Assessment of predator, prey & habitats in

Kumbhalgarh Wildlife Sanctuary

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

Government of Rajasthan
Forest Department

Citation: Sadhu, A., Kanswal, S., Roy. A., Rana, A., Tripathi, P., Qureshi, Q. (2024). Assessment of Predator, Prey, and Habitats in Kumbhalgarh Wildlife Sanctuary, 2024. Wildlife Institute of India, Dehradun. TR/WII/2024/24

Assessment of Predator, Prey, and Habitats in Kumbhalgarh Wildlife Sanctuary, 2024

Research Team

Wildlife Institute of India

Prof. Qamar Qureshi
Scientist & Nodal Officer Tiger Cell
qnq@wii.gov.in

Dr Ayan Sadhu
Research Scientist, Tiger Cell
ayan@wii.gov.in

Ms. Sheela Kanswal
Technical Assistant, AITE

Ms. Aritra Roy
Research Biologist, AITE

Sh. Akash Rana
Technical Assistant, AITE

Sh. Piyush Tripathi
Technical Assistant, AITE

Rajasthan Forest Department

Sh. R. K. Khairwa
Chief Conservator of Forests, (Wildlife) Udaipur

Sh. Alok Nath Gupta
Dy. Conservator of Forests, (Wildlife) Rajsamand

Sh. R.K Jain
Chief Conservator of Forests, (Wildlife) Udaipur

Sh. Sudarshan Sharma
Dy. Conservator of Forests, Rajsamand

Sh. Bheru Singh Rathore
Assistant Conservator of Forest, Kumbhalgarh

Design by: Sheela Kanswal & Ayan Sadhu

Acknowledgement

We express our gratitude to the Chief Wildlife Warden, Rajasthan and the Director, Wildlife Institute of India for necessary permissions and logistics support to carry out the field work. We are also thankful to Mr. Vinod K. Rai, ACF who was supported us during the survey to his best capacity, and the Forest Staff from our field sites, especially Mr. Mohir Singh, Mr. Bheru Bishnoi, Mr. Mahavir Singh and Mr. Harish. We are grateful to Ms. Vaishnavi Gusain, Ms. Deepali Chatrath, Ms. Kainat Latafat, Ms. Genie Murao, and Mr. Mohit K. Patra, Wildlife Institute of India for their help with RS-GIS work, analysis and report draft checking. Finally, we extend our most profound gratitude to the wild denizens of the Kumbhalgarh, whose [illegible] realm graciously allowed us to uncover the mysteries of their enchanting [illegible].

CONTENTS

Executive Summary *i*

Background *iv*

1. Introduction 1

2. Methods 3

3. Results 9

3.1. Species Distribution & Abundance

3.2. Leopard Population Density

3.3. Leopard occupancy

3.4. Activity pattern

3.5. Ungulate Density

Species Account

Carnivores 13

Leopard, Striped hyena, Sloth bear, Jungle cat, Golden jackal, Rusty spotted cat

Ungulates 21

Sambar, Nilgai, Wild pig

Others 27

Livestock, Cattle, Humans

5. Discussions 31

References 33

List of Tables

Table 1. Relative abundance index (RAI) of major mammal species in Kumbhalgarh WLS. 9

Table 2. Leopard density estimates (obtained from SECR) in the Kumbhalgarh WLS. 10

Table 3. Distribution models used in occupancy analysis for leopards in Kumbhalgarh WLS. 11

Table 4. The projected ungulate densities for Kumbhalgarh WLS. 12

List of Figures

Figure 1. Study area map with camera traps in Kumbhalgarh WLS. 4

Figure 2. Individual identification of leopards. 5

Figure 3. Spatial leopard density in Kumbhalgarh WLS. 6

Figure 4. Relative abundance index (RAI) of major mammals in Kumbhalgarh WLS. 10

Figure. 5. Leopard spatial distribution & activity pattern in Kumbhalgarh WLS. 14

Figure. 6. Striped hyena spatial distribution & activity pattern in Kumbhalgarh WLS. 15

Figure. 7. Sloth Bear spatial distribution & activity pattern in Kumbhalgarh WLS. 16

Figure.8. Jungle Cat spatial distribution & activity pattern in Kumbhalgarh WLS. 17

Figure.9. Golden jackal spatial distribution & activity pattern in Kumbhalgarh WLS. 18

Figure 10. Rusty-spotted cat spatial distribution & activity pattern in Kumbhalgarh WLS. 19

Figure 11. Indian Fox spatial distribution & activity pattern in Kumbhalgarh WLS. 20

Figure.12. Sambar spatial distribution & activity pattern in Kumbhalgarh WLS. 22

Figure.13. Nilgai spatial distribution & activity pattern in Kumbhalgarh WLS. 23

Figure.14. Wild pig spatial distribution & activity pattern in Kumbhalgarh WLS. 24

Figure.15. Chowsingha spatial distribution in Kumbhalgarh WLS. 25

Figure.16. Livestock spatial distribution & activity pattern in Kumbhalgarh WLS. 28

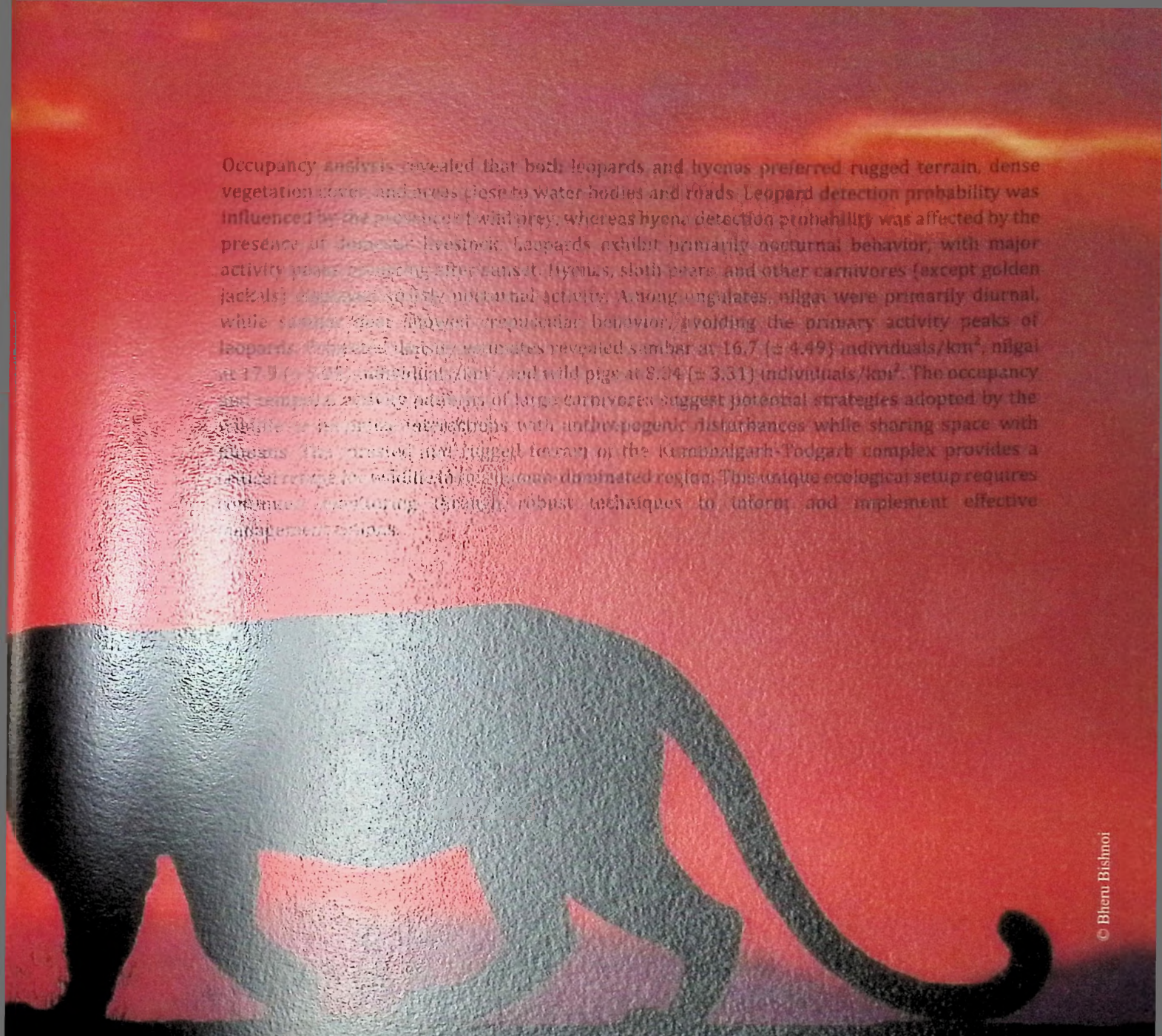
Figure.17. Cattle spatial distribution & activity pattern in Kumbhalgarh WLS. 29

Figure.18. Human spatial distribution & activity pattern in Kumbhalgarh WLS. 30

Executive Summary

Kumbhalgarh Wildlife Sanctuary, located in the southern Aravalli Hills of Rajasthan, serves as an ecotone between semi-arid and desert ecosystems. Camera trap surveys conducted in 2022 and 2024 have revealed a diverse community of large mammals inhabiting the sanctuary. In 2022, 52 camera traps were deployed with a trapping effort of 2,162 trap-nights, while in 2024, 49 camera traps were deployed with a trapping effort of 1,568 trap-nights. In 2024, leopards (*Panthera pardus*) were the most frequently photographed carnivores (Relative Abundance Index (RAI): 21.14 ± 3.25), followed by striped hyenas (*Hyaena hyaenu*, RAI: 15.15 ± [illegible]) and sloth bears (*Melursus ursinus*, RAI: 8.09 ± 1.17). Among herbivores, sambar deer (*Rusa unicolor*) had the highest RAI (39.30 ± 9.51), followed by nilgai (*Boselaphus tragocamelus*, [illegible] 7.6) and wild pigs (*Sus scrofa*, RAI: 11.39 ± 2.38). Notably, there was a significant decline in photo capture rates (RAI) of sloth bears and ratels (*Mellivora capensis*) in 2024 [illegible] 2022. A total of 55 individual leopards were identified from 762 photographs in 2022, while 38 leopards were identified from 638 photographs in 2024. Among these, 26 leopards were common between 2022 and 2024. The spatially explicit leopard density was estimated at [illegible] (SE ± 2.68) leopards/100 km^2 in 2022 and 16.91 (SE ± 2.45) leopards/100 km^2 in 2024.

Occupancy analysis revealed that both leopards and hyenas preferred rugged terrain, dense vegetation cover, and areas close to water bodies and roads. Leopard detection probability was influenced by the presence of wild prey, whereas hyena detection probability was affected by the presence of domestic livestock. Leopards exhibit primarily nocturnal behavior, with major activity peaks occurring after sunset. Hyenas, sloth bears, and other carnivores (except golden jackals) also showed nocturnal activity. Among ungulates, nilgai were primarily diurnal, while sambar and wild pigs showed crepuscular behavior, avoiding the primary activity peaks of leopards. Density estimates revealed sambar at 16.7 (± 4.49) individuals/km², nilgai at 17.9 (± 7.02) individuals/km², and wild pigs at 8.24 (± 3.31) individuals/km². The occupancy and temporal activity patterns of large carnivores suggest potential strategies adopted by the [illegible] to coexist in human-dominated landscapes with anthropogenic disturbances while sharing space with predators. The mosaic of rugged terrain in the Kumbhalgarh-Todgarh complex provides a [illegible] for wildlife in this human-dominated region. This unique ecological setup requires [illegible] monitoring efforts to robust techniques to inform and implement effective [illegible] actions.



© Bheru Bishnoi

Background

Office of the Deputy Conservator of Forest, Wildlife Rajsamand
TulsiSadhnaShikhar, Kankroli, Rajsamand

Letter No. 12358 Date: 02/11/23

To:
Prof. QamarQureshi,
Nodal Officer,Tiger Cell,
Wildlife Institute of India.
Chandrabani, Dehradun – 248001.

Subject: Request for conducting training for carrying out ecological survey in KumbhalgarhandTodgarhRaoliWLS

Sir,

As you are aware that in-principle approval has been granted by NTCA for making KumbhalgarhandTodgarhRaoliWLS a tiger reserve along with adjoining areas, we are continuously working on the betterment of the landscape. In this regard, we are planning to conduct scientific surveys using camera traps, line transect (habitat assessment) and sign surveys in the Kumbhalgarh TR area, in the same manner as Phase IV (winter season). In the past, your team from Tiger Cell carried out camera trapping and ecological survey as a part of the All India exercise and made the baseline of ecological data for the landscape. It would be great if you can share a brief report highlighting the key ecological findings of the survey, so that we can use this for future reference. Moreover, we are also implementing M-STrIPES in Kumbhalgarh TR area for systematic management and better protection. Therefore, I am requesting you to send 2-3 researchers to conduct a training workshop on camera trapping and ecological surveys as well as to orient our frontline staff about M-STrIPES.
Looking forward to your kind cooperation and support.

Yours sincerely,

(Dr. A N Gupta)
Deputy Conservator of Forest,
Wildlife Rajsamand

Letter No. 12359-60 Date: 02/11/23

Copy to:

1. PCCF and Chief Wildlife Warden, AranyaBhawan, Jaipur
2. Director, Wildlife Institute of India, Chandrabani, Dehradun – 248001.

Deputy Conservator of Forest,
Wildlife Rajsamand

In November 2023, Sh. Alok Nath Gupta, Deputy Conservator of Forests, Wildlife Rajsamand, requested the Wildlife Institute of India to conduct survey in the Kumbhalgarh Wildlife Sanctuary and Todgarh wildlife sanctuary. This was planned to be an extension of the previous survey conducted by the Wildlife Institute of India in 2022. A team of researchers from the Wildlife Institute of India, supervised by Dr. Ayan Sadhu and Prof. Qamar Qureshi, was assigned to conduct the survey. Due to logistical constraints, the survey had to be restricted in the central part of KWLS, however, this survey provides a crucial insight on the distribution and abundance of major wildlife in the landscape.

01 Introduction

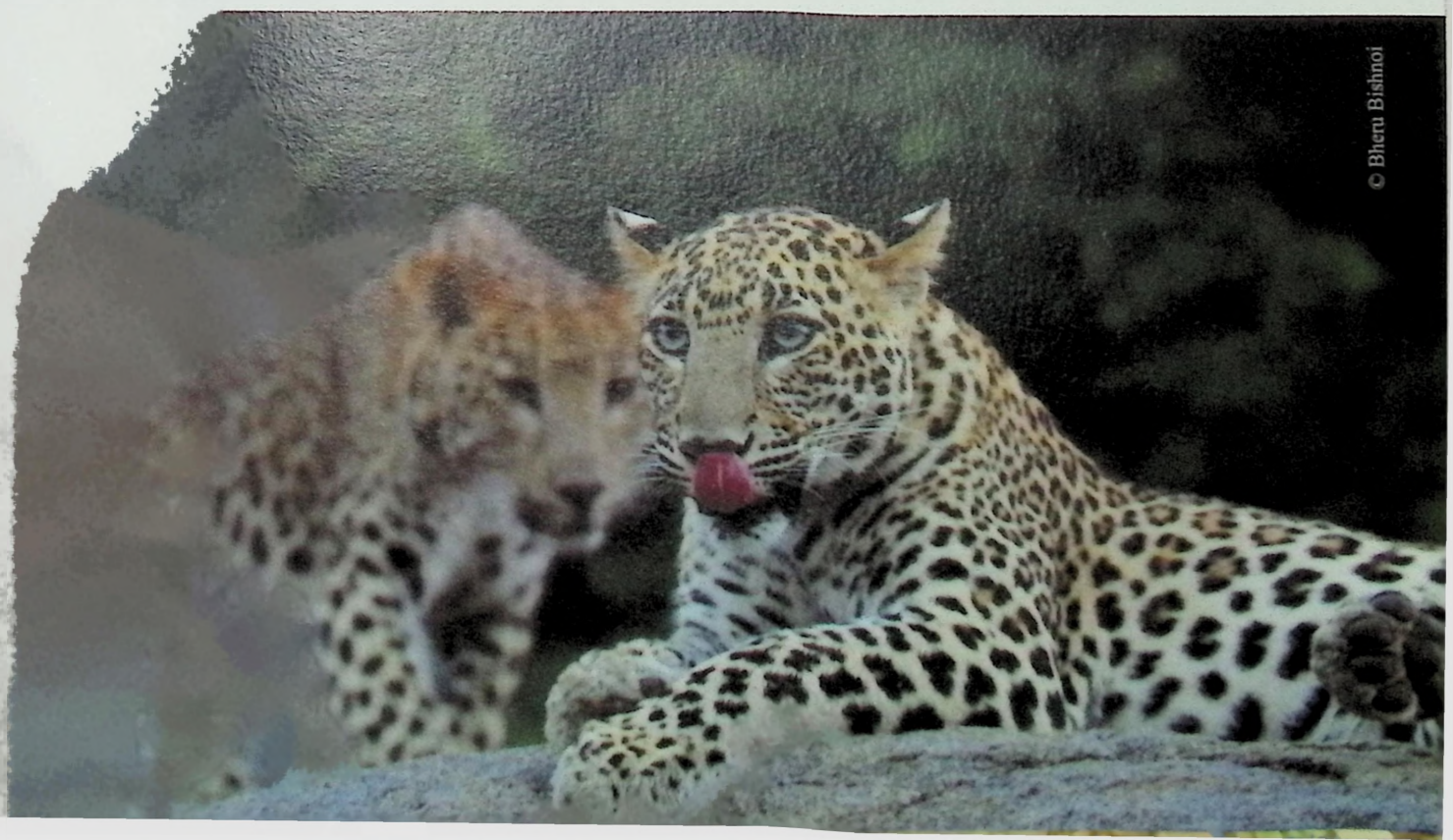
In the Anthropocene, the growing human population and expanding land use exert enormous pressure on wildlife and their habitats, causing habitat loss, degradation, and population declines for many species (Dirzo et al., 2014). Increasing human footprint often changes the distribution and behaviour of wildlife species, alter the species composition, and cause a cascading effects which may disrupt the equilibrium of the ecosystem (Woodroffe and Ginsberg 1998). In India, where the protected areas are small and surrounded by human populations, it is important to monitor the wildlife population to counteract these impacts, and to take informed conservation decisions in a proactive and timely manner (O'Brien, 2008). Estimating population of wild animals is crucial to evaluate the efficacy of any monitoring program as well as it gives critical insights on species wellbeing, population dynamics, (Williams et al., 2002) and effects of various stressors (i.e., habitat loss, poaching, disease, climate change etc.).

