

**STRIKING A BALANCE: STRIPED HYENA (*HYAENA HYAENA*) IN THE
HUMAN-INTERSPERSED SEMI-ARID LANDSCAPE OF RAJASTHAN**

by

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Wildlife Science

Under the supervision of

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DECLARATION

I hereby declare that the work conducted under the thesis entitled “**Striking a balance: Striped hyena (*Hyaena hyaena*) in the human-interspersed semi-arid landscape of Rajasthan**”, is a record of original and independent research work done by me and subsequently submitted for the award of the degree of **Master’s in Wildlife Science** at the **Academy of Scientific and Innovative Research**. This research work has been carried out under the guidance and supervision of **Dr. Ramesh Krishnamurthy, Scientist F**, and co-supervision of **Dr. Ramesh Chinnasamy, Scientist E** of Wildlife Institute of India, Dehradun. The work has not formed the basis for the award of any other degree, diploma, or any other qualification. I also declare that the thesis embodies my own work, analysis, observation, understanding and the particulars given in it are true to the best of my knowledge.

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Dedicated to the Indokh clan of striped hyena who allowed me to understand them closely.....





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CERTIFICATE

This is to certify that the thesis by **Ms. Khushi Soni** entitled “**Striking a balance: Striped hyena (*Ihyaena hyaena*) in the human-interspersed semi-arid landscape of Rajasthan**”, is an original and independent research work submitted to the **Academy of Scientific and Innovative Research**, for the award of the degree of **Master’s in Wildlife Science**.

Ms. Khushi Soni has put one semester of research work embodied in this thesis under my guidance and supervision. The work presented in this thesis has not been submitted to any other University or Institute for the award of any degree, diploma or distinction.

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EXECUTIVE SUMMARY

This study investigates the spatial ecology and conservation need of critical habitat refugia of a large carnivore, striped hyena (*Hyaena hyaena*), in Sariska Tiger Reserve (STR) within the Aravalli Range in Rajasthan, India. Striped hyena plays an important role in maintaining ecosystem health through scavenging and occasional predation, yet faces significant threats from habitat loss, decrease in denning refugia, and increased human disturbance in human-interspersed landscapes. The research focuses on understanding the occupancy patterns and den-site use of striped hyenas in STR, their adaptability to human presence, and their interactions with co-occurring large carnivores such as tigers and leopards, which will provide insights into their persistence in this landscape of coexistence.

The study was conducted in an occupancy framework covering 130 survey units of 9 Km² each. Single season single species occupancy was modeled using environmental and ecological covariates. Den-site use was analyzed using binomial generalized linear models (GLM) incorporating first only environmental covariates, and later both environmental and ecological covariates combined to look if striped hyena shows a tradeoff in utilizing the available denning refugia. Spatial interaction with tigers and leopards was also analyzed through conditional occupancy estimates and species interaction factors (SIF) to look at the change in their spatial ecology over a decade.

The best-fit occupancy model (AIC = 435.38) identified open habitat as the strongest positive influence ($\beta = 1.607 \pm 0.417$, $p < 0.001$), followed by wild prey index ($\beta = 1.226 \pm 0.434$, $p < 0.005$), closed habitat ($\beta = 0.668$, $p < 0.05$), and ruggedness, which showed a negative effect ($\beta = -0.584 \pm 0.285$, $p < 0.05$). Striped hyenas exhibited a higher probability of site utilization in the presence of tigers (0.73 ± 0.09) and leopards (0.83 ± 0.06), with SIF values of 1.18 for tigers and 1.29 for leopards, indicating co-occurrence and potential resource sharing. Compared to a 2014 study when tiger numbers were lower ($n=11$), site utilization in the presence of tigers increased from 0.53 to 0.73, revealing behavioral adaptations following tiger reintroduction in STR. High SIF with leopards suggested that high prey availability in STR mitigates interspecific competition. This challenges the mesopredator release hypothesis, as both striped hyena and leopard populations have increased alongside rising tiger numbers, likely due to abundant resources and available habitat refugia. Den-site selection was analyzed using two approaches: environmental

predictors alone and a combination of environmental and ecological predictors. The best environmental model (AIC = 132.47) included elevation ($\beta = -1.0961$, $p < 0.01$), ruggedness ($\beta = 0.5166$, $p < 0.05$), distance to road ($\beta = 0.6249$, $p < 0.05$), and distance to village ($\beta = 0.4363$, not significant), indicating a preference for moderate elevations, rugged terrain, and areas away from roads. The combined model (AIC = 131.07) included elevation ($\beta = -0.9766$, $p < 0.01$), ruggedness ($\beta = 0.5452$, $p < 0.05$), and human disturbance index (HDI, $\beta = -1.0113$, $p < 0.05$), which indicated towards the striped hyena's ability to tolerate moderate human disturbance. The shift in the denning refugia, after including ecological variables- Human Disturbance and Wild prey index, indicated towards the tradeoff in the den-site selection by striped hyena that would offer both security and access to essential resources.

The findings suggested that open habitats facilitate foraging due to enhanced carcass visibility, while closed habitats and rugged terrain provide secure denning and resting sites. The Aravalli Range, particularly STR, serves as a critical refugia, supporting one of India's highest striped hyena densities (15.44 ± 2.48 individuals/100 km²). High wild prey abundance and scavenging opportunities from tiger and leopard kills would have likely reduced the reliance on livestock, which too occur in high density. These spatially explicit results showing critical denning refugia in STR as well identifying intensively utilized areas would allow managers to develop evidence-based habitat monitoring program, that would allow to delineate critical habitats as well as include it in the village relocation plan to create more inviolate spaces for wildlife and reduce the anthropogenic pressure on forests as well as check the spread of invasives in the protected area.

Chapter 1: INTRODUCTION

Large carnivores are among the world's most threatened species facing geographic range contraction, global population decline and habitat loss (Ripple et al. 2014). They face a wide variety of anthropogenic threats including rapid land use change, rising human density, persecution by humans, particularly over livestock related conflicts, hunting, trapping, and loss of prey base (Wolf et al. 2016). Their unique life-history features- long gestation period, high metabolic requirements, slow growth aggravates the effect of anthropogenic threats on their population densities (Wolf et al. 2017). Carnivores have a critical role to play in regulating ecosystems. By consuming large prey, they negatively influence ungulate population growth, resulting in greater plant diversity and supporting dependent wildlife (Boyce 2018). Due to interspecific interactions among coexisting predators, the removal of an apex predator would allow mesopredators to rise (mesopredator release) and therefore would reduce the ecosystem stability (Valkenburgh & Wayne 2010). In addition to that, some carnivores scavenge on the carrions and help in environmental cleaning and prevent disease transmission. While co-occurring carnivores often interact to depress subordinates' population size through both exploitative and interference competition that affects the distribution and resource selection of the carnivores interacting (Glen & Dickman 2005), other carnivores might take advantage from the presence of large carnivores as they provide hunting or scavenging opportunities (Panda 2023). Such strongly interacting species also exert ecological cascade by altering the behavior and prey selection of the subordinate competitors (Ripple & Beschata 2004). Range losses of such large carnivores can result in local population extinctions, which can result in disruption of ecosystem and socio-economic services.

1.1 Carnivores in the human interspersed landscape

Large carnivores are declining across the globe and conservation of their populations is essential in not only protected areas but also human interspersed landscapes for their long-term persistence (Carter & Linnell 2016; Ripple et al. 2014). However, sharing space with humans comes with a combination of costs. Direct anthropogenic mortality and persecution are often high for those living outside of protected areas (Loveridge et al. 2017). Even the populations within the protected reserves may be at risk if it ends in a hard edge. Increased human contact due to their wide-ranging behavior and dispersal, is a major cause of mortality, which may cause local population extinctions

in small, isolated reserves to hold their viable populations (Woodroffe & Ginsberg 1998). In response, large carnivores exhibit behavioral avoidance of humans, altering their movement pattern, habitat selection (Suraci et al. 2019), and feeding behavior (Smith et al. 2019) to avoid human. Such behavioral responses often lead to increased energetic expenditure during movement (Nickel et al. 2021) and reduced feeding times at kills (Smith et al. 2015). Hence, habitat integrity of the landscape is crucial for maintaining the equilibrium in population dynamics of both prey and predators.

Due to habitat destruction and fragmentation, the last remaining natural areas are becoming progressively smaller, leading to the formation of more isolated patches floating within a human-modified matrix (Taylor 1993). Consequently, carnivores might not be able to persist for long in those landscapes, considering a lack of functional linkages or a permeable habitat matrix in form of habitat patches called stepping stones (Herrera et al. 2017). According to small population paradigm theory (Caughley 1994), small populations are vulnerable to stochastic events, thus large carnivores should be especially prone to extinction owing to their trophic position that constrains them to live at low population densities. Additionally, carnivore populations are also exposed to strong external pressures by living near humans. Even within protected areas, conflict with humans is usually the single most important cause of adult mortality (Kruuk 1972). The impact will be more pronounced in small reserves with high perimeter: area ratios and in species that range widely and therefore come into frequent contact with humans. Habitat reduction and degradation could also negatively affect the survival of carnivores in human-dominated landscapes by reducing the wild prey abundance and a carnivore's ability to avoid detection by people. In large carnivores, then, both stochastic processes and strong edge effects could contribute to the extinction of isolated populations. The response of each carnivore will differ considerably due to species biology, where carnivores such as tigers, lions with larger home range size would be more vulnerable (Woodroffe & Ginsberg 1998) than other carnivores such as spotted hyena, common leopard, cougar, striped hyena which show greater behavioral plasticity and tend to adjust their home ranges and prey selection in response to disturbance.

Species that can survive in the prevailing conditions of anthropogenic disturbance requires a different approach that can be defined realistically by 'Landscape of Coexistence' (Oriol-Cotterill et al. 2015) where presence of habitat refugia and spatio-temporal variations in behavior could

reduce the predation risk and ensure long term coexistence. Such concepts for large terrestrial carnivores result from the type of interactions, level of human disturbance and their attitudes towards conservation, carnivore's behavioural ecology (e.g. critical resource availability, habitat use, foraging patterns and behavioural plasticity), and environmental attributes (e.g. land cover type, dense cover), and wild prey densities. Carnivores increase their use of habitat refugia in response to risk of intraspecific and intraguild predation and competition during vulnerable activities such as while siring litter (Fernandez & Palomares 2000), resting (Switalski 2003), or feeding on a carcass that might attract the attention of larger carnivores (Hunter et al. 2007). Such refugia refers to any habitat structure that is not accessible or goes unnoticed by people, for example, rocky outcrops are preferred by striped hyena (Mandal 2018, Singh et al. 2010); dense canopy cover and riparian beds provide refugia for leopards in Jhalana (Athreya et al. 2013; Kumbhojkar et al. 2020), riparian woodlands provide refugia to cougars moving through a landscape mosaic in California (Dickson et al. 2005); spotted hyena in southern Kenya favors thicker bush when their range is used more intensively by people and livestock (Kolowski & Holekamp 2009), particularly during nursing young in the dens; brown bears select den sites that offer greater cover when resting near areas of higher perceived anthropogenic risk (Cristescu et al. 2013). Thus, large carnivores in a Landscape of Coexistence will show the greatest selection for such refuge habitat structures when navigating through human-dominated landscape, even though they might face reduced foraging time. Many carnivores tend to avoid humans temporally by shifting their peak activity to time when humans are less active (e.g. cougars- Van Dyke et al. 1986, tigers – Carter et al. 2012, striped hyena- Panda et al. 2022). This is also the time during which carnivores tend to utilize anthropogenic provisioning and predate on livestock.

Further, large carnivores have also shown a remarkable adaptability to share spaces with humans, specifically in India, the most populated country with 450 persons per km² and with the largest livestock population (20th All India Livestock Census, 2019), which holds the highest number of large terrestrial carnivore species (with average body weight > 15 kg) in the world (Johnsingh 1986). Of these carnivores, the striped hyena is placed in a unique position of being predator as well as a scavenger, with relatively higher interface with humans, due to scavenging opportunities from livestock mortality, especially in the villages surrounded by forest matrix.

1.2 Species profile: Striped Hyena

1.2.1 Introduction

Striped hyena (*Hyaena hyaena*) is an important large scavenger, belonging to the functional group of 'Bone crushers' (Wagner 2006). It is one of the four extant members of the family Hyaenidae, along with spotted hyena (*Crocuta Crocuta*), largest among all, and being sympatric with striped hyena across much of the range of African subcontinent. It is a social carnivore known to live and hunt in large clans. Aardwolf (*Proteles cristatus*), found in South and East Africa, is the smallest member and an insectivorous carnivore with rudimentary cheek teeth. Brown hyena (*Parahyaena brunnea*) distributed only in Southern Africa, resembles striped hyena most closely in terms of both size and sociality. It is distinct by having stripes on only legs with an underdeveloped mane. Striped hyena range extends from Africa, including East and North-east Africa, Middle East, Central Asia, and the eastern limit of West Bengal in Indian subcontinent. Their population is patchily distributed across the range and is composed of isolated small populations (Hofer 1998). In India, striped hyena is distributed broadly across the landscape but exists at low densities in most of the regions (Alam et al. 2015; Singh et al. 2014).

1.2.2 Morphology

Striped hyena has black stripe patterns on a thick dusky shade pelage, which helps in individual identification, although the color varies by season (Ilani 1975). The Legs are slender, with forelegs taller than the hindlegs giving the animal a loping gait. Feet have four toes with four non-retractable claws (Prater 1948). An invertible anal pouch is used while displaying pasting behavior during social encounters (Spagnuolo 2016). Although there is no apparent sexual dimorphism in body measurements, males usually weigh more and possess a dark spot on throat. Permanent dentition is distinctly carnassial, and the dental formula is $i\ 3/3, c\ 1/1, p\ 4/3, m\ 1/1=34$. The presence of carnassial allows them to extract nourishment in the form of bone marrow, even from old bones (Wagner 2006). The high sagittal crest of the skull increases the area of attachment for the temporal muscles while the masticatory muscles help in seizing and crushing of prey (Buckland-Wright 1969). Striped hyenas are also known for caching food to the den to feed the cubs (Bopanna 2014).

1.2.3 Habitat

In Indian subcontinent, striped hyena generally prefers open habitats in arid to semi-arid environments (Prater 1948) usually for foraging, where water is available within 10 km (Bopanna 2014). However, they also actively seek out dense cover or rocky terrain for resting and denning (Leakey et al. 1999, Singh et al. 2010). Striped hyenas may frequent villages, while showing temporal niche segregation with humans (Rosevear 1974, Panda 2022). Studies have suggested that striped hyena shows a high degree of plasticity in their ability to thrive in a diverse habitat. Variation in home range size with respect to resource availability has also been reported (Wagner et al. 2008).

1.2.4 Food habits and foraging

Striped hyena shows high diversity in diet, ranging from vertebrates, invertebrates, vegetative matter, and organic wastes (Alam & Khan 2015; Mandal et al. 2018). Hence, hyena could be regarded as an omnivorous scavenger. They have been reported actively hunting hares, fawns of ungulates, goats, sheep, dogs, peafowls (Skinner & Ilani 1979, Mandal et al. 2018). Striped hyenas appear to forage alone in African system but are observed to form small groups at dump yards and kills (Skinner & Ilani 1979). Cubs have been observed to accompany their mothers on foraging walks once they reach around 12-24 months (Kruuk 1976; Wagner 2006). Striped hyenas spend the early night and dawn foraging and are known to walk about 2-3 km a day (cheetah report)

1.2.5 Reproduction

They have unseasonal parturition, and gestation is for around 90 days as observed in captivity (Skinner & Ilani 1979). Litter sizes range from 1-4 cubs and maximum 5 (Rieger 1981; Wagner 2006). Studies have established that the helpers used to help raise their younger siblings by food provisioning and learn important survival techniques while the mother is involved in foraging, along with den maintenance and guarding the family against potential predators (Hadad et al. 2023).

1.2.6 Threats

Striped hyena is listed as Near Threatened by IUCN red list and Schedule I in Indian Wildlife (Protection) Act, while it is not included in CITES. Humans are considered the primary threat throughout its evaluated range (Hofer 1998; Wagner 2006). Negative perceptions of the species exists in many parts, regarding its scavenging behavior, perceived threat to livestock, feeding on

human dead remains through “grave robbing” (Ilani 1975) and negative image created through folklores. Since they exist mostly outside protected areas specifically in regions where pastoralism and animal husbandry is practiced, they are an easy target of retaliatory killing and persecution often due to misidentification (Mills and Hofer 1998; Tourani et al. 2012), mortality due to road traffic (Mandal 2018) and habitat destruction (Ripple et al. 2014). Understanding how near threatened species alter their behavior, space use and temporal patterns in response to changing landscapes is critical for the effective conservation and management of this pivotal scavenger.

