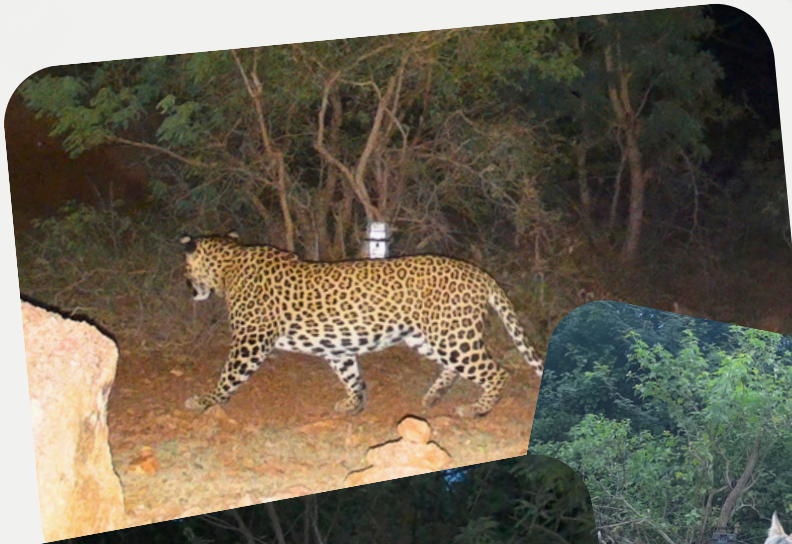


Evaluating Leopard Population and Mammalian Species Richness in the Raichur Forest Division



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I N T R O D U C T I O N



The leopard (*Panthera pardus*), one of the most adaptable and widespread large carnivores, occupies a remarkable variety of ecosystems across the Indian subcontinent, ranging from dense forests and grasslands to semi-arid scrub and even human-dominated landscapes. In India, this species is represented by the subspecies *Panthera pardus fusca* (Meyer, 1794), which is the most widely distributed leopard lineage on the subcontinent holding an important ecological role significance within its respective ecosystems (Gubbi *et al.*, 2024).

Globally, leopards are classified as 'Vulnerable' on the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (Stein *et al.*, 2023). In India they are placed under Schedule I of Wildlife Protection Act, 1972 thus, attaining the highest level of legal protection in the country. However, its population is decreasing across its range chiefly due to habitat loss, poaching, retaliatory killings, illegal trade, human-wildlife conflict and other unconventional threats (Gubbi *et al.*, 2014; Jacobson *et al.*, 2016; Gubbi *et al.*, 2020; Gubbi *et al.*, 2021).

As a large predator, leopards play a pivotal role in maintaining ecosystem health by controlling mesocarnivore population, regulating prey species and even benefiting human health (Ripple *et al.*, 2014; Braczkowski *et al.*, 2018). They exhibit striking adaptability in terms of diet and habitat preferences, which even thrives in agroforests, pasture lands, mono-culture plantations and also near urban and rural human settlements (Nowell & Jackson, 1996).

Approximately 13,800 leopards are estimated to inhabit India, predominantly reflecting the populations within Protected Areas (PAs) and tiger habitats (Qureshi *et al.* 2024). However, leopards also thrive in other habitats such as Reserve Forests (RFs), Deemed Forests, agricultural landscapes, and urban fringes (Gubbi *et al.*, 2024). Thus, population estimation is vital for understanding the ecology of leopards which provides scientific insights to protect leopards in such habitats.

Based on fine-scale ecological data Kolekar *et al.* (2024) estimated that 33.5% of Karnataka state (1,91,791 km²) as a suitable leopard habitat. However, no systematic camera trap studies have been carried out in the state especially in northern Karnataka also known as Kalyana-Karnataka region, which hosts a mosaic of dry deciduous forests, scrublands, grasslands, rocky-outcrops and human-modified landscapes which are also considered to be the leopard habitats. Understanding leopard ecology and distribution in these habitats enables managers and stakeholders to effectively manage and conserve the leopards and their habitat beyond national parks and wildlife sanctuaries.

Management and conservation of the leopard population based on scientific understanding remains poorly studied in India especially in areas outside PAs. In line with this, here we report the leopard's presence and distribution of leopard's prey and other mammals found in Raichur division falling under Kalyana Karnataka region. We also report ecological information about other large mammalian species for which scientific information from this area is lacking.

