Comparison of small carnivore detection rates between two different leopard density regimes in Kuno National Park

By

Srajal Namdev
Enrollment number: 50BB24A73032

A dissertation submitted to the

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For partial fulfilment of the degree

Masters of Science
In
Wildlife Sciences

Under the Supervision of

Dr Lallianpuii Kawlni

Scientist-D, WII

Dr. Vishnupriya Kolipakam
Scientist-E, WII

C.M. Bipin
Project Scientist, WII

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

AcSIR

Wildlife Institute of India, Mehuwala Mafi, Chandrabani, Dehradun- 248001

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भारतीय वन्यजीव संस्थान
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DECLARATION

I hereby declare that the work conducted under the thesis entitled **'Comparison of small carnivore detection rates between two different leopard density regimes in the Kuno National Park'**, is a record of original and independent research work done by me and subsequently submitted for the award of the degree of Master's in Wildlife Science at the Academy of Scientific and Innovative Research. This research work has been carried out under the guidance and supervision of Dr.Lallianpuii Kawlni, Scientist-D, and co-supervision of Dr.Vishnupriya Kolipakam, Scientist- E and C.M. Bipin, Project Scientist of Wildlife Institute of India, Dehradun. The work has not formed the basis for the award of any other degree, diploma, or any other qualification. I also declare that the thesis embodies my own work, analysis, observation, understanding and the particulars given in it are true to the best of my knowledge. No AI has been used for any aspect of the work therein.

Srajal Namdev
Enrollment Number: 50BB24A73032,
Place: Dehradun
Date:17th July, 2026

(Dr Lallianpuii Kawlni)
Supervisor

K. Vishnupriya

Dr. Vishnupriya Kolipakam
Co- Supervisor

C.M. Bipin
Co-Supervisor

पत्रपेटी सं. 18, चन्द्रबनी, देहरादून-248 001, (उत्तराखण्ड), भारत
Post Box No. 18, Chandrabani, Dehradun-248 001, (Uttarakhand), INDIA
ई.पी.ए.बी.एक्स. +91-135-2640111 से 2640115, एवं 2644462 से 2644464, फैक्स 0135-2640117, तार WILDLIFE
EPABX : +91-135-2640111 to 2640115 & 2644462 to 2644464 Fax : 0135-2640117, GRAM : WILDLIFE
ई-मेल/E-mail : wii@wii.gov.in

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

Certificate

This is to certify that the thesis by **Srajal Namdev** titled **'Comparison of small carnivore detection rates between two different leopard density regimes in the Kuno National Park'** is an original and independent research work submitted to the **Academy of Scientific and Innovative Research**, for the award of the degree of **Master's in Wildlife Science** of Wildlife Institute of India

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

(Dr Lallianpuii Kawlni)

Supervisor

Dr. Ruchi Badola

Dean

पत्रपेटी सं. 18, चन्द्रबनी, देहरादून-248 001, (उत्तराखण्ड), भारत
Post Box No. 18, Chandrabani, Dehradun-248 001, (Uttarakhand), INDIA
ई.पी.ए.बी.एक्स. : +91-135-2640111 से 2640115, एवं 2644462 से 2644464, फैक्स: 0135-2640117, तार: WILDLIFE
EPABX : +91-135-2640111 to 2640115 & 2644462 to 2644464 Fax : 0135-2640117, GRAM : WILDLIFE
ई–मेल/E-mail : wii@wii.gov.in

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Wildlife Institute of India

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Chandrabani, Dehradun - 248 001

16/7/26
(Dr Lallianpuii Kawlni)
Supervisor

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Executive summary

The study assessed the detection patterns of small carnivores in Kuno National Park using a camera-trap survey conducted across two sampling areas, blocks representing contrasting leopard density regimes. Camera traps were deployed using a systematic 0.5 km^2 grid design with approximately 700 m spacing between stations to maximise detections of small carnivores while maintaining standardised sampling. A total of ten small carnivore species were targeted, and Relative Abundance Indices (RAI) were calculated to compare detection rates among species and sampling blocks.

Another study design with trail cameras on the same blocks was used to investigate the small carnivore community in two blocks representing high and medium density areas to understand community composition between the two study areas, although some species differed in their relative abundance.Small Indian civet, leopard, and golden jackal were detected more frequently in the high-density block, while jungle cat was relatively more common in the medium-density block.

Spatial and temporal analyses indicated that most small carnivore species shared the same habits and were active during similar periods of the day.However, some species delayed their visits after another carnivore had recently used the same location, suggesting that coexistence is maintained mainly through short-term temporal avoidance rather than by occupying different habitats.

This study also evaluated the effect of camera-trap sampling scale (grid size) on Relative abundance Index (RAI) showed that common species which were detected consistently throught

out the camera trap with adequate sample size produced estimates with lower coefficient of variation comparative to rarely detected species which became increasingly variable as sampling scale increased.These findings highlight the importance of using finer camera-trap grids when monitoring smaller species with less movement or home ranges.

Introduction

Small carnivores are members of the mammalian order Carnivora with a body mass of less than 21.5 kg that occur worldwide. They are represented by 210-282 species, which account for approximately 90% of terrestrial carnivores globally (San et al., 2022). South-east Asia has a rich assemblage of small carnivores belonging to the following families: Felidae, Mustelidae, Viverridae, and Procyonidae. Habitat use by these carnivores is primarily influenced by food availability, interspecific competition, predator presence, and disturbances (Saharia & Saikia, 2021; Marneweck et al., 2022). Many carnivores, such as civets, play a vital role as seed dispersers. Apart from being carnivores, this group of animals can have a very rich diet; on the contrary, some carnivores are extremely specialised regarding their diet, making this trophic level very diverse.

Small carnivores are also considered sentinels of global change and exhibit varied responses to human disturbance or other biotic and abiotic factors that lead to changes in the structural and functional complexity of their habitat (Marneweck et al., 2022). The use of biological resources was one of the leading threats that affected almost 96% of threatened small carnivores. This category refers to poaching and overhunting, though the reasons for such activities are regionally different. South East Asia has the highest number of affected small carnivores.

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The order Carnivora is one of the richest orders of all mammalian orders, after Rodentia and Chiroptera. In South and Southeast Asia, studies have very little focus on small carnivores (Rabinowitz, 1990, 1991; Joshi et al., 1995; Grassman, 1998; Mudappa, 2001; Mudappa et al., 2010; Colon, 2002; Grassman et al., 2005; Jennings et al., 2006, 2010). Most of the small carnivores are nocturnal, inhabiting areas with limited or no accessibility and poor detection.

They are represented by approximately 280 species, which correspond to approximately 90% of terrestrial carnivores globally (San et al., 2022). Families include Ailuridae, Eupleridae, Herpestidae, Mephitidae (skunks), Mustelidae, Nandiniidae (two-spotted civet), Prionodontidae, Procyonidae (raccoons and relatives) and Viverridae (Wilson and Mittermeier 2009). These families exhibit a high degree of endemism in various regions of the world. Herpestidae, Mephitidae (a family of skunks and stink badger) and Procyonidae (family of New World carnivores including raccoons) are restricted to America. Herpestidae, including mongooses and meerkats; Viverridae, comprising civets and their relatives; Eupleridae, constituting small carnivores restricted to Madagascar, the monotypic red panda *Ailurus fulgens* (Ailuridae), and the two-spotted civet *Nandinia binotata* (Nandiniidae) and the elusive linsangs (Prionodontidae) are all originally restricted to the Old World. In contrast, the Mustelidae (weasels and their kin) are found worldwide, except in Australia and Antarctica. They are the most diverse, with 57 species in 22 genera, followed by the herpestids and viverrids with 34 species each and 15 and 14 genera, respectively. These families occupy habitats ranging from the snow-covered tundra to the dense tropical rainforest.

There are 32 species of small carnivores in India (Menon 2003) belonging to 5 families. This includes 6 species of herpestids, 2 species of prionodontids,11 species of viverrids, 17 species of Mustelids, one ailurid and 10 species of small felids. Western Ghats, Himalayas, Northeast and some regions of Western India are high in small carnivore diversity, possibly due to confluence between multiple biogeographic zones creating habitat heterogeneity as well as complexity, vegetation structure, prey base, topography and rainfall.

Some species are endemic to 1 or 2 countries (sometimes only islands), while others, like the red fox, *Vulpes vulpes*, are present in nearly 90 countries over 5 continents. Small carnivores inhabit all of the Earth's ecosystems virtually, adopting terrestrial, fossorial, arboreal or aquatic lifestyles. They occupy multiple trophic levels, and they play important roles in the regulation of ecosystems. Tropical small carnivores play a significant role in regulating the ecosystem as they are crucial predators, prey, and seed dispersers (Mudappa et al., 2007). Ecosystem dynamics are directly impacted by changes such as population growth and decline in small carnivore communities (González-Maya et al., 2009).