1.3 Striped hyena and agropastoral landscape

Striped hyenas are known to thrive in the semi-arid landscape of India which is often attributed to the high density of livestock (~166 livestock per Km² (20th Livestock census, 2019)), anthropogenic food provisioning of carrions at village dump yards (Das 2022) due to traditional practice of pastoralism. Perspective of scrubland as a wasteland and their commercial conversions are often restricting population dispersion as well as survival of their population outside protected areas where no habitat refugia for retreating might affect their survival (Panda et al. 2022; Singh et al. 2014). Striped hyena persists in higher densities in the agropastoral landscape of Rajasthan (Gupta et al. 2009; Singh et al. 2010; Mandal 2018). Singh 2014 reported that rugged terrain, dense cover and distance to village explains hyena distribution in Ranthambore. In this landscape of change, the Aravalli chain of mountains have emerged as a crucial refuge for striped hyena and many other species by providing shelter during daytime heat, and protection from anthropogenic risks.

1.3.1 Aravallis and its importance

Aravalli Range, the oldest fold mountain range in the world is extended across four states of India- Delhi, Haryana, Rajasthan and Gujarat, with a length of 692 Km (Habib et al. 2017). The Aravalli range gradually increases in elevation in the southwest direction, where climatic and edaphic factors describe the vegetation pattern. Western India is shaped by the presence of the Aravalli range. Due to its historical significance, it is important from the lens of both zoogeography and evolutionary by having a mix of Saharan, Ethiopian, peninsular, oriental and even Malayan elements of flora and fauna (Habib et al. 2017).

Aravalli acts as a green barrier between arid and semi-arid zones, hence, effectively acting as terrain, moisture and vegetation constraint, preventing further the spread of Thar desert towards the east. It comprises of mosaic habitats including Tropical Deciduous Forest dominated by *Anogeissus pendula*, *Acacia sp.*, *Butea monosperma* and *Ziziphus* mixed forest along with scrublands with pockets of dense shrub cover, rocky outcrops and grasslands (Shankar report). Such dense forests mediate rainfall patterns and check the rate of evapotranspiration over the hilltops, thus preventing drought conditions. It also regulates the microclimatic conditions during extreme summers by providing refugia to the biodiversity as well pastoral communities. Aravalli acts as important groundwater aquifers, providing seasonal streams and small pools as seasonal water sources during dry summers. Such characteristics make Aravalli a rich biodiverse island among the human dominated landscape, offering suitable habitat to fauna and floral species comprising of tiger, leopard, striped hyena, jungle cat, rusty spotted cat, desert cat, honey badger, desert fox, Indian wolves, caracal and other diverse taxa. A chain of protected areas dotted along the Aravalli landscape, act as pockets to provide refugia from rapid urbanization around Aravallis. In addition to that, territorial divisions and ecological corridors (e.g. Great Green Wall, Haryana) ensure connectivity among various species to ensure viable populations.

In recent times, Aravalli has undergone major land use land cover changes. Its environmental status has changed rapidly due to large scale destruction of forest cover over the hills followed with unusual rainfall patterns, increase in soil erosion, sediment transportation, siltation of water sources and drying up of lakes, lowering of water table without considering recharge capacity of the ground water aquifers (Chander & Kant 2019). The Aravalli range is not a continuous chain but with gaps which are more vulnerable to deforestation, allowing the drifting of desert sand towards fertile plains. Through change analysis using remotely sensed data, twelve such gaps have been identified through the desert sand is drifting towards northeastern plains (Rathore 2012). The degeneration of natural pastures in such areas has increased the pressures on the forest cover on the hills to feed the ever-increasing livestock population in the region. Due to loss of vegetative cover, Aravalli is gradually getting converted into 'Rocky Desert'. Rapid urbanization, including liner infrastructure and mining, poses a significant threat to wildlife by disrupting the wildlife corridor, causing mortality and reduced gene flow. The situation is more grave for the isolated protected areas of the region that has lost connectivity from the neighboring protected areas.

One such existing refugia known to hold one of the highest densities of striped hyena (15 individuals/ 100 km²) in India, as compared to the other studies conducted in semi-arid landscapes of India and Africa (Kruuk 1976; Wagner et al. 2008) is Sariska Tiger Reserve (STR) (Gupta et al. 2010; Mandal 2018). High density of wild prey and domestic carrions present inside the tiger reserve (Bhattacharjee 2014) and availability of denning refugia together converge to make Sariska Tiger Reserve an ideal habitat for Striped Hyena.

1.3.2 Sariska Tiger Reserve: a protected refugia in the Aravallis

Sariska Tiger Reserve is the largest protected area (1216.35 Km² area) located within the Aravalli range. With over 24 villages in the critical tiger habitat and approximately 175 villages and a major city in and around the tiger reserve (Bhardwaj et al. 2022), STR, by its location remains isolated from nearby protected areas. Tigers became locally extinct in 2004 in STR as the reserve could not sustain the poaching pressure due to this isolation. In 2008, tigers were reintroduced back into STR, following which the reserve has seen a significant increase in the tiger number from n=11(2014) to n=43 (2024). Villages inside the critical tiger habitat are getting relocated to create more inviolate areas for tiger breeding. Tiger reintroduction in STR has dramatically changed the population dynamics of a sympatric carnivore, leopard (Mondal et al. 2012). After the tigers got exterminated from Sariska in 2004, common leopard occupied the national park that was previously occupied by tigers (Mondal et al. 2012) and existed in high densities (10.7/100 km²) (Mondal et al. 2012). When the tiger got reintroduced in 2009-10, leopard density first reduced significantly due to inter-specific competition, but later started increasing after adaptation to tiger's presence through slight modifications in habitat use, prey selection and activity patterns (Mondal et al. 2012). Similarly, studies on striped hyena revealed that the density of striped hyena in STR increased from 12.52±2.17 (SE) individuals/ 100 km² in 2009 to 15.44±2.48 (SE) individuals/ 100 km² in 2015 (Mandal 2018). Availability of high prey density, wild ungulate density= 54.49 individuals/ km² and livestock density= 69.31 individuals/km² might have allowed to have such relaxed competition. This allows us to rethink about the 'theory of Mesopredator Release' by looking at its reverse effect in STR due to resource availability.

While there has been an ongoing village relocation program and traffic regulation on highways crossing the reserve, the isolated position and fragmented nature of STR is facing the effects of rapid human population growth and urbanization. This would make STR even more vulnerable to

habitat destruction, spread of invasive species, loss of functional connectivity and biodiversity loss due to its isolated position. Rising levels of disturbance can have far-reaching impacts on even the adaptable species such as striped hyena and other carnivores shaping their behavioral patterns, altering habitat use, influencing the selection of key resources like dens (Mandal 2018), shifting circadian rhythms (Wagner 2006), and modifying habitat preferences (Bopanna 2014; Mandal 2018). Such key aspects of the ecology of striped hyena must be addressed for the continued survival and maintenance of ecosystem services provided by the species, in the protected area with both predators and human pressure as well as non-protected regions. Hence, Aravallis with increasing level of human interspersed provides an ideal opportunity to understand the concept 'landscape of coexistence' for striped hyena by providing it foraging opportunities and denning refugia.

Through this study, I aim to understand the pattern of striped hyena occupancy with focus on its adaptability to consistent human presence and assess the change in the interactions with other large carnivores in their habitat over time.

1.4 Objectives:

1. To understand the occupancy pattern of striped hyena in Sariska Tiger Reserve.

Hypothesis: Striped hyena's occupancy would likely be influenced by open habitat, wild prey availability and ruggedness.

2. To document the den site use by striped hyena in Sariska Tiger Reserve.

Hypothesis: Striped hyena will non-randomly select den sites to ensure both security and access to resources.

CHAPTER 2: STUDY AREA

2.1 Location and extent

Sariska Tiger Reserve (STR) is situated in the Alwar district of Rajasthan state and is within the oldest range of Aravallis. The core area of STR lies between Latitude 27°05'41" N to 27°38'55" N and Longitude 76°14'30" E to 76°32'31" E. STR constitutes Sariska National Park, Sariska Wildlife Sanctuary and Alwar Buffer in an area of 1213 sq. Km (Fig. 2.1).

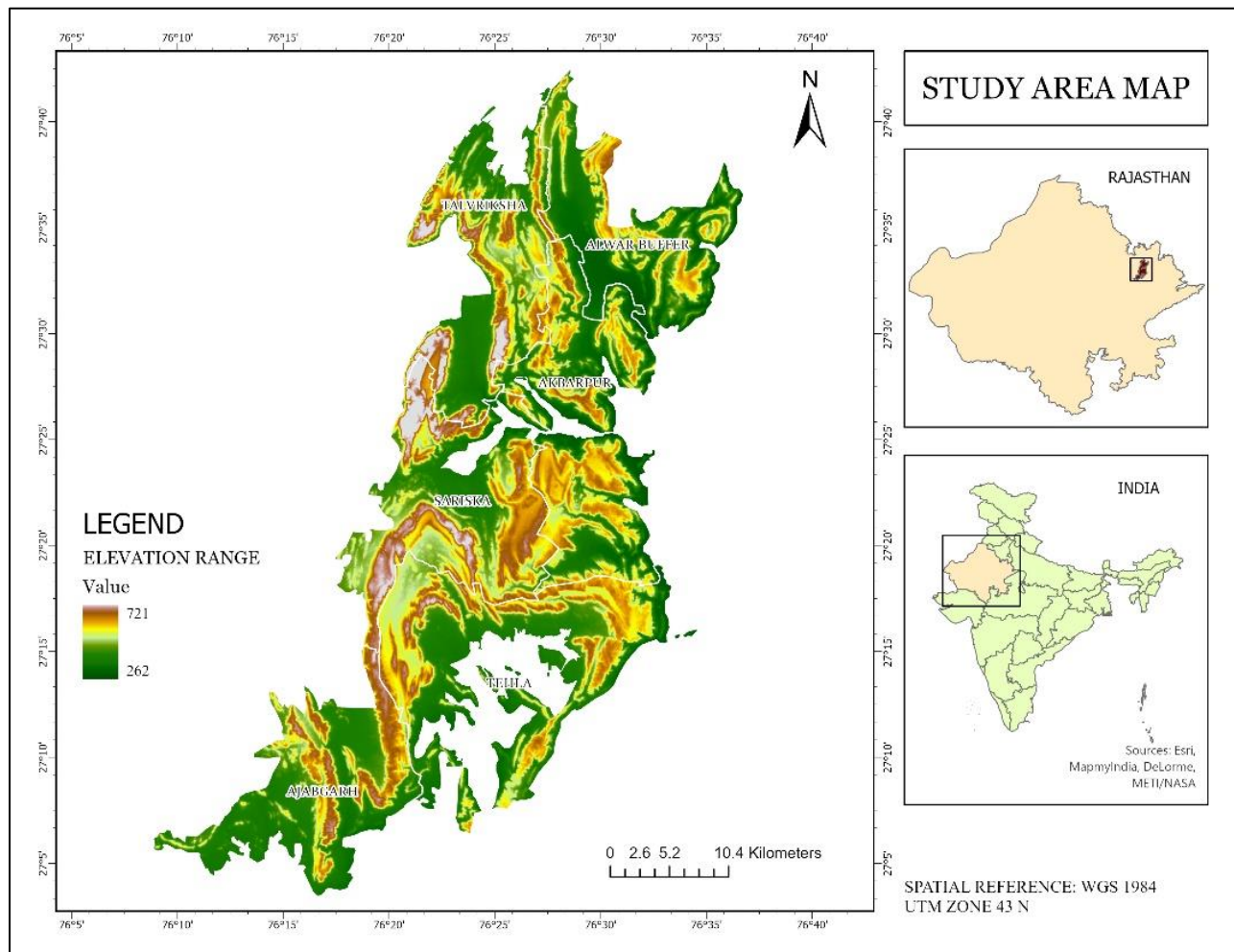


Figure 2.1 Elevation map showing the location of Sariska Tiger Reserve

2.2 History and Constitution:

Before becoming a part of Rajasthan state, the forests of STR were a part of Alwar, then princely state and were managed as hunting reserves. Sariska National Park was declared on 27 August 1982 under Wild Life (Protection) Act 1972 section 35 (1). Section 38V of WLPA 1972 has declared core area inside the reserve (Table 2.1).

Table 2.1: Table showing constitution of Sariska Tiger Reserve (Source: Sariska report 2016)

NP/WLS	Area	Date of Notification	Sec. Under which notified	Remarks
Critical Tiger Habitat	881.11 sq.km.	28.12.2007	Sec.38v WLPA, 1972 amended in 2006	Settlement not required
Buffer Area	332.23 sq.km.	06.07.2012	Sec.38v WLPA, 1972 amended in 2006	Settlement not required
Sariska Wildlife Sanctuary	492.00 sq.km	05.08.1958	Sec.5 of the Wild Animals & Birds Protection Act, 1951 and Sec 66(4) of WLPA,1972	Settlement not required; this area overlaps in CTH
Sariska 'A'	3.01 sq.km.	20.06.2012	Section 18 of WLPA, 1972	Settlement proceeding under progress
National Park (proposed)	400.14 sq.km.	27.08.1982	Sec.35 of WLPA, 1972	Settlement proceeding not completed, this area overlaps in CTH

2.3 Physical characteristics

2.3.1 Geology and Soil composition

The geology of Aravallis is described by quartzite's conglomerate and grits in higher ridges, limestone, phyllites, granites and schists in the valleys. Soil differs from the rock bed. The soil type is red sandy soil and loam soil (Mondal et al. 2020). These soils are alkaline due to phosphorus and humus contents with low nitrogen. River valleys and plain areas comprise of fertile soils often utilized for agriculture. The terrain of STR is characterized by rugged terrain, valleys and plateau with the altitudinal variation from 262 m to 721 m (Figure 2.1.). The two main plateaus are Kankawadi (524 m above mean sea level) and Kiraska (592 m above the mean sea level) (Mandal 2018).

2.3.2 Climate

The region has a subtropical dry climate with defined months of cold (November-February), hot (March-June) and rainy (July-September) seasons. The highest temperature reaches upto 50°C in summers and the lowest temperature of up to 2°C during peak winters. Droughts are common during summers. Relative humidity remains around 30-34%. Hot summer winds called “loo”. The south-westerly winds bring maximum precipitation (average 600mm) along with thunderstorms and dust storms. Cold westerly waves from North-Northwest direction blow during winter. The winter rains from NE monsoon are common.

2.3.3 Water sources

There is no perennial water sources except for a few lakes in the STR region. The terrain of STR have a poor water holding capacity and often quickly lose water through runoff and ground water recharge. Water usually gets accumulated in valleys, khoh or nallahs, and lakes, available even during summers. Ruparel river, passing through the middle of Tiger Reserve, creates drainage network, along with discharge of Bandipul stream in the northwest region. Fresh water streams start flowing out during monsoon and provide water for the surrounding region of the reserve. The lakes- Mangalsar, Silished lake, Ajabgarh talab, Mansarovar serve as important wetlands areas. Under project Tiger, many artificial water holes have been created to ensure water availability during dry season by the irrigation department. During monsoon, when water is available throughout, animals move higher up to plateau tops offering drier spaces. As the water starts drying up after autumn, the animals return to khoh and valleys where water is available. This seasonal variation in water availability allows animals to utilize a variety of habitats throughout the year (Sariska report).

2.4 Biological characteristics

2.4.1 Vegetation Cover Types

The forests can be classified into (1) Northern tropical dry deciduous forests (subgroup 5B; 5/E1 and 5/E2) and Northern Tropical Thorn Forest (subgroup 6B) (Champion and Seth 1886). *Anogeissus pendula* is the dominant tree species forming pure patches throughout its range. *Boswellia serrata* and *Lannea coromandelica* grow at higher elevation in rugged terrain. Valleys and plains usually has *Acacia catechu*, *Butea monosperma* and *Zizyphus mauritiana*.

Dendrocalamus strictus has a restricted distribution in riverine regions (Dukar 2015). Sariska tiger reserve is named by tree species *Albizia lebbek*, Parmar (1985) and Rodgers (1991) have classified vegetation of Sariska as follows:

1. *Anogeissus pendula* forest
2. *Boswellia serrata* forest
3. *Acacia catechu* forest and
4. Miscellaneous forest, which can be further sub-divided into three categories viz.,
 - *Butea monosperma* forest,
 - Forest along nallas and,
 - Scrub land

Nine different vegetation and land cover categories have been delineated in STR (Sankar et. al. 2010). They are *Anogeissus* dominated forest, *Boswellia* dominated forest, *Butea* dominated forest, *Acacia* mixed forest, *Zizyphus* mixed forest, Scrubland, Agricultural land, Water body and Barren land.

2.4.2 Wild fauna and their ecological status

Sariska tiger reserve holds a good diversity and high density of wild mammals. The apex predator is a tiger (*Panthera tigris*). Other large carnivores include leopard (*Panthera pardus*) and hyena (*Hyaena hyaena*). Small carnivores include Jungle cat (*Felis chaus*), Ratel (*Mellivora capensis*), Desert cat, etc. Since the prey density in Sariska (Table 2.2) is higher than some of the well-known Tiger reserves like Ranthambore, Panna, Satpura (Sankar et al. 2010), it has the capacity to hold a viable tiger population as well as other carnivores could exist in higher densities. The dense forest cover provides both shade and secure breeding areas in the semi-arid region..