Numerous field and analytical methods have been developed and refined, but the use of camera trapping for surveying and monitoring wildlife has increased rapidly in recent years (O'Connell et al., 2011). Camera trapping has emerged as a crucial technique in wildlife monitoring, providing a non-invasive, continuous means of tracking trends in species across diverse habitats (Burton et al., 2015). Camera traps support various methodologies, including capture-mark-recapture for population estimation, occupancy surveys for determining species distribution, and distance sampling to assess animal density and abundance. Camera traps have been widely used as a wildlife monitoring tool due to their objectivity, ease of use, and ability to generate data on a wide range of species (O'Connell et al., 2011).

Kumbhalgarh Wildlife Sanctuary (KWLS) is located in the semi-arid western Indian landscape (24°33′54″N, 73°54′22″E) and spans the Pali, Rajsamand, and Udaipur districts of Rajasthan. The sanctuary covers approximately 611 km^2, comprising a 225 km^2 core zone and a 386 km^2 buffer zone. Despite its significant size, the sanctuary has a linear shape and is surrounded by human-modified landscapes. Semi-arid ecosystems, characterized by low rainfall and high evaporation, support unique flora and fauna adapted to scarce resources. KWLS is situated in the Aravalli hill region, where the terrain is undulating, with elevations ranging from 346 m to 1,190 m. The area features hills and hillocks interspersed with narrow streams (nallahs) that drain onto the plains, forming broader channels. The Aravalli hill range (from the Sanskrit 'ara' and 'vali', meaning "line of peaks") serves as an important biogeographic zone, influencing the region's floral and faunal communities. This range acts as a critical ecological corridor, sustaining biodiversity, regulating the local climate, and aiding groundwater recharge. KWLS functions as an ecotone—a transition zone between the hilly forests of the Aravalli and the desert—playing a vital role in maintaining ecological balance. The Aravalli Hills also act as a geographical barrier, marking the eastern edge of the Thar Desert.

The landscape experiences a subtropical climate with three distinct seasons: summer, monsoon, and winter. Summers are extremely hot and dry, characterized by frequent droughts and erratic, uneven rainfall. Winters, in contrast, are moderate. The forest in Kumbhalgarh Wildlife Sanctuary (WLS) is predominantly an edaphic-climate climax forest, shaped by soil and climatic conditions. The vegetation is classified as northern tropical dry deciduous forest (Champion and Seth, 1968). The most common tree species in the area is dhonk (*Anogeissus pendula*), while the upper ridges of the hills are dominated by salar (*Boswellia serrata*). Other common species include *Anogeissus latifolia, Lannea coromandelica, Butea monosperma, Acacia catechu, Acacia leucophloea, Ficus benghalensis, Ficus racemosa, Diospyros melanoxylon, Azadirachta indica, Acacia senegal, Acacia nilotica, Mitragyna parviflora, Ziziphus nummularia, Ziziphus mauritiana, and Ziziphus jujuba.* In areas disturbed by human activity, the invasive species *Prosopis juliflora* dominates the vegetation.

The large carnivore community in Kumbhalgarh includes leopards (*Panthera pardus*), striped hyenas (*Hyaena hyaena*), and sloth bears (*Melursus ursinus*). Historical records indicate the presence of tigers (*Panthera tigris*) in this region; however, the population went extinct in the last century, likely due to hunting (Singh and Reddy, 2017). The medium and small carnivores include honey badgers (*Mellivora capensis*), golden jackals (*Canis aureus*), Indian foxes (*Vulpes bengalensis*), jungle cats (*Felis chaus*), rusty-spotted cats (*Prionailurus rubiginosus*), small Indian civets (*Viverricula indica*), common palm civets (*Paradoxurus hermaphroditus*), ruddy mongooses (*Herpestes smithii*), and Indian grey mongooses (*Herpestes edwardsii*). The sanctuary supports healthy populations of herbivores, including sambar (*Rusa unicolor*), nilgai (*Boselaphus tragocamelus*), and wild pigs (*Sus scrofa*). A small population of four-horned antelopes (*Tetracerus quadricornis*) also inhabits the area. Both Hanuman langurs (Semnopithecus entellus) and rhesus macaques (*Macaca mulatta*) are commonly observed, but chital (*Axis axis*) are notably absent. This report, based on survey data, provides insights into the faunal and landscape characteristics of the sanctuary, which will help formulate effective conservation and management strategies for this protected area.



02| Methods

2.1 Camera Trap Survey

Camera trapping was conducted in Kumbhalgarh from January to March 2024, covering an area of approximately 200 km^2, which included all five ranges—Kumbhalgarh, Sadri, Desuri, Jhilwada, and Bokhada. The area was divided into 2 km^2 grids, and in each grid, a pair of camera traps was placed. The cameras were set up along trails and near forest roads to maximize the probability of capturing the target species. These locations were selected based on a reconnaissance survey conducted in search of large carnivore signs along gipsy tracks, animal trails, and dry stream beds. A total of 49 pairs of cameras were deployed. The distance between the two camera trap stations was 700 to 1,000 meters. At each station, two camera traps facing each other were placed at a height of 30--45 cm above the ground, with a 5-7meter spacing between them to capture both flanks of large carnivores. The cameras were checked every 2-5 days to monitor battery status and download data. Camera traps were programmed to capture two events with a 2-second interval in the fastest possible mode.

2.2 Data Processing

The data collected from the camera traps was processed and geotagged (with date, time, and location stamps) using CaTRAT software (Camera Trap Data Repository and Analysis Tool). The geotagged images were classified at the species level. In cases of blurred or unrecognizable images, they were classified as unidentified. Images containing humans, vehicles, livestock, and blanks were also segregated; however, human photographs were further classified into two categories: department personnel (forest department and research team) and outsiders (villagers, tourists, daily wage workers, etc.). The EXIF information for all species was extracted for further analysis.

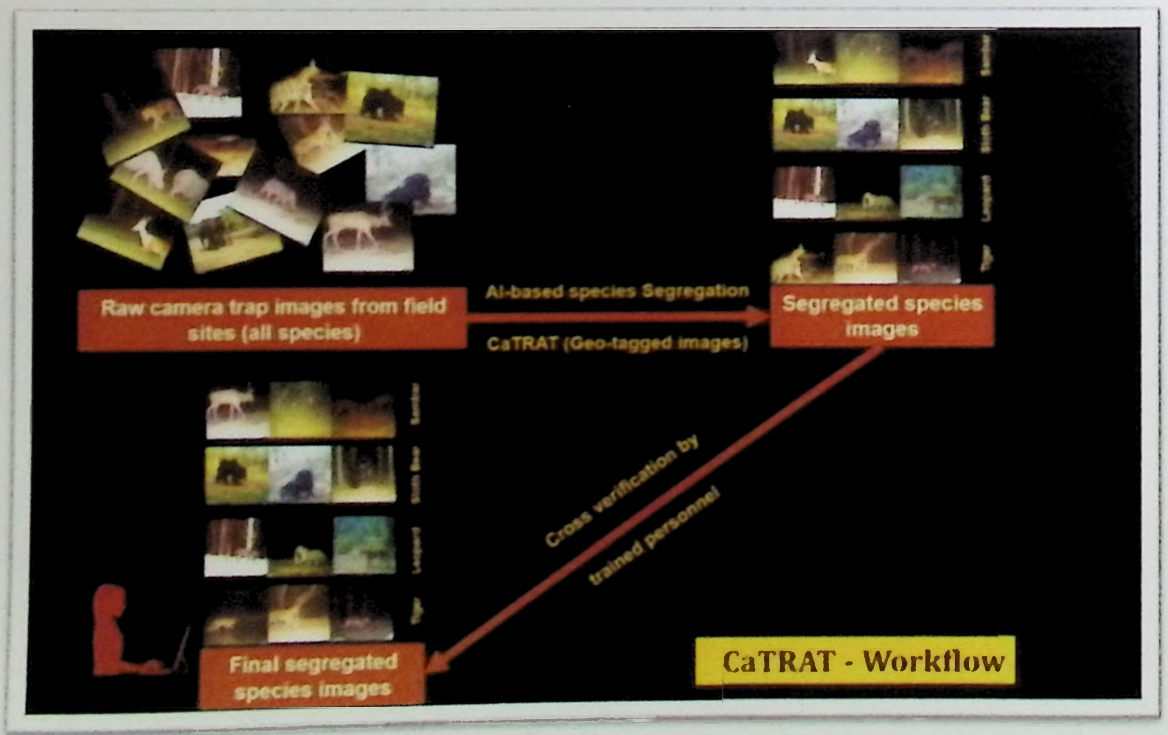
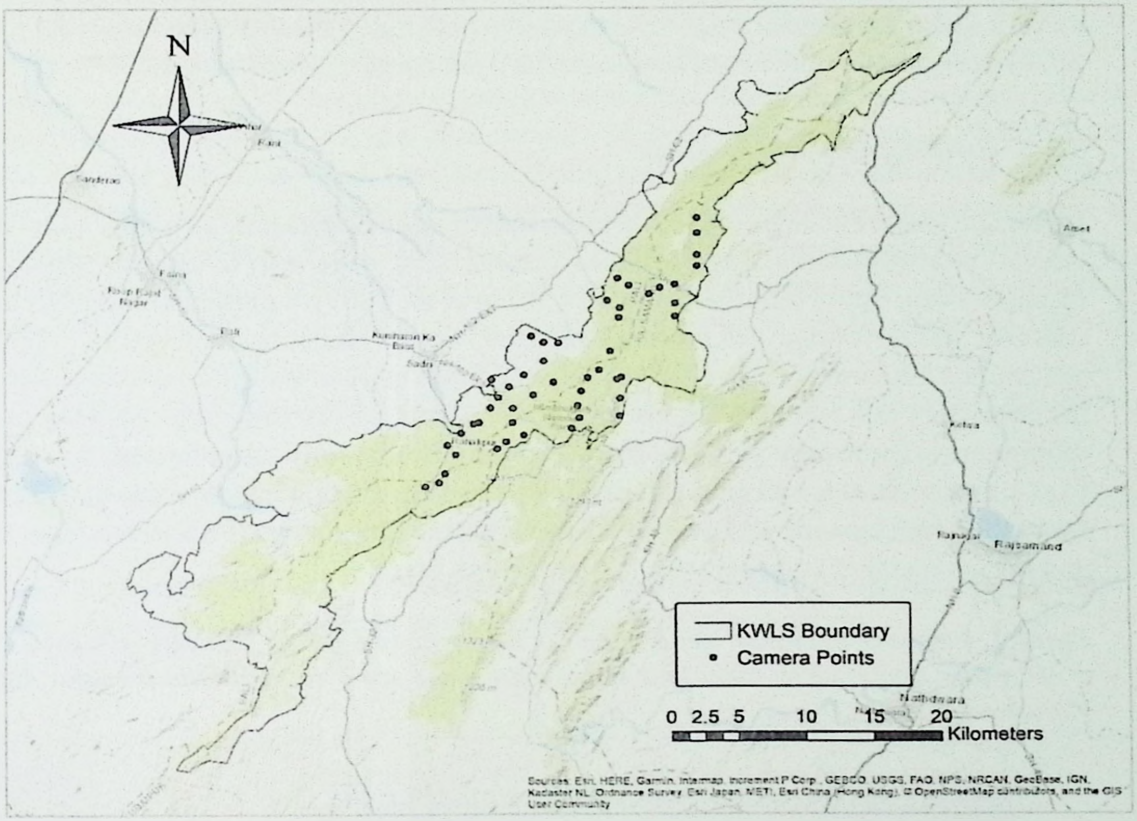


Figure 1. Map showing the camera trap placement in the intensive study area of Kumbhalgarh Wildlife Sanctuary.



2.3. Data Analyses

2.3.1. Species abundance & distribution

For calculating the Relative Abundance Index (RAI) of each species, we considered the independent photo captures of the species obtained from the camera traps (Carbone et al., 2001). Photo captures of animals from the same camera trap station, taken simultaneously (double-sided cameras), were considered as a single event. If consecutive photo captures of the same species were 30 minutes apart, we considered them as independent events, as well as when more than one individual was present in the same frame (O'Brien et al., 2003). The 30-minute time interval was applied to all images to correct for the bias of over counting the same animals foraging in front of the camera traps, while at the same time minimizing the loss of information for elusive solitary species. The independent number of photographs was divided by the trapping effort of each camera trap station to calculate the RAI of the target species (Eq. 1). The relative abundance index is considered a surrogate for population abundance, i.e., it is directly proportional to abundance. Moreover, the RAI does not require the identification of individual animals and has been widely used to quantify trends in animal populations (Kinnaird & O'Brien, 2012; O'Brien et al., 2003).

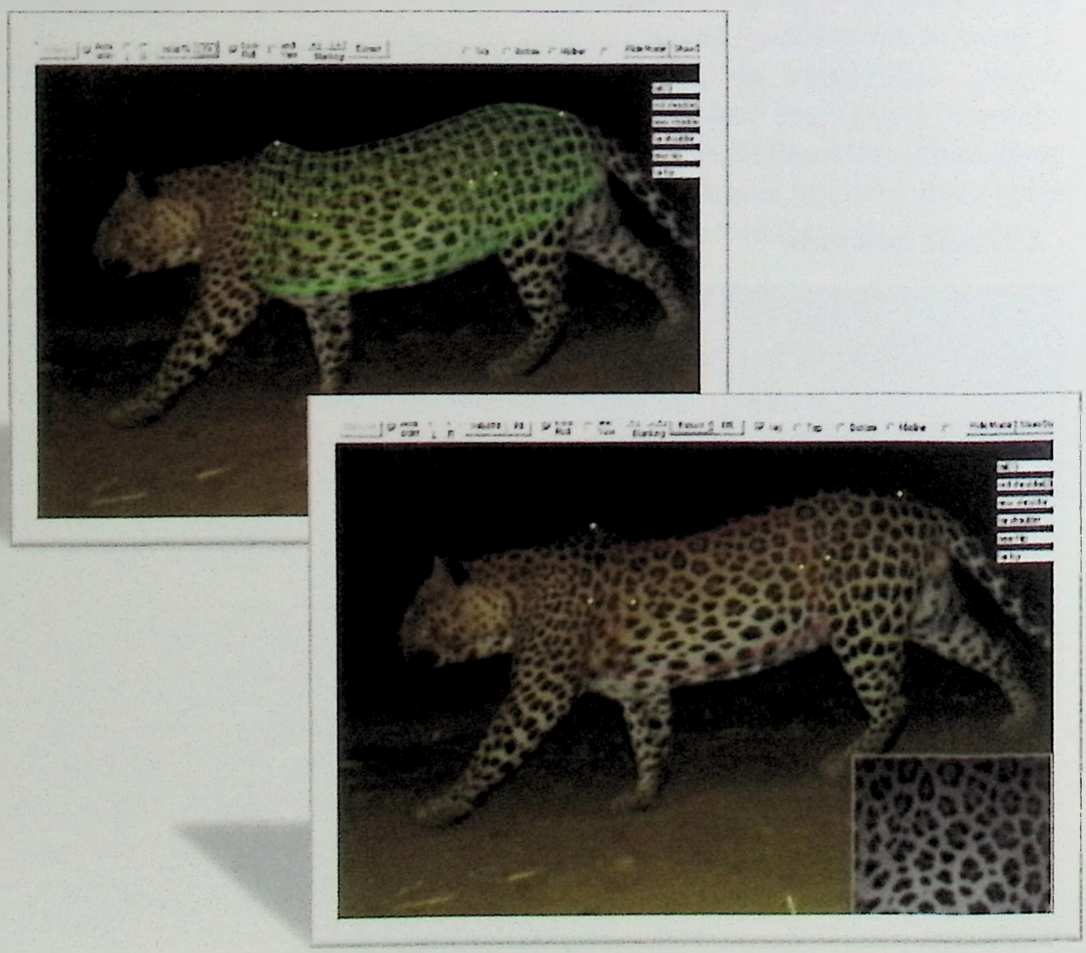
$$RAI = \frac{No.of\ independent\ capture}{Trapping\ effort} * 100 \ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 1}$$

The spatial distribution of large carnivores, small carnivores and major herbivores was plotted using the Inverse Distance Weighted (IDW) function in ArcMap (ver. 10.5 ESRI 2016) using the relative abundance index (RAI) obtained from camera traps.

