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Landscape level patterns of mammalian assemblages in Bellary district, Karnataka

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MANIPAL ACADEMY OF HIGHER EDUCATION**

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BY

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This is to certify that the work incorporated in this thesis “**Landscape level patterns of mammalian assemblages in Bellary district, Karnataka**” submitted by **Mr. Asit Kumar Behera** was carried out under my supervision. No part of this thesis has been submitted for a degree or examination at any university. References, help and material obtained from other sources have been duly acknowledged.

Research Guide

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Abbreviations

PAs : Protected Areas

RFs : Reserved Forests

FMFL : Fringe Mosaic Farmlands

NTFP : Non-timber forest products

LULC : Land Use Land Cover

RAI : Relative Abundance Index

AIC : Akaike Information Criterion

SE : Standard Error

IUCN : International Union of Conservation of Nature

Abstract

The rapid growth of the human population and intensification of land-use practices are transforming natural ecosystems at an unprecedented global scale, leading to extensive habitat loss, fragmentation, and deterioration of ecological processes. These changes are now recognized as the primary drivers of biodiversity decline, reshaping species distributions, altering behaviour, upsetting community structure and disrupting ecosystem functioning. Mammalian species are particularly vulnerable to anthropogenic stresses due to their diverse ecological roles, extensive geographical requirements, and sensitivity to habitat disturbance, making them ideal indicators of environmental change. Globally, conservation landscapes are increasingly characterized by mosaics of protected areas embedded within human-modified matrices, where wildlife persistence is determined not only by habitat quality but also by species' ecological traits, behavioural plasticity, and the permeability of surrounding landscapes. Understanding how mammals respond to anthropogenic disturbance at the spatial, temporal, and organisational scales has become a critical concern in conservation ecology, particularly in areas associated with rapid land-use change.

In India, human-dominated landscapes are increasingly becoming the principal settings for wildlife persistence, as much of the remaining biodiversity lies outside protected areas. This makes it essential to examine how land-use change, habitat fragmentation, and human disturbance affect mammalian habitat use, activity patterns, community composition, extinction vulnerability, and species interactions. This PhD thesis investigates these processes in the highly modified and fragmented landscape of Ballari district, Karnataka, India. By integrating species-level, community-level, and guild-level approaches with long-term camera-trap data, the study provides a comprehensive assessment of how anthropogenic pressures, landscape configuration, and species ecological traits shape mammal assemblages and interactions in multi-use landscapes.

Using a landscape-scale systematic camera-trapping survey, camera traps were deployed at 1,457 sampling grid cells across 1,457 across three land-use types, namely Protected Areas (PAs), Reserved Forests (RFs), and adjoining fringe mosaic farmlands (FMFLs). This survey was conducted between 2019 and 2021. Camera traps were deployed using standardized protocols, generating extensive detection and non-detection data for terrestrial mammals. A

suite of environmental and anthropogenic covariates was quantified at multiple spatial scales, including habitat structure, landscape composition, proximity to anthropogenic features, indices of direct human presence, and climate variables.

The first objective evaluated the impacts of land-use change and human activities on mammalian habitat use, activity patterns, and community composition. Single-season occupancy models were employed to assess the influence of 19 environmental covariates representing habitat features, landscape- and local-scale human presence, and climatic conditions on species-specific habitat use and the probability of detection of seven representative mammalian species. I further investigated the diel activity patterns and activity levels of mammals across three land-use types. In addition to species-specific analysis, I assessed community-level responses. I calculated relative abundance indices (RAI) for all 24 mammalian species, assessed species richness, and Shannon diversity indices across three land-use types. Then, I used Bray-Curtis dissimilarity to analyse community turnover across land-use types. Species' responses to anthropogenic disturbance were quite diverse, reflecting variation in ecological traits and life-history strategies. Broadly, four out of seven species exhibited a net negative response to increased human activity, indicating sensitivity to disturbance, whereas three species showed positive responses with increased human activity, suggesting tolerance or adaptation to human-modified environments. The leopard (*Panthera pardus*) preferred habitats away from farmlands, while the black-naped hare (*Lepus nigricollis*) preferred habitats away from human settlements. Increased human relative abundance had a favourable effect on the habitat use of generalist mesocarnivores such as golden jackals (*Canis aureus*) and jungle cats (*Felis chaus*) but had a detrimental effect on wild pig habitat use. Higher habitat use by sloth bears and black-naped hares was associated with PAs, whereas golden jackals and Indian foxes showed higher habitat use in RFs. Large-bodied, forest-dependent species, such as leopards, sloth bears (*Melursus ursinus*), and wild pigs (*Sus scrofa*) used more habitat as the availability of canopy cover increased. Temporal analysis showed that the study species had nocturnal to crepuscular activity patterns. These diel activity pattern analyses revealed pronounced variation across land-use types and body-size classes. Large-bodied species like leopard, sloth bear and wild pig exhibited higher levels of nocturnal activity within FMFLs compared to PAs and RFs, suggesting temporal adaptation to avoid disturbance and higher human pressure. Open-habitat generalist species like golden jackal and fox showed higher day-time activity in RFs and FMFLs with respect to PAs, demonstrating behavioural adaptability in human-modified habitats and reduced potential risk from apex predators.

Smaller-bodied species like the hare and jungle cat largely maintained consistent activity patterns across land-use types, indicating greater behavioural flexibility. These findings underscore the significance of temporal partitioning as a behavioural mechanism that promotes persistence in human-modified landscapes. Community-level analyses revealed that both richness and diversity were highest in PAs and RFs and lowest in FMFLs, indicating the loss of disturbance-sensitive species in human-dominated areas. I found that canopy cover and livestock abundance were two key factors affecting richness and diversity, as increased canopy cover promoted richness and diversity, while higher livestock abundance had an opposite effect. Bray–Curtis dissimilarity analyses revealed moderate community turnover among land-use types, with mammalian assemblages in PAs and RFs being most similar, while FMFLs were more compositionally distinct, reflecting community shifts in human-dominated landscapes. These patterns reflect community reorganization driven by the selective persistence of generalist and disturbance-tolerant species.

The second objective focused on understanding how habitat fragmentation shapes mammalian assemblages by assessing the impact of forest patch attributes on the persistence of mammals and identifying key life-history traits that determine differential vulnerability to local extinction through nestedness analysis. Using presence data for 18 mammalian species across 30 isolated forest patches, a species-by-site matrix was constructed to quantify nestedness patterns. Nestedness was assessed as an indicator of selective species loss driven by habitat fragmentation and anthropogenic disturbance. The mammalian assemblage exhibited significant nestedness, indicating that species-poor patches were subsets of species-rich patches. Spearman’s correlation analyses revealed that patch area, edge density, and proximity index were the most influential patch-level determinants of nestedness, emphasizing that larger and better-connected forest patches with lower edge density were critical for maintaining community structure and minimizing species loss. To assess species-specific extinction vulnerability, nestedness ranks were related to life-history traits, including body mass, trophic level, sociality, arboreality, dispersal ability, and niche breadth. Model selection based on corrected Akaike Information Criterion (AICc) identified niche breadth, sociality, and arboreality as the important determinants of extinction vulnerability. Extinction vulnerability was strongly and significantly associated with niche breadth, underscoring niche breadth’s central role in species persistence in fragmented landscapes and indicating that species with narrower niche breadth, such as the Indian pangolin and four-horned antelope require conservation intervention for their survival in fragmented landscapes. Species with broader

niche breadths were more resilient to fragmentation, whereas highly social and arboreal species exhibited greater vulnerability in increasingly fragmented and disturbed landscapes. These findings demonstrate that the interplay between habitat configuration and species ecology underpins non-random species loss, emphasizing the need to prioritize larger, well-connected forest patches to mitigate biodiversity decline.

The third objective examined the spatiotemporal dynamics of carnivore communities and predator-prey associations to understand how anthropogenic disturbance reshapes species interactions and trophic regulation. Multispecies occupancy modelling proposed by Rota et al. (2016) was used to evaluate: 1) co-occurrence patterns among a carnivore guild comprising the apex predator leopard and meso-carnivores, including golden jackal, Indian fox, and jungle cat and 2) co-occurrence patterns between leopard and its two major prey species, namely black-napped hare and wild pig. The influence of 10 covariates categorized into human disturbance, habitat fragmentation, landscape features, and prey availability on carnivore interactions was explicitly modelled. I also analyzed the activity patterns of the study species to explore temporal segregation. The results demonstrate that human disturbance strongly governs carnivore interactions. Leopard–jungle cat co-occupancy declined in areas with higher settlement cover, whereas jackal–jungle cat co-occupancy increased, indicating contrasting responses of carnivore species to human-modified landscapes. These patterns reflect differential habitat preferences, with smaller carnivores persisting in areas of high human influence by exploiting anthropogenic resources and altered habitat conditions. Consequently, landscapes with greater settlement coverage may act as spatial refugia for smaller carnivores by constraining the occurrence or effectiveness of larger carnivores, thereby reshaping carnivore co-occurrence patterns in human-dominated environments. Broadly, carnivore interactions were sensitive to human disturbance variables, displaying negative associations of meso-carnivores with leopards at higher human disturbance. Prey availability further mediated these interactions, as Indian fox occupancy declined in leopard-occupied areas with increasing abundance index of black-napped hare, consistent with intraguild predation theory whereby subordinate predators reduce space use in areas of high predation risk despite shared reliance on key prey resources. Temporal activity analyses showed that meso-carnivores reduced temporal overlap with leopards by shifting peak activity periods, demonstrating fine-scale temporal avoidance as a coexistence mechanism. Prey species exhibited positive spatial associations and high temporal overlap with leopards, suggesting limited capacity to avoid apex predators in human-modified environments. These findings highlight that carnivore

spatiotemporal dynamics are influenced by species-specific behaviours, competitive interactions, and human disturbance, with apex predators still playing an important role in structuring carnivore groups in highly modified landscapes. Maintaining functional carnivore assemblages in multi-use landscapes will necessitate habitat restoration, sustainable land-use practices, and targeted management strategies that promote coexistence between apex predators and meso-carnivores, thereby supporting biodiversity conservation and ecological stability.

Overall, this thesis demonstrates that mammalian responses to human disturbance are multidimensional, influencing habitat use, activity patterns, community structure, extinction vulnerability, and species interactions. Anthropogenically modified landscapes benefit generalist, disturbance-tolerant species while gradually eliminating ecological specialists and altering trophic dynamics. Although apex predators continue to shape carnivore communities, their regulatory roles are increasingly constrained by anthropogenic pressures. This study offers a holistic framework for analyzing wildlife persistence in multi-use settings by integrating occupancy, activity, nestedness, and multispecies interaction analyses. It also highlights the importance of landscape-scale conservation strategies that enhance connectivity, limit human disturbance, and promote human-wildlife coexistence.

CHAPTER 1

Introduction

Chapter 1

Introduction

1.1. General Overview

Global biodiversity is declining at an extraordinary rate, as human activities increasingly transform natural ecosystems across the globe (Díaz et al., 2019). Increasing anthropogenic land-use changes and human disturbance are among the prominent drivers of ongoing biodiversity loss (Powers & Jetz, 2019), resulting in widespread habitat loss, fragmentation, and ecological degradation throughout terrestrial landscapes (Foley et al., 2005; Sala et al., 2000). These forces have a strong impact on the distribution, persistence, and population viability of mammalian species (Ramesh & Downs, 2015), and underpin population declines of many species by altering habitat availability, connectivity and ecological processes. The ability of wild mammals to persist in anthropogenically-dominated landscapes is mediated by species-specific ecological and life-history traits, resulting in varying responses to anthropogenic pressures (Cardillo et al., 2005; Swihart et al., 2003). This selective filtering favours generalist and disturbance-tolerant species, whereas habitat specialists and disturbance-sensitive species are disproportionately lost, leading to shifts in community composition (Bellon et al., 2022). Wild mammalian species performing the critical ecological roles as ecosystem engineers, seed dispersers, predators, and herbivores are particularly sensitive to landscape-level changes and hence serve as crucial indicators of environmental change (Cardillo et al., 2005; Ripple et al., 2014). The loss of species not only reduces biodiversity but can also disrupt ecological networks, causing cascading effects that compromise ecosystem functioning and resilience (Brodie et al., 2014; Terborgh & Estes, 2010). As functional redundancy declines, ecosystems become increasingly vulnerable to environmental perturbations such as climatic extremes, disease outbreaks, and other anthropogenic disturbances, potentially leading to community instability and partial or complete ecosystem collapse (Clavel et al., 2011; Säterberg et al., 2013). For our own health and prosperity, maintenance of biodiversity and ecosystem function is essential (Chivian & Bernstein, 2008; Sandifer et al., 2015).

Anthropogenic drivers such as agricultural expansion, mining, infrastructure development, unsustainable resource extraction, and biological invasions are exacerbating habitat degradation and fragmentation (Didham et al., 2005; Haddad et al., 2015; Laurance et al., 2014). All species are not equally affected by anthropogenic activities, some being unable

to adapt, are ultimately extirpated, while others thrive. Functional traits that promote adaptation to human activity include wide habitat tolerance, nocturnal activity, small body size and general diet (Larson et al. 2015; Šálek et al. 2015). Generalist species, those with broader habitat tolerance, behavioural flexibility, diverse diets, and smaller body size, frequently survive or thrive in modified habitats (Devictor et al., 2008; Swihart et al., 2003). Specialist species reliant on particular habitats, resources, or microclimates face a high risk of local extinction when those key resources are eliminated or monopolised by human use (Burin et al., 2016; Clavel et al., 2011; Pardini et al., 2010). Understanding the characteristics or traits that determine species persistence or decline is crucial for effective conservation planning in fragmented landscapes, particularly to ensure that species specialisations are adequately incorporated into conservation action plans and PAs management (Schwartz et al., 2000).

Human pressures are particularly intense around forest edges, where illegal and unregulated timber, fuelwood, and other NTFP extraction, along with livestock overgrazing alters habitat structure and composition (Olupot et al. 2009; Mackenzie et al. 2012). Rapid human population growth near forest boundaries, especially near the borders of Protected Areas (PAs) (Wittemyer et al. 2008), increases habitat fragmentation and exerts constant pressure on PAs. As habitat loss and fragmentation advance, community structures shift with species with broader ecological niches out-compete specialists (Šálek et al. 2015). Even highly adaptable species can be locally extirpated through exploitative competition with humans (Henschel et al. 2011), generating vacant ecological niches that may accelerate subsequent trophic cascades. Effective management therefore requires a comprehensive understanding of species-specific ecological requirements, including optimal and minimum habitat needs, spatiotemporal activity patterns, dietary preferences, and niche plasticity, as well as how species interact within communities to sustain ecological stability.

1.2. Literature Review

Human population growth is the leading cause of biodiversity loss (Tilman et al., 1994; Wittemyer et al., 2008), which is driven by deforestation, habitat alteration, unsustainable resource use, and removal due to perceived conflict with human interests (Dirzo et al., 2014; Tilman, 2001). Such changes in the ecosystem can trigger reconfiguration of species assemblages, leading to cascading ecological degradation, extinctions, and niche expansions throughout the trophic web (Estes et al., 2011; Valiente-Banuet et al., 2015). Anthropogenic activities such as deforestation, land conversion to farmland, mining, and human settlement

cause habitat modification (Laurance et al., 2014). Abrupt ecotones formed between native forest and deforested landscapes, and species assemblages change over very short distances (Tölle et al., 2017). Communities dominated by specialist species often exhibit pronounced shifts in assemblage composition across ecotones (Alves et al., 2017; Clavel et al., 2011). When such ecotones also represent gradients from low to intense human activity, species persisting across these boundaries must minimize direct interactions with people (Ditchkoff et al., 2006). Nocturnal species tend to hold a competitive advantage under these conditions, as their activity patterns inherently reduce overlap with human presence (Ditchkoff et al., 2006; Zapata-Ríos & Branch, 2018). Species exhibiting greater niche plasticity can persist longer, disperse more effectively in modified landscapes, and tolerate smaller remnants of native habitat (Gehring & Swihart, 2003; Moreira-Arce et al., 2015). Hyper-generalists, in particular, are consistently identified as the most successful species in human-dominated systems (Larson et al., 2015; Šálek et al., 2015), with rapidly expanding populations that can intensify extinction risks for less competitive guild members (Newsome et al., 2015). Edge effects, driven jointly by habitat loss and human disturbance, influence community composition and population dynamics, with the magnitude of these effects diminishing with increasing distance from habitat boundaries (Laurance, 1991). Carnivores are especially sensitive to anthropogenic pressures and habitat modification (Di Minin et al., 2016), experiencing elevated mortality due to retaliatory killing, poisoning, prey depletion through human hunting, and conflicts involving domestic and free-ranging dogs (Gabriel et al., 2012; Farris et al., 2015; Zapata-Ríos & Branch, 2018). To mitigate the risk of lethal encounters with humans, small carnivores may shift toward nocturnality, alter activity patterns selectively in high-disturbance areas, or temporally avoid spaces of intense human use until disturbance levels decline (Moreira-Arce et al., 2015; Wang et al., 2015). However, the extent of behavioral adjustment, tolerance to human activity, and risk-mitigation strategies varies substantially among species (Caruso et al., 2016; Schuette et al., 2013).

Forests are becoming degraded and fragmented as a result of increasing demands from the growing human population, associated livestock grazing pressure and land transformation for agriculture and development (Kalle et al., 2013; Shamoon et al., 2018). With time, habitat loss and fragmentation have resulted in increased patchiness, longer isolation distances and a decrease in patch size. These factors exert various types of pressures on biodiversity at community and assemblage levels (Fahrig, 2003; Magrath et al., 2014; Pardini et al., 2005), while specifically impacting species with specialised habitat requirements or large home-ranges (Hector et al., 2001; Ries et al., 2004). Fragmented forest patches are referred to as habitat islands in a sea of modified landscapes (Broadbent et al., 2008; Gibson et al., 2013;

Laurance et al., 2009). MacArthur and Wilson's (1967) Island Biogeography Theory is based on the idea that large, connected habitat patches support more species diversity than small, isolated patches. Studies on the fragmentation of tropical rainforests have shown that the area of available habitat influences changes in animal occurrences and densities, with larger areas typically having a greater number of species (Umapathy & Kumar, 2000). However, small, isolated forest patches are also repositories of biodiversity (Turner & Corlett, 1996). When habitat and niche availability are reduced, species richness may remain constant while functional diversity decreases, as specialist species are replaced by generalist species (Safi et al., 2011). Thus, habitat fragmentation drives functional trait loss, causing relaxation or extinction of species with pressured traits. So, understanding the influences of landscape-scale habitat fragmentation on both taxonomic and functional diversity is crucial for addressing ecological concerns and conservation challenges (Mason & De Bello, 2013).

Large predators play crucial roles in ecosystems by regulating the populations of subordinate predators and prey species (Del Rio et al., 2001; Ripple et al., 2014; Steneck, 2005). They influence the trophic web through direct predation and lethal interference competition (Polis et al., 1989; Zhang et al., 2015), as well as creating a landscape of fear among prey and subordinate predators (Laundré et al., 2014; Lima, 1998; Ramesh et al., 2017). To avoid encounters with large predators, species at risk generally modify their activity patterns and habitat use (Berger & Gese, 2007). This restriction of access to the feeding area and prey items may cause a change in diet (Laundré et al., 2009; Laundré et al., 2014). Therefore, large predators keep the population density of smaller predators and prey under control (Creel & Christianson, 2008). Interference competition and predation support biodiversity by limiting movements, abundance, and population densities of subordinate species and prey, hence preventing overexploitation of their food sources (Ritchie & Johnson, 2009; Suraci et al., 2017). In many places, anthropogenic changes have resulted in the extirpation of large or apex predators as they are more vulnerable to disturbances (Estes et al., 2011; Ripple et al., 2014). According to the Mesopredator Release Hypothesis, the extirpation of apex predators triggers a trophic cascade that can have far-reaching consequences for biodiversity across trophic food webs (Estes et al., 2011; Roemer et al., 2009; Terborgh & Estes, 2013). As the landscape of fear is altered or removed, population densities and niche breadths of species in the trophic level below the extirpated large predator increase (Droge et al., 2017; Ritchie & Johnson, 2009). The released mesopredator may assume the role of apex predator, reshaping predation dynamics and the landscape of fear for smaller carnivore species, potentially triggering further trophic cascades (Berger et al., 2007; Levi & Wilmers, 2012; Ritchie & Johnson, 2009; Wallach

et al., 2015). However, if a new apex predator exerts adequate top-down control on subordinate predators, the system may stabilize although such outcomes are likely context-dependent (Ritchie & Johnson, 2009).

1.3 Rationale of the study

Globally, rapid land-use change, habitat fragmentation, and rising human pressure are changing terrestrial ecosystems, with biodiversity persistence now largely depending on species' ability to survive in human-modified landscapes rather than pristine habitats (Newbold et al., 2015). Although ecological research has typically concentrated on intact forests, recent syntheses emphasize the need of understanding species responses across multi-use landscapes comprising PAs, RFs, and agricultural mosaics. However, community-level research is still heavily biased towards temperate and moist tropical systems, leaving dry, low-productivity ecosystems underrepresented despite their high vulnerability. Dry, low-productivity habitats support distinct faunal assemblages that have adapted to seasonal resource scarcity, but their community structure, extinction risk, and species interactions under anthropogenic pressure remain poorly understood (Janzen, 1988).

Most wildlife studies in India have focused on single species or broad distributional information for select mammalian groups (Kumara & Singh, 2007; Mudappa et al., 2007), with limited attention to the ecological processes shaping entire mammalian assemblages across heterogeneous land-use gradients. In particular, there is a paucity of integrative studies investigating the patterns shaping the diverse mammalian community assemblages in detail across land use gradients, i.e., PAs, Reserved Forests (RFs) and fringe adjoining mosaic farmlands (FMFLs) in India. This knowledge gap is especially evident in human-dominated fragmented landscapes such as Ballari district in Deccan region, where mining, agricultural expansion, settlement growth, livestock overgrazing, timber and non-timber forest products (NTFP) collection have resulted in extensive habitat loss and fragmentation. The Deccan region is dominated by dry deciduous, dry thorn, scrub, and open forest ecosystems, many of which are severely degraded, fragmented, and often categorised as wastelands despite harbouring various animal species that have adapted to poor productivity and seasonal resource constraints (Champion & Seth, 1968; Roy et al., 2015).

Understanding how land-use gradients shape mammalian communities and assemblages is therefore crucial, as remnant forest patches may play a major role in the conservation of mammalian species that are vulnerable to disturbance and habitat

fragmentation. There are few studies on the impact of habitat fragmentation on the population of Lion-tailed Macaque (Umapathy & Kumar, 2000), elephant (Kumar et al., 2010), leopard (Athreya et al., 2016) and arboreal mammals (Umapathy & Kumar, 2000), but none of them have looked at its impact on diverse mammalian community assemblages in detail. This study investigates the effect of habitat fragmentation on mammalian assemblages. Besides that, it also addresses how large predators can shape the behavioural patterns of prey and subordinate predators if diverse mammalian species need to be conserved. Such studies are urgently required in India, as landscape transformation is taking a toll at an alarmingly high rate in the name of development. Furthermore, fragmented Deccan landscapes provide a unique opportunity to examine how species interactions and behavioural adjustments facilitate coexistence under anthropogenic pressure, particularly within carnivore guilds where apex predators, mid-level carnivores, and prey species increasingly overlap with humans (Behera et al., 2024). Despite this, integrative assessments combining habitat use, community structure, fragmentation dynamics, and species interactions remain rare in peninsular India. By combining occupancy modelling, activity pattern analysis, community metrics, nestedness analysis, and multispecies interaction models, my study provides a comprehensive assessment of how mammals respond to human-modified landscapes. The findings offer critical insights for biodiversity conservation, landscape management, and coexistence strategies in multi-use ecosystems.

1.4. Objectives

My broad research objectives:

1. To determine land use gradients shaping mammalian communities.
2. To assess the impact of patch characteristics (size and isolation) on mammalian assemblage.
3. To assess species interactions driving behavioural responses of mammals.

The study aims to understand how landscape-level factors and interspecific interactions shape mammalian communities in a human-modified, fragmented and semi-arid ecosystem. By integrating data across anthropogenic land-use gradients, patch characteristics, and interspecies behavioural responses, this research provides a comprehensive understanding of the mechanisms influencing mammalian persistence in fragmented landscapes. Specifically, the study examines how different land-use types, such as PAs, RFs, and adjoining Fringe Mosaic

Farmlands (FMFLs), support varying levels of mammalian abundance, richness, diversity, community, and activity. It examines how anthropogenic and natural habitat variables determine the responses of mammals. It further investigates how forest patch attributes influence species assemblage, identifying which life-history traits make species more vulnerable to extinction. Beyond habitat features, the study explores species interactions, including spatial and temporal segregation among top carnivores, meso-carnivores, and prey species to understand coexistence strategies under anthropogenic pressure.

All these findings shed light on the relative importance of land-use intensity, habitat configuration, and interspecific interactions in structuring mammalian communities. It will help to identify conservation priorities and management strategies that improve connectivity, maintain ecological function, and encourage wildlife-human coexistence in highly modified, fragmented, and low-productivity landscapes.

1.5 Thesis organization

The present thesis is organised into six chapters, each addressing specific components of the research objectives.

Chapter 1 provides the general introduction to the study and presents a comprehensive review of the existing literature on the effects of human disturbance, land-use change, habitat fragmentation, and species interactions on mammalian communities. This chapter outlines the theoretical framework underpinning the study and presents the rationale, objectives, and overall structure of the thesis. Chapter 2 describes the study area in detail, covering its geographic setting, climate, vegetation types, land-use patterns, and anthropogenic pressures. This chapter also highlights the ecological significance of the study region. Chapter 3 addresses the first objective of the study and examines the influence of land-use gradients on mammals and mammalian communities across PAs, RFs, and FMFLs. This chapter evaluates species habitat use, activity patterns, and community-level responses to varying degrees of human disturbance and land-use intensity. Chapter 4 focuses on the second objective and investigates the effects of habitat fragmentation and patch characteristics. Using a nestedness framework, this chapter assesses patterns of species persistence and extinction vulnerability across forest patches in a fragmented landscape. Chapter 5 addresses the third objective of the study and examines species interactions and behavioural responses of mammals in human-modified landscapes. This chapter evaluates spatial and temporal interactions among apex predators, mesopredators,

and prey species, highlighting the role of human disturbance in shaping interspecific relationships and activity patterns. Finally, Chapter VI synthesises the key findings of the study, presents overall conclusions, and discusses their implications for mammalian conservation and landscape management. This chapter also outlines future research directions and management recommendations aimed at mitigating biodiversity loss in human-dominated and fragmented ecosystems. The thesis concludes with a comprehensive bibliography of all references cited and photo plates related to this study.

CHAPTER 2

Study Area

Chapter 2

Study Area

Bellary Territorial forest division (in Ballari district) is situated in the central part of the north-eastern sector of the State of Karnataka and lies within the southern portion of the Deccan peninsula, India (Fig. 1). Currently, its name has been changed from Bellary to Ballari, so I will be addressing it as Ballari district from now on. The district extends geographically between 14° 30' and 15° 50' North latitude and 75° 40' and 77° 11' East longitude. In late 2021, Ballari was divided into two districts, namely Ballari district and Vijayanagara district. Since this official division happened after the data collection of this study, I will be considering it as a single whole district.

Ballari district was previously administered under the Madras presidency and, after India's independence and the linguistic reorganization of Indian states, was incorporated into Karnataka's Kalyana-Karnataka region. The district shares its border with Anantapur and Kurnool districts of Andhra Pradesh on the east, Raichur and Koppal districts on the north, Gadag and Haveri districts on the west and lastly, Davanagere and Chitradurga districts on the south. Ballari is home to Hampi, a UNESCO World Heritage site, which was possibly known as Kishkindha and has a strong connection with the Ramayan folklore. Agriculture is the district's primary occupation, employing about 75% of the entire labour force. Cotton, jowar, rice, cereals, groundnuts and sunflowers are among the most widely grown crops, with the Tungabhadra dam serving as the primary source of irrigation.

Ballari is rich in mineral wealth, especially in iron ore and manganese deposits. It is bestowed with rich mineral resources, which mainly include metallic minerals ores of iron, manganese, copper, and gold, and non-metallic minerals ores of andalusite, limestone, asbestos, and granite. Most of the mines are located in forested areas (Behera et al., 2024). Over 5000 hectares of forest land are under mining activity at present (Meena, 2013). In mined areas, the ecosystems are drastically altered, and the resultant environment is not suitable for any productive use. As one of the most economically challenged districts in India, the local people are highly dependent on NTFP collection and maintain a large livestock population for the sustenance/economic prosperity. Encroaching on the forested land for farming places further pressure on the remaining forest patches. Therefore, the natural forest is being fragmented into patches. With huge human and livestock population pressure, changing land-use patterns and encroachment of forest land to extensive agriculture in the forests, leading to

increasing human-animal conflict like livestock depredation, human injury or death, wild animal mortality and crop destruction, particularly from leopard and sloth bear (KS & Hosetti, 2016; Manjunatha et al., 2023; Reddy & Chandrashekar, 2025; Sharp, et al., 2020).

2.1 Geo-climatic characteristics

The study was conducted within forest patches of Ballari territorial forest division, covering PAs (Daroji and Gudakote Wildlife Sanctuaries), RFs and adjoining fringe mosaic farmland areas up to 1 km from PAs and RFs (Fig. 2.1). Daroji Sloth Bear Sanctuary was established in 1994 and spreads over 82.72 km². While about 90 km away from it lies Gudakote Sloth Bear Sanctuary (declared in 2013), which spreads over 167.59 km². In total, an area of around 2,600 km² was surveyed. Ballari has two different major seasons: long dry season (October–May) and short wet season (June–September). The average annual temperature varies from 20 °C to 45 °C. The region lies between 500m and 800m AMSL. Except for the hilly region in the centre, the terrain varies from open plains to undulating areas with some patches of rugged hills (Meena 2013). The eastern region is open and plain, with vast stretches of black-cotton soil that are gloomy and devoid of sand. The average annual rainfall is 574.9 mm. The geographical area of the district and consequently of the division is 8447 km², which accounts for 6% of the State's geographical area. The lands classified as 'forest' constitute 16.28% of the gross area of the district.

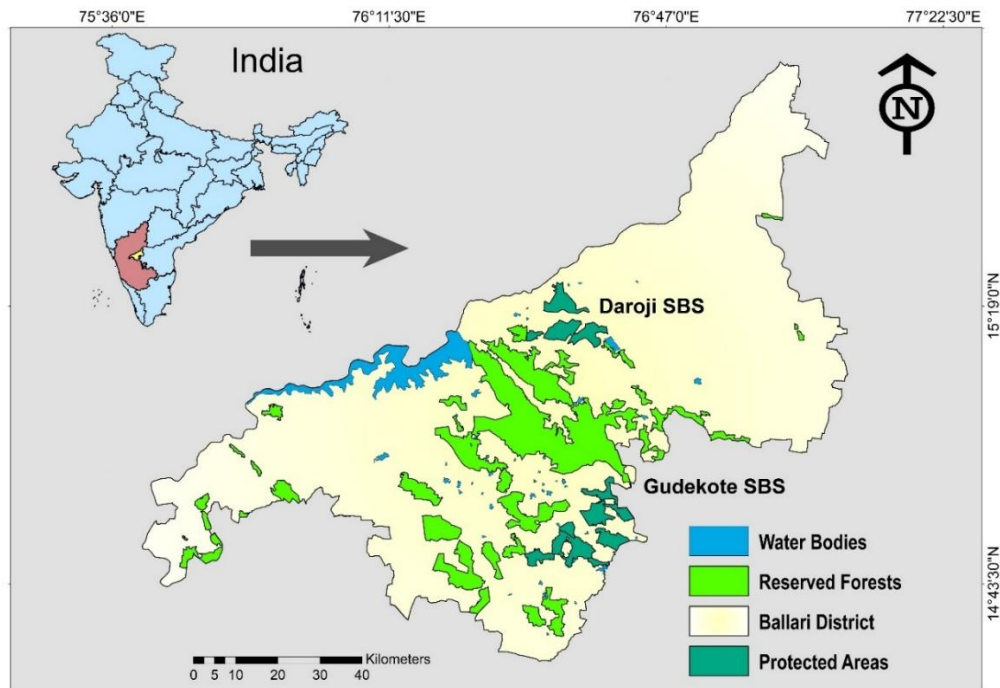


Figure 2.1: Protected Areas (PAs) and Reserved Forests (RFs) of Ballari district, Karnataka (PAs are represented by Daroji and Gudakote Sloth Bear Sanctuary (SBS))

2.2 Flora and Fauna

Ballari Forest area covers eight forest ranges: Ballari, Daroji, Gudekote, Hadagali, Hosapete, Kudligi, Sandur South and Sandur North (Figure 2). According to Champion and Seth (1968), the forests of the division have been broadly classified as tropical dry deciduous forests (predominantly composed of *Anogeissus latifolia*, *Albizzia amara*, *Boswellia serrata*, *Chloroxylon swietenia*, *Dalbergia paniculata*, *Hardwickia binata*, *Erythroxylon monogynum*, *Grewia tiliaefolia* and *Azadirachta indica*) and tropical dry thorn forests (largely dominated by *Albizzia amara*, *Acacia sundra*, *Cassia fistula*, *Carissa carandus*, *Cassia auriculata*, *Dodonea viscosa*, *Euphorbia spp*, *Randia dumetorum* and *Zizyphus spp.*) (Fig. 2.2). A small stretch of the forest has tropical moist deciduous forests, characterised by *Pongamia pinnata*, *Terminalia tomentosa* and *Mangifera indica*.

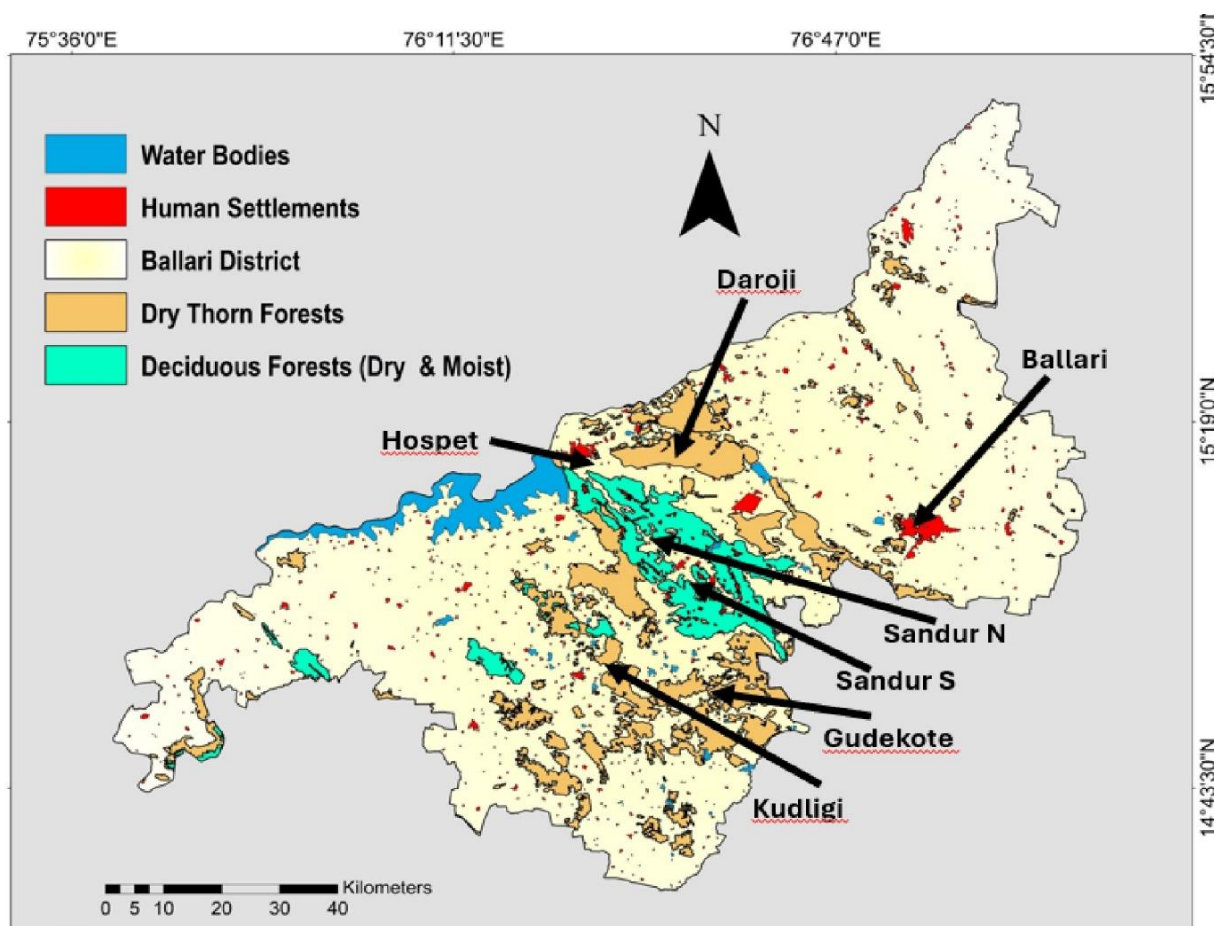


Figure 2.2: Forest types and forest range headquarters of Ballari Territorial Division, Karnataka

Despite its arid and semi-arid environmental conditions, Ballari supports diverse medium-sized carnivores and prey, including leopards (*Panthera pardus*), sloth bears (*Melursus ursinus*), Indian wolves (*Canis lupus pallipes*), striped hyenas (*Hyaena hyaena*), golden jackals (*Canis aureus*), Indian foxes (*Vulpes bengalensis*), jungle cats (*Felis chaus*), rusty-spotted cats (*Prionailurus rubiginosus*), Indian pangolin (*Manis crassicaudata*), blackbuck (*Antelope cervicapra*), wild pigs (*Sus scrofa*), black-naped hares (*Lepus nigricollis*), etc (Behera et al., 2024).