The large sized ungulates are Nilgai (*Boselephous tragocamelus*), Sambar deer (*Cervus unicolor*), Spotted deer (*Axis axis*), Wild pig (*Sus scrofa*). Nilgai is commonly seen in open type of habitat near human habitation, while sambar prefers forested habitats and grasslands. Spotted deer occupy zizhyphus mixed forests and grasslands, they generally rely on fruits of *Zizhyphus mauritiana* in association with common langur (*Seminopithecus entellus*), which is most common primate followed by the Rhesus macaque (*Macaca mulatta*) in the surrounding human habitations. The

other smaller mammals are small Indian civet (*Viverricula indica*), Rufous tailed hare (*Lepus nigricollis*), Common Mongoose (*Herpestes edwardsii*), Ruddy Mongoose (*Herpestes smithi*), Palm Civet (*Paradoxurus hermaphroditus*), Pangolin (*Manis crassicaudata*), Porcupine (*Hystrix indica*), etc.

Sariska also recorded around 211 species of birds, notably high density of peafowl and grey francolin. Some unique birds visiting the reserve are red-headed vulture, Egyptian vulture, white-rumped vulture, painted spurfowl, Aravalli red spurfowl, common sand grouse, Indian pitta, great horned owl, etc. (Sankar et al. 2010). The common fish species found in water bodies of the park are *Noemachilus botia*, *Labio boggut*, *Puntius sarana*, *Garra gotyla* and *Rasbora daniconius*.

Table 2.2: Density estimates of available prey in Sariska Tiger Reserve

Species	Scientific Name	Density (individuals/ km ²)	Reference
Chital	<i>Axis axis</i>	16.25±3.00	Bhattachaijee 2014
Sambar	<i>Rusa unicolor</i>	6.94±1.27	Bhattachaijee 2014
Nilgai	<i>Boselaphus tragocamelus</i>	19.66±1.85	Bhattachaijee 2014
Wild Pig	<i>Sus scrofa</i>	11.64±2.11	Bhattachaijee 2014
Common Langur	<i>Seminopithecus entellus</i>	15.30±2.90	Bhattachaijee 2014
Rufous tailed hare	<i>Lepus nigricollis ruficaudatus</i>	1.92±0.4	Bhattachaijee 2014
Rodent	-	16.15 ±2.76	Gupta et al. 2013
Indian peafowl	<i>Pavo cristatus</i>	53.1 ± 5.6	Kidwai et al. 2011
Grey francolin	<i>Francolinus pondicerianus</i>	21.6 ± 4.8	Kidwai et al. 2011
Buffalo	<i>Bubalus bubalis</i>	28.3±4.68	Bhattachaijee 2014
Cattle	<i>Bos taurus</i>	41.01±6.58	Bhattachaijee 2014

2.5 Socio-economic profile

Sariska has a multi-demographic profile consisting of majorly two castes groups- Gujjars and the Meenas. Officially classified as an "Other Backward Caste," the Gujjars depend for their livelihoods mainly on livestock and secondarily on agriculture (in buffer villages within the Reserve where cultivation permitted). Meenas, currently classified as a "Scheduled Tribe", are primarily agriculturalists, along with animal husbandry. Roondhs are their major grazing areas where communities graze their livestock such as buffaloes, goats, camels, cows during monsoon season. They also collect forest resources such as fodder, grass, wood from Roondhs. They also have demarcated areas that are dedicated to a local deity usually called Devbannis which serve as grazing areas even in summer through conservation of some parts. The community lives in traditional houses made of mud, wood and grass, many of which are now replaced by concrete houses. Each village would have water sources called johad (Jain & Sajjad 2016; Krapavis report 2015). Villages inside CTH put extensive pressure on the forests, making conservation and management of the reserve difficult. Expansion and land conversions for agriculture and grazing reduces grass biomass for the ungulates. Although utilizing forestland for any purpose is completely restricted in the core areas of the STR, those who owned land can only practice agriculture, along with animal husbandry. Forest Department has started putting restrictions on the use of forest products; livestock husbandry; grazing; construction activities; and agriculture to reduce impact of anthropogenic disturbance. Additional steps have been taken to stop encroachment, mining, and poaching to create a secure habitat space for the tiger population.

2.6 Management

The 1216.35 sq. kms of Tiger Reserve area is administratively divided into two divisions-DCF Sariska, DCF Alwar. There are 6 ranges –Sariska, Tehla, Akbarpur, Talvraksh, Ajabgarh and Alwar Buffer covering 102 beats.

2.6.1 Tiger Re-introduction

In 2008, Sariska witnessed the world's first tiger reintroduction. Since then, 11 tigers have been relocated, with four of them alive. Currently, STR is home to 43 tigers including 25 adults and 18 cubs (Fig. 2.2) (Sariska Report 2024).

Tiger Monitoring Protocol: As the tiger population in Sariska recovers following the reintroduction program, continuous monitoring has become essential. Each tiger is individually tracked by dedicated monitoring teams. These teams consist of an in-charge (FD staff) and a field assistant (local) and are assigned to monitor each individual adult and sub-adult tiger (11 males, 14 females, and 18 cubs). The teams track the tigers and report evidence and locations to the control room on an hourly basis. Daytime monitoring is conducted using motorbikes, while nighttime monitoring utilizes four-wheelers. Additionally, camera traps are deployed within each tiger’s territory to gather more accurate evidence (Sariska Report 2024).

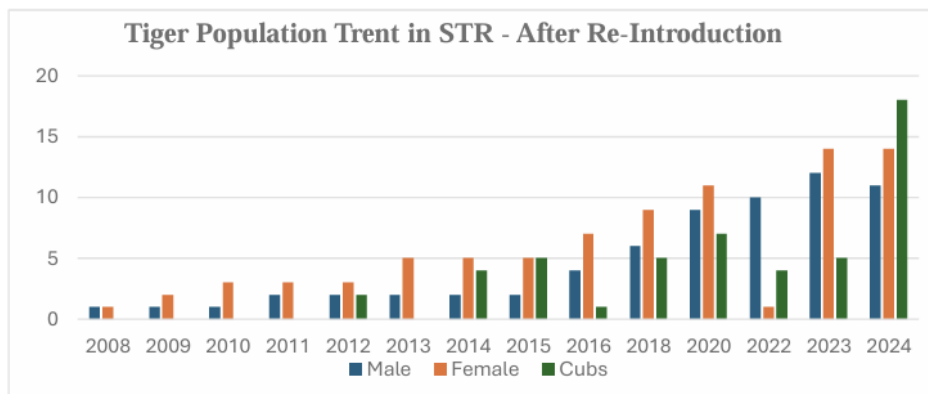


Figure 2.2: Trend in Tiger population (Credit: Sariska Report 2024)

2.6.2 Relocation of Villages

STR lost its connectivity with Ranthambore Tiger Reserve, becoming an isolated reserve with defined boundaries and significant human habitation. There are 24 villages inside the reserve and approximately 170 villages within a 3-kilometer radius of its boundary (Fig. 2.3) (Sariska Report 2024). Additionally, two highways intersect the reserve. Relocation, within the reserve area was initiated in 1960s when temporary bases called ‘guadas’ were shifted. When sariska got the status of Tiger reserve, relocation became a tool in PA management. Karnakabas and Kiraska villages were the first ones to undergo the relocation process in 1976 where the land identified outside the reserve was allocated to the relocated families. However, the remaining villages with larger families and illegal expansions has started putting intense biotic pressure on the forests (Shahabuddin et al. 2006). Continuous efforts for the relocation of some of the villages, from the reserve area, have always been in the management’s vision.

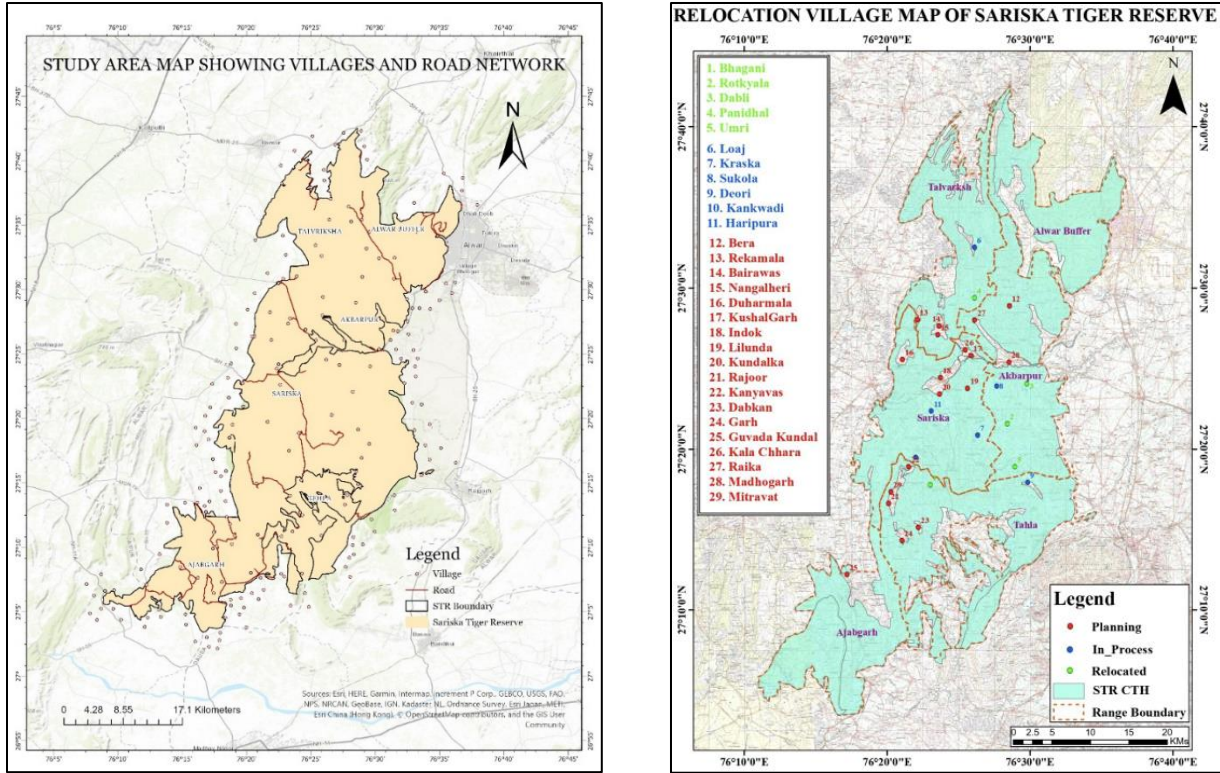


Figure 2.3 Map showing 1. Villages within and surrounding the tiger reserve within 3 Km; 2. Showing status of relocated villages within the core area of tiger reserve (Source: Sariska Report 2024).



Figure 2.4 Typical habitat for striped hyena with human settlements interspersed, open scrubland, rugged terrain of Aravallis

CHAPTER 3: STUDY DESIGN AND METHODS

3.1 Occupancy modelling

Large-scale surveys of striped hyena are essential to assess changes in their spatial distribution over time, which may result from land-use changes or conservation interventions. This chapter deals with the occupancy estimation method developed by MacKenzie et al. (2006). I used detection and non-detection data collected through sign surveys for striped hyena, and other animals within an occupancy modeling framework to assess the status of distribution of the species and the covariates influencing the pattern. Occupancy models estimate where species occur (a biological process) while accounting for imperfect detection (an observational process). This is important because the probability of detecting a species during any survey is often always below 1. Without accounting for imperfect detection, estimates of species distribution are considered to be biased. Occupancy models provide insights on species' distributions and relationships between species occurrence and habitat or landscape variables.

Occupancy is defined as the probability that a site or patch is occupied by a target species. By explicitly determining ecological factors and management problems, they can meet conservation and management needs (MacKenzie et al. 2005). Two approaches were designed for the study: At the landscape scale, a spatially replicated sign survey method is designed to generate estimates of striped hyena distribution that explicitly deals with imperfect detection of signs (MacKenzie et al. 2006) and secondly, to assess which ecological variables and management factors could influence these occupancy patterns. To make a valid inference about changes in the occurrence of a species requires addressing two important things: addressing spatial variation and detectability (Thompson 2002). The sampled units are then used to draw inference to the landscape. I employed a single season occupancy framework (MacKenzie et al. 2006) to statistically determine the occupancy pattern of striped hyena using sign-survey data while explicitly addressing the concern of imperfect detection (Duangchantrasiri et al. 2015). This study was designed to provide probability of site or habitat use by striped hyena and not 'true occupancy'.

3.1.1 Study Design and Field Methods

I divided the study area into 190 grids of 3X3 Km² each grid taken as a survey unit. Since there has been no effort to radio collar striped hyena in STR, it was decided based on the expected home

range of striped hyena to be 6-9 Km² due to high density in STR (Gupta et al. 2009; Mandal 2018) and to balance both logistical constraints of using camera traps and shorter duration of the study, to get reliable estimates of site use probabilities.

Meeting the conditions of selecting survey sites randomly with replacement was not logistically feasible for a large-scale sign survey for striped hyena in STR (Kendall & White 2009). The survey effort per cell was designed using stratified sampling, such that both habitat for striped hyena and terrain of the grid could be considered (Karanth et al. 2011). I fixed the total sampling effort (distance walked) in a cell with 100% habitat at 4 km, reducing the effort in decreasing proportion to habitat available for striped hyena (Harihar et al. 2012). Prior planning of the sampling trails using Google Earth Pro ensured adequate spatial coverage of the cells.

I opted for spatial replication over temporal (Kendall & White 2009) primarily for logistical reasons and shorter duration of the study (Hines et al. 2010). Each trail was further subdivided into segments of equal length (250 m) which were later treated as spatial replicates. For each segment presence/absence (0/1) data was recorded. For every 500 m, human disturbance data and vegetation data were recorded using circular plots of radius 15 m.

I conducted the sign survey during the dry season (December–March) to reduce the variations in animal sign detection probabilities due to influence of weather. Striped hyena, like other carnivores, move along forest trails to forage and avoid predators (Gupta et al. 2009), and leave track signs and scat deposits on the trail. Hyena scats were identified by the patterns of shape, size and colour, mostly oval to cylindrical shaped with white or off white in colour (Bopanna 2013). Each scat was identified with reference pictures of the scat collected from the active den. The starting point of the trail was chosen randomly. The survey was done by walking the trails from morning to dusk using Locus Map application version 4.29.0, spending ~3 hours on each sampling trail to minimize the bias arising from movement of animals from neighboring cells (Nath et al. 2023). The signs were georeferenced using NoteCam application. Each sign detected was assigned only once to each 250-m trail segment, thus yielding the standard ‘1’ (detection) or ‘0’ (non-detection) histories required for occupancy analyses (Johnsingh et al. 2004; Hines et al. 2010; MacKenzie et al. 2006). Only fresh signs, of striped hyenas, tigers, leopards, dogs, major prey species, livestock, along with signs of human disturbance in the form of cutting, lopping, and the number of humans encountered, accurately identified by the survey team comprising of two

observers, were recorded. In <10% of the cells surveyed, where I encountered unsuitable habitat along the trail (e.g. human settlements, large water reservoirs), the resulting disjointed trail segments were combined sequentially (Karanth et al. 2011).