2.3.2. Identification of Leopards

Individual leopards can be identified using their unique rosette pattern on the body. The leopard photographs obtained from the camera traps were used to identify individual leopards using ExtractCompare software (Hiby et al., 2009), a pattern recognition tool that searches for similarities between digitized leopard coat patterns (Figure 2). Before processing, different body parts of the leopards were marked using the software, such as the shoulders, tail, hip, hind leg, etc. (Figure 2). These are the body parts with the most differences in the rosette patterns. The identified leopards were assigned unique IDs, e.g., L1, L2, and so on. Once all unique individuals were identified, a matrix of spatial capture history for each leopard was developed, including the camera trap IDs, their coordinates, and the deployment and operation history of each camera.

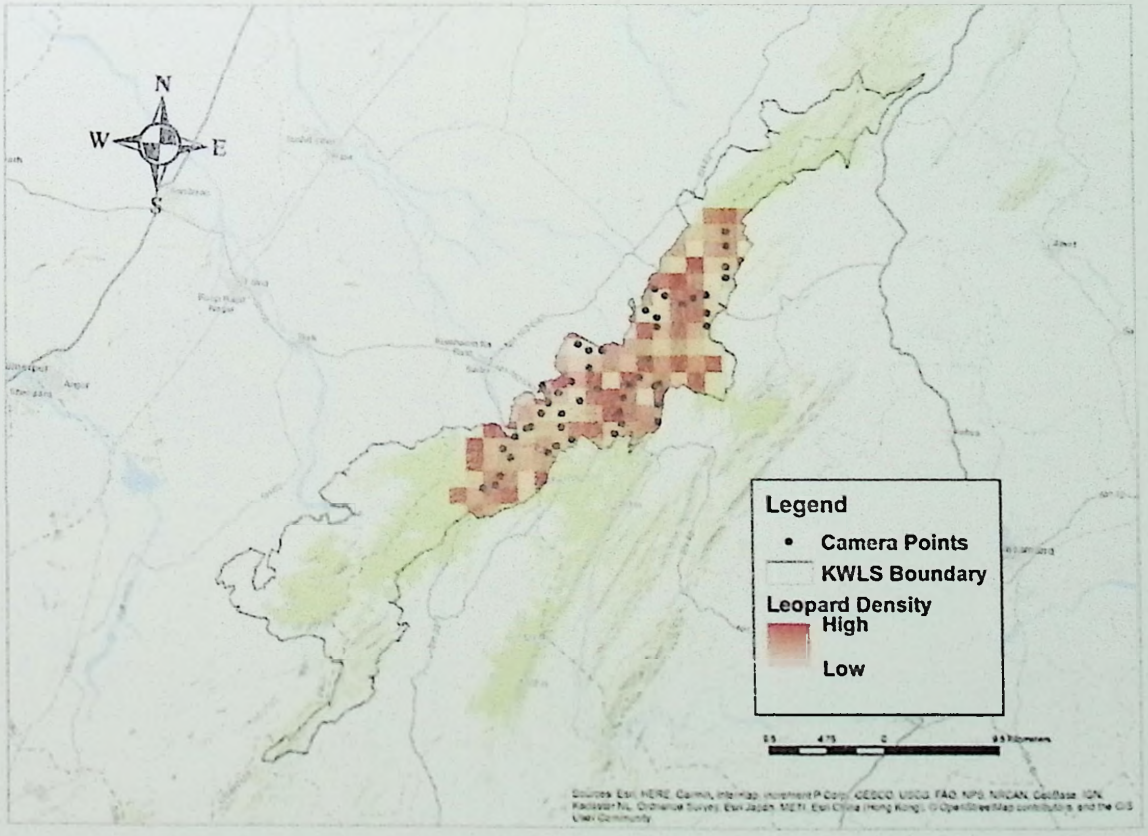
Figure 2. Process of individual identification of leopards using Extract Compare software. Left: a 3D model fitting which takes into account the angle at which the photo is taken; Right: Pattern extracted.



2.3.3. Leopard Population Density

Leopard density was estimated using the Spatially Explicit Capture-Recapture (SECR) framework (Efford and Borchers, 2008). The capture history matrix was prepared from the identified leopards, where individual leopard captures were recorded in the matrix along with the trap ID and the occasion of capture. The capture matrix comprised "1" (photo-captured) or "0" (not photo-captured), and a trap matrix represented each camera trap's effort (operational – 1, Non-operational – 0) along with its spatial location (Efford, 2012). In the SECR framework, the animal spatial captures are taken into consideration to model animal activity centres (or home range centres). SECR assumes the distribution of the home range centre in the statistical state-space follows some a-priori pattern, e.g., Poisson point process. The detection probability (g0) at the home range centre decreases with distance, which is modelled by the movement parameter (σ) (Borchers and Efford, 2008). Finally, the density ($\hat{D}$) is a derived parameter, which is estimated using the probability of detection at the home range center (g0) and the scale parameter (σ) (Efford et al., 2009).

Figure 3. Spatial leopard density derived from the Spatially Explicit Capture-Recapture analysis based on the camera trap sampling in the Kumbhalgarh Wildlife Sanctuary.



2.3.4 Leopard & Hyena Occupancy

We used occupancy framework to estimate site use intensity of leopards and find out the factors affecting leopard distribution in the landscape (MacKenzie et al., 2002). The occupancy model is based on two key parameters: site occupancy (ψ) – the probability that a cell is occupied by a leopard, and detection probability (p) – the probability of detecting a leopard in the cell when it is occupied (MacKenzie et al., 2002). A site-wise (camera trap grid) detection history matrix was prepared, where '1' denoted leopard/hyena detection in that occasion at the camera trap site, and '0' depicted non-detection. To model leopard and hyena site occupancy, we used ruggedness, distance from nightlight, distance from water, and normalized difference vegetation index (NDVI)—the key ecological parameters, likely to influence large carnivore occupancy. Furthermore, to model detection probability, we incorporated the capture rates of wild prey (sambar, nilgai, four-horned antelope, wild pig, porcupine, Indian hare, and langur) and domestic prey species (cattle, livestock, domestic dogs) at each site (i.e., camera trap). All covariates were tested for collinearity, and the non-correlated variables were used to model occupancy (Cohen et al., 2009). Using these covariates, we prepared candidate models and ran them in PRESENCE software (Hines et al. 2006). These models range from covariates describing leopard and hyena site-use intensity to detection probability and also the null model, where the site-use intensity and the detection probability were considered uniform. The best model was selected using the Akaike Information Criterion (AIC) (Burnham and Anderson, 2002).

2.3.5 Activity Pattern

The temporal information for each independent photo capture of the species (obtained from camera traps) was extracted and used for temporal activity analysis. This temporal information was used to generate activity curves using the 'overlap' package in R (Meredith and Ridout, 2014). The 'overlap' package applies a kernel density function to fit activity curves based on species' photo-capture rates over time intervals.

2.3.6 Ungulate Density

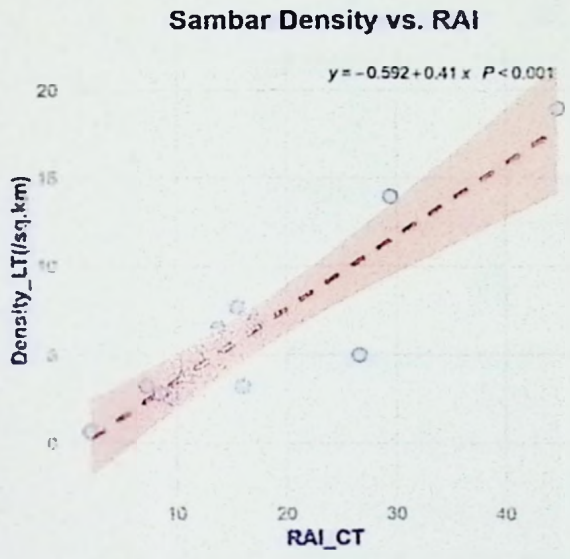
We have attempted to estimate the prey density from the camera trap capture rates in the Kumbhalgarh WLS. In practice, line transect-based distance sampling is widely used for estimating ungulate population; however, due to rugged terrain, dense vegetation in the narrow valleys, and low detection of wild ungulates due to human disturbances, estimates were not feasible in distance sampling framework (Buckland et al. 2004). As an alternative, we have derived a projected population by regressing camera trap photo-capture rates with ungulate densities estimated using distance sampling from similar habitats across India. The following species specific equations was derived from this relationship to predict the densities of ungulate species (i.e., sambar, nilgai, and wild pig) in Kumbhalgarh Wildlife Sanctuary:

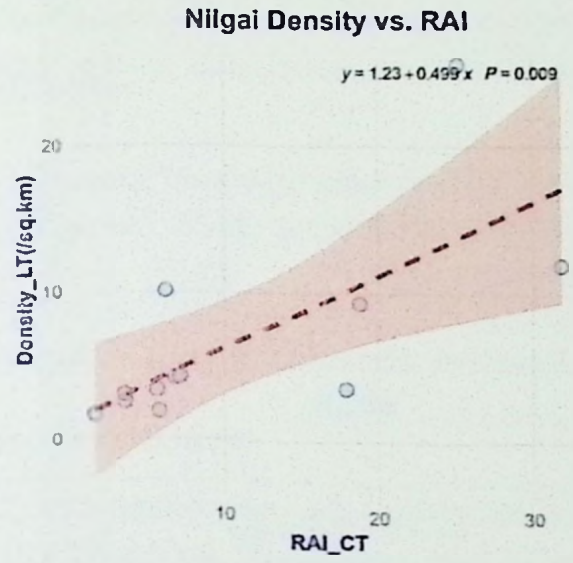
Sambar density = *0.41x + 0.592, significance (p-value) <0.01, R^2 = 0.83*

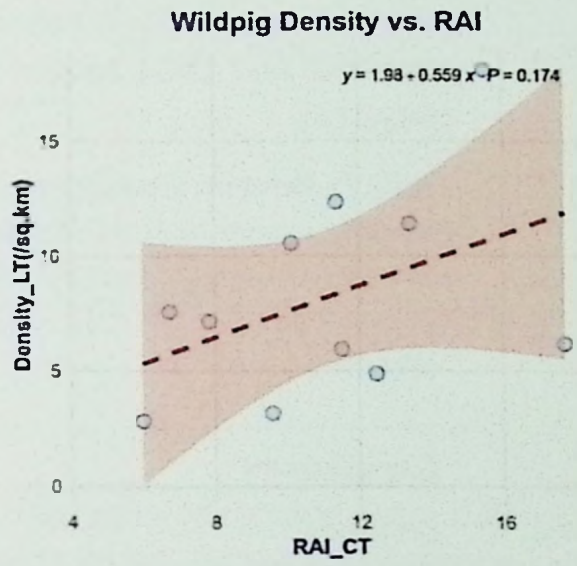
Nilgai density = *0.499x + 1.23, significance (p-value) <0.01, R^2 = 0.51*

Wild pig density = *0.559x + 1.98, significance (p-value) >0.05, R^2 = 0.22*

Where *y* represents the estimated density of each species, *x* is the camera trap photo-capture rate (RAI), m is the slope.







03| Results

3.1. Species Distribution & Abundance

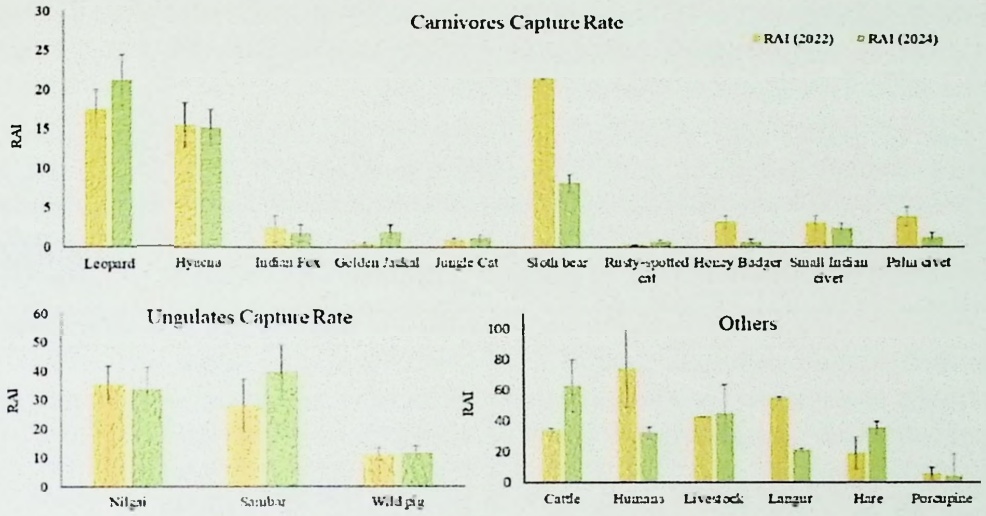
A total of 153241 photographs of 23 species were obtained from 49 camera trap pairs (1568 trap nights). The most photo-captured carnivore was leopard, followed by striped hyena and sloth bear, while the most photo-captured ungulate was sambar followed by nilgai and wild pig (Table 1). Among domestic stocks, cattle were most photo-captured followed by livestock and domestic dogs. The detailed record of all the species photo-captured and their spatial distribution is mentioned in the 'Species Account' section (page.13).

Table 1: Relative abundance index (RAI) of major mammal species obtained from the camera trapping survey in Kumbhalgarh Wildlife Sanctuary in 2024. The same has been compared with the camera trapping survey conducted in 2022.

Species	Relative abundance (SE) 2024	Relative abundance (SE) 2022
Carnivores		
Leopard	21.14 (± 3.25)	17.48 (±2.4)
Hyaena	15.15 (± 2.24)	15.45 (±2.8)
Sloth bear	8.09 (± 1.17)	21.40 (±2.94)
Honey Badger	0.66 (±0.28)	3.18 (±0.77)
Golden Jackal	1.90 (± 0.87)	0.36 (±0.19)
Jungle Cat	1.07 (± 0.35)	0.82 (±0.29)
Indian Fox	1.73 (± 1.05)	2.36 (±1.64)
Rusty-spotted cat	0.59 (± 0.25)	0.2 (±0.1)
Small Indian civet	2.37 (± 0.61)	3.02 (±0.86)
Common palm civet	1.25 (±0.55)	3.87 (±1.23)
Herbivores		
Sambar	39.30 (± 9.51)	27.54 (±9.2)
Nilgai	33.41 (± 7.61)	35.05 (±6.57)
Wild pig	11.39 (± 2.38)	10.82 (±2.11)
Indian hare	35.19 (±13.91)	18.84 (±4.35)
Langur	21.03 (±4.14)	54.50 (±10.24)
Indian crested porcupine	4.02 (±1.11)	5.46 (±0.89)
Human disturbances		
Cattle	62.73 (± 16.65)	33.60 (±1.37)
Livestock	44.56 (± 18.64)	42.62 (±14.48)
Humans	32.18 (± 3.79)	73.81 (±25.04)

SE: Standard error

Figure 4. Relative abundance index (RAI) of major mammal species photo-captured during the camera trapping survey 2022 & 2024 at Kumbhalgarh Wildlife Sanctuary.



3.2. Leopard Population Density

During the camera trapping session, 52 individual leopards were identified from 638 photographs, including 16 males, 19 females, and 17 individuals whose sex could not be determined. The leopard density in Kumbhalgarh Wildlife Sanctuary is estimated to be 16.91 (SE 2.45) leopards per 100 km² (Table 2). The detection corrected sex-ratio (male: female) was 1:3. We have compared the individual leopard photographs from 2022, and find out 26 leopards were common between two sessions (2022 and 2024), while in 2024 26 new leopards were photo-captured.