This can potentially be because of the following reasons:

- Small carnivore communities are usually more diverse than large carnivore communities, due to body size effects that affect a host of life history strategies, including home ranges, reproduction, abundance and a varied response to habitat alterations at finer scales. The response is exhibited through behavioural, physiological and ecological changes. (Marneweck et al., 2022).

- They hold an intermediate position that is more directly affected by changes at the producer, primary consumer, and tertiary consumer levels. Behavioural and ecological changes can signify habitat alterations (Marneweck et al., 2022).
- Small carnivores have shorter life spans and higher reproductive rates and exhibit more rapid responses to change (Marneweck et al., 2022)

For maximising the optimal foraging decisions, mesopredators may assess the likelihood of encountering large predators during their visitations on the same space and time so that the benefits of scavenging are worth the costs of interspecific interaction risk(Orazi et al.,2025).

Roles of small carnivores

It has been mistakenly thought that small carnivores exert a weaker force on the ecosystem level (San *et al.,*2022). Their presence does not affect the spectrum of the prey species, similar to a large carnivore does, but they are equally responsible for the regulation of the ecosystem by invertebrate or small mammal communities, including in rural agro-ecosystems (Williams et al., 2018). Rodents and other pests account for approximately 15% of the damage caused to rural farming crops in Africa (Swanepoel et al., 2017). Such damage is due to large proportions of pests consisting of rodents (Brown et al., 2007). Since small carnivore diets include a large proportion of rodents, it is likely that small carnivore predation could be a key factor affecting rodent abundance, and therefore reduce crop damage (C´irovic et al., 2016).

Conservation status and threats

Small carnivores make up diverse assemblages in tropical forests (Rabinowitz 1991). They are also functionally important to these ecosystems. Many frugivorous small carnivores contribute significantly to seed dispersal and the regeneration of numerous, often rare, forest tree species, although this role has not been adequately studied (Herrera 1989). Some studies have shown that habitat loss and habitat modification negatively affect wide-ranging carnivorous and frugivorous mammals (Heydon and Bulloh 1996).

According to the IUCN Red List of Threatened Species, among small carnivores, two species are classified as Extinct (EX), one as Critically Endangered (CR), ten as Endangered (EN), 22 as Vulnerable (VU), ten as Near Threatened (NT), 15 as Data Deficient (DD), and 105 as Least Concern (LC). Of the 33 viverrid species (civets, genets, and oyans), 14 are currently listed as globally threatened (Schipper et al. 2008), including the Critically Endangered Malabar civet. Among species that were not classified as Data Deficient, 22% were assessed as threatened (CR, EN, or VU), compared with 25% for mammals overall (Schipper et al. 2008). Among otters, seven of the 12 species for which a category was assigned (58%) were identified as threatened.

Table 1. Small carnivore species in Kuno National Park

S.no	Species	Body mass (kg)	Social structure	Activity pattern	Home range
1	Indian grey mongoose	1.4 (Menon, 2014)	Solitary	Diurnal	_
2	Small Indian mongoose	0.5-1	Solitary	Diurnal	Male 2 km^2, 0.5km^2 (Tomich,1969)
3	Ruddy mongoose		Solitary	Diurnal	_
4	Small Indian civet	2-4	Solitary	Nocturnal	_
5	Common palm civet	1.4-4.5	Solitary	Nocturnal	0.105 km^2-1.7 km^2 (Nakashima et al.,2013)
6	Golden jackal	6.5-9.8	Group living	Cathemeral	3-30 km^2 (Leopard report,2018)
7	Honey badger	7-13	Solitary	Nocturnal	138 km^2 to 548 km^2 (Begg et al .,2004)
8	Jungle cat	2.5-12 (Mukherjee 2013)	solitary	Crepescular (Prater,1971)	2.6-16.7 km^2 (Cheetah report2023-2024)
9	Rusty spotted cat	1.1-1.6 (Phillips 1980)	Solitary	Nocturnal	_

Camera trapping and spatial scale influencing detections

Grid-based designs are widely used in camera-trapping studies. When combined with camera trapping, such designs can be analysed to estimate occupancy or habitat use of a given species, and to calculate relative abundance indices (RAI) that provide a broad indication of detection rates and spatial distribution across the study area. More robust population parameters, such as density, can be estimated using capture–recapture models for individually identifiable (marked) animals. For unmarked and elusive species, alternative approaches, including the random encounter model (REM) and camera trap distance sampling (CTDS), have been developed to estimate density. Over time, CTDS has been refined and optimised to improve logistical feasibility and the precision of estimates. However, uncertainties regarding its accuracy remain, and the method continues to be critically evaluated in the peer-reviewed literature.

Across studies on small mammals and carnivores, evidence consistently suggests that grid size influences population estimation and detection probability primarily through its interaction with species movement patterns, home range size, trap spacing, and sampling intensity, rather than through area alone. The movement range of target species will determine how far apart traps should be spaced to achieve either independence of sampling units (a prerequisite for occupancy modelling) or to make sure all individuals in the sampled area are exposed to traps (an assumption of capture-recapture models (Sunarto et al,2013). Moreau (1996) identified that tighter spacing and higher trap density captured more individuals when using live trapping, which made species richness look higher at first. But when controlling for the number of individuals captured was done analytically, the different trap densities gave roughly similar species richness, which means the apparent increase in richness was mainly a sampling-effort effect, not a true grid-size effect.

Camera trapping has been carried out for small carnivores, mostly based on tiger-based surveys or grid sizes specifically designed for large carnivores. One study was done in KMTR based on the camera trap in Kalakad-Mundanthurai Tiger Reserve, Tamil Nadu. Paired camera traps were set in a grid of 1.413 x 1.413 km area of 180km^2. A total of 11 species were recorded in different habitat types (A.Venkatesh *et al.,* 2021).

Top-down suppression

One of the principal factors that influences the presence of small and medium-sized carnivores is the presence of an apex predator. These effects have been extensively studied in ecology with respect to different large carnivores (> 21kg) across the globe. Large carnivores can exert a ripple effect on the ecosystem by predating organisms occupying the lower trophic levels, which in turn regulate the behaviour and population of several small predators and prey beneath them.

Overlap in resource use within biological communities can also lead to complex interactions among species, which in turn can influence their behaviour, spatial distribution, and population dynamics (Orazi et al., 2025). In carnivore communities, these interactions are commonly explained through concepts of interspecific competition and the "landscape of fear," which together describe both direct competitive effects and behaviour changes driven by perceived predation risk across space and time. Interspecific killing has been found across mammalian carnivores.Canidae(wolves, coyotes, Foxes), Felidae(Lions, leopards, lynx)and several members of the Mustelidae family have been studied for interspecific killing(Palomares and Caro,1998). Body size plays a crucial role in facilitating interspecific competition or, in extreme cases, intraguild predation of two sympatric carnivore species (Palomares and Caro, 1998).

Apart from competition and suppression, which are recognised as dominant forces that structure predator communities, facilitation via carrion provisioning to medium and small-sized predators may weaken the effect of suppression. Studying these dynamics of positive and negative relationships between carnivores at the community level becomes necessary to understand the responses of small carnivores to large predators (Sivy et al., 2017).

In India, limited research has been conducted on the habitat use, movement and diet of small carnivores. Most of the studies deal with distribution, diet and habitat use utilising bycatch data from large carnivore studies. While intraguild predation had been discussed theoretically across the globe, there was no comprehensive synthesis documenting how common interspecific killing is among mammalian carnivores, what patterns it follows, and what consequences it has for populations and communities (Palomares and Caro, 1998). Due to the elusive nature and rarity of some species of the family Felidae, Mustelidae, and Viverridae, robust studies with strong ecological inferences become difficult for this group of Carnivora.

Objectives and Aims

Objective I

a. To estimate the detection rates of leopards and small carnivores in two different leopard density areas.

b. To evaluate the effect of grid size on small carnivore detection rates.

Objective II

To study the effect of leopard detection rates on small carnivores in two areas with different leopard densities.

Hypothesis

1. Small carnivore detections will be lower in a high leopard density block.

Study Area

Kuno National Park

Kuno NP falls under the northern tropical dry deciduous forest as per the revised classification of forest types of India (Champion & Seth 1968). The dominant trees in this landscape are *Terminalia pendula* and *Boswellia serrata*, while the middle story is dominated by *Senegalia catechu*, *Vachellia leucophloea* and *Diospyros melanoxylon*. *Zizyphus sp*. makes up the lowest part of the canopy cover. Shrub species comprise *Grewia flavescens*, *Helicteres isora*, and *Vitex negundo*. Grass species include *Heteropogon contortus*, *Apluda mutica*, *Aristida hystrix*, *Themeda quadrivalvis*, *Cenchrus ciliaris*, *Dicanthium annulatum* and *Desmostachya bipinnata*. Kuno is probably one of the only wildlife sites in the country where there has been a complete relocation of villages from inside the park (one village relocation is underway, in a part of the recently added area of the National Park). These village sites and their agricultural fields that were inside the NP have now been taken over by grasses and are managed as a savannah habitat.(Cheetah report 2023-24)

Physiography of the Study Area

Kuno National Park is situated in Sheopur District of Madhya Pradesh. It is interspersed with small streams, having a rugged mosaic of geographical and ecological features like ravines, tropical thorn scrub, open semi-arid forests, short grasslands, barren land, and agricultural matrix. The study area is classified under the Semi-arid zone (Rodger 2000).In terms of terrain, the study area is heterogeneous, hosting one of the most abundant leopard areas in India and home to several species of small carnivores. Studying the activity of small carnivores in response to areas with medium leopard density and high leopard density made this area appropriate for the study.