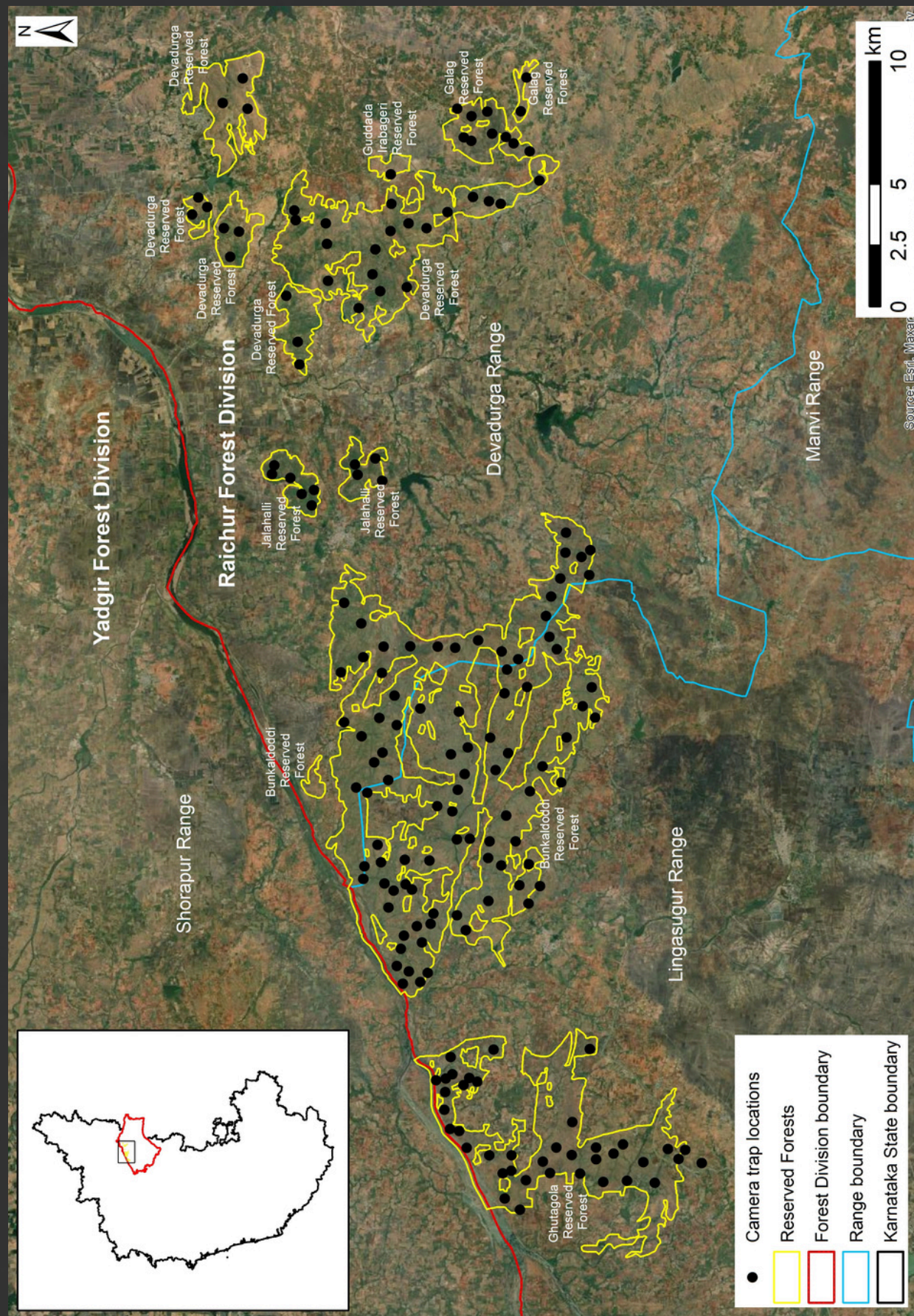
S T U D Y A R E A



The Raichur Forest Division (8,470 km²) is located in the north-eastern part of Karnataka, within the administrative boundaries of Raichur district. Geographically, the division lies between 15°10' N to 16°34' N latitude and 76°10' E to 77°35' E longitude. The division is administratively divided into two forest sub-divisions: Raichur and Devadurga which are further split into four forest ranges: Raichur, Devadurga, Lingasugur and Manvi. The forests of Raichur are largely characterized by dry deciduous and scrub forest ecosystems, interspersed with rocky outcrops, open grasslands, and cultivated lands.

Climatically, the region is classified as semi-arid, experiencing intense summers, a brief monsoon season, and relatively mild winters. The average annual rainfall ranges from 600 mm to 700 mm, with the majority of precipitation occurring between June and September. Temperatures can be extreme, often rising above 40°C during summer months and dropping to around 15°C in winter. While the Krishna and Tungabhadra rivers traverse parts of the district, the forested zones themselves depend primarily on seasonal streams and rain-fed surface water sources.

The present study was carried out across an area of 188.27 km² encompassing 13 RFs (Map 1 and Table 1) from the Lingasugur Forest Range and Devadurga Forest Range of the Raichur Forest Division. These RFs are present on the south of the Krishna river.



Map 1 Locations where camera traps were deployed in Lingasugur and Devadurga Range of Raichur Forest Division.

