental or when lions were provoked. Rarely do lions consider humans as
399 prey, and those that do, are removed from the population. Currently the PA managers actively
400 remove extremely aggressive lions involved in attacks on humans and bring them into captivity.
401 We believe that the close association of lions with humans since historic times in this landscape

402 and removal of conflict-prone lions, has possibly promoted unique behavioural traits that result in
403 lions that avoid confrontations with humans (Chakrabarti et al. 2023). Such behaviours are also
404 found in some other wild animal populations – the urban hyenas (*Crocuta crocuta*) of Ethiopia
405 (Struller et al. 2022), night time crop raiding behaviour of chimpanzees (*Pan troglodytes*) around
406 Kibale National Park in Uganda (Krief et al. 2014), and response of African elephants (*Loxodonta*
407 *africana*) towards different ethnic groups of people in Kenya (Bates et al. 2007). Nocturnal activity
408 peaks (Jhala et al. 2019) coupled with high abundance of food in terms of livestock and carrion
409 allow lions to coexist alongside humans. The subtle behavioural traits of avoiding humans can also
410 be adaptive and beneficial for individual lions because aggressive/conflict/problem lions are
411 typically removed from the population.

412 No amount of money can compensate loss of human lives adequately; however, the
413 Government of Gujarat pays a compensation of about 500,000 INR (~ USD 6000) for human
414 deaths by lions, and about 100,000 to 200,000 INR (~ USD 1200-2400) for injury. Since the
415 number of attacks and human deaths were few (in comparison to deaths caused by other wildlife
416 like elephants, tigers, leopards, and snake bites [[Search | Open Government Data \(OGD\) Platform](#)
417 [India](#)]) people rarely retaliated. Additionally, the compensation helped to further reduced
418 retaliations.

419 The current livestock compensation scheme, although periodically revised and one of the
420 best in India, is usually not in sync with market rates of livestock and do not account for lost
421 opportunity costs (Banerjee et al 2013) thereby causing significant deficits between livestock value
422 and compensated amounts (Appendix S9). Such a growing deficit adversely affects local
423 livelihoods, and can evoke negative reactions from the public and the press (e.g. Express News
424 Service, 2019; Kausik, 2022; Republicworld.com, 2021; The Times of India, 2021; The Wire Staff,
425 2021; Venkataraman, 2018). Therefore, more frequent revisions of the government compensation
426 rates as well as exploring a livestock insurance scheme that covers depredation losses similar to
427 the one implemented for snow leopards (Loch-Temzelides 2021), has the potential to reduce the
428 dependency on government sponsored compensation while giving more agency to local
429 communities.

430 Areas of high lion conflict were found to be in the proximity of *CTH* and lion refuge
431 patches (Figure 4h and 5f). These attack hotspots extend up to 15 km and 10 km for livestock and

432 human attacks respectively from *CTH* (Figure 4 c). Baiting of lions is often practiced at these *CTH*,
433 and such provisioning can cause lions to lose fear of humans and impede the learning of hunting
434 techniques in juvenile lions, consequently resulting in adult lions becoming habituated to humans
435 and losing their wild instincts. This can also artificially inflate lion densities, thereby creating more
436 conflict (Kojola & Heikkinen 2012; Massé et al. 2014; Gogoi et al. 2020). These negative aspects
437 of *CTH* could be managed once they are legitimised and brought under the ambit of the prevailing
438 laws. The Wildlife Protection Act has a provision for declaring *Community Reserves*, which with
439 some modifications can be used to harness the positive aspects of *CTH* while safeguarding against
440 their undesired effects. As expected, attacks on humans were also observed to increase with an
441 increasing frequency of attacks on livestock in a village (Figure 5c) which were both high in areas
442 having low to medium density of lions, livestock, and humans – in ecotone areas where natural
443 habitats mosaic with agro-pastoral-industrial areas. Attacks on humans and livestock decreased
444 with increasing human density; areas of high human density represent urban pockets in the
445 landscape (Figure 5g) that were usually avoided by lions. Based on our models, wildlife managers
446 need to be extra vigilant and proactive to reduce conflicts in the coastal areas of Veraval,
447 Sutrapada, Una, Rajula and Mahua (Figure 5h) which were predicted to be high-risk areas.

448 Despite livestock predation and occasional attacks on humans, it was intriguing to find that
449 majority of the local communities were tolerant towards lions in their neighbourhood. The
450 economic status of a person was one of the major driving factors of such positive attitudes (Table
451 1). Economically well-off people rarely need to deal with lions at a personal level and thus have
452 the scope of tolerating them in the neighbourhood. While livestock herders, one of the most
453 economically impoverished strata in the society, confront lions on a daily basis with detriment to
454 their livelihoods, and thus have a more pragmatic attitude (Table 1, Figure 7). In this landscape,
455 female cattle and calves are cared for and used for dairy purposes, while male calves, that were
456 earlier used as bullocks for ploughing farms, are now redundant due to mechanised farming. These
457 male calves are set free, and along with old abandoned cattle, form feral herds that that often raid
458 crops and cause losses to farmers. These feral cattle along with other agricultural pests like wild
459 pigs and nilgai are preyed upon by lions and this service is greatly appreciated by the farming
460 community.