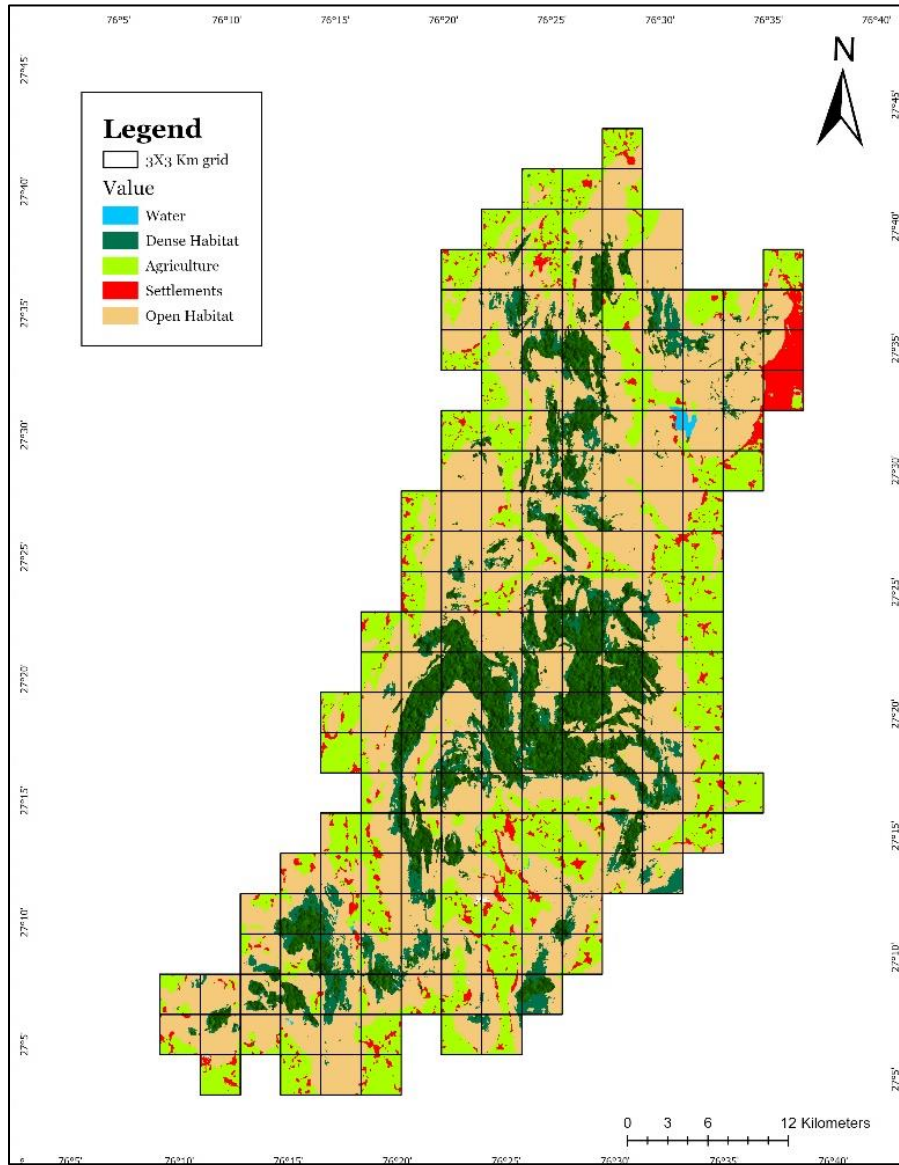


Figure 3.1 3X3 Km survey grids superimposed on Classified Land Use Land Cover map of Sariska Tiger Reserve

We chose ecological and anthropogenic covariates (Table 3.1) that would be of importance to the ecology of the study species- striped hyena. We collected both field based as well as landscape variables for each survey unit from Remote sensing & GIS. A prior hypothesis was then generated to predict the influence of each covariate on the occupancy probability and detection of the species (Nath et al. 2023).

Table 3.1 Table showing the covariates and A prior hypothesis against each.

Covariates (Code)	Description	Justification for selection	A prior hypothesis	
			p	ψ
Open Habitat (OH)	Represents Scrubland. Data obtained from Sentinel 2 10 m Land Use/Land Cover data by ESRI 2024.	Striped Hyena prefers open habitat for foraging and movement.	+	
Closed Habitat (CH)	Represents dense vegetation. Data obtained from Sentinel 2 10 m Land Use/Land Cover data by ESRI 2024.	Striped Hyena prefers closed habitat for rest during the day and denning to provide safety to the cubs.	+	
Distance to Village (Village)	Distance to nearest settlements and agricultural fields. Calculated with the help of Distance Accumulation tool in ArcGIS Pro 3.1.0.	Villages provide anthropogenic provisioning in the form of livestock carcasses and organic matter.	+	

Distance to Water (Water)	Distance to water sources (natural and artificial) calculated with the help of Distance Accumulation tool in ArcGIS Pro 3.1.0.	Important for the metabolic needs of the species.	+	
Vector Ruggedness Measure (VRM)	Measure of terrain ruggedness as the variation in 3-D orientation of grid cells within a neighborhood. Calculated using Vector Ruggedness Measure tool on DEM layer in ArcGIS Pro 3.1.0.	Rugged terrain is preferred for protection from daytime heat, predators, humans and to sire litter.	+	
Human Disturbance Index (HDI)	Equal weighted composite of human encounter rate, Cutting, Lopping, Dog presence collected from field survey.	High human disturbance is thought to negatively affect striped hyena presence.	+	
Wild Prey Index (WPI)	Equal weighted composite of wild prey encounter rate calculated by dividing number of segments with presence by total surveyed segments.	Wild prey forms a major portion of the diet of striped hyena in protected areas, thus must be positively influencing its distribution.	+	
Livestock Encounter Rate (LER)	Calculated by dividing number of segments with livestock presence by total surveyed segments.	LER will be negatively affecting hyena detection due to trampling on the survey trail.		+

Leopard Encounter Rate (Leo)	Calculated by dividing the number of segments with leopard presence by total surveyed segments.	Sympatric competitor for similar kinds of resources.	+	
Tiger Encounter Rate (Tig)	Calculated by dividing number of segments with tiger presence by total surveyed segments.	Dominant carnivore presence will be enhancing	+	
Substrate (Subs)	Categorical variables are divided into three categories: Loose soil, Hard soil, Rocky	Since the surveys were focused on detecting signs in the form of tracks and scats along the trails, substrate would likely influence sign detections.		+

3.1.2 Analytical method

To determine the smallest segment length at which the effect of spatial autocorrelation could be considered negligible, spatial autocorrelation models (Hines et al. 2010) were used on PRESENCE 2.15.13 (Thron et al. 2011). This model explicitly accounts for spatial dependence in the adjacent replicates by splitting the sampling trail into segments of a defined length which are then used as replicated surveys. Bias due to autocorrelation between adjacent observations can be considered negligible when model selection by AIC (at the level of $\Delta AIC > 2$) favors the null model over the spatial autocorrelation model (McHenry et al. 2016; Thorn et al. 2011). The minimum segment length with negligible spatial dependence for my study was estimated to be ≥ 1 Km, by comparing the standard single season model to spatial autocorrelation occupancy models constructed using the same segment length on PRESENCE 6.4 (Hines 2006) .

Hence, I used the standard single season single species occupancy model developed by MacKenzie et al. 2006 to estimate the occupancy and detection probability of species using sign surveys. All the covariates were screened for multi-collinearity on R version 4.4.3 using package corrplot. Covariates with Variance Inflation Factor (VIF) greater than 0.7 were either removed or not used

in combination within the same model. The covariates did not show any correlation amongst themselves, so all were retained for analysis (Fig. 3.2). All the covariates were scaled through Z score standardization. The analysis was done on R using Unmarked package. Models with different combinations were made. For the model selection, Akaike Information Criterion (AIC) values (2) were compared to selecting the best model (Burnham & Anderson 2002). The goodness of fit of the model was then tested by MacKenzie-Bailey test. This approach simulates detection history sets, assuming the detection model fits appropriately, and then compares the binomial distribution of simulated data to the real data.

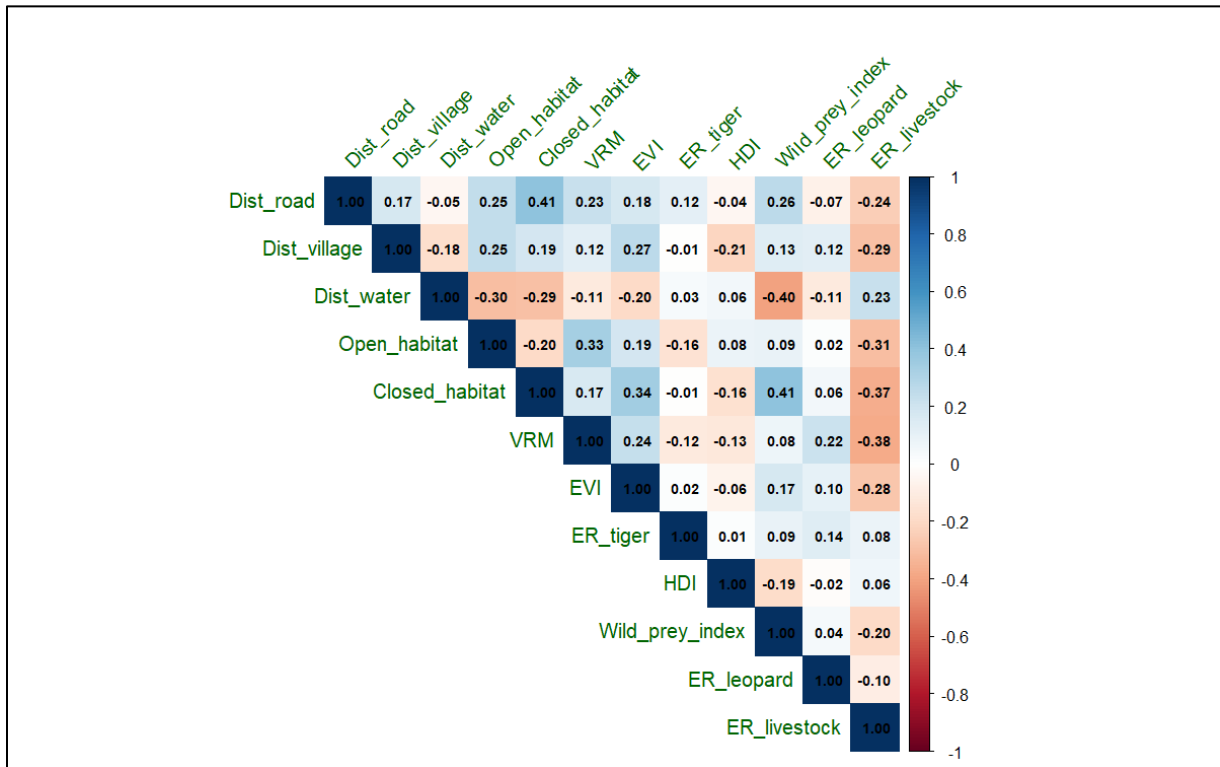


Figure 3.2 Correlation plot for variable in occupancy modelling

3.2 Striped hyena spatial interaction with other large carnivores

3.2.1 Analytical method

A matrix was built from presence/absence data for two combinations- striped hyena and tiger as well as striped hyena and leopard. The data was analyzed on program PRESENCE 6.4 (Hines, 2006) in a single session two species conditional occupancy (ψ) model (Richmond et al. 2010). The parameterization of the models assumes that Species A (striped hyena) represents the species whose occupancy is being modeled as potentially influenced by the presence of Species B (tiger and leopard respectively). The model also modeled the detection probabilities (p) of striped hyena and other carnivores in the study area in the presence or absence of either species.

The parametrization for this 2-species conditional occupancy model (Richmond et al. 2010) follows.

ψ^A = Probability of occupancy for species A

ψ^{BA} = Probability of occupancy for species B, given species A is present

ψ^{Ba} = Probability of occupancy for species B, given species A is absent

p^A = Probability of detection for species A, given species B is absent

p^B = Probability of detection for species B, given species A is absent

r^A = Probability of detection for species A, given both species are present

r^{BA} = Probability of detection for species B, given both species are present and species A is detected

r^{Ba} = Probability of detection for species B, given both species are present and species A is not detected

For the conditional occupancy model, $SIF = (\psi^A \psi^{BA}) / (\psi^A (\psi^A * \psi^{BA} + (1 - \psi^A) \psi^{Ba})$.

SIF refers to the species interaction factor. Its value could be interpreted in the following way:

If $SIF=1$, then the two species are likely to occur independently

If $SIF<1$, then species B is less likely to co-occur with species A (avoidance)

If $SIF>1$, then species B is more likely to co-occur with species A than expected (Aggregation).

3.3 Den-site use in striped hyena

This section aims to evaluate whether striped hyena actively selects the den sites (used) compared to randomly distributed points (available) in the landscape.

3.3.1 Field method

I conducted a search along with the sign survey in the defined survey grids, with one observer, to locate striped hyena dens (only natal dens were included). The forest department staff, tiger trackers and shepherds in few beats were enquired about the dens and striped hyena activity. Dens were identified based on signs such as bone depositions, striped hyena pugmarks, fresh scats and direct sightings. Only dens utilized during the study conducted in 2014 (Mandal 2018) as well as new active dens identified during this study were considered for analysis. I also deployed camera traps at a total of eight dens to confirm den usage and record ad-libitum behavioral interactions of striped hyena at den site.

3.3.2 Analytical method

The analysis was based on a used (den locations) and available (random locations) framework under resource selection function (Johnson 1980). I generated a circular buffer of 1 Km radius around the identified den site by considering its estimated home range in STR and four random locations were generated within each buffer using Buffer tool in ArcGIS Pro 3.1.0. The locations were surveyed and data on environmental and ecological variables were collected (Table 3.2). In total, 31 den sites and 124 random points were identified. The variables were checked for correlation using Pearson correlation test and highly correlated variables were removed. As a result, BioClim layers (Fick & Hijmans 2017) were excluded due to their strong correlation (Fig. 3.3). Binomial Generalized Linear Model (GLM) was used to understand den site use by striped hyenas in STR, considering Den site=1 and Random point=0. The resultant linear equation was later used to map den site suitability of striped hyena in the study area using raster calculator in ArcGIS Pro 3.1.0. Using Jenks natural breaks, suitable areas were categorized into 5 classes (i.e. Highest, High, Moderate, Low and Least) for denning.

Table 3.2 Table showing environmental variables and A priori hypothesis against each.

Variable (Code)	Description	Justification	A priori Hypothesis
BioClim 1	Annual Mean Temperature. Obtained from WorldClim database (1 km resolution).	Striped hyena prefers moderate temperature for denning.	+
BioClim 5	Max Temperature of Warmest Month. Obtained from WorldClim database (1 km resolution).	Striped hyena prefers sites with lower temperatures during extreme summers.	-
BioClim 6	Min Temperature of Coldest Month. Obtained from WorldClim database (1 km resolution).	Striped hyena prefers sites with warmer temperatures during extreme winters.	-
Elevation	Obtained from SRTM digital elevation (30 m resolution)	Striped hyena prefers sites at moderate elevations to cut down energetic costs.	-
Ruggedness	Obtained from Vector Ruggedness Measure tool ran on DEM layer.	Striped hyena prefers sites at highly rugged terrain to go undetected by potential predators.	+
Shrub_cover	Obtained from Enhanced Vegetation Index data from MODIS (250 m resolution)	Striped hyena prefers sites with higher shrub cover for protection.	+
Distance to water (Dist_water)	Obtained from surface generated by calculating euclidean distance from water sources.	Striped hyena prefers sites closer to water source.	-

Distance to village (Dist_village)	Obtained from surface generated by calculating euclidean distance from villages.	Striped hyena prefers sites away from village.	+
Distance to road (Dist_road)	Obtained from surface generated by calculating euclidean distance from road network.	Striped hyena prefers sites away from road.	+
Wild Prey index (WPI)	Equal weighted score to large, medium and small prey pellet count in 10 m radius plot. (Scale: 0-25 = 0.25, 25-50= 0.5, 50-100= 0.75, 100+ =1)	Striped hyena highly depends on wild prey for scavenging and opportunistic hunting.	+
Human Disturbance Index (HDI)	Equal weighted composite of human presence, Livestock dung/pellet, Dog presence in 10 m radius plot collected from field survey. (Scale: 0-25 = 0.25, 25-50= 0.5, 50-100= 0.75, 100+ =1)	Striped hyena chose secure denning sites to avoid human and dogs.	-