No.	Name of Reserved Forests	Area (km ²)	Forest Range	Location Coordinates
1	Bunkaldoddi Reserved Forest	95.32	Lingsugur & Devadurga	16°15'57.39" N - 16°22'10.62" N 76°36'43.75" E - 76°47'21.86" E
2	Bunkaldoddi Reserved Forest	0.78	Devadurga	16°22'12.19" N - 16°22'43.74" N 76°41'06.48" E - 76°42'02.38" E
3	Devadurga Reserved Forest	28.03	Devadurga	16°17'03.41" N - 16°23'22.32" N 76°51'08.40" E - 76°55'14.58" E
4	Devadurga Reserved Forest	3.85	Devadurga	16°22'17.42" N - 16°23'20.19" N 76°50'24.44" E - 76°52'25.14" E
5	Devadurga Reserved Forest	3.27	Devadurga	16°23'33.27" N - 16°24'38.44" N 76°52'46.70" E - 76°54'26.97" E
6	Devadurga Reserved Forest	1.22	Devadurga	16°24'42.48" N - 16°25'19.35" N 76°53'24.28" E - 76°54'20.46" E
7	Devadurga Reserved Forest	8.40	Devadurga	16°23'30.63" N - 16°25'22.67" N 76°54'45.83" E - 76°57'32.04" E
8	Galag Reserved Forest	0.90	Devadurga	16°17'30.52" N - 16°18'04.42" N 76°55'58.20" E - 76°57'19.94" E
9	Galag Reserved Forest	5.16	Devadurga	16°17'38.75" N - 16°19'36.43" N 76°55'03.44" E - 76°56'30.38" E
10	Ghutagola Reserved Forest	34.39	Lingsugur	16°14'14.51" N - 16°20'14.74" N 76°30'59.91" E - 76°36'01.39" E
11	Guddada Irabageri Reserved Forest	1.09	Devadurga	16°20'19.21" N - 16°21'14.60" N 76°54'40.47" E - 76°55'17.05" E
12	Jalahalli Reserved Forest	2.70	Devadurga	16°20'49.61" N - 16°21'54.32" N 76°47'37.88" E - 76°49'02.76" E
13	Jalahalli Reserved Forest	3.16	Devadurga	16°22'18.83" N - 16°23'36.56" N 76°47'17.25" E - 76°48'45.50" E
TOTALS		188.27		

Table 1 List of Reserved Forests covered during the study in Raichur Forest Division.



M E T H O D O L O G Y



CAMERA TRAPPING

Camera trapping, a widely adopted technique for assessing populations and abundance of large carnivores with distinctive natural markings, was the primary method used in this study. We employed this approach to monitor leopards and to document other mammalian fauna in the study area.

Geographical features such as roads and trails were mapped using Google Earth Pro (Google LLC, 2023) and converted into GIS-compatible files. These spatial data informed the identification of potential survey sites for preliminary reconnaissance.

Subsequent field assessments were conducted to finalise camera trap locations, with a focus on areas exhibiting indirect signs of leopard and canids such as scats, pugmarks, and scrape marks.

Motion-sensitive cameras, including models Panthera V4, V6, and Spartan Lumen SR3-CX, were securely mounted on tree trunks or stumps ~40 cm above ground level using robust python cables. To maximize the probability of capturing images of leopards of both flanks (right and left), camera traps were installed on either side of selected trails and roads.

Cameras remained continuously operational for 16 days, functioning 24/7 and undergoing maintenance every 2–3 days for tasks like image retrieval, battery replacement, and SD card exchange to ensure consistent performance. An automated image classification tool developed in Python (version 3.6) was used to

sort images into species-specific folders (Rampi et al., unpublished). This automated process was followed by manual validation, during which identified species were tagged into the metadata using Digikam software (Version 5.8.0, Gilles et al., 2018).

Each photograph was labeled with a unique identifier comprising the camera trap location and camera ID, facilitating extraction of date, time, and geographic coordinates. The camera trap survey was conducted in July and August 2024.

DENSITY AND ABUNDANCE ESTIMATION

Striped hyena (*Hyaena hyaena*) density and abundance within the study area was estimated using the SECR (Spatially Explicit Capture-Recapture) package in R (Efford, 2025). Input files for SECR analysis included the detector layout, capture history matrix, and mask layer, all prepared in line with operational guidelines.

The detector file documented the operational status of camera traps, marked as '1' for functional and '0' for non-functional. The capture history matrix recorded individual striped hyena detections by camera location and sampling occasion. The mask layer represented spatial data for suitable habitat within the study area, with a concave polygon buffer created around the camera array using the `suggest.buffer` function.

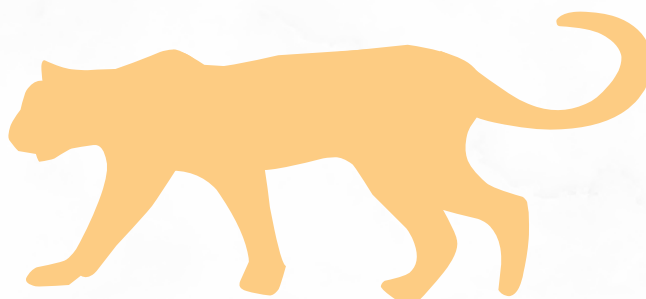
These spatial inputs were used to estimate capture probabilities, and models were fitted using maximum likelihood methods within the SECR package (Borchers & Efford, 2008). The model yielding the best fit was selected based on the Akaike Information

Criterion (AIC), providing the most accurate estimate of striped hyena density and abundance in the area.