Kuno National Park is located in the Plateau of Central India, which covers the northern part of the lower basin of the Chambal River. This area is formed by the Vindhyan rock with the Deccan trap in the south and the Bundelkhand gneiss rocks in the east. The central part of Madhya Pradesh spreads across Morena, Bhind, Gwalior, Shivpuri, Sheopur, Guna, and Mandsaur districts. The maximum height of this region is 500 m; however, the plain situated to the north and northeast has a height between 150 and 300 m. The geomorphology of Kuno National Park can be attributed to several geological processes that have shaped the landscape over millions of years. These include tectonic activity, erosion by rivers and streams, and weathering. The Vindhyan Range, where the park is located, was formed as a result of intense folding and faulting during the geological past. The topography image of the Kuno National Park area shows that the altitude of this region is situated in the range of 238- 498 m above MSL. The Kuno River flows from south to north and bisects the national park into two parts, i.e., the east and west Kuno region. The valley of the Kuno River is located at an altitude of 238 m above mean sea level.

Historical aspect

Historically, due to dacoits, human intensity has always been regulated. However, now with the control of dacoit farmers from outside, localities are setting and practising irrigated intensive agriculture outside of the forest areas. Tribal communities like the Mogiyas, who are known for their hunting prowess, reside close to the northern and eastern boundaries of the park. Sahariya, a sub-caste within the Gonds, constitutes the major clump among tribes, and their populations are settled in villages all around the sanctuary. On the contrary, the Bhil community frequently gets caught up in poaching and encroachment activities, getting them into problematic scenarios with the forest department. People from the Kachchh region of Gujarat immigrated and settled in the areas nearly 30-35 years back, and have been given the right to cultivate ('patta' land) by the forest department. Almost every village has 'baniya' (trader) families who own provision shops and operate small-scale money-lending business within the village, while land lords 'thakurs' in these villages continue to own some of the largest agricultural land holdings in the area. The other predominant communities in the area are Gujjar and Yadav, who are landowners and pastoralists. The other communities are Dhakad and Jatav, who own some of the largest agricultural holdings. The main livelihoods of people are agriculture, pastoralism, casual labour, and the collection of non-timber forest products.

The 748 km^2 protected area within the national park is largely devoid of human settlements and domestic livestock, although the incentivised voluntary relocation of one village (Bagcha) is currently in progress. The 24 villages that were previously located inside the park were resettled outside the protected area boundaries in 1998 (Kabra 2009). The park also supports an estimated 500 feral cattle (Banerjee 2005) that were left behind when residents relocated. These feral animals contribute to the prey base available to large carnivores within the park.

Fauna

The wild ungulates and herbivorous mammals found in the area are chital (*Axis axis*), sambar (*Rusa unicolour*), nilgai (*Boselaphus tragocamelus*), wild pig (*Sus scrofa*), chinkara (*Gazella bennettii*), chousingha (T*etracerus quadricornis*), blackbuck (*Antilope cervicapra*), now only on the periphery of the NP, northern plains grey langur (*Semnopithecus entellus*), rhesus macaque (*Macaca mulatta*), Indian porcupine (*Hystrix indica*) and black-naped hare (*Lepus nigricollis*).

Mammalian carnivores include leopard (*Panthera pardus*), sloth bear (*Melursus ursinus*), striped hyaena (*Hyaena hyaena*), gray wolf (*Canis lupus pallipes*), golden jackal (*Canis aureus*), Indianfox (*Vulpes bengalensis*), ratel (*Mellivora capensis*), jungle cat (*Felis chaus*), Asiatic wild cat (*Felis lybica ornata*), rusty spotted cat (*Prionailurus rubiginosus*), Indian gray mongoose (*Herpestes edwardsii*), ruddy mongoose (*Herpestes smithii*), Small Indian mongoose (*Urva auropunctata),* Asian palm civet (*Paradoxurus hermaphroditus*) and small Indian civet (*Viverricula indica*).

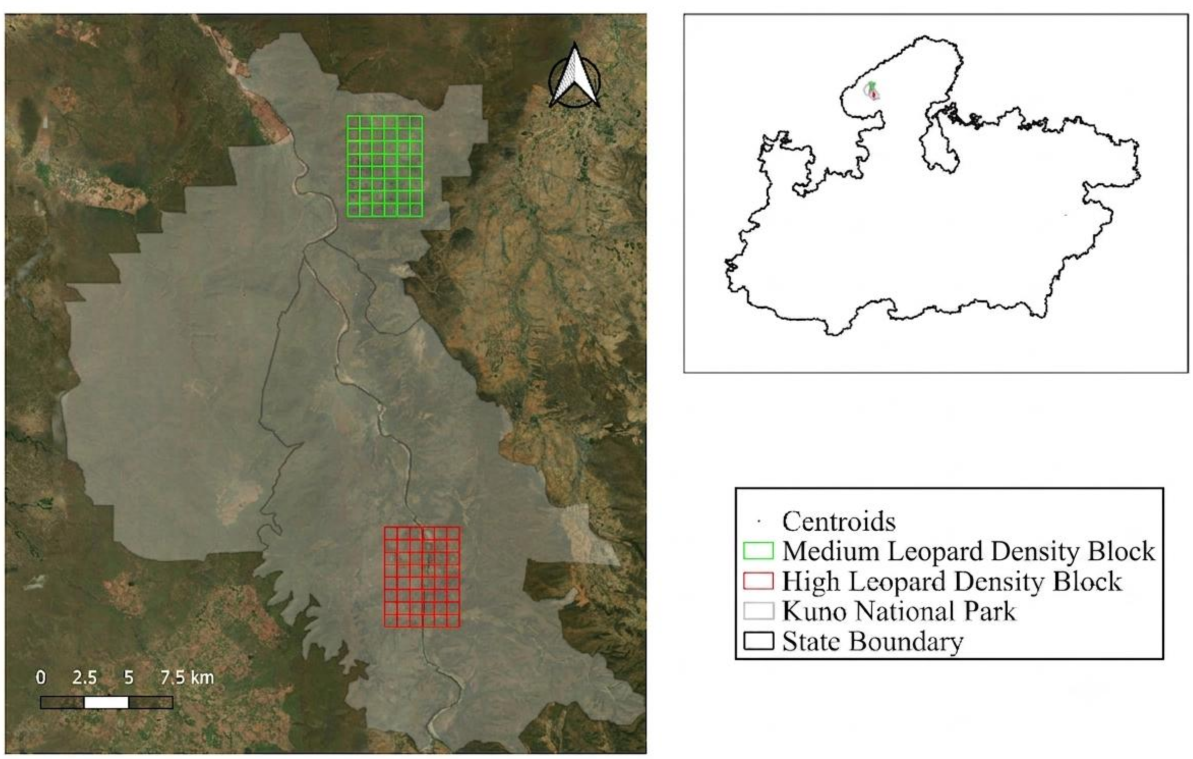

Figure 1. Map of Study Area: Kuno National Park

Field methodology

The study aimed to understand the habitat use of small carnivores in Kuno National Park with two different density regimes of the apex predator (*Panthera pardus).* To achieve this, camera trapping was carried out, a study area of 24 Km^2 was selected in the middle of Palpur east and west as a high leopard density area from the previous cheetah report (2024), and another sampling block was chosen in the Northern range (Dhauret) as a medium density or density area of leopard from unpublished data.

Random cameras (centroid)

To determine the density of small carnivores, cameras were systematically placed in a 707x707 m area using ArcMap, and 48 centroids were generated in high leopard density and moderate density areas of the study region from the previous literature and recent reports. We deployed 48 camera traps (Reconyx HC500) to capture small carnivores. Camera deployment was done in the first sampling block in January and February, and in the second sampling block. Camera traps were active for the second sampling block. Camera traps were active for 45-50 days for both sampling blocks. The Reconyx camera was mounted 30-35 cm above the ground, and programmed to trigger 5 images per trigger with every movement without any delay or time lapse. To estimate the distance of the photo-captured individuals from the camera trap, we calibrated image measurements during deployment of the camera. For this, we laid a measuring tape in front of the camera, took a whiteboard with the distance written on it and triggered the camera to capture an image at every distance. This calibration was done for all 96 cameras (48 in the high leopard density area and an equal number in the medium leopard density area.