461 Legitimate ecotourism associated with lions (operated through the Gujarat Forest
462 Department) provides livelihood opportunities (employment in resorts, shops, 4WD vehicles for
463 rent, employment by Park Management, etc.) and economic benefits to communities living near
464 the official tourism area. However, people living in villages distant from such regularised/official
465 tourism centres don't get these benefits legitimately. These communities often resort to the
466 currently illegal *lion tourism* practice (Singh 2017; Meena & Macdonald 2023). From our
467 observations, it seems that compensation is often claimed in these villages for livestock that might
468 have been offered as bait to lions at these *CTH*. The currently illegal practice of *lion tourism* at
469 *CTH* seems to be thus subsidised through public funds. However, the concept of generating
470 revenue associated with lions appears to be an important factor in shaping human-lion coexistence
471 (Figure 8a). This might explain why contrary to our expectations, people living in high lion conflict
472 areas had more positive attitudes towards lions than people from areas with *no to moderate* levels
473 of conflict (Figure 6; Table 1 a & b). We suggest that while formulating policy and management
474 strategies, it would be beneficial to ensure that local communities continue to profit from lion-
475 based ecotourism opportunities (Meena & Macdonald 2023), while simultaneously addressing the
476 negative impacts of baiting, dangerous night tourism, and illegitimate claims for livestock
477 predation (Jhala et al. 2019). If in the long run, the government decides to legitimise *CTH* on
478 private lands, the government should ensure a socially just mechanism by which revenues earned
479 are equitably shared amongst all strata of the society. The current illegality of such an activity
480 favours despotism, and the profits are monopolised by certain (privileged) section/s of the society.

481 We observed that people who have lived for several generations with lions tend to be more
482 positively aligned to having them in their neighbourhoods, and are less fearful of encountering
483 them (Table 1). Communities that have been living with lions for a considerable duration, have
484 adopted practices that reduce economic losses (Figure 9) and threats to life. In addition, many
485 local communities showed strong religious and cultural sentiments of symbolising lions as a
486 carrier/*vahana* of Goddess Durga, noble animal, and pride of their native land that were rooted in
487 the religious and mythological symbolism of the lion (Kak 2019; Bhaty 2020) .

488 Exploring the reasons for intolerant attitudes towards lions, we observed that livestock loss
489 and perceived threat to human life played a major role (Figure 8b). As expected, among the less-
490 and intolerant people, a high proportion were pastoralists because their livelihoods were

491 detrimentally affected from lion depredation, coupled with their economic constraints that
492 aggravated such losses (Figure 7). Though lions fed mostly on cattle carrion and feral cattle in
493 this landscape, and livestock predation was compensated by the government, pastoralists still
494 suffered losses borne out of the disparity among market rates of livestock and compensation
495 amounts, added with the lost opportunity costs (Banerjee et al. 2013).

496 The current human-lion coexistence in India is thus borne out of the fine play of coadaptation
497 between humans and lions, coupled with the prevalent religious, socio-cultural and economic
498 predispositions of local communities. As expected, coexistence with a formidable carnivore is
499 variable and nuanced, and sustaining this delicate balance where the benefits to both humans and
500 lions outweigh the costs of sharing space would probably require reimagining conservation
501 paradigms to include *land-sharing* and participatory approaches instead of just relying on
502 conventional *land-sparing* strategies (Srivathsa et al. 2023). From our results, we offer the
503 following recommendations that can potentially safeguard this balance for lions in India, and large
504 carnivores elsewhere:

- 505 1. The economic dynamics of local communities were observed to be a key factor governing
506 the balance of coexistence between lions and humans. Therefore, to minimise the economic
507 cost of living with lions, the livestock compensation scheme should be revised regularly in
508 a manner to maintain parity with market values, and also include lost opportunity costs
509 (Banerjee et al. 2013). Implementation of a livestock insurance scheme against depredation
510 needs to be explored which can offset the dependency of local communities on government
511 funding.
- 512 2. Education is considered an effective tool to increase awareness and acceptance of wild
513 animals among communities (Kvaalen, 1998; Zimmermann et al., 2001). While we did not
514 observe any significant effect of education in enhancing tolerance towards lions (Appendix
515 S11a), we believe that there is scope for incorporating appropriate modules related to
516 nature and carnivore (lion) awareness within school and higher education curricula to
517 support behavioural change towards wildlife among local communities. Specifically,
518 awareness programs should be undertaken regularly in areas with recent recolonization of
519 lions to educate local people about lifestyle changes required to avoid negative lion
520 interactions.

- 521 3. Our study identifies the risk hotspots of lion attacks on humans and livestock, which should
522 be monitored proactively. We recommend that certain lion prides in these sensitive areas
523 be fitted with radio-collars that have virtual geo-fences with early warning signals that will
524 permit wildlife managers to monitor their movement and pre-emptively mitigate conflict
525 (Weise et al. 2019; Khorozyan & Waltert 2021). Identified problem/conflict lions should
526 be efficiently removed following guidelines for removal of conflict tigers (NTCA, 2013).
527 While removal of animals from an endangered population is contentious, fostering good-
528 will for conservation among local communities is of paramount importance for the long-
529 term survival of the population and should take precedence.
- 530 4. Our study highlights the economic benefits for communities coexisting with lions as a key
531 factor in promoting tolerance. *CTH* provide economic benefits to local people from living
532 with lions, and also offers subsidised food and space for the lions in the human-dominated
533 landscape. Such *CTH* are currently considered illegal. Under the Indian Wildlife Protection
534 Act of 1972, there is provision for declaring areas as “community reserves”. This will allow
535 legal frameworks to be established, addressing concerns and outlining specific guidelines
536 for community-based tourism. These guidelines may include provisions for permitting
537 economic benefits and ensuring equitable sharing amongst all sections of the society, thus
538 fostering a sense of ownership and incentivizing conservation efforts among the residents,
539 while regulating their detrimental impacts on lion behaviour and risks to humans.