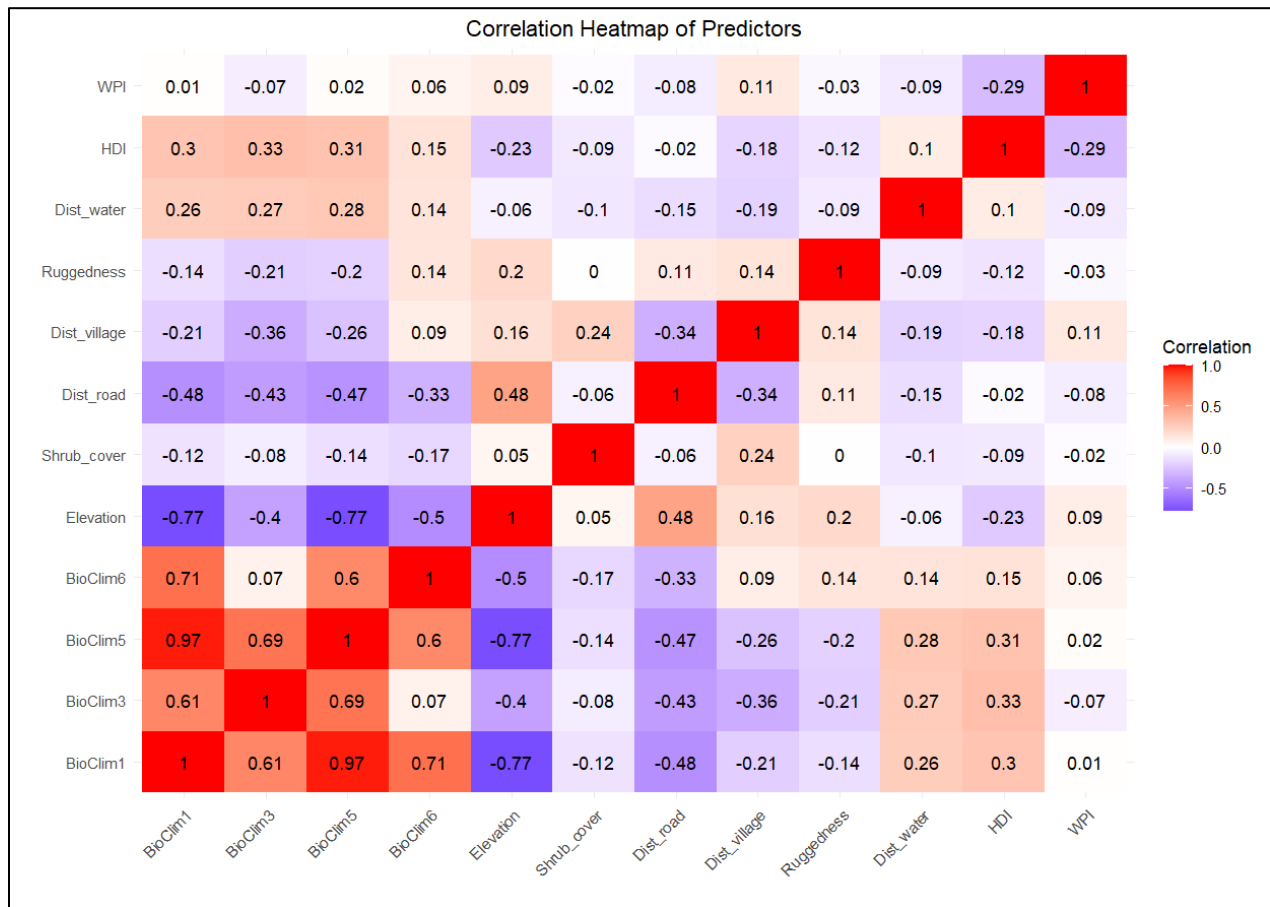


Figure 3.3 Correlation plot for variables used in den-site use of striped hyena

4.1 Occupancy Pattern

A total survey effort of 65 man-days covered 349 km of trail walks, resulting in 480 signs detected, including 64 striped hyena scat deposits. In total, 77 sites had at least one detection out of 130 sites. The naïve occupancy estimate was found to be 0.59, indicating presence at almost 60 % of sites surveyed. The overall occupancy estimate was 0.75 ± 0.05 while detection probability estimate was 0.58 ± 0.03 . The predictive models of occupancy and habitat use for striped hyena, including a complete set of models with AIC values are provided in table 4.1:

Table 4.1: Model selection using AIC values

Model	K	AIC	Δ AIC	AICwt	cumltv Wt
$p(\text{LER} + \text{Subs}) \psi(\text{OH} + \text{CH} + \text{WPI} + \text{VRM})$	9	435.38	0	0.21	0.21
$p(\cdot) \psi(\text{OH} + \text{CH} + \text{VRM} + \text{WPI})$	6	435.60	0.22	0.19	0.40
$p(\text{LER} + \text{Subs}) \psi(\text{OH} + \text{CH} + \text{WPI})$	8	437.36	1.98	0.078	0.65
$p(\cdot) \psi(\text{OH} + \text{CH} + \text{WPI})$	5	437.58	2.20	0.07	0.80
$p(\cdot) \psi(\text{OH} + \text{VRM} + \text{WPI})$	5	437.85	2.47	0.061	0.86
$p(\cdot) \psi(\text{Road} + \text{OH} + \text{CH} + \text{WPI})$	6	439.19	3.81	0.031	0.89
$p(\cdot) \psi(\text{Road} + \text{Village} + \text{Water} + \text{VRM} + \text{LER} + \text{Subs} + \text{OH} + \text{CH} + \text{WPI} + \text{Leo} + \text{Tig} + \text{HDI})$	15	439.70	4.32	0.024	0.98
$p(\text{VRM}) \psi(\text{OH} + \text{WPI})$	5	440.03	4.65	0.021	1.00
$p(\text{VRM} + \text{LER} + \text{Subs}) \psi(\text{Road} + \text{Village} + \text{Water} + \text{OH} + \text{CH} + \text{WPI} + \text{Leo} + \text{Tig} + \text{HDI})$	15	444.80	9.42	0.0019	1.00
$p(\cdot) \psi(\text{Leo} + \text{Tig} + \text{WPI})$	5	452.70	17.32	0.00004	1.00
$p(\cdot) \psi(\cdot)$	2	464.45	29.07	0.00000 010	1.00

The occupancy pattern of striped hyena was best explained by Open habitat, followed by Wild Prey index, Closed habitat and Ruggedness. Detection probability was influenced by livestock encounter rate and substrate type, though neither was statistically significant (see table 4.2).

Table 4.2: Estimates of individual covariates from the best fit model

Occupancy (logit-scale):				
	Estimate	SE	z	P(> z)
Intercept	0.935	0.356	2.62	0.008667
Open habitat	1.607	0.417	3.85	0.000118***
Closed habitat	0.668	0.332	2.01	0.044252
Wild prey index	1.226	0.434	2.83	0.004701**
Ruggedness	-0.584	0.285	-2.05	0.040397*
Detection (logit-scale):				
Intercept	0.5726	0.207	2.760	0.00577
Livestock Encounter Rate	0.0838	0.159	0.526	0.59899
Substrate_Loose soil	-0.4739	0.308	-1.541	0.12337
Substrate_Rocky	0.5386	0.420	1.284	0.19931

The positive intercept value ($\beta = 0.935 \pm 0.356$) suggests that the species is likely to be present and is statistically significant ($p < 0.05$). Open habitat has the strongest positive influence ($\beta = 1.607 \pm 0.417, p < 0.001$), suggesting preference for less vegetated areas. Wild prey index also has a significant positive effect ($\beta = 1.226 \pm 0.434, p < 0.005$), suggesting higher dependency on wild prey. Ruggedness has a **negative effect** ($\beta = -0.584 \pm 0.285, p < 0.05$), indicating avoidance of steep/rocky terrain possibly due to prey availability. Closed habitat ($\beta = 0.668 \pm 0.332, p > 0.05$) has a weaker effect. **None of the detection covariates** were statistically significant. This could justify the robustness of occupancy estimates being unaffected by detectability variation, hence, detection probability is more likely to be consistent across sites.

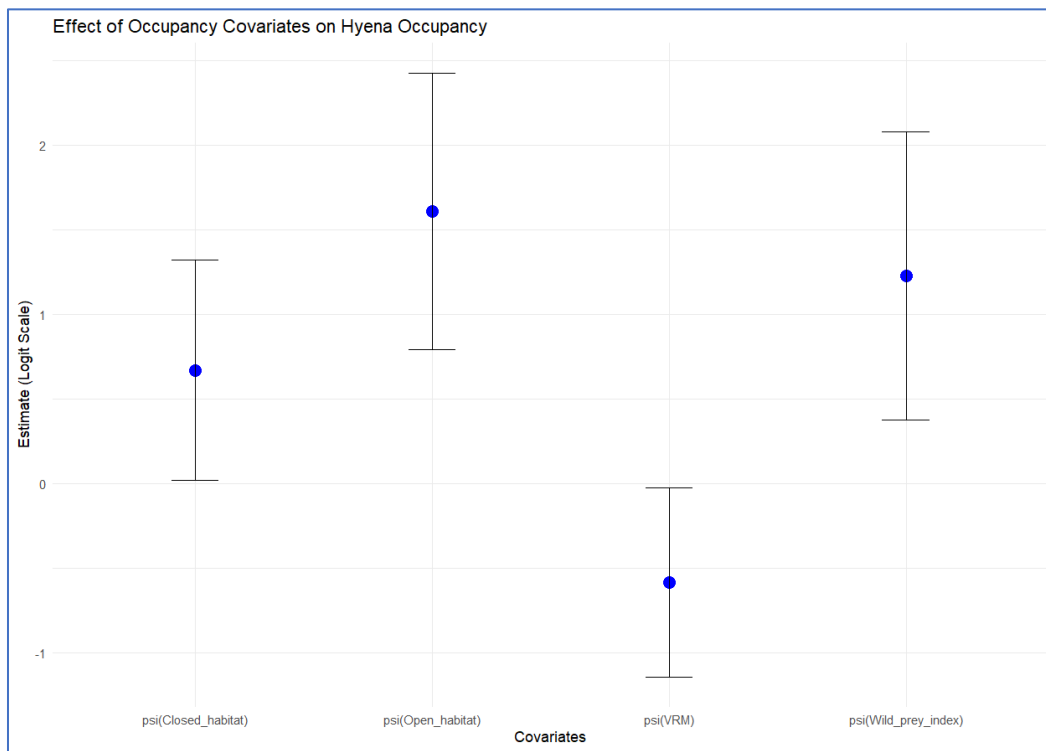


Figure 4.1 Comparative plot of effect of occupancy covariates

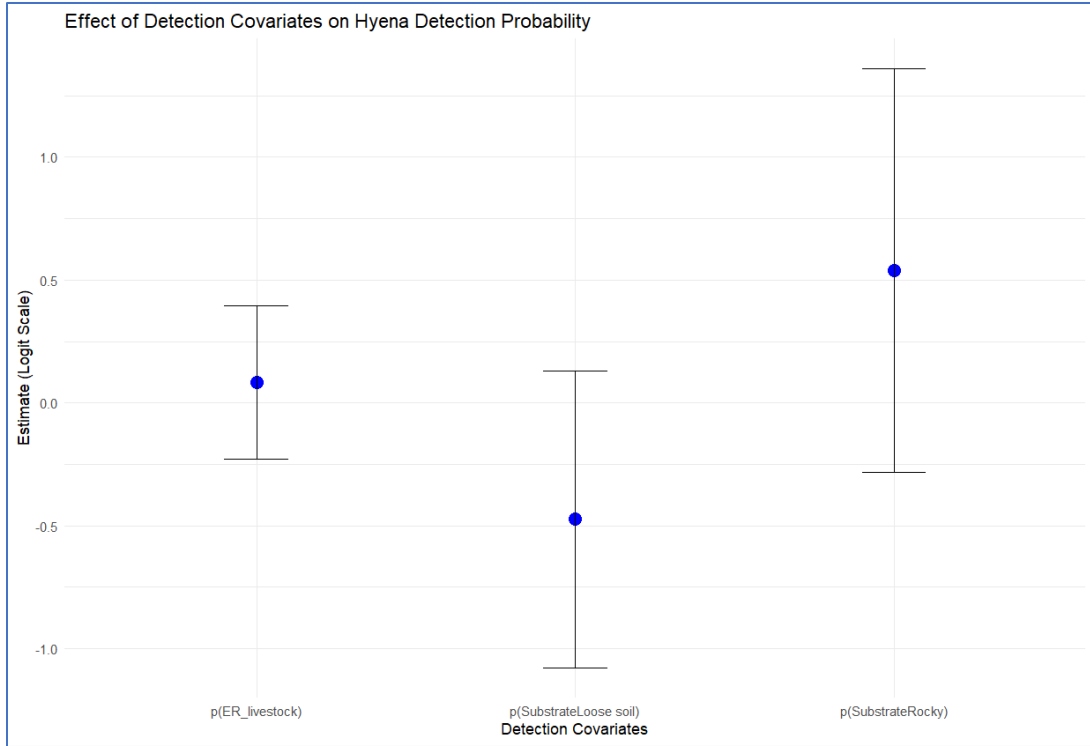


Figure 4.2 Comparative plot of effect of detection covariates

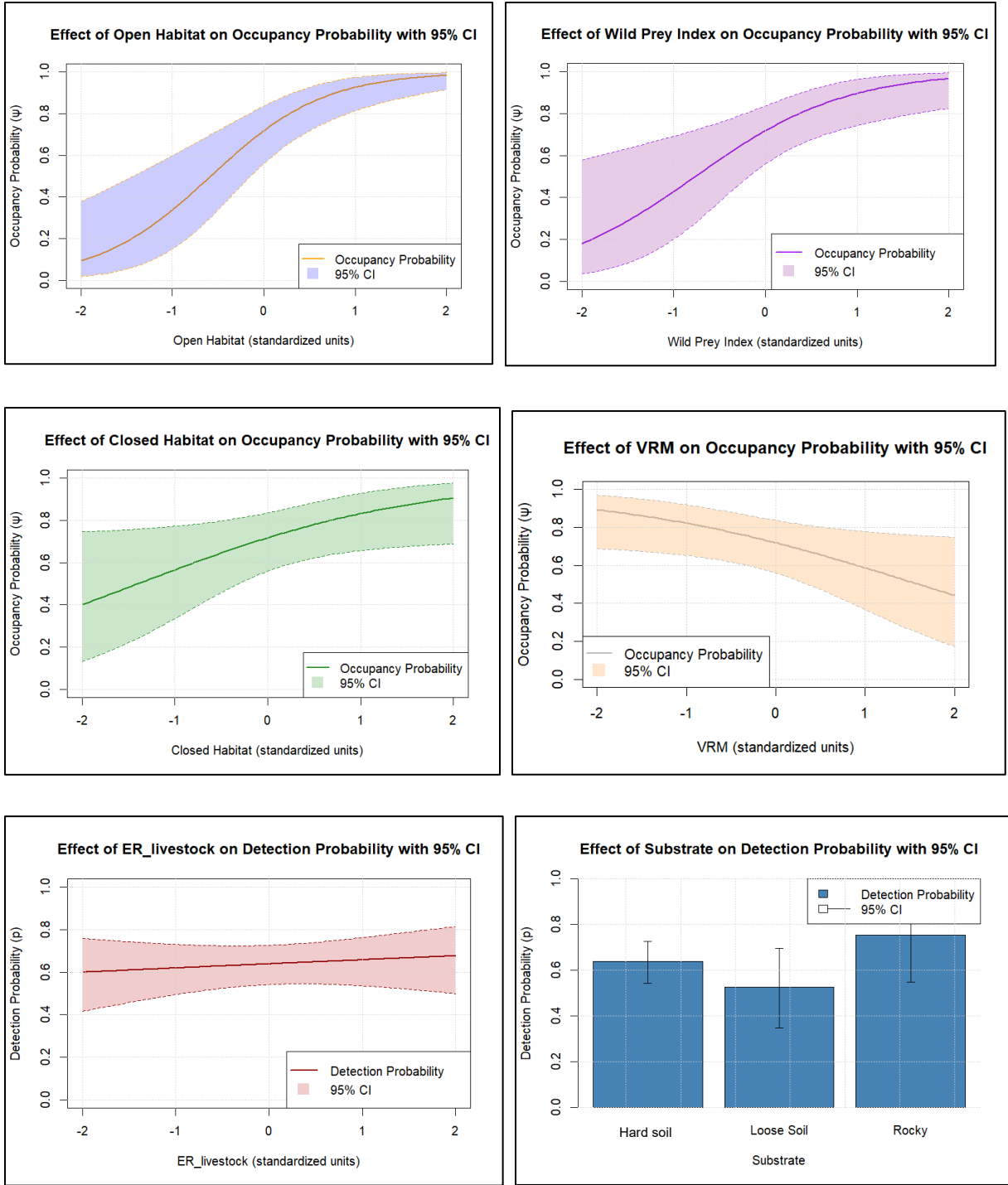


Figure 4.3 Effect of individual covariates from the best fit model on the occupancy probability and detection probability of striped hyena habitat use

Site specific occupancy and detection probabilities were mapped using Joint function in 3X3 Km² grids in ArcGIS pro version 3.1.0 (Fig. 4.4; Fig. 4.5)