Trail cameras

Trail cameras (Cuddeback) were deployed along animal trails in the high-density (12 cameras) and medium-density (11 cameras) blocks using a 1.417 × 1.417 km grid following a preliminary carnivore sign survey. A total of 23 camera stations were operated for 30–45 days during March–April 2026. Cameras were programmed to capture two photographs per trigger during daylight hours and one photograph per trigger at night.

Covariates collection

Vegetation cover, like canopy cover, and the number of tree species were measured in a 30m x 30m plot, which was divided into four equal sub-plots and the canopy cover was measured (ocularly) in all the subplots and was averaged to give the canopy cover.. The number of trees was counted in the plot. Shrub cover was taken around the camera trap in 4 plots of 5m x 5m. Similarly, grass height and herb cover were measured from 4 plots of (1m x 1m).

From the previous cheetah report (2024) and literature review, we selected the high and medium leopard density areas. But, due to increased protection in the past few years, leopard density has changed within the national park or erstwhile sanctuary

Analytical methods

Relative Abundance Index

The relative abundance index (RAI) was calculated as the number of independent detections of a species divided by the total camera-trap nights, multiplied by 100. It represents the visitation rate of that species per 100 camera trap days.

$$Relative\ Abundance\ Index = \frac{Number\ of\ Independent\ Detections}{Total\ Trap\ Nights}\ x\ 100$$

Every first capture of consecutive triggers was taken as an independent event for every species. We used all the random cameras in the high leopard density block (n = 48) as well as the medium density block (n = 44). The total sampling effort was the sum of the number of nights each camera was deployed successfully. For assessing the effect of leopard detection rates on smaller carnivores Relative abundance index was plotted for every species in both the blocks.

Results

Trail cameras

Table 2. Relative abundance index of 12 trail cameras deployed in a 2 km2 grid-based block (high-density block), Palpur

S.no	Species	Trap nights	Independent captures	RAI
1	Leopard	500	115	23
2	Striped hyaena	500	70	14
3	Golden jackal	500	91	18.2
4	Jungle cat	500	15	3
5	Honey badger/Ratel	500	34	6.8
6	Small Indian civet	500	62	12.4
7	Common palm civet	500	22	4.4
8	Indian Fox	500	7	1.4
9	Grey mongoose	500	2	0.4
10	Ruddy mongoose	500	7	1.4
11	Rusty spotted cat	500	2	0.4

Table 3. Relative abundance index of 11 trail cameras deployed in a 2 km2 grid-based block (medium density block), Dhauret

S.no	Species	Trap nights	Independent captures	RAI
1	Leopard	655	63	9.62
2	Striped hyaena	655	74	11.30
3	Golden jackal	655	56	8.55
4	Jungle cat	655	52	7.94
5	Honey badger/Ratel	655	10	1.53
6	Small Indian civet	655	35	5.34
7	Common palm civet	655	4	0.61
8	Indian Fox	655	2	0.31
9	Grey mongoose	655	4	0.61
10	Ruddy mongoose	655	5	0.76
11	Rusty spotted cat	655	3	0.45

Table 4. Relative abundance index of trail cameras deployed in both high and medium density blocks

Species	Dhauret (n = 11 cameras)	Palpur (n = 12 cameras)
Leopard	9.56 ± 3.82 (9/11)	22.56 ± 7.10 (9/12)
Hyena	14.13 ± 4.25 (8/11)	13.94 ± 2.98 (11/12)
Jungle cat	15.25 ± 9.07 (6/11)	3.01 ± 1.09 (6/12)
Golden jackal	12.67 ± 5.65 (7/11)	20.65 ± 12.45 (6/12)
Small Indian civet	7.19 ± 2.48 (9/11)	12.07 ± 3.04 (9/12)
Honey badger	1.53 ± 0.85 (3/11)	7.73 ± 4.38 (5/12)
Asian palm civet	0.55 ± 0.30 (3/11)	3.98 ± 2.04 (5/12)
Ruddy mongoose	0.68 ± 0.55 (2/11)	1.14 ± 0.98 (2/12)
Bengal fox	0.40 ± 0.40 (1/11)	1.28 ± 0.64 (4/12)

Bar plots of relative abundance index of carnivores in high and medium density block

The relative abundance index was plotted for every species in both blocks. Comparatively, leopard, golden jackal, and honey badger detection were considerably higher in the high leopard density block. Species like the Bengal fox and ruddy mongoose detection remained sporadic. Hyena detection rates remained marginally similar in both blocks. Small Indian civet detection rates were considerably higher in the medium-density block.

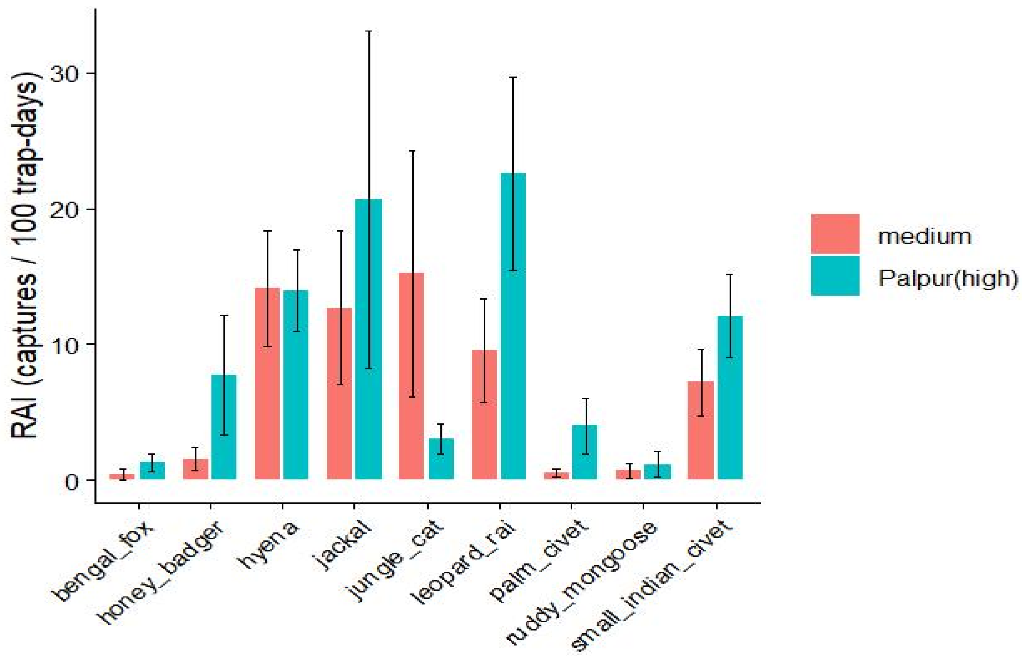

Figure 2.Relative abundance index bar plots of high and medium leopard density block

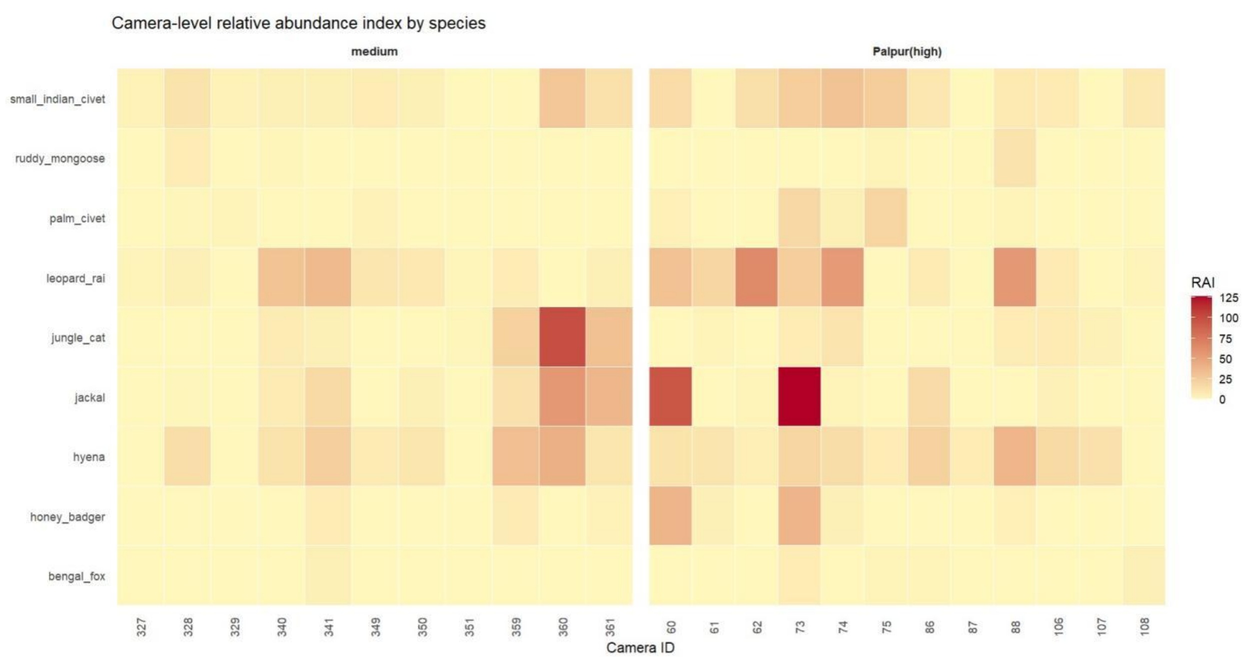

Figure 3. Heat map showing detections across the camera stations

A heat map for the detection across the camera stations was obtained in RStudio, which shows that the detection rates are not distributed homogeneously across the camera stations. Overall, the Palpur (high density) block exhibited higher RAI values and greater spatial heterogeneity than the medium-density block, with several cameras showing frequent detection in some camera stations.The medium-density block showed comparatively lower RAI values for most species, although elevated activity was observed for jungle cat around 360 camera.