2.3 Land-use types

For this study, the study area landscape was classified into three distinct land-use types that represent a gradient of protection intensity and human disturbance: Protected Areas (PAs), Reserved Forests (RFs), and adjoining Fringe Mosaic Farmlands (FMFLs) (Fig. 2.3). Protected Areas represent the most strictly regulated land-use category, where legal frameworks offer strong protection against human activities like natural resource extraction and other forms of direct human interference, along with livestock grazing, thereby offering relatively intact and secure habitats for wildlife. In India, PAs are wildlife sanctuaries that fall into IUCN category IV and include a high degree of protection from poaching, grazing, and NTFP collection (Badola, 1999; Ghosh-Harihar et al., 2019). In contrast, Reserved Forests are the forested areas that experience a lower level of protection and permit varying degrees of human use, including NTFP collection and grazing. In the Ballari landscape, extensive mining operations are permitted. Thus, RFs serve as partially modified habitats that sustain species but are vulnerable to ongoing disturbance and habitat deterioration (Milda et al., 2020). Many mammalian species thrive in farmlands, barren lands and near settlements, outside PAs and RFs (Schmitt et al., 2009), which I refer to as Fringe Mosaic Farmlands (FMFLs). FMFLs represent the anthropogenic land-use mosaic of agricultural lands. Therefore, FMFLs are prone to more human disturbance and have lower habitat heterogeneity than PAs and RFs. For biodiversity conservation, it is essential to evaluate anthropogenic landscape variables associated with land-use types within the multi-use landscape mosaic and their effects on species (Noon et al., 2012; McDonald et al., 2015).

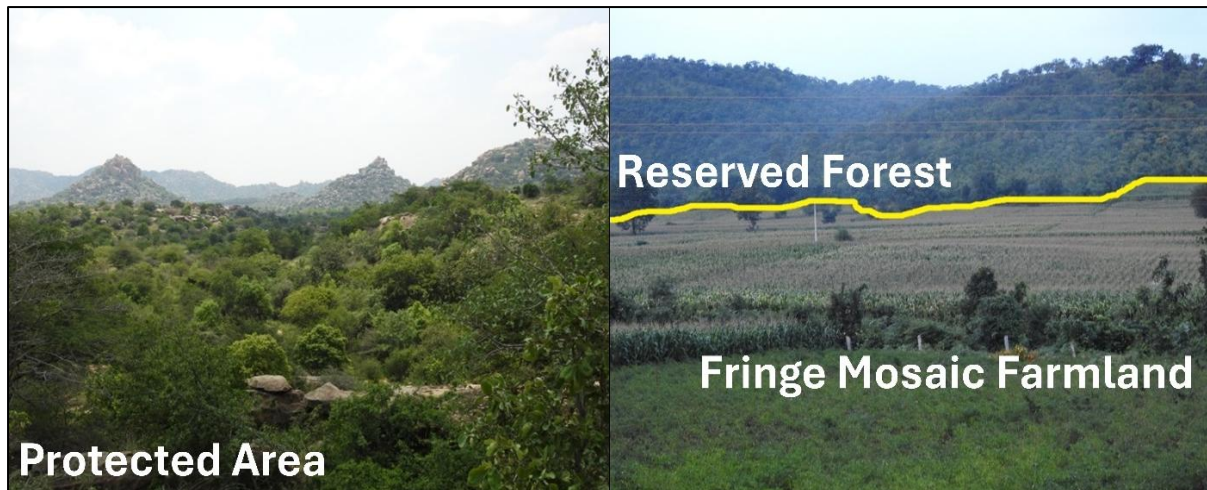


Figure 2.3: Photographs displaying three land-use types of Ballari, Karnataka

2.4 Threats and management issues

Ballari territorial forest division represents a highly human-modified and fragmented landscape where several anthropogenic pressures operate simultaneously, posing significant challenges for forest management and wildlife conservation. Large-scale mining is one of the severe threats to the area. The district has abundant natural resources, especially manganese and iron ore, and most mining operations take place in forested areas (Meena, 2013). More than 50 km² of forest are currently being mined (Meena, 2013). Ecosystem structure and function are drastically altered because of mining's substantial habitat destruction, soil removal, landscape modification, and pollution (Ghose, 2001; Sonter et al., 2017). Long-term habitat loss, fragmentation, and decreases in wildlife result from the post-mining landscape's frequent ecological degradation and general unsuitability for natural regeneration (Laurance et al., 2014; Sonter et al., 2017). Frequent vehicular movements related to mining activities also affect wildlife (Benítez-López et al., 2010).

Another major driver contributing to the study area's habitat degradation is agricultural expansion. Agriculture constitutes the primary livelihood for approximately three-quarters of the district's labour force, creating intense pressure on land resources (Meena, 2013). The encroachment of agricultural fields into forested areas decreases the amount of forest cover and makes the surviving remnant patches more isolated (Haddad et al., 2015). The persistence of disturbance-sensitive species is jeopardised by this conversion, which not only diminishes the amount of habitat accessible for wildlife but also increases edge effects, human access, and disturbance within forest interiors (Laurance et al., 2002).

Livestock overgrazing exacerbates habitat degradation across forest patches and in adjacent landscapes. High livestock densities in and around forests cause competition with wild herbivores for food, suppression of natural vegetation regeneration, soil compaction, and the expansion of invasive plant species (Mishra et al., 2003; Prins, 2000). Overgrazing indirectly affects the higher trophic levels and the general functioning of ecosystems, lowering habitat quality (Ripple et al., 2014).

Dependence on forest resources poses a significant management challenge in Ballari. Local people rely heavily on NTFPs, timber and firewood extraction for subsistence and income (Ticktin, 2004; Mishra et al., 2003). Intensive NTFP collection and frequent human movement increase disturbance that degrades habitats and disrupts wildlife behaviour (Haddad et al., 2015; Mishra et al., 2003). Unsustainable timber and firewood extraction leads to loss of structural complexity, disproportionately affecting forest-dependent and disturbance-sensitive mammals (Geist & Lambin, 2002; Laurance et al., 2002).

Finally, increasing human-wildlife conflict has emerged as a serious conservation and management concern in the landscape. Expanding human settlements, agricultural encroachment, and declining habitat quality have resulted in increased spatial overlap between humans and wildlife (Karanth et al. 2012). This has resulted in frequent incidences of human injuries, human deaths, livestock predation, and agricultural destruction, particularly involving large species like leopards and sloth bears (Athreya et al., 2016; Manjunatha et al., 2023; Reddy & Chandrashekar, 2025). In reaction, retaliatory killing, illegal persecution, and poaching endanger wildlife populations and undermine long-term conservation efforts. In the Ballari landscape, poaching remains a persistent threat, particularly in RFs and adjoining fringe areas, where poachers employ trained dogs, single-barrelled rifles, wire snares, and traditional trapping methods (Behera et al., 2022a). These activities primarily target medium-sized and small mammals such as black-naped hare, wild pig, antelopes, Indian crested porcupine, and Indian pangolin.

Collectively, these management-related threats interact synergistically to intensify habitat fragmentation, reduce landscape connectivity, and alter species distributions, behaviour, and interactions. Understanding how mammals respond to these stressors across land-use gradients is critical for developing effective conservation and management strategies in the Ballari landscape.

2.5 Field study methods

Data were collected across the forest patches and adjoining fringe mosaic farmlands (extending up to 1 km from forest boundaries) through a systematic camera trapping survey. A grid-based sampling design was adopted, using 1×1 sq. km grid cells as sampling units to capture the spatial distribution of a wide range of mammalian species. Using ArcGIS 10.1, grids were overlaid across the study area with verified LULC layers obtained from the local forest department (resolution: 30m) (Fig. 2.4). A total of 1,480 grids were surveyed using camera traps, out of which data from 1,457 grid cells were used for this study.

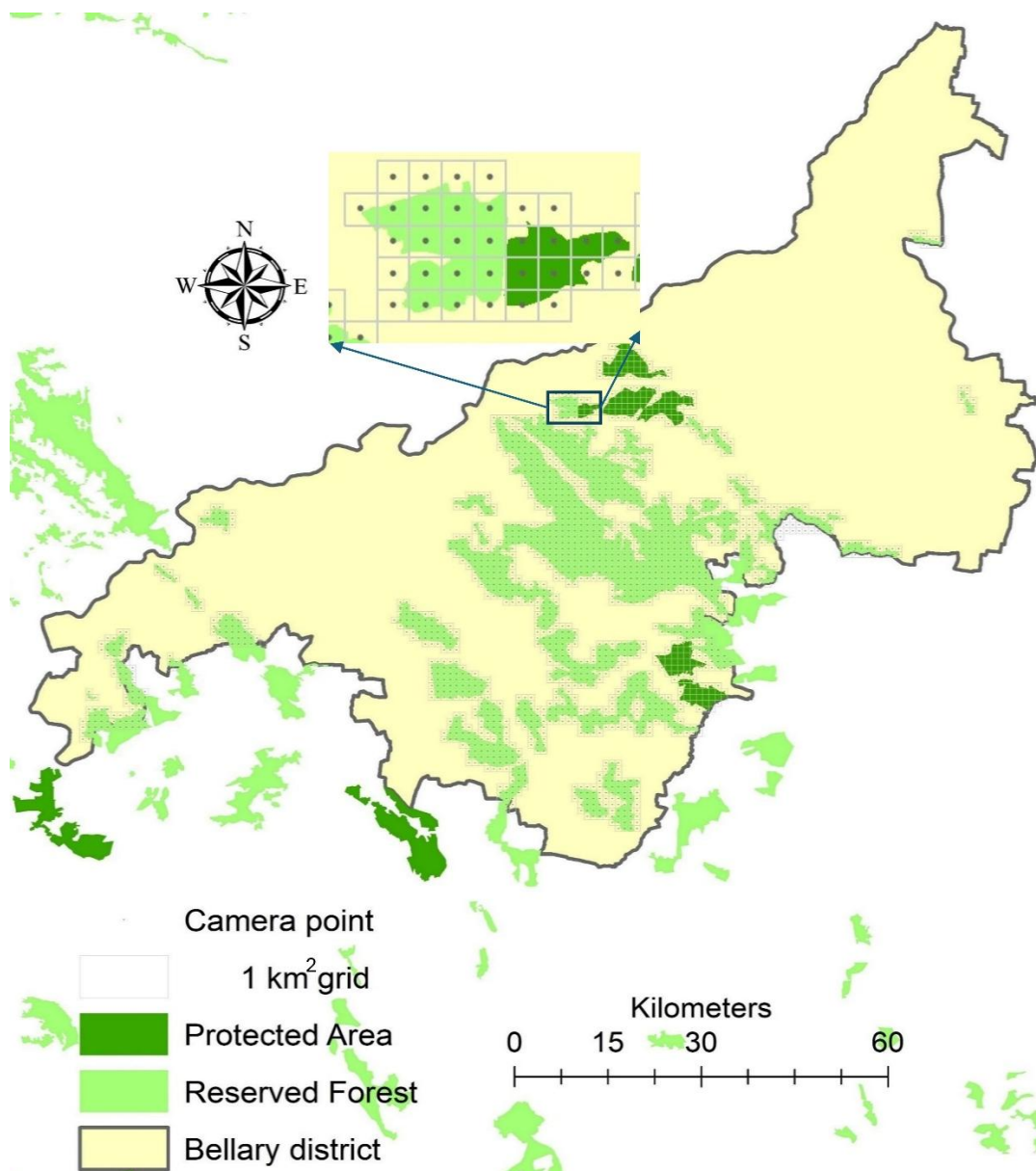


Figure 2.4: Map of study area (Bellary/Ballari) overlaid with 1 sq. km sampling grid cells

Within each grid cell, I conducted mammalian sign surveys with the support of trained forest staff. Best camera trapping locations were identified based on the presence of animal tracks, scats, pellets, sightings and knowledge of local staff (Jhala et al., 2008; Karanth & Nichols, 2002; Ramesh et al., 2012) (Fig. 2.5). A single passive infrared camera trap (Cuddeback- White Series) was deployed per grid cell, maintaining a minimum inter-trap distance of ~500m. The survey was done in multiple phases (block-wise) using a total of 150 camera traps at a time and subsequently relocated to cover the entire study area across different land-use types. Cameras were positioned 30 cm above the ground and were operated for 22 days. At each camera location, GPS coordinates and habitat variables, including terrain, elevation, vegetation type, canopy cover, tree height, and distances to water sources, roads, and settlements, were recorded (Fig. 2.6).

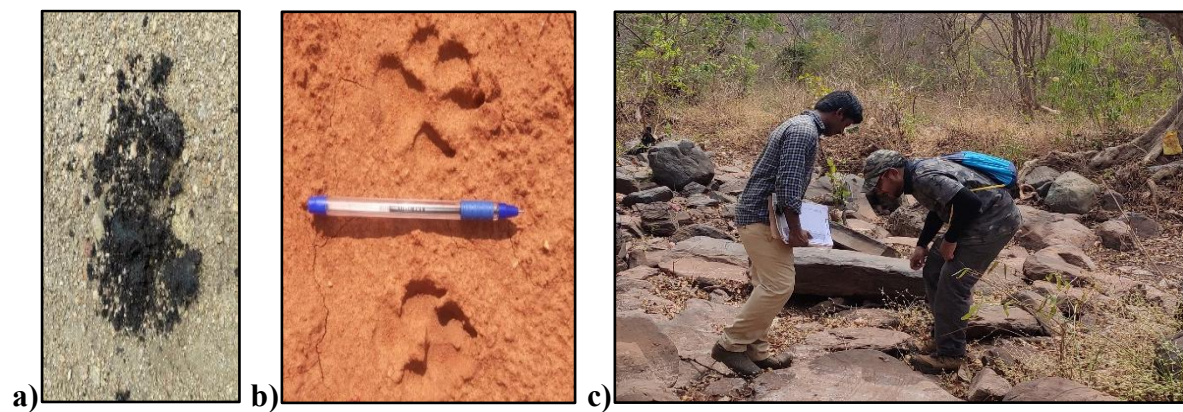


Figure 2.5: Field data collection through 'Mammalian sign survey' (Sign evidence- Sloth bear scat (a), Leopard pugmark (b), and photo of the field team conducting mammalian sign survey)



Figure 2.6: Camera trap placement: A camera trap placed on a well-used animal trail (left); Placing camera traps (right)

In each grid, I captured the microhabitat structure within a 20 m radius around each camera site. A foliage profile was subsequently developed for each site by visually estimating the percentage cover of different vegetation classes within the four quarters of each circular plot, with total coverage summing to 100% coverage per plot. The vegetation classes assessed included bare ground, grass cover, herbaceous vegetation (including seedlings), canopy cover, and woody vegetation (including saplings). In addition, tree stem density, vegetation type, and dominant tree species within that 20 m radius circular plot were recorded (Jhala et al., 2017; Ehlers Smith et al., 2017). Indicators of human disturbance (fire, lopping, grazing, cattle presence) were also documented within 20 m radius plot. In each 20 m radius plot, subplots (5 m and 1 m radius) were used to quantify shrubs, weeds, herbs, grasses, and ground cover (Jhala et al., 2017) (Fig. 2.7). Plant species were identified using standard field guides (Keystone Foundation, 2006; Balasubramanian et al., 2015).

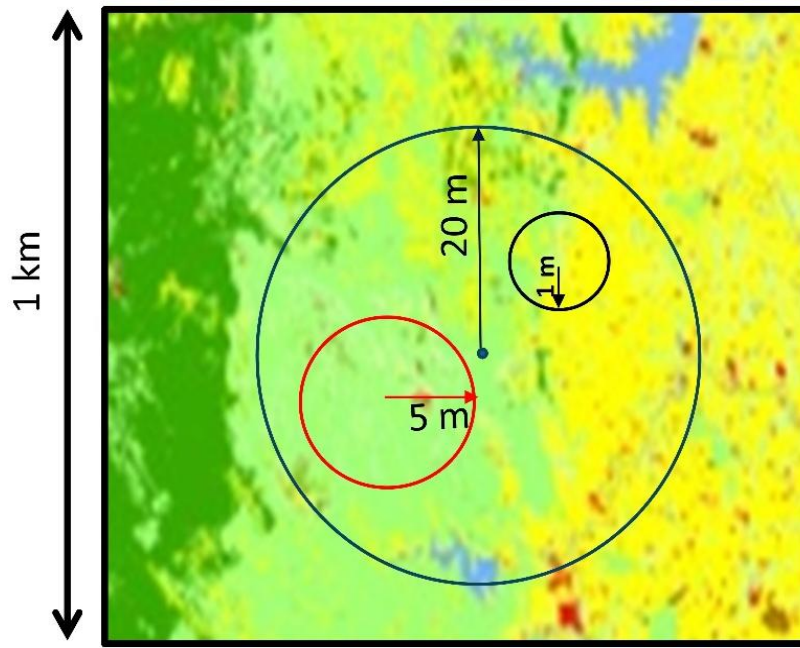


Figure 2.7: A diagram of the plot for the vegetation quantification survey in each sampling grid cell

2.6 Study species

Camera trapping survey at 1457 sampling sites, $n = 31,702$ trap-nights, yielded photographs of 24 wild mammalian species, along with records of livestock, dogs, and humans (Table 2.1; Fig. 2.8). Here, the leopard plays the role of apex predator. The mid-level predator guild comprised of Indian wolf, golden jackal, Indian fox, jungle cat and rusty-spotted cat. The sloth bear is the

flagship species, and the main prey species are wild pig and black-naped hare. Even though striped hyenas were sighted in some revenue lands of Ballari, none were recorded.

Table 2.1: List of wild mammalian species recorded during camera trapping survey in Ballari district, Karnataka, India

Sl. No.	Species	Biological name	IUCN status
1.	Leopard	<i>Panthera pardus</i>	VU
2.	Indian wolf	<i>Canis lupus</i>	VU
3.	Golden jackal	<i>Canis aureus</i>	LC
4.	Indian fox	<i>Vulpes bengalensis</i>	LC
5.	Jungle cat	<i>Felis chaus</i>	LC
6.	Rusty spotted cat	<i>Prionailurus rubiginosus</i>	VU
7.	Sloth bear	<i>Melursus ursinus</i>	VU
8.	Asian palm civet	<i>Paradoxurus hemaphroditus</i>	LC
9.	Small Indian civet	<i>Viverricula indica</i>	LC
10.	Ruddy mongoose	<i>Herpestes smithii</i>	LC
11.	Common grey mongoose	<i>Herpestes edwardsii</i>	LC
12.	Wild pig	<i>Sus scrofa</i>	LC
13.	Smooth-coated otter	<i>Lutrogale perspicillata</i>	VU
14.	Indian pangolin	<i>Manis crassicaudata</i>	EN
15.	Gray langur	<i>Semnopithecus dussumieri</i>	LC
16.	Bonnet macaque	<i>Macaca radiata</i>	LC
17.	Blackbuck	<i>Antelope cervicapra</i>	NT
18.	Indian gazelle	<i>Gazella bennetti</i>	LC
19.	Four-horned antelope	<i>Tetracerus quadricornis</i>	VU
20.	Indian crested porcupine	<i>Hystrix indica</i>	LC
21.	Black-naped hare	<i>Lepus nigricollis</i>	LC
22.	Indian palm squirrel	<i>Funambulus palmarum</i>	LC
23.	Indian gerbil	<i>Tatera indica</i>	LC
24.	Bandicoot rat	<i>Bandicota indica</i>	LC

EN- Endangered species, VU- Vulnerable species, NT- Near threatened species, LC – Least concerned species.



Figure 2.8: List of the wild mammalian species photographically recorded during camera trapping survey in Ballari district, Karnataka [Top or first row (Left-Right): Leopard, Indian wolf, Sloth bear, Golden jackal, Indian fox, and Jungle cat; Second row (L-R): Rusty-spotted cat, Small Indian civet, Asian palm civet, Ruddy mongoose, Common grey mongoose, and Smooth-coated otter; Third row (L-R): Gray langur, Bonnet macaque, Wild pig, Blackbuck, Indian gazelle, and Four-horned antelope; Fourth row (L-R): Black-naped hare, Indian pangolin, Indian crested porcupine, Indian gerbil, Indian palm squirrel, and Bandicoot rat]

CHAPTER 3

Land-Use Gradients Shaping Mammalian Communities

Chapter 3

Land-Use Gradients Shaping Mammalian Communities

3.1 Abstract

Human disturbance and land-use practices have a profound influence on community structure, habitat use and activity of mammals. It is critical to investigate both the ecological and anthropogenic determinants that drive these relationships. I examined the effects of land-use change and human presence on mammalian habitat use, activity patterns, and community composition. Using a landscape-scale camera-trapping survey, I deployed camera traps at 1,457 sampling grid cells across PAs, RFs, and FMFLs in Ballari district, India. I investigated the effect of 19 covariates related to habitat features, landscape-level human presence, climate, and local-level human presence on species habitat use by using single-season occupancy modelling. I further investigated the diel activity patterns and activity levels of mammals within different land-use types. Four species exhibited a net negative response to increasing human presence, while three species exhibited positive responses. Leopard and hare benefited from increasing proximity to farmlands and settlements, respectively, by increasing their habitat use. While increasing direct human presence negatively affected wild pig habitat use. Larger-bodied species had increased diurnal activity in PA and RF compared to FMFL, whereas smaller-bodied species had similar activity patterns across land-use types. Generalist meso-predators displayed increased diurnal activity in RFs and FMFLs. I also quantified the community-level responses to supplement these species-specific analyses. I computed relative abundance indices (RAI) of all mammalian species, estimated species richness and Shannon diversity indices across the three land-use types. I assessed community turnover between land-use types using Bray-Curtis dissimilarity. Species richness and diversity were found to be higher in PAs/RFs and lower in FMFLs, indicating the loss of disturbance-sensitive species along the land-use gradient. Bray-Curtis dissimilarity revealed moderate compositional differences among land-use types, with mammalian communities in PAs and RFs being most similar, whereas FMFLs were more dissimilar to both, reflecting community shifts in human-dominated landscapes. Ecological and life-history traits were major determinants of species responses to increasing human presence, favouring smaller and more generalist species. By integrating occupancy modelling, activity analysis, community-level metrics and GLM, my study provided comprehensive insights into the complex mechanisms by which human activities influence

mammal communities, offering important landscape level perspectives for conservation in human-modified ecosystems.

3.2 Introduction

Land-use changes and increased human activities are among the prominent drivers of ongoing biodiversity loss (Powers & Jetz, 2019; Suraci et al., 2021). These forces have a stark impact on mammalian species distribution and persistence (Polaina et al., 2019; Ramesh & Downs, 2015) and underlie the declining population size of many mammals (Baisero et al., 2020; Rondinini & Visconti, 2015). Mammals are especially susceptible to human disturbance due to their multiple ecological roles as predators, prey, and seed dispersers (Ripple et al., 2014). The ability of wild mammals to coexist with humans in human-dominated landscapes is influenced by a species' ecological and life-history traits (Gascon et al., 1999; Samia et al., 2015; Suraci et al., 2021). The resulting differential responses of species to human disturbance have a filtering effect at the community level, favouring disturbance-tolerant species that can adapt to modified landscapes (Bellon et al., 2022; Drouilly et al., 2018; Ehlers Smith et al., 2018; Penjor et al., 2021). These filtering effects manifest at the community level, resulting in turnover of species composition and biotic homogenization along land-use gradients, and such restructuring can be predicted from suites of species traits (Estes et al., 2011; Schmitz et al., 2018). Therefore, recognizing the impact of anthropogenically-induced modifications on wild mammals has become a vital aspect in biodiversity conservation at many scales, ranging from local to global.

Species survival and success in disturbed and modified landscapes are heavily influenced by their ecological and life-history traits (Galan-Acedo et al., 2019; Parsons et al., 2018). These traits interact with multiple anthropogenic stressors, changing species behavior and distribution (Doherty et al., 2021; Nickel et al., 2020). Specifically, human presence can induce fear responses that alter habitat use and suppress activity (Gaynor et al., 2018; Oberosler et al., 2017). Such changes are often influenced by body size, home range requirements, and trophic position (Clinchy et al., 2016; Suraci et al., 2021). Species with large home ranges are most vulnerable to habitat loss due to landscape transformation (Crooks et al., 2017; Milda et al., 2023; Ripple et al., 2014). Carnivores are very susceptible to human activities and habitat changes (Di Minin et al., 2016; Milda et al., 2023). In contrast, species that are habituated to human disturbance and can exploit anthropogenic food subsidies thrive in human-modified areas (Athreya et al., 2016; Wang et al., 2015). Species with traits like wide habitat type

tolerance, nocturnal lifestyle, and higher dietary flexibility can more easily adapt to modified landscapes (Larson et al., 2015; Newsome & Van Eeden, 2017; Šalek et al., 2015). Furthermore, prey species and meso-predators can benefit when human presence reduces local predation pressure (Crooks, 2002; Ordenana et al., 2010). Thus, identifying how functional traits of wild mammals influence their response to human disturbance can provide insights for conservation planning.

The importance of conserving biodiversity by creating Protected Areas (PAs) has been recognized by authorities around the globe (Dudley, 2008; Hockings, 2003). In India, PAs are wildlife sanctuaries that fall into IUCN category IV and include a very high degree of protection from poaching, grazing, and Non-timber Forest Product (NTFP) collection (Badola, 1999; Ghosh-Harihar et al., 2019). However, PAs only encompass a small fraction of the landscape, less than 5% of the overall landmass (Ghosh-Harihar et al., 2019). Consequently, PAs are only efficient in safeguarding a small proportion of diversity, as majority of species persist outside PAs (Schmitt et al., 2009). The non-protected forested areas in India are recognized as Reserved Forests, Community Reserves, and unclassed forests (Macura et al., 2011). Reserved forests (RFs), owned by state governments, cover 13.2% of India's landmass and often contribute to buffers and corridors for PAs (Ghosh-Harihar et al., 2019; Shahabuddin & Thadani, 2018). RFs have weaker safeguards against wildlife harvesting and livestock grazing by local people compared to PAs (Milda et al., 2020). Natural resource extraction is allowed in many RFs, putting additional pressure on these landscapes (Forest Survey of India, 2019). The degradation of natural habitats (PAs and RFs), together with the increasing expansion of agricultural land, has a strong adverse effect on biodiversity. Many mammalian species thrive in farmlands and forest remnants outside of PAs and RFs (Schmitt et al., 2009), which I refer to as Fringe Mosaic Farmlands (FMFLs) in this study. FMFLs represent the anthropogenic land-use mosaic of agricultural lands. Thus, FMFLs are prone to more human disturbances and have lower habitat heterogeneity than PAs or RFs. Assessing anthropogenic landscape variables related to land-use types within the multi-use landscape mosaic and their impact on species distribution and behaviour at different scales and time frames is critical for biodiversity conservation (Noon et al., 2012; Roland et al., 2013; McDonald et al., 2015).

Globally, the conversion of natural forests by humans into agricultural lands and other uses reduces species diversity, richness and lowers the occupancy of forest-dependent species (Gibson et al. 2011). In the Deccan Plateau of South Asia, dryland ecosystems are particularly vulnerable due to extensive fragmentation but nevertheless provide refuge for a range of

mammalian species (Karanth et al., 2009). Despite this, few studies have looked into how land-use gradients influence mammalian occupancy, activity, richness and community structure in semi-arid Indian landscapes, highlighting the need for research investigating factors shaping diverse mammalian community assemblages in less studied parts of the globe (Pardikar, 2020; Rowan et al., 2020). The landscape of the Ballari district, situated in the Deccan plateau of India is one of such less-studied areas which has undergone extensive land-use change during the last century. Specifically, mining activities within forested habitats, including more traffic from heavy vehicles, have increased (Intercultural Resources, 2014). Encroachment into forests from agrarian activities by locals, including heavy overgrazing, and the collection of NTFP collection, as well as poaching have increased (Behera et al., 2022a; Meena, 2013; Rudramuniyappa, 1997). All these activities exert intense pressure on the remnant forest patches, contributing to the decline of many mammalian species. These activities also raise the frequency of negative human-wildlife interactions in the form of livestock depredation, human injury or death, wild mammal mortality, and crop destruction (Martins-Oliveira et al., 2021; Meena, 2013; Sharp et al., 2020). Resolving increasing anthropogenic pressure and the associated decline of mammalian species in such disturbed ecosystems requires broad landscape-level studies. Such studies can help distinguish the key predictors of species extinction at the local level and identify solutions to help forest managers ensure effective wildlife conservation (Jones, 2011). I address a critical knowledge gap regarding the impact of anthropogenic and ecological factors on specific species in my study system to understand forces shaping the mammalian assemblage.

My first objective of the thesis aimed to determine how land use gradients shape mammalian communities in Ballari district, India. I examined the impact of anthropogenic disturbances and habitat characteristics on seven representative mammal species found within Ballari district using landscape-scale variables from four broad categories (habitat features, landscape-level human presence, climate, and local-level human presence). I report habitat use of black-naped hare, golden jackal, Indian fox, jungle cat, leopard, sloth bear, and wild pig. These species represent a wide range of functional traits like body sizes, diets, trophic positions, and home range sizes, making them suitable indicators for assessing functional responses to landscape modifications. To capture multi-scale responses to land-use change, I integrated species-specific, behavioural and community-level analyses. Predicted responses are provided in Table 3.1. Single-season occupancy models were used to evaluate habitat use in relation to habitat features, climate and anthropogenic covariates, while diel activity patterns and activity levels were compared across PAs, RFs and FMFLs. At the community level, I computed

relative abundance indices (RAI), assessed species richness and Shannon diversity and measures community turnover using Bray-Curtis dissimilarity. In addition, I used Generalized Linear Models (GLMs) to determine the key ecological and anthropogenic factors influencing species richness and diversity. My main objective is to understand how the combination of a species' functional traits influences its response to human activities. I predicted that species with larger body sizes, larger home range sizes, specialized diets and top carnivores, will be negatively affected by variables associated with landscape-level or local level human presence (Ripple et al., 2014). I predicted large-bodied and forest-dependant species to respond positively to natural habitat with dense canopy coverage (Andrade-Nunez & Aide, 2010), while small, disturbance-tolerant generalist meso-predators were predicted to display greater tolerance for increased human presence and availability of farmlands, reflected in higher occupancy and altered activity patterns (Katna et al., 2022). I expected the hare habitat use to be positively associated with PA. I predicted that disturbance-sensitive species would exhibit higher nocturnality and narrower activity windows in disturbed land-use type (FMFL), followed by RFs and PAs. I hypothesized that as human modification increased, species richness and diversity would decrease, with FMFLs having the lowest and PAs having the highest, and that mammalian communities would differ significantly between PAs and FMFLs, reflecting the turnover from specialist to generalist dominated assemblages.

Table 3.1: Predicted responses of functional traits of mammals to land use changes and the presence of humans and livestock

Predicted responses of wild mammals to human disturbances				
Functional Traits ↑ ↓		Landscape modification	Direct human presence	Livestock presence
	Large body size	(-)	(-)	(-)
	Nocturnal activity	(+)	(+)	(+)
	Generalist diet	(+)	(+)	(+)
	Specialist diet	(-)	(-)	(-)
	Large home range	(-)	(-)	(-)
	Carnivores	(-)	(-)	(+)

3.3 Methodology

Study area

I conducted the study within the jurisdictional area of the Ballari territorial forest division, which is located on India's Deccan Peninsula (between 14° 30' and 15° 50' North latitude and 75° 40' and 77° 11' East longitude; Fig. 3.1). The region lies between 550 and 750 m AMSL with the terrain varying from open plains to undulating areas with some patches of rugged hills (Meena, 2013). Average annual temperature varies between 20 and 40 °C. The study area comprises a mostly dry landscape with an average annual rainfall of around 574.9 mm (Meena, 2013). The central portion of the district contains tropical dry deciduous forests predominantly composed of species like *Albizzia amara*, *Chloroxylon swietenia*, *Hardwickia binata*, *Grewia tiliaefolia*, and *Azadirachta indica*. The other forested patches represent dry thorn forests with sparse vegetation (Champion & Seth, 1968), that are dominated by *Albizzia amara*, *Acacia catechu*, *Cassia auriculata*, *Euphorbia spp.*, and *Zizyphus spp.*). Vegetation is dictated by dry thorn (scrub) forests and dry deciduous forests, interspersed with agricultural mosaics.

Ballari is among the country's economically most vulnerable districts, and its economy is primarily based on mining and agrarian activities. For sustenance and economic prosperity, the locals maintain large cattle populations and are highly dependent on NTFP collection. The district contains rich deposits of economically important minerals such as iron and manganese (Meena, 2013). More than 5000 ha of land within the study area is actively mined, with most of the mines situated within RFs.