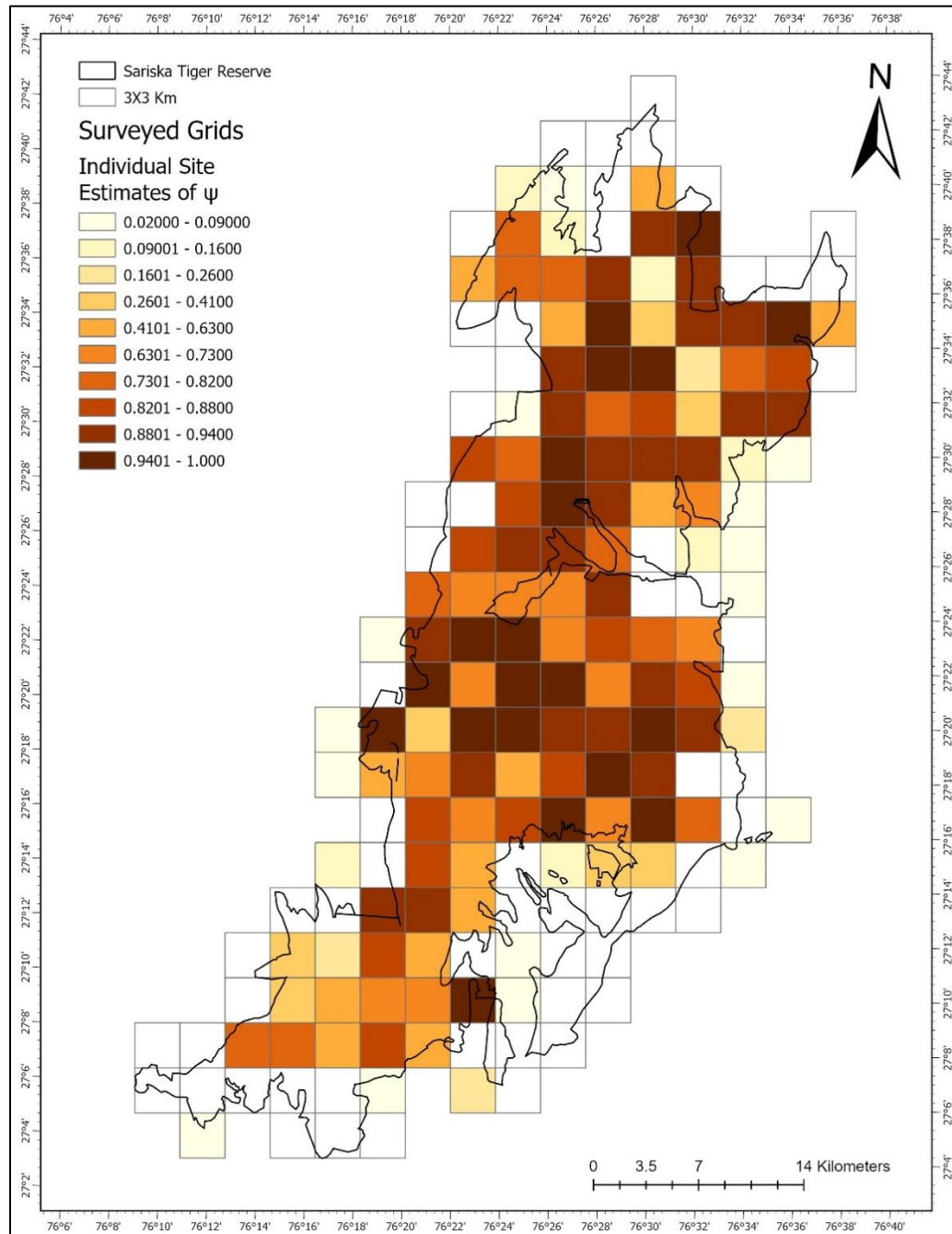


Figure 4.4 Spatially explicit prediction map showing site specific occupancy estimates for striped hyena in Sariska Tiger Reserve

4.2 Spatial interaction of striped hyena with other carnivores

The probability of site utilization by striped hyena in the presence of tiger and leopard were 0.73 ± 0.09 and 0.83 ± 0.06 respectively. Whereas the probability of site utilization by striped hyena in absence of tiger and leopard were 0.56 ± 0.06 and 0.45 ± 0.10 respectively. Detection probability of striped hyena in the presence of tiger and leopard was higher than in the absence of the co-predators (Table 4.3).

The present study indicates that striped hyena is likely to co-occur with both tiger (SIF=1.18) and leopard (SIF=1.29).

Table 4.3 Conditional occupancy estimates between tiger and leopard with striped hyena

Conditional Occupancy Parameters	Tiger (A) & Striped Hyena (B)	Leopard (A) & Striped Hyena (B)
ψ^A	0.33 ± 0.05	0.50 ± 0.08
ψ^{BA}	0.73 ± 0.09	0.83 ± 0.06
ψ^{Ba}	0.56 ± 0.06	0.45 ± 0.10
p^A	0.10 ± 0.04	0.12 ± 0.04
p^B	0.22 ± 0.02	0.13 ± 0.06
r^A	0.15 ± 0.02	0.09 ± 0.01
r^{BA}	0.53 ± 0.07	0.40 ± 0.07
r^{Ba}	0.26 ± 0.03	0.30 ± 0.02
Species Interaction Factor (SIF)	1.18	1.29

Table 4.4: Comparison between spatial interaction of hyena with Tiger and Leopard with the decade old study when tiger number was less (n=11) (Sankar et al. 2010)

Conditional Occupancy Parameters	Present Study (2024 - 25)		2014 (Mandal 2019)	
	Tiger (A) & Striped Hyena (B)	Leopard (A) & Striped Hyena (B)	Tiger (A) & Striped Hyena (B)	Leopard (A) & Striped Hyena (B)
ψ^A	0.33±0.05	0.50±0.08	0.93±0.11	0.55±0.08
ψ^{BA}	0.73±0.09	0.83±0.06	0.53±0.09	0.83±0.09
ψ^{Ba}	0.56±0.06	0.45±0.10	0.37±0.79	1.00±0.00
p^A	0.10±0.04	0.12±0.04	0.04±0.01	0.09±0.06
p^B	0.22±0.02	0.13±0.06	0.08±0.08	0.05±0.01
r^A	0.15±0.02	0.09±0.01	0.31±0.02	0.12±0.02
r^{BA}	0.53±0.07	0.40±0.07	0.13±0.03	0.58±0.07
r^{Ba}	0.26±0.03	0.30±0.02	0.08±0.01	0.28±0.03
Species Interaction Factor (SIF)	1.18	1.29	1.02	1.95

Compared to 2014, site utilization by striped hyena in the presence of tiger has increased from 0.53 to 0.73, indicating a potential shift in habitat sharing or prey base dynamics (Table 4.4).

4.3 Den-site use by striped hyena

4.3.1 Den characteristics:

Maximum dens were found to be in the Anogeissus dominated forest (n=17) likely due to its presence in rugged terrain, followed by scrubland (n= 8) which provides moderate ruggedness and elevation, along with proximity to human settlements (Fig. 4.6). The orientation of den entrances was on average directed towards the South, showing an inclination towards a particular aspect (Fig. 4.8).

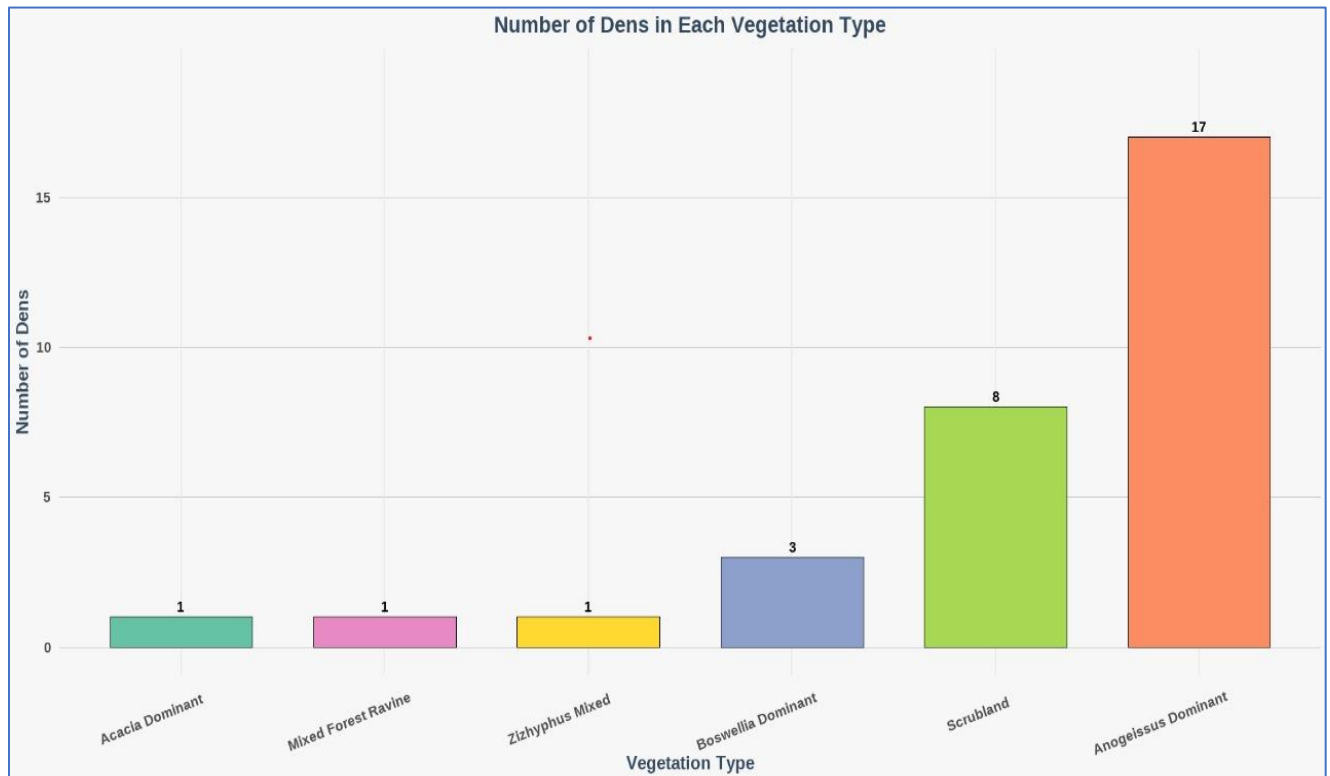


Figure 4.6 Bar graph showing proportion of dens in each vegetative class

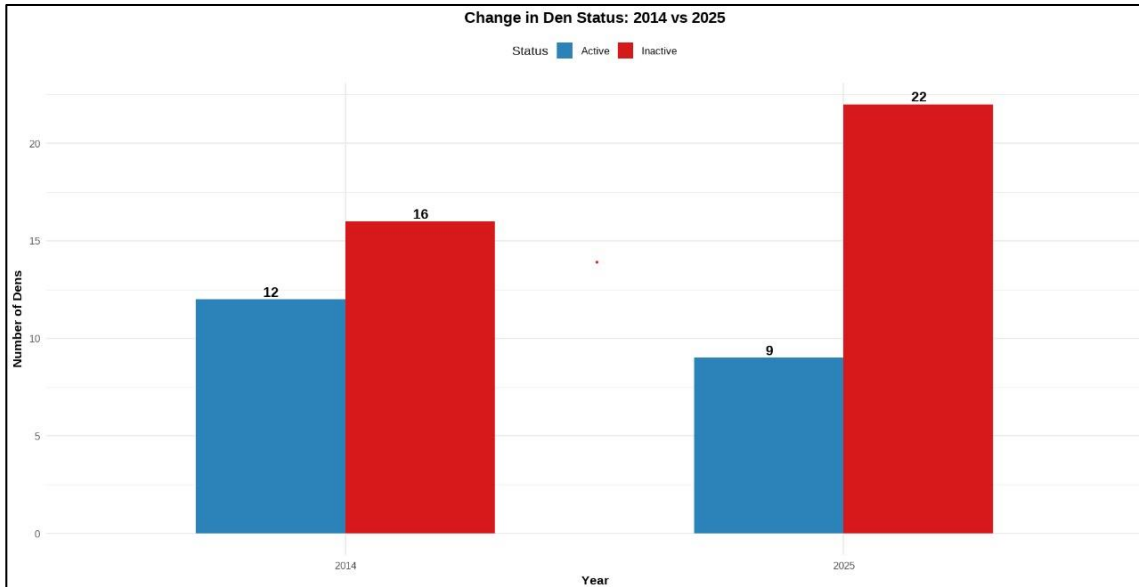


Figure 4.7 Bar graph showing change in den status from 2014 to 2025

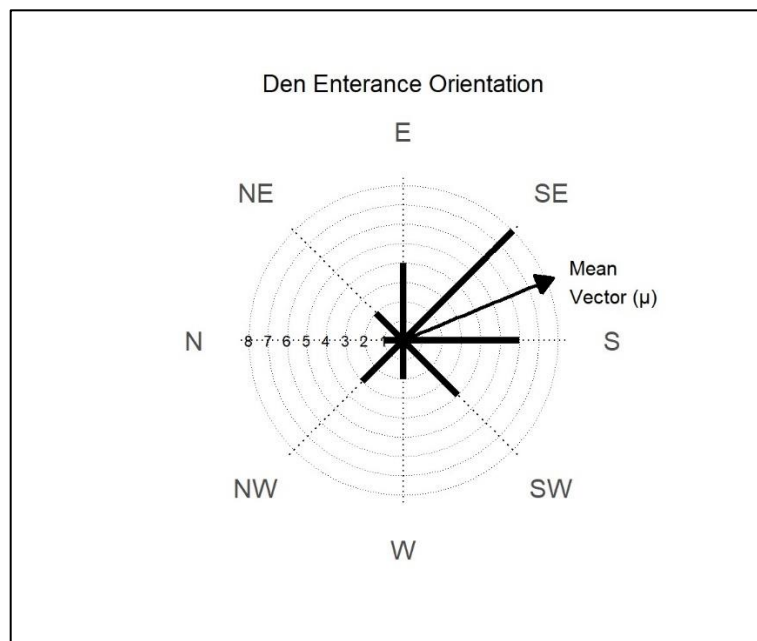


Figure 4.8 Orientation of den entrances showing inclination towards South direction

The den site use was determined in two ways to identify potential tradeoff in choosing den sites:

1. Using only environmental predictors

The AIC of the model was estimated to be 132.47. The estimates of each variable are given in Table 4.5.

Table 4.5: AIC comparison of Binomial GLM models for striped hyena den site selection

Model	Num_Predictors 'k'	AIC	Delta_AIC
Elevation + Dist_road + Ruggedness + Dist_village	4	132.47	0.00
Elevation + Dist_road + Ruggedness	3	132.99	0.52
Elevation + Shrub_cover + Dist_road + Dist_village + Ruggedness + Dist_water	6	135.64	3.17
Elevation	1	138.02	5.55
BioClim5+ BioClim6 + Elevation + Shrub_cover + Dist_road + Dist_village + Ruggedness + Dist_water	8	139.28	6.81

Table 4.6: Results of Binomial Generalised Linear Model (GLM)

	Estimate	Std. Error	z value	P (> z)
Intercept	-1.7802	0.2672	-6.662	2.7e-11 ***
Elevation	-1.0961	0.4121	-2.660	0.00782 **
Dist_road	0.6249	0.3135	1.993	0.04624 *
Dist_village	0.4363	0.2798	1.560	0.11885
Ruggedness	0.5166	0.2021	2.556	0.01059 *

The best fit model was explained by 4 environmental variables, elevation ($\beta = -1.0961 \pm 0.412$) which has a highly significant negative relation to den-site selection indicating that hyena prefer a moderate elevation, Ruggedness ($\beta = 0.5166 \pm 0.202$) which is positively related indicating to the utilization of more rugged terrain, Distance to road ($\beta = 0.6249 \pm 0.313$) is positively related indicating to selecting den sites away from the road and Distance to village ($\beta = 0.4363 \pm 0.273$) shows positive relation but is not significant. The difference in variables explaining occupancy and den site use additionally supports the hypothesis that striped hyena actively selects den sites within its home range.