RELATIVE ABUNDANCE INDEX (RAI)

The Relative Abundance Index (RAI) for each prey species was determined based on photographic capture rates, calculated as the number of independent photo captures per/100 trap days. RAI has been shown to correlate with density estimates of large terrestrial mammals, making it a valuable proxy for unmarked species (Rovero & Marshall, 2009; Palmer *et al.*, 2018).

Images were sorted into folders based on species, and timestamps were used to count independent capture events. A capture was considered independent if it occurred more than 30 minutes after a previous sighting of the same species at the same location. If multiple individuals of the same species appeared in a single image, it was counted as one event (O'Brien *et al.*, 2003). The total number of independent events was divided by the number of camera trap days and multiplied by 100 to compute the RAI per 100 trap days.



Block	Name of Reserved Forests	Area (km ²)	Date of Camera Trap Placement		Number of camera trap locations	Occasion for each camera trap location	Camera trapping effort (in days)*
			Deployment	Removal			
Block 1	Ghutagola Reserved Forest	34.39	03-July-2024	19-July-2024	39	16	624
	Bunkaldoddi Reserved Forest	95.32	05-July-2024	20-July-2024	23	16	1,371
Block 2	Bunkaldoddi Reserved Forest	0.78	23-July-2024	09-August-2024	66		
	Bunkaldoddi Reserved Forest		12-August-2024	27-August-2024	0	0	0
Block 3	Devadurga Reserved Forest	28.03	12-August-2024	28-August-2024	19	16	304
	Devadurga Reserved Forest	3.27	12-August-2024	27-August-2024	3	16	48
	Devadurga Reserved Forest	1.22	12-August-2024	27-August-2024	3	16	48
	Devadurga Reserved Forest	8.40	12-August-2024	27-August-2024	3	16	48

Block	Name of Reserved Forests	Area (km ²)	Date of Camera Trap Placement		Number of camera trap locations	Occasion for each camera trap location	Camera trapping effort (in days)*
			Deployment	Removal			
Block 3 (cont'd)	Devadurga Reserved Forest	3.85	12-August-2024	27-August-2024	3	16	48
	Galag Reserved Forest	0.90	14-August-2024	29-August-2024	2	16	32
	Galag Reserved Forest	5.16	14-August-2024	29-August-2024	9	16	144
	Guddada Irabageri Reserved Forest	1.09	13-August-2024	28-August-2024	1	16	16
	Jalahalli Reserved Forest	3.16	15-August-2024	30-August-2024	6	16	96
	Jalahalli Reserved Forest	2.70	15-August-2024	30-August-2024	4	16	64
TOTALS		188.27			181		2,843

*The camera trapping effort was calculated by multiplying the total number of surveyed locations by the number of functional occasions, representing the times when the camera trap was operational.

Table 4 Mammalian species photo-captured in camera traps in the study area.



R E S U L T S



A detailed reconnaissance survey identified 181 locations for camera trap deployment within the RFs of the Lingsugur and Devadurga Ranges in the Raichur Forest Division (Map 1). Due to logistical limitations, the study area was divided into three blocks. Camera traps were deployed in each block for 16 days, resulting in a total camera trap effort of 2,843 trap-days. Detailed information on the surveys is provided in Table 2.

LEOPARDS IN RAICHUR

During the camera trapping survey in Raichur Forest Division, three images of leopards were captured, all representing the same male individual. Due to this extremely low capture rate, Spatially Explicit Capture-Recapture (SECR) analysis could not be conducted to estimate leopard density and abundance.



Fig. 1 Leopard photo-captured during the study in Bunkaldoddi Reserved Forest in Raichur Forest Division.

HYENAS IN RAICHUR

Our camera trap study documented 58 images of striped hyena. By examining the distinct striped patterns on their bodies, we identified eight individual adult striped hyenas in the study area.

Density and Abundance

The abundance and density for striped hyena in the study area was estimated by running the SECR package. The result from the analysis is mentioned in Table 3.