540 The lions of Saurashtra are not an isolated case where humans share space with large
541 carnivores, instead India abounds with such examples of coexistence - the urban leopards of
542 Mumbai (Athreya et al. 2016; Braczkowski et al. 2018), tigers in the outskirts of the city of Bhopal
543 (Saxena 2023), leopards of Jawai-Beda (Dutta Gupta et al. 2021) and sloth bears of Mt. Abu (Philip
544 et al. 2021; Patel et al. 2022), amongst others. Each situation has its unique features that permits
545 coexistence yet some commonalities are evident; that of human tolerance; adaptive behaviour by
546 both carnivores and humans; and the benefits of coexistence outweighing the costs. Our
547 recommendations can support governance and conservation management, facilitate human
548 tolerance through lifestyle changes required to live alongside carnivores, and create opportunities
549 for economic profits arising from charismatic carnivores to promote sustainable land-sharing in
550 the Anthropocene.

551

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785 **Tables in Main Text:**

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Table 1: Coefficients of the best model representing individual contribution of each predictor in explaining the variability in the odds of liking lions by respondents.

Effect type	Variable type	Variables	Estimate (SE)	z value	Odds Ratio	95% CI	P value	
Fixed Effect	Continuous	(Intercept)	-3.02 (SE 0.61)	-4.93	0.05	0.01 – 0.16	<0.001	
		Conflict Magnitude	0.71 (SE 0.25)	2.84	2.04	1.25 – 3.34	0.004	
		Distance to CTH	-0.36 (SE 0.18)	-2.01	0.69	0.48 – 0.99	0.045	
	Categorical	Occupation	Farmer	0.74 (SE 0.29)	2.53	2.1	1.18 – 3.74	0.011
			Job, business & other profession	0.87 (SE 0.34)	2.52	2.38	1.21 – 4.69	0.012
			Pastoralist	-2.07 (SE 0.29)	-7.17	0.13	0.07 – 0.22	<0.001
		Economic Status	Economically well off	0.95 (SE 0.27)	3.54	2.6	1.53 – 4.40	<0.001
			Economically wealthy	1.75 (SE 0.47)	3.72	5.75	2.29 – 14.45	<0.001
		Lion Colonisation Year	< 5 years	1.41 (SE 0.59)	2.37	4.09	1.28 – 13.10	0.018
			5-15 years	2.03 (SE 0.63)	3.23	7.58	2.22 – 25.92	0.001
			15-30 years	5.26 (SE 0.80)	6.58	192.73	40.25 – 922.79	<0.001
	30-50 years		4.37 (SE 0.78)	5.58	78.85	17.02 – 365.41	<0.001	
> 50 years	5.81 (SE 0.68)	8.49	332.88	87.01 – 1273.57	<0.001			
Random Effect	σ^2		3.29					
	τ_{00} Villages		4.23					
	ICC		0.56					
	Marginal R ² / Conditional R ²		0.540 / 0.799					

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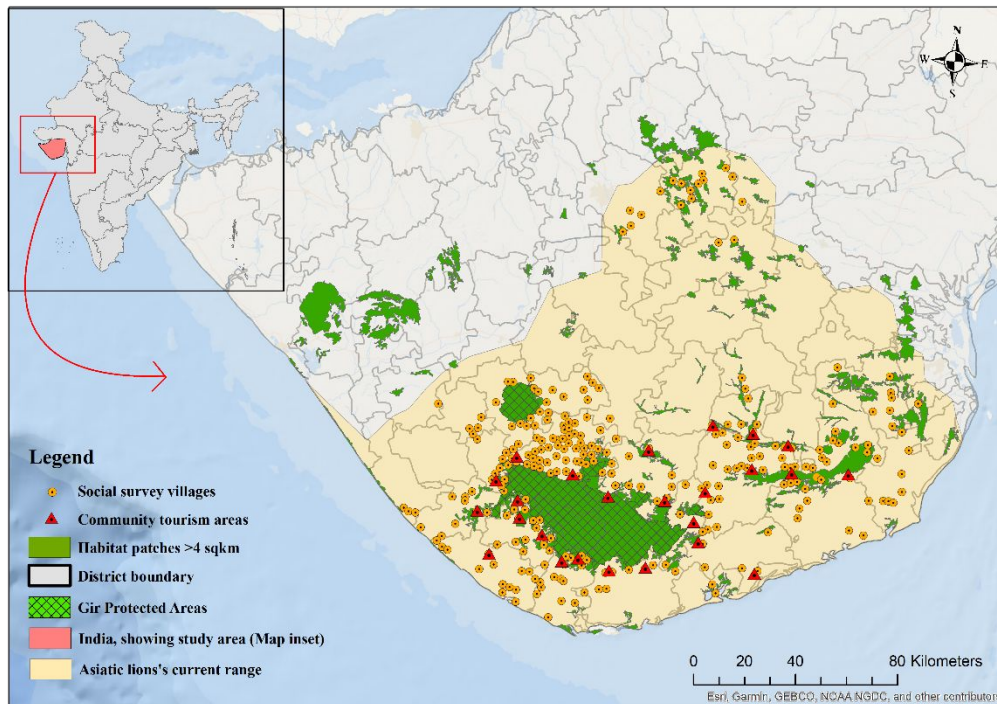
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Abbreviations: Distance to CTH = Distance to community tourism hotspots; CI = confidence interval, σ^2 = Residual variance, τ_{00} Villages = random intercept variance, ICC = Intraclass Correlation Coefficient. The reference category for Occupation = Agropastoralist, Economic Status = Economically poor and Lion colonisation year = 0 years (no lions in the vicinity).