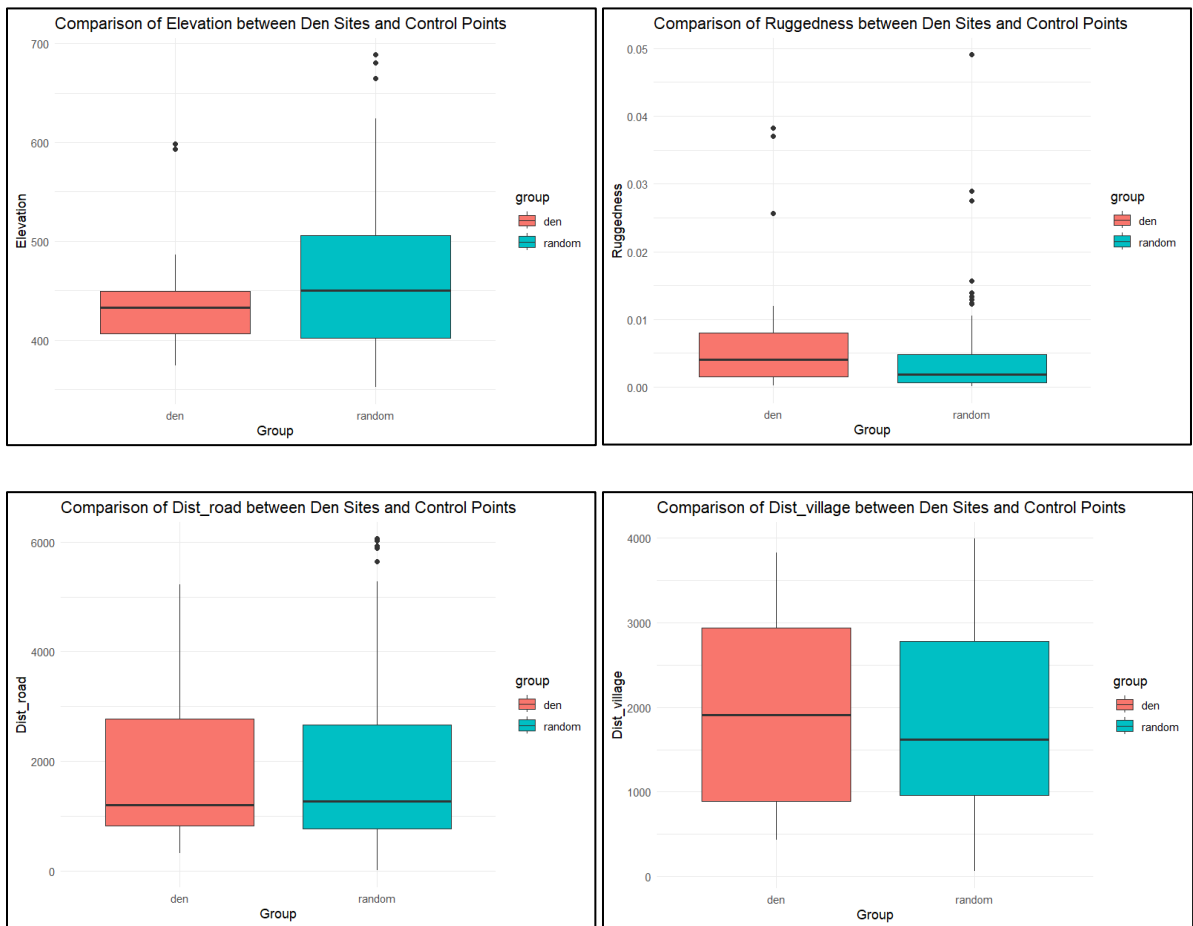


Figure 4.9 Box Plots showing comparison of each variable between Den and Random sites

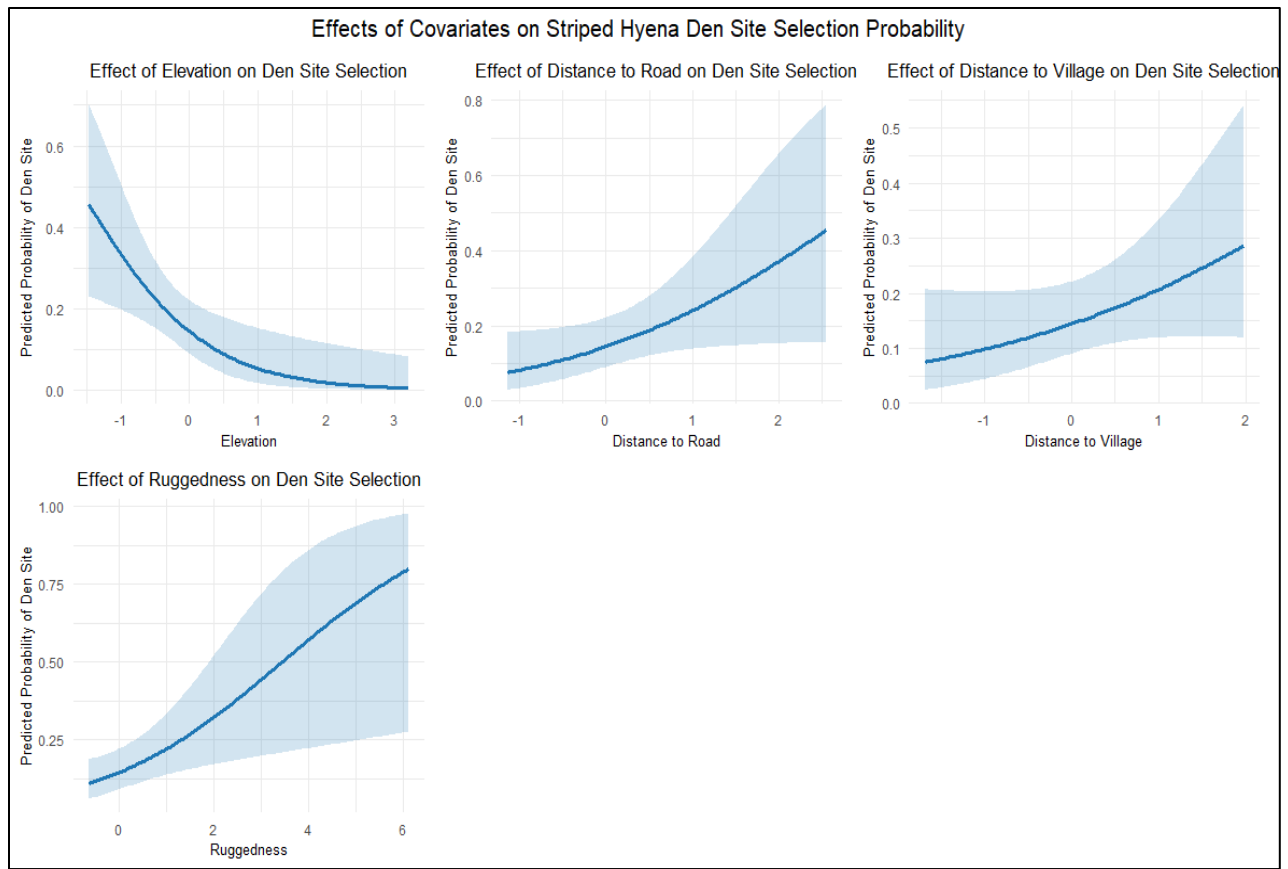


Figure 4.10 Graphs showing effect of individual environmental variable on den site selection

The result from the Binomial GLM was used to derive a linear equation:

$$(-1.7802 + (-1.0961 * "dem") + (0.6249 * "EucDist_road2") + (0.4363 * "EucDist_Sett1") + (0.5166 * "vrm"))$$

This equation was then used to map denning refugia in Sariska Tiger Reserve using raster calculator in ArcGis Pro version 3.1.0:

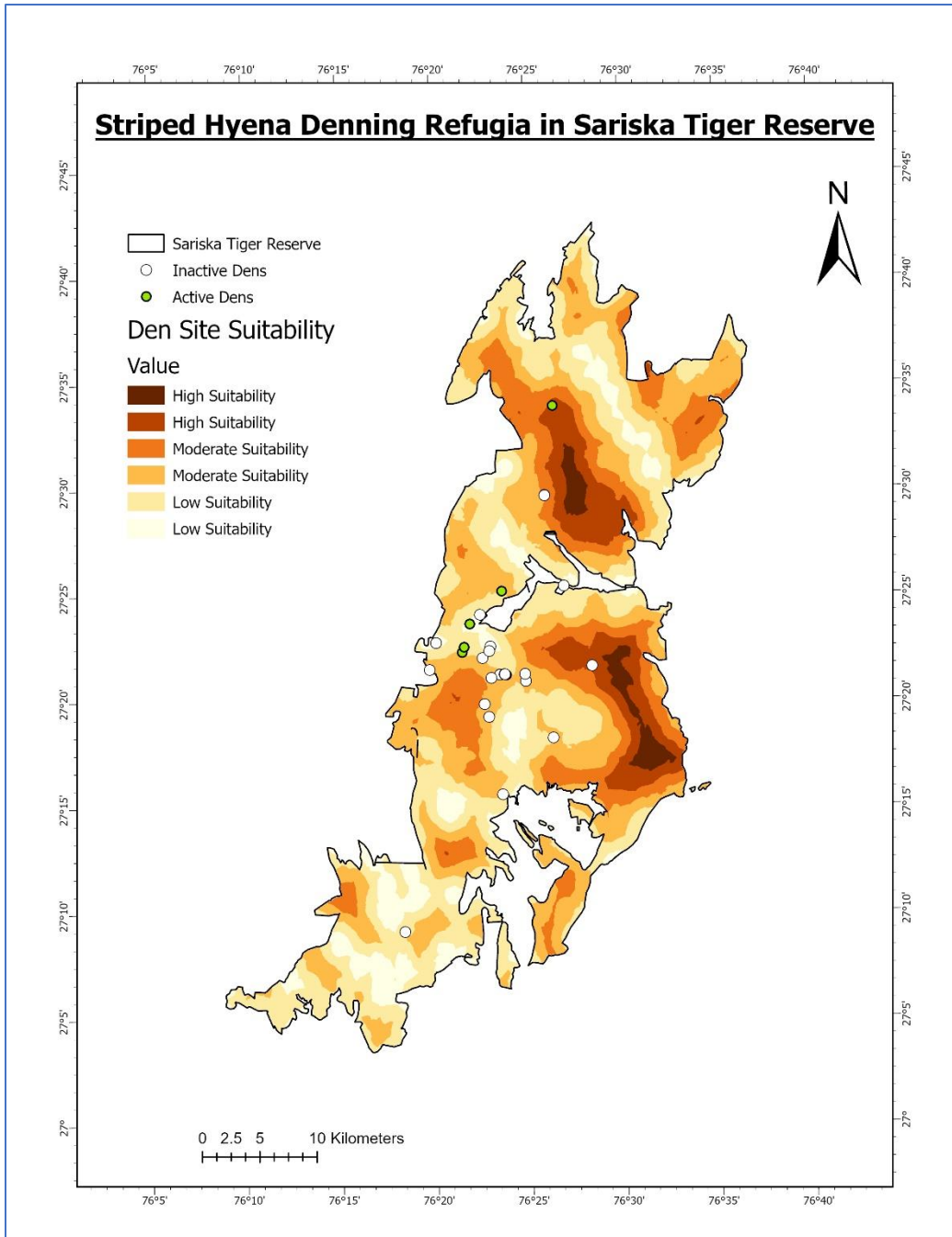


Figure 4.11 Map of Denning refugia in Sariska Tiger Reserve identifying regions of high, moderate and low suitability zones for striped hyena

2. Using both environmental and ecological predictors

The AIC of the model was estimated to be 132.47. The estimates of each variable are given in Table 4.5.

Table 4.7: AIC comparison of Binomial GLM models for striped hyena den site use

Model	'k'	AIC	Delta_AIC
Elevation + Ruggedness + HDI	3	131.07	0.00
Elevation+ Shrub_cover + Dist_road + Dist_village + Ruggedness + Dist_water + HDI + WPI	8	136.20	5.13
Elevation + Ruggedness	2	139.11	8.04
Elevation + Ruggedness + WPI	3	142.26	8.73
Elevation	1	145.05	13.98

Table 4.8: Results of Binomial Generalised Linear Model (GLM)

	Estimate	Std. Error	z value	Pr (> z)
Intercept	-1.7968	0.2991	-6.008	1.88e-09 ***
Elevation	-0.9766	0.3508	-2.784	0.00537 **
Ruggedness	0.5452	0.2148	2.539	0.01113 *
Human Disturbance Index	-1.0113	0.4173	-2.424	0.01537 *

The best fit model was explained by three variables, elevation ($\beta = -0.9766 \pm 0.3508$) which has a highly significant negative relation to den-site selection indicating that striped hyena prefer a moderate elevation, Ruggedness ($\beta = 0.5452 \pm 0.2148$) which is positively related indicating to the utilization of more rugged terrain, den site use probability reduces gradually with Human Disturbance Index ($\beta = -1.0113 \pm 0.4173$) (Fig. 4.12; Fig. 4.13).

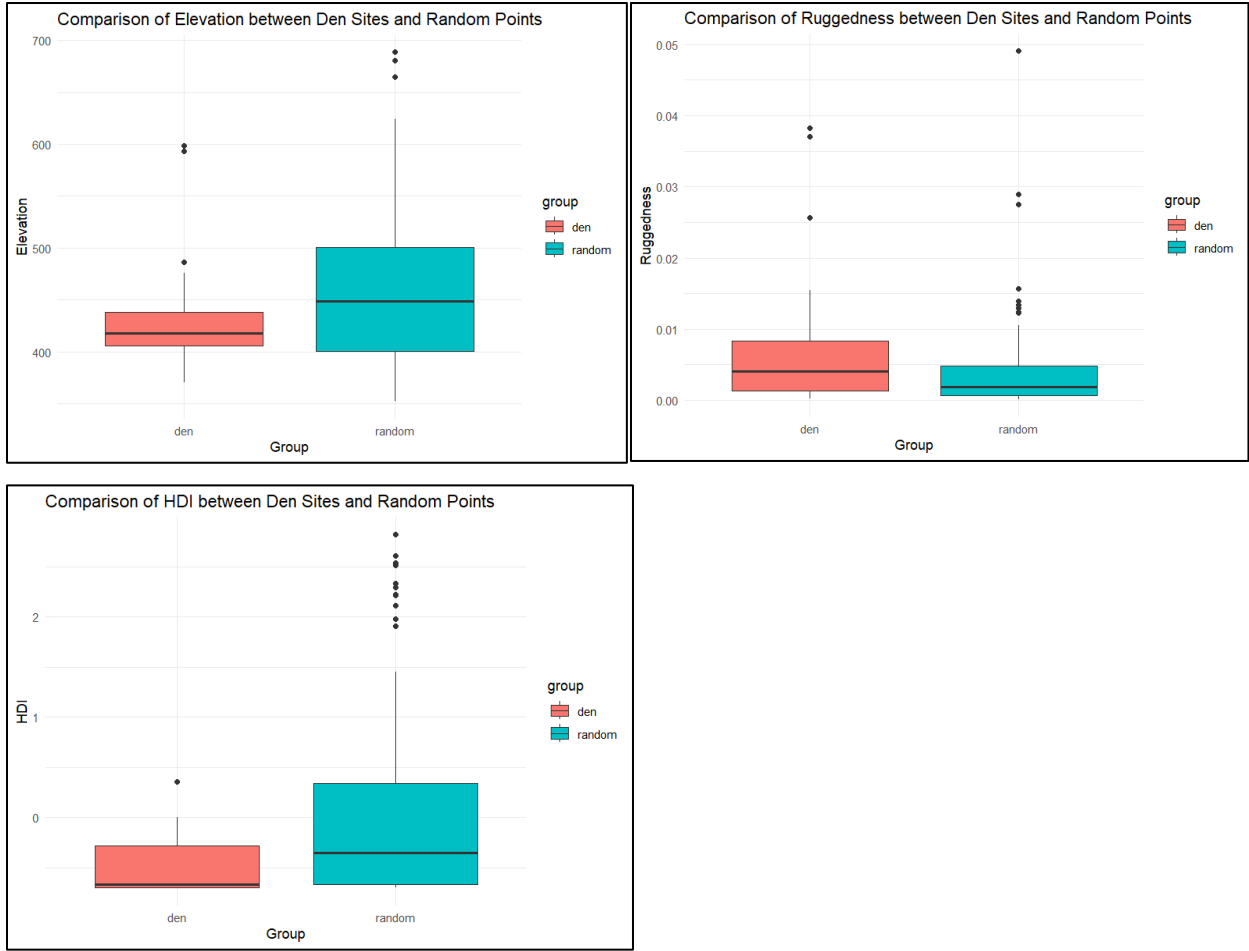


Figure 4.12 Box Plots showing comparison of each variable between Den and Random sites

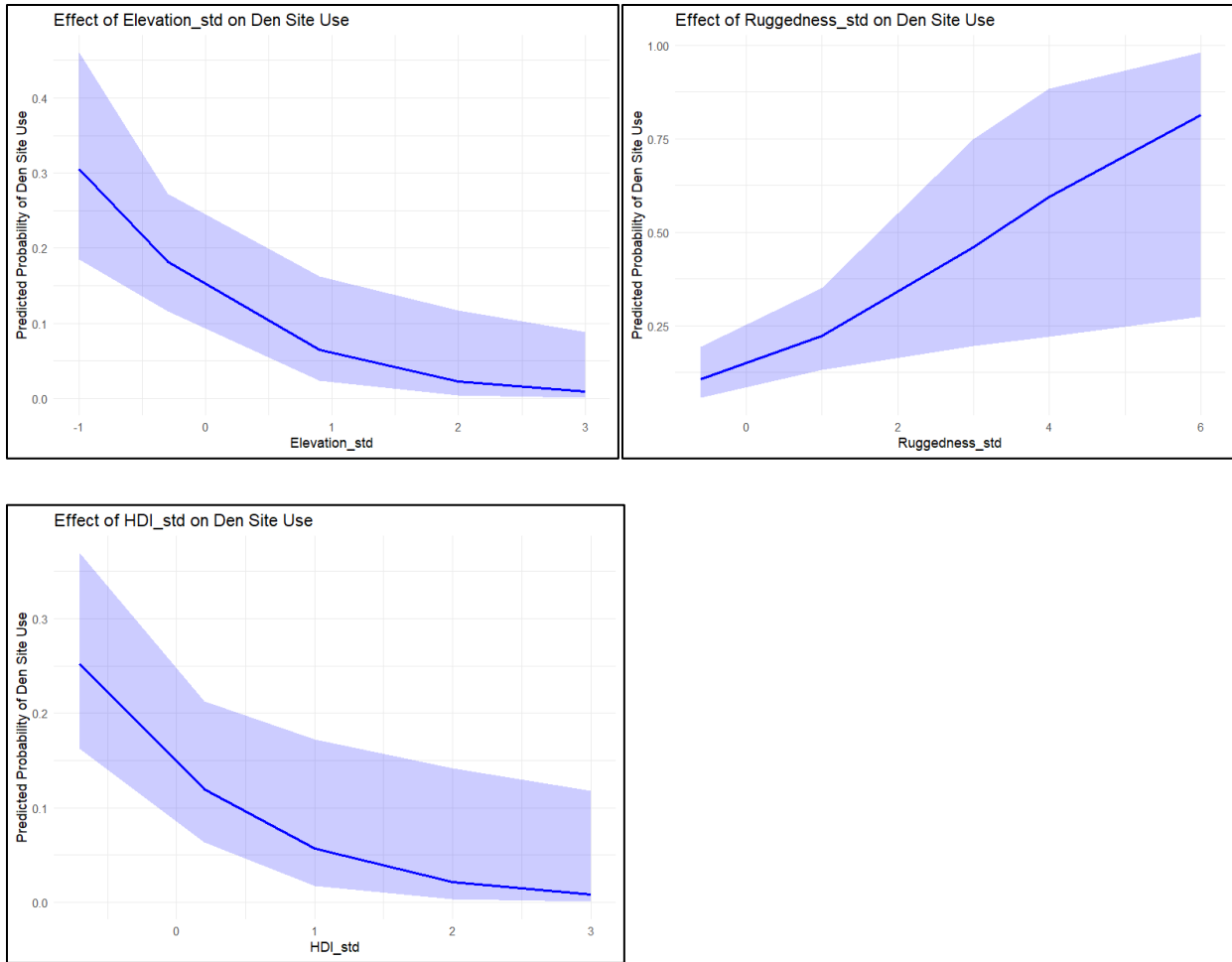


Figure 4.13 Graphs showing effect of individual variable on den site selection

The result from the Binomial GLM was used to derive a linear equation:

$$(-1.7968 + (-0.9766 * \text{"Elevation"}) + (0.5452 * \text{"Ruggedness"}) + (-1.0113 * \text{"HDI"}))$$