Table 2: Sampling details and leopard density parameter estimates using spatially explicit capture-recapture analysis in a likelihood framework Kumbhalgarh Wildlife Sanctuary.

Variables	**Estimates (2024)**	**Estimates (2022)**
Model space (km²)	529	533
Camera points	49	52
Trap nights (effort)	1568	2162
Unique Leopard captured	**52**	**55**
$\hat{D}$ SECR (/100 km²)	**16.9 (SE 2.45)**	**19.2 (SE 2.68)**
Model	$\hat{D}$ ~1, $\hat{g}0$ ~sex, $\hat{\sigma}$ ~sex	$\hat{D}$ ~1, $\hat{g}0$ ~1, $\hat{\sigma}$ ~sex
^σ Female (km)	1.26 (SE 0.08)	0.82 (SE 0.04)
^σ Male (km)	1.46 (SE 0.10)	1.75 (SE 0.09)
^g0 Female/Male	0.06 (SE 0.01) /0.16 (SE 0.01)	0.12(SE 0.012)
Pmix - Female: Male	0.710:0.289 (SE 0.065)	0.72:0.28(SE 0.06)

SE: Standard error

$\hat{D}$ SECR: Density estimate from Maximum Likelihood-based spatially explicit capture-recapture; ^σ (Sigma): Spatial scale of detection function; ^g0: detection probability at home range centre; Pmix: an estimate of the proportion of male /female (detection corrected sex ratio)

3.3 Leopard & Hyena Occupancy

The best model for leopard occupancy included distance from water (-1.49 S.E 0.67), ruggedness (2.57 S 0.86), NDVI April (1.34 SE 0.69), and distance from road (-1.61 S.E 0.65) while the detection of wild prey influence leopard detection in sites (0.15 SE 0.06). The best model for striped hyena was explained by distance from water (-2.14 S.E 0.69), ruggedness (1.78 S 0.68), and NDVI April (1.55 SE 0.71).

Table 3. List of models used in occupancy analysis for (A) Leopards & (B) Hyenas in Kumbhalgarh Wildlife Sanctuary, 2024. Covariates considered RAI of wild prey (W_P), Domestic prey (D_P), Distance from water (dst_wtr), distance from road (dst_road), ruggedness, distance from nightlight, NDVI.

(A) Leopard

Model	AICc	ΔAICc	AICwgt	#Parameters
psi(rugg+NDVI_A+dst_wtr+dst_road),p(W_P)	1318.89	0	0.8551	6
psi(rugg+NDVI_A+dst_road),p(W_P)	1323.02	4.13	0.1084	5
psi(rugg+NDVI_A+dst_wtr_),p(W_P)	1325.67	6.78	0.0288	5
psi(NDVI_N+dst_wtr+),p(W_P)	1329.46	10.57	0.0043	4
psi(dst_road+dst_wtr_),p(W_P)	1331.17	12.28	0.0018	4
psi(rugg+dst_wtr_),p(W_P)	1332.65	13.76	0.0009	4
psi(dst_road+human_rai),p(D_P)	1334.35	15.46	0.0004	4
psi(dst_road+dst_nitelite+human_rai),p(D_P)	1335.61	16.72	0.0002	5
psi(.),p(.)	1342.37	23.48	0	2

(B)Hyena

Model	AICc	ΔAICc	AICwgt	#Parameters
psi(dst_wtr+NDVI_A+rugg),p(D_P)	1125.01	0	0.9399	5
psi(dst_wtr+NDVI_A),p(D_P)	1132.71	7.7	0.02	4
psi(dst_wtr+human_rai),p(D_P)	1133.14	8.13	0.0161	4
psi(dst_wtr+dst_nitelite),p(D_P)	1134.19	9.18	0.0095	4
psi(dst_wtr+dst_road+dst_nitelite),p(D_P)	1135.71	10.7	0.0045	5
psi(dst_nitelite+human_rai),p(D_P)	1136.13	11.12	0.0036	4
psi(dst_road+humanrai+NDVI_A),p(D_P)	1136.56	11.55	0.0029	5
psi(dst_road+dst_nitelite+humanrai),p(D_P)	1137.66	12.65	0.0017	5
psi(dst_road+humanrai),p(D_P)	1137.66	12.65	0.0017	5
psi(dst_wtr+rugg+NDVI_A),p(W_P)	1146.78	21.77	0	5
psi(dst_wtr+dst_nitelite+rugg+NDVI_A),p(w_p)	1148.7	23.69	0	6
psi(.),p(.)	1166.76	41.75	0	2

3.4 Activity Pattern

Most of the carnivores exhibited nocturnal activity. Leopards showed activity peaks around dusk, while striped hyenas exhibited nocturnal activity with crepuscular peaks. The sloth bear is predominantly nocturnal, with very few captures during the day. The Indian fox, jungle cat, honey badger, common palm civet, and small Indian civet all showed activity peaks at night, while the jackal was mostly active during the day and showed activity peaks around noon. Among the ungulates, wild pigs showed activity throughout the day and night, while nilgai were predominantly diurnal with very few captures at night. Sambar showed activity peaks in the early morning, late afternoon, and at night.

3.5 Ungulate density

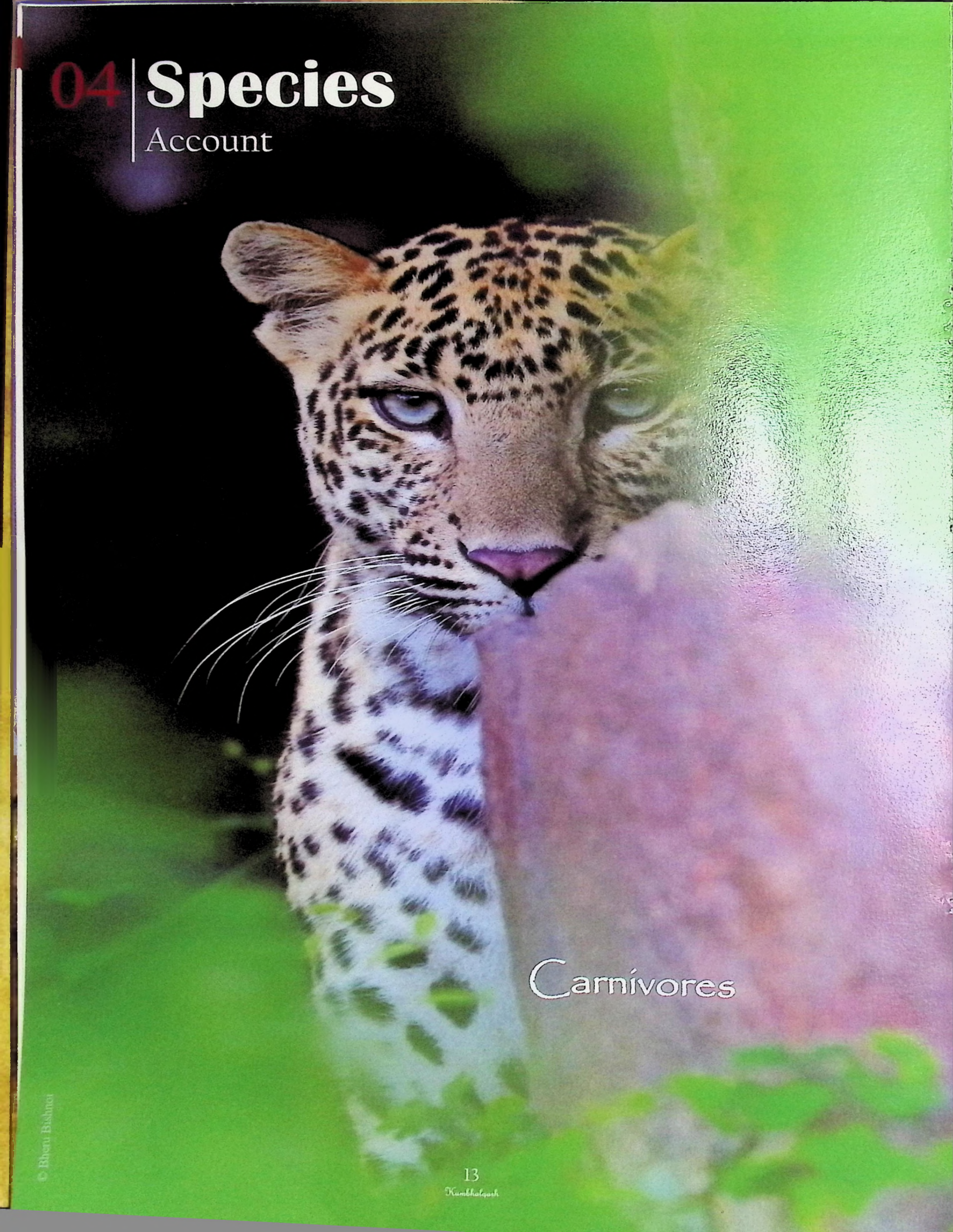
Kumbhalgarh has a diverse community of herbivores. Except for the chital (*Axis axis*), most of the key prey species for large carnivores are found in the sanctuary. The nilgai sambar population appears to be healthy, likely due to presence of inviolate areas inside the reserve. The estimated density of sambar in Kumbhalgarh is 16.7 (SE 4.49) individuals per sq. kilometre. Nilgai is the most common herbivore, with a density of 17.9 (SE 5.02) individuals per sq. kilometre. The density of wild pigs is estimated at 8.34 (SE 3.31) individuals per sq. kilometre. However, caution should be taken while considering wild pig density, as feral/semi-domestic pigs are difficult to differentiate from their wild counterparts. Therefore, the relative abundance index (photo-capture rate) or the projected density might be inclusive of semi-wild or feral wild pigs inthe vicinity.

Table 4. The projected ungulate densities, estimated using the species specific equations (where, relative abundance index of the target prey species was regressed against their line transect-based estimates from similar ecosystems) for Kumbhalgarh wildlife sanctuary.

Species	Relative Abundance Index (RAI) (±SE)		Projected density/km² (±SE) *	
	RAI 2024	RAI 2022	2024	2022#
Sambar	39.30 (± 9.51)	27.54 (±9.2)	**16.70** (±4.49)	**11.88** (±4.36)
Nilgai	33.41 (± 7.61)	35.05 (±6.57)	**17.90** (±5.02)	**18.71** (±4.5)
Wild pig	11.39 (± 2.38)	10.82 (±2.11)	**8.34** (±3.31)	**8.02** (±3.15)

**Projected density – Projected density should be treated with caution while comparing with the line-transect based density estimates. However, these estimates can be used to monitoring the trend of the population. #The 2022 estimates were recalculated using the new equations mentioned in the method.*

04 Species Account



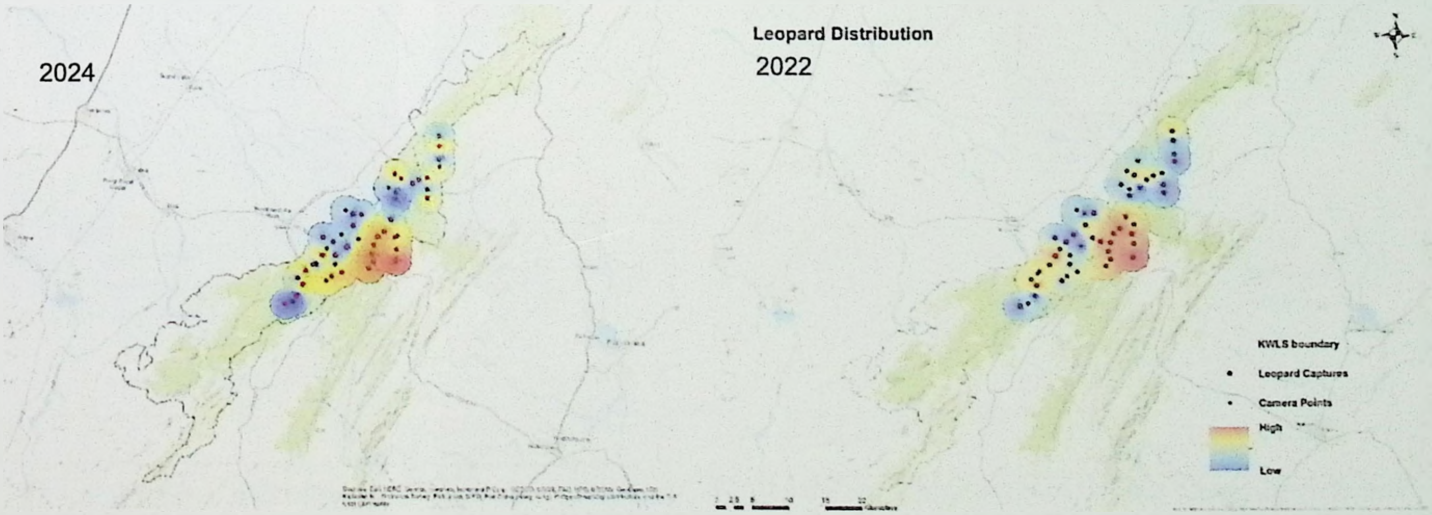
Carnivores

Leopard

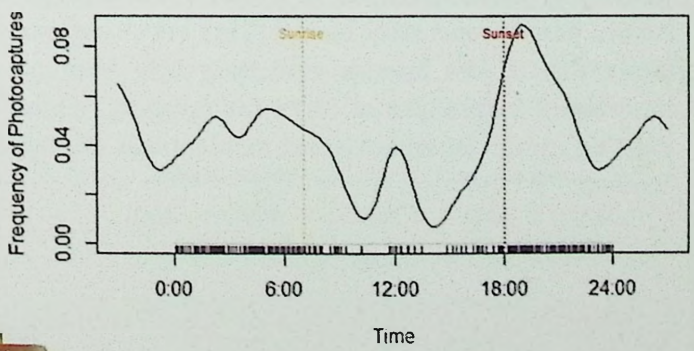
Panthera pardus

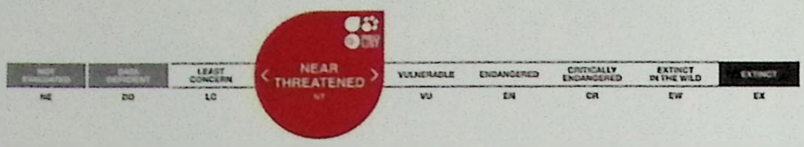
Leopards are the most adaptable big cats of the Indian subcontinent and can survive in human-dominated landscapes when refuge habitats are available. Their diet includes deer, wild pigs, langurs, and smaller mammals like hares and rodents; they can sustain themselves in areas with low or no wild prey by preying on domestic livestock and dogs. In 2024, a total of 52 individual leopards were photo-captured, compared to 55 individuals recorded in 2022, indicating a notable turnover of around 23.5% within the leopard population. They were recorded in 43 out of the 49 camera traps, with a notably higher intensity of captures in the eastern region of the Kumbhalgarh Wildlife Sanctuary (Kumbhalgarh range, Fig. 5).

Figure 5. Leopard spatial distribution obtained from camera trap captures (left - 2024, right - 2022) in Kumbhalgarh WLS. Below: Activity pattern obtained from camera trap captures.



The leopard exhibited a crepuscular activity pattern, with a major activity peak occurring after sunset. This crepuscular activity peak coincides with the activity peaks of the major wild prey species, namely sambar, nilgai, and wild pig.