793 **Figures in Main Text:**

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795 **Figure 1:** The Saurashtra landscape that is currently occupied by lions. The map shows locations
 796 of surveyed villages (n= 277) and locations of *community-tourism hotspots (CTH)*. The map inset
 797 shows the location of the study area within the state of Gujarat, India.
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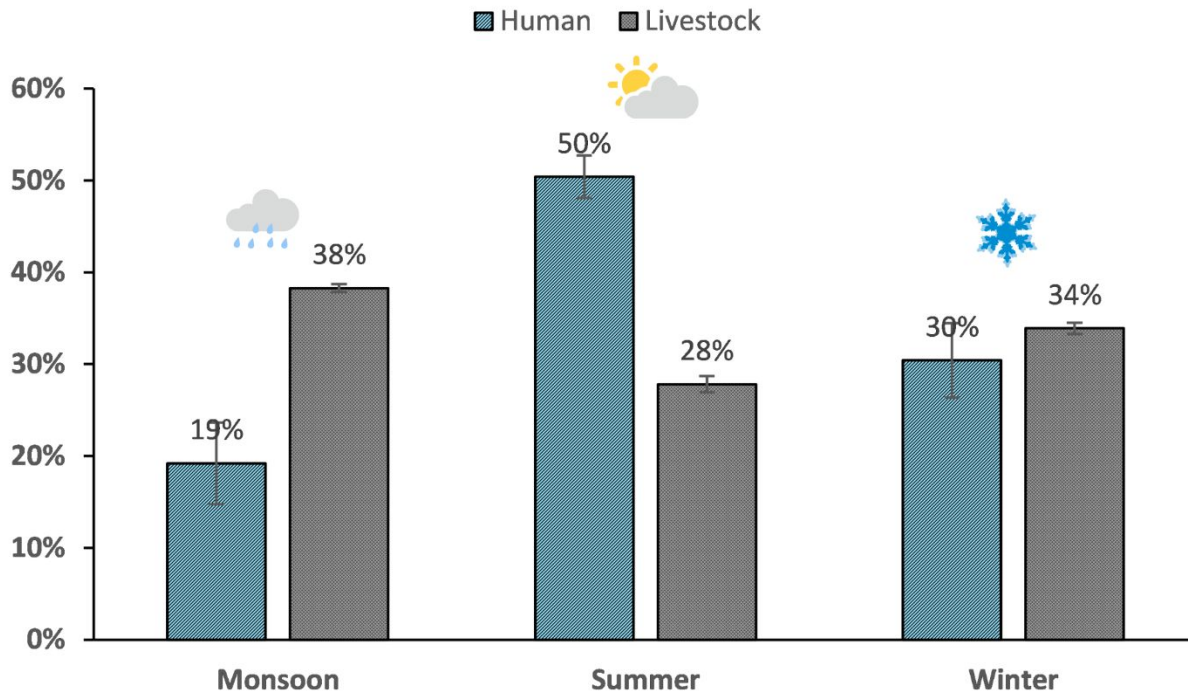


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801 **Figure 2:** Seasonality of human attacks (n=125) and livestock predation (n= 14099) by lions in
802 the Saurashtra landscape between 2012-2017.