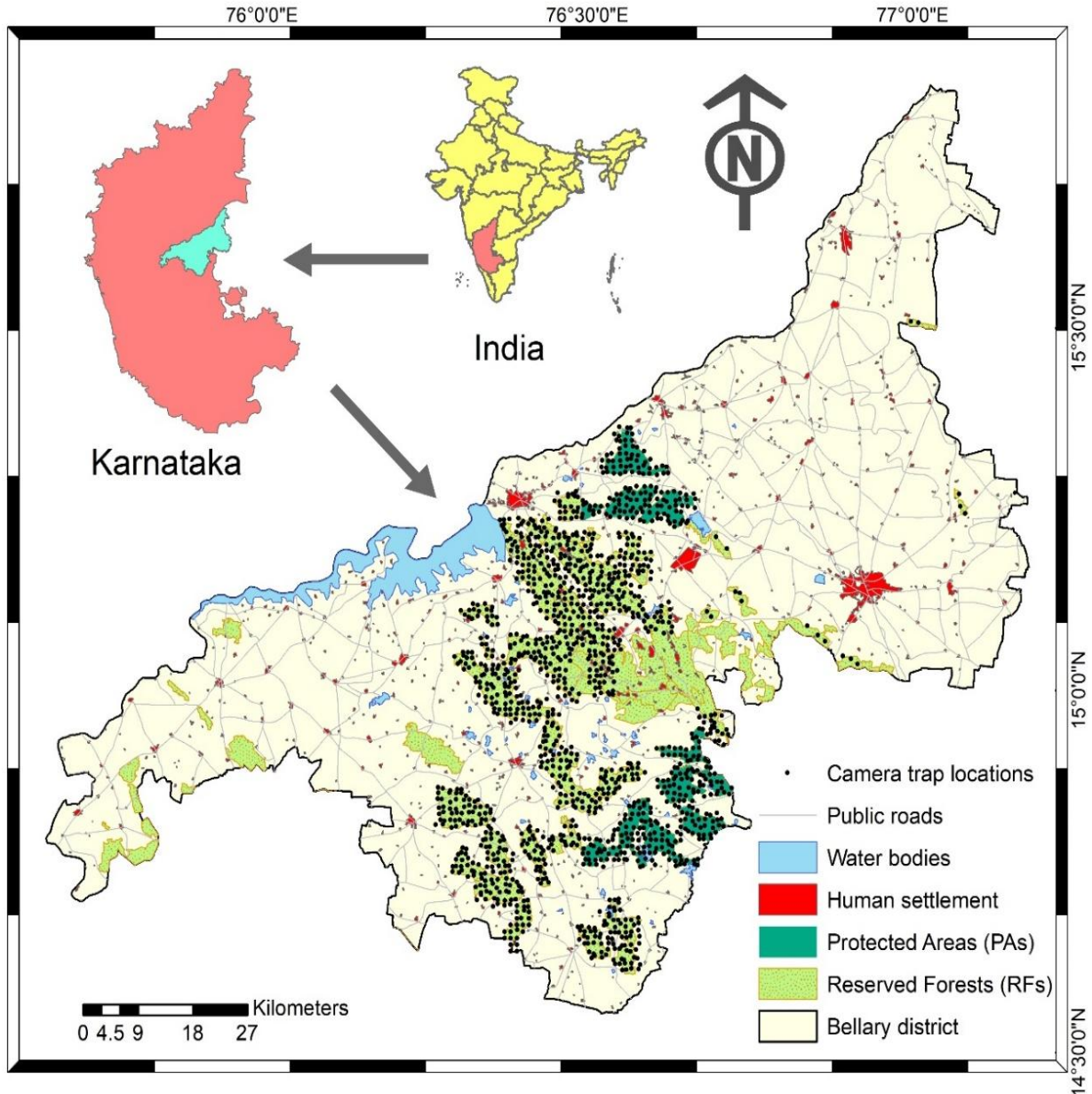


Figure 3.1: Camera trap locations of the survey area in Ballari district, Karnataka, across Protected Areas (PAs), Reserved Forests (RFs) and the adjoining fringe mosaic farmlands (FMFL) (Camera traps located outside PAs/RFs, are the traps located in FMFL)

Data collection and analysis

Camera trapping data were collected within the forested areas of Ballari district including PAs [Daroji (est. 1994) and Gudekote (est. 2013) Sloth bear sanctuaries], RFs, and FMFL (a 1 km buffer surrounding forest boundaries). I established a camera trapping grid composed of 1 km² cells as sampling units by overlaying a 1 × 1 km² grid across the study areas using ArcGIS 10.1 (ESRI, Redlands, CA, USA). I used a land-use land-cover layer that I procured from the Karnataka Forest Department to identify the land-cover types in the study area.

Camera-trapping surveys were conducted to collect occurrence data during a period of 21 months between January 2019 and October 2021. Within each 1 km² grid cell, I walked for at least 1 km inside the grid cell, identifying the best potential camera sites based on mammalian sign evidence (sightings, scats/pellets, and tracks of mammals) (Jhala et al., 2008; Kalle et al., 2013; Karanth & Nichols, 2002; Ramesh et al., 2012). I installed a single passive infrared camera trap (Cuddeback digital 20MP Blue Series, USA) at each sample site within each grid cell. Camera traps were fitted 30 cm above the ground level and placed along dirt roads, animal trails, rivers, and stream beds, near water holes, etc., that are commonly used by the study species. A minimum distance of approximately 500 m was maintained between any two cameras to ensure spatial independence of my samples. In total, I sampled 1457 grid cells, including 251 grid cells within PAs, 756 grid cells within RFs, and 450 grid cells within FMFL. The number of sampling sites per land-use type was proportional to the occurrence of those land-use types within the study area. I deployed 142–145 camera traps simultaneously and shifted those cameras to other grid cells throughout the study period. I set camera traps (30s motion-triggered delay setting) to run continuously for 22 days within each grid cell and collected data weekly. In each camera trap location, I visually estimated the percentage of canopy coverage, tree density, percentage of rockiness, and shrub coverage within a circular plot with a radius of 20 m (Table 2). After retrieving photos from the camera traps, I measured local-level human presence at each site using four proxies: relative abundance index (RAI) of humans (on foot or in vehicles), cattle, goats-sheep, and domestic dogs. I calculated RAI of a species as the total number of independent (one photograph with 30 min intervals) photographs of that species divided by the total number of camera trap-nights at that location (Palmer et al., 2018; O’Brien et al., 2003).

$$RAI = \left(\frac{\text{Number of independent detections}}{\text{Total trap nights}} \right) * 100$$

I estimated proximity variables like proximity to road, settlements, farmlands, etc. using verified spatial layers like GRIP global roads database, and Roy et al., 2015 (after converting these rasters into shapefiles) and the Euclidean distance tool in ArcMap 10.3 (Arc-Map 10.3, Software. Redlands, CA: Esri Inc, 2016). Details for the covariates are provided in Table 2.

Mammalian Community

In total, 24 wild mammals were recorded during the camera-trapping survey across three land-use types. Seven focal species, i.e. the black-naped hare, golden jackal, Indian fox, jungle cat, leopard, sloth bear, and wild pig were chosen for occupancy modelling and activity pattern analyses based on detection consistency, ecological relevance and representation of different trophic and body size classes. These species served as indicators of habitat use patterns and mammalian responses to anthropogenic disturbance, while the remaining species contributed to analysing community richness, diversity and relative abundance across the land-use types.

Relative Abundance Index

The RAI was determined for 24 mammals across land-use types (PA vs RF vs FMFL) using the formula explained earlier. RAI values were used descriptively to compare relative abundance patterns of mammalian species across the three land-use types.

Community Structure and Diversity

To assess landscape-level mammalian community responses, I estimated species richness and Shannon diversity per sampling site based on detection counts. Species richness was measured by counting the number of distinct mammals found at each site, and Shannon diversity was calculated using the `diversity()` function in the “vegan” package in R 4.4.3 (Oksanen et al., 2019). Richness and Shannon diversity were calculated for each land-use type. Non-parametric Kruskal-Wallis tests were used to evaluate differences in richness and diversity across land-use types, as the distributions of the response variables are non-normal. Post-hoc pairwise comparisons were carried out using Dunn’s tests with Bonferroni correction.

To determine the environmental and anthropogenic drivers influencing mammalian communities, variations in species richness and Shannon diversity were modelled as functions of multiple habitat and disturbance covariates. The predictor variables considered in the analysis included land-use types (PA, RF, and FMFL), canopy coverage, tree density, proximity to farmland, proximity to human settlements, human RAI, dog RAI, and livestock RAI. Together, these variables provided a complete framework for assessing how environmental and human disturbance influence mammalian community patterns across the landscape. Species richness, as a count variable, was modelled using a GLM with a negative binomial error distribution using the `glm.nb()` function in R 4.4.3 (McCullagh, 2019). This choice was made following preliminary analysis that revealed overdispersion in the Poisson

model. Shannon diversity (continuous variable) was log-transformed to improve normality and homoscedasticity before analysis. The transformed diversity was then analyzed with a Gaussian GLM {glm() function} to assess the effects of predictor variables on community diversity. I verified multicollinearity among predictor variables and selected variables with an acceptable Variance Inflation Factor (VIF) values and ecological importance using “car” package (Fox et al., 2012). To determine the best-supported models, model selection was performed using the Akaike Information Criterion corrected for small sample size (AICc) framework through “MuMIn” package (Barton, 2022). Models with $\Delta AICc \leq 2$ were considered (Burnham & Anderson, 2002). Community dissimilarity among land-use types was quantified using the Bray-Curtis index in ‘vegan’ package of Program R, to assess variation in species composition and the extent of biotic homogenization across the land-use mosaic (Oksanen et al., 2019).

Habitat use and detection probability

I considered 21 predictor variables estimated from camera sites to be important to the study species. I categorised these variables into- (1) Habitat features, comprising naturally occurring features or habitat characteristics; (2) Landscape-level human presence, comprising features associated with varying degrees of human footprint and landscape management; (3) Climate, comprising two climatic features; and (4) Local-level human presence, comprising the RAI of humans, dogs, and livestock at camera stations (Appendix S1).

Considering the average home range size of the study species [hare: 0.01–0.02 km² (Kirk & Bathe, 1994), jackal: 3.1–23.7 km² (Katna et al., 2022), fox: 1.16–10.71 km² (Katna et al., 2022), jungle cat: 1.01–26.48 km² (Katna et al., 2022), leopard: 8–65 km² (Odden et al., 2014), bear: 12–85 km² (Yoganand et al., 2005), and wild pig: 0.62–48.3 km² (Garza et al., 2018), I interpreted occupancy estimates as habitat use because the home ranges of some of my study species are larger than the grid cell size used. This interpretation of my results as probability of habitat use, and not probability of occupancy at each sampling unit is done to in part minimize the impact of likely violation of the assumption of closure (Burton et al., 2015). I treated each camera site as an independent sample and sampling occasion as a temporal repeat of the survey. In my analyses, I assumed the habitat use of a species to be independent of other species. I developed ‘0’-‘1’ matrices for each species. Rows represented sample locations and columns represented daily sampling occasions. Detection and non-detection during successive sampling occasions were respectively indicated with ‘1’ and ‘0’ in this matrix (Otis et al.,

1978). I used a single-season occupancy model to estimate site occupancy/habitat use (ψ) and detection probability (p) of study species (MacKenzie et al., 2017) using the package “unmarked” (Fiske & Chandler, 2011) in program R (R Core Team, 2020). Prior to modelling, I standardized all continuous site covariates to z-scores, allowing model coefficients to be interpreted as the change in the log-odds ratio of habitat use relative to a 1-standard deviation change in a covariate from its mean (Cooch & White, 2005). To avoid multi-collinearity issues, I tested the correlations among independent variables (Graham, 2003) using Pearson’s correlation coefficient (Fig. 3.2) using the package “corrplot” in program R and didn’t use highly correlated variables ($r > 0.60$) in the same model (Wei & Simko, 2021). I removed a few highly correlated independent variables (decidist: proximity to deciduous forests and FMFL: fringe mosaic farmlands) before modelling. Details on the selection of relevant variables to estimate habitat use and detection probability in my models are provided in Table 2. I followed stepwise model selection procedures and the goodness of fit for model selection as described in Burnham & Anderson (2002) and ranked the models using AIC. I considered the models with the lowest AIC values ($\Delta AIC \leq 2$) as the best descriptors of species habitat use and detection probability among candidate models (Burnham & Anderson, 2002).

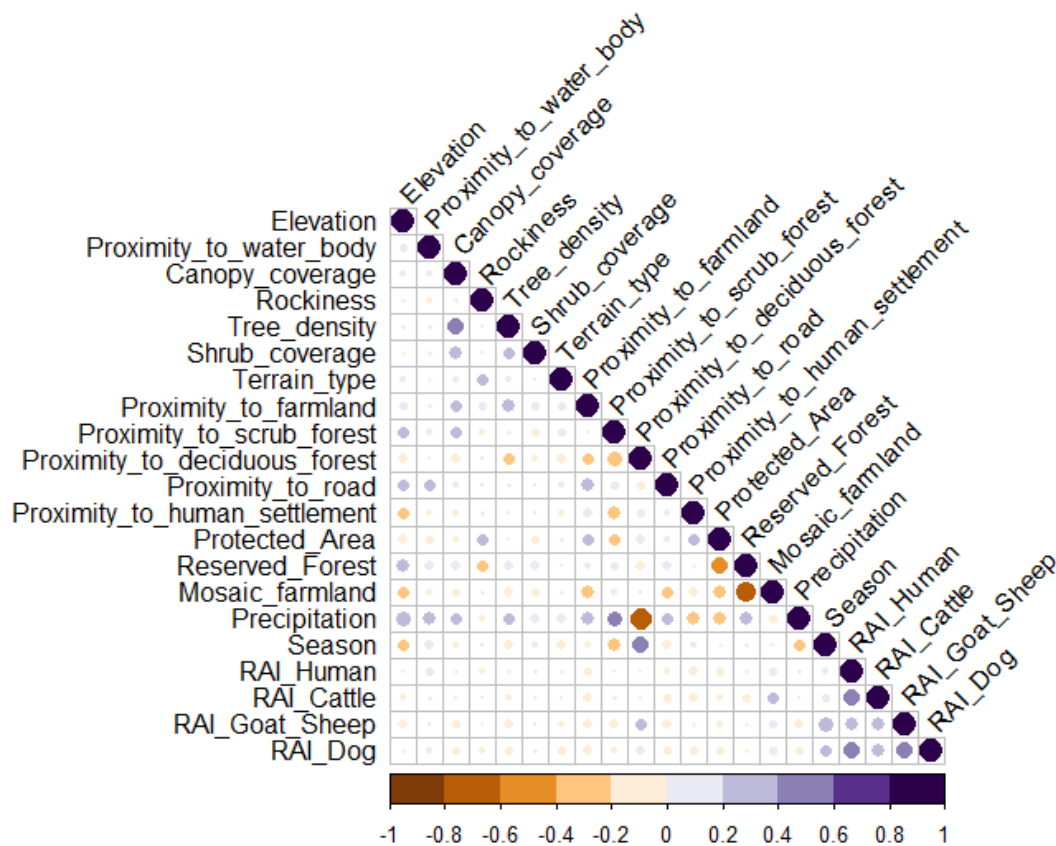


Figure 3.2: Pearson’s correlation coefficient of all covariates on occupancy of mammalian species in the study sites (RAI: Relative Abundance Index)

Activity patterns and activity levels

I investigated the diel activity patterns for the seven focal species across three land-use types. The activity patterns of a species are the temporal data that provide information on the diel trends of its actions (Gerber et al., 2012). Studying activity patterns provides insight into the ecological processes that shape the space use by an animal community (Houngbegnon et al., 2020). I subsampled the detection data, treating consecutive detections within a 30 min span as a single event (Meek et al., 2014; Zimmermann et al., 2016). I segregated all independent events of a species into three categories for activity pattern analysis based on land use type (Table 1). Then I performed pairwise comparisons of activity patterns of species between all three land use types (PA vs. RF, RF vs. FMFL, and FMFL vs. PA) by estimating the overlap coefficient Δ (ranging from 0 to 1 i.e., no overlap to complete overlap) and its confidence interval (Ridout & Linkie, 2009). I performed statistical analyses and produced Kernel density estimation curves using the ‘Overlap’ package (Meredith & Ridout, 2016) in Program R 4.0.5 (R Core Team, 2020). Kernel density estimation is a non-parametric approach used to estimate the probability density function of activity records (Linkie & Ridout, 2011). Activity level of a species is the proportion of time that the species spends being active during an entire day (Rowcliffe et al., 2014). This method assumes that all individuals in the sampled population are active at the peak of the daily activity cycle. I used the function `compareAct()` in the package “Activity” Program R 4.0.5 (R Core Team, 2020) to conduct a Wald test for the statistical difference between two or more activity level estimates. I quantified the activity level estimates of focal species in the different land-use types.

3.4 Results

Camera trapping survey at 1457 sampling sites, $n = 31,702$ trap-nights, yielded photographs of 24 wild mammalian species, along with records of livestock, dogs, and humans (Fig. 3.3).

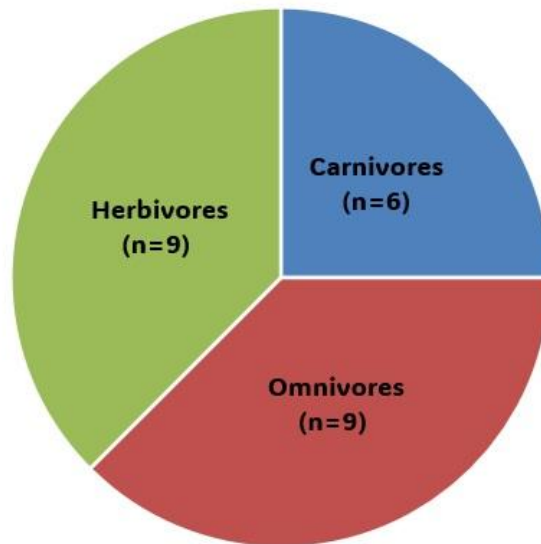


Figure 3.3: Mammalian species of different trophic levels in Ballari district, Karnataka

Relative Abundance Index

Total Relative Abundance Index (RAI) varied from 0.01 for Indian pangolin to 41.98 for black-naped hare, with RAI patterns revealing marked differences across the three land-use types (Table). Forest-dependent species like the sloth bear and leopard were primarily observed in PAs, with leopards also frequently detected in RFs. Generalist carnivores like the Indian wolf, jackal, fox and civets occurred more frequently in RFs. Smaller and habitat-flexible species, including the jungle cat, rusty-spotted cat and mongooses, were mostly recorded around FMFLs and RFs. The black-naped hare and wild pig, two major prey and poached species, had the highest RAI in PAs, followed by RFs, and the lowest in FMFLs (Fig. 3.4).

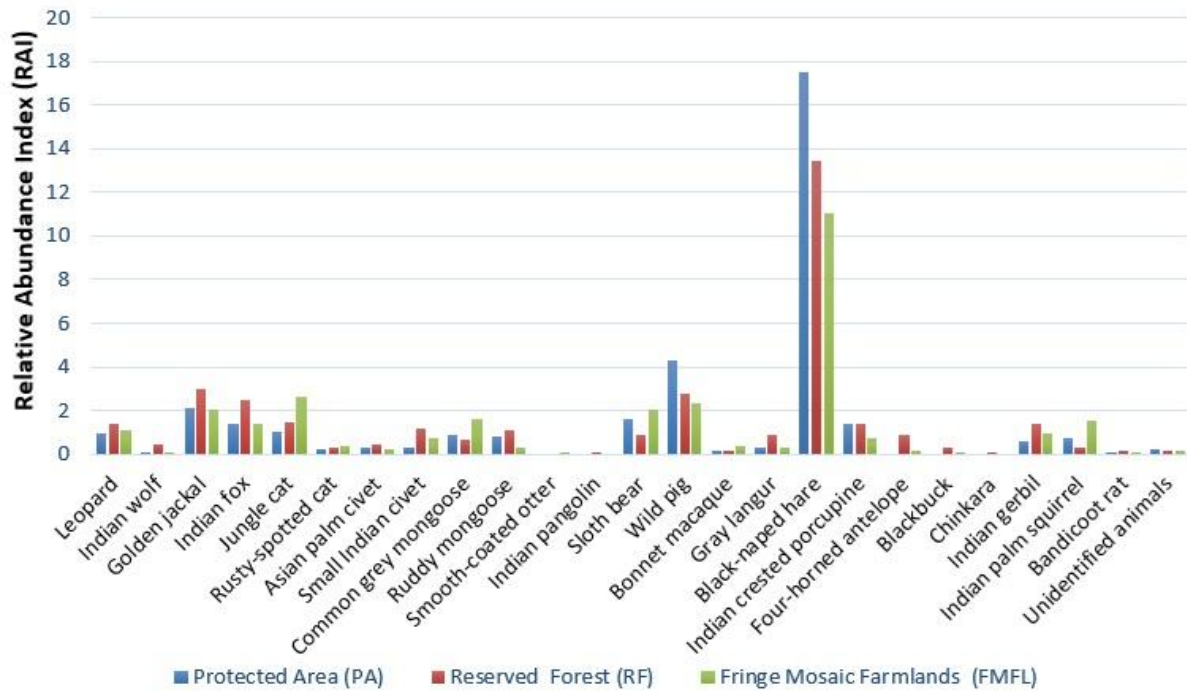


Figure 3.4: Relative Abundance Index (RAI) of the study species in Ballari, Karnataka, across land-use types [(Protected Areas: PA vs Reserved Forests: RF vs Fringe mosaic farmlands: FMFL)]

Species Richness and Diversity

The three land-use types showed modest variations in species richness and Shannon diversity (H') (Fig. 3.5). While FMFLs displayed the lowest values (Mean richness = $2.19 \pm 1.69_{SD}$; mean $H' = 0.551 \pm 0.54_{SD}$), RFs had the highest values for both metrics (Mean richness = $2.54 \pm 1.83_{SD}$; mean $H' = 0.654 \pm 0.54_{SD}$) and PA had slightly lower values (Mean richness = $2.51 \pm 1.75_{SD}$; mean $H' = 0.637 \pm 0.52_{SD}$). Slightly lower richness values of PAs could be due to less sampling effort in PAs compared to RFs. The observed pattern indicates a decline in mammalian diversity along the land-use gradient from less disturbed forest to human-dominated farmlands. The Kruskal-Wallis test showed significant differences in species richness among land-use types ($\chi^2 = 11.897$, $df = 2$, $p = 0.003$). Post-hoc Dunn's test indicated that richness was significantly higher in PAs and RFs compared to FMFL ($p < 0.05$), and significant difference between PAs and RFs. A similar pattern was observed for Shannon diversity ($\chi^2 = 10.958$, $df = 2$, $p = 0.004$).

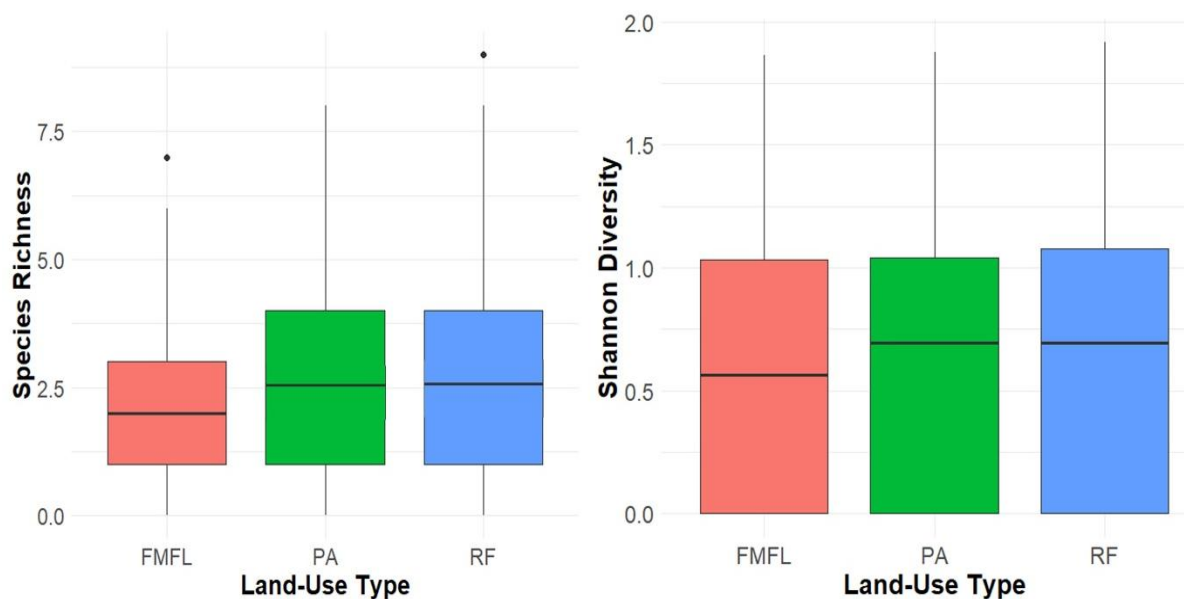


Figure 3.5: Mammalian Richness and Diversity in Ballari, Karnataka, across Protected Areas (PAs), Reserved Forests (RFs) & Fringe Mosaic Farmlands (FMFLs)

GLMs revealed significant influence of land-use type and environmental variables on mammalian richness and diversity (TABLE Supplementary). Richness increased with canopy cover and human abundance but decreased with livestock abundance (TABLE a). PAs ($p = 0.021$) and RFs ($p = 0.017$) had significantly higher richness than FMFLs. Shannon diversity showed similar trends, with diversity increasing with canopy cover and human abundance, but had a weak negative effect of livestock ($p = 0.096$). PAs ($p = 0.020$) and RFs ($p = 0.012$) showed greater diversity than FMFLs (Table 3.2).

Table 3.2: Beta estimates of explanatory covariates from the top models for species richness and Shannon diversity in Ballari district, Karnataka

Richness - Explanatory covariates from the top model			
Covariate	β Estimate	SE	p -value
Intercept	0.797	0.036	0.000
canopy	0.112	0.017	0.000
human	0.062	0.020	0.002
LandUsePA	0.135	0.058	0.021
LandUseRF	0.108	0.045	0.017
livestock	-0.049	0.023	0.032

Diversity - Explanatory covariates from the top model			
Covariate	β Estimate	SE	<i>p</i> -value
Intercept	0.386	0.016	0.000
canopy	0.047	0.009	0.000
human	0.026	0.010	0.011
LandUsePA	0.064	0.027	0.020
LandUseRF	0.052	0.021	0.012
livestock	-0.017	0.010	0.096

Bray-Curtis dissimilarity analysis revealed moderate compositional variation in the mammalian community across land-use types (Fig. 3.6). PAs and RFs shared the greatest similarity (0.192), whereas FMFLs showed greater dissimilarity to both, i.e. PAs and RFs, reflecting mammalian community shifts in human-dominated landscapes.

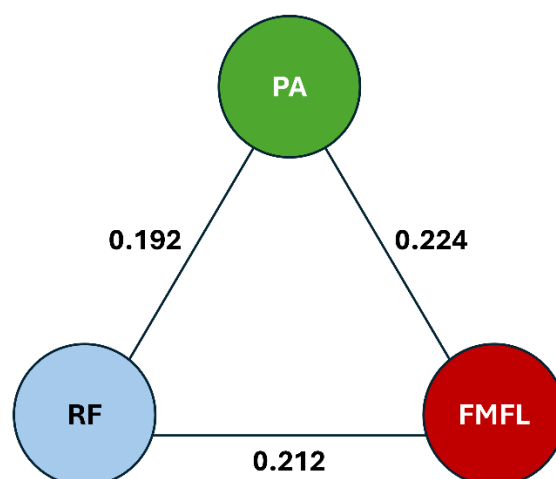


Figure 3.6: Bray-Curtis dissimilarity Index: Protected Areas (PAs) vs Reserved Forests (RFs) vs Fringe mosaic farmlands (FMFLs) in Ballari, Karnataka, India

Habitat use and detection probability

I conducted occupancy analysis for seven wild mammalian species that are widely distributed across my study site and for which I had sufficient data for occupancy analysis (MacKenzie et al., 2017). I didn't include some species for analysis as they occurred in low densities (Neilson et al., 2018). Hare had the highest naive occupancy 0.528, followed by wild pig = 0.318, jungle cat = 0.217, jackal = 0.203, fox = 0.189, leopard = 0.173, and bear = 0.15. I determined the best fit models for each species, and their log-transformed parameter estimates of habitat use

Ψ and detection probabilities p , with detailed results listed in Table 3.3; Fig. 3.7, respectively. The summary of AIC model selection and parameter estimates of habitat use and detection for the study species are listed in supplementary tables S2-S8. The number of covariates influencing patterns of habitat use and detection probability in top models ($\Delta AIC \leq 2$), ranged from 4 to 8 across the study species (Table 3). Estimates of habitat use Ψ with standard errors varied from 0.239 ± 0.023 to 0.538 ± 0.028 across study species and models (Fig. 2). Hares had the highest estimates for habitat use. Wild pigs had the second highest habitat use after hares (Fig. 2). Jackals, foxes, and sloth bears had lower habitat use compared to other study species (Fig. 2). Hares had the highest detection probability, followed by jackals and foxes (Fig. 2). The residuals of the top models for jackal, fox, jungle cat, and hare did not exhibit any spatial autocorrelation [Moran's I for jackal = 0.0006 ($P = 0.38$); fox = -0.0026 ($P = 0.82$); jungle cat = 0.0009 ($P = 0.17$); and hare = -0.0007 ($P = 0.84$)]. However, top model residuals for leopard, bear, and wild pig documented some spatial autocorrelation [Moran's I for leopard = 0.0066 ($P = 0.00$); bear = 0.0108 ($P = 0.00$); and pig = 0.0022 ($P = 0.03$)].

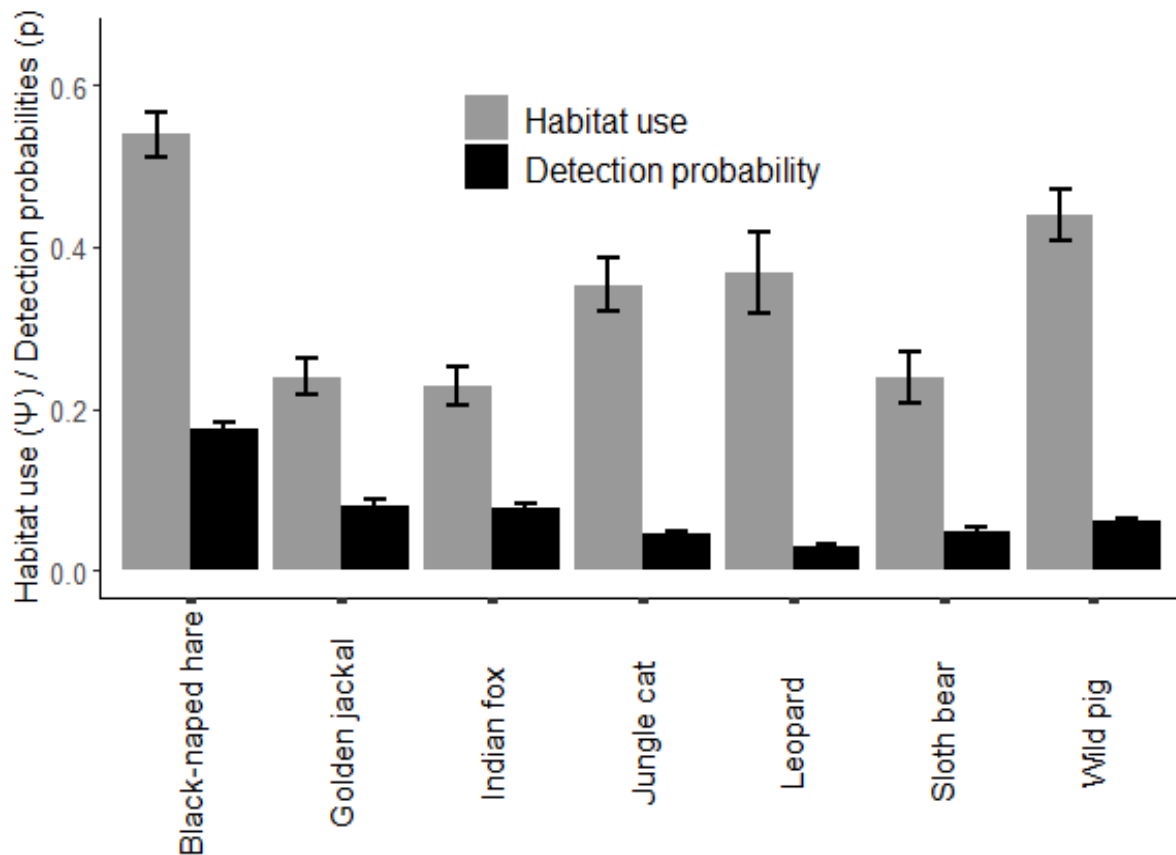


Figure 3.7: Habitat use and detection probabilities of study species present in Ballari district, Karnataka

Table 3.3: Best-fit logistic models based on the Akaike Information Criterion scores for predicting the habitat use and detection probability of seven mammal species

Species	Top Model(s)	AIC	Δ AIC	AIC Weight	No. Par.
Black-naped hare	p (~farmdist + settlement + elevation + preci) Ψ (~settlement + elevation + preci + PA)	17943.66	0.00	0.77	10
Golden jackal	p (~farmdist + season + preci) Ψ (~preci + RF + dog)	5635.96	0.00	0.66	8
Indian fox	p (~terrain + road) Ψ (~scrubdist + rockiness + RF + preci)	4899.16	0.00	0.71	8
Jungle cat	p (~scrubdist + farmdist) Ψ (~human + elevation)	4887.23	0.00	0.65	6
Leopard	p (~terrain + season) Ψ (~preci + canopy + waterbody)	3703.19	0.00	0.85	7
Sloth bear	p (~waterbody + human) Ψ (~cattle + PA + canopy + scrubdist)	3722.90	0.00	0.75	8
Wild pig	p (~goatsheep + PA + shrub) Ψ (~preci + canopy + human)	7363.58	0.00	0.71	8

Abbreviations: I listed all models with an Δ Akaike Information Criterion $\Delta AIC < 2.00$, number of parameters No. par., AIC Weight., proximity to agricultural land ‘farmdist’, proximity to the nearest extent of scrub forest ‘scrubdist’, elevation at the camera site ‘elevation’, type of terrain (undulating/plain) ‘terrain’, rocky coverage of at the camera trapping grid ‘rockiness’, percentage of canopy coverage at the camera site ‘canopy’, proximity to the natural water source ‘waterbody’, proximity to human settlement ‘settlement’, proximity to the public road ‘road’, camera sites in PAs “PA”, camera sites in RFs ‘RF’, mean annual precipitation ‘preci’, type of season (wet/dry) ‘season’, relative abundance index of human ‘human’, relative abundance index of cows and buffaloes ‘cattle’, relative abundance index of goats and sheep ‘goatsheep’, relative abundance index of free-ranging dogs ‘dog’

I found that variables related to human presence whether at landscape level or local level, were associated with the study species habitat use. Proximity measures like distance to human settlements and agricultural farmlands were positively associated with the habitat use of hares and leopards, respectively. Distance to major water bodies was positively associated with the habitat use of leopards. Variables associated with local-level human presence were negatively associated with wild pig habitat use while they were positively associated with habitat use by jackals and jungle cats. Habitat use of bears and hares was highest in PAs while the habitat use of jackals and foxes was highest in RFs. Unexpectedly, relative cattle abundance emerged as an important predictor for increased habitat use of bears. Canopy coverage and mean annual precipitation were the two common predictors across top models for three and five species,

respectively (Fig. 3.8a and 3.8b; Appendices S2-S8). The dense canopy coverage positively influenced the habitat use of leopards, bears, and wild pigs. Mean annual precipitation positively influenced the habitat use of hares, leopards, and wild pigs, while it had a negative impact on the habitat use of jackals and foxes. The availability of plains positively influenced the habitat use of hares and jungle cats. Proximity to the farmlands was the most prevalent covariate for the detection probability. Higher detection probabilities for jackals and jungle cats were associated with close proximity to farmlands, while this significant trend was reversed for hares.