Study area	N (SE)	N Range	D (SE)	D Range	σ (SE)
Raichur Forest Division	17.25 (6.82)	8.17 - 36.43	0.61 (0.23)	0.29 - 1.25	4.21 (0.59)

N - Estimate of total number of individuals in the study area
 D - Number of striped hyena/100 km²
 σ - Baseline detection probability in km

Table 3 SECR analysis results for striped hyena in the Raichur Forest Division



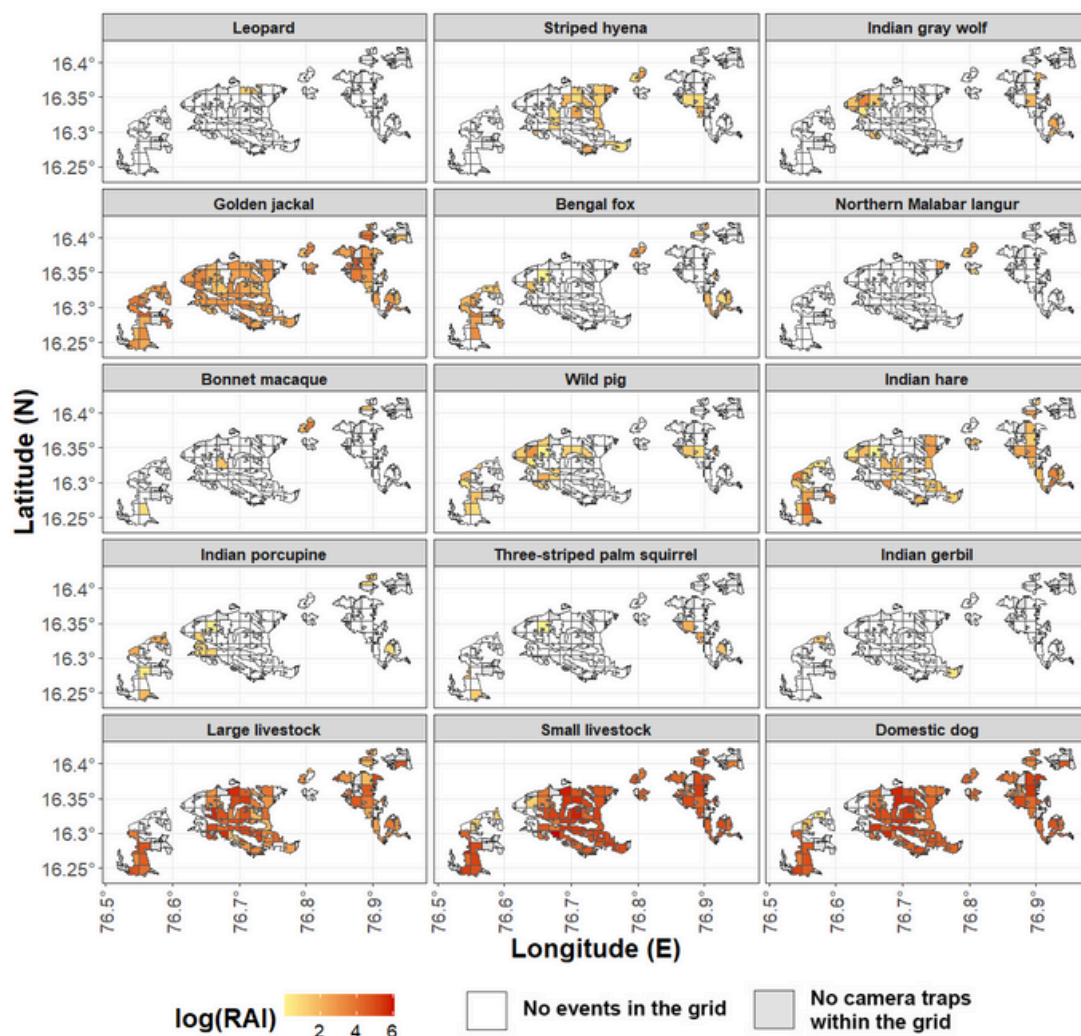
Figure 2 Striped hyena photo-captured during the study in the Raichur Forest Division.

MAMMALIAN DIVERSITY

During the study period, including leopard and striped hyena, camera traps captured a total of 17 different wild mammal species in the study area (Table 4, Appendix - 1). This includes three species of canids (Indian gray wolf, golden jackal and Bengal fox) and two species of felids (jungle cat and rusty-spotted cat).

RELATIVE ABUNDANCE INDEX (RAI)

The RAI results of leopard, striped hyena, canids and their wild and domestic prey is provided in Table 5. The distribution maps for these species were developed using the RAI values in the study area. (Map 2).



Map 2 Relative abundance and distribution of leopard, striped hyena, canids and their wild and domestic prey in the study area.