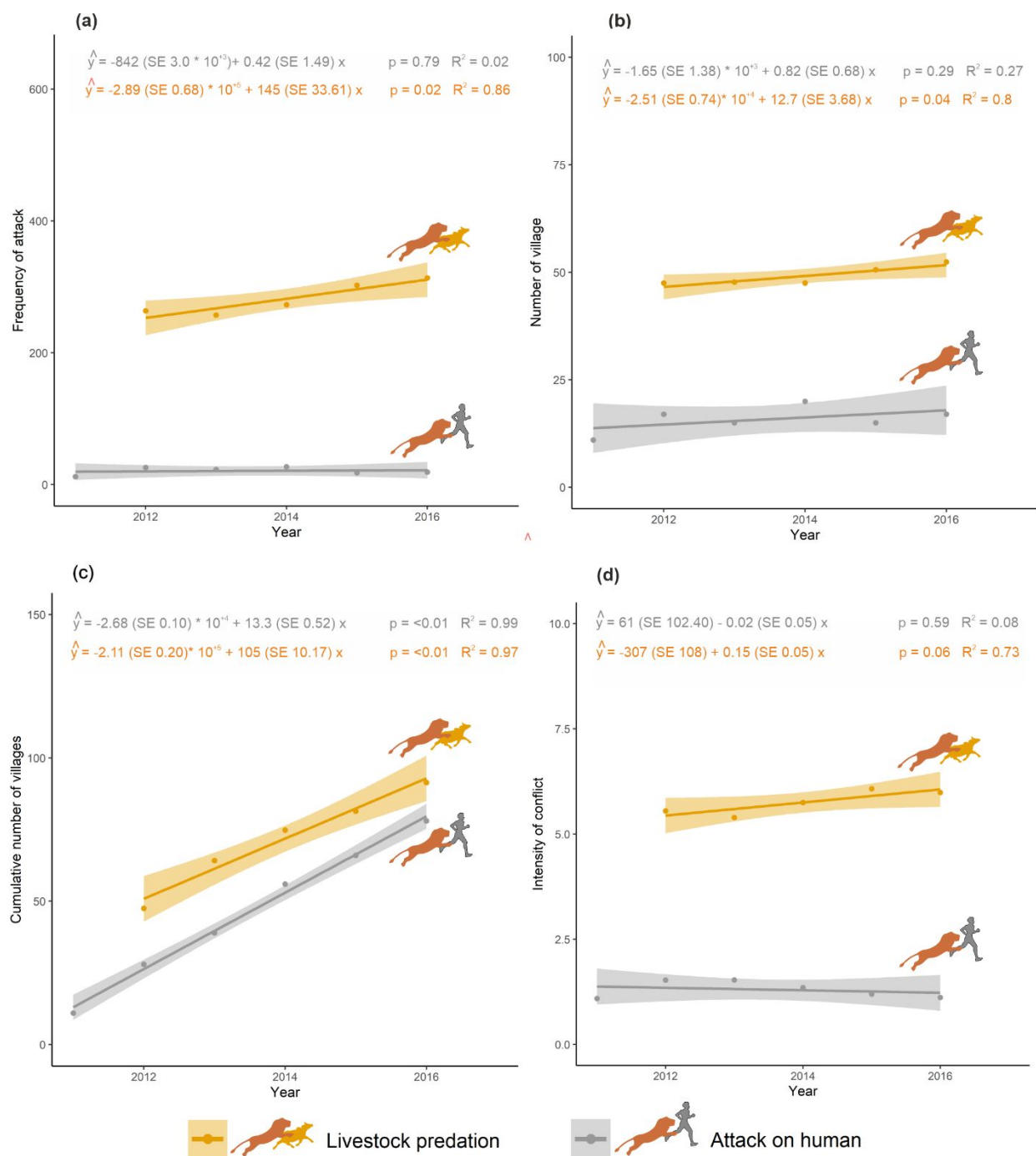
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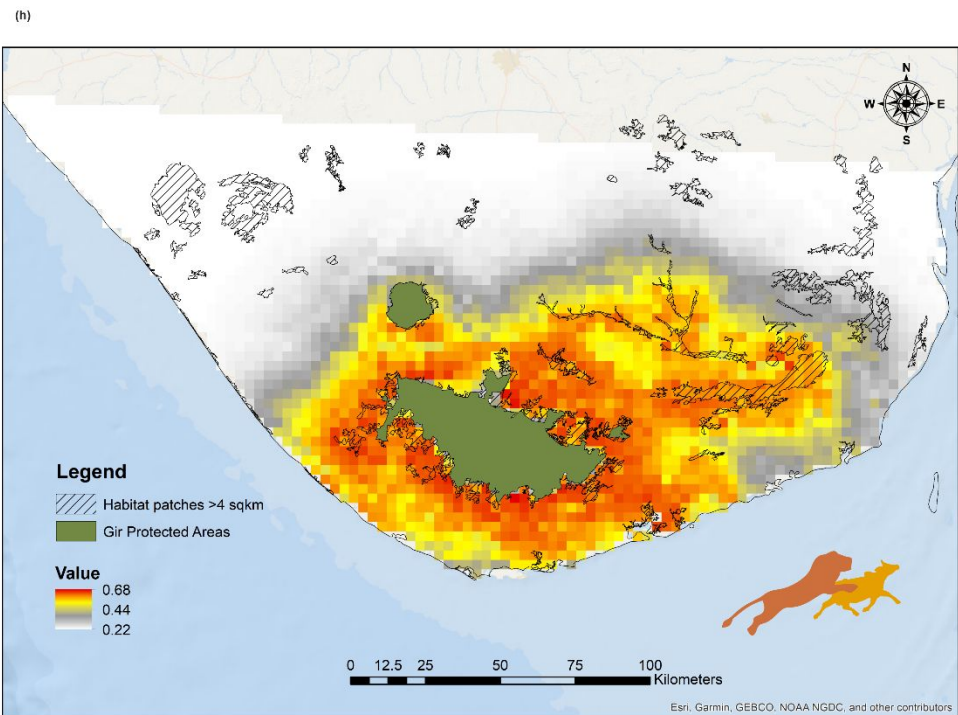
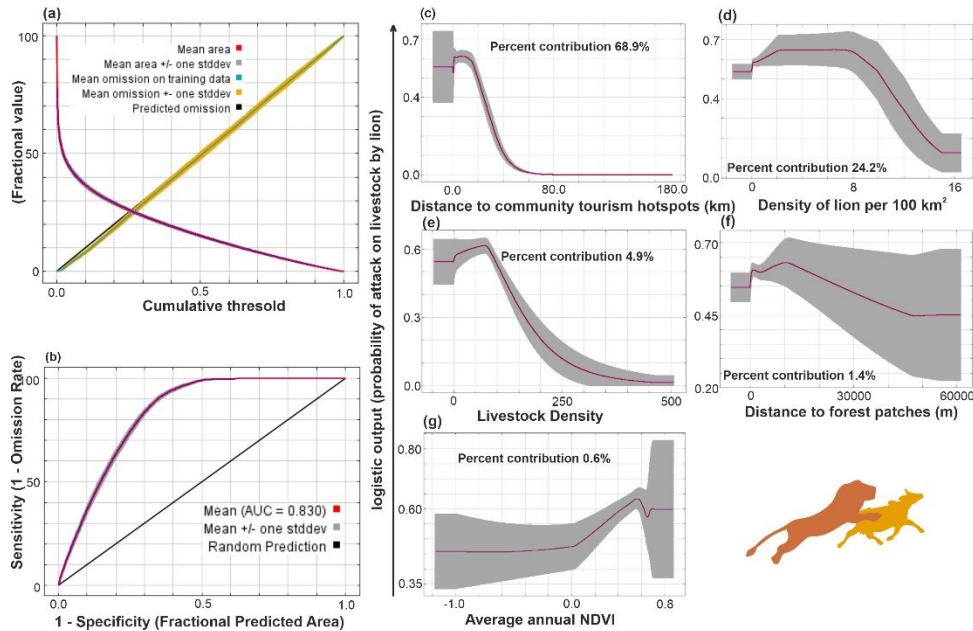
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807 **Figure 3:** (a) Annual trend of attacks on human (grey line) and livestock (yellow line; scaled down
 808 by a factor of 10, for fitting in the figure) by lions in the Saurashtra landscape, (b) Annual trend in
 809 the number of villages experiencing attacks on humans (grey line) and livestock (yellow line;
 810 scaled down by a factor of 10) by lions, (c) Annual cumulative trend in the number of villages that
 811 experienced attacks on humans (grey line) and livestock (yellow line; scaled down by a factor of
 812 10) by lions, and (d) Annual trend in the intensity of conflict (i.e. total number of attacks in a year
 813 divided by the total number of villages experiencing attacks) for human (grey line) and livestock
 814 (yellow line).
 815