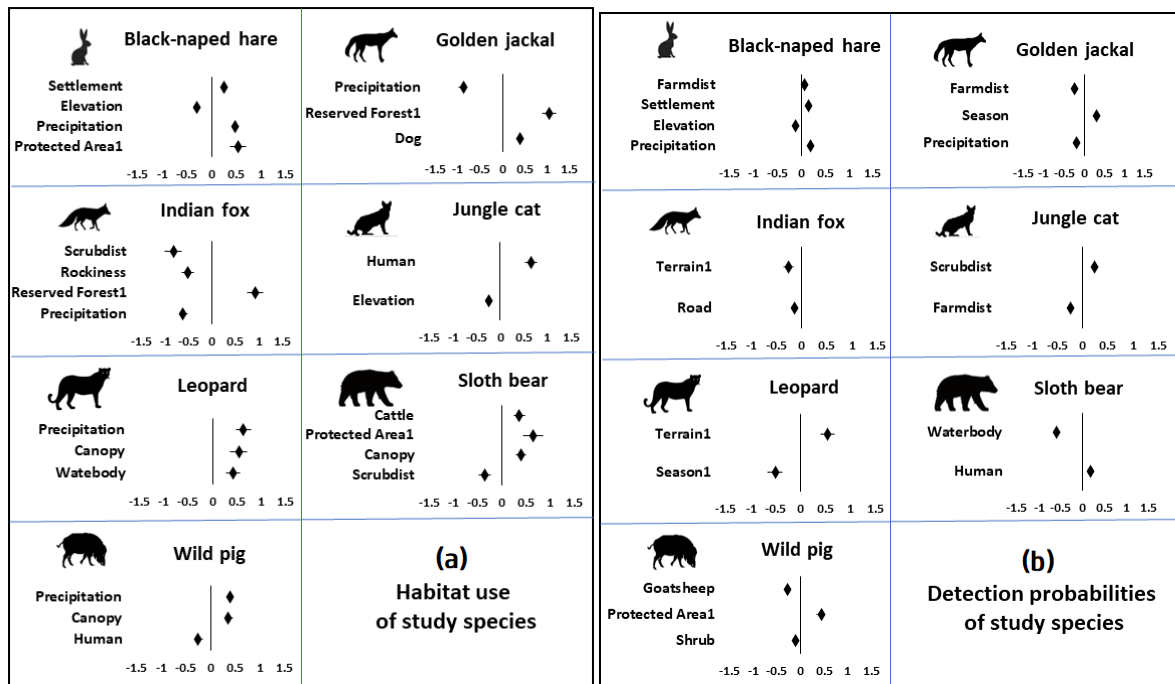


Figure 3.8: Log-transformed parameter estimates for explanatory variables from the top (a) habitat use and (b) detection probability model for mammalian species of the study area

Activity patterns and activity levels

Activity patterns were generated using detection data of study species (Table 3.4), and they showed species-specific variation across the three land use types (PA vs. RF, RF vs. FMFL, and FMFL vs. PA) (Fig. 3.9). Activity patterns of all species showed bimodal peaks, with the first peaks occurring between late evening and midnight, while the second peaks occurred during early mornings. Hares and jungle cats exhibited similar activity patterns across three land use types. Activity patterns of hares in RF and FMFL were very similar to each other, with the mean kernel temporal overlap coefficient estimate of 0.94 (Table 3.5). Jackals and foxes had higher diurnal activities in RF and FMFL than in PA (Fig. 3.9; Table 3.5). While leopards,

sloth bears, and wild pigs had higher diurnal activity patterns in forested habitats like PA/RF than in FMFL (Fig. 3.9; Table 3.5). Activity level estimates of all study species varied across land use types. The activity level of sloth bears and hares in PAs and RFs was significantly higher than in FMFL (Table 3.6). Leopards, jackals, wild pigs, and hares had significantly higher activity levels in PAs/RFs, relative to FMFL (Table 3.6). Foxes had significantly higher activity levels in RFs, relative to PAs/FMFLs, while there was no significant difference in activity level estimates for jungle cats across land-use types.

Table 3.4: List of study species with their important functional traits and the number of independent photographs across land-use types. Protected Areas (PAs), Reserved Forests (RFs) and Fringe Mosaic Farmlands (FMFLs)

Sl. No.	Species	Functional traits (Body-size - Home range - Diet - Activity)	No. of individual photographs across land-use types		
			PAs	RFs	FMFLs
1	Black-naped hare	Small- Small- Herbivore- Crepuscular/Nocturnal	972	2272	1111
2	Golden jackal	Small- Small- Omnivore- Nocturnal	125	491	203
3	Indian fox	Small- Small- Omnivore- Crepuscular/Nocturnal	77	402	146
4	Jungle cat	Small- Small- Carnivore- Typically diurnal	59	238	264
5	Leopard	Large- Large- Carnivore- Nocturnal	54	245	109
6	Sloth bear	Large- Medium- Omnivore- Mostly nocturnal	95	151	206
7	Wild pig	Large- Medium- Mostly herbivore- Diurnal	236	466	696

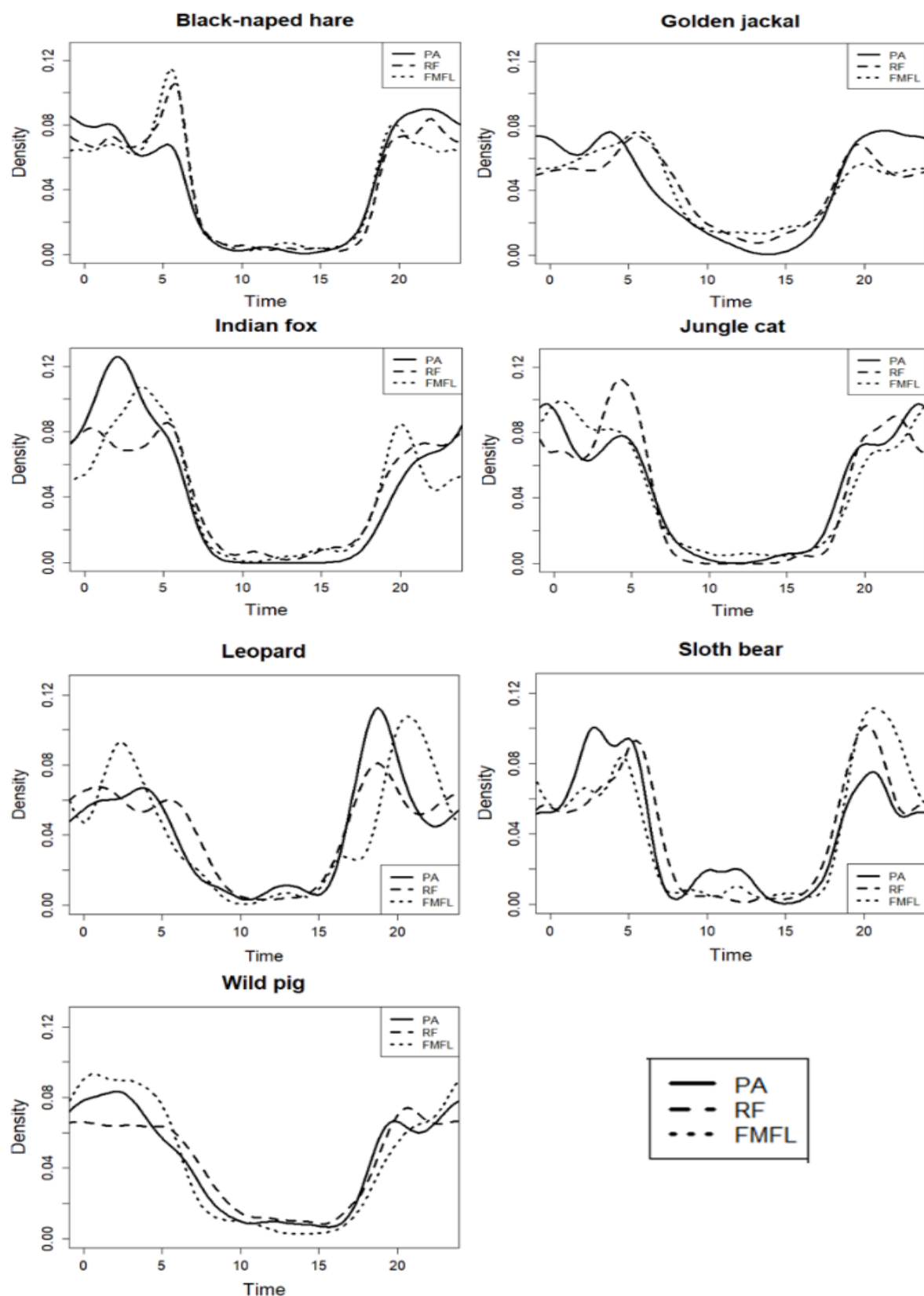


Figure 3.9: Comparison of diel activity patterns of focal species across different land-use types [Protected Areas (PAs) vs Reserved Forests (RFs) vs adjoining fringe mosaic farmlands (FMFL) in Ballari, Karnataka

Table 3.5: Temporal overlap coefficient estimates of study species across land use types (pairwise)

Species	PA vs RF	RF vs FMFL	FMFL vs PA
Black-naped hare	0.90	0.94	0.88
Golden jackal	0.85	0.94	0.85
Indian fox	0.84	0.87	0.83
Jungle cat	0.87	0.85	0.90
Leopard	0.87	0.78	0.79
Sloth bear	0.84	0.87	0.82
Wild pig	0.91	0.85	0.90

Land-use types: PA = Protected Areas, RF = Reserved Forests & FMFL = Fringe Mosaic Farmlands

Table 3.6: Comparison of activity level estimates of seven study species across three land use types

Species	Activity level (With standard error)	Activity level comparison			
		Difference	Standard error	Wald test	p-value
Black naped hare	PA: 0.463 ± 0.012	PA vs RF: 0.069	0.022	9.837	0.001
	RF: 0.393 ± 0.017	PA vs FMFL: 0.100	0.018	28.446	0.000
	FMFL: 0.362 ± 0.013	RF vs FMFL: 0.031	0.022	1.902	0.167
Golden jackal	PA: 0.463 ± 0.020	PA vs RF: 0.069	0.037	3.340	0.067
	RF: 0.393 ± 0.031	PA vs FMFL: 0.100	0.035	7.920	0.004
	FMFL: 0.362 ± 0.028	RF vs FMFL: 0.031	0.042	0.530	0.466
Indian fox	PA: 0.330 ± 0.042	PA vs RF: - 0.156	0.048	10.328	0.001
	RF: 0.486 ± 0.023	PA vs FMFL: - 0.056	0.061	0.839	0.359
	FMFL: 0.387 ± 0.045	RF vs FMFL: 0.099	0.050	3.811	0.050
Jungle cat	PA: 0.427 ± 0.060	PA vs RF: 0.056	0.071	0.636	0.425
	RF: 0.370 ± 0.037	PA vs FMFL: 0.008	0.061	0.017	0.895

	FMFL: 0.419 ± 0.009	RF vs FMFL: - 0.048	0.038	1.598	0.206
Sloth bear	PA: 0.413 ± 0.056	PA vs RF: 0.003	0.065	0.003	0.952
	RF: 0.409 ± 0.032	PA vs FMFL: 0.039	0.067	0.352	0.552
	FMFL: 0.373 ± 0.036	RF vs FMFL: 0.036	0.049	0.537	0.463
Leopard	PA: 0.370 ± 0.085	PA vs RF: - 0.143	0.098	2.109	0.146
	RF: 0.514 ± 0.048	PA vs FMFL: - 0.015	0.866	0.090	0.028
	FMFL: 0.386 ± 0.027	RF vs FMFL: 0.128	0.056	5.207	0.022
Wild pig	PA: 0.499 ± 0.032	PA vs RF: - 0.063	0.058	1.193	0.274
	RF: 0.563 ± 0.048	PA vs FMFL: 0.052	0.038	1.886	0.169
	FMFL: 0.446 ± 0.020	RF vs FMFL: 0.116	0.052	4.908	0.026

Abbreviations: Protected Area ‘PA’, Reserved Forest ‘RF’, fringe mosaic farmland ‘FMFL’, Wald test to check if estimates are significantly different from 0.

3.5 Discussion

Intensification of human disturbance has driven local extinction for most mammals during recent centuries (Wan et al., 2019). Landscape-level studies describing the effects of human disturbance on the distribution of large mammals are essential to understand how to protect their populations from further extinction. My investigation into habitat use and activity of seven mammalian species provides a thorough understanding of mammalian responses to anthropogenic disturbances in a highly fragmented landscape. I found that all species’ habitat use and activity patterns are not affected equally by human presence and land use activities. Mammalian richness, diversity and relative abundance varied markedly across land-use types. PAs and RFs supported significantly higher species richness and diversity than FMFLs. These results emphasise the importance of higher habitat heterogeneity, intact vegetation and low disturbance in maintaining diverse mammalian assemblages (Fox & Fox, 2000; Holland & Bennett, 2007). The proxy of habitat heterogeneity and structure, i.e. canopy cover positively influenced richness and diversity, indicating that structurally complex habitats improve resource heterogeneity and niche availability (Williams et al., 2002). Conversely, RAI of livestock had negative effects, implying that disturbance, overgrazing and competition from

domestic animals lead to simplification of mammalian community structure (Filazzola et al., 2020). RAI patterns revealed that generalist species like the fox and mongooses dominated FMFLs, while forest-dependent mammals like the sloth bear and leopards were abundant in PAs and RFs. These trends were consistent with Bray-Curtis dissimilarity results, indicating species filtering along the disturbance gradient. All these findings show that anthropogenic modification drives a shift of mammalian communities towards a generalist-dominated assemblage.

My landscape-level spatial analysis results confirmed that accelerated anthropogenic activities have more detrimental effect on species with larger body size, larger home range size, higher trophic level, specialist diet, and less nocturnal habit. The results of my analysis of temporal trends of larger mammals showed that adjustment in diel activity pattern towards more nocturnality is strongly influenced by increasing human activity and reduction of habitat heterogeneity across land-use types. Some of my focal study species were extremely vulnerable to land conversion and natural habitat loss, while others showed varying tolerance to human-modified habitats. My findings are consistent with previous studies demonstrating that pristine natural habitats like Protected Areas are the best habitats for large mammals (Pacifici et al., 2020). Thus, my study provided an informative perspective on the decline of several species by identifying the important land use changes that altered their habitat use and behavior within the poorly understudied study area.

In landscapes that are prone to heavy anthropogenic disturbances, it's important to identify how land use changes impact different species (Ramesh & Downs, 2015; Sodhi et al., 2010). Ballari district is a landscape that experiences heavy human pressure in the form of mining activities, livestock over-grazing, and illegal wildlife harvesting. My analysis revealed that each study species was distributed throughout the entire study area, but they used land types differently. The difference in the distribution of these species indicates varying levels of tolerance to human disturbances. The two most widely distributed species within this landscape were hare and wild pig which may be important as these are two major prey species in this system. Leopards, sloth bears, wild pigs, and hares preferred intact undisturbed forests (Ripple et al., 2014), while meso-predators like jackals, foxes, and jungle cats used more modified landscapes. This is consistent with many prior studies on meso-predators (Beasley et al., 2011; Torre et al., 2022; Zamuda et al., 2022).

Species occurrence can be strongly influenced by the quantity and quality of available habitat (Ceballos & Brown, 1995; Ramesh & Downs, 2015; White et al., 1997), and my results supported these findings. Agricultural lands negatively influenced the leopards' habitat use,

suggesting the importance of natural forested habitats for them as shown by Gubbi et al. (2020). On the other hand, the abundance of small prey species for meso-carnivores like jackals, foxes and jungle cats is higher in agricultural lands than forest habitats (Alain et al., 2006). High food availability, protection against large predators, and their ability to use human resources undoubtedly all contribute to increased habitat use and detection of these meso-predators within RF and FMFL (Carricondo-Sanchez et al., 2019; Šalek et al., 2014; Vanak & Gompper, 2010). The preference of hares for PAs within the study area may be associated with restricted poaching activities within this land use because hares are heavily poached across this landscape (Behera et al., 2022a). The positive association of hare habitat use with proximity to human settlement supports this hypothesis. My finding that leopard habitat use was positively associated with proximity to water is likely specific to my study area. Ballari district is a dry landscape, and all the major water sources are either situated near human settlement or associated with higher human presence (Meena, 2013). Habitat use of sloth bears was higher in PA. Thus, my results that two existing sloth bear sanctuaries in the district were placed in locations that are highly valuable for bear conservation. Relative abundance of humans was positively associated with the habitat use of jungle cats which could be due to their strong dependence on the availability of small prey like rodents that are mostly found in human-modified landscapes (Mukherjee et al., 2004). The habitat use of foxes was negatively associated with proximity to scrub forest and landscape rockiness. Higher habitat use of foxes and jackals in RFs relative to PAs maybe be explained by two factors. First, the moderately disturbed landscape of RFs might provide additional food resources (Jaegar et al., 2007) as well as reducing the frequency of encounters with large predators. Second, the RFs in my study area are associated with the plain landscapes and that feature could provide suitable sites for denning (Carricondo-Sanchez et al., 2019; Kumara & Singh, 2012). Wild pigs are heavily poached throughout the study site (Behera et al., 2022a) which likely explains their negative response to increased RAI human. The habitat use of two large mammals in my study i.e. leopard, and sloth bear, were positively influenced by the canopy coverage, which concurs with the findings of prior studies (Ngoprasert et al., 2007; Whitworth et al., 2019). According to Gould et al. (2001), high termite densities are associated with cattle dung patches, which explains my identification of RAI cattle as a strong positive predicting factor for sloth bear habitat use.

I found that mean annual precipitation was one of the important predictor variables for habitat use by five mammals. Precipitation positively influenced the habitat use of leopards, wild pigs, and hares, but it was negatively associated with the habitat use of jackals and foxes.

This affirms a strong relationship of precipitation with the distribution of these mammals in dry landscapes (Ogutu & Owen-Smith, 2005; Yusefi et al., 2021). With increased human activities, more species inhabit modified landscapes consisting of a mosaic of both natural and anthropic land covers. The ability of species to adapt and employ anthropic land covers is a significant factor in their survival in human-modified landscapes (Galan-Acedo et al., 2019).

Intensification of human disturbances causes wild mammals to avoid direct confrontation with humans to survive (Ditchkoff et al., 2006). Human disturbances and presence have negative effects on many mammals causing them to avoid disturbed landscapes, suppress their activity levels, or alter their activity patterns (Ikeda et al., 2022; Oriol-Cotterill et al., 2015; Suraci et al., 2021). With human activities being primarily diurnal in the study area, all species showed nocturnal activity patterns. I found that species with larger body sizes like leopards, sloth bears, and wild pigs increased nocturnal activity patterns in more disturbed land-use type like FMFL relative to PAs/RFs, which is consistent with earlier studies (Carter et al., 2015; Johann et al., 2020; Ohashi et al., 2013; Ramesh et al., 2013; Van Cleave et al., 2018). Meso-predators like jackals and foxes increased diurnal activity in RF or FMFL relative to PA. Sunquist & Sunquist (2002) found that jungle cats are typically diurnal. However, in my study jungle cat exhibited nocturnal activity patterns in all land use types. This difference in my data maybe a response to the high intensity of human disturbance across the study area. Activity patterns of jackals, foxes, and jungle cats across land-use types may relate to their tolerance of human presence. Hare had similar activity patterns across land-use types, but a spike was observed in their activity patterns in RFs and FMFL. Hares' activity pattern varies from crepuscular to nocturnal, and their increased activity in the twilight period suggests a heightened concentration of activity in human-modified landscapes. I also observed a shorter window in their activity patterns within human-dominated landscapes (Shamoon et al., 2018). Estimates of activity level of four out of seven of my study species showed higher activity in PAs or RFs than in FMFL, suggesting wild mammalian species prefer spending more time in less-disturbed landscapes. Thus, my mammalian activity-related results supported my prediction that mammalian species would show increased nocturnal activity patterns in FMFL relative to PAs/RFs and increased concentration of activity, i.e., a shorter activity window with increasing habitat disturbance.

Widespread habitat degradation and conversion due to anthropogenic activities are accelerating the global decline of biodiversity (Newbold et al., 2015). Mammalian distribution and diversity in disturbed landscapes are largely shaped by variation in vegetation structure, resource availability, and anthropogenic pressures (Laurance et al. 2014). Canopy cover,

representing habitat heterogeneity, had a positive effect on mammalian richness and diversity, which implies that complex habitats enhance resource diversity and provide a wider range of ecological niches (Williams et al., 2002). Dense canopy enhances habitat heterogeneity, supporting forest-dependent mammals while reducing exposure to disturbance (Barlow et al., 2016). High livestock abundance had a deleterious impact on species richness and diversity. Livestock grazing alters vegetation structure and ground cover, simplifying habitat heterogeneity, which many mammals rely on for food and shelter (Schielitz & Rubenstein, 2016). Competition for forage and interference from livestock, along with disturbances facilitated by accompanying humans and guard dogs, likely displace wild herbivores and carnivores out of their preferred habitats, increasing stress and predation risks for sensitive forest species (Schielitz & Rubenstein, 2016; Smith et al., 2020). While a few disturbance-tolerant species may thrive in over-grazed areas, most forest-dependent species are declining, resulting in a loss of overall richness and functional diversity. Thus, sustained livestock grazing pressure can promote community homogenization.

The study furnished novel insights into the complex relationship between anthropogenic disturbance and mammalian assemblage by quantifying the filtering effect of human land use change on seven mammal species with diverse traits (Belote et al., 2020; Hill et al., 2020). My consideration of several land use variables provides quantitative insights to inform strategic decision-making in the conservation of mammals. Even though my analyses focused on the Deccan plateau of India, I strongly advocate that the patterns observed are likely applicable to mammal species worldwide. For example, a shift in mammal community composition towards smaller and generalist species with reduced space requirements can be a consequence of the increasing human footprint (Suraci et al., 2021). The structure and diversity of mammal communities are the key determinants of ecosystem processes (Estes et al., 2011; Schmitz et al., 2018). However, more studies need to investigate the links between functional traits and habitat use of species in different land use types. Similar studies which also incorporate inter-specific interaction along environmental gradients, will provide more robust information about ecosystem function. Conservationists and wildlife managers are typically focused on the protection of wildlife species in PAs. Given that the majority of species reside outside PAs, my results emphasize the shortcomings of the forest PA network. Despite being detrimental to many species, semi-disturbed non-protected areas like RFs, provide opportunities for some species to prosper while also connecting PAs (Berger, 2007). Expanding PAs will certainly help the populations of large mammals (Milda et al., 2023), but for species that thrive outside PAs, I recommend new studies determining their habitat requirements to

provide effective refuge areas for conservation (Li et al., 2021). Conservation objectives require approaches for managing landscapes holistically by incorporating anthropogenic habitats like RFs, and farmlands with PA networks.

Ongoing landscape alteration and increasing human usage of remnant natural areas make it important to identify species that will thrive as well as those that will perish under anthropogenic pressure. Such inference is critical to conserving mammal communities and to maintaining mammalian diversity and associated ecological services. Natural habitats in a mosaic of anthropogenic-modified habitats can reduce negative effects on wildlife (Ehlers Smith et al., 2018; Galan-Acedo et al., 2019). Therefore, forest patch protection should be encouraged through continued reforestation and restoration, which will benefit a diverse range of mammalian species. Regulating mining activities and vehicular movements within forests, along with strict enforcement of rules related to illegal resource extraction, such as overgrazing and poaching, could further mitigate adverse effects on wildlife. So, I advocate for new studies that analyze the effects of mining-related activities, overgrazing, and poaching on wildlife conservation in Ballari district I urge conservation agencies to increase awareness by organizing training programs for local communities. Such programs should improve the understanding of human-wildlife interactions while providing suitable incentives and compensation to people who suffer wildlife damage. My findings illustrate the need for conservationists, forest managers, and local people to work together to create landscape-level planning that integrates local livelihoods and wildlife conservation.

CHAPTER 4

Patch Characteristics Influencing Mammalian Assemblages

Chapter 4

Patch Characteristics Influencing Mammalian Assemblages

4.1 Abstract

Habitat loss and fragmentation caused by increased human activities often result in species extinction and altered community structure. Nestedness is defined as a pattern in which species in species-poor sites are subsets of those in species-rich sites and is thought to be caused by the selective extinction of species. This provides valuable insights into the processes that drive biodiversity decline in fragmented landscapes. I investigated the nestedness patterns of terrestrial mammalian assemblages across forest patches in a highly anthropogenically modified and fragmented landscape in Ballari district, Karnataka, India. Data was collected using a systematic camera trapping survey from 2019 to 2021. Information regarding mammalian presences (18 species) across forest patches (30 isolated patches) was utilized to create a species-by-site matrix, and nestedness was quantified to assess species distributional order. The relationship between nestedness ranking and patch attributes (area, shape, edge, isolation, habitat heterogeneity, and anthropogenic disturbance) was evaluated using Spearman's correlation test. Furthermore, the impact of species' life-history traits (body mass, trophic level, sociality, arboreality, dispersal ability, and niche breadth) on extinction vulnerability was examined. The mammalian assemblage within the study area exhibited a statistically significant nestedness, with patch area, edge density, and proximity index emerging as key determinants. Among species life-history traits, niche breadth, sociality, and arboreality were the most effective predictors of extinction vulnerability as per the top models determined by the corrected Akaike Information Criterion (AICc). Notably, niche breadth exhibited a strong and significant association with extinction vulnerability. Therefore, larger and more connected forest patches with lower edge density play a principal role in maintaining community structure and minimizing species loss in the landscape. Furthermore, species with broader niche breadths are more resilient to the impacts of fragmentation, while highly social and arboreal species are prone to extinction in increasingly fragmented and disturbed landscapes. These findings highlight the combined influence of habitat configuration and species ecology in shaping mammalian assemblages in anthropogenically modified landscapes, emphasising the necessity of conserving larger and less-disturbed forest patches to maintain diversity and prioritize species most at risk of local extinction.

4.2 Introduction

Accelerating human expansion and land-use development activities have substantially reduced natural habitats, resulting in their fragmentation into isolated patches (Foley et al., 2005; Mullu, 2016; Scanes, 2018). Habitat loss and fragmentation through this process increase the species extinction rates, posing a severe threat to global biodiversity and disrupting ecosystem services (Fahrig, 2003; Haddad et al., 2015; Rybicki & Hanski, 2013). However, not all species respond uniformly to habitat loss and fragmentation (Ewers & Didham, 2006; Betts et al., 2014), thus resulting in nested patterns (Wang et al., 2010; 2013). Nestedness refers to the extent to which assemblages in smaller, species-poor habitats form subsets of those found in progressively larger, species-rich habitats (Hill et al., 2011; Patterson & Atmar, 1986). This leads to patterns where rare species are restricted to the most diverse assemblages, whereas common species persist across nearly all assemblages (Wang et al., 2010; Patterson & Atmar, 1986). Nestedness is primarily driven by non-random processes such as selective extinction and colonization (Cutler, 1991; Millien et al., 2024). When selective extinction drives nestedness in systems, habitat fragments within a region may converge in species composition, indicating that certain life-history traits make some species more prone to extinction than others (Patterson & Atmar, 1986). Therefore, nestedness analysis can be used as a powerful approach for identifying species most vulnerable to ongoing habitat modification and informing conservation efforts (Feeley et al., 2007; Fleishman et al., 2007).

Evidence of nestedness across diverse ecosystems and taxa indicates that it is widely prevalent in species assemblages in fragmented habitats (Feeley et al., 2007; Fischer & Lindenmayer, 2005; Hill et al., 2011). Unlike species-area relationships, nestedness analysis offers a more comprehensive framework for insights on biodiversity patterns in fragmented habitats, considering both species richness and composition, and thus has important conservation applications (Ulrich et al., 2009). Nestedness has several important applications for conservation. One key application is to guide site selection in multi-use landscapes by identifying patches that provide complementary and compensatory conservation value (Louzada et al., 2010; Schouten et al., 2007). In addition, it can help in identifying species that are restricted to species-rich communities, thereby serving as potential indicator species (Fleishman & Nally, 2002; Kerr et al., 2000). Furthermore, as species loss often follows predictable sequences, nestedness analysis provides a valuable paradigm for anticipating species at higher extinction risk (Dardanelli & Bellis, 2021; Zungu et al., 2019). Lastly,

nestedness analysis can help in identifying key patch- and landscape-level factors influencing species distributions (Fleishman & Nally, 2002; Zungu et al., 2019).

Nestedness arises from gradients in fragment or patch attributes, making it crucial to comprise these factors in analyses to identify the important drivers of species distribution patterns across different environments (Ulrich et al., 2009; Wright et al., 1997). The key patch attributes or variables influencing nestedness are patch size, shape complexity, isolation, habitat heterogeneity, and anthropogenic disturbance (Cook & Quinn, 1995; Ulrich et al., 2009; Wang et al., 2010). Among these, patch size and isolation are typically the strongest determinants, with larger patches generally supporting more viable populations and a wider range of habitats, while isolation affects species movement and recolonization (Fahring, 2003; Zungu et al., 2019). Furthermore, patch shape complexity and habitat heterogeneity influence nestedness by affecting resource availability and microhabitat diversity (Hill et al., 2011; Honnay et al., 1999). Patch shape and edge density can exacerbate edge effects, resulting in altered microclimatic conditions, reduced suitable interior habitat and increased exposure to anthropogenic pressures, all of which may have an impact on forest-dependent mammalian species and contribute to nestedness patterns via selective local extinctions (Laurance et al., 2002; Murica, 1995). Together, variation in patch shape, edge density, and habitat heterogeneity play role in structuring gradients in resource availability and microhabitats, thereby influencing species persistence across modified and fragmented landscapes (Garmendia et al., 2013; Hill et al., 2011; Watling et al., 2009). Anthropogenic disturbance can operate as an additional filter, either directly amplifying extinction risk through resource extraction and poaching, or indirectly by altering habitat quality and connectivity (Foley et al., 2005; Laurance et al., 2014; Moore et al., 2021).

Species' ecological and life-history traits also shape nestedness patterns by determining their persistence ability in fragmented landscapes (Matthews et al., 2015; Wang et al., 2010). Traits such as body mass, habitat specialization, diet specialization, trophic level, dispersal ability, social organisation, arboreality, and area requirements all influence species' extinction probability and resilience to habitat loss in fragmented habitats (Henle et al., 2004; Purvis et al., 2000; Schouten et al., 2007). For instance, species with high dispersal ability and broad niches are more likely to survive fragmentation, whereas specialists with limited mobility face higher extinction risks (Ewer & Didham, 2006; Henle et al., 2004). Thus, nestedness often emerges from the interplay between patch attributes and traits of species (Fischer &

Lindenmayer, 2005; Ulrich et al., 2009). Despite this, relatively few researchers have examined both dimensions simultaneously (Dardanelli & Bellis, 2021; Feeley et al., 2007; Ulrich et al., 2009; Soga & Koike, 2012; Zungu et al., 2019). Forest mammalian species are highly dependent on forests and vary in their sensitivity to habitat loss and fragmentation due to their ecological and life-history traits (Crooks et al., 2017). Many species require specific habitats to thrive and struggle to cross open or anthropogenically modified areas, thereby increasing their risk of isolation (Taylor et al., 1993). Therefore, investigating their responses to habitat loss and fragmentation is crucial for conservation, especially in modifying landscapes (Fahrig, 2017; Swihart et al., 2006).

The goal of this chapter is to assess the effect of patch characteristics on mammalian assemblages in a highly fragmented landscape. Ballari district, located in India's Deccan Plateau, is characterised by extensive deforestation, habitat fragmentation, agricultural expansion, and mining activities, making it an ideal site to study the extinction vulnerability among forest-associated mammalian species (Behera et al., 2024; Meena, 2013). Mammalian fauna plays a crucial role in maintaining the ecosystem balance of the region; however, increased habitat fragmentation threatens local extinction and drives shift in community composition. Nestedness provides a useful framework for analysing biodiversity loss in such fragmented landscapes, as it often reflects the processes of selective species extinction. Accordingly, this study aims to (i) establish whether mammalian assemblages display nestedness, (ii) evaluate the relationship between nestedness and patch attributes, and (iii) assess the influence of species' life-history traits. The analysis is based on a presence-absence matrix of 18 mammalian species recorded from 30 forest patches using camera traps, to identify which life-history traits (body mass, trophic level, sociality, arboreality, niche breadth, and dispersal ability) best explain vulnerability to fragmentation. By integrating patch attributes with species traits, I aim to elucidate the processes shaping species distribution in fragmented landscapes and inform conservation planning and strategies in anthropogenically modified ecosystems.

4.3 Methodology

Study Area

The study was carried out within the jurisdictional region of the Ballari territorial forest division in Ballari district (now, Ballari district is officially divided into two districts, namely Ballari and Vijayanagara districts) of Karnataka. It constitutes a part of India's unique Deccan

Plateau and rests between 14° 30' and 15° 50' North latitude and 75° 40' and 77° 11' East longitude (Fig. 4.1). The region is situated between 550m and 700m AMSL and has a varied geography, including broad plains, undulating areas and rocky hills (Meena, 2013). The landscape receives little rainfall (average annual rainfall being around 575mm) and consists mostly of a dry landscape with an average annual temperature varying from 20°C to 40°C. The district's core area is home to tropical deciduous forests dominated by *Albizzia amara*, *Chloroxylon swietenia*, *Hardwickia binata*, *Grewia tiliaefolia*, and *Azadirachta indica*. The remaining forest patches comprise dry thorn forests characterized by sparse vegetation, with dominant species including *Albizzia amara*, *Acacia catechu*, *Cassia auriculata*, *Euphorbia spp.*, and *Zizyphus spp* (Champion & Seth, 1968). 16.28% of the gross area of the district is considered forest land. The study area covers 30 isolated forest patches across Protected Areas (Daroji Sloth Bear Sanctuary and Gudekote Sloth Bear Sanctuary), Reserved Forests and adjoining Fringe Mosaic Farmlands. Despite its arid and semi-arid habitat conditions, Ballari supports a diverse range of medium-sized mammals, including leopards, sloth bears, Indian wolves, golden jackals, Indian foxes, jungle cats, rusty-spotted cats, wild pigs, black-naped hares, etc (Behera et al., 2024). It also has a healthy population of ground-dwelling birds, like peafowl *Pavo cristatus*, grey francolin *Francolinus pondicerianus*, etc.

Ballari is one of India's most economically disadvantaged districts, with local people relying on agriculture, non-timber forest products (NTFP) collection, and maintaining large herds of livestock (Meena, 2013). Active mines of iron and manganese cover more than 50 km² of land and are mostly located in forested areas (Meena, 2013). The landscape undergoes significant land-use changes due to mining, forest encroachment, overgrazing, and illegal forest and wildlife harvesting (Behera et al., 2024). Natural forests are increasingly fragmented into smaller patches due to anthropogenic pressure and changing land-use patterns. Such drivers not all alter habitat continuity but also exacerbate human-wildlife conflicts, manifesting in livestock predation, crop damage, human injury or mortality, wildlife deaths, and water scarcity linked to climate change (Meena, 2013).

Data collection

As a part of a long-term survey, I collected data from 1457 camera trapping sites during 21 months between 2019 and 2021. I established camera trap grid cells of dimensions 1 x 1 km² as the sampling units using ArcGIS 10.1 (ESRI, Redlands, CA, USA) and placed cameras in each grid cell based on mammalian sign surveys in each cell (Jhala et al., 2008) to collect the

occurrence data of mammals. A single infrared motion-triggered camera trap was placed (Cuddeback digital 20MP Blue Series, USA) in each unbaited camera station placed at least ~0.7 km apart. Camera traps were installed 30 cm above ground level along animal trails, dirt roads, rivers, stream beds, artificial water sources, and near waterholes. Obstructive vegetation was removed to reduce false triggers. The cameras were active for 22 days (30s motion-triggered delay settings), and data were retrieved weekly. Bias from multiple captures of the same individual by a single camera trap was avoided by considering only consecutive photos of the same species recorded at an interval of at least 30 minutes (O'Brien et al., 2003).

Forest patch attributes

Forest patch attributes were quantified using the LULC map procured from the local forest department (Karnataka Forest Division, 30m spatial resolution). I employed the spatial analysis tools ArcGIS 10.4 (ESRI, Redlands, USA) and FRAGSTATS 4.2 (McGarigal, 2015) to quantify forest patch characteristics known to influence nestedness patterns of mammalian species. Variables selected for analysis included patch area, edge density, shape complexity, isolation, habitat heterogeneity, and anthropogenic disturbance (Foley et al., 2005; Honnay et al., 1999; Wright et al., 1997; Zungu et al., 2019). The patch area was calculated as the total size of each forest patch (in km²) in the study area (Fig. 2). Edge density is a landscape-level metric that quantifies how much edge, i.e. the length of boundary between habitat and non-habitat (here, perimeter of the patch), relative to the area of a patch. It can serve as a useful indicator of fragmentation and edge effects (Ewers & Didham, 2006).

$$\text{Edge Density} = \frac{\text{Total edge length of the patch or Perimeter (in km)}}{\text{Patch area (in km}^2\text{)}}$$

To assess patch isolation, the proximity index was used, which is considered a more ecologically meaningful metric than simple distance-based measures, as it accounts for variation in patch size, shape and the overall amount of habitat in the landscape (Bender et al., 2003; McGarigal, 2015):

$$\text{Proximity Index} = \sum_{s=1}^n \frac{a_k}{h_k}$$

Where a_k is the area of the neighbouring patch k within a specified buffer around the focal patch, and h_k is the edge-to-edge distance between the focal patch and patch k . A buffer of 2

km was applied around each focal patch, considering the wide range of study mammalian species. Shape complexity was evaluated using the following formula (McGarigal, 2015):

$$\text{Shape Complexity} = 0.25 * \frac{p_i}{\sqrt{a_i}}$$

Where p_i is the perimeter of patch i (km) and a_i its area (km²).