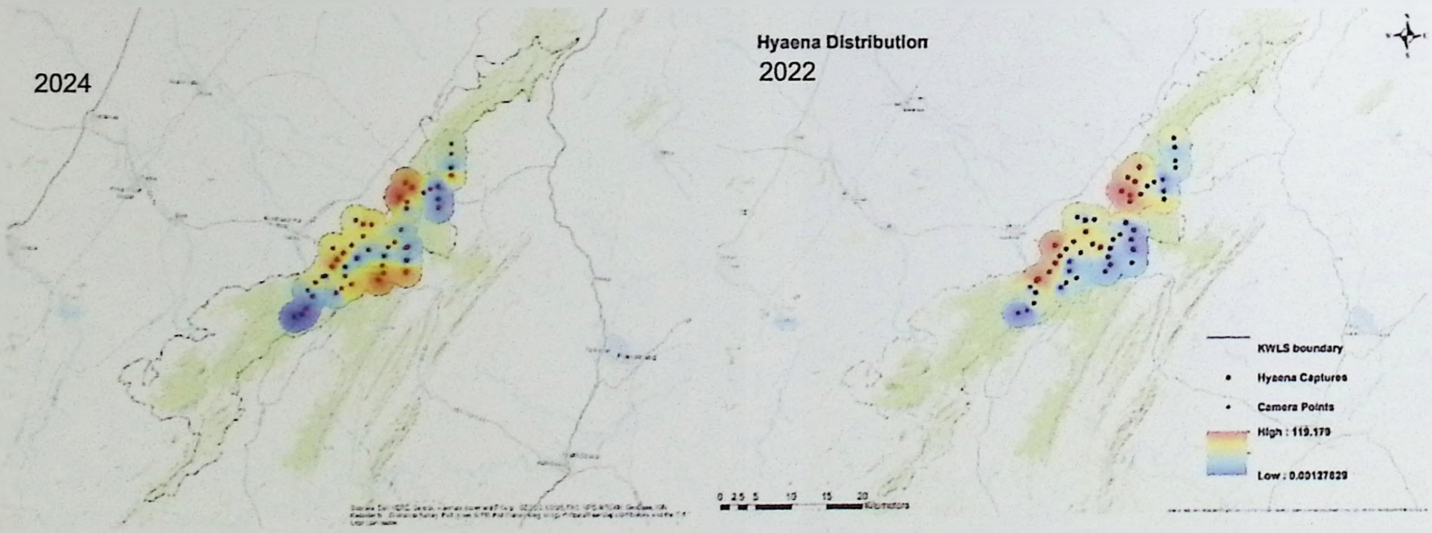


Striped hyena

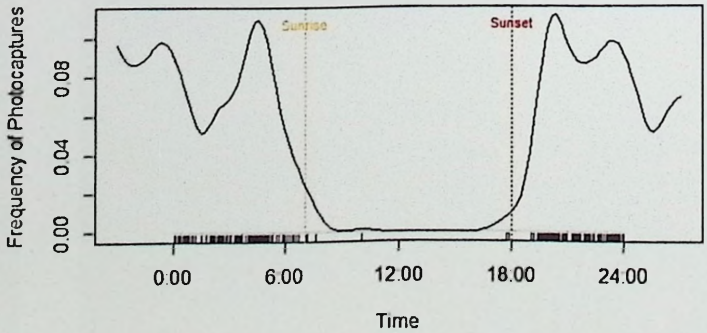
Hyaena hyaena

The striped hyena is the only species of hyena found in India and marks the easternmost distribution of the species. It is widely distributed across India's arid and semi-arid landscapes. Recognized as a facultative scavenger, it is known to coexist in human-dominated areas by feeding on livestock carcasses. Striped hyenas are frequently persecuted due to misconceptions or unfounded beliefs. During the present survey, striped hyenas were photo-captured in 39 out of 49 camera traps. Interestingly, the majority of striped hyena photo-captures were recorded in the western part of the sanctuary, where leopard capture rates were lower (Fig. 6).

Figure. 6. Striped hyena spatial distribution obtained from camera trap captures (left - 2024, right - 2022) in Kumbhalgarh WLS. Below: Activity pattern obtained from camera trap captures.



The striped hyena exhibited completely nocturnal activity in the sanctuary, with major activity peaks before sunrise and after sunset. This behavior was likely due to the hyenas venturing into human-dominated landscapes at night for foraging, while seeking refuge in undisturbed forest areas during the day.

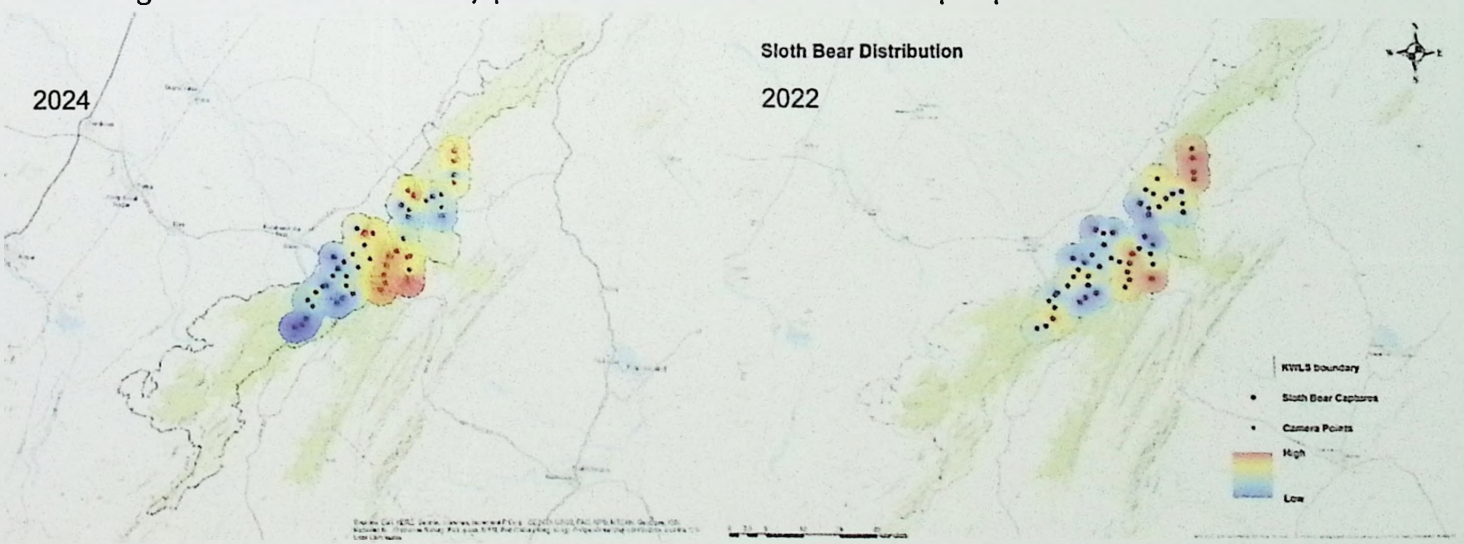


Sloth bear

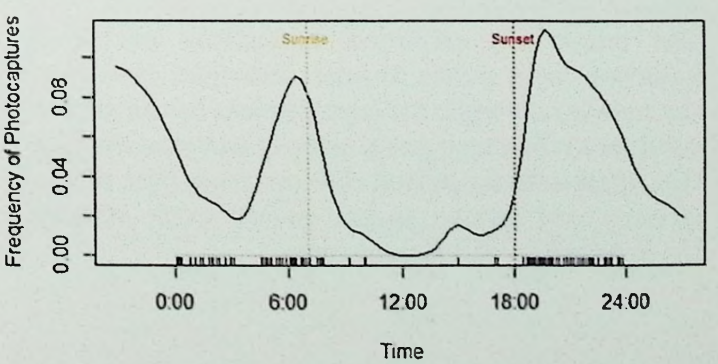
Melursus ursinus

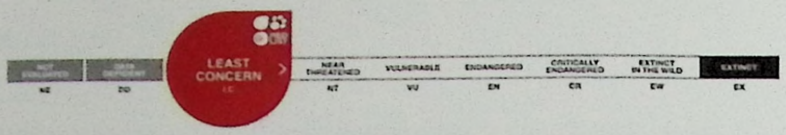
The sloth bear is widely distributed and endemic to the Indian subcontinent. The semi-arid western Indian landscape marks the western limit of the species. The rugged terrain of Kumbhalgarh and the adjoining forest areas, such as Mount Abu, Phulwari ke Nal, and Ambaji Balaram, harbor sizable populations of sloth bears. They primarily feed on termites and ants, but their diet also includes varying proportions of other insects and fruits, depending on availability. The sloth bear was recorded by 34 out of 49 camera traps, with a higher capture rate in the eastern part of the Reserve (Kumbhalgarh Range, see Fig. 7).

Figure. 7. Sloth Bear spatial distribution obtained from camera trap captures (left - 2024, right - 2022) in Kumbhalgarh WLS Below: Activity pattern obtained from camera trap captures.



The sloth bear exhibited a crepuscular temporal activity pattern, with two prominent activity peaks—shortly after sunset and just before sunrise. There were a few daytime captures of the sloth bear.



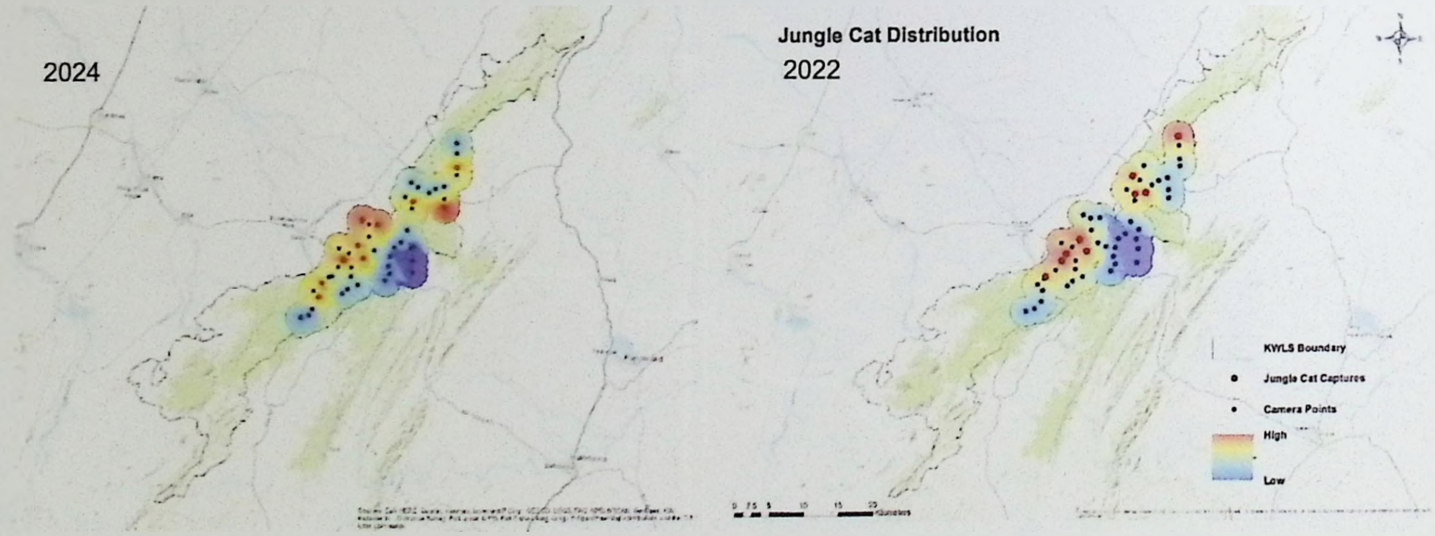


Jungle cat

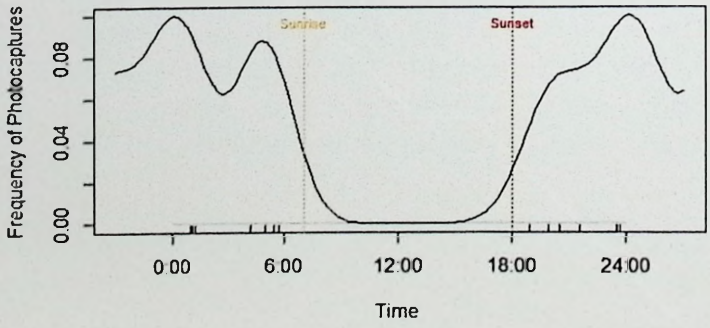
Felis chaus

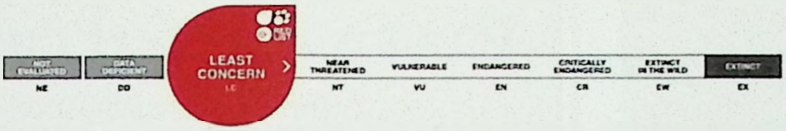
Jungle cats are medium-sized wildcats and the most widespread felid in India. Their coat color varies from sandy or greyish-brown to tawny red, and they have a slender body. Rodents make up the primary diet of jungle cats, although they are capable of preying on animals much larger than themselves. Jungle cats are commonly found in agricultural landscapes outside protected areas, as well as in grassland and open forest ecosystems (historically known as reed cats). In the study area, jungle cats were detected in only 10 out of 49 camera traps (Figure 8). Interestingly, no jungle cat captures occurred in areas with high leopard activity.

Figure.8. Jungle Cat spatial distribution obtained from camera trap captures (left - 2024, right - 2022) in Kumbhalgarh WLS. Below: Activity pattern obtained from camera trap captures.



The jungle cat exhibited exclusively nocturnal behavior, with peaks around midnight. However, the number of jungle cat captures was too limited to conduct a robust temporal activity analysis. Despite this, their activity period differed from that of the leopard and golden jackal, whose peak activity times occurred at different times.



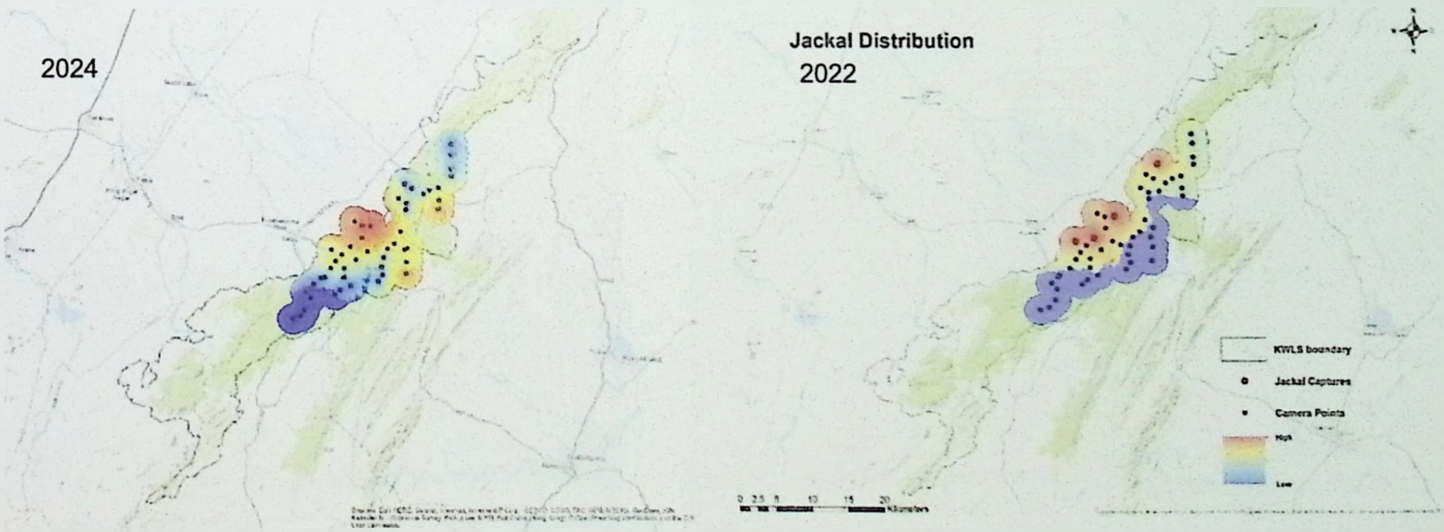


Golden jackal

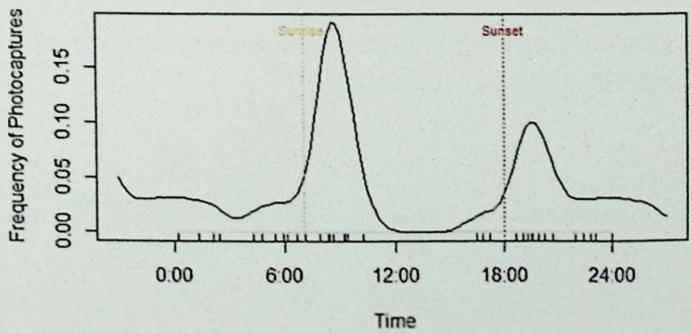
Canis aureus

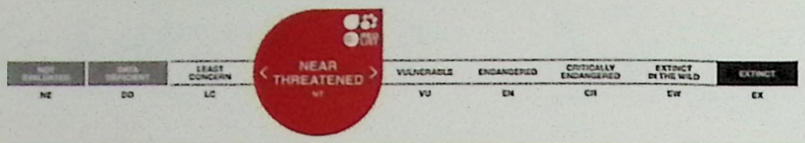
The golden jackal, a medium-sized canid species, is known for its opportunistic and omnivorous foraging behavior. It is a habitat generalist, thriving in a wide variety of environments, from deserts to tropical evergreen forests, as well as in human-dominated areas near agricultural lands. Golden jackals also scavenge from kills made by larger predators and often venture into human habitations at night to feed on garbage dumps or scavenge livestock carcasses. In the study area, golden jackals were captured in photos by only nine camera traps (Figure 9), predominantly in the western region.

Figure.9. Golden jackal spatial distribution obtained from camera trap captures (left - 2024, right - 2022) in Kumbhalgarh WLS. Below: Activity pattern obtained from camera trap captures.



Golden jackals exhibited primarily diurnal activity, with a prominent peak just after sunrise and a smaller peak after sunset. The activity patterns of golden jackals showed temporal avoidance of the activity peaks of leopards and hyenas.