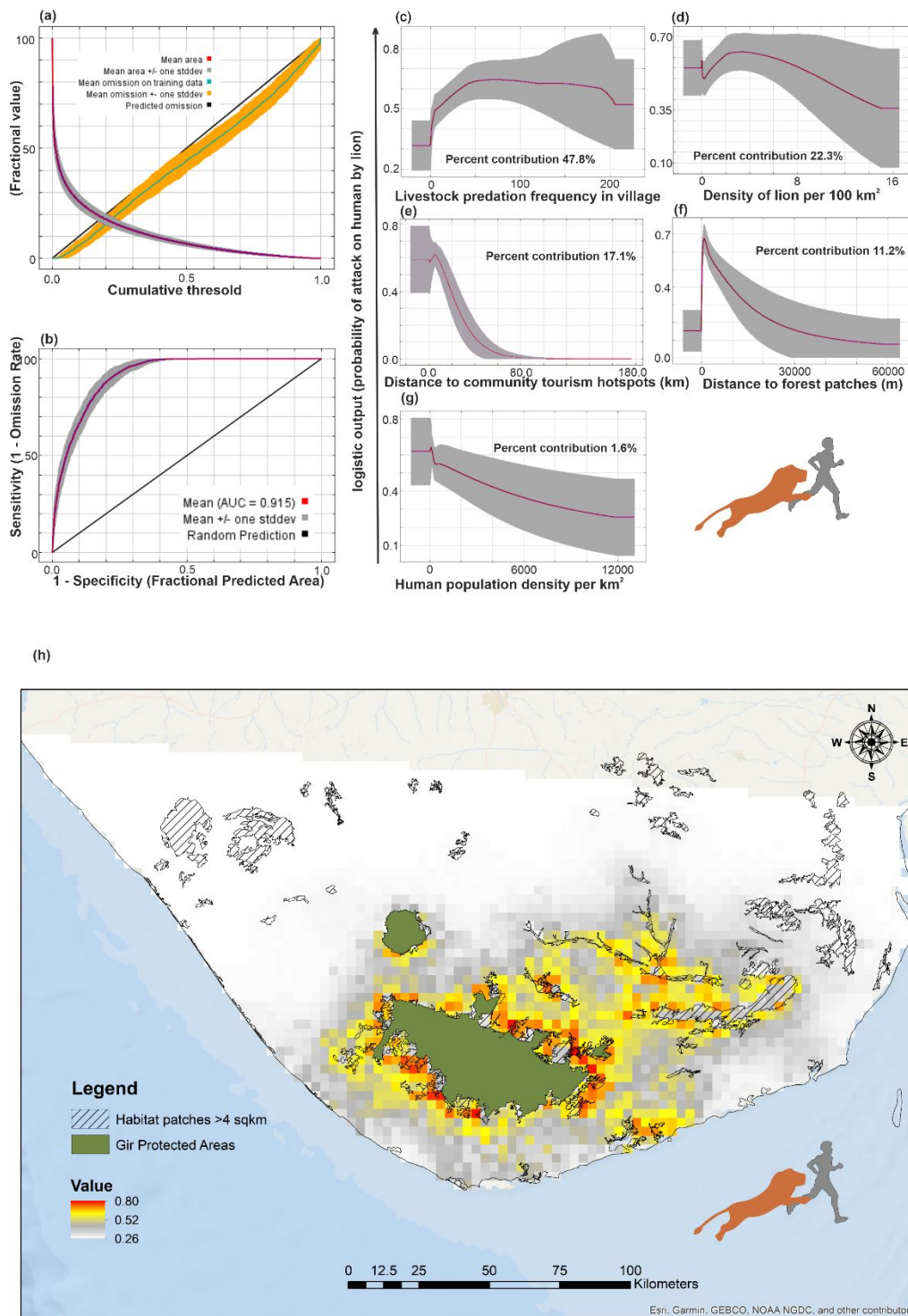
816

817 **Figure 4:** (a) Receiver operator curve for assessing MaxEnt model fit for livestock predation by
 818 lion, (b) Omission/Commission analysis for model accuracy. Response curves obtained from the
 819 100-bootstrap run, where (c) Distance to *community-tourism* hot-spots, (d) Lion density per 100
 820 km², (e) Livestock density/km², (f) Average Normalized Difference Vegetation Index (NDVI) and
 821 (g) Distance to forest patches, (h) The probability risk map of livestock predation by lions in the
 822 Saurashtra landscape.
 823



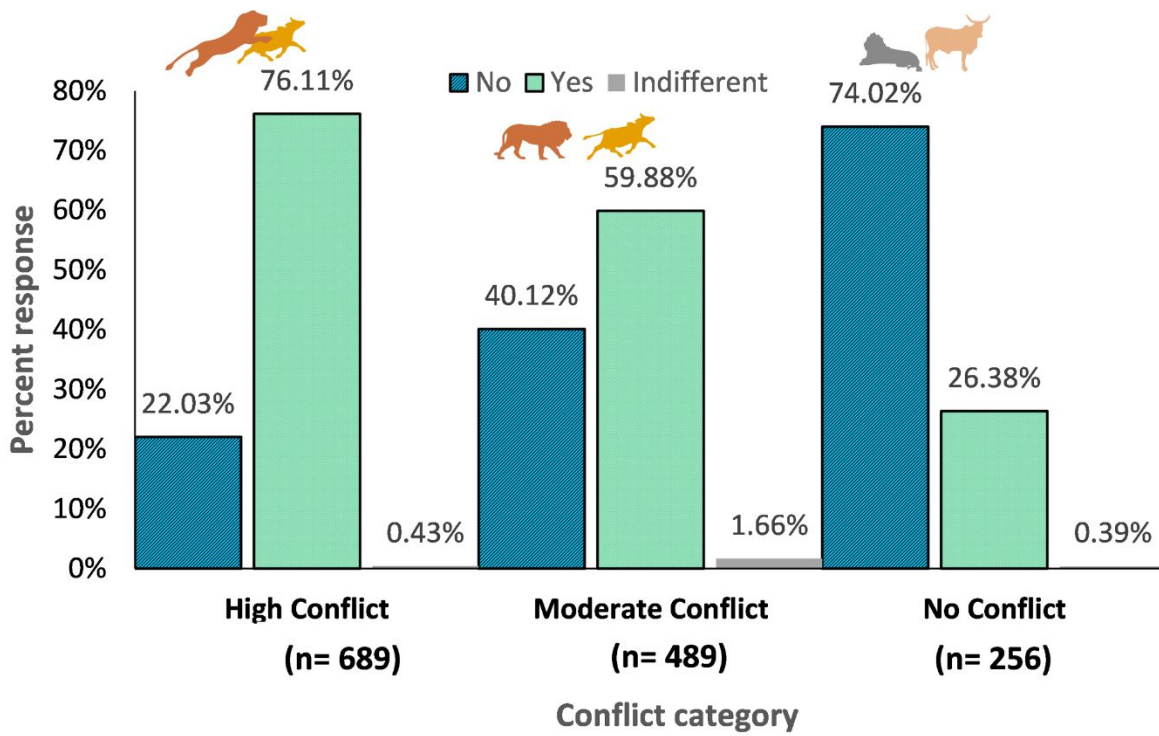
824
825

826 **Figure 5:** (a) Receiver operator curve for assessing MaxEnt model fit for attacks on humans by
 827 lions, (b) Omission/Commission analysis for model accuracy. Response curves obtained from
 828 the 100-bootstrap run where (c) Livestock predation frequency in a village, (d) Distance to
 829 *community-tourism* hot-spots, (e) Lion density, (f) Distance to forest and (g) Human population
 830 density, (h) The probability risk map of attacks on humans by lions in the Saurashtra landscape.



831

833 **Figure 6:** Percentage of total respondents (n= 1434) who were tolerant (Yes, 61.86%), intolerant
 834 (No, 37.30%) or indifferent (0.84%) towards lions living in their neighbourhood from villages that
 835 recorded no conflict, moderate conflict, and high conflict with lions.
 836