Species	Schedule Status Wild Life (Protection) Act 1972	Global Status (IUCN Red List)
Leopard (<i>Panthera pardus fusca</i>)	I	Vulnerable
Striped hyena (<i>Hyaena hyaena</i>)	I	Near Threatened
Indian gray wolf (<i>Canis lupus pallipes</i>)	I	Least Concern
Golden jackal (<i>Canis aureus indicus</i>)	I	Least Concern
Bengal fox (<i>Vulpes bengalensis</i>)	I	Least Concern
Common palm civet (<i>Paradoxurus hermaphroditus</i>)	I	Least Concern
Small Indian civet (<i>Viverricula indica</i>)	I	Least Concern
Jungle cat (<i>Felis chaus</i>)	I	Least Concern
Rusty-spotted cat (<i>Prionailurus rubiginosus</i>)	I	Near Threatened
Grey mongoose (<i>Herpestes edwardsii</i>)	I	Least Concern
Wild pig (<i>Sus scrofa</i>)	II	Least Concern
Indian porcupine (<i>Hystrix indica</i>)	I	Least Concern
Indian hare (<i>Lepus nigricollis</i>)	II	Least Concern
Bonnet macaque (<i>Macaca radiata</i>)	I	Least Concern
Northern Malabar langur (<i>Semnopithecus hypoleucos achates</i>)	I	Near Threatened
Indian gerbil (<i>Tatera indica</i>)	Unlisted	Least Concern
Three-striped palm squirrel (<i>Funambulus palmarum</i>)	Unlisted	Least Concern

Table 4 Mammalian species photo-captured in camera traps in the study area.

Species	RAI/100 trap days (SE)
Leopard (<i>Panthera pardus fusca</i>)	0.070 (0.000)
Striped hyena (<i>Hyaena hyaena</i>)	1.054 (0.001)
Indian gray wolf (<i>Canis lupus pallipes</i>)	1.124 (0.002)
Golden jackal (<i>Canis aureus indicus</i>)	18.686 (0.009)
Bengal fox (<i>Vulpes bengalensis</i>)	3.056 (0.003)
Wild prey	
Wild pig (<i>Sus scrofa</i>)	1.300 (0.001)
Indian porcupine (<i>Hystrix indica</i>)	0.948 (0.001)
Indian hare (<i>Lepus nigricollis</i>)	6.639 (0.009)
Bonnet macaque (<i>Macaca radiata</i>)	0.632 (0.002)
Northern Malabar langur (<i>Semnopithecus hypoleucos achates</i>)	0.351 (0.001)
Indian gerbil (<i>Tatera indica</i>)	0.140 (0.001)
Three-striped palm squirrel (<i>Funambulus palmarum</i>)	0.386 (0.001)
Domestic prey	
Large livestock	49.895 (0.035)
Small livestock	102.602 (0.041)
Domestic dog	82.736 (0.041)

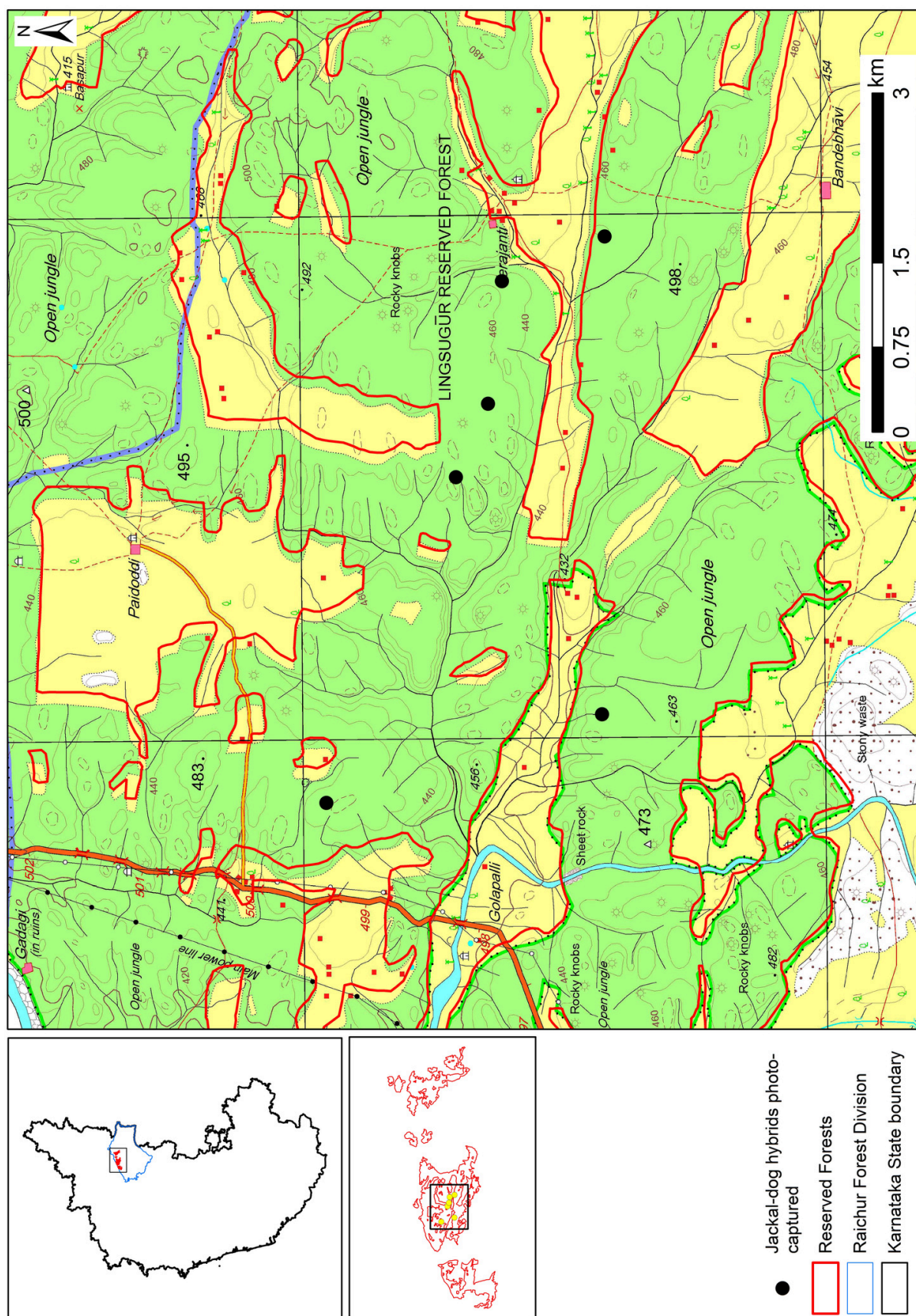
Table 5 Results of the RAI per 100 trap days calculated for leopard, striped hyena, canids and their wild and domestic prey in the study area.