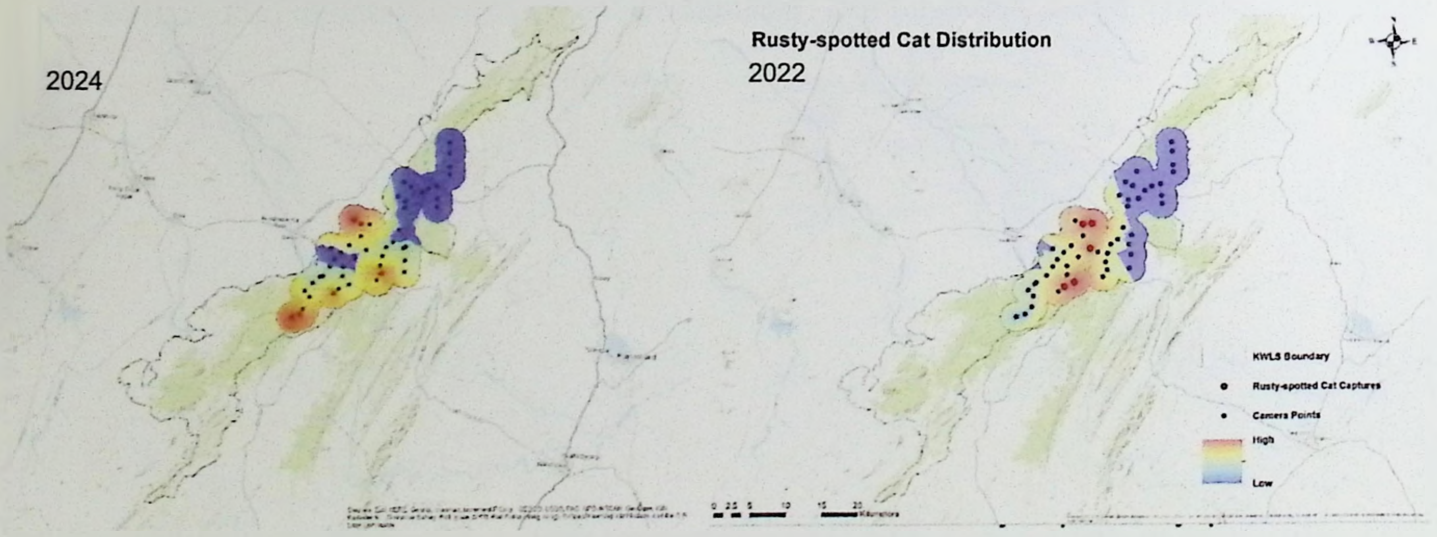


Rusty spotted cat

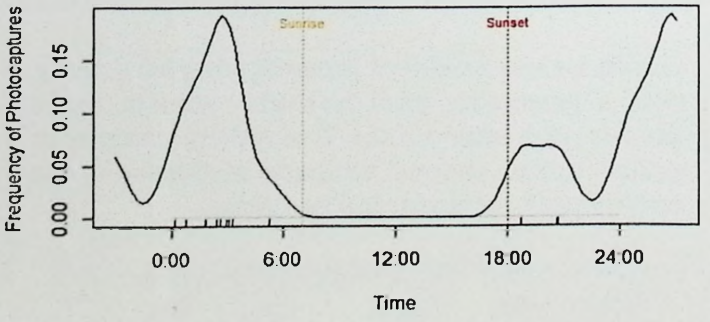
Prionailurus rubiginosus

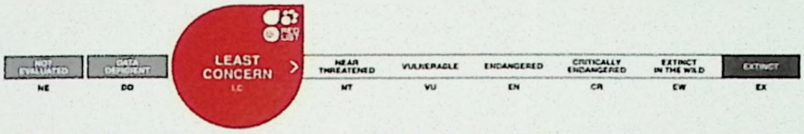
The rusty-spotted cat is the smallest wildcat in the world, endemic to India, Nepal, and Sri Lanka. Although it has been recorded across India, its ecology is poorly understood. The dry forests of the Aravalli range mark the western distribution of the species, where it has been photographed recently in multiple protected areas. In 2024, we recorded the rusty-spotted cat in six out of 49 camera traps (Figure 10). Since the species is semi-arboreal, trail-based camera traps may not be the most suitable method for documenting its activity or distribution.

Figure 10. Rusty-spotted cat spatial distribution obtained from camera trap captures (left - 2024, right - 2022) in Kumbhalgarh WLS. Below: Activity pattern obtained from camera trap captures.



As reported in previous studies, rusty spotted cats showed completely nocturnal behaviour with major activity peak post-midnight.



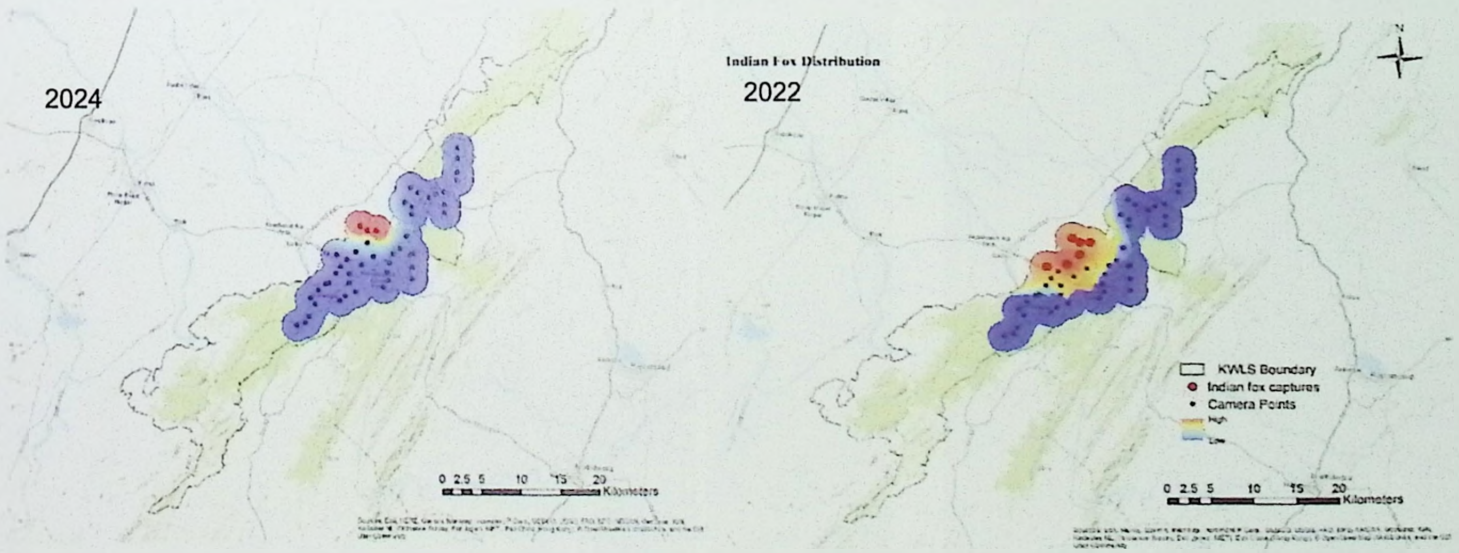


Indian Fox

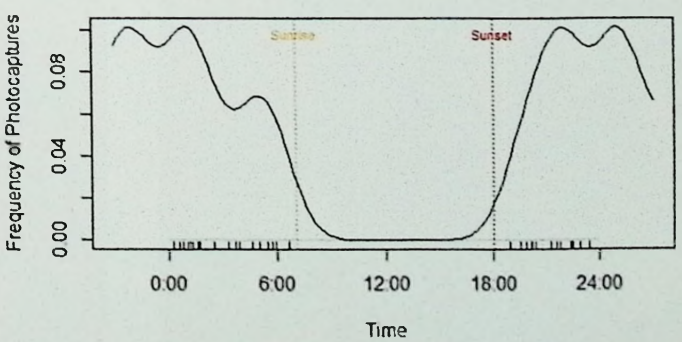
Vulpes bengalensis

The Indian fox, also known as the Bengal fox, ranges from the Himalayan foothills to the southern tip of the Indian peninsula. It prefers semi-arid plains, open scrub, and grasslands, which make hunting and digging dens easier. The fox avoids dense forests and tall grasslands. It is opportunistic and has an omnivorous diet consisting of small mammals, reptiles, birds, insects, and fruit. The Indian fox was photographed in only 3 out of 49 traps (Figure 11), predominantly in the western region.

Figure 11. Indian Fox spatial distribution obtained from camera trap captures (left - 2024, right - 2022) in Kumbhalgarh WLS.

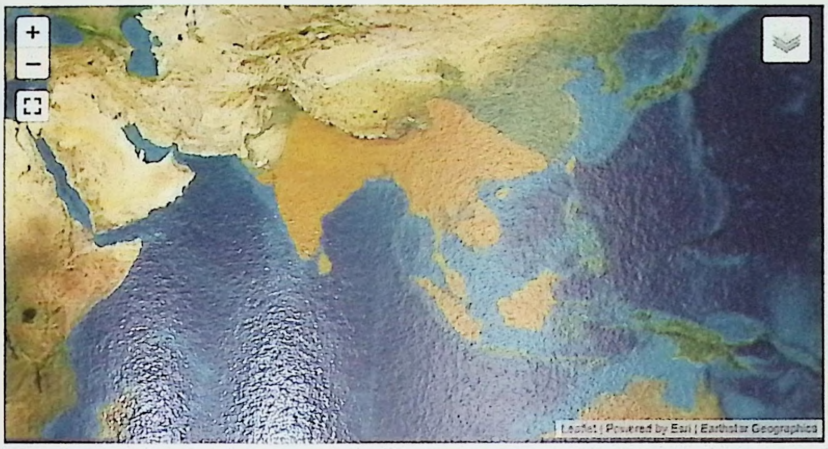


The Indian fox showed completely nocturnal activity patterns with a major peak in the midnight.



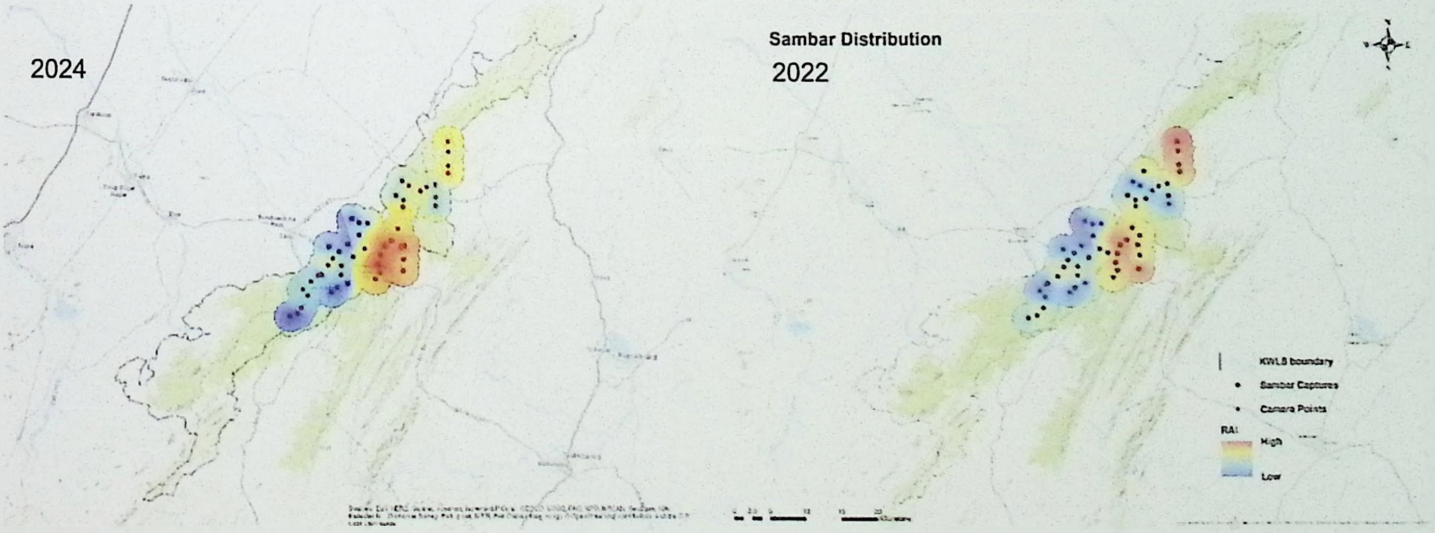
Sambar

Rusa unicolor

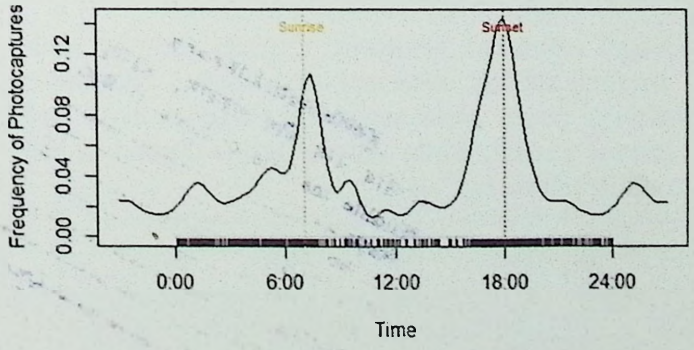


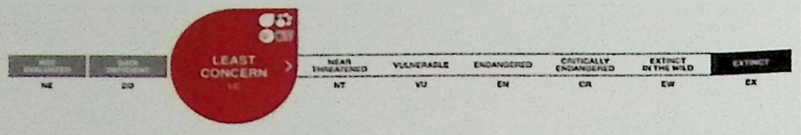
The sambar is a large deer species native to the Indian subcontinent and Southeast Asia. It is found in a wide range of forest habitats, from dry deciduous forests to evergreen and semi-evergreen forests. The sambar prefers hilly, undulating terrain and does not thrive in flat, open forest ecosystems. Sambars are among the most preferred prey species of large carnivores, such as tigers. The hill forests of Kumbhalgarh mark the westernmost distribution range of the species. In the present survey, the sambar was detected in 35 out of 49 camera traps, with higher capture rates on the eastern side of the sanctuary (Figure 12).

Figure.12. Sambar spatial distribution obtained from camera trap captures (left - 2024, right - 2022) in Kumbhalgarh WLS. Below: Activity pattern obtained from camera trap captures.



In the study area, sambar exhibited crepuscular behavior, with two prominent activity peaks at sunset and sunrise. They were also active during the day and were photographed at night.



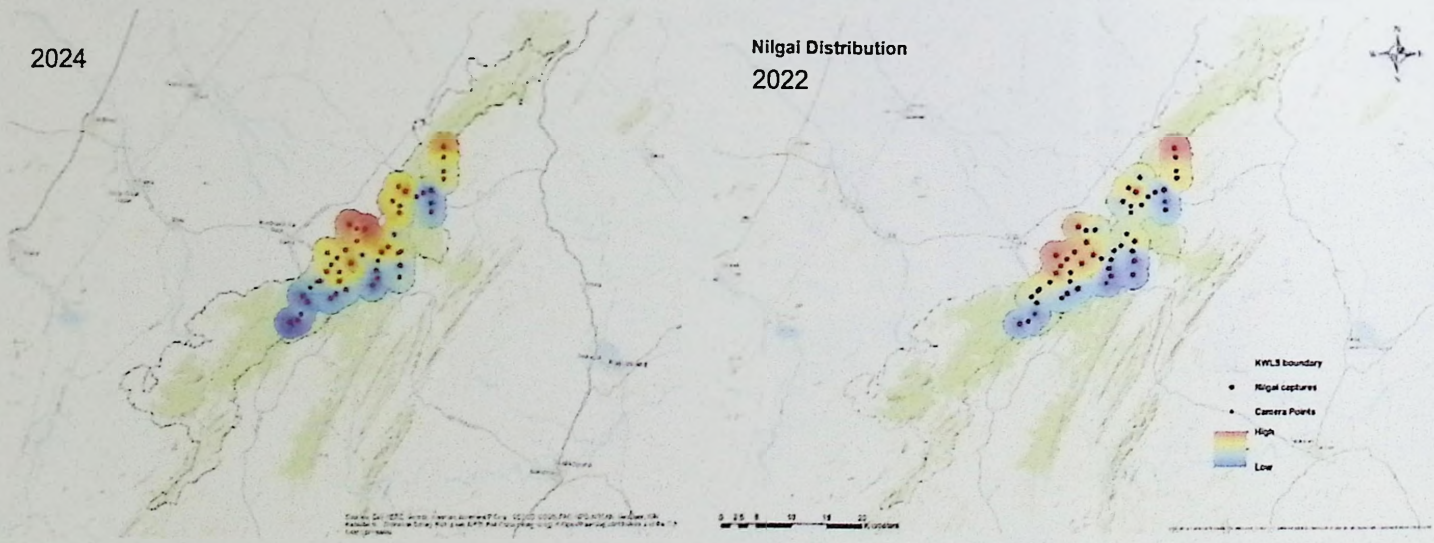


Nilgai

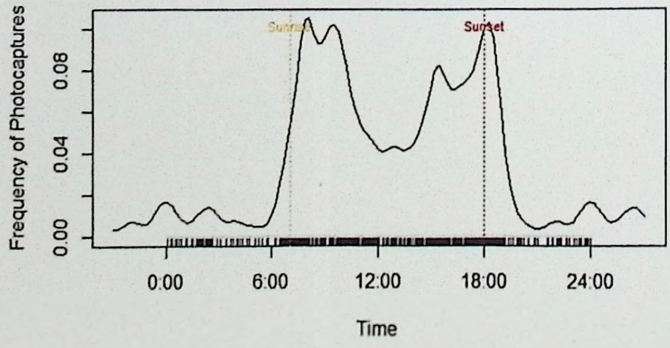
Boselaphus tragocamelus

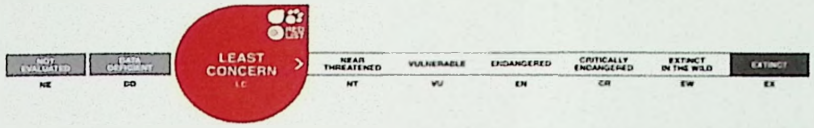
The nilgai, or blue bull, is the largest antelope in Asia and is widely distributed across India. Nilgai are habitat generalists, found in a variety of environments ranging from the dry forests of western and central India to the foothills of the Himalayas. However, they are absent from desert regions and evergreen forest patches. Due to their high tolerance for anthropogenic disturbances, nilgai are commonly observed in human-dominated landscapes, where they often come into conflict with local communities. In the study area, nilgai were photo-captured in 36 out of 49 camera traps. Capture rates were higher in the western part of the sanctuary, which is less hilly compared to the southern and eastern regions (Figure 13).