Community composition

Bray-curtis similarity index Bray-curtis dissimilarity, averaged over camera pairs). Mean pairwise similarity was marginally different from each other (within high and medium density block), Dhauret (medium density showed mean similarity index of 0.305) and Palpur as high density showed (0.305).Between two sites, there was no essential difference found (0.288), i.e. two randomly chosen Dhauret and Palpur cameras are, on average, no less similar in species RAI profile than two cameras drawn from the same grid.

Table 5. Similarity index ranges 0 (no shared species/abundance) to 1 (identical RAI profile). Within- and between-site values are nearly identical.

Comparison	Mean similarity index
Within Dhauret	0.283
Within Palpur	0.305
Between Dhauret : Palpur	0.288
Overall (all camera pairs)	0.291

PERMANOVA on the Bray–Curtis dissimilarity matrix found no significant difference in small carnivore community composition between the Dhauret and Palpur grids (pseudo-F1,21 = 1.150, R^2 = 0.052, p = 0.325, 9,999 permutations). Site accounted for only about 5% of the total variance in community dissimilarity among camera stations, with the remaining ~95% attributable to among-camera variation within each grid.

Table 6. PERMANOVA values

Source	Df	Sum Of Sqs	Mean Sqs	F	R^2	p-value
Site	1	0.308	0.308	1.150	0.052	0.325
Residual	21	5.628	0.268		0.948	
Total	22	5.937			1.000	

Non-metric multi dimensional scaling

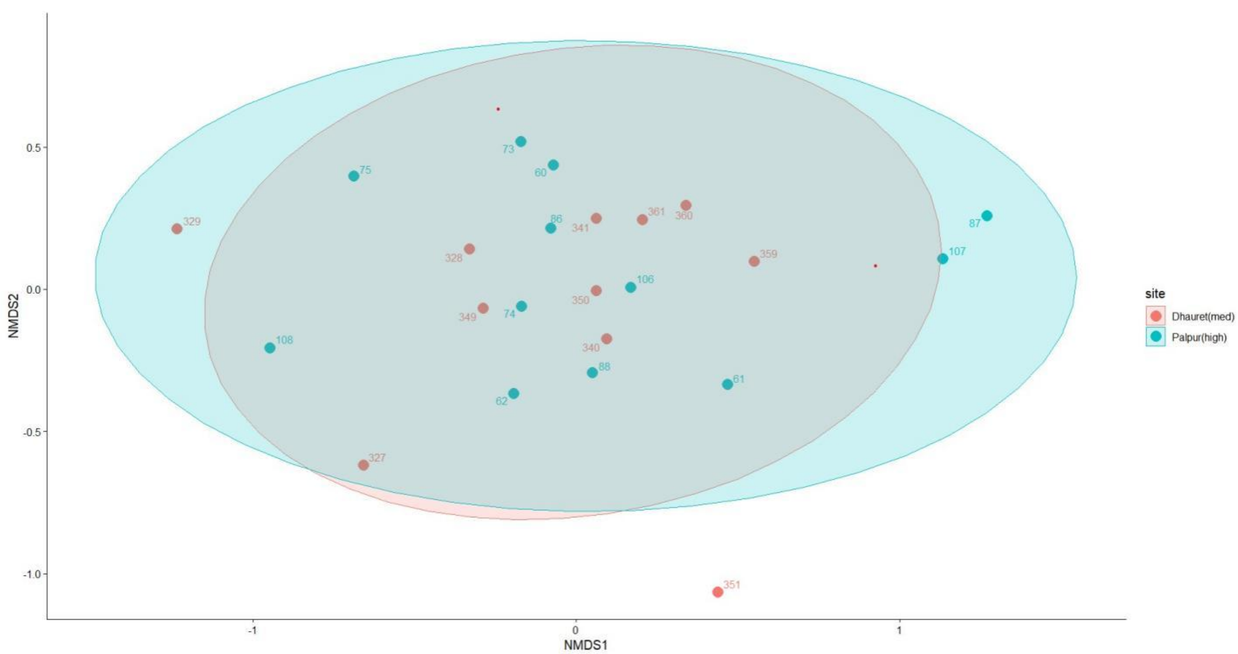

Figure 4. Non-metric multi-dimensional scaling showing extensive overlap between high and medium density block detection rates of camera stations

NMDS ordination summarises the similarity in camera-level carnivore community composition between the medium-density (Dhauret) and high-density (Palpur) blocks. Each point represents a camera station, and the distance between points reflects the similarity of species composition based on the Bray-Curtis dissimilarity index. Confidence ellipses overlap extensively, indicating no clear separation between the carnivores communities of the two blocks. Overall species composition at camera stations is broadly similar between the blocks.

Spatiotemporal overlap

Species with fewer than 15 independent captures in the raw detection were excluded from the analyses due to small sample size.

Table 7. Species retained vs. excluded under the 15-capture minimum. Three of ten species fell below the inclusion threshold and are discussed only qualitatively.

Species	Independent captures	Status
Leopard	177	Included
Golden jackal	147	Included
Hyena	144	Included
Small Indian civet	94	Included
Jungle cat	70	Included
Honey badger	44	Included
Asian palm civet	25	Included
Ruddy mongoose	12	Excluded (< 15 captures)
Bengal fox	11	Excluded (< 15 captures)
Indian grey mongoose	6	Excluded (< 15 captures)

Spatial co-occurrence

Out of twenty-one pairs, two showed significant positive spatial association (co-occurrence rather than avoidance): golden jackal and hyena ($\varphi = 0.52$, $p = 0.024$) and honey badger and jungle cat ($\varphi = 0.52$, $p = 0.027$). No pair showed significant spatial segregation; several pairs had negative φ (e.g. jungle cat vs. small Indian civet, $\varphi = -0.29$) but none reached significance at this sample size

Table 8. Only two pairs reach significance, both indicating co-occurrence.

Species A	Species B	Phi	p-value
Golden jackal	Hyena	0.52	0.024
Honey badger	Jungle cat	0.52	0.027
Golden jackal	Leopard	0.39	0.127
Jungle cat	Small Indian civet	-0.29	0.317

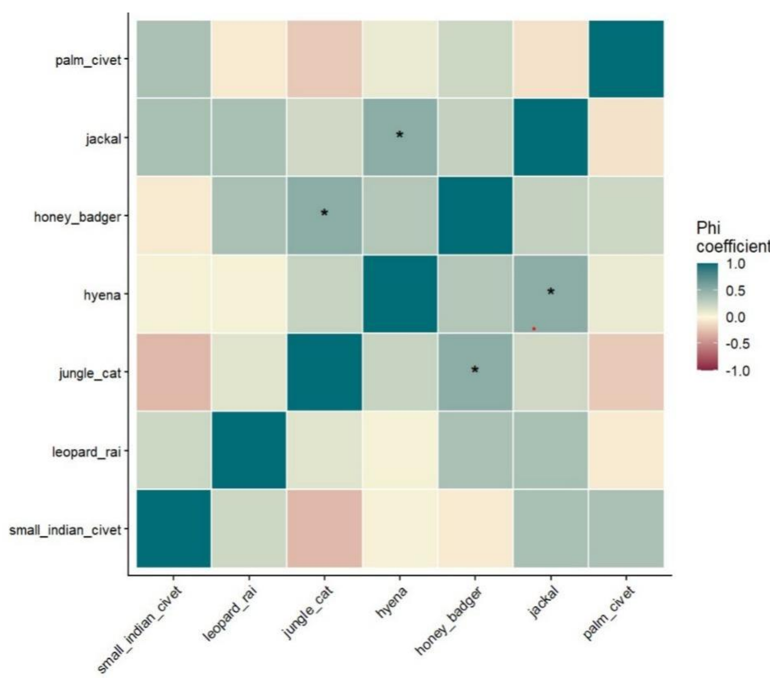

Figure 5. Co-occurrence heat map

All 21 pairs showed moderate to high activity overlap ($\Delta = 0.59 - 0.88$) where no pair segregated temporally in a way that would suggest avoidance of the other's general activity window. However, 13 of 21 pairs differed significantly in the shape of the activity curves (Watson's U^2, $p < 0.05$), most strongly golden jackal vs small Indian civet and golden jackal vs hyaena (both $p < 0.001$), indicating even broadly nocturnal/cathemeral species partitioning their peak timings.