JACKAL-DOG HYBRID

During the camera trapping survey, we recorded the presence of potential jackal-dog hybrids at multiple locations within the study area. Based on tail morphology, we were able to identify four individual hybrids (Figure 3). These individuals displayed distinct physical characteristics closely resembling those of golden jackals, especially in facial structure. Notably, three of these suspected hybrids were observed moving alongside a pack of normal coloured golden jackals, indicating social integration within the group.



Figure 3 Four jackal-dog hybrid individuals were photo-captured during the camera trap study and identified based on differences in tail shape, and colouration.



Map 3 Camera trap locations where jackal-dog hybrid individuals were photo-captured in the study area.



D I S C U S S I O N



The present study represents the first systematic camera trap survey across the RFs of the Lingsugur and Devadurga Ranges in the Raichur Forest Division, aiming to document large carnivore presence and broader mammalian diversity. The camera trap deployment, spanning 181 locations and 2,843 trap-days, offers comprehensive details of mammalian presence and distribution, focusing particularly on large carnivores such as leopards and striped hyenas. This is the first study to estimate the density and abundance of striped hyenas in Karnataka.

The documentation of a single leopard in the study area highlights that leopards are extremely low in number here, possibly due to lack of suitable habitat and prey. However, documentation of single individual leopard demonstrates that either this felid species is expanding its range into Raichur Forest Division or this individual was captured elsewhere and released here.

This study documented 17 wild mammalian species within the Raichur Forest Division, reflecting the ecological richness of the region despite its semi-arid and human-impacted landscape. This included key carnivores such as leopards, striped hyenas, Indian gray wolves, and golden jackals, along with smaller felids and omnivores like jungle cats, rusty-spotted cats, and civets. Notably, many of these species are afforded the highest level of legal protection under Schedule I of the Wildlife Protection Act, 1972, underscoring their conservation significance. The presence of Near Threatened species like the striped hyena, rusty-spotted

cat, and northern malabar langur further shows the area's role as a safe habitat for sensitive and lesser-known fauna.

In contrast, striped hyenas were more frequently detected, with 58 photographic records identifying eight individual adults. SECR analysis estimated a density of approximately 0.61 ± 0.23 (SE) striped hyena individuals/100 km² which was lower compared to other regions in India. For instance, striped hyena density was estimated at 9.3 ± 1.3 (SE) individuals/100 km² in Ranthambore Tiger Reserve (Latafat et al., 2023), 4.40 ± 0.69 (SE) individuals/100 km² in Rajaji Tiger Reserve (Harihar et al., 2010), and 6.5 ± 2.6 (SE) individuals/100 km² in Kumbalagarh Tiger Reserve (Singh et al., 2010). Though the above studies documented striped hyena population within PAs, other studies outside PAs also had higher striped hyena individuals compared to our study area such as Esrana Forest Range (Rajasthan) had an estimated density of 3.67 ± 0.3 (SE) individuals/100 km² (Singh et al., 2010), Akole Tahsil (Ahmedabad) with an estimated density of 5.03 ± 1.3 (SE) individuals/100 km² (Athreya et al., 2013). The lower density could be attributed to high degree of habitat fragmentation, conversion of scrub forests and grasslands into agricultural lands and planting of *Eucalyptus hybrid* and *Gliricida sp.* making them unsuitable for the hyenas.

Among carnivores, golden jackals exhibited the highest RAI (18.686), followed by Bengal foxes (3.056) and Indian gray wolves (1.124), while leopards had a very low RAI (0.070), suggesting leopards' limited presence or activity. This depicts that Raichur Forest Division is an important area for wild canids.