Canopy cover was used as a proxy for habitat heterogeneity (August, 1983; Tews et al., 2004). Using standard visual estimation, the percentage of canopy cover was recorded within a 20-meter radius around each camera, which was divided into four quadrants (Jhala et al., 2008; Kent, 2011). These values were averaged to determine canopy coverage at each camera site and further averaged across all sites within a patch to represent the overall vegetation structure, hence its habitat heterogeneity. Anthropogenic disturbance was quantified using both spatial and field data-based indicators. A LULC map was used to determine the coverage of human settlements and mines inside each forest patch (Roy et al., 2015), while camera trap data provided the mean RAI of humans, livestock, and free-ranging dogs, which indicated direct disturbance pressure. Both variables were standardized with z-scores, and the mean value was derived to generate a composite anthropogenic disturbance index, with higher scores indicating greater disturbance intensity.

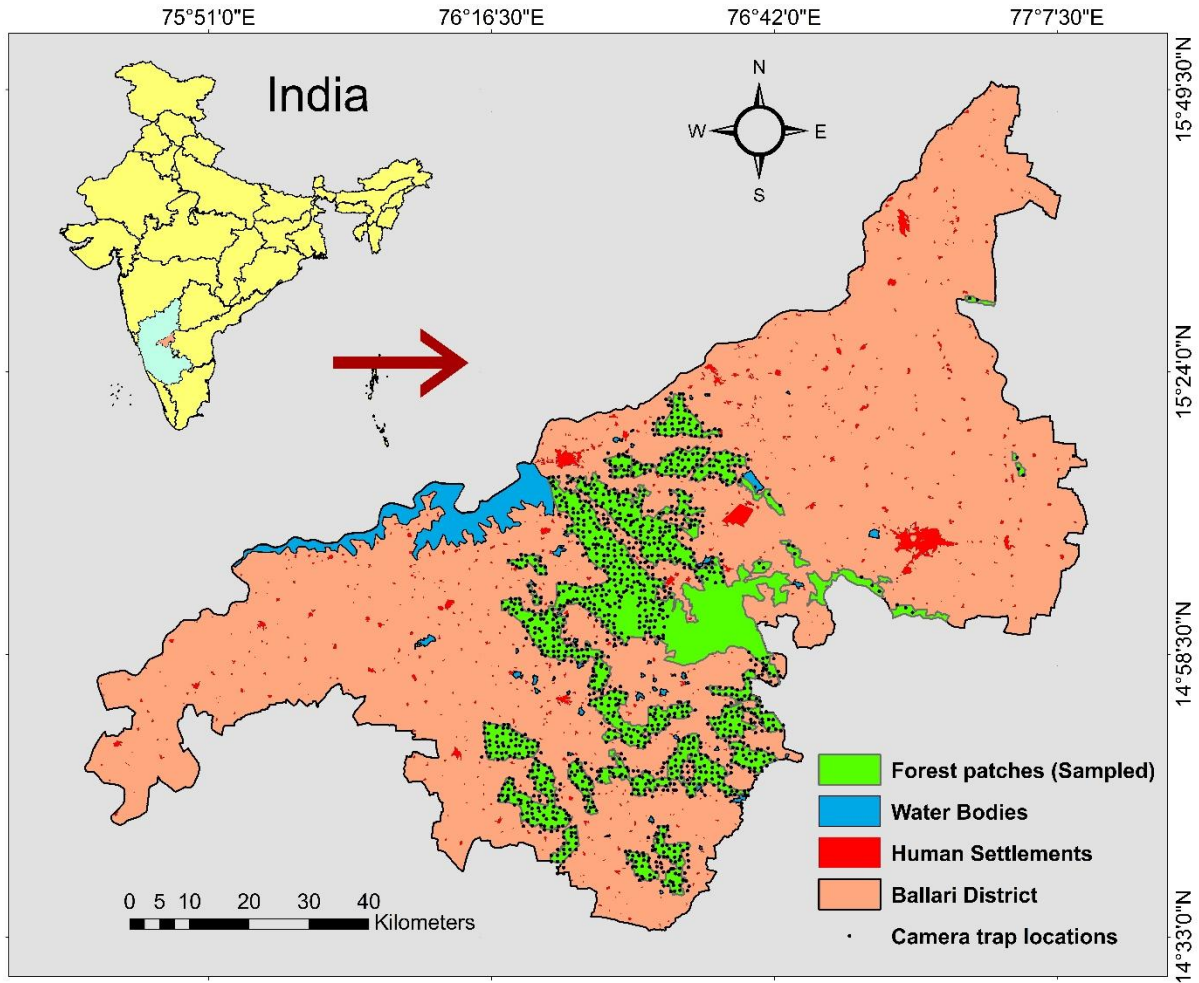


Figure 4.1: Camera trap locations across forest patches (sampled) of Ballari district, Karnataka

Ecological and life-history traits

I considered six key traits: body mass (Chichorro et al., 2019; McKinney, 1997), niche breadth (Chichorro et al., 2019; Swihart et al., 2003; Zungu et al., 2019), sociality (Courchamp et al., 1999), trophic level (Cagnolo et al., 2009), arboreality (Laurance, 1990; Munstermann et al., 2022), and dispersal ability (Bregman et al., 2014) to evaluate the influence of ecological and life-history traits on extinction risk (Table 4.1). Body mass (in kg) for each species, obtained from the literature, was calculated as the average of male and female values, incorporating multiple records to account for variation across studies and regions (Johnsingh & Manjrekar, 2016; Menon, 2023). To measure niche breadth, I investigated two key dimensions: diet and habitat, as these dimensions reflect how species respond to local environmental conditions and processes which are more directly linked to their abundance and presence than broader-scale factors. Diet breadth was estimated by calculating the number of diet categories of a species'

overall diet (out of 18 possible categories) (Swihart et al., 2003; Zungu et al., 2019). These categories included mammals, birds, amphibians, reptiles, fish, molluscs, annelids, arthropods, fungi, flowers, shoot/stem, tuber/balls, seeds, fruits, leaves, grasses, and bark (Johnsingh & Manjrekar, 2016; Menon, 2023; Wilman et al., 2014). Habitat breadth was measured by tallying the number of habitat types utilized by each species within the South Indian landscape (out of ten). I considered 10 major habitat types that comprised dry deciduous forest, scrub forest, evergreen/semi-evergreen forest, grassland, agricultural fields, barren land, rocky outcrops/hillocks, riparian vegetation, plantation, and human settlements (Johnsingh & Manjrekar, 2016; Menon, 2023; Wilman et al., 2014). Standardized z-scores were computed separately for each study species' diet and habitat breadth. The overall niche breadth score was obtained by averaging these two standardized values for each species.

Sociality was quantified on a four-point scale ranging from 0 to 3 (Swihart et al. 2003; Zungu et al., 2019). Completely asocial species were scored as 0, species showing basic social behaviours such as huddling or overlapping home ranges were scored as 1, monogamous species were assigned a score of 2 and species that form cohesive and communal groups were scored as 3 (Johnsingh & Manjrekar, 2016; Menon, 2023; Wilman et al., 2014). To classify species by trophic level, each species was categorized as herbivore, omnivore or carnivore (Johnsingh & Manjrekar, 2016; Menon, 2023). Arboreality was assessed on a four-point scale (0-4) based on de Castro and Fernandez (2004). Here, 0 indicates completely terrestrial species, 1 indicates species that are primarily terrestrial but occasionally arboreal, 2 indicates species that spend roughly equal time on the ground and in trees, and 3 describes species that mostly spend time in trees (Johnsingh & Manjrekar, 2016; Menon, 2023). To quantify species dispersal ability, natal dispersal distance was computed using trophic group-specific allometric equations proposed by Sutherland et al. (2000) and Bowman et al. (2002). Since maximum dispersal distances were too large to fit the spatial scale of the study, median dispersal distance was used instead, as it better represents a species' typical movement patterns regardless of sex. The dispersal distance for carnivores (Sutherland et al., 2000) was calculated using the equation

$$C_{DD} = 3.45 M^{0.89}$$

while for herbivores and omnivores, the equation

$$H + O_{DD} = 1.45 M^{0.54}$$

was applied, where $H + O_{DD}$ and C_{DD} represent the dispersal distances (in km) of herbivores and omnivores combined, and carnivores, respectively. M represents body mass in kg, and the remaining constants are derived from allometric relationships. These equations provided a meaningful estimate of species' dispersal abilities within the study landscape.

Table 4.1: Ecological and life-history traits of study species in Ballari, Karnataka

Species	Mass (kg)	Trophic	Society	Arboreality	Dispersal	Niche breadth
Leopard	49.25	3	0	1	110.68	0.516
Indian wolf	38	3	3	0	87.87	-0.326
Golden Jackal	8.7	2	2	0	23.66	0.033
Indian Fox	2.38	2	2	0	7.46	-0.685
Jungle Cat	4	3	0	1	11.85	-0.202
Rusty-spotted Cat	1.43	3	0	2	4.74	-0.920
Sloth Bear	90	2	0	1	16.47	-0.202
Asian Palm Civet	3	2	0	2	9.17	0.392
Small Indian Civet	3	2	0	2	9.17	0.986
Wild Pig	85	2	3	0	15.97	1.691
Black-naped Hare	2.45	1	0	0	2.35	0.268
Four-horned Antelope	20	1	0	0	7.31	-1.514
Indian-crested Porcupine	17.5	1	2	0	6.8	-0.202
Grey Mongoose	1.4	2	1	0	4.65	0.033
Ruddy Mongoose	2.5	2	1	0	7.8	0.033
Gray Langur	13.1	1	3	3	5.82	0.392
Bonnet Macaque	6.13	2	3	2	3.86	1.208
Indian Pangolin	13	3	0	0	33.82	-1.501

Trophic levels: Herbivore-1, Omnivore-2, Carnivore-3; **Society:** Completely asocial-0, basic social behaviours such as huddling or overlapping home ranges-1, monogamous-2, form cohesive and communal groups-3; **Arboreality:** Completely terrestrial-0, primarily terrestrial but occasionally arboreal-1, species that spend roughly equal time on the ground and in trees-2, species that mostly spend time in trees-3. Niche breadth values are expressed in z-scores.

Analysis

Nestedness quantification

To assess nestedness, the mammal presence/absence data of 18 mammalian species across 30 forest patches were arranged into a 1/0 binary matrix, with species represented by rows and forest fragments by columns. Mammalian assemblages' nestedness was measured using the Nestedness metric based on Overlap and Decreasing Fill (NODF) implemented through “bipartite” package in R program (Dormann et al., 2008). The NODF metric was used as it is less sensitive to matrix size and fill and provides a more robust and interpretable measure of nestedness than temperature-based indices. The significance of nestedness was determined by comparing the observed NODF value against expectations under a null model implemented in the bipartite package. The reordered matrix was used to generate nestedness-based rankings of forest patches and species, which were then utilised to investigate the relationships between patch attributes and species life-history traits.

Factors Influencing Nestedness and Extinction Risk

Nestedness was quantified using “bipartite” package, which reorders the presence-absence matrix to maximize nested structure and produces nestedness-based ranks for both forest patches and species. These nested rankings provide an index of relative habitat suitability for forest patches as well as species vulnerability to local extinction, with species restricted to fewer or larger patches receiving lower rankings, indicating a higher risk of extinction, and widespread species receiving higher rankings (Feeley et al. 2007). To identify key patch-level drivers of nestedness, I used Spearman's rank correlation test to investigate relationships between nested ranking of forest patches and patch attributes such as patch area, proximity index, edge density, shape complexity, canopy cover (a proxy for habitat heterogeneity), and anthropogenic disturbance. Significant correlations between patch rankings and specific attributes were interpreted as evidence that these attributes contribute to the observed nested structure (Rodríguez-Gironés & Santamaría, 2006). Before analysis, all patch attributes were standardised to ensure comparability and reduce scale effects.

To investigate the influence of species' life-history qualities on extinction vulnerability, Generalised Linear Models (GLMs) with a Gaussian error distribution were fitted, with species nested ranking as the response variable and life-history traits as explanatory variables. Multiple candidate models reflecting various combinations of attributes were analysed, and model selection was performed using Akaike's Information Criterion corrected for small sample size

(AICc) (Burnham & Anderson, 2002). Model averaging was done for the top models within 2 Δ AICc. The R program was used to carry out all statistical analyses.

4.4 Results

A total of 30 forest patches were included in the analysis, which varied significantly in terms of their attributes. Patch area varied greatly throughout the landscape (0.80 – 413.29 km²), revealing a highly fragmented forest system, while attributes such as edge density (0.62 – 5.14), shape complexity (1.11 – 3.26), proximity index (0 – 4137015.6), canopy coverage (3.07 – 41.13 %), and anthropogenic disturbance showed significant variation between patches. Data was collected with an effort of 31,702 trap-nights. Camera traps across all forest patches recorded a total of 24 wild mammalian species, out of which 18 species were utilized for nestedness analysis. The mammalian assemblage exhibited a moderate but statistically significant nested structure, as indicated by the Nestedness metric based on Overlap and Decreasing Fill (NODF = 42.91, $p < 0.01$). This pattern suggests a non-random distribution of species across forest patches, characterised by ordered species loss or persistence along gradients of patch suitability. This pattern implies that species are not distributed randomly across forest patches, with ordered species loss or survival along patch suitability gradients.

Spearman's rank correlation analysis revealed that the nestedness rank of forest patches was significantly associated with three patch attributes (Table 4.2). Patch area showed a strong positive correlation with nestedness rank ($r = 0.758$, $p < 0.01$), suggesting that larger patches occupied higher positions in the nested hierarchy. The closeness index showed a positive correlation with patch rank ($r = 0.439$, $p < 0.02$), indicating that less isolated patches maintained more complete assemblages. Edge density had a strong negative correlation with nestedness rank ($r = -0.755$, $p < 0.01$), indicating that patches with more edge exposure were more likely to lose species. Shape complexity, canopy cover, and anthropogenic disturbance had no significant relationship with patch nestedness rank.

Table 4.2: Spearman's rank correlation coefficients describing the association between forest patch ranks and rank of patches in terms of area, shape complexity, isolation and habitat heterogeneity

Sl. no.	Patch Characteristics	Correlation coefficient (rho)	p-value
1	Area	0.758	<0.01
2	Edge density	- 0.755	<0.01
3	Shape complexity	0.354	0.06
4	Proximity index	0.439	0.02
5	Habitat heterogeneity	0.023	0.9
6	Human disturbance	- 0.317	0.09

Species-level nestedness rankings illustrated these patterns (Table 4.3). Black-naped hare exhibited the highest nestedness rank, followed by jungle cat and wild pig, showing widespread persistence across patches. In contrast, the Indian pangolin and four-horned antelope had the lowest nestedness ranks, identifying them as the most vulnerable species within the fragmented landscape (Table 4.3). GLMs investigating the influence of species' ecological and life-history traits on extinction vulnerability indicated niche breadth, sociality, and arboreality as the most important predictors based on AICc-based model selection (Table 4.3 and 4.4). Niche width was positively associated with nestedness rank, implying that generalist species were more likely to persist across a greater range of forest patches. In contrast, sociality and arboreality were found to be negatively associated with nestedness rank, implying that social and arboreal species are more vulnerable to extinction in fragmented forest landscapes. Among all traits, niche breadth exhibited a significant effect on extinction vulnerability ($\beta = 3.039 \pm 1.399$, $p < 0.04$; Table 4.5; Fig. 4.2).

Table 4.3: Nestedness rank of mammalian species in Ballari district, Karnataka

Species	Nestedness rank	Species	Nestedness rank
Leopard	8	Wild pig	3
Indian grey wolf	16	Black-naped hare	1
Golden jackal	4	Four-horned antelope	17
Indian fox	9	Porcupine	10
Jungle cat	2	Common grey mongoose	6
Rusty-spotted cat	11	Ruddy mongoose	12
Sloth bear	5	Gray langur	14
Asian palm civet	13	Bonnet macaque	15
Small Indian civet	7	Indian pangolin	18

Table 4.4: Best-supported models linking species' ecological and life-history traits to extinction variability

Sl. No.	Top models	df	logLik	AICc	Delta	Weight
1	Sociality + Arboreality + Niche breadth	5	-49.74	114.49	0.00	0.30
2	Niche breadth	3	-53.45	114.61	0.13	0.29
3	Sociality + Niche breadth	4	-52.01	115.09	0.61	0.22
4	Arboreality + Niche breadth	4	-52.20	115.47	0.98	0.19

Table 4.5: Model-averaged beta estimates for predictors linking species' ecological and life-history traits to nestedness ranking

Sl. No.	Variable	Beta Estimates	SE	Z Value	P-Value
1	Intercept	11.344	2.142	5.063	<0.01
2	Niche breadth	3.039	1.399	2.032	0.04
3	Sociality	-1.776	0.958	1.703	0.08
4	Arboreality	-2.100	1.185	1.627	0.10

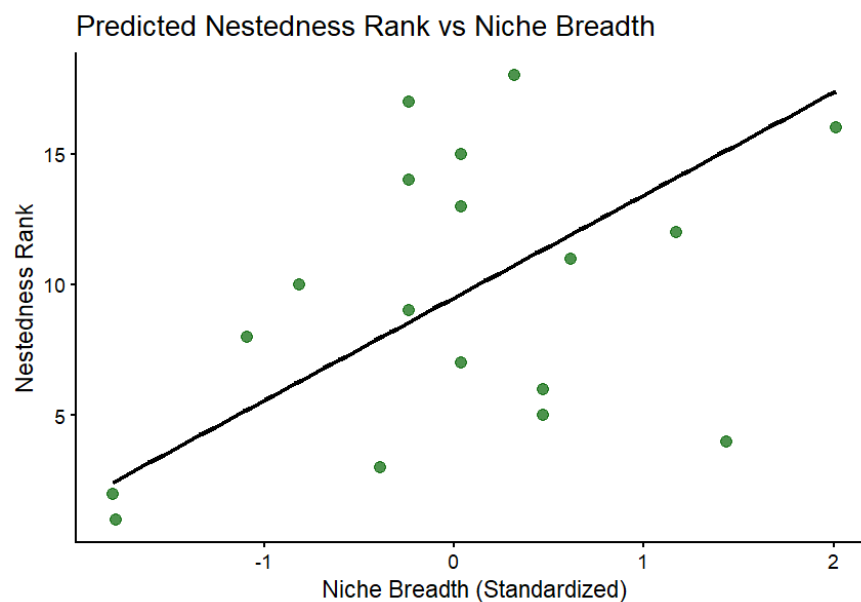


Figure 4.2: Patterns describing how niche breadth relates to the nestedness ranking of study species within the study area

4.5 Discussion

Nestedness analysis is a powerful tool for the identification of species that are especially vulnerable to habitat loss, fragmentation and landscape modification, providing valuable insights for conservation planning in fragmented ecosystems. In Ballari, the mammalian assemblage exhibited a moderate but statistically significant nested structure, indicating non-random patterns of species loss and survival across forest patches. This finding implies that mammalian assemblages in this highly anthropogenically modified landscape are structured by

a combination of patch-level attributes and species-specific life-history traits. According to classical nestedness theory proposed by Patterson & Brown (1991), nested patterns occur when species and sites share a common biogeographic history, experience similar contemporary ecological conditions, and differ in their susceptibility to extinction or colonisation due to differences in habitat attributes or species traits. These conditions are mostly met in the Ballari landscape, where forest patches evolved from a once-continuous habitat matrix and are now embedded in an intensely changed agricultural, mining, and settlement-dominated matrix. The observed nestedness is therefore likely due to differential extinction processes operating across gradients of patch size, connectivity, and disturbance pressure.

Effects of patch attributes on nestedness

Patch attributes performed a vital role in shaping the nestedness patterns of mammalian assemblages. Patch area emerged as the strongest positive determinant of nestedness rank, implying that larger forest patches supported more diverse species assemblages. This pattern is consistent with area-driven persistence, in which species with larger area requirements are progressively lost from smaller patches, resulting in an ordered pattern of species loss (Wright et al., 1997; Hu et al., 2011). Given that a substantial proportion of Ballari's forest patches are small and isolated, area constraint is most likely a primary driver of local extinctions in the landscape.

Patch isolation, as quantified by the proximity index, also had a positive correlation with nestedness rank. Less isolated forest patches supported more diverse assemblages, emphasising the importance of landscape connectivity in maintaining mammalian communities (Hanski, 1999; Taylor et al., 1993). This finding suggests that, even in human-dominated landscapes, functional connectivity can reduce extinction risk by facilitating movement and recolonisation among patches (Fahrig, 2003; Crooks & Sanjayan, 2006). However, the ongoing expansion of agricultural lands, mining activities, and human settlements is expected to further reduce connectivity, potentially exacerbating nestedness through selective species loss (Laurance et al., 2011; Haddad et al., 2015). In contrast, edge density had a strong negative association with patch nestedness rank, showing that patches with increased edge exposure were more species-poor. High edge density is likely to amplify edge effects such as microclimatic alteration, increased human access, poaching pressure, and interactions with livestock and other domestic animals, all of which disproportionately affect interior-dependent and disturbance-sensitive species (Murcia, 1995; Laurance et al., 2002; Pfeifer et al., 2017).

Consequently, edge-dominated patches may experience accelerated local extinctions while favouring generalist and disturbance-tolerant species, reinforcing nestedness patterns (Ewers & Didham, 2006; Fischer & Lindenmayer, 2007). Other patch attributes, such as shape complexity, canopy cover (habitat heterogeneity), and anthropogenic disturbance indices, had no significant influence on nestedness ranking. However, these attributes may still have an indirect or interactive effect on habitat quality and species persistence, particularly at finer spatial or temporal scales (Didham et al., 2012; Fahrig et al., 2019).

Effect of species' ecological and life-history traits on extinction vulnerability

Species' trait-level analysis demonstrated that ecological and life-history traits are strongly linked to species extinction vulnerability in fragmented landscapes (Zungu et al., 2019). Niche breadth emerged as the key predictor of extinction vulnerability, with species with broader dietary and habitat requirements occupying higher nestedness ranks. This finding reflects the frequently documented pattern that generalist species are more resilient to habitat fragmentation and human disturbance because they are able to exploit a wider range of resources and tolerate modified landscapes (Swihart et al., 2003; Devictor et al., 2008). Contrarily, specialist species such as Indian pangolins and four-horned antelopes were primarily constrained to bigger or less disturbed patches, making them more vulnerable to continued habitat loss and degradation (Henle et al., 2004).

Arboreality and sociality showed a negative association with nestedness rank, indicating increased vulnerability for arboreal and social animals, although these effects were less pronounced. Arboreal species are more vulnerable to canopy disruption and fragmentation, which limit their arboreal movement pathways (Arroyo-Rodríguez et al., 2013), while social species require larger contiguous areas to maintain viable group sizes (Blumstein & Fernández-Juricic, 2010). The relatively weak effects of these features indicate that their influence on extinction vulnerability is context-dependent and likely mediated by interactions with habitat configuration and disturbance intensity (Cardillo et al., 2005). Overall, body mass and trophic level did not emerge as key drivers of extinction vulnerability of mammalian species in this system, highlighting that traditional indicators of extinction risk may not operate uniformly across landscapes. Instead, functional traits related to resource-use flexibility and habitat tolerance appear to be more important predictors of persistence in the modified and fragmented landscape of Ballari (Purvis et al., 2000; Newbold et al., 2013).

These findings emphasize that conservation efforts should prioritize large forest patches, reduce edge effects, and maintain or restore functional connectivity across the landscape (Haddad et al., 2015). At the species-trait level, niche breadth emerged as the most important predictor of extinction vulnerability, implying that continued habitat loss will disproportionately affect ecological specialists and promote biotic homogenisation dominated by generalist species (McKinney & Lockwood, 1999; Devictor et al., 2008; Swihart et al., 2006). Arboreal and social species also showed increased susceptibility to fragmentation (Henle et al., 2004). Overall, integrating patch attributes and species life-history traits via nestedness analysis provides valuable guidance for proactive mammalian conservation in human-dominated landscapes.

CHAPTER 5

Species Interactions Driving Behavioural Responses of Mammals

Chapter 5

Species Interactions Driving Behavioural Responses of Mammals

5.1 Abstract

Human-induced land-use changes, including agricultural expansion, mining, increased human settlements, livestock overgrazing, and unsustainable non-timber forest products collection, rapidly transform landscapes, altering carnivore interactions and ecological stability. Spatiotemporal relationships among sympatric carnivores can shape the ecological community's structure. Large carnivores control prey and meso-carnivore populations through top-down processes, but their influence is diminishing in human-modified landscapes. This study investigated the occupancy dynamics and patterns of species interactions within a carnivore guild comprising a large carnivore/apex predator (leopard *Panthera pardus*) and meso-carnivores (golden jackal, Indian fox, and jungle cat) to understand the effect of anthropogenic and environmental variables, as well as the apex predator. I collected landscape-level camera-trapping data in the fragmented, anthropogenically stressed landscape of Ballari district, India and analysed the data using multispecies occupancy models. I evaluated the co-occurrence patterns and interactions among carnivores and the influence of human disturbance, habitat fragmentation, landscape features, and prey abundance on them. Then I examined the co-occurrence patterns and interactions between apex predator (leopard) and prey species, i.e., wild pig and black-naped hare. I also analysed the diel activity patterns of the study species to explore temporal segregation. My results showed that human disturbance strongly governed carnivore interactions, with leopard-jungle cat co-occupancy declining in areas associated with higher human settlement cover, while jackal-jungle cat co-occupancy increased. Broadly, carnivore interactions were sensitive to human disturbance variables, displaying negative associations of meso-carnivores with leopards at higher human disturbance. Prey availability also shaped interactions, with fox occupancy decreasing in leopard-occupied areas as an index of hare abundance increased. Activity patterns revealed that meso-carnivores avoided leopards by adjusting their peak activity periods. Prey species showed positive spatial association and high temporal overlap with the apex predator. My findings highlight that carnivore spatiotemporal patterns are shaped by species-specific behaviours, competitive interactions, and human disturbance, with apex predators playing a crucial role in shaping carnivore communities. Maintaining functional carnivore communities requires habitat restoration and

sustainable land-use practices, alongside species-specific management approaches that support coexistence between apex predators and meso-carnivores in multi-use landscapes—essential for biodiversity conservation and ecosystem stability.

5.2 Introduction

In terrestrial mammalian communities, interspecific interactions amongst carnivores are crucial for biodiversity conservation, and ecosystem stability (Linnell & Strand, 2000; Ripple et al., 2014; Srivathsa et al., 2023). Competitive interactions among carnivores influence individual and population dynamics and ultimately determine how species coexist (Caro & Stoner, 2003; Creel, 2001). Large or top/apex carnivores typically dominate other species (prey species and smaller carnivores) through direct and exploitative competition (Ray et al., 2013). They influence trophic structure by moderating meso-carnivore and regulating prey populations, which helps maintain ecological balance (Ford & Goheen, 2015; Hoeks et al., 2020). They preclude subordinate species from accessing resources through aggressive interactions, or by necessitating spatial shifts to alternative resources (Rodriguez Curras et al., 2020; Vanak et al., 2013). Extirpation and reduction of top carnivores due to increasing anthropogenic disturbance disrupts these controls (Atkins et al., 2019; Ripple et al., 2014; Suraci et al., 2017). Understanding how disturbance alters these population-level interactions is therefore crucial for forecasting ecosystem responses and guiding conservation strategies (Svenning et al., 2016).

Competition plays a vital role in structuring carnivore communities, especially among sympatric species that occupy similar ecological niches (Cano-Martinez et al., 2024; Caro & Stoner, 2003). Resource availability often drives exploitation-based competitive interactions (Dutta et al., 2024). Carnivores are more likely to occur together when resources are abundant and widely distributed, whereas degraded ecosystems can enhance competitive interactions (Karanth et al., 2017). Interference competition, including aggression or intraguild predation, frequently prompts less-competitive interacting species to adjust space or time use. However, under strong competitive pressure, especially in resource-scarce systems, less-competitive/subordinate species may experience population declines or local extirpation (Schippers et al., 2015). Carnivores can reduce potentially lethal interactions through niche partitioning, i.e. by segregating along at least one or more axes of biological niches to co-exist (Herrera et al., 2018; Ramesh et al., 2012; Schoener, 1974). While the distribution of large carnivores is mostly determined by resource availability, meso-carnivore distributions reflect

trade-offs between predation risk and access to resources (Polis & Holt, 1992; Prugh et al., 2009; Ritchie & Johnson, 2009). With human disturbance causing habitat loss and prey base depletion the available niche space may be reduced, potentially altering interactions between coexisting meso-carnivores. These changes are influenced by factors like environmental productivity, human disturbance, land use patterns, and the presence of large carnivores (Cano-Martinez et al., 2024; Penjor et al., 2022).

Interactions between apex predators and prey species are the foundation of ecological communities as prey availability has a direct impact on the distribution, abundance and behaviour of predators (Karanth & Sunquist, 1995; Ripple et al., 2014). Across heterogeneous landscapes, large predators often structure their occurrence and habitat preferences around high prey-availability areas, reflecting the close dependency of their distribution on prey occurrence and density (Odden et al., 2010). For instance, large carnivores like tigers *Panthera tigris* and leopards within a human-modified landscape in South Asia showed high densities and occurrence in prey-rich areas with a mosaic of habitats (Lamichhane et al., 2019). Similarly, lions *Panthera leo* in south-central Africa select habitats with greater prey availability, and their occupancy is strongly predicted by the presence of large-bodied prey species (Goodheart et al., 2024). Such findings demonstrate that prey populations and presence mediate the spatial ecology of apex predators, beyond merely serving them as a food resource.

Growing human populations drive habitat loss, landscape modification, and fragmentation (Scanlon, 2018) compromise the long-term persistence of large carnivores (Crooks, 2002; Crooks et al., 2011; Zemanova et al., 2017). Large carnivores are particularly sensitive to human disturbance and habitat alteration due to their larger habitat requirements which increases their risk of lethal encounters with humans (Gantchoff et al., 2020; Ordiz et al., 2021; Ripple et al., 2014). Depletion of prey base through overhunting by humans, retaliatory killings, and poisoning, accelerates carnivores' mortality (Mbise, 2021; Nattrass & Conradie, 2018; Wolf & Ripple, 2016). Human activities also influence carnivores through bottom-up processes such as food subsidisation (Manlick & Pauli, 2020; Newsome et al., 2015). Modified landscapes offer abundant and clumped food resources that disproportionately benefit smaller and generalist carnivores (Oro et al., 2013; Rotem et al., 2011). In modified landscapes, high human presence often displaces large carnivores, reducing opportunities for interference competition and thereby releasing mesocarnivores from top-down suppression (Berger, 2007). As larger carnivores tend to avoid zones with intense human activity, smaller carnivores experience reduced predation risk and consequently flourish (Berger, 2007; Moll et al., 2018). Thus, in modified landscapes, the absence of top-down regulation by large carnivores can lead

to the ‘meso-predator release’ effect, increasing the abundance of meso-carnivores with broader niches, leading to cascading effects on smaller carnivores and prey species populations (Crooks & Soule, 1999; Ritchie & Johnson, 2009). Meso-predator outbreaks are commonly observed in fragmented and modified habitats (Crooks & Soule, 1999). Prey populations may decline due to increased hunting, habitat loss and competition with livestock near human habitation, while some highly adaptable species like wild pigs persist (Prins, 2000; Schneider, 2001; Soofi et al., 2019; Stillfried et al., 2017). Assessing large predator co-occurrence with meso-predators and prey species can therefore reveal how anthropogenic pressures reshape carnivore guilds and predator-prey dynamics. Addressing and managing these shifts is essential for preserving ecosystem stability and curbing further biodiversity loss in landscapes heavily influenced by humans.

In India’s dry forest landscapes, escalating anthropogenic activities have driven the local extirpation of several large carnivores, including tigers (Gopal et al., 2010; Karanth et al., 2010). In many such systems, particularly those that are highly modified, Indian leopards now function as the effective apex predators, co-occurring with a suite of meso- and small carnivores (Latafat et al., 2023). Concurrently, leopard populations have declined across their range due to increasing anthropogenic pressure and habitat degradation (Athreya et al., 2011; Sidhu et al., 2017). Reduction in leopard distribution or activity can alter interactions within the carnivore guild, potentially influencing mesocarnivore space use and behaviour, with broader implications for ecosystem processes (Palei et al., 2022; Puri et al., 2020). Despite numerous studies that have explored intraguild competition among top predators and mesopredators in North America and African continent (Ripple et al., 2013; Ritchie & Johnson, 2009), such knowledge is lacking from the Indian Peninsula, where forested landscapes experience intense human pressure (Karanth & DeFries, 2010). Studies focusing on intraguild interaction, particularly involving the charismatic species and inside Protected Areas (PAs; PAs are generally associated with more intact habitats and lower anthropogenic pressures), have garnered the attention of ecologists (e.g. Karanth et al., 2017), thus leaving several important questions about meso-carnivores’ interactions beyond PAs unanswered.

The Ballari district landscape in the southern Deccan plateau, India has undergone extensive land-use changes over the past century due to mining expansion, agricultural encroachment, excessive livestock overgrazing, and heavy dependence on Non-timber Forest Product (NTFP) (Behera et al., 2022a; Meena, 2013; Rudramuniyappa, 1997). These activities have resulted in severe habitat fragmentation and depletion of natural habitats. In the current

human-modified system, leopards function as the apex predator, as more disturbance-sensitive large carnivores historically present in parts of the region no longer persist. I assessed interactions among leopards and three less-studied meso-carnivores i.e. golden jackal, Indian fox, and jungle cat. Leopards are listed as “Vulnerable” by IUCN (IUCN, 2023). Jackals, foxes, and jungle cats, classified as “least concern”, are syntopic with leopards across most of their range in the Deccan plateau and exhibit some adaptability to human-altered landscapes (Katna et al., 2022). I also included the most commonly preyed species of leopards in the landscape, i.e. wild pigs and black-naped hares, for analysis.

My third objective of the thesis is to assess species interactions driving behavioural responses of mammals. Using camera-trapping data from a systematic survey in the Ballari Forest division, I investigated co-occurrence patterns among four carnivore species (one apex predator and three meso-predators) as well as between the apex predator and two key prey species. I further examined the relationship of species co-occurrence with environmental and anthropogenic predictors or variables. I hypothesized that carnivores’ co-occurrence will change along a gradient of human disturbance (human influence and forest fragmentation) and prey availability. As leopards prefer using natural habitats with abundant wild prey (Gubbi et al., 2020), I predicted meso-carnivores co-occurrence with leopards will reduce with increased human disturbance and habitat fragmentation to reduce the probability of possible lethal encounters (Palomares et al., 2016; Wilson et al., 2010). Since the prey base in the study area is small, I predicted the co-occurrence of meso-carnivores with large competitors would be lower in places with fewer prey. Small carnivores can use humans as ‘shields’ against large competitors (Moll et al., 2018); hence, I predicted a negative association of their co-occurrence with leopards at higher levels of anthropogenic disturbance but positive associations with other carnivores. Jackals were expected to co-occur with leopards due to scavenging opportunities. I hypothesized that leopard occurrence would be positively correlated with prey occupancy, reflecting prey-mediated predator distribution. I predicted that human disturbance, habitat and landscape features mediate predator-prey associations, with human disturbance weakening such associations. I also assessed temporal activity, predicting meso-carnivores would adjust activity to minimise the risk of negative encounters with leopards (Havmøller et al., 2020). It was predicted that leopard will have high activity overlap with prey species as the study area is a highly anthropogenically disturbed landscape.

Broadly, this study asks how human disturbance together shapes the spatial and temporal interactions of mesocarnivores and prey with apex predators in highly modified landscapes. This question has global implications, as similar combinations of fragmentation, limited

resources, and human pressures occur across many dryland, arid, and semi-arid ecosystems. By revealing how carnivores partition space and time under overlapping ecological and anthropogenic constraints, my findings will provide insights that can inform conservation and management in other anthropogenically modified landscapes.