Figure 6. Diel activity pattern. Activity pattern graphs of carnivores showing their distribution of time throughout 24 hrs.

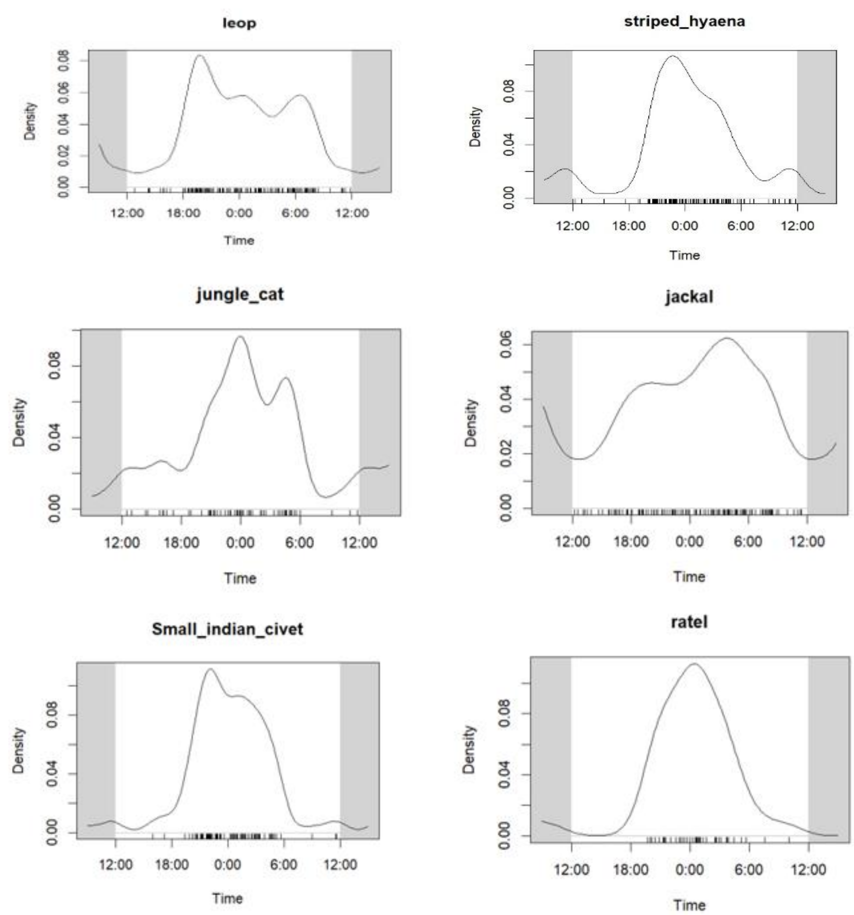

Table 9. High overlap throughout; significance marks curve-shape differences, not separation in mean timing.

Species A	Species B	Overlap Δ̂	95% CI	Watson's U^2
Golden jackal	Small Indian civet	0.65	0.53–0.71	$p < 0.001$
Leopard	Small Indian civet	0.65	0.56–0.72	$p < 0.001$
Golden jackal	Hyena	0.68	0.58–0.74	$p < 0.001$
Golden jackal	Jungle cat	0.75	0.61–0.80	$p < 0.025$
Honey badger	Jungle cat	0.75	0.59–0.79	$p < 0.10$ (ns)
Honey badger	Hyena	0.87	0.70–0.86	$p > 0.10$ (ns)

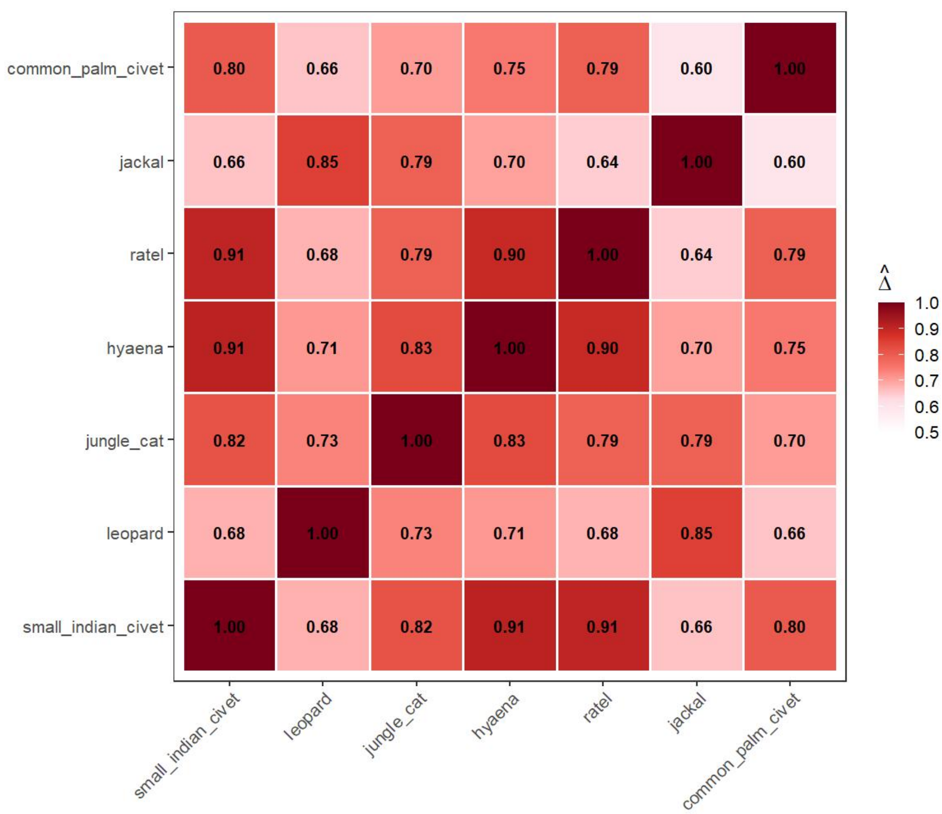

Figure 7. Diel activity overlap coefficient, Watson's U2 p<0.05(shape differs)

Consecutive-capture time gaps

Out of 21 pair, 4 pairs showed a significant difference between the wait-time following a conspecific(same species) vs a heterospecific (different species) detection at shared cameras.Three of the four showed delayed use of trails after the after other species (a temporal-avoidance signature): honey badger -jungle cat (5.2× longer, p = 0.003), leopard–small Indian civet (1.6×, p = 0.012), and hyena–small Indian civet (1.5×, p = 0.045). The exception is hyena–leopard, where leopards detected sooner after a hyena than after another leopard (0.62×, p = 0.019).

Table 10. 17 of 21 pairs show no significant timing difference; the four listed here do.

Species A	Species B	Shared cameras	Median gap: con → hetero (hrs)	Ratio	p-value
Honey badger	Jungle cat	7	23.7 → 124	5.24× longer	0.003
Leopard	Small Indian civet	11	24.5 → 38.5	1.57× longer	0.012
Hyena	Leopard	15	37.7 → 23.2	0.62× (shorter)	0.019
Hyena	Small Indian civet	12	42.2 → 62.6	1.48× longer	0.045

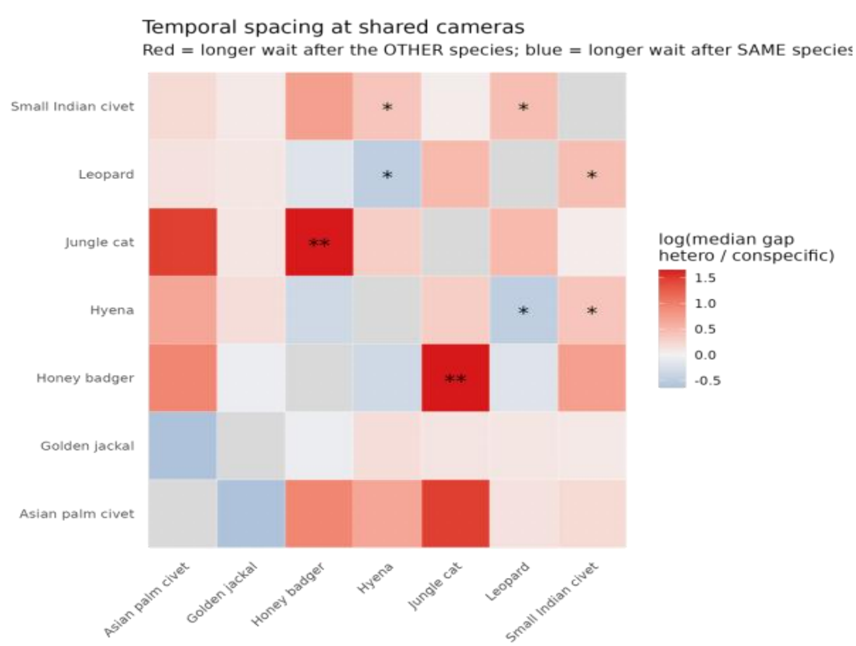

*Figure 8. log(median heterospecific gap / median conspecific gap). Red = longer wait after the other species; blue = shorter. * p<0.05, ** p<0.01.*