This equation was then used to map denning refugia in Sariska Tiger Reserve using raster calculator in ArcGis Pro version 3.1:

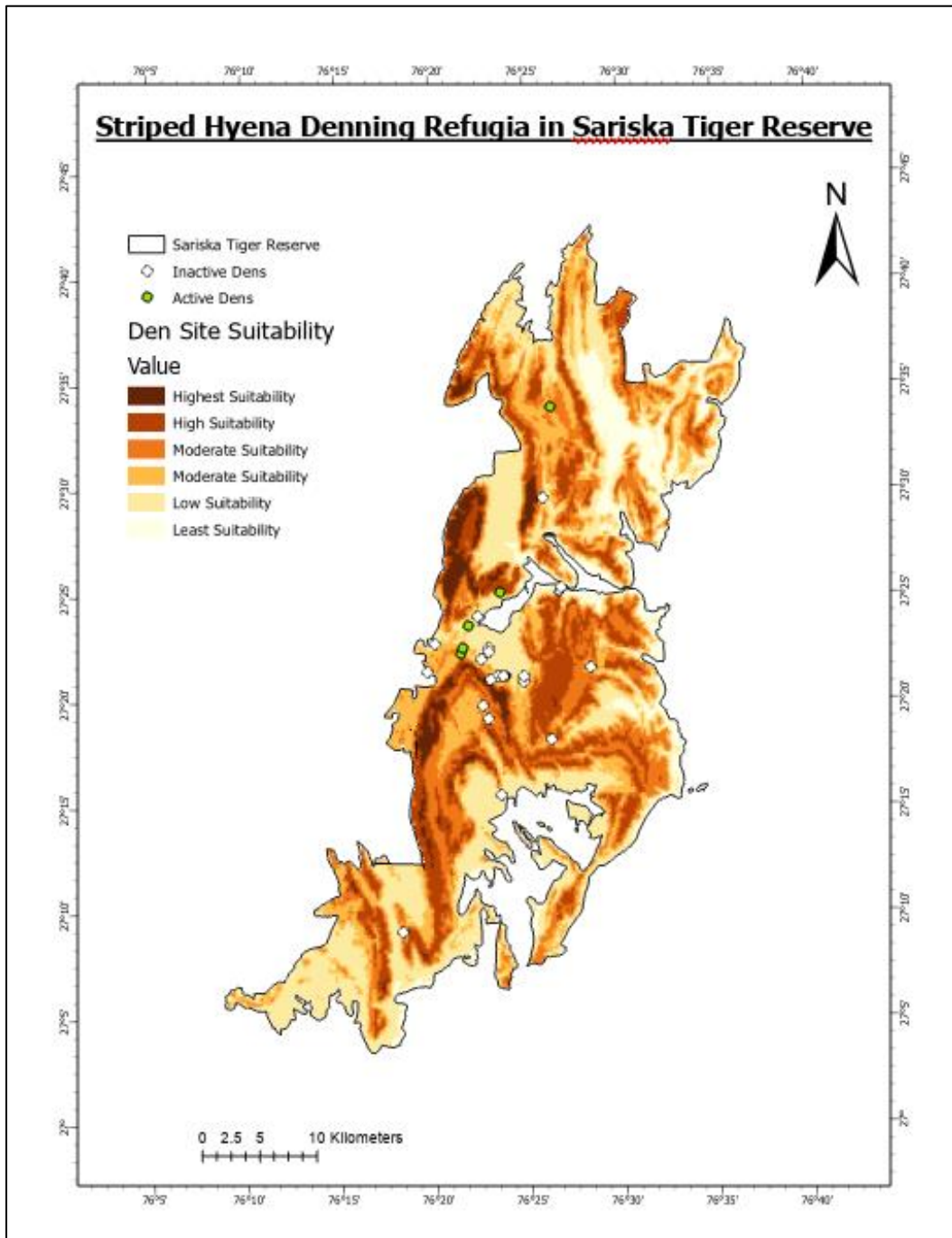


Figure 4.14 Map showing shift in Denning refugia in Sariska Tiger Reserve

5.1 Occupancy Pattern

The result suggests that striped hyena occupancy pattern is determined by open habitat, wild prey index, closed habitat, and ruggedness measure. Open habitat is the most widespread habitat in the semi-arid landscape of Rajasthan. It provides more foraging opportunities for striped hyena by enhancing the visibility of the carcasses and easy detection of prey. Bhandari et al. 2021 reported that striped hyena in Nepal prefers open habitat near rivers which would additionally provide cover through shrub thickets and would allow the animal to move from one resource patch to another without going detected. Similarly, Almasieh et al. 2022 reported higher grassland density would predict occurrence of the species in southwestern Iran. Panda et al. 2022 reported that scrubland is also preferred during the movement of striped hyena within the landscape. This allows it to forage near humans and spatially avoid large predators. Since the study has been carried out inside a protected area, the proportion of habitat is higher compared to the non-protected areas where a suitable habitat occurs in patches. Sariska also has one of the highest prey abundances among the other tiger reserves in India (Gupta et al. 2009; Bhattacharjee 2014). This suggests the dependence of large carnivores on wild prey more, even though a high livestock density exists within the reserve. Dietary studies in Sariska Tiger Reserve (Mandal et al. 2018) showed a higher reliance on large sized ungulate prey. Alam & Khan 2015 indicated wild prey preference in Gir national park. The prey preference of striped hyena is often influenced by the protection status of the region, in protected areas, they often rely on mostly wild prey and scavenge on kills of large carnivores such as tiger and lion (Kruuk 1976; Mandal et al. 2018; Panda et al. 2023). In addition to the utilization of open habitat, hyenas require closed habitat in form of forests for resting and denning. Panda et al. 2022 study in Rajasthan reported higher relative abundance indices in the forest cover, while Singh et al. 2014 emphasized on the importance of closed canopy in Ranthambore in determining striped hyena occupancy. Closed habitats are important for denning and providing security for the litter. Highly rugged terrain provides a niche in space that is often not utilized by humans and therefore helps them to survive in human-interspersed landscapes. Many studies reported it as an important variable in determining the occurrence of the striped hyena (Bhandari et al. 2021; Mandal 2018; Singh et al. 2010; Singh et al. 2014) as it provide safe refuge. Aravallis in Sariska,

thus, acts as an important refuge for striped hyena providing both resting and denning sites for its survival.

5.2 Spatial interaction of striped hyena with other carnivores

The results indicate that striped hyenas are likely to co-occur both with tigers and leopards in Sariska Tiger Reserve. Comparative results from a decade old long term tiger monitoring program in sariska show that hyenas used to occur independently of tigers in Sariska (SIF=1.02), probably because tigers were recently reintroduced in 2008 and tiger numbers were low (n=09). Hyenas have learnt to utilize space over the years following the reintroduction, probably because additional food resources generated by tigers and safety from leopards in tiger usage areas. Parameters for hyenas in presence/absence of leopards have remained largely the same. However, there has been relaxed competition observed between hyenas and leopards at kill site where either they feed at kills with a gap of few minutes or even observed feeding together (Mandal et al. 2018) suggesting an increase in leopard-striped hyena interaction with an increase in tiger number and apparently higher kill rate and availability of carcasses. In Jhalana, kleptoparasitism between striped hyena and leopards has also been documented (Yosef & Kumbhojkar 2025). In over 10 years, Sariska has also observed a reverse of mesopredator release where hyena and leopards are increasing with an increase of the apex predator Tiger, which could again be interpreted in the light of both available refugia in the landscape and resource selection. This, however, needs to be checked through long term camera trapping program. Striped hyenas do not show vocalization as distinctly as the spotted hyenas (Rosevear 1974), though the cubs often display loud sounds while playing. This is more evident in regions where dominant carnivores persist and may reflect a behavioral response to avoid such negative encounters. Striped hyenas also are known to take advantage of carrion made available via predation of large prey animals by sympatric large carnivores such as tiger and leopard in India (Panda et al. 2023). Studies in the protected areas of India has suggested increase in scavenging opportunities in the presence of large carnivores (Panda et al. 2022; Mandal et al. 2018).

5.3 Den site use by striped hyena

Although striped hyena utilized around 59% of the study area, they are selective about den-site selection, a critical resource necessary for their important life history strategies. It was evident by the results that the variables predicting den-site use were different from the ones predicting its occupancy. This indicates some degree of active selection of denning sites within the landscape. In the Sariska landscape, striped hyena selected dens at a moderate elevation, in a high rugged terrain. A moderate elevation cuts down the energetic cost and time to travel between resource patches and the den site. While raising litters, females stay close to den and protect their litter from potential predators especially at a place such as tiger reserves where co-predators occur at a significant number. There have been instances where an adult hyena has been killed by a leopard with cubs at a den site (Mandal et al. 2018). Few dens have also been used by tigers for raising litter. A rugged terrain allows hyenas to go undetected from the ground and is beneficial where pastoralism is a norm. Such places also provide relatively lower temperatures as compared to the outside external temperatures of 40-48°C during extreme summers of Rajasthan. The probability of den use showed a gradual decline with human disturbance index that indicates to some degree of tradeoff between site suitability (Fig.4.11) and food resources (Fig.4.14). When den site use was assessed after including ecological variables into the analysis, elevation and ruggedness were retained, but HDI was better explaining the cumulative effect of distance to road and village and hence improved the model with lower AIC value. Striped hyenas are dependent on wild prey and anthropogenic presence for food resources and therefore den in areas where human and carnivores present, otherwise they would have only chosen inviolate spaces like critical tiger habitats as shown by Environmental only model. Most of the dens show aggregation in one part of the tiger reserve. This region falls into the national park area, which provides additional security by providing complex terrain and prey base. Such knowledge of denning could be a result of learned behavior which needs to be established. Hence, striped hyena does show some tolerance of anthropogenic disturbance, provided availability of anthropogenic food and a secure refuge. This was evidently observed in two of the dens I located during my field survey between January and March 2025 in the Indokh village. Both the dens were about 152 m and 212 m respectively from the village. One cub and an adult hyena were observed at den 1 through direct sighting while den 2 had two cubs, and two adults observed through direct sighting and confirmed through camera

trapping. Both dens were in an open habitat with rocky outcrops and shrub cover in form of *Zizyphus numularia* and *Euphorbia* thickets. The denning areas were often visited by goats for grazing. There have been instances of livestock carcass provisioning by villagers due to recognized ecosystem service of them as scavengers. However, living in proximity with village comes at the cost of safety from the dogs which are often observed accompanying shepherds. A dog was observed chasing away a striped hyena from its den during the late afternoon (Fig.5.1). Out of the two dens, Den 1 was abandoned in February due to unknown reasons. However, den 2 gave significant insights on their denning behavior.



A.



B.

Figure 5.1 Striped hyena interaction with dogs near den: A.Striped hyena actively chased by a guard dog. B. Striped hyena (Right) avoiding dog (Left) by moving through shrub thickets

The high suitability zones in Fig. 4.11 in the Akbarpur and Sariska range encompasses the status of critical tiger habitat. Such areas have witnessed large-scale village relocation in recent years and thus, have provided enough refugia in terms of undisturbed habitat. However, most of the dens were inactive. This could be due to increased human disturbance over time. Another possibility could be the shorter duration of my study that didn't allow me to monitor all the dens for some more time. Striped hyenas show a temporal pattern in den usage, the den currently abandoned, could be reused after few months or even years (Bopanna 2013; Mandal 2018).

5.4 Limitations

While only signs that were identified confidently were recorded, occupancy pattern using sign survey could still produce biased results due to heavy trampling issues encountered on survey trails and lack of temporal repeats. Latest technologies using camera trapping will additionally enhance the data quality. Spatial interactions among carnivores could be better understood through long term camera trapping to allow interpret the results better. While BioClim layers were not included in analysis, use of more fine scale temperature data such as data loggers would give more reliable estimates than a coarser data of resolution 1 Km to assess effect of microclimatic needs on den use, which was lacking in my study. Additionally, few covariates might be missed that would better explain the results.

5.5 Conclusion and Future Scope

Striped Hyena is the only large scavenger and member of family Hyaenidae found in the Indian subcontinent. While its ecological role in maintaining the ecosystem health is widely recognized, there are fewer studies in India which explicitly addresses the spatial requirements and refugia for striped hyena. Spatial explicitly defined regions help managers to better understand the use of large carnivores as well as ensure higher protection and management of those areas in the form village relocation to create inviolate spaces for breeding, managing livestock populations inside reserve to stop rampant grazing, controlling populations of feral dogs entering the core habitats.

Sarsika Tiger Reserve, along with Panna Tiger Reserve in India witnessed local extinction and reintroduction of a large carnivore to preserve their landscape integrity and diversity. Such areas could be vulnerable to local extinction if not managed properly, for example, protected areas like Sariska Tiger Reserve which is an isolated tiger reserve and is only connected through very small territorial divisions with a large human footprint. An adaptive management is essential to answer significant questions of importance to reintroduction biology, such as how will the species affect species composition of the ecosystem? Will there be a need for constant translocation to compensate for the isolated nature of the place? How do other species utilize spaces in presence of the apex predators? These questions must be addressed for the species survival and its cascading effects on trophic levels. A proper management of habitats necessary for the breeding population must be available with the least amount of anthropogenic disturbance to allow long term population persistence.

The agropastoral landscape of Rajasthan has been proved as the strong holds of striped hyena. Composed of majorly open habitats and scrublands, such areas with high pastoral activity provide ample opportunities for striped hyena to scavenge. Rocky outcrops of Aravallis are significantly used in their daytime retreat to avoid humans both spatially and temporally in this landscape of coexistence. It is thus imperative to prioritize certain regions of the Aravalli belt to be conserved to provide the habitat refugia for carnivores in a human-interspersed landscape. Such regions would also act as critical tiger habitat to protect the last remaining population of western Rajasthan as well as ensure connectivity in the Aravalli landscape.

While the Aravalli system has been rapidly losing its ecological balance, certain areas are more ecologically vulnerable to rapid changes. Such areas require proper identification, assessment,

mapping and monitoring for the restoration of ecological balance. (Rathore, 2002). For example, Aravalli ranges in the Gurgaon district in Haryana along with Alwar district of Rajasthan have been notified as ecologically sensitive areas. Loopholes in the legal framework have also allowed unsustainable development. The legal status of the forests of Aravallis is yet to be confirmed and determined by the Haryana state government despite many High courts and Supreme Court directives, paving ways for change of Land Use (CLU) for construction and infrastructure development projects. The definition of the forests must follow the Godavarman case verdict (Supreme Court of India, 1996) which covers all statutorily recognized forests, whether designated as reserved, protected, or any area recorded as forest in the government records (1996). Sustainable development is extremely necessary to manage the Aravalli Landscape and must be declared as hill areas under 'Hill Area Development Programme [HADP]'.

Understanding how such habitat features could allow large carnivores to persist in human-dominated landscape and can explain the source–sink dynamics, which occur when certain areas support positive population growth while others cannot. Habitat selection is dynamic and would change with the prevailing land use changes. Thus, a long-term monitoring program would allow to reveal how population density and occupancy dynamics change over the years. This would also certainly allow us to measure the effectiveness of management interventions in this landscape of coexistence.

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APPENDIX:

Reference for striped hyena sign survey:



Figure 1: Pugmark of striped hyena



Figure 2: Scat deposits of striped hyena