5.3 Methodology

Study area

I conducted this study within the territorial forest division of the Ballari district (between 14° 30' and 15° 50' North latitude and 75° 40' and 77° 11' East longitude). This site covers an area of approximately 2,600 km² and lies in the southern part of the Deccan plateau of India (Fig. 5.1). Tropical dry deciduous forests and dry thorn forests constitute the two major vegetation types (Champion & Seth, 1968). *Acacia catechu*, *Albizia amara*, *Azadirachta indica*, *Chloroxylon swietenia*, *Hardwickia binata*, and *Zizyphus spp.* are the dominant tree species (Behera et al., 2024). Ballari district has a low-productivity landscape characterized by dry forests, limited water and less tree coverage. Despite, the majority of Ballari containing arid and semi-arid environmental conditions, the site supports a diversity of medium-sized carnivores and prey species, including leopards, golden jackals, Indian foxes, jungle cats, rusty-spotted cats, wild pigs and black-naped hares, among others. The landscape also inhabits a good number of ground-dwelling birds i.e. galliformes (peafowls *Pavo cristatus*, grey francolin *Francolinus pondicerianus*, painted spurfowl *Galloperdix lunulata*, red spurfowl *Galloperdix spadicea*, etc.). The forested areas of Ballari district include two sanctuaries (namely Daroji and Gudekote Sloth Bear Sanctuaries; IUCN category IV), reserved forests, and the adjoining fringe mosaic farmlands (buffer surrounding areas up to 1 km from forest boundary). Ballari, being one of India's most economically backward districts, with its local population depending on agricultural activities, NTFP collection and maintaining large herds of cattle, goats, and sheep. Active mines (Iron and manganese) encompass over 5000 hectares of land and are found primarily within forested areas (Meena, 2013).

Data collection and analyses

I collected 21 months of data (2019-2021) from 1457 camera trap locations within 1 km² grid cells as part of a long-term survey. I placed cameras in each cell based on mammalian sign surveys (Jhala et al., 2008; Karanth & Nichols, 2002), to collect the occurrence data of

mammals. Camera locations were selected where sign surveys indicated the presence of multiple mammalian species, ensuring placement in general mammal activity spots, rather than in areas used by any particular species. Each unbaited camera station had a single infrared motion-triggered camera trap (Cuddeback digital 20MP Blue Series, USA) spaced at least ~0.7 km apart and installed 30-35 cm above ground along animal trails, dirt roads, and near water sources like rivers, stream beds, and artificial waterholes. Obstructing vegetation was cleared to minimize false triggers. Cameras remained active for 22 days (30s motion-triggered delay settings), and data was retrieved on a weekly basis. To access spatiotemporal interactions between the four carnivores, I overlaid 4 x 4 km² grid cells across the study area using ArcGIS 10.1 (ESRI, Redlands, CA, USA) and divided the study area into 167 camera-trapping grid cells (16 km² each). I treated these cells as sampling units based on the home ranges of leopards and other carnivores (Table 5.1). For the predator-prey multispecies occupancy modelling, I considered 1457 camera trapping grid cells.

Table 5.1: Ecological characteristics of the study species – apex / top predator and meso-predators in Ballari district, Karnataka

Species	Average weight (in kg)	Diet	Home range size (in km ²)	Habitat preference
Leopard	45-77	Carnivorous; preferably ungulates; livestock; small mammals.	8-65	Tropical savannah; woodland; deciduous; scrub; evergreen
Golden jackal	4.5-15	Omnivorous; small mammals, ungulates, fruits, birds, invertebrates, etc.	3.1-23.7	Semi-arid grasslands; savannah; scrub; rural; semi-urban
Indian fox	1.8-3.0	Omnivorous; rodents; arthropods; small mammals; fruits, etc.	1.16-10.71	Semi-arid; scrub; grassland; dry deciduous
Jungle cat	4	Carnivorous; small mammals, majorly rodents, birds, insects, etc.	1.01-26.48	Scrub, grassland and marshy areas

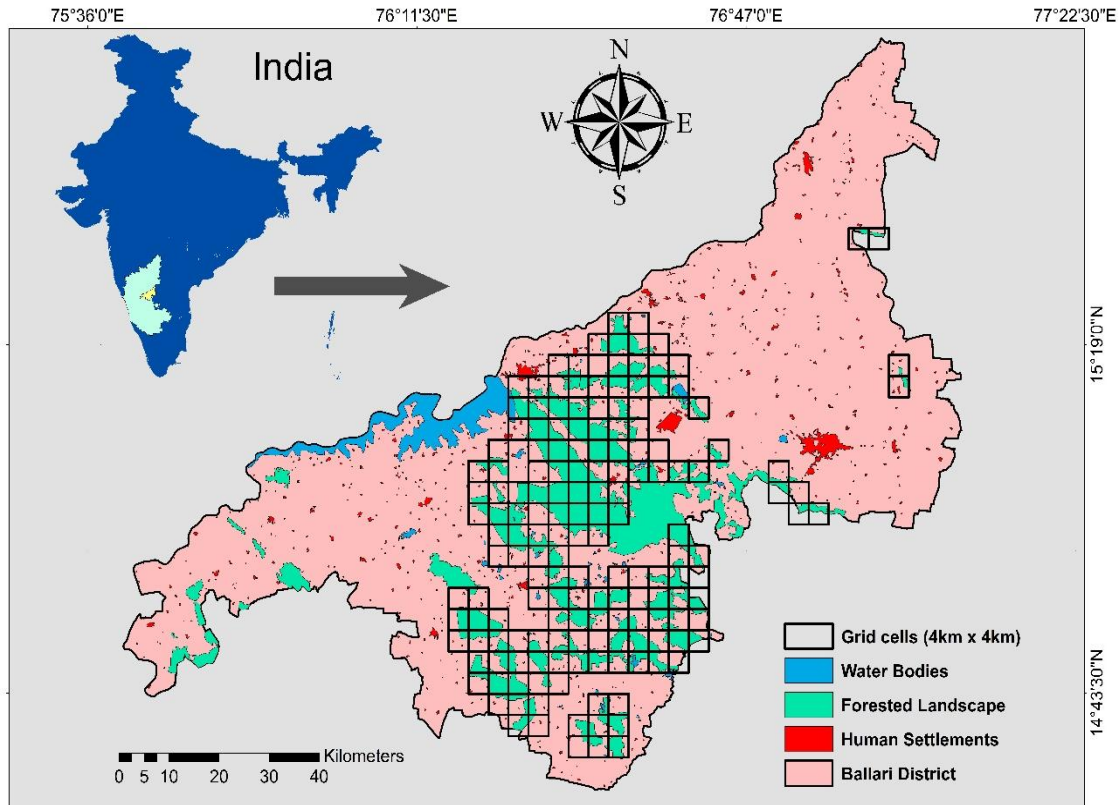


Figure 5.1: Study area showing sampling grid cells (4 x 4 sq. km) (n=167) in Ballari district, Karnataka

Model Covariates

To model variation in occupancy probability, I identified potential environmental limiting factors and proxies of human disturbance as covariates. Based on species ecology, for the first part of multi-species modelling (apex predator – meso-predators, i.e. predators only), I included 10 environmental covariates, categorized into anthropogenic features, habitat fragmentation, and natural habitat features, along with three prey abundance covariates (Appendix S9). Anthropogenic features included human settlement coverage, human abundance index, free-ranging dog abundance index, and livestock abundance index; Habitat fragmentation covariates comprised proximity to farmland, main-patch proximity, patch size, and forest cover; Natural habitat feature including canopy cover, served as an indicator of vegetation density and habitat quality; and Prey abundance indices including the common prey species of all study species i.e., hare, galliformes and wild pig abundance indices. For the second multi-species modelling (predator-prey modelling), I used the same covariates except for the ones related to prey abundance.

I developed predictor variables ranging from local site characteristics through proximity variables and indices of detection of prey species using appropriate variable-specific approaches. Human settlement and forest cover data were calculated at the sampling-grid level and extracted from the spatial layer (Roy et al., 2015). Field sampling covered 30 forest patches of varying sizes (0.80 -413.25 km²), classified as either main-patch (intact large patch >100 km²) or fragment (<100 km²). Fragment area and main-patch isolation distance was calculated using Patch Analyst for each sampling grid in ArcGIS 10.1 (Environmental Systems Research Institute Inc., Redlands, CA, USA). While all other covariates were first estimated at the camera trap level, then averaged with each sampling grid. Proximity to habitat categories such as farmlands was derived from upgraded shapefiles procured from the state forest department, rasterized using the Euclidean distance tool in ArcMap 10.3 (ArcMap 10.3, Redlands, CA: Esri Inc, 2016). The canopy coverage percentage was visually calculated inside a 20-meter radius around each camera using standard visual estimation (Jhala et al., 2008; Kent, 2011). A circular plot around each camera was divided into four quadrants, and the proportion of sky obscured by foliage was visually estimated in each quadrant. The four values were averaged to obtain canopy cover for that camera location, and these estimates were then averaged across camera traps to generate a grid-level canopy cover value. Human, dog, and livestock (cattle, goats, and sheep) abundance at each site was quantified using three relative abundance indices (RAI): humans (on foot or vehicles), cattle-goats-sheep, and free-ranging dogs. I estimated the RAI of a species as the total number of its independent photographs (one per 30-minute interval) in the total trap-nights (Palmer et al., 2018) at each camera site, then averaged it across the sampling grid.

Black-naped hares, wild pigs, and galliformes are the only three widely distributed prey species in the study region (Behera et al., 2024), so I calculated their RAI for modelling. Continuous site covariates were standardized to Z scores (Cooch & White, 2005), and Pearson's correlation coefficient was used to detect multi-collinearity. If two covariates showed a correlation above 0.65 (Graham, 2003; Wei & Simko, 2021; Fig 5.2) I discarded the one with lower predictive power. I developed '0'-'1' matrices for each species ('1' indicating detection and '0' indicating detection and non-detection), during each 1-day sampling occasion (Otis et al., 1978). I also included one detection covariate, i.e. trap effort (total trap nights per sampling grid), to account for unequal sampling effort. For predator-prey modelling, instead of human settlement coverage, I used another anthropogenic covariate i.e. proximity to human settlement using Roy et al. (2015) layer.

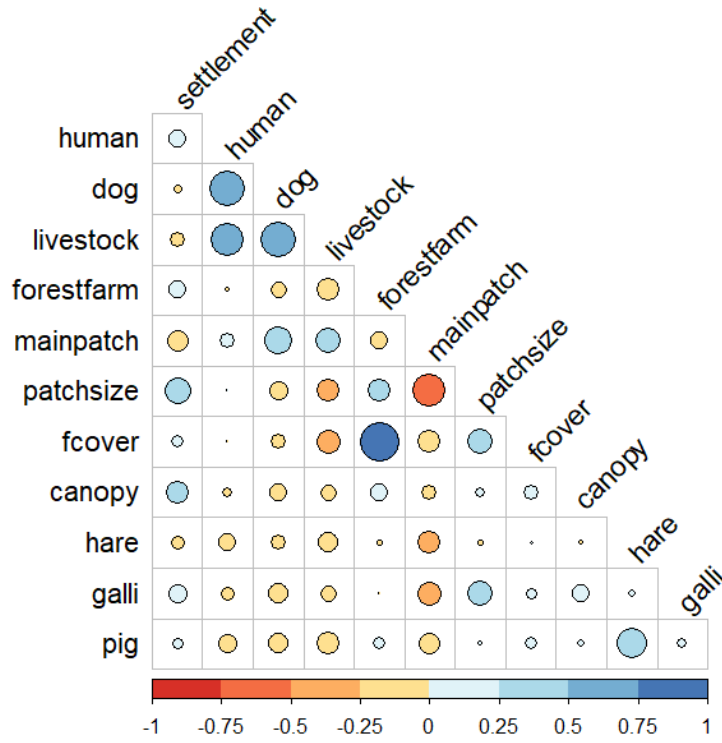


Figure 5.2: Pearson's correlation coefficient of all covariates on the occupancy of mammalian species in the study area [fcover and patchsize were removed ($r > 0.65$); Here, settlement: human settlement cover, human: Relative Abundance Index (RAI) of humans, dog: RAI of free-ranging dogs, livestock: RAI of livestock, mainpatch: proximity to main patch, patchsize: size of forest patch, forestfarm: proximity to forest boundary, fcover: forest coverage, canopy: canopy coverage, hare: RAI of black-naped hare, galli: RAI of galliformes, pig: RAI of wild pig]

Multispecies interaction model

I used a Bayesian multi-species co-occurrence model developed by Rota et al. (2016) to analyse the spatial interaction among my four ($S = 4$) study species concurrently using detection/non-detection data. This approach extends MacKenzie et al.'s (2002) single-species model to multiple interacting species, and it accommodates covariate effects. The framework comprises a latent occupancy state (Z_i) of species s at site i as a multivariate Bernoulli random variable: $Z_i \sim \text{MVB}(\Psi_i)$, where $Z_i = \{z_{1i}, z_{2i}, z_{3i}, \dots, z_{Si}\}$ for each of the $s = 1, \dots, S$ species at site $i = 1, \dots, I$. Z_i is an S -dimensional vector represented by a sequence of 1's and 0's denoting whether the species is present (1) or absent (0) at site I and Ψ_i is a vector of length 2^S probabilities for each possible presence/absence combination of S species that Z_i can obtain. These probabilities are modelled on the logit scale, as log odds of species occupancy and are referred to as the natural parameters. The vector of natural parameters for each site (f_i) can have a maximum

length of $2^S - 1$, depending on the number of species and the nature of the interactions included in the model. Species occurrence is assumed independent if all second-order and higher natural parameters are fixed at 0, whereas dependence between species can be modelled by estimating parameters associated with second-order and higher natural parameters. Here, I used a model with four species (first part) and considered only second-order pairwise interactions between species, thus resulting in ten natural parameters being modelled. I did not model higher-order, i.e. three-species and four-species interactions, assuming the probability of three species or four species occurring together as a function of species-specific and pair-wise interaction parameters (Penjor et al., 2022). I examined marginal occupancy (probability of one species occurrence regardless of other species), conditional occupancy (change in the probability of a species occurrence whether another species is present or absent), and species co-occurrence. I conducted the analysis at a $4 \times 4 \text{ km}^2$ grid resolution, selected to reflect the ecologically relevant scale for leopard-mesocarnivore interactions, based on leopard home-range size in similar semi-arid Indian landscapes (14.5 km^2 , Snider et al., 2021).

In the predators-only modelling, I fitted a set of 53 candidate models to test my hypotheses regarding the effects of anthropogenic, prey abundance, and habitat variables on interspecific interactions between species. I selected the best models by comparing the Akaike information criterion (AIC), Akaike weight (AIC weight), and the significance of beta estimates of the models within $2 \Delta\text{AIC}$ (Burnham & Anderson, 2002) (Appendix S10). While in predator-prey modelling, I used a two-step approach (Salvatori et al., 2021). First, I chose the most influential covariates for single species using single-species occupancy modelling, then I incorporated those top covariates from single-species models into the multi-species model as predictors of occupancy and detectability of single species. I restricted models that examined the impact of variables to no more than two ecologically significant covariates, due to the complexity of these models (Justa & Lyngdoh, 2023). The relatively close spacing of camera traps along with the leopard's large ranging patterns, may compromise the independence of sampling units, so the study's occupancy estimates serve as a proxy for "habitat use" instead of true occupancy estimates (Burton et al., 2015). I implemented the models using the packages "unmarked" and "AICcmodavg" in R (Fiske & Chandler, 2011).

Temporal overlap

I investigated diel activity patterns of the four carnivore species by retrieving the time information from camera trap images. I subsampled the detection data by treating multiple photo captures within a 30-minute window as one event (Zimmermann et al., 2016). I generated temporal activity curves using the “overlap” package in R (Ridout & Linkie, 2009). This package fits activity curves concerning the species' photo-capture rates over a time interval using a kernel density function (Meredith and Ridout, 2016). First, I executed pairwise comparisons of activity patterns among all species by estimating the overlap coefficient Δ (ranging from 0, no overlap, to 1, complete overlap) using Δ_4 when the sample size exceeded 75 and Δ_1 when the sample size was below 50 (Meredith & Ridout, 2016). Confidence intervals for overlap estimates were generated using 1,000 bootstrap resamples. Next, I categorized meso-carnivore detections based on leopard presence or absence at a site and compared their activity patterns to understand the influence of leopards on meso-carnivore behaviour. Activity curves and overlap coefficients were computed using the same estimator selection and bootstrap procedures. Similarly, I compared the activity patterns of prey species with leopards to interpret the predator-prey temporal association.

5.4 Results

The camera trapping survey effort lasted for 31,702 trap nights across 167 (4x4) sampling grid cells and provided 408 photographs of leopards, 819 photographs of jackals, 625 photographs of foxes and 550 photographs of jungle cats. The naïve occupancy (i.e., the proportion of sites in which the species was detected) of leopard, jackal, fox, and jungle cat were 0.52, 0.61, 0.54 and 0.75, respectively.

Multispecies occupancy modelling

Model selection demonstrated that models considering interspecific interactions performed better. The top model included a global first-order model including all variables (i.e. settlement cover, human, dog, livestock, prey abundance (hare, wild pig, and galliformes), canopy, proximity to farmland and main-patch) and a second-order model comprising all variables related to the categories of anthropogenic features, and prey availability (Appendix S9). Models that included trap effort (number of trap nights) as a detection covariate outperformed those without it, with detection probabilities positively correlated with trap effort ($\beta_{\text{Leopard}} =$

$0.75 \pm 0.08_{SE}$, $\beta_{Jackal} = 0.39 \pm 0.06_{SE}$, $\beta_{Fox} = 0.31 \pm 0.07_{SE}$ and $\beta_{Jungle\ cat} = 0.51 \pm 0.06_{SE}$). The detection probabilities were $0.125 \pm 0.009_{SE}$ for leopards, $0.222 \pm 0.013_{SE}$ for jackals, $0.211 \pm 0.014_{SE}$ for foxes, and $0.145 \pm 0.009_{SE}$ for jungle cats.

Table 5.2: Model selection results for a multi-species occupancy (carnivore interactions) analysis from a camera trapping survey in Ballari district, Karnataka, India

First order model	Second order model	Detection	AICc	$\Delta AICc$
Global	settlement + human + dog + livestock + hare + galli + pig	tnight	9828.41	0.00
Global	settlement + human + dog + livestock + forestfarm + mainpatch	tnight	9830.80	2.39
Global	settlement + human + dog + livestock + forestfarm + mainpatch + hare + galli + pig + canopy	tnight	9831.38	2.97
Global	settlement + human + dog + livestock + forestfarm + mainpatch + hare + galli + pig	tnight	9832.20	3.79
Global	settlement + human + dog + livestock + hare + galli + canopy	tnight	9833.23	4.82

All no-interaction models set pairwise interaction components to zero (i.e., effectively removed second-order models). Global sub-models refer to those where all covariates were included. Anthropogenic features (AF) include human settlement density (settlement), human abundance (human), dog abundance (dog) and livestock abundance (livestock); Habitat fragmentation (HF) includes proximity to farmland (forestfarm) and proximity to main-patch (mainpatch); Prey abundance (PA) includes hare abundance (hare), galliformes abundance (galli) and wild pig abundance (pig); and Natural habitat features (NF) include canopy cover (canopy). Detection covariate: trap-nights (tnight). This table contains the top five models. The list of all 53 models is provided in Appendix S5.

Jungle cats had the highest mean marginal occupancy estimate ($\Psi_{\text{Jungle cat}} = 0.830 \pm 0.049_{\text{SE}}$), followed by leopards ($\Psi_{\text{Leopard}} = 0.657 \pm 0.067_{\text{SE}}$), jackals ($\Psi_{\text{Jackal}} = 0.628 \pm 0.058_{\text{SE}}$), and foxes ($\Psi_{\text{Fox}} = 0.561 \pm 0.066_{\text{SE}}$). The best-performing model identified human and dog abundance as important human disturbance first-order predictor variables (Table 5.2). Free-ranging dog and hare abundance had a strong positive effect on both leopard and fox occupancy (Fig. 5.3). Marginal occupancy for all study species showed expected trends for main-patch variable, but it was only a strong first-order predictor for leopard and jackal (Appendices S11–S14). Proximity to the main-patch negatively influenced leopard occurrence ($-1.91 \pm 0.50_{\text{SE}}$; p -value = 0.00) but positively affected jackals ($0.85 \pm 0.35_{\text{SE}}$; $p = 0.01$), and jungle cats ($1.52 \pm 0.57_{\text{SE}}$; $p = 0.01$; Figure 2). The availability of dense canopy was negatively associated with fox occupancy ($0.76 \pm 0.30_{\text{SE}}$; $p = 0.01$).

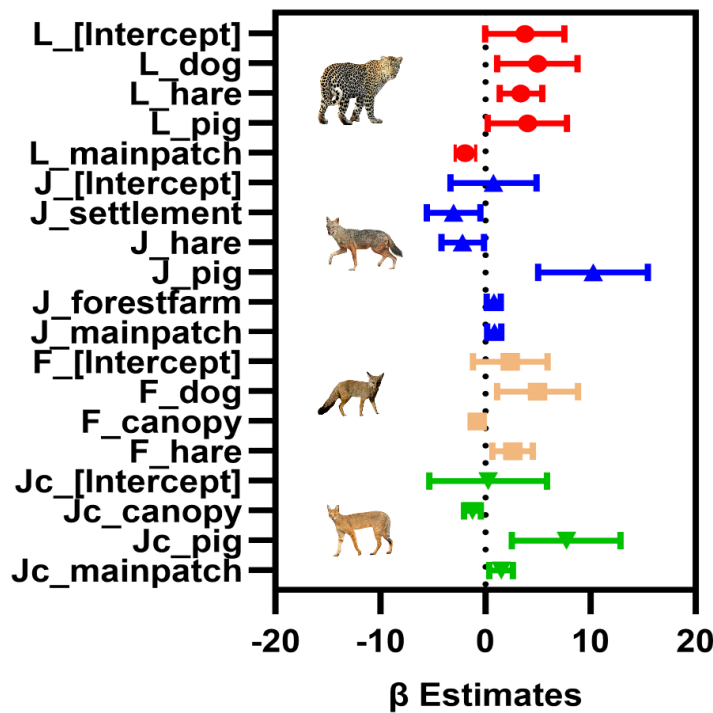


Figure 5.3: The effects of environmental variables on occupancies of individual species (first order models): Leopard (L), golden jackal (J), Indian fox (F) and jungle cat (Jc). The log-transformed parameter (β -coefficients) estimates for explanatory variables from the top model. Lines indicate median and 95% credible intervals. Significant relationships are illustrated with coefficient estimates. Different colour stands for different species

Pairwise second-order models provided strong statistical support for multiple interactions among the four species (Figure 5.4b; Appendices S15–S20). The leopard-jungle cat pair showed a positive slope coefficient, indicating they occur together more frequently than expected by chance. In contrast, the negative slope coefficient for the leopard-fox suggested foxes were less likely to occupy sites with leopards. Positive slope coefficients for jackal-fox and jackal-jungle cat pairs indicated that jackals were more likely to occur when foxes or jungle cats were also present, and vice versa (Figure 5.4a). There was no evidence of significant interaction among pairs of leopard-jackal and fox-jungle cat.

The probability of two species occurring together varied as a function of settlement cover for the leopard–jungle cat and jackal–jungle cat pairs (Figure 5.4b). At low settlement cover, the jungle cat was more likely to co-occur with the leopard while at a higher settlement cover jungle cat was more likely to co-occur with the jackal, and independent of other species (Figures 5.4b & 5.5). Similarly, the relationship between the probability of leopard occurrence and the relative abundance of humans varied significantly depending on whether jackals and jungle cats were present (Figure 5.5). At low human abundance, jackals were more likely to occupy sites with leopards and occurred independently of other species, whereas jungle cats co-occurred with leopards at higher human abundance. The conditional occupancy of foxes with leopards and jungle cats was best explained by the function of free-ranging dog abundance (Figures 5.4b & 5.5), where occupancy of foxes decreased with an increased abundance of dogs when leopards were present, but it increased when jungle cats were present. Jungle cat co-occupancy in relation to leopards and jackals was influenced by livestock abundance (Figures 5.4b & 5.5), it declined with increasing livestock abundance when leopards were present but increased in the presence of jackals. Carnivore co-occurrence also varied with prey availability, particularly hares and pigs. Fox–leopard co-occurrence declined with the increasing availability of hares (Figures 5.4b & 5.5). I also observed that the increased availability of wild pigs negatively affected carnivores' co-occurrence (Leopard-fox, jackal-fox and jackal-jungle cat; Figures 5.4b & 5.5).

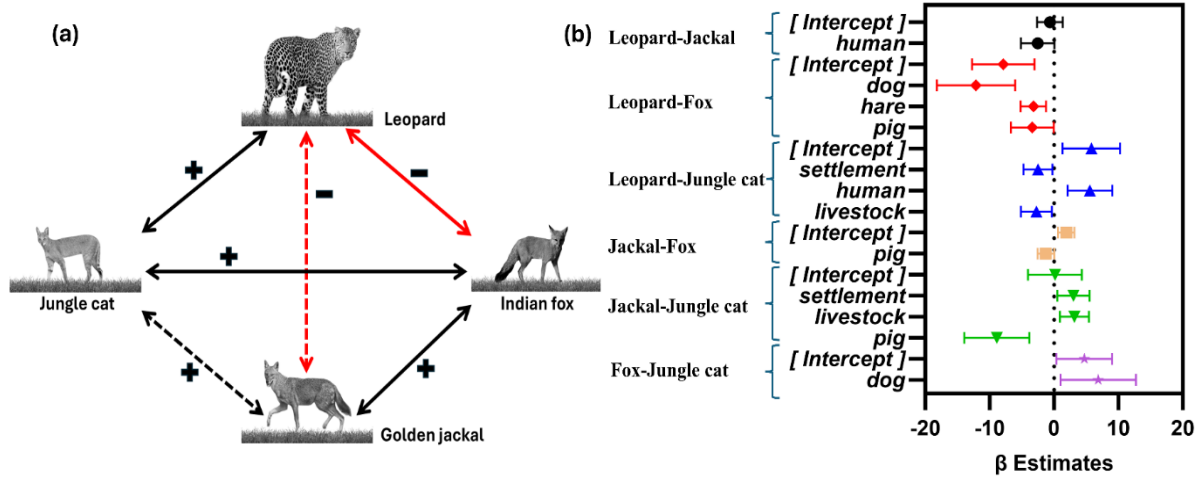


Figure 5.4: The schematic representation of the sign of co-occurrence relationships between species pairs (a) and the effects of anthropogenic and environmental variables on pairwise interactions (b). 3a) The solid lines depict significant relationships while the dashed lines represent insignificant relationships. Black lines represent positive association, while red represents negative association. 3b) The log-transformed parameter (β -coefficients) estimates for explanatory variables from the top model. Lines indicate median and 95% credible intervals. Significant relationships are illustrated with coefficient estimates. Different colours represent different species' interactions

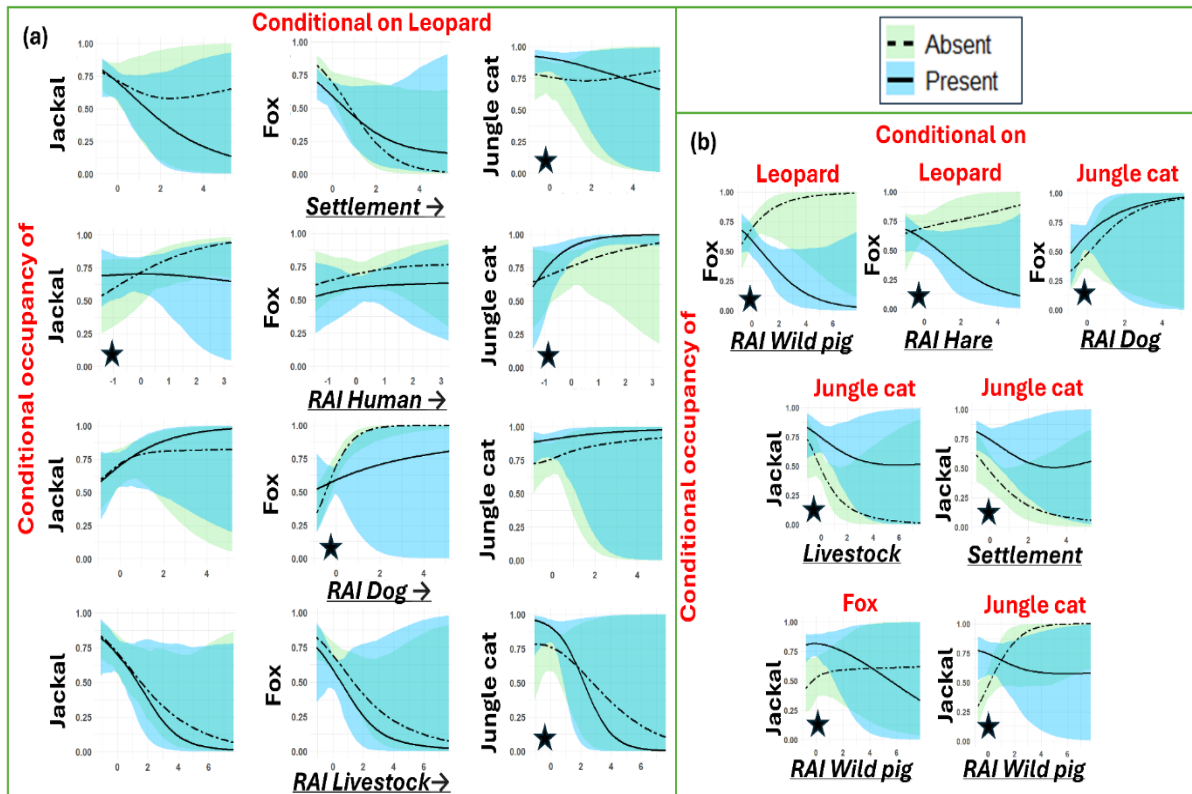


Figure 5.5: Conditional occupancy of one species in the presence and absence of another species: Conditional occupancy of jackals, foxes and jungle cats in the presence and absence of leopards along human disturbance variables: human settlement density, human abundance, free-ranging dog abundance and livestock abundance [left panel (a)]; Since I am mainly focusing on understanding the effect of leopards on meso-carnivores], conditional occupancy graphs from other significant interactions between species i.e. between meso-predators along human disturbance gradient or between species along prey abundance gradient [right panel (b)]. The posterior means are depicted by lines, while 95% credible intervals are depicted by shaded ribbons. The star symbol indicates a significant relationship

Predator-prey multi-species occupancy models revealed that leopard occupancy was positively related to both black-naped hare and wild pig occurrence. Anthropogenic covariates had a strong influence on these associations. Leopard-hare co-occurrence declined as the RAI of dogs increased, as did proximity to human settlements. Leopard-pig co-occurrence also declined in areas with higher RAI of dogs but increased further inside forested landscapes, away from forest boundaries. Meanwhile, hare-pig co-occurrence decreased with increasing RAI human and RAI dog (Table 5.4).

Table 5.3: Covariate coefficient estimates from the multi-species co-occurrence model for leopard, black-naped hare, and wild pig in Ballari district, India

Species pair	Estimate	SE	z	p-value
[Leopard: Hare]				
RAI dog	-0.274	0.148	-1.849	6.44e-02
Settlement	-0.107	0.110	-0.971	3.32e-01
[Leopard: Wild pig]				
RAI dog	-0.566	0.236	-2.394	1.67e-02
Forestfarm	0.244	0.095	2.580	9.87e-03
[Hare: Wild pig]				
RAI human	-0.288	0.123	-2.352	1.87e-02
RAI dog	-0.170	0.134	-1.270	2.04e-01

Temporal interactions

All four carnivores exhibited crepuscular to nocturnal behaviour. Leopards exhibited a mix of nocturnal and crepuscular activity, with peaks at 2:30 am and 7 pm. Jackals, although largely crepuscular, displayed relatively more early-morning activity than leopards, with peaks at 6 am and 7:30 pm. Whereas both Indian foxes and jungle cats were strongly nocturnal. Although all meso-carnivores showed higher overlap with leopards, the leopard-jungle cat overlap (0.797, $CI_{95\%} = 0.760-0.854$) was relatively lower compared to leopard-jackal (0.855, $CI_{95\%} = 0.808-0.902$) and leopard-fox (0.839, $CI_{95\%} = 0.800-0.884$) pairs (Figure 5.6). Activity pattern graphs revealed that all meso-predators adjusted their activity in response to the leopard's peak activity periods (Figure 5.7). Jackals and foxes displayed increased nocturnal activity, whereas jungle cats exhibited a slight temporal shift towards more daytime activity in the presence of leopards. Activity pattern graphs revealed that there were no significant changes in activity patterns of meso-predators when the leopards were present, from when the leopards were absent, but they slightly adjusted their activity by shifting peaks relative to the leopard's peak activity periods (Figure 5.7). Despite the high temporal overlap between activity patterns of meso-carnivores in the presence and absence of leopards (Jackal: $\Delta = 0.868$, Fox: $\Delta = 0.862$, Jungle cat: $\Delta = 0.863$), subtle but clear fine-scale shifts in activity peaks were evident (Figure 6). In the presence of leopards, jackals shifted from crepuscular to predominantly nocturnal activity,

foxes showed an increase in nocturnal activity, while jungle cats exhibited a slightly increased diurnal activity. Both hare and wild pig showed bimodal peaks at dawn and dusk, demonstrating crepuscular activity. Activity pattern analysis revealed high temporal overlap of leopard with hare (0.84) and wild pig (0.87), with small shifts in prey peaks (Fig. 5.8).