Table 11. Sympatric carnivore pairs with similar body mass and diet showing some significant result from spatio-temporal analysis

Pair	Spatial (co-occurrence)	Diel activity	Fine-scale timing (gap)
Jungle cat and Honey badger	$\varphi = 0.52$, $p = 0.027$	High overlap ($\Delta = 0.75$), activity shape not significantly different (non-significant)	Strong avoidance (5.2× longer gap, $p = 0.003$)
Golden jackal and Jungle cat	non-significant	High overlap ($\Delta = 0.75$), activity shape differs ($p < 0.025$)	No effect (non-significant)
Golden jackal and Honey badger	ns	Moderate overlap ($\Delta = 0.60$), activity shape differs ($p < 0.001$)	No effect (non-significant)

Influence of spatial scale on detection rates

Relative abundance index table with independent captures

Table 12. Relative abundance index of 48 randomly deployed cameras in 0.5 km2 (High density block), Palpur

S. No.	Species (small carnivores)	Camera nights days	Independent captures	RAI
1	Common palm civet	2897	2	0.069
2	Small Indian civet	2897	38	1.312
3	Golden jackal	2897	1	0.035
4	Indian fox	2897	3	0.104
5	Indian grey mongoose	2897	3	0.104
6	Ruddy mongoose	2897	5	0.173
7	Jungle cat	2897	6	0.207
8	Honey badger	2897	2	0.069
9	Leopard	2897	33	1.139

Table 13. Relative abundance index of 48 randomly deployed cameras in 0.5 km2 (Medium density block), Dhauret

S.no	Species (small carnivores)	Camera trap effort days	Independent captures	RAI
1	Common palm civet	2219	10	0.451
2	Small Indian civet	2219	32	1.442
3	Golden jackal	2219	9	0.406
4	Ruddy mongoose	2219	9	0.406
5	Jungle cat	2219	19	0.856
6	Honey badger	2219	1	0.045
7	Rusty spotted cat	2219	1	0.045
8	Leopard	2219	19	0.856

Interpretation of tables

High leopard density block:

Among 10 small mammalian carnivore species present in the protected area, the survey was able to successfully detect 8 species. Very low RAI values are due to random placements of the cameras, irrespective of animal movement and have to be inferred with scrutiny, as the relative abundance index shows how frequent visitation of targeted species per 100 days within the survey length.

Medium leopard density block:

Relative abundance values for the detected 7 species of small carnivores. The detections of species like the small Indian civet are marginally lower than the high leopard density block. Common palm civet, ruddy mongoose, and jungle cat detection were higher in the medium density block, with a slight increase in the relative abundance index.

The absence of certain species, like the grey Indian mongoose from the medium leopard density block and rusty spotted cat from the high leopard density block, does not necessarily indicate differences in species richness between the two areas. Given the random placement of camera traps and the relatively low number of detections for several species, non-detection is likely influenced by imperfect detectability and sampling limitations. Consequently, observed differences in species richness should be interpreted with caution and may not represent true differences in community composition.

Table 14. RAI = captures per 100 trap-nights. CV = coefficient of variation of landscape RAI across 2,000 Monte Carlo resamples.

Species	Native RAI	CV (1 km²)	CV (2 km²)
Small Indian civet	1.43	18%	32%
Striped hyaena	1.09	22%	38%
Leopard	1.05	20%	35%
Jungle cat	0.42	30%	53%
Ruddy mongoose	0.29	33%	59%
Common palm civet	0.25	56%	95%
Golden jackal	0.11	67%	116%
Honey badger	0.11	58%	102%
Indian grey mongoose	0.10	59%	100%

The Palpur and dhauret arrays used here were both deployed as random cameras respective to the movement of the animal in 0.5 km² (one camera roughly every ~700 m). Detections were pooled because of extremely low sample size in both blocks.The 0.5 km² grid (finest resolution) was treated as the 'reference', and was reconstructed with GPS coordinates and clustered into an adjacent 0.5 km² grid forming a 2 km² grid. Coarser sampling designs were then simulated by sub-sampling. RAI of one camera was retained at once in the simulated coarser grid size (2 km²) and for two cameras, RAI was retained for a 1 km² design out of 4 cameras within each coarser simulated grid. Monte Carlo resampling was performed with 2000 independent iterations for every species at each grid resolution. During each iteration, cameras were randomly selected within every 4 units x 0.5 km² (2 x 2 block), independent captures and trap effort were pooled across the retained cameras, and a landscape-level RAI was calculated. The distribution of simulated RAI values was compared with the reference (0.5 km²) RAI to assess the influence of grid resolution on the estimate.

The uncertainty associated with each simulated grid design was quantified using the coefficient of variation (CV) of the 2,000 simulated RAI values.

$$CV(\%) = SD/Mean \times 100$$

Where, SD = standard deviation
Mean = mean RAI

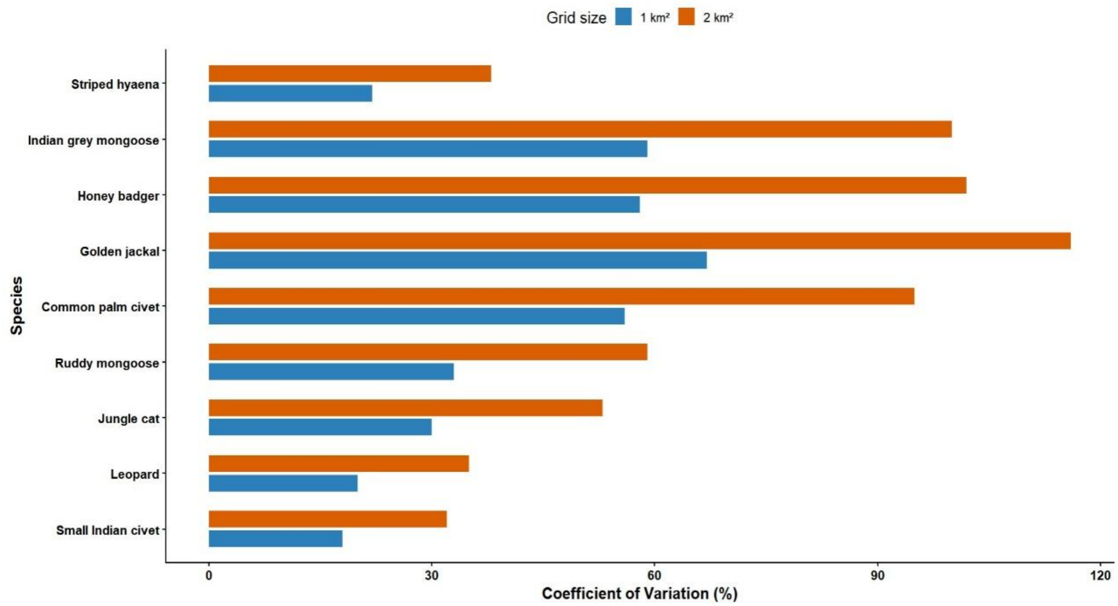

Figure 9. Coefficient of variation of detection rates plotted for carnivore species with different grid size

This CV (coefficient of variation) plot showed effect of grid coarsening considerably among species and was strongly related to their relative abundance and spatial distribution.Species with higher native RAI, such as small Indian civet (1.43), striped hyaena (1.09) and leopard (1.05), exhibited lowest coefficients of variation (CV), indicating that their landscape-level RAI estimates remained relatively stable despite reducing grid resolution. Small Indian civet showed stable CV increasing only from 18% at 1 km² to 32% at 2 km², followed by leopard (20-35%) and striped hyaena (22-38%), suggesting that widespread and higher detection frequencies reduce sensitivity to camera stations. Species with intermediate native RAI, including Jungle cat(0.42) and Ruddy mongoose (0.29), exhibited moderate uncertainty , with CV increasing from 30% to 53% and 33% to 59%, respectively.This indicates that reducing camera density increases variability in RAI.In contrast, species with low native RAI were much more affected by larger grid sizes. Common palm civet (0.25), Golden jackal (0.11), Honey badger (0.11), and Indian grey mongoose (0.10) showed much higher CV values, reaching 95–116% at the 2 km² resolution. Golden jackal had the highest uncertainty (CV: 67–116%), while Honey badger (58–102%) and Indian grey mongoose (59–100%) also showed high variation. This means that the estimated RAI for these species changed greatly depending on which cameras were included, mainly because they were detected less often and occurred at only a few camera locations.