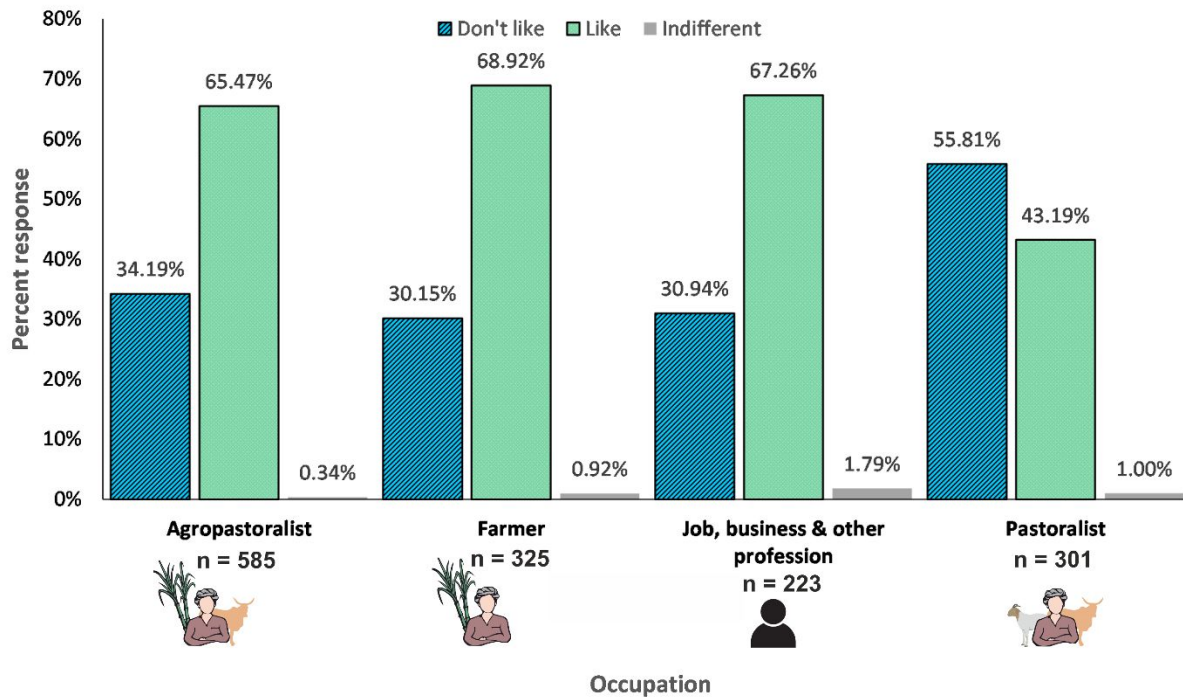
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838

only

839 **Figure 7:** Bar plot showing the percentage of respondents from different occupational
 840 backgrounds who expressed tolerance, intolerance or indifference towards lions in their
 841 neighbourhood.

842

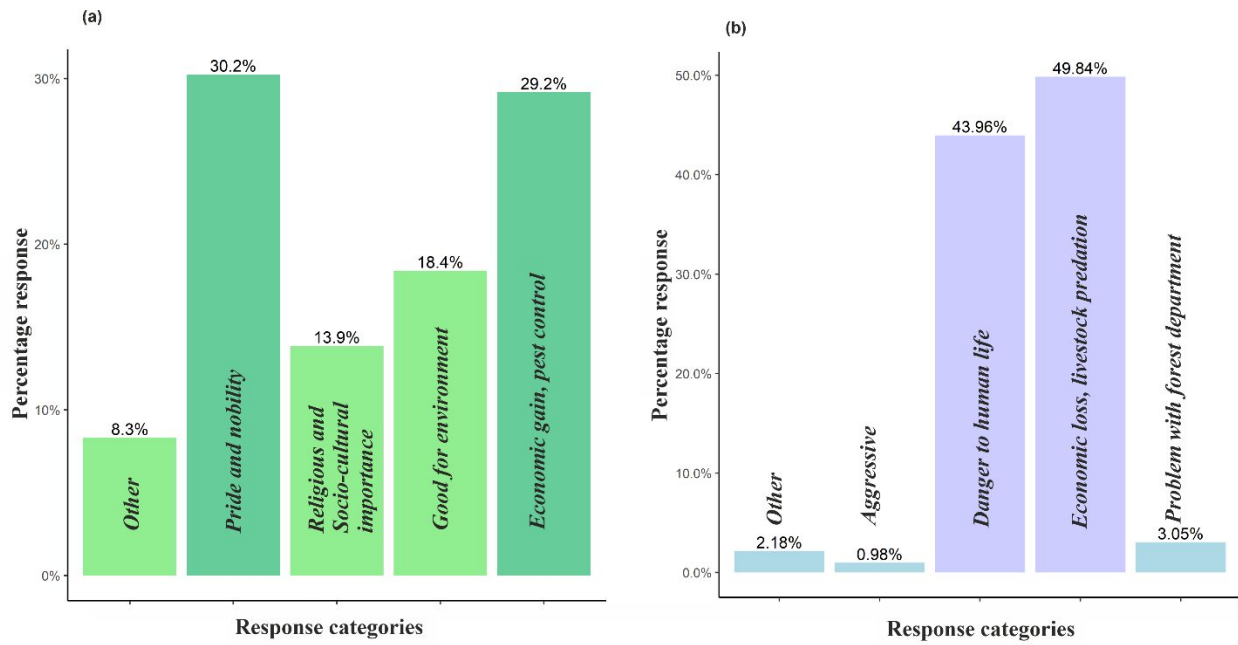


843

844

845 **Figure 8:** The bar plots represent the percentage of response in each category of (a) reasons of
 846 being tolerant of lions and (b) reasons for intolerance towards lions.

847



848

849

view only

850 **Figure 9:** Livestock rearing practices in relation to the duration of exposure to living with lions.
 851 (a) Quality of night corralling facilities for livestock and (b) livestock herd composition taken out
 852 for foraging. The x-axis represents duration of exposure to living with lions.

853