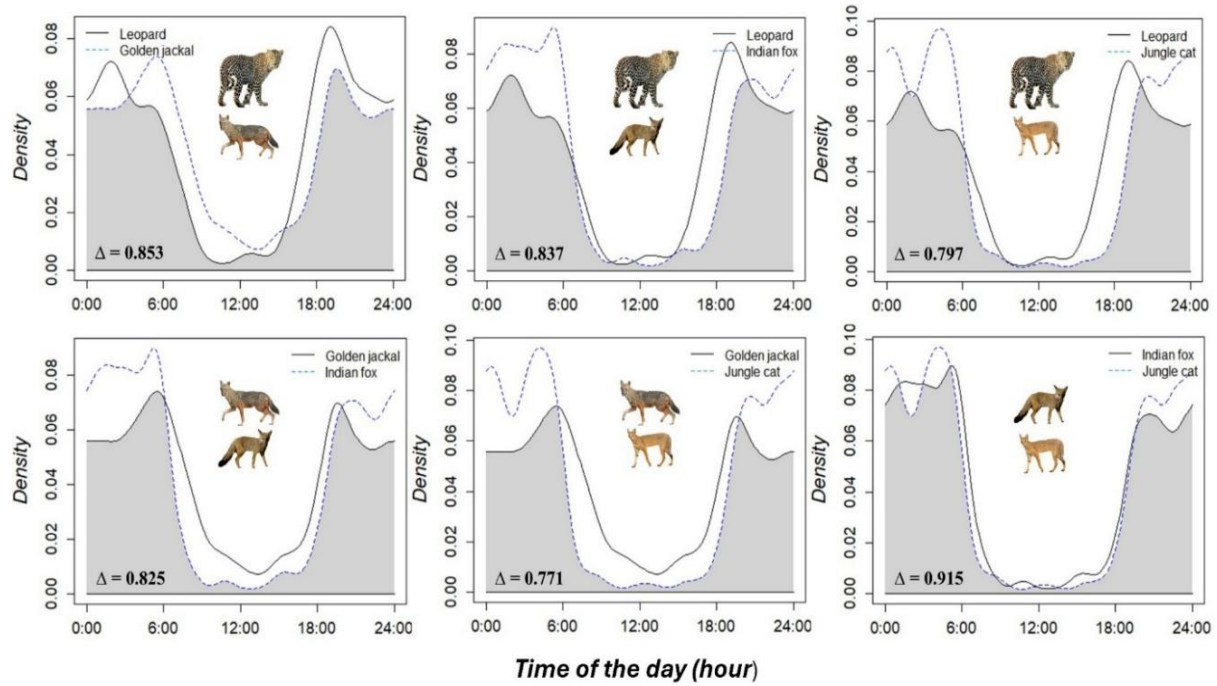


Figure 5.6: Pairwise comparison of Kernal density activity patterns of focal species in Ballari district, Karnataka, India; with overlap coefficients and the shaded grey area is overlap

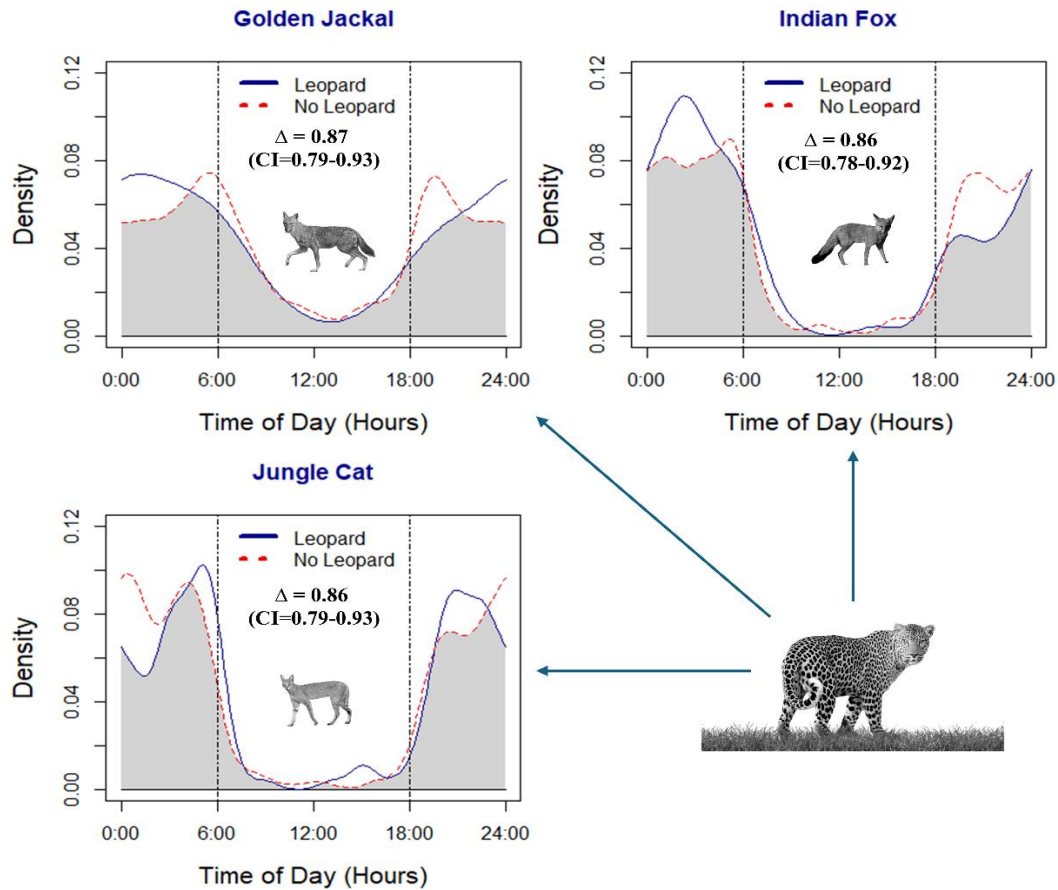


Figure 5.7: Pairwise comparison of Kernal density activity patterns of meso-carnivores in the presence and absence of leopards in Ballari district, Karnataka, India

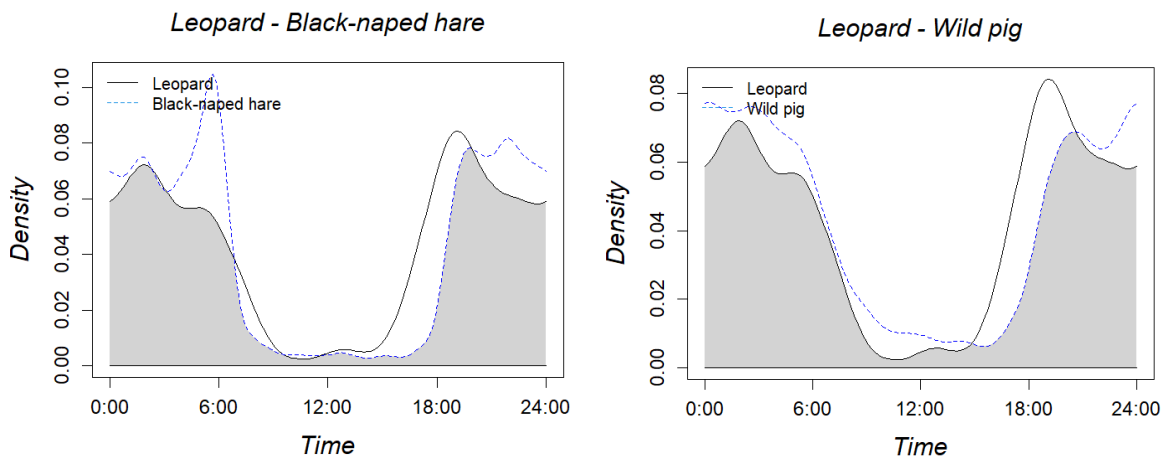


Figure 5.8: Pairwise comparison of Kernal density activity patterns of apex predator, i.e. leopard and prey species in Ballari district, Karnataka, India

5.5 Discussion

This research underscores the profound impact of human activities on carnivore communities, highlighting how anthropogenic disturbance alters the top-down control of top carnivores and shapes the spatiotemporal dynamics of sympatry patterns among carnivores in highly disturbed, modified, and low-productivity landscapes. Although differences in habitat preferences and species-specific responses to human disturbance can influence meso-carnivores' co-occurrence and temporal patterns, my results indicate that the top-down effects of large predators still play a key role in driving spatio-temporal segregation among carnivores, but these effects weaken with increasing human disturbance. The key insight is the evident influence of human disturbance on the interaction among carnivores, consistent with previous studies (Parsons et al., 2019; Sévêque et al., 2020). The inclusion of interspecies interactions improved model inference as seen in similar studies (Justa & Lyngdoh, 2023; Parsons et al., 2019; Penjor et al., 2022), emphasising the need for holistic multi-species conservation strategies that account for both competition and coexistence. Large carnivores play a vital role in maintaining ecological balance by driving ecological niche segregation among meso-carnivores through spatial and temporal axes (MacArthur & Levins, 1967; Schoener, 1974), reinforcing their importance in ecosystem stability. However, my results showed that in areas with high human pressure, the influence of large predators i.e., leopards, on mesocarnivore occurrence and behaviour is substantially diminished. The disproportionate impact of anthropogenic pressures threatens large predators' survival, which could lead to meso-predator release and subsequently disruptions in trophic dynamics (Villalva et al., 2024). The results also revealed that predator-prey interactions in the study area are determined not just by prey availability but also shaped by human disturbance (Dorresteijn et al., 2015). Meso-carnivores typically avoid large carnivores through temporal partitioning (Di Bitetti, 2010). Temporal analysis suggests that this segregation is reduced under high human disturbance, as the activity windows of carnivores are narrowed. Such compression of activity periods could affect meso-carnivores' survival and compromise coexistence among carnivore species. Prey adjust their activity to partially overlap with apex predators, but they fine-tune their peaks to limit direct encounter risk (Monterroso et al., 2013).

Spatial interactions between sympatric carnivores play an critical role in structuring ecological communities (Boron et al., 2023). Predator species compete for shared prey and pose direct and indirect threats to each other (Prugh et al., 2009). The negative association of foxes and jackals with leopards in this study indicates that the potential avoidance of large

predators influences the spatial distribution of meso-carnivores (Boron et al., 2023), although local habitat features may also play a role in determining suitability. Additionally, jackals' co-occurrence with leopards was not statistically significant, possibly due to their opportunistic scavenging on carcasses of leopards' prey (Hayward et al., 2017). Positive co-occurrence of leopard and jungle cats suggests that habitat fragmentation concentrates them into remaining forest patches with dense vegetation. Both leopards and jungle cats are felids and need dense cover to stalk and ambush their prey (Tossens et al., 2025). Overall, my results highlight the significance of spatial interactions among carnivores, while also considering that habitat characteristics can modulate these patterns.

Modification of natural habitats alters carnivore distribution (Crooks et al., 2011) and increases spatial interactions between carnivores (Parsons et al., 2019). Multi-species analysis showed that human disturbance affected species interactions differently. As human settlement coverage increased, the spatial overlap between leopards and jungle cats decreased, while the overlap between jackals and jungle cats increased. The strong positive co-occurrence between jackals and jungle cats in high settlement areas could be due to their ability to utilize anthropogenic resources like garbage and livestock, and thrive in moderately modified agrosystems (Ćirović et al., 2016; Mahato et al., 2023). In Ballari, most agricultural lands near forests are small-scale farms bordering human settlements (Meena, 2013). Agricultural lands provide vegetative matter and abundant small prey like rodents and insects, benefiting meso-carnivores (Alain et al., 2006). In arid and semi-arid landscapes, rodents and other small mammals are key prey for meso-carnivores like jackals, foxes, and jungle cats (Home & Jhala, 2009; Majumder et al., 2011; Mukherjee et al., 2004). Higher food availability along with reduced predation risk presumably increased their occupancy in these areas (Carricondo-Sanchez et al., 2019). Leopards–jungle cats (both felid) show strong negative associations in high-settlement areas, likely due to more direct competition and negative human impacts on leopard habitat use (Behera et al., 2024; Gubbi et al., 2020). This indicates that high human settlement areas may serve as spatial refugia for smaller carnivores from larger carnivores (Moll et al., 2018).

Carnivores respond differently to human disturbances at local (measured from camera-trap data) and landscape levels (Behera et al., 2024; Suraci et al., 2021). Human presence instils fear in carnivores (Gaynor et al., 2018), leading to spatial or temporal avoidance (Suraci et al., 2021). My analysis shows that human abundance negatively affected leopard–jackal interactions, signifying their varying response to humans, which is likely due to their different

ecological traits, particularly body size and diet (Suraci et al., 2021). Conversely, leopard-jungle cat co-occupancy increased with human abundance, suggesting that in low-productivity prey-scarce landscapes, felids use modified landscapes for domestic prey species like livestock, which are generally accompanied by humans (Athreya et al., 2016; Mahato et al., 2023). However, they avoid direct conflict with humans through nocturnal activity.

In human-dominated landscapes, predators rely heavily on domestic animals as a primary source of prey (Athreya et al. 2016; Katna et al. 2022). My results showed that spatial overlap between jungle cats and leopards was lower in areas with high livestock abundance, whereas it was higher between jungle cats and jackals in similar situations. Increasing livestock abundance may concentrate leopard activity in areas that become riskier or less suitable for jungle cats, resulting in spatial avoidance. While jackals and jungle cats are both generalist meso-predators that benefit from livestock-related resources e.g., carcasses (Ćirović et al. 2016; Katna et al. 2022). Unlike leopards, jackals pose less direct threat to jungle cats, so the two meso-predators can coexist where livestock are abundant. Furthermore, higher rodent populations are found around livestock feed and dung (Lovera et al. 2019). Thus, shared habitat tolerance and dietary overlap increased the co-occurrence of jungle cats and jackals.

Free-ranging, guard, and feral dogs rely on humans for food while preying on local wildlife (Hughes & Macdonald, 2013). Fox occupancy declined with increasing dog abundance, given the presence of leopards. Marginal occupancy estimates indicated that higher dog abundance reduces fox occupancy, likely due to dog harassment (Vanak & Gompper, 2009a). In prey-scarce landscapes, leopards often prey on domestic animals, primarily dogs (Athreya et al., 2016). Consequently, high dog abundance may draw leopards, compelling foxes to avoid these areas.

Prey abundance was a key predictor of carnivore co-occurrence. Hare abundance index negatively mediated leopard-fox interaction, supporting my hypothesis. In the prey-scarce Ballari landscape, hares and wild pigs are the primary prey species of leopards (Behera et al., 2024), as shown by results from the first-order submodel (Figure 2). Intraguild predation theory states that top predators are shaped by food availability, while subordinate species balance food access and predation risk (Polis & Holt, 1992). This framework helps interpret lower fox occupancy in areas used by leopards with an increase in hare abundance. Although foxes and leopards differ markedly in body size and overall prey use patterns, hares constitute a major prey source for both in the study area. Thus, shared reliance on a key prey species in prey-

scarce landscapes may intensify risk-driven spatial avoidance by meso-carnivores, which could magnify dietary segregation. I observed that higher wild pig abundance was associated with a decrease in co-occurrence between certain carnivore pairs, specifically leopard-fox, jackal-fox and jackal-jungle cat, suggesting that pigs may influence spatial segregation among carnivores in the landscape. Leopards prey on wild pigs, especially adult sows and piglets (Andheria et al. 2007; Palei et al. 2022). The areas with a higher abundance of pigs would attract leopards, increase the predation risk and thus causing spatial avoidance by foxes. Wild pigs are highly competitive and aggressive omnivorous generalists who can out-compete and displace smaller meso-carnivores from foraging and scavenging sites through both interference and exploitative competition (Brogi et al. 2025; Hegel et al. 2019). Wild pigs are also known to alternate habitat structure by their rooting and wallowing behaviour, making areas less suitable for smaller carnivores (Ickes et al. 2001). In such cases, meso-carnivores may become more spatially segregated to reduce interference. Henceforth, wild pigs can mediate indirect interspecific interactions among carnivores.

The positive co-occurrence of leopards with both hares and wild pigs underscores the importance of prey availability in driving predators' distribution (Ripple et al., 2014). Similar trends have been monitored in other systems where large predators closely track the presence of major prey species (Odden et al., 2010; Hayward et al., 2006; Lamichhane et al., 2019). These findings reveal that predator-prey interactions in highly modified landscapes are influenced not just by prey availability, but also by human disturbance. The reduced co-occurrence of leopard-hare and leopard-wild pig in areas with high dog abundance suggests that high dog activity may displace hares and wild pigs due to predation risk and increased competition (Vanak & Gompper, 2009b). The increased co-occurrence of leopards and hares near human settlements indicates the role of hares in supporting the leopard's diet in fragmented and disturbed landscapes (Ram et al., 2024). The positive relationship between leopard and wild pig in forest interiors emphasises the importance of undisturbed habitats in maintaining predator-prey interactions (Ram et al., 2024). In areas with elevated human and dog abundance, the negative correlation between hare and pig reflects their shared sensitivity to disturbance, especially poaching activities, resulting in reduced co-occurrence (Behera et al., 2022; Home et al., 2018). Furthermore, pigs often exploit crops and anthropogenic waste in disturbed areas, while hares are less adaptable to such environments (Stillfried et al., 2017).

Future studies to analyse carnivore diet analysis using gross faecal, isotope, or genetic analyses to improve habitat models are recommended. Long-term studies are needed to explore

interspecific interaction dynamics in changing landscapes. In addition, future work should apply Structural Equation Modelling (SEM) to disentangle direct and indirect pathways through which predators influence one another, and to evaluate how environmental covariates mediate these relationships, thereby complementing occupancy-based approaches.

Large carnivores rely on landscape connectivity to thrive in a mosaic of human-modified landscapes (Crooks et al., 2011). Leopard marginal occupancy increased near the main forest patch, while meso-carnivores showed a negative association, underlining the significance of habitat connectivity, restoration, and permeability for large carnivores (Crooks et al., 2011; Smith et al., 2019).

Even though my temporal findings revealed high activity overlap between leopards and mesocarnivores, fine-scale adjustments in activity peaks of mesocarnivores were observed, thus aligning with my prediction that mesocarnivores adjust their activity to avoid large carnivores. Jackals and foxes became more nocturnal, while jungle cats increased diurnal activity in leopard presence. Jackals and foxes had relatively higher temporal overlap with leopards compared to jungle cats. Lower temporal overlap between leopards and jungle cats may result from shared habitat preferences, and jungle cats, as subordinates, temporally avoid leopards for coexistence. My spatial and temporal results complemented each other, showing jackals and foxes had lower spatial overlap with leopards, while jungle cats had lower temporal overlap with leopards. This suggests meso-carnivores mitigate predation risk by avoiding large carnivores across space and time, consistent with previous studies (Burgos et al., 2023; Zhao et al., 2019). However, in highly human-modified landscapes, this temporal segregation appears constrained, as increased human presence narrows the available activity window for wildlife, resulting in high temporal overlap. Such compression of activity periods may limit the ability of meso-carnivores to effectively avoid large carnivores and could heighten predation risk. Prey activity peaks shifted slightly later towards the day in the morning and towards night in the evening, implying fine-scale temporal adjustments to reduce predation risk in modified landscapes (Gaynor et al., 2018; Valeix et al., 2009).

Conservation implications

Amid increasing anthropogenic disturbance, disentangling apex predators' influence on meso-carnivores and prey is vital for effective conservation (Burgos et al., 2023; Cano-Martínez et al., 2024). By elucidating these spatial and temporal coexistence mechanisms, my study provides critical insights into carnivore interactions in human-altered landscapes, informing

conservation efforts for both apex and mesopredators. My results revealed that meso-carnivores reduce predation risk by adjusting space and time differently, even within a human-dominated landscape. Jackals and foxes avoided leopards spatially, while jungle cats relied on temporal segregation, indicating that different species require different types of refugia for coexistence. Conservation actions should therefore prioritise maintaining spatial heterogeneity, ensuring safe temporal activity windows, and limiting disturbance in areas where subordinate carnivores concentrate. As modified landscapes restrict opportunities for fine-scale avoidance, managing mining intensity, regulating NTFP collection and reducing livestock pressure would support multi-carnivore persistence. Conservation efforts have historically prioritized large carnivores, often overlooking mesocarnivores despite their critical roles in ecosystem functioning as prey regulators, seed dispersers, and pest controllers. Although their adaptability to human-modified landscapes makes them essential for biodiversity resilience, a lack of targeted conservation can result in trophic imbalances and population declines. Excessive population growth of large carnivores might drive meso-carnivores more towards human settlements, causing heightened human-wildlife conflict. Thus, effective conservation must integrate meso-carnivores' needs while considering interspecific interactions. Habitat fragmentation and human activities like land-use changes, mining, poaching, over-grazing, and illegal forest harvesting threaten large carnivores like leopards (Behera et al. 2022; Crooks, 2002) in Ballari, and their decline could lead to an increased abundance of meso-predators, disrupting avian and mammalian prey populations and ecosystem balance (Crooks & Soule, 1999). Without leopards in the landscape, wild pig populations may rise, harming agriculture, biodiversity, and ecosystem function (Bengsen et al., 2014). Enhancing connectivity among forest patches will enhance the ability of subordinate species to shift space and time more effectively in response to apex predators. Reducing forest conversion, promoting habitat heterogeneity, and sustainable land-use strategies aid in maintaining a balanced multi-carnivore system. These targeted landscape-level measures can guide carnivore management in Ballari and similar fragmented landscapes. Additionally, collaboration among conservationists, forest managers, and local communities would help in developing landscape-level plans that support both wildlife conservation and human livelihoods.

CHAPTER 6

Summary & Conclusion

Chapter 6

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6.1 Summary

This PhD thesis examined the effect of human-induced land-use change, habitat fragmentation, and anthropogenic disturbance on mammalian communities in a highly modified, multi-use landscape of Ballari district, Karnataka, India. By integrating species-level habitat use, behavioural responses, community-level patterns, extinction vulnerability, and species interactions, the study provides a holistic understanding of mammalian persistence and restructuring in human-dominated landscapes. Using extensive camera-trapping data collected across PAs, RFs, and FMFLs, the research combined occupancy modelling, diel activity analysis, community metrics, nestedness analysis, and multispecies occupancy models to address three interlinked objectives.

The first objective focused on assessing the influence of land-use change and human presence on mammalian habitat use, activity patterns, and community composition. Single-season occupancy modelling revealed species-specific and trait-mediated responses to anthropogenic disturbance. While several disturbance-sensitive species exhibited reduced habitat use with increasing human presence, adaptable species showed positive associations with anthropogenic features such as settlements, farmlands, and increased abundance index of humans. Diel activity pattern analyses demonstrated that temporal adjustments serve as an important behavioural mechanism for persistence, particularly in areas with higher human activity. Large-bodied mammals showed increased nocturnality in more disturbed habitats. Whereas smaller-bodied and generalist species maintained relatively stable activity patterns across land-use types or higher diurnal activity in disturbed habitats compared to others. Community-level analyses revealed reduced species richness and diversity in FMFLs, along with moderate turnover in species composition, indicating selective loss of sensitive species and increasing dominance of generalists.

The second objective examined patterns of nestedness in mammalian assemblages across fragmented forest patches, revealing a non-random and structured pattern of species loss along gradients of habitat fragmentation. The analysis showed a clear and statistically significant nested pattern, wherein forest patches with few species consistently represented

subsets of richer patches, indicating selective extinctions shaped by habitat fragmentation and influenced by both patch attributes and species-specific life-history traits (Patterson & Atmar, 1986; Ulrich et al., 2009). Patch attributes, particularly patch area, edge density, and proximity index, were key determinants of nestedness patterns, underscoring the importance of habitat configuration in maintaining community integrity. Larger, better-connected patches with lower edge density supported higher species assemblage, while smaller and highly isolated patches primarily retained disturbance-tolerant generalists. Increased connectivity, reflected by higher proximity index values, favoured species with larger spatial requirements, whereas edge effects and human-dominated matrices likely accelerated local losses of sensitive taxa. Species trait-level analyses demonstrated that niche breadth was the strongest predictor of extinction vulnerability, indicating species with broader niche breadths were more resilient to fragmentation and ecological specialists were mostly confined to larger or less-disturbed patches as they were disproportionately affected by fragmentation. Arboreality and sociality showed weak negative associations with extinction vulnerability, suggesting limited but detectable sensitivity to habitat modification. Overall, these findings highlight the importance of conserving larger, less disturbed, and well-connected forest patches to maintain mammalian community structure and to identify species most vulnerable to ongoing fragmentation in human-dominated landscapes.

The results from third objective demonstrate that spatiotemporal patterns of carnivores in Ballari are shaped by species-specific behavioural strategies, interspecific interactions, and gradients of human disturbance, with the apex predator playing a key role in structuring the carnivore guild. Carnivore co-occurrence patterns were highly sensitive to anthropogenic pressures, reflecting altered spatial associations and trophic relationships in human-modified landscapes. Differential co-occurrence among leopards, jungle cats, jackals, and foxes highlighted species-specific habitat preferences and coexistence strategies, with smaller carnivores increasingly associated with human-dominated areas where anthropogenic food subsidies and elevated prey availability provide both resources and refuge from larger predators. Prey availability further mediated carnivore interactions, consistent with intraguild predation theory, which predicts that top predators are primarily shaped by food availability, while subordinate species balance resource acquisition against predation risk (Polis & Holt, 1992). Shared reliance on key prey species intensified risk-driven spatial avoidance by subordinate carnivores in leopard-occupied areas, thereby influencing space use and community structure. The positive co-occurrence of leopards with both hares and wild pigs

underscores the importance of prey availability in driving predators' distribution. Temporal analyses revealed that meso-carnivores reduced overlap with leopards through fine-scale activity shifts, supporting the hypothesis that temporal partitioning facilitates coexistence under predation risk. Prey species exhibited substantial temporal overlap with apex predators but showed only limited shifts in peak activity timing, likely constrained by intense human presence and disturbance during daytime in this highly human-modified landscape, which restricts the scope for stronger temporal avoidance.

Overall, these findings illustrate how behavioural plasticity, prey dynamics, and human disturbance interact to reshape carnivore spatiotemporal organization, emphasizing the continued—but increasingly constrained—role of apex predators in maintaining trophic structure and ecological regulation within modified, multi-use landscapes.

6.2 Conclusion

This study presents a detailed assessment of mammalian ecology in the human-modified and highly fragmented landscapes of the Ballari district, located in the southern Deccan Plateau. By integrating land-use gradients, patch attributes, species life-history traits, and interspecific interactions, this research provides important baseline information on mammalian assemblages and their responses to human disturbance, habitat fragmentation, and land-use changes. The findings offer valuable insights for conservation planning and management, particularly for landscapes where biodiversity persists largely outside protected areas. Importantly, these results provide a scientific foundation to support evidence-based decision-making by the local Forest Department and other stakeholders, aiding in the prioritization of habitats, regulation of anthropogenic pressures, and development of effective, landscape-level wildlife management and conservation strategies.

At the landscape scale, analyses across PAs, RFs, and FMFLs revealed pronounced differences in habitat use, activity patterns, and disturbance tolerance among species. Increasing human disturbance and land-use change disproportionately impacted disturbance-sensitive mammals, particularly those characterized by large body size, extensive habitat requirements, carnivorous diets, and specialized niche requirements (Cardillo et al., 2005; Swihart et al., 2003). Forest-dependent large-bodied species like sloth bears and leopards were strongly associated with intact forest habitats and higher canopy cover, whereas disturbance-tolerant mid-level predators such as jackals, foxes, and jungle cats exhibited greater association with moderately disturbed RFs and FMFLs. Anthropogenic pressures also induced behavioural

responses, with several species shifting towards increased nocturnality, highlighting behavioural plasticity as a key persistence mechanism in disturbed habitats (Gaynor et al., 2018). Maintaining higher habitat heterogeneity while lowering disturbance intensity is therefore essential for sustaining intact mammalian assemblages.

The study further demonstrates that the adverse effects of human disturbance on wildlife can be mitigated through targeted management interventions, including the regulation of mining activities and mining-related vehicular movement within forested areas, strict control of illegal forest resource extraction, reduction of livestock overgrazing, and enforcement against poaching activities. Given that a significant proportion of mammalian assemblage persists outside Protected Areas, the findings emphasize the need to strengthen management priorities beyond the existing PAs network. Enhancing conservation efforts in RFs and other multi-use landscapes, alongside strategic expansion of the PA network, will improve forest patch connectivity, reinforce movement corridors, and reduce isolation effects (Lindenmayer & Fischer, 2006; Saura et al., 2014).

Nestedness analysis showed that mammalian assemblages across forest patches in Ballari district exhibited a non-random structure driven by habitat fragmentation and disturbance. Larger, well-connected patches with lower edge density supported higher species assemblage, whereas smaller and more disturbed patches were dominated by species which are common across all forest patches. Species with broader niche breadths demonstrated greater persistence across fragmented landscapes, while ecological specialists were restricted to fewer, high-quality patches, indicating increased extinction risk. These findings underscore the utility of nestedness analysis in the identification of species that are less adaptable to human disturbance and forest patches that are of high conservation priority, thereby aiding the selection of suitable sites for targeted conservation planning and biodiversity preservation (Ulrich et al., 2009).

At the species-interaction scale, the study highlights the pivotal role of apex predators, particularly leopards in this case, in structuring carnivore communities through top-down processes. However, this regulatory influence was increasingly diminished in heavily modified landscapes with high anthropogenic pressure. Meso-predators expanded into disturbed habitats, most likely due to greater access to anthropogenic food resources and lower encounter risk with apex predators. These findings highlight important limitations of apex-predator-centric conservation approaches that overlook subordinate carnivores (Ritchie & Johnson,

2009; Wallach et al., 2015). As a result, species-specific management strategies are recommended that safeguard apex predators while simultaneously ensuring coexistence with meso-carnivores to maintain functional trophic interactions.

Beyond ecological insights, the camera-trapping survey also provided direct and indirect information on local people's dependence on forest resources, particularly through intensive livestock grazing and firewood extraction. High livestock densities are maintained as a primary livelihood strategy, and herds are routinely brought into RFs for grazing, resulting in overgrazing, further leading to suppression of natural vegetation regeneration, competition with wild herbivores, and degradation of habitat quality. Reducing local reliance on forest resources through targeted alternate livelihood options and improved resource management is therefore critical for enhancing prey availability, restoring habitat structure, and mitigating human-wildlife conflict (Mishra et al., 2003). Sustainable alternatives such as rotational grazing systems, promotion of improved fodder cultivation outside forests, regulation of herd sizes, and prohibition of destructive browsing (exclusion of goat grazing) through productivity-based livestock management can substantially lower grazing pressure on forest ecosystems. For households heavily dependent on firewood, the provision of alternative energy sources, such as subsidised LPG connections, solar lighting systems, and energy-efficient cookstoves, can reduce extraction pressure while improving household well-being. Collectively, integrating livelihood support with conservation interventions will promote long-term coexistence between communities and wildlife in multi-use landscapes.

Notably, this study documented the first record of the Indian gazelle (*Gazella bennettii*) in Ballari district, restricted to a single forest patch and representing one of the southernmost populations of the species (Behera et al., 2022b). Without urgent conservation intervention, this isolated population faces a high risk of local extinction, underscoring the immediate need for site-specific protection measures.

Lastly, this thesis demonstrates that mammalian assemblages in human-dominated landscapes are shaped by intricate relationships between habitat configuration, species traits, behavioural flexibility, and anthropogenic stressors. Effective conservation in such landscapes necessitates spatially differentiated and taxa-specific management strategies, rather than uniform, protected-area-centric approaches (DeFries et al., 2010). While large forest patches and corridors must be prioritised to sustain forest-dependent and disturbance-sensitive species such as leopards and sloth bears, open, degraded, and non-forest habitats, including RFs,

wastelands, and inactive mining areas, emerge as critical management units for open-habitat and disturbance-tolerant fauna, such as jackals, foxes, and jungle cats, which are often overlooked in conventional conservation planning (Srivathsa et al., 2019). Inactive and abandoned mining landscapes should be actively managed through habitat restoration and promotion of natural vegetation regeneration, as these areas can serve as secondary habitats or movement zones for several mammalian species (Sonter et al., 2018). Management in mosaic farmlands and wastelands should prioritize on regulating grazing intensity, minimizing conflict-prone anthropogenic attractants, and retaining habitat heterogeneity to support both prey populations and subordinate carnivores. Importantly, conservation strategies must go beyond PAs by strengthening management in Reserved Forests and other multi-use landscapes, thereby improving functional connectivity and reducing isolation effects across the broader landscape. Raising awareness, adopting participatory management approaches, and incorporating local perceptions are essential for promoting long-term coexistence between humans and wildlife. By providing robust empirical evidence from a rapidly transforming region of India, this study contributes to applied conservation science and offers actionable guidance for sustaining diverse mammalian biodiversity (including both charismatic and neglected taxa) in the Anthropocene.

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Appendices

Appendix S1: List of 21 predictor variables classified under four broad categories that are used in analysis.

Sl.	Group	Covariates	Description	Type	Models		Source of extraction
					[Occupancy(O) /Detection(D)]	Abbreviation	
1	Habitat features	Elevation / Altitude	Elevation of the camera site	Continuous	O	elevation	ArcGIS Online – DEM of Asia (Spatial resolution: 1km)
2		Water body	Proximity to the nearest water body	Continuous	O, D	waterbody	Vegetation-type map (Roy et al., 2015; spatial resolution: 60m)
3		Canopy coverage	Percentage of canopy coverage in the 20m radius around sampling sites	Continuous	O	canopy	Field data collection
4		Rockiness	Rocky coverage of the 20m radius	Continuous	O	rockiness	Field data collection

5	Tree density	around sampling sites Number of trees in the 20m radius around sampling sites	Continuous	O	tree	Field data collection
6	Shrub coverage	Percentage coverage of shrub in the 5m radius around sampling site	Continuous	O, D	shrub	Field data collection
7	Terrain type	Type of terrain Undulating or Plain	Categorical	O	terrain	Field data collection
8	Proximity to farmland	Proximity to the near agricultural land	Continuous	O, D	farmdist	Vegetation type map (Roy et al. 2015)
9	Proximity to scrub forest	Proximity to the nearest extent of scrub forest	Continuous	O	scrubdist	Vegetation type map (Roy et al. 2015)

10		Proximity to deciduous forest	Proximity to the nearest extent of deciduous forest (both dry and moist deciduous)	Continuous	O	decidist	Vegetation type map (Roy et al. 2015)
11	Landscape-level human presence	Proximity to road	Proximity to the nearest public road (Including mining roads)	Continuous	O, D	road	GRIP global roads database (Spatial resolution: 8km), modified using Google Earth and field observation
12		Proximity to human settlement	Proximity to nearest human settlement (Village, town, or mine)	Continuous	O, D	settlement	Vegetation type map (Roy et al. 2015)
13		PA	Camera sites located in PAs	Categorical	O	PA	LULC map obtained from Karnataka Forest Department (Spatial resolution: 60m)
14		RF	Camera sites located in RFs	Categorical	O	RF	LULC map obtained from Karnataka Forest Department
15		FMFL	Camera sites located in mosaic farmlands	Categorical	O	FMFL	LULC map obtained from Karnataka Forest Department

16	Climate	Precipitation (in mm)	Mean annual precipitation	Continuous	O	preci	Bioclim layer obtained from Worldclim (Spatial resolution: 1km) https://www.worldclim.org/
17		Season	Type of season 1) Wet 2) Dry	Categorical	O, D	season	weatherspark.com
18	Local-level human presence	RAI Human	Human relative abundance index	Continuous	O, D	human	Camera trap data
19		RAI Cattle	Cattle relative abundance index	Continuous	O, D	cattle	Camera trap data
20		RAI Goat- Sheep	Goat and Sheep relative abundance index	Continuous	O, D	goatsheep	Camera trap data
21		RAI Dog	Dog relative abundance index	Continuous	O, D	dog	Camera trap data

Appendix S2. Overview of AIC-based model selection and parameter estimates of site habitat use and detection: ‘Black-naped hare’

Models	nPars	AIC	Δ AIC	AIC Weight
~farmdist + settlement ~settlement + preci + elevation + PA	8	18003.80	0.00	0.79
~farmdist + settlement ~settlement + preci + elevation + tree	8	18006.73	2.93	0.19
~farmdist + settlement ~settlement + preci + elevation + road	8	18011.44	7.64	0.01
~farmdist + settlement ~settlement + preci + elevation	7	18013.30	9.50	0.01
~farmdist ~settlement + elevation + preci + PA	7	18027.41	23.61	0.00
~farmdist + settlement ~settlement + preci + shrub	7	18031.70	27.90	0.00
~farmdist + settlement ~settlement + preci	6	18038.50	34.70	0.00
~farmdist ~settlement + preci	5	18062.12	58.32	0.00
~farmdist ~settlement + tree	5	18078.57	74.77	0.00
~farmdist ~settlement	4	18094.81	91.01	0.00
~farmdist ~1	3	18111.92	108.12	0.00
~elevation ~1	3	18129.26	125.46	0.00
~goatsheep ~1	3	18135.84	132.04	0.00
~1 ~shrub	3	18136.60	132.80	0.00
~1 ~elevation	3	18137.78	133.98	0.00
~1 ~dog	3	18145.80	142.00	0.00
~1 ~1	2	18150.71	146.91	0.00
~canopy ~1	3	18152.70	148.90	0.00

Appendix S3. Overview of AIC-based model selection and parameter estimates of site habitat use and detection: ‘Golden jackal’

Models	nPars	AIC	Δ AIC	AIC Weight
~season + farmdist ~preci + RF + dog + terrain	8	5635.16	0.00	0.90
~season + farmdist ~preci + RF + dog + scrubdist	8	5640.34	5.18	0.07
~season + farmdist ~preci + RF + dog	8	5641.85	6.69	0.03
~season + farmdist ~preci + RF + human	7	5647.77	12.61	0.00
~season + farmdist ~preci + RF + terrain	7	5656.86	21.69	0.00
~season + farmdist ~preci + RF + scrubdist	7	5663.55	28.39	0.00
~season + farmdist ~preci + RF	6	5665.86	30.69	0.00
~season ~preci + RF	7	5677.48	42.32	0.00
~season ~preci + dog	6	5691.82	56.65	0.00
~season ~preci + rockiness	5	5700.47	65.31	0.00
~season ~preci + terrain	5	5707.92	72.76	0.00
~season ~preci	5	5721.73	86.57	0.00
~1 ~preci	3	5748.24	113.07	0.00
~preci ~1	3	5801.56	166.39	0.00
~1 ~farmdist	3	5818.42	183.26	0.00
~season ~1	3	5832.20	197.04	0.00
~1 ~1	2	5862.76	227.60	0.00