Figure.13. Nilgai spatial distribution obtained from camera trap captures (left - 2024, right - 2022) in Kumbhalgarh WLS. Below: Activity pattern obtained from camera trap captures.



Nilgai exhibited primarily diurnal activity, with minimal activity observed after sunset. The major activity peaks occurred shortly after sunrise and around sunset, while activity levels dipped in the middle of the day.



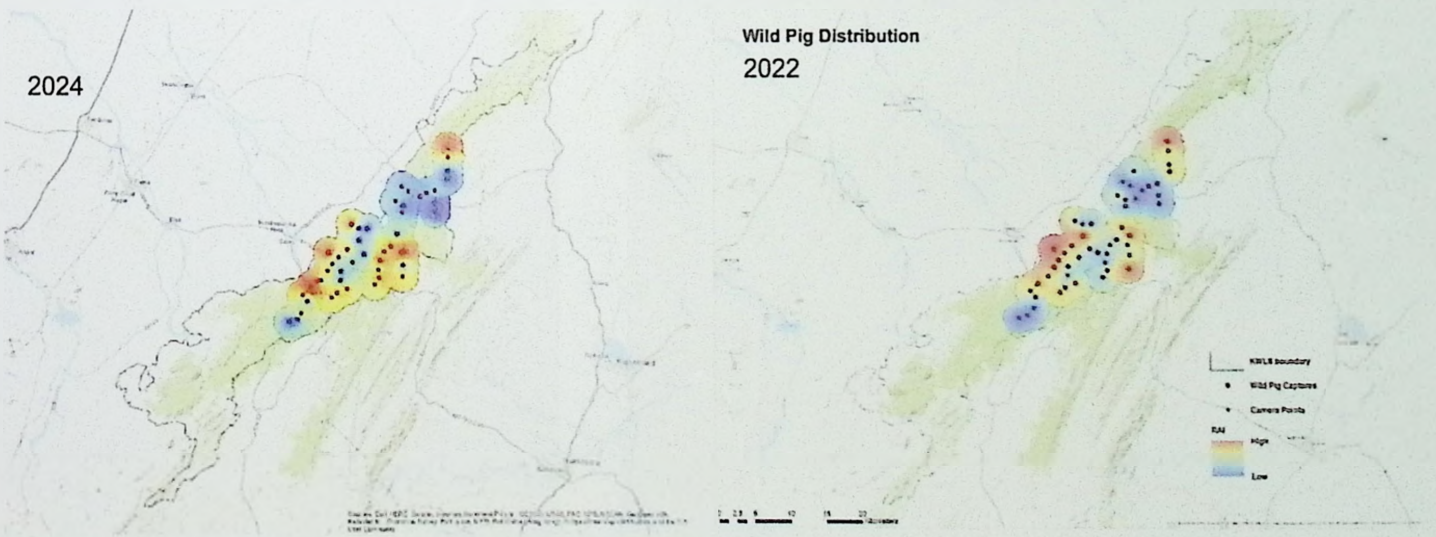


Wild Pig

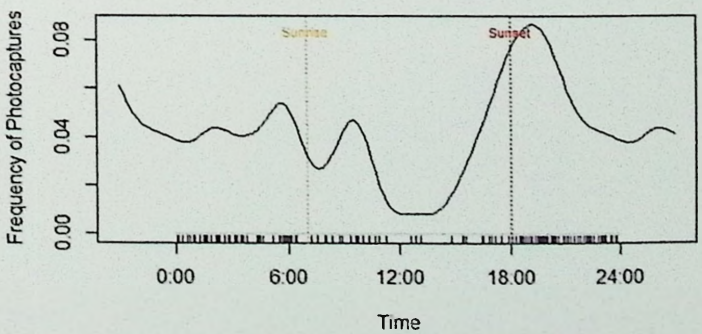
Sus scrofa

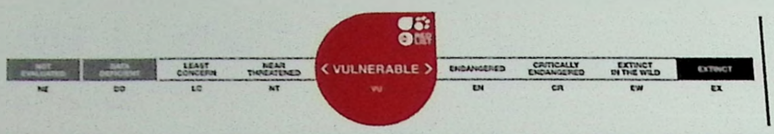
The wild pig is the most widely distributed ungulate species in the Indian subcontinent and constitutes a significant portion of the diet of large carnivores. Wild pigs can tolerate low to moderate levels of human disturbance and are therefore often found near human settlements. Consequently, there is a high risk of hybridization with domestic or feral pigs. Wild pigs are omnivorous, primarily relying on plant material but often scavenging on large carnivore kills or animal carcasses. They are predominantly nocturnal and live in herds; however, males often roam solitarily. During the study, wild pigs were photo-captured in 33 out of 49 camera traps distributed across the sanctuary (Fig. 14).

Figure.14. Wild Pig spatial distribution obtained from camera trap captures (left - 2024, right - 2022) in Kumbhalgarh WLS. Below: Activity pattern obtained from camera trap captures.



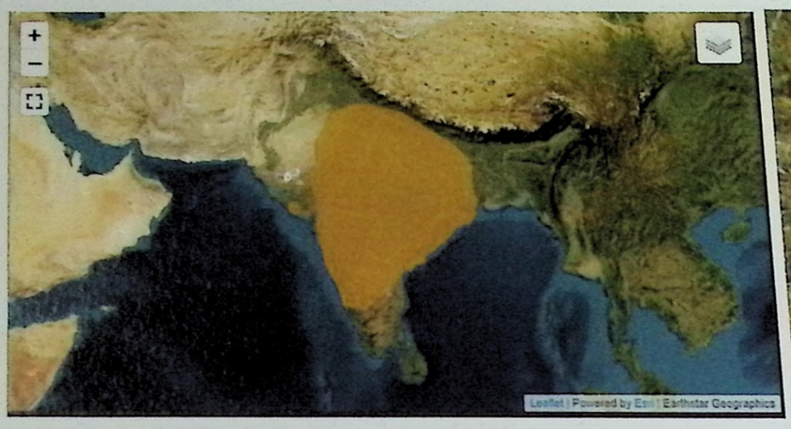
Wild pigs were mostly nocturnal; the activity patterns show the peak after the sunset. The activity of wild pigs around dusk was higher than that around dawn.





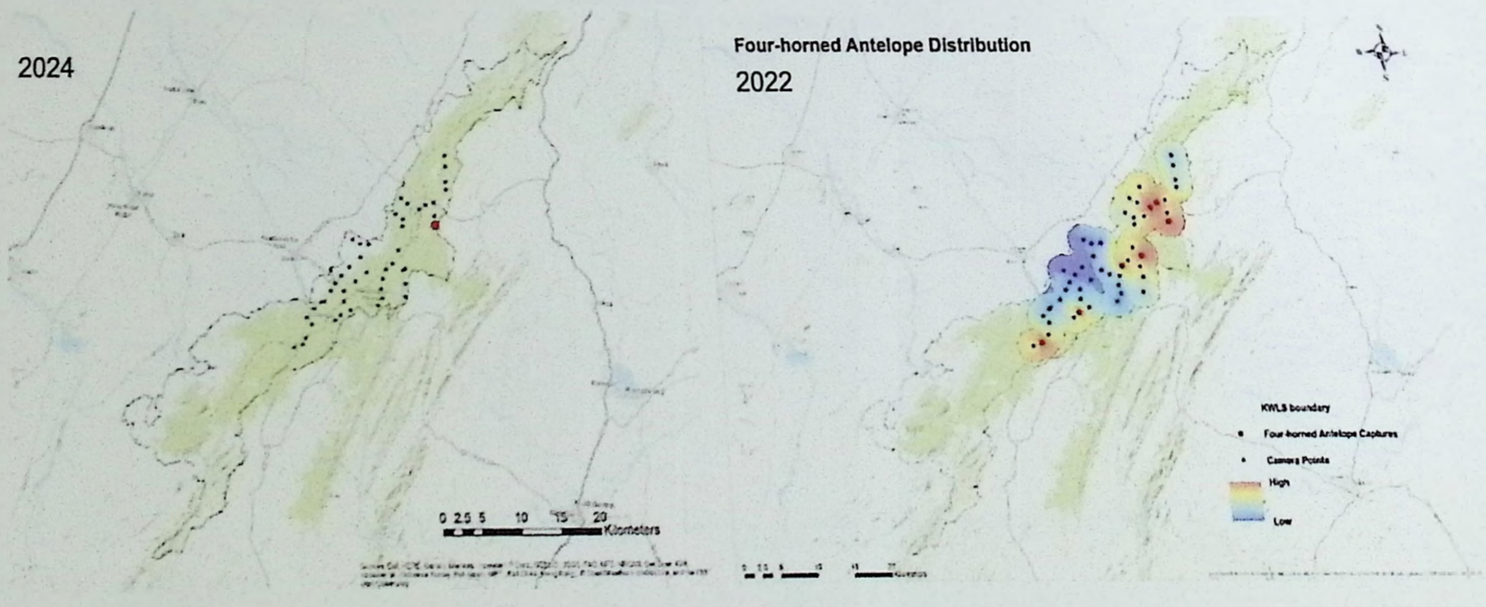
Chowsingha

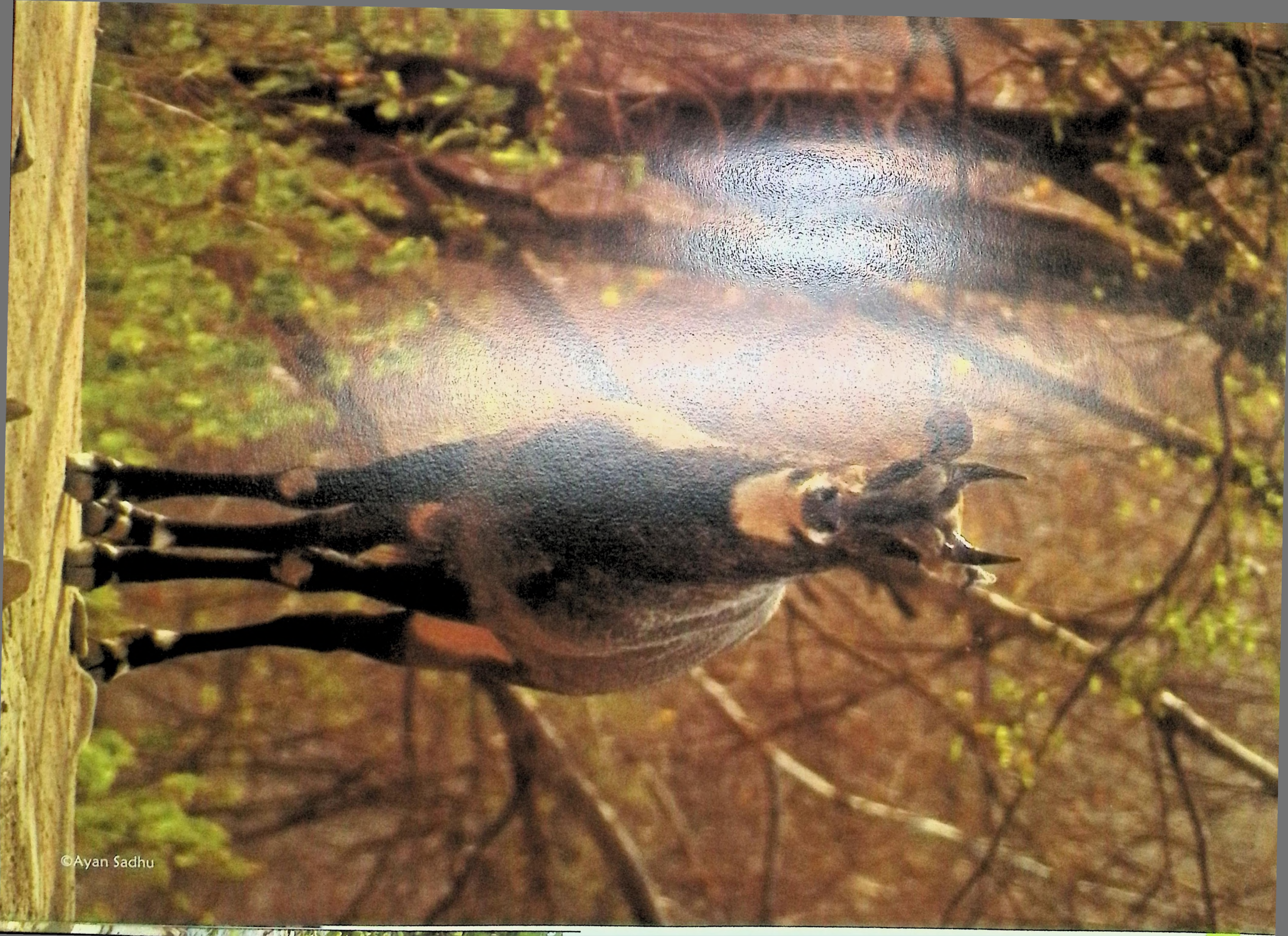
Tetracerus quadricornis



The four-horned antelope, or chowsingha, is a solitary forest-dwelling antelope found across India. Although four-horned antelopes are diurnal, they occur at low densities and are elusive, making direct sightings rare. In the western Indian landscape, the antelope is known to inhabit the forests of the Aravalli range. However, there is very little information available regarding their occupancy, habitat use, and population. They primarily inhabit open, dry deciduous forests. Males possess four true horns, which distinguish them from most other antelopes. One pair of horns is located between the ears, and the other on the forehead. Four-horned antelopes were photo-captured at only one location, in the Jhilwada range of Kumbhalgarh Wildlife Sanctuary (Fig. 15).

Figure.15. Four-horned Antelope spatial distribution obtained from camera trap captures (left - 2024, right - 2022) in Kumbhalgarh WLS.