The high relative abundance of golden jackals (18.686 per 100 trap-days), making them the most frequently detected carnivore

species in the study area. This suggests that jackals are thriving in the landscape, likely benefiting from anthropogenic food sources and landscape heterogeneity. Indian gray wolves and Bengal foxes were also recorded with moderate RAI values, suggesting their continued presence in the area.

However, the detection of four jackal-dog hybrids raises serious conservation concerns. Hybridisation between golden jackals and free-ranging domestic dogs could lead to loss of genetic integrity and disruption of ecological behaviors within native canid populations. The observation that hybrids were integrated into jackal packs further raises the possibility of continued introgression. Such phenomena, increasingly reported in fragmented or human-dominated habitats, warrant immediate genetic and behavioral studies to assess the scale and ecological consequences of hybridization in Raichur.

Wild prey species such as Indian hare (6.639) and wild pig (1.300) were more frequently detected than others, but still much lower than domestic prey. The overall low RAI values for large wild prey such as wild pig suggest a limited prey base for sustaining large carnivore populations such as leopard. The RAI results highlight a notable dominance of domestic prey in the study area, with small livestock (102.602), domestic dogs (82.736), and large livestock (49.895) showing significantly higher RAI values compared to wild prey and carnivores.

These results also indicate a prey base heavily skewed toward domestic animals, which may influence carnivore behavior and ecology in the landscape, potentially increasing the likelihood of human-wildlife conflict and underscoring the need for management strategies focused on livestock protection and habitat restoration.



R E C O M M E N D A T I O N S



- Based on the widespread distribution and high Relative Abundance Index (RAI) of golden jackals recorded in the study area, we recommend proposing the study area for designation as a Jackal Conservation Reserve to ensure long-term protection of this ecologically important species. This would be the first such initiative in the country.
- Long-term monitoring using camera traps to cover all the seasons and longer durations to improve detection probabilities for elusive species like leopards and implement repeated monitoring for striped hyenas to assess population trends over time.
- Identify and secure habitat corridors connecting the fragmented RFs with other forest patches to facilitate wildlife movement, particularly for wide-ranging species like leopards and wolves.
- Removal of exotic species such as *Eucalyptus hybrid* and *Gliricidia sp.* Planting these invasive species has led to the degradation of habitat. Thus, making the habitat unsuitable for the species thriving there. Investigate the genetic makeup of suspected jackal-dog hybrids to confirm hybrid status and understand the extent of introgression.
- Develop dog population control programs, including sterilisation and vaccination, to prevent further hybridisation and disease transmission.
- Work closely with local communities to raise awareness about the importance of wildlife conservation.
- Strengthen patrolling and law enforcement to reduce illegal activities such as poaching and forest encroachment.

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A P P E N D I X



LEOPARD
Panthera pardus fusca



STRIPED HYENA
Hyaena hyaena



INDIAN GREY WOLF
Canis lupus pallipes



GOLDEN JACKAL
Canis aureus indicus



BENGAL FOX
Vulpes bengalensis

Appendix 1

Photographs of mammal species captured during camera trapping in the study area.

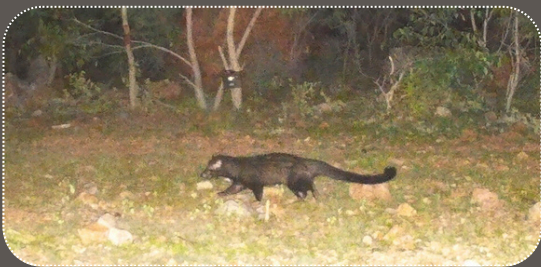
A P P E N D I X



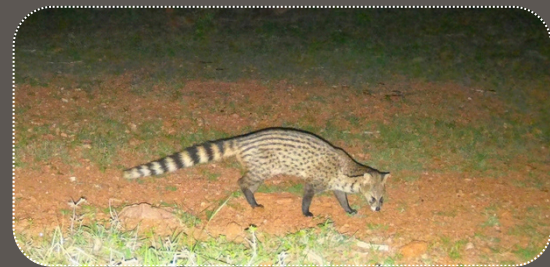
JUNGLE CAT
Felis chaus



RUSTY-SPOTTED CAT
Prionailurus rubiginosus



COMMON PALM CIVET
Paradoxurus hermaphroditus



SMALL INDIAN CIVET
Viverricula indica



GREY MONGOOSE
Herpestes edwardsii



WILD PIG
Sus scrofa

Appendix 1 (cont'd)

Photographs of mammal species captured during camera trapping in the study area.

A P P E N D I X



NORTHERN MALABAR LANGUR
Semnopithecus hypoleucos achates



BONNET MACAQUE
Macaca radiata



INDIAN HARE
Lepus nigricollis



INDIAN PORCUPINE
Hystrix indica



INDIAN GERBIL
Tatera indica



THREE-STRIPED PALM SQUIRREL
Funambulus palmarum

Appendix 1 (cont'd)

Photographs of mammal species captured during camera trapping in the study area.





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