Appendix S4. Overview of AIC-based model selection and parameter estimates of site habitat use and detection: ‘Indian fox’

Models	nPars	AIC	Δ AIC	AIC Weight
~terrain + road ~scrubdist + rockiness + RF + preci	8	4899.16	0.00	0.71
~terrain + elevation ~scrubdist + rockiness + RF + preci	8	4901.69	2.54	0.20
~terrain ~scrubdist + rockiness + RF + preci	7	4903.59	4.43	0.08
~1 ~scrubdist + rockiness + RF + preci	6	4908.14	8.98	0.01

~settlement ~scrubdist + rockiness + RF + preci	7	4910.03	10.87	0.00
~terrain + preci + human ~scrubdist + rockiness + RF + farmdist	9	4922.98	23.82	0.00
~terrain + preci + farmdist ~scrubdist + rockiness + RF	8	4925.52	26.36	0.00
~terrain + preci + farmdist ~scrubdist + rockiness + canopy	8	4928.19	29.03	0.00
~terrain + preci + farmdist ~scrubdist + rockiness	7	4940.65	41.50	0.00
~terrain + preci ~scrubdist + rockiness	6	4944.69	45.54	0.00
~terrain ~scrubdist + rockiness	5	4956.36	57.20	0.00
~scrubdist ~scrubdist + rockiness	5	4961.22	62.06	0.00
~preci ~scrubdist	4	4995.17	96.01	0.00
~1 ~scrubdist	3	5005.76	106.60	0.00
~scrubdist ~1	3	5017.84	118.69	0.00
~1 ~canopy	3	5040.75	141.59	0.00
~rockiness ~1	3	5059.38	160.22	0.00
~1 ~tree	3	5069.85	170.69	0.00
~1 ~1	2	5077.77	178.61	0.00
~1 ~road	3	5079.72	180.57	0.00

Appendix S5. Overview of AIC-based model selection and parameter estimates of site habitat use and detection: ‘Jungle cat’

Models	nPars	AIC	Δ AIC	AIC Weight
~farmdist ~human + elevation	5	4913.51	0.00	0.79
~farmdist ~human	4	4916.22	2.71	0.21
~1 ~human	3	4932.72	19.20	0.00
~1 ~cattle	3	4940.40	26.89	0.00
~farmdist ~1	3	4952.64	39.12	0.00
~1 ~farmdist	3	4961.07	47.55	0.00
~human ~1	3	4963.38	49.87	0.00
~cattle ~1	3	4964.47	50.95	0.00

~dog ~1	3	4966.75	53.24	0.00
~rockiness ~1	3	4967.49	53.98	0.00
~1 ~1	2	4973.67	60.16	0.00
~canopy ~1	3	4975.67	62.16	0.00

Appendix S6. Overview of AIC-based model selection and parameter estimates of site habitat use and detection: ‘Leopard’

Models	nPars	AIC	Δ AIC	AIC Weight
~terrain + season ~preci + canopy + farmdist + waterbody	8	3700.81	0.00	0.74
~terrain + season ~preci + canopy + waterbody	7	3703.19	2.38	0.22
~terrain + season ~preci + canopy + farmdist	7	3707.61	6.80	0.02
~terrain + season + preci ~preci + canopy + farmdist	8	3709.45	8.64	0.01
~terrain + season ~preci + canopy + season	7	3711.30	10.49	0.00
~terrain + road ~preci + canopy	6	3713.25	14.78	0.00
~terrain ~preci + canopy	5	3715.59	16.74	0.00
~terrain + canopy ~preci + canopy	6	3717.55	21.33	0.00
~terrain ~preci + human	5	3722.14	25.96	0.00
~terrain ~preci + season	5	3726.77	30.84	0.00
~terrain ~preci	4	3731.65	41.82	0.00
~1 ~preci	3	3742.63	61.36	0.00
~preci ~1	3	3762.17	96.63	0.00
~1 ~canopy	3	3797.43	106.20	0.00
~1 ~season	3	3807.01	110.44	0.00
~season ~1	3	3811.25	116.13	0.00
~canopy ~1	3	3816.94	122.71	0.00
~1 ~shrub	3	3823.52	131.76	0.00
~1 ~1	2	3837.00	136.19	0.00
~rockiness ~1	3	3838.99	138.19	0.00

Appendix S7. Overview of AIC-based model selection and parameter estimates of site habitat use and detection: ‘Sloth bear’

Models	nPars	AIC	Δ AIC	AIC Weight
~waterbody + human ~cattle + PA + canopy + scrubdist	8	3722.90	0.00	0.75
~waterbody + human + RF + farmdist ~cattle + PA + canopy + settlement	10	3725.47	2.57	0.20
~waterbody + human + road ~cattle + PA + canopy	8	3729.43	6.52	0.03
~waterbody + human + farmdist ~cattle + PA + canopy	8	3730.74	7.84	0.00
~waterbody + cattle ~cattle + PA + canopy	7	3734.26	11.36	0.00
~waterbody + road ~cattle + PA + canopy	7	3738.51	15.60	0.00
~waterbody ~cattle + PA + canopy	6	3741.49	18.58	0.00
~waterbody ~cattle + PA + rockiness	6	3748.69	25.79	0.00
~waterbody ~cattle + PA	5	3752.22	29.31	0.00
~waterbody ~cattle + rockiness	5	3755.48	32.58	0.00
~waterbody ~cattle + RF	5	3757.31	34.40	0.00
~waterbody ~cattle	4	3763.36	40.46	0.00
~waterbody ~human	4	3769.80	46.89	0.00
~waterbody ~PA	4	3775.88	52.98	0.00
~waterbody ~waterbody	4	3783.91	61.01	0.00
~cattle ~waterbody	4	3790.62	67.72	0.00
~1 ~waterbody	3	3801.95	79.05	0.00
~1 ~cattle	3	3810.55	87.65	0.00
~1 ~1	2	3826.48	103.57	0.00
~PA ~1	3	3828.12	105.21	0.00

Appendix S8. Overview of AIC-based model selection and parameter estimates of site habitat use and detection: ‘Wild pig’

Models	nPars	AIC	Δ AIC	AIC Weight
~goatsheep + shrub + road ~preci + canopy + human	8	7375.29	0.00	0.82
~goatsheep + shrub + terrain ~preci + canopy + human	8	7379.28	3.99	0.11
~goatsheep + shrub ~preci + canopy + human	7	7381.27	5.98	0.05
~goatsheep + shrub ~preci + canopy + farmdist	7	7382.39	7.10	0.02
~goatsheep + shrub ~preci + canopy	7	7389.77	14.48	0.00
~goatsheep + road ~preci + canopy	7	7393.39	18.10	0.00
~goatsheep ~preci + canopy	7	7399.00	23.72	0.00
~goatsheep ~preci	4	7414.57	39.28	0.00
~1 ~preci	3	7442.23	66.94	0.00
~goatsheep ~1	3	7443.98	68.69	0.00
~1 ~canopy	3	7448.93	73.64	0.00
~1 ~dog	3	7457.82	82.53	0.00
~1 ~1	2	7481.95	106.66	0.00
~1 ~shrub	3	7483.87	108.58	0.00

Appendix S9: List of 12 predictor variables classified under four broad categories for the analysis. And one additional detection variable

Sl.	Category	Covariate	Description	Type	Models	Abbreviation	Source of extraction
1.	Anthropogenic features (AF)	Human settlement density	The portion of land covered by human settlements, mines, and factories in each sampling grid	Continuous	Occupancy	settlement	Vegetation type map (Roy et al. 2015; spatial resolution: 60m)
2.		RAI Human	Human (humans by foot or any vehicle) relative abundance index	Continuous	Occupancy	human	Camera trap data
3.		RAI Dog	Free-ranging dog relative abundance index	Continuous	Occupancy	dog	Camera trap data
4.		RAI Livestock	Livestock (Cow, buffalo, goat, and sheep) relative abundance index	Continuous	Occupancy	livestock	Camera trap data
5.	Habitat fragmentation (HF)	Proximity to farmland/forest	Proximity to the nearest	Continuous	Occupancy	forestfarm	LULC map obtained from

			boundary of farmland; value becomes positive towards deeper forest and negative towards deeper farmland.				Karnataka Forest Department (Spatial resolution: 60m)
6	Proximity to main-patch	Distance from the nearest border of main forested patch	Continuous	Occupancy	mainpatch	LULC map obtained from Karnataka Forest Department (Spatial resolution: 60m)	
7	Patch size	Size of the forested patch/fragment	Continuous	Occupancy	patchsize	LULC map obtained from Karnataka Forest Department (Spatial resolution: 60m)	
8.	Forest cover	The portion of land covered by forests in each sampling grid	Continuous	Occupancy	fcover	LULC map obtained from Karnataka Forest Department (Spatial	

						resolution: 60m)
9.	RAI Hare	Black-naped hare relative abundance index	Continuous	Occupancy	hare	Camera trap data
10.	RAI Galliformes	Relative abundance index of Galliformes i.e peafowl, grey francolin, painted spurfowl and red spurfowl	Continuous	Occupancy	galli	Camera trap data
11.	RAI Pig	Wild pig relative abundance index	Continuous	Occupancy	pig	Camera trap data
12.	Canopy cover	Percentage of canopy coverage in the 20m radius around camera traps	Continuous	Occupancy	canopy	Field data collection
13.	Trap effort	Number of trap nights per sampling grid	Continuous	Detection	tnight	Field data collection; Camera trap data

Appendix S10: Results of model selection for a multi-species occupancy analysis from the camera trapping survey in Ballari district, India. All no-interaction models set pairwise interaction components to zero (i.e., effectively removed second-order models). Global sub-models included all covariates. Anthropogenic features (AF) include human settlement density, human abundance, dog abundance and livestock abundance; Habitat fragmentation (HF) includes proximity to farmland and proximity to main-patch; Prey abundance (PA) includes hare abundance, galliformes abundance and wild pig abundance; and Natural habitat features (NF) include canopy cover

First order sub-model	Second-order (Pairwise) sub-model	Description	AICc	Delta AICc
Global	AF + PA	Interactions, Humans & Prey	9828.41	0.00
Global	AF + HF	Interactions, Humans, & Habitat fragmentation	9830.80	2.39
Global	Global	Interactions Global	9831.38	2.97
Global	AF + HF + PA	Interactions, Humans, Habitat fragmentation, & Prey	9832.20	3.79
Global	AF + PA + NF	Interactions, Humans, Prey, & Natural habitat variation	9833.23	4.82
Global	AF + HF + NF	Interactions, Humans, Habitat fragmentation, & Natural habitat variation	9835.74	7.33
Global	HF	Interactions, & Habitat fragmentation	9836.32	7.91
Global	HF + PA + NF	Interactions, Habitat fragmentation, Prey, & Natural habitat variation	9841.87	13.46
Global	Global: Leopard-Fox; all others 0	One pairwise interaction	9842.10	13.69
Global	HF + PA	Interactions, Habitat fragmentation, & Prey	9845.58	17.17
Global	PA	Interactions & Prey	9848.15	19.74
Global	Global: Leopard-Jackal; all others 0	One pairwise interaction	9848.23	19.82
Global	AF	Interactions, & Humans	9848.40	19.99

Global	HF + NF	Interactions, Habitat fragmentation, & Natural habitat variation	9849.23	20.82
Global	PA + NF	Interactions, Prey, & Natural habitat variation	9849.90	21.49
Global	AF + NF	Interactions, Humans, & Natural habitat variation	9852.35	23.94
Global	1	Unmediated interactions	9855.26	26.85
AF + HF + PA	1	Humans, Habitat fragmentation, & Prey; with unmediated interactions	9856.21	27.80
Global	Global: Jackal-Jungle cat; all others 0	One pairwise interaction	9856.32	27.91
AF + HF + NF	1	Humans, Habitat fragmentation, & Natural habitat variation; with unmediated interactions	9856.44	28.03
Global	NF	Interactions, & Natural habitat variation	9858.76	30.35
AF + HF	1	Humans, & Habitat fragmentation; with unmediated interactions	9858.98	30.57
Global	Global: Jackal-Fox; all others 0	One pairwise interaction	9862.71	34.30
HF + NF	1	Habitat fragmentation, & Natural habitat variation; with unmediated interactions	9864.57	36.16
Global	Global: Leopard-Jungle cat; all others 0	One pairwise interaction	9865.59	37.18
HF + PA + NF	1	Habitat fragmentation, Prey, & Natural habitat variation; with unmediated interactions	9868.15	39.74
Global	0	No interactions	9870.54	42.13

AF + HF + PA	0	Humans, Habitat fragmentation & Prey; without interactions	9871.54	43.13
AF + PA + NF	1	Humans, Prey, & Landscape variation; with unmediated interactions	9872.62	44.21
HF	1	Habitat fragmentation; with unmediated interactions	9872.91	44.50
HF + PA	1	Habitat fragmentation, & Prey; with unmediated interactions	9873.09	44.65
AF + HF + NF	0	Humans, Habitat fragmentation & Natural habitat variation; without interactions	9873.66	45.22
AF + HF	0	Humans, & Habitat fragmentation; without interactions	9876.17	47.76
AF + NF	1	Humans, & Natural habitat variation; with unmediated interactions	9877.81	49.40
AF + PA	1	Humans, & Prey; with unmediated interactions	9878.75	50.34
Global	Global: Fox-Jungle cat; all others 0	One pairwise interaction	9886.22	57.81
AF + PA + NF	0	Humans, Prey, & Natural habitat variation; without interactions	9886.37	57.96
AF	1	Humans; with unmediated interactions	9887.09	58.68
HF + NF	0	Habitat fragmentation, & Natural habitat variation; without interactions	9888.52	60.11
HF + PA + NF	0	Habitat fragmentation, Prey, & Natural habitat variation; without interactions	9890.45	62.04
AF + PA	0	Human, & Prey; without interactions	9891.29	62.88

PA + NF	1	Prey, & Natural habitat variation; with unmediated interactions	9891.51	63.10
HF + PA	0	Habitat fragmentation, & Prey; without interactions	9895.39	66.98
HF	0	Habitat fragmentation; without interactions	9897.29	68.88
NF	1	Natural habitat variation; with unmediated interactions	9897.67	69.26
AF + NF	0	Humans, & Natural habitat variation; without interactions	9897.70	69.29
PA	1	Prey; with unmediated interactions	9905.48	77.07
AF	0	Humans; without interactions	9906.85	78.44
PA + NF	0	Prey, & Natural habitat variation; without interactions	9917.26	88.85
1	1	Null model with unmediated interactions	9924.49	96.08
PA	0	Prey; without interactions	9929.15	100.74
NF	0	Natural habitat variation; without interactions	9932.97	104.56
1	0	Null model without interactions	9963.34	134.93

Appendix S11: First-order natural parameter estimates of **leopard**.

<i>Parameter</i>	<i>Estimate</i>	<i>Standard Error</i>	<i>p-value</i>
Intercept	3.76	1.93	0.05
settlement	1.63	1.17	0.01
human	-0.95	1.47	0.05
dog	4.96	1.95	0.01
livestock	-0.70	0.92	0.44
canopy	0.36	0.32	0.26
hare	3.40	1.03	0.00
galli	1.13	1.26	0.37
pig	4.00	1.92	0.04
forestfarm	0.79	0.43	0.06
mainpatch	-1.91	0.50	0.00

Appendix S12: First-order natural parameter estimates of **golden jackal**.

<i>Parameter</i>	<i>Estimate</i>	<i>SE</i>	<i>p-value</i>
Intercept	0.79	2.09	0.71
settlement	-3.01	1.30	0.02
human	0.37	1.42	0.79
dog	1.62	1.67	0.33
livestock	-3.36	1.60	0.36
canopy	0.47	0.31	0.13
hare	-2.16	1.04	0.04
galli	-1.60	1.80	0.37
pig	10.25	2.66	0.00
forestfarm	0.81	0.34	0.02
mainpatch	0.85	0.35	0.01

Appendix S13: First-order natural parameter estimates of **Indian fox**.

<i>Parameter</i>	<i>Estimate</i>	<i>SE</i>	<i>p-value</i>
Intercept	2.39	1.81	0.19
settlement	-1.36	0.97	0.16
human	0.77	1.33	0.56
dog	4.98	1.96	0.01
livestock	-1.54	0.94	0.10
canopy	-0.76	0.30	0.01
hare	2.60	0.99	0.01
galli	-0.42	1.16	0.72
pig	2.18	1.75	0.21
forestfarm	0.12	0.25	0.64
mainpatch	0.11	0.39	0.78

Appendix S14: First-order natural parameter estimates of **jungle cat**.

<i>Parameter</i>	<i>Estimate</i>	<i>SE</i>	<i>p-value</i>
Intercept	0.26	2.85	0.93
settlement	1.20	1.08	0.27
human	-2.64	1.52	0.08
dog	-5.56	2.99	0.06
livestock	0.01	0.98	0.99
canopy	-1.23	0.41	0.03
hare	-0.44	0.83	0.60
galli	2.08	1.25	0.09
pig	7.71	2.65	0.00
forestfarm	-0.07	0.38	0.85
mainpatch	1.52	0.57	0.01

Appendix S15: Log odd ratios for the pair of **leopard – jackal** (Conditional occupancy parameter estimates).

<i>Parameter</i>	<i>Estimate</i>	<i>SE</i>	<i>p-value</i>
Intercept	-0.63	1.01	0.53
settlement	-0.58	0.51	0.26
human	-2.53	1.33	0.05
dog	1.44	1.20	0.23
livestock	0.55	0.89	0.54
hare	0.47	0.78	0.55
galli	-0.24	0.45	0.59
pig	-1.41	0.93	0.13

Appendix S16: Log odd ratios for the pair of **leopard – fox** (Conditional occupancy parameter estimates).

<i>Parameter</i>	<i>Estimate</i>	<i>SE</i>	<i>p-value</i>
Intercept	-7.89	2.47	0.00
settlement	1.56	0.91	0.09
human	-0.60	1.21	0.62
dog	-12.12	3.10	0.00
livestock	1.51	1.09	0.16
hare	-3.19	1.01	0.00
galli	-0.04	0.58	0.94
pig	-3.35	1.69	0.05

Appendix S17: Log odd ratios for the pair of **leopard – jungle cat** (Conditional occupancy parameter estimates).

<i>Parameter</i>	<i>Estimate</i>	<i>SE</i>	<i>p-value</i>
Intercept	5.80	2.28	0.01
settlement	-2.48	1.15	0.03
human	5.59	1.78	0.02
dog	5.45	3.00	0.07

livestock	-2.71	1.22	0.03
hare	-0.13	0.91	0.89
galli	-1.34	1.29	0.30
pig	0.41	1.23	0.74

Appendix S18: Log odd ratios for the pair of **jackal – fox** (Conditional occupancy parameter estimates).

<i>Parameter</i>	<i>Estimate</i>	<i>SE</i>	<i>p-value</i>
Intercept	1.91	0.65	0.00
settlement	0.01	0.56	0.98
human	-0.24	0.65	0.71
dog	-0.28	1.13	0.81
livestock	-0.56	0.82	0.49
hare	0.85	0.67	0.21
galli	-0.23	0.42	0.59
pig	-1.27	0.65	0.05

Appendix S19: Log odd ratios for the pair of **jackal – jungle cat** (Conditional occupancy parameter estimates).

<i>Parameter</i>	<i>Estimate</i>	<i>SE</i>	<i>p-value</i>
Intercept	0.17	2.13	0.94
settlement	3.02	1.27	0.02
human	1.88	1.69	0.27
dog	-2.32	1.40	0.10
livestock	3.19	1.15	0.03
hare	0.67	0.77	0.38
galli	1.83	1.80	0.31
pig	-8.89	2.58	0.00

Appendix S20: Log odd ratios for the pair of **fox – jungle cat** (Conditional occupancy parameter estimates).

<i>Parameter</i>	<i>Estimate</i>	<i>SE</i>	<i>p-value</i>
Intercept	4.71	2.21	0.03
settlement	-0.58	0.71	0.42
human	0.11	1.38	0.94
dog	6.88	2.99	0.02
livestock	0.18	1.06	0.86
hare	-0.31	0.66	0.64
galli	0.35	1.14	0.76
pig	1.31	1.00	0.19

List of Publications from PhD thesis

- 1. Coexistence in multi-use landscape: linking human activities with functional traits of wild mammals in southern India. *Landscape Ecology*, 39(3), 41. (2024).**

Asit K. Behera^{1,4,6}, P. Ramesh Kumar², M. Malathi Priya³, Patrick A. Zollner⁴, T. Ramesh^{1,7}, and Riddhika Kalle^{5,7}

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- 2. The impacts of COVID-19 lockdown on wildlife in Deccan Plateau, India. *Science of The Total Environment*, 822, 153268. (2022).**

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3. Extension of the Known Range of Chinkara and its Conservation Importance in Karnataka, India. *National Academy Science Letters*, 45(3), 241-244. (2022).

Asit K. Behera^{1,4}, P. Ramesh Kumar², M. Malathi Priya³, T. Ramesh^{1,5}, and Riddhika Kalle^{1,5}

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List of Conference Presentations

- **Association for Tropical Biology and Conservation (ATBC 2023)** (59th) held at **Coimbatore, Tamil Nadu, India** between 2nd and 6th July 2023. Topic titled “Land use changes shaping habitat use and activity patterns of wild mammals in the Ballari district, India”. (Oral Presentation)
- **The Wildlife Society (TWS 2022)** (29th Annual Conference) held at **Spokane, Washington, USA** between 6th and 10th November 2022. Topic titled “Land use gradients shaping mammalian community in the fragmented landscape of Bellary district, India”. (Oral Presentation)
- **The American Society of Mammalogists (ASM 2022)** (101st Annual Meeting) was held at **Tucson, Arizona, USA**, between 17th and 21st June 2022. Topic titled “A once-in-a-lifetime opportunity: COVID-19 lockdown highlights the effect of humans on wildlife”. (Oral Presentation)
- **International Congress for Conservation Biology (ICCB-2021)** by Society for Conservation Biology (13th -17th December 2021) (Virtual) – Topic titled “Impact of COVID-19 lockdown on wild mammals”. (Oral Presentation)



Coexistence in multi-use landscape: linking human activities with functional traits of wild mammals in southern India

Asit K. Behera · P. Ramesh Kumar ·
M. Malathi Priya · Patrick A. Zollner ·
Tharmalingam Ramesh · Riddhika Kalle

Received: 24 March 2023 / Accepted: 10 January 2024
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Abstract

Context Human presence and land-use activities influence habitat use and activity of species. It is crucial to study the ecological and anthropogenic determinants that drive these relationships.

Objectives We investigated the effects of land-use change and human presence on the habitat use of seven mammalian species and on their activity patterns.

Methods We conducted a camera-trapping survey in Ballari district, India. We deployed camera-traps at 1457 sampling grid cells across Protected Areas

(PAs), Reserved Forests (RFs), and adjoining fringe mosaic farmlands (FMFLs). We assessed the influence of 19 covariates related to habitat features, landscape-level human presence, climate, and local-level human presence on species habitat use. We examined the diel activity patterns and activity levels of mammals within different land-use types.

Results Four species exhibited a net negative response to increasing human presence, while three species exhibited positive responses. Respectively, proximity to farmlands, and settlements positively influenced habitat use by *Panthera pardus*, and *Lepus nigricollis*. Increasing direct human presence negatively affected *Sus scrofa* habitat use. Large body-sized species exhibited higher diurnal activity in PA/

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s10980-024-01847-7>.

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The impacts of COVID-19 lockdown on wildlife in Deccan Plateau, India

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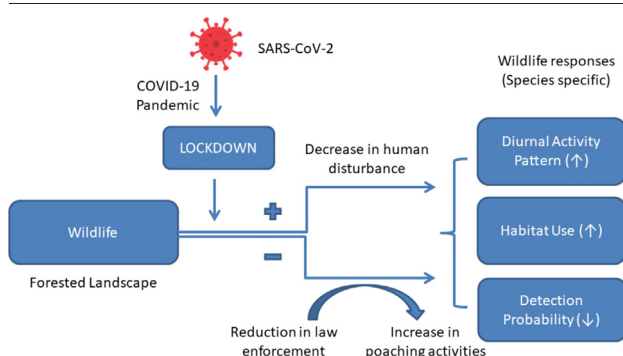
^e Centre for Functional Biodiversity, University of KwaZulu- Natal, South Africa



HIGHLIGHTS

- The COVID-19 lockdown has both positive and negative impact on wildlife.
- Reduced human activities led wildlife to increase their diurnal activities.
- Rise in illegal wildlife activities was observed during lockdown.
- Species-specific increase of habitat use was observed during lockdown.
- Reduced detection probabilities of species during lockdown

GRAPHICAL ABSTRACT



ARTICLE INFO

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ABSTRACT

The outbreak of the COVID-19 pandemic brought unprecedented changes in human activity via extensive lockdowns worldwide. Large-scale shifts in human activities bestowed both positive and negative impacts on wildlife. Unforeseen reduction in the activities of people allowed wildlife to venture outside of forested areas to exploit newfound habitats and increase their diurnal activities. While on a negative note, a reduction in forest-related law enforcement led to substantial increase in illegal activities such as poaching. We conducted mammal surveys in forested and nearby farmland of a fragmented landscape under two distinct scenarios: pre-lockdown and lockdown. An increase in poaching activities observed during the lockdown period in our study area provided us an opportunity to investigate the impact of the lockdown on wildlife. Camera trapping data of four highly poached mammalian species, namely black-naped hare *Lepus nigricollis*, wild pig *Sus scrofa*, four-horned antelope *Tetracerus quadricornis* and leopard *Panthera pardus* were considered to investigate activity patterns and habitat use, to understand the effect of lockdown. The pre-lockdown period was used as a baseline to compare any changes in trends of activity patterns, habitat use and detection probabilities of targeted species. Species-specific changes in activity patterns of study species were observed, with an increment in day-time activity during lockdown. The results showed species-specific increase in the habitat use of study species during lockdown. Reduction in the detection probability of all study species was witnessed. This is the first study to highlight the effect of the COVID-19 lockdown on the responses of wildlife by considering the changes in their temporal and spatial use before and during lockdown. The knowledge gained on wildlife during reduced human mobility because of the pandemic aid in understanding the effect of human disturbances and developing future conservation strategies in the shared space, to manage both wildlife and humans.

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Extension of the Known Range of Chinkara and its Conservation Importance in Karnataka, India

Asit K. Behera^{1,4} · P. Ramesh Kumar² · M. Malathi Priya³ · T. Ramesh^{1,5}  · Riddhika Kalle^{1,5}

Received: 3 August 2021 / Revised: 9 March 2022 / Accepted: 23 March 2022
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Abstract Chinkara (*Gazella bennetti*) is a widespread antelope in the arid and semi-arid regions of Deccan Peninsula, but it is relatively unfathomed in the southern part of its distribution range. We report the first photographic evidence of chinkara from Ballari district of Karnataka that comprises six camera-trap records representing six different individuals from Chiribi Reserved Forest. During June–August 2019, chinkaras were detected through camera trapping surveys in a single forest patch, with predominately dry scrub forest. This finding adds information on the extended distribution range of the species across the globe. Presence of a fawn indicates the existence of a viable population with breeding pairs, which is a positive indication in terms of conservation importance of the region. An extensive occupancy survey in this forest patch and neighboring areas would help in acquiring a better understanding of the distribution of this elusive species and facilitate protection, conservation and restoration of its critical habitat for sustaining their population.

Keywords Camera trapping · Conservation · *Gazella bennettii* · First record · Distribution range

Chinkara *Gazella bennettii* also known as Indian gazelle is an elegant and elusive ungulate [1]. Out of the total 19 species of gazelle, chinkara is the only one found in the Indian subcontinent [2]. It belongs to the Bovidae family (Subfamily: Antilopinae) and it is known to inhabit the arid and semi-arid grasslands [3]. Even though its IUCN status is ‘Least Concern’, because of the rapid declination of its population, highest protection status is being given by listing it under the Schedule I of Indian Wildlife Protection Act 1972 and is not authorized to be hunted from anywhere in India [4].

Chinkara’s geographic range covers much of western and central India, extending through Pakistan, south-western Afghanistan and into north-central Iran [5]. In India, the north-eastern border is Bihar, while southern boundary is considered to be Andhra Pradesh-Karnataka border [6]. Chinkara is found in eleven states of India that includes Rajasthan, Madhya Pradesh, Chhattisgarh, Gujarat, Maharashtra, Haryana, Uttar Pradesh, Bihar, Jharkhand, Andhra Pradesh and Karnataka [6, 7]. Even though the distribution is widespread, the population is declining throughout its distribution range [8]. Its distribution in southern India has not been studied properly because of the sporadic reports of its occurrence. Except in the northern Karnataka and a small population in Sandur forest [6] it was once believed to be more or less extinct in Karnataka. Despite given the highest status of protection, it continues to face threats due to poaching for bushmeat [9]. Habitat alterations like expansion of agricultural lands, mining, quarries and construction of canals have far-reaching negative consequences on the distribution of

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November 19, 2024

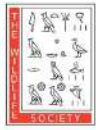
Dear Asit Behera:

The 101st Annual Meeting of the American Society of Mammalogists (ASM) was held in-person and virtually 14-18 June 2022 in Tucson, Arizona. On behalf of the ASM Program Committee, we are happy to verify your attendance at this year’s annual conference, as well as the presentation of your talk, *A once in a lifetime opportunity: COVID-19 lockdown highlights the effect of humans on wildlife* . The success of the meeting rests with the quality and diversity of participants and presenters, and we thank you for your participation in the meeting. Please do not hesitate to contact us should you have any questions.

Sincerely,

Cody Thompson

Cody W. Thompson, PhD
Program Director & Committee Chair
American Society of Mammalogists
Email: mammalmeetings@gmail.com



THE WILDLIFE SOCIETY

Leaders in Wildlife Science, Management and Conservation

November 19, 2024

To whom it may concern,

This letter confirms that Asit Kumar Behera attended The Wildlife Society's 29th Annual Conference in Spokane, Washington USA from November 6-10, 2022, at the Davenport Grand.

Asit Kumar Behera presented during our conference on his research, "Land use gradients shaping mammalian community in the fragmented landscape of Bellary district, India." (Abstract ID: C-2706).

You may learn more about our conference at twconference.org. Please do not hesitate to contact us at tw@wildlife.org or 301-897-9770 if you need any more information.

Sincerely,

Ed Arnett, CWB®, Ph.D.
Chief Executive Officer
The Wildlife Society



**59th ANNUAL MEETING OF THE
ASSOCIATION FOR TROPICAL
BIOLOGY AND CONSERVATION**

Certificate

of attendance

This certifies that

Asit Behera

has attended the 59th Annual Meeting of the
Association for Tropical Biology and Conservation
"Balancing Science, Conservation, and Society"
held in Coimbatore, India, from July 02-06, 2023.

RAMESH KRISHNAMURTHY

CHAIR

ATBC 2023

LUCIA G. LOHMANN

Executive Director

ATBC





Society for Conservation Biology

CERTIFICATE OF PRESENTATION

THIS CERTIFICATE IS AWARDED TO

Asit Kumar Behera

For presenting: Impact of COVID-19 lockdown on wild mammals

on December 17, 2021

at the 2021 International Congress for Conservation Biology

Tony Lynam
President, Society for Conservation Biology

ICCB2021

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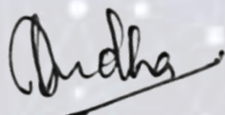
Asit Kumar Behera

of Salim Ali Centre for Ornithology and Natural History (South India Centre of Wildlife Institute of India)

has presented a poster titled Landscape level patterns of mammalian assemblages in Bellary

District, Karnataka

in the **Mandatory Ph.D. Presentation category** as a part of **Manipal Research Colloquium 2025** organized from 28th to 30th April 2025.



Dr. Vasudha Devi

Deputy Director, Centre for Doctoral Studies
MAHE, Manipal



Dr. Satish Rao B.S.

Director – Research
MAHE, Manipal

ANNEXURE 1

Biodata of Candidate

Name: Asit Kumar Behera

Age: 31 years (DoB: 15/1/1994))

Contact Address: Asit Kumar Behera, INSPIRE Fellow, Division of Conservation Ecology, Salim Ali Centre for Ornithology and Natural History (SACON), Anaikatty Post, Coimbatore-641108, Tamil Nadu, India.

Permanent Address: Qr. No. E/1, M. I. Colony, Unit – 9 (Flat), Bhoinagar post, Bhubaneswar-751022, Odisha, India.

Email ID: asit.vicky@gmail.com

Contact Number: 8116786460, 8903133699

Achievements:

1. INSPIRE Fellowship, Department of Science and Technology (DST/INSPIRE/Fellowship/2018/IF180359).
2. SERB Overseas Visiting Doctoral Fellowship (OVDF) (SB/S9/Z-03/2017-V (2020-21))

Educational qualification:

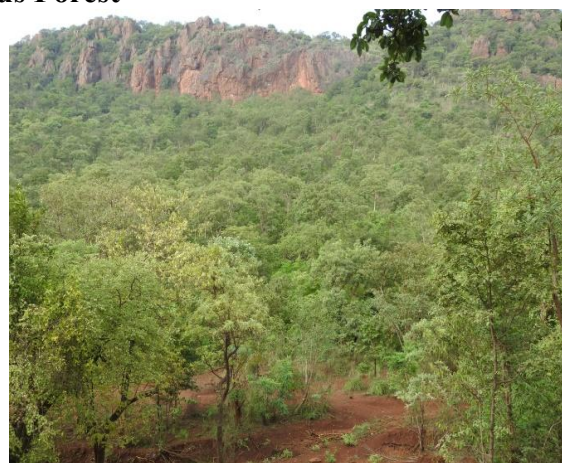
2011-2016: BS-MS Integrated dual degree, Biological Science, IISER-Kolkata.

ANNEXURE-2: PHOTO PLATES

Dry Thorn Forest



Dry Deciduous Forest



Moist Deciduous Forest

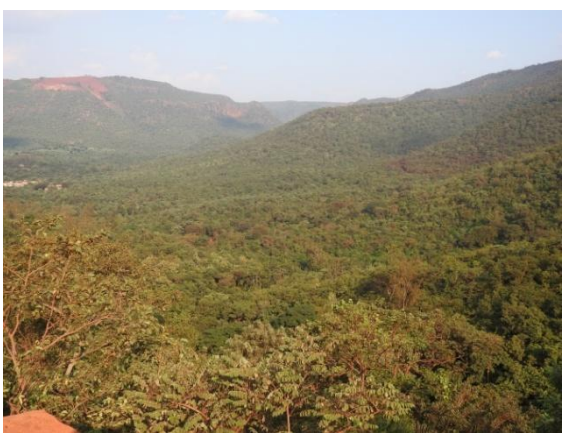


PLATE B- THREATS TO HABITAT MANAGEMENT

Mines in Ballari, Karnataka



PLATE B- THREATS TO HABITAT MANAGEMENT



Agricultural Expansion



Livestock Overgrazing



Timber Collection



Firewood Collection

PLATE B- THREATS TO HABITAT MANAGEMENT

Human- Wildlife Conflict



Livestock depredation by a leopard



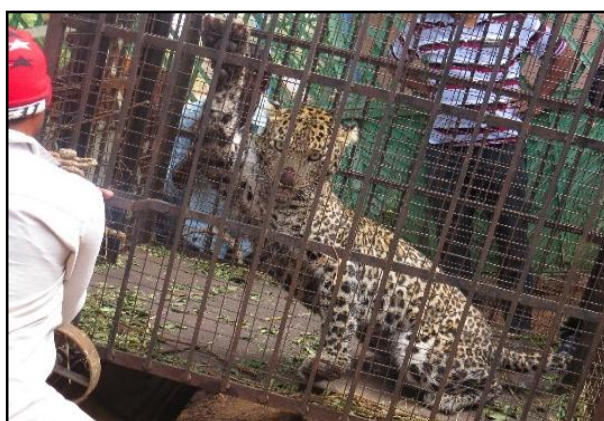
Livestock depredation by an Indian wolf



Poachers with trained dogs



Poachers with a kill



A leopard was captured by the local forest department after the death of a human



A traditional trap to catch species like hare

Landscape level patterns of mammalian assemblages in Bellary District, Karnataka

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