Discussion

Trail based cameras(grid size 1.417x1.417 km)

Detection rates of small carnivores in high and medium leopard density blocks

This is an exploratory attempt to understand the ecology of small carnivores in a large carnivore abundant landscape with different density regime.This shows the effect of leopard detection rates on carnivores occupying lower trophic level.Although, the detections were considerably different in both the blocks but community level analysis showed similar detection rates in between both the blocks/sites.The overall community composition remained broadly similar. PERMANOVA and bray-curtis similarity analyses showed the most variation occurred among camera stations within each site rather than between sites .The NMDS ordination further supported these findings by showing substantial overlap between detections in camera station between two blocks.These results indicate that the detection rates of carnivore remained similar with different leopard density regime. Although there was no significant difference found between both the sites in terms of leopard detections.

Spatio-temporal overlap

The spatio-temporal analyses indicate that small co-occurence is primarily mediated through fine scale temporal partitioning rather than spatial segregation. Spatial co-occurrence analysis showed detection species pairs like hyaena-jackal and honey badger- jungle cat detecting frequently in same camera station showing overlap in the same space. Like, wise diel activity analysis revealed moderate to high temporal overlap among most species pairs, indicating that most of the species remained active during similar periods of the day. However, consecutive-capture gap analysis demonstrated that some species delayed their use of the trails following recent detections of heterospecifics despite sharing the same space and broad activity periods.This pattern was particularly evident for the jungle cat-honey badger pair, which exhibited strong temporal avoidance despite significant spatial overlap in terms of habitat and high diel overlap.Together, these findings suggest that direct interactions among small carnivores are minimized through adjustments operating over short time intervals rather than through large-scale spatial or daily temporal separation, highlighting fine-scale temporal avoidance as an important mechanism promoting co-occurence within overlapping time and space(Karanth et al.,2017; Muller et al., 2022).

Random camera traps (centroid 707x707 m)

Relative abundance index

In the relative abundance index, species like the common palm civet were captured in specific camera traps with closed canopy cover, which may depict their arboreal nature (SU SU and John Sale, 2007). Though they are widely abundant in the Indian subcontinent, they prefer closed habitats and are found in patches and other areas with closed canopy structures. To improve detections of arboreal and nocturnal species like palm civets, spotlight surveys can be used in addition to camera trapping (Chutipong et al., 2014). Rusty spotted cats are an elusive and rare species that showed very low RAI in this study, owing to their patchy distribution pattern.

Detections of animal captures through camera trapping are a function of the abundance of that species and the likelihood of detecting that species in the camera (Kolowski and Forrester, 2017), and placing camera traps on the trails can maximise the detection probability of carnivores (Cusack et al., 2015). The small Indian civet is the most frequently detected in both blocks; jungle cat and ruddy mongoose also show use of the sampled area, while golden jackal, honey badger, and rusty spotted cat are rare detections (n = 1).

The relative abundance index (RAI) is a widely used camera trap metric expressed as detections per 100 camera-trap days (O' Brien et al., 2003). RAI provides a measure of relative density or site use and allows comparisons among species, sites, or sampling periods. However, it should be interpreted as an index of relative occurrence rather than a direct estimate of population abundance. A study found that animals tend to move less and use smaller home ranges when population density is high, but this does not necessarily mean the number of animals has changed. Because animal movement increases in sparsely dense areas, they are more likely to get detected by the camera. Relative abundance indices are influenced by both the number of animals and their movement behaviour as an index of relative density, habitat use, or broad trends. It should be interpreted carefully (Broadley et al., 2019).

Influence of sampling scale on detection rates

The grid size comparison demonstrated that the reliability of RAI estimates is strongly influenced by both sampling resolution and species detectability. Common and frequently detected species with adequate sample size produced relatively stable RAI estimates when grid was fine than the coarser grid, whereas rare or patchily distributed species showed substantially greater uncertainity. Increasing grid from 1 km^2 to 2 km^2 consistently increased the coefficient of variation across all the species, indicating a progressive loss of precision as fewer cameras represented the block with low captures. Detection can vary for smaller carnivores because of their smaller home range or daily movement range(Broadley et al., 2019),. These findings suggest that finer camera trap grids with adequate sample size provide more robust and repeatable estimates of relative abundance, particularly for species with low detection rates while coarser grids are more suitable for common but might give inappropriate or inconsistent estimates for rarely detected species. Intensive camera-trap sampling at finer spatial scales is generally recommended for small carnivores to increase the probability of detecting individuals and capturing species with low encounter rates (Conard, 2008) with appropriate survey length (Kays et al., 2020).

Limitations

This study provides a useful preliminary assessment of small carnivore detections in Kuno National Park, but several limitations must be stated clearly. First, the study was conducted within a short MSc field season, and detections may reflect seasonal density during the sampling months rather than year-round patterns.

Field methodology was carried out for Camera Trap Distance Sampling (CTDS) to estimate densities of unmarked small carnivores, which could not be achieved due to low species-wise capture rates. Therefore, further analyses were based on detection data. Leopard density in both blocks appeared very similar, although the number of captures differed between the blocks. However, the detection trends of leopards did not necessarily indicate any effect on smaller carnivores.

The Relative Abundance Index (RAI) provides an estimate of animal density and site use per camera station per 100 camera-trap days. Camera-trap detection rates may be useful for comparing density, habitat use, or broad trends, but stronger conclusions about population abundance require more robust methods. Movement behaviour can affect detection rates independently of abundance. Hence, it should not be interpreted as absolute abundance, as animal movement and species behaviour can influence detection rates. Unless robust methodologies are applied or individuals can be reliably identified, RAI should be interpreted with caution.

Since the detections used for grid-size comparisons were derived from the original 0.5 km^2 camera array, there is a possibility of pseudoreplication. Therefore, the observed differences among grid sizes may not represent completely independent samples.

Small sample size for both the camera study design was a constraint. A finer grid size for assesing the spatio-temporal overlap will gave more robust inference about spatio-temporal interaction for a small carnivore community , since the trail based design was used for large carnivores(2 km^2).Due to the extremely low sample size in centroid based design (0.5 km^2) for which species like the Indian grey mongoose, honey badger ,rusty spotted cat and other rarely detected species, detection rates remained uncertain with high coefficient of variation.

Future works

For robust inference of habitat use by small carnivore species, study designs targeting rare, elusive, and semi-arboreal species should incorporate a combination of methods, including night surveys and transects, along with camera trapping. Camera traps should be deployed both on trails and off trails to ensure adequate spatial coverage of the study area. Population estimation should be conducted using robust models for unmarked species and capture–recapture approaches for naturally marked species, supported by appropriate spatial coverage and sufficient survey duration.

Conclusion

The thesis was a survey designed to estimate detection rates for small carnivores (n = 10) in Kuno National Park using camera traps deployed in an unbiased manner, irrespective of the movement of the animal. Camera survey were carried out with 0.5 km^2 grid based approach with 700m trap distance between each camera trap which was optimal according to the movement of small carnivores in two blocks, where the leopard density from previous literature was 27.04 (2.89 SE) per 100 km^2 (92 individuals), Cheetah report (2024), and 22.4 (3.9 SE) per 100 km^2 (36 individuals). For assessing the effect of leopard detection rates on smaller carnivores and spatio-temporal overlap among sympatric carnivores trail based camera study design was used with 2 km^2 grid.

The comparative community analysis indicated the small carnivore community composition did not differ significantly between the high and medium-leopard density blocks, despite variation in the relative abundance of individual species.The NMDS ordination showed considerable overlap between camera station with detection similar to each other , and PERMANOVA detected no significant difference in overall community composition.These findings suggests that leopard density did not result in a measurable shift in the overall small carnivore assemblage and detection rates, although individual species exhibited differences in their relative detection rates between the two blocks.

The spatio-temporal analysis further showed that large carnivores did not strongly exclude smaller carnivores from the shared habitats. Most species pairs exhibited little evidence of spatial segregation and generally showed moderate to high diel activity overlap, indicating that they frequently occupied the same cameras locations and remained active during similar periods of the day. However, the consecutive-capture analyses revealed that several species delayed their visits following recent detections of other carnivores, demonstrating fine-scale temporal avoidance. Thus, coexistence within the carnivore community appears to be maintained primarily through delaying in use of the same space with different time of visitation on camera stations.

Grid size comparison demonstrated that sampling design strongly influences the precision of camera-trap relative abundance estimates. Common and frequently detected species produced stable RAI estimates even at coarser resolution, whereas rare species showed increase in uncertainty as grid size increased .Consequently, finer grid resolutions provide more reliable estimates for uncommon species but may produce highly variable estimates for species with low detections.

This study was completed within a short field season and should be interpreted as a preliminary camera trap assessment rather than a definitive test of leopard-driven suppression. The two sampling blocks were selected using prior information on leopard density and were not replicated across multiple high and medium leopard areas; therefore, block level differences may also reflect habitat, season, prey, human-use history, or sampling-effort differences may also reflect habitat, season, prey, human-use history, or sampling- effort difference. Several small measures of detection or relative density per unit effort should not be inferred as abundance.

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