©Ayan Sadhu

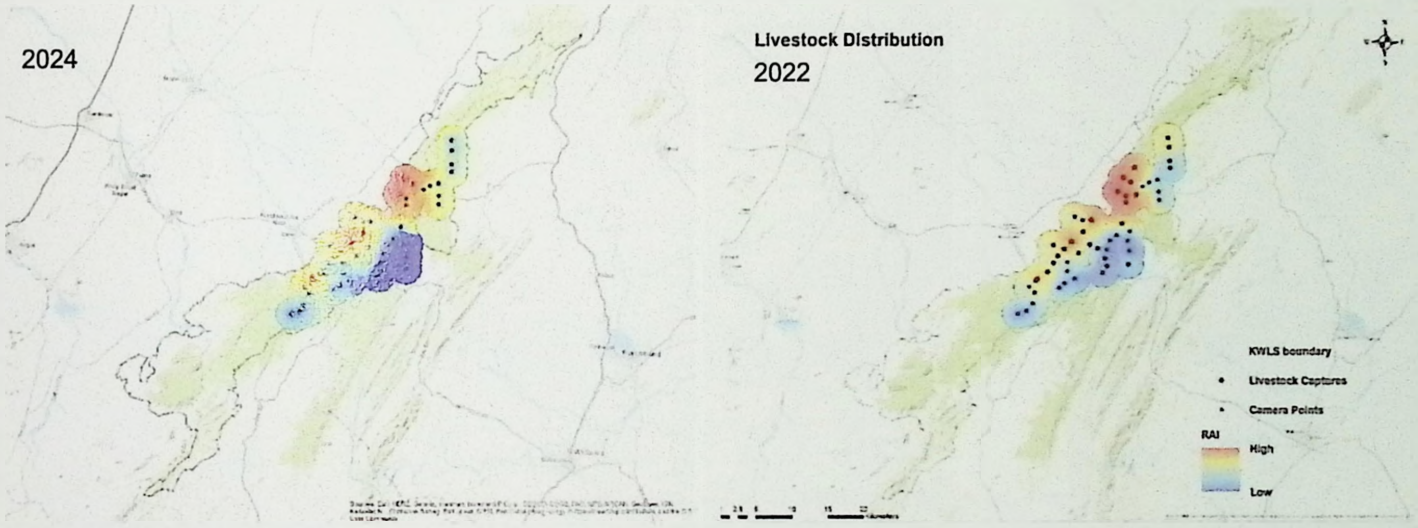
Others

Livestock

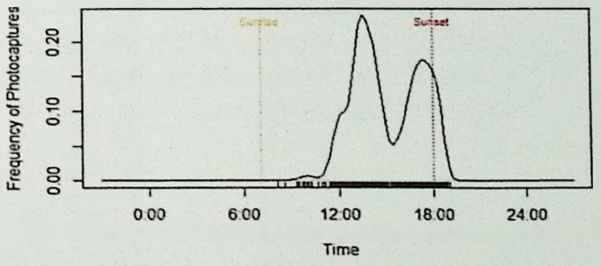
Goat, Sheep

Rajasthan hosts the largest livestock population in the country, with the Mewar region being particularly renowned for its abundance. Livestock farming serves as a vital source of income and livelihood for many rural and semi-rural communities residing in and around the Kumbhalgarh Sanctuary. For this analysis, goats and sheep were included in the livestock category. Livestock were photo-captured by 14 camera traps, with higher photo-capture rates recorded in the northwestern part of the sanctuary (Figure 16). Most livestock photo-captures were accompanied by images of humans and domestic dogs, indicating the presence of guarded livestock.

Figure.16. Livestock spatial distribution obtained from camera trap captures (left - 2024, right - 2022) in Kumbhalgarh WLS. Below: Activity pattern obtained from camera trap captures.



The livestock population exhibited a diurnal activity pattern within the Sanctuary, beginning around noon and showing bimodal peaks at approximately 2 PM and 5 PM.

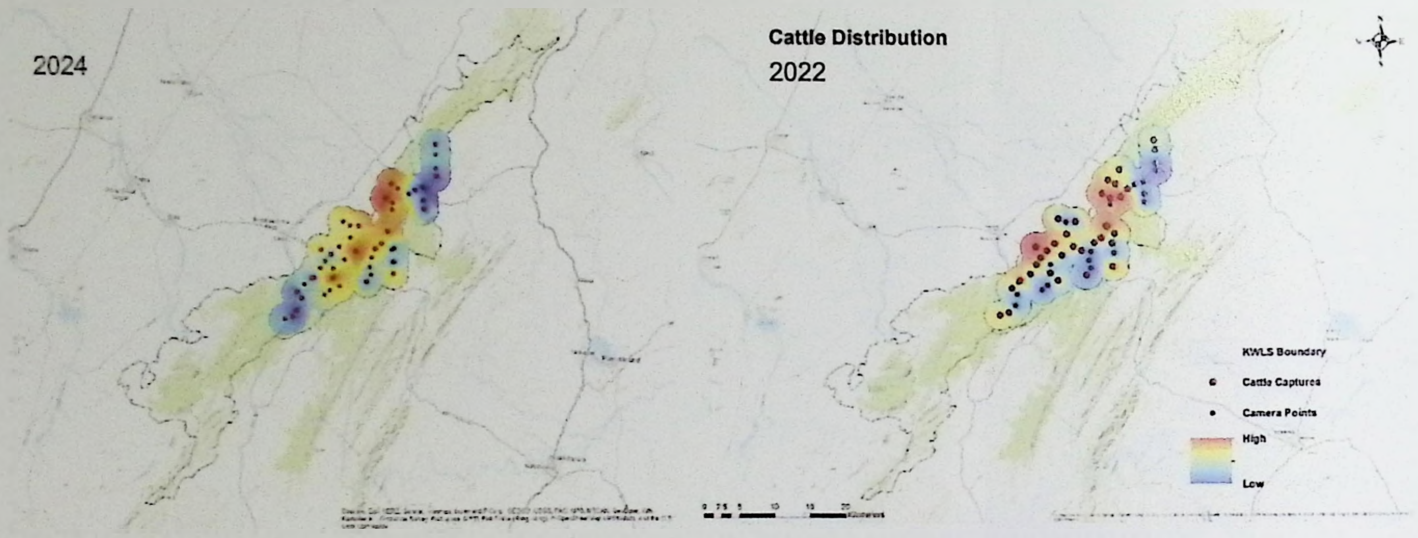


Cattle

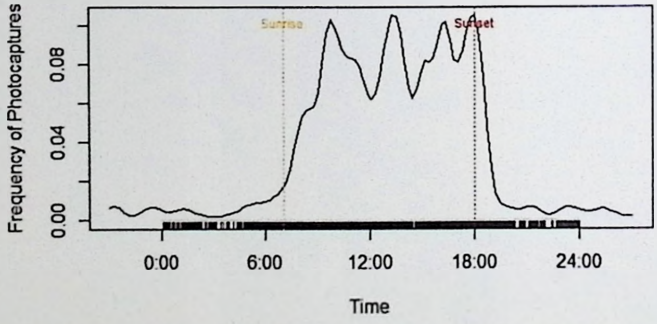
Cow, Buffalo

Rajasthan harbors one of the largest cattle populations in India. Many communities in Rajasthan have been pastoralists for generations, relying on grazing lands to sustain their cattle. However, traditional grazing lands have diminished due to conversion to human land use, agricultural expansion, and desertification. Consequently, many pastoralists are forced to move their cattle into protected areas. For this study, we categorized cattle to include buffalo and cows. Cattle were among the most frequently photo-captured species in the sanctuary, with 45 out of 49 camera traps detecting their presence. They were distributed throughout the sanctuary, with higher photo-capture rates observed in the western part (Figure 17).

Figure.17. Cattle spatial distribution obtained from camera trap captures (left - 2024, right - 2022) in Kumbhalgarh WLS. Below: Activity pattern obtained from camera trap captures.



The cattle exhibited primarily diurnal activity patterns, with activity ceasing after dusk. Activity resumed after dawn, with multiple activity peaks observed in the study area.

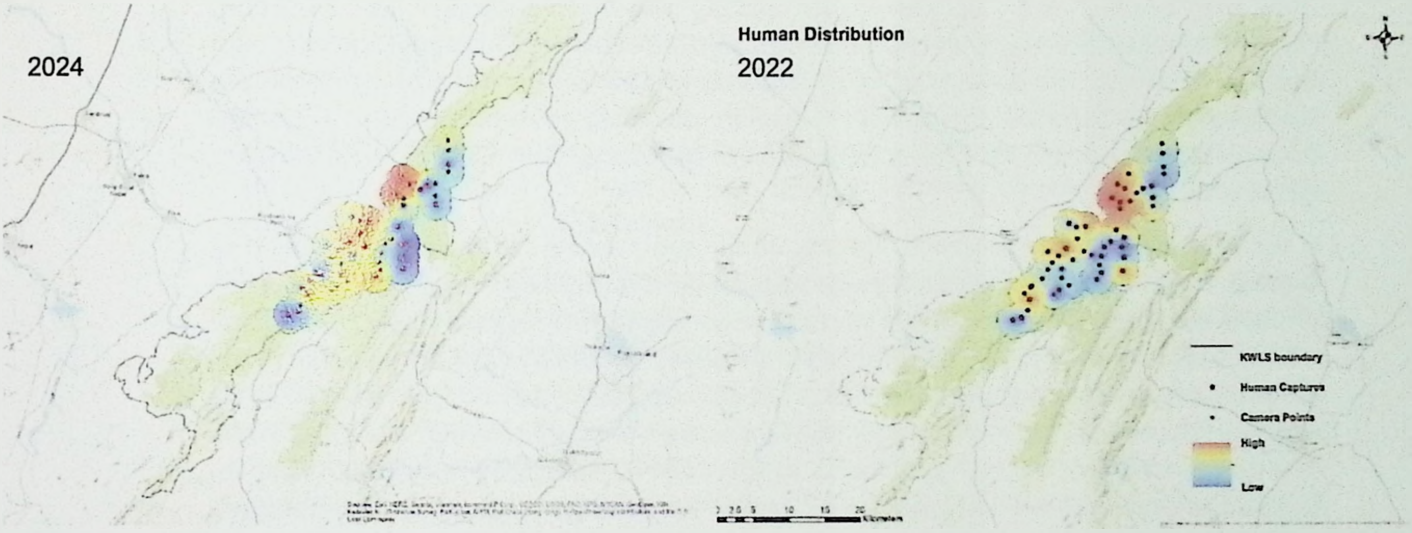


Humans

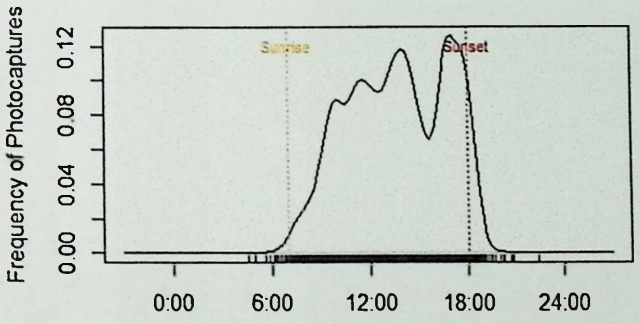
Homo sapiens

Kumbhalgarh is surrounded by human-dominated landscape, and many of these people are dependent on forest resources for their livelihood, therefore, human footfalls inside the sanctuary is quite significant. During the survey, humans were observed in 44 camera traps, mostly accompanying the cattle and collecting fuelwood. The western part of the Sanctuary experienced comparatively higher photo-capture rate of human (Figure. 18). It is worth to mention that, in the north-western part of the Sanctuary, construction work was going on (by the Forest Department), therefore, photo-captures of daily labours were also there and likely to inflate the capture rates.

Figure.18. Human spatial distribution obtained from camera trap captures (left - 2024, right - 2022) in Kumbhalgarh WLS.



Human activity was restricted exclusively in the day time with a major peak before sunset.



05| Discussions

In the Anthropocene, widespread human activities have caused range loss and population decline for most wildlife species across the globe. In this scenario, protected areas act as the cornerstone for biodiversity conservation. Therefore, monitoring the status of protected areas and the wildlife living inside the PAs is the need of the hour. The present camera trapping survey depicted the presence of a diverse carnivore and herbivore community in the semi-arid landscape of Kumbhalgarh Wildlife Sanctuary. This information, along with the previous camera trapping sampling (2022), will provide a robust baseline for the distribution and abundance of wildlife in the landscape. Prior to this survey, such information was not readily available for this landscape; therefore, this study shall be used as the benchmark for making site-specific conservation decisions. The forests of the Kumbhalgarh region were once the westernmost distribution of Bengal tigers in the world. However, local extinctions caused mostly by hunting wiped out the tiger population from this landscape. Presently, the state government has earmarked Kumbhalgarh as a potential Tiger Reserve, which shall safeguard the ecological integrity of this area.

In the absence of tigers, leopards operate as the top predator in these hilly forests of Aravalli. Kumbhalgarh harbors a high-density leopard population, ranging between 17-19 individuals per 100 km^2. While there was no significant difference in the leopard density between 2022 and 2024 (Table 2), our study observed substantial turnover in the population, depicting a dynamic leopard population in the study area. Out of 52 leopards photo-captured in 2024, only 26 were found common between 2022 and 2024. This turnover in the leopard population needs to be investigated with long-term, in-depth ecological studies. The detection-corrected sex ratio for leopards in Kumbhalgarh was female-biased (Female: Male ~3:1). It is likely that female leopards are using the rugged, forested landscape of Kumbhalgarh as a refuge from the relatively hostile, human-dominated landscape outside the sanctuary. It would be interesting to study the change in space use and behavior of leopards (if any) post-reintroduction of tigers in the landscape, almost after a century.

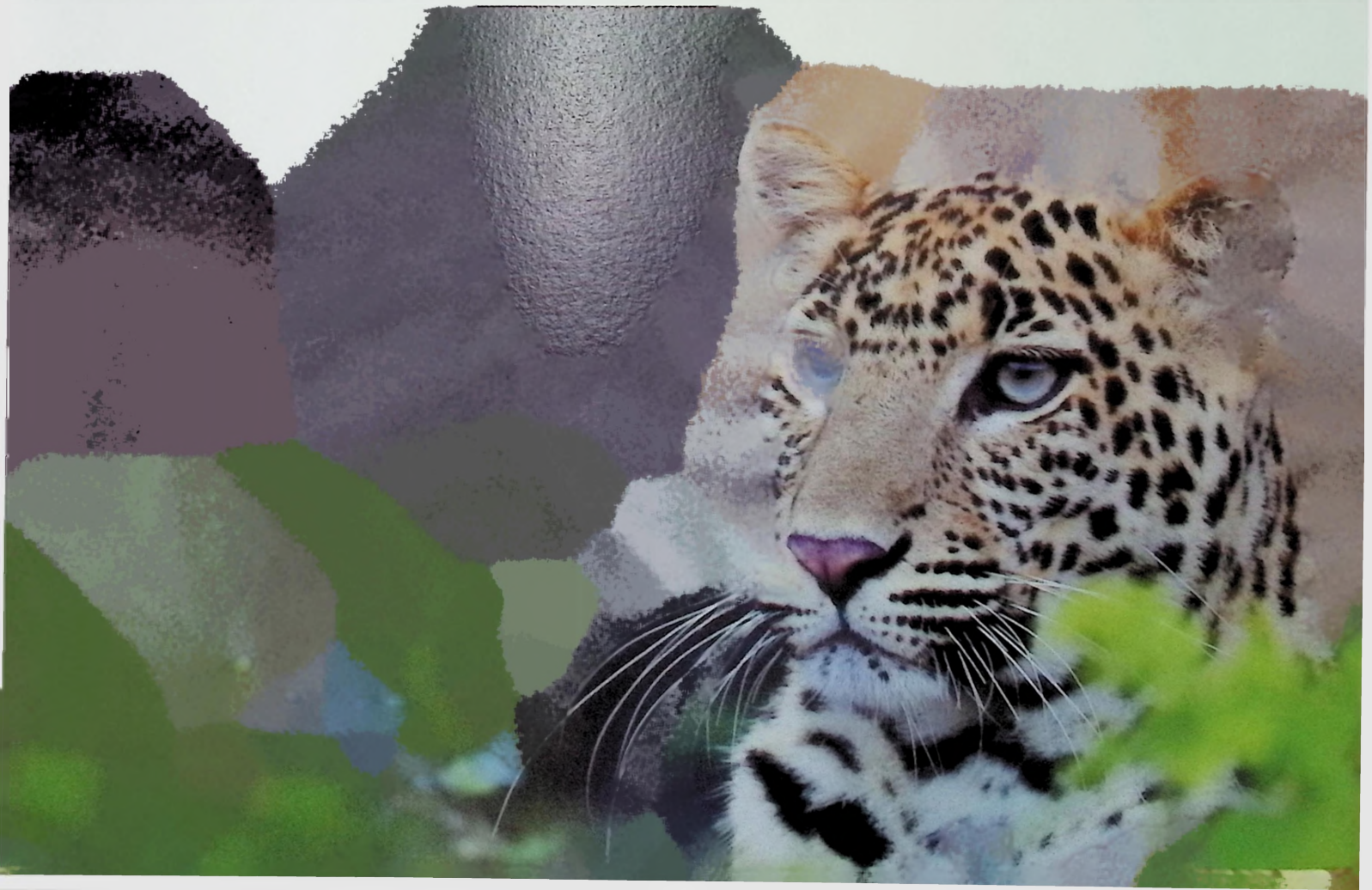
Besides leopards, Kumbhalgarh also harbors a sizable population of striped hyenas and sloth bears. The striped hyena remained one of the most photo-captured carnivores in the area, and the relative abundance index of striped hyenas for both 2022 and 2024 remained stable, depicting a stable hyena population in the sanctuary. While the leopard and hyena populations seem to be stable, the relative abundance index of the sloth bear dropped drastically in 2024 (compared to 2022, Table 1), and a similar pattern was observed in the case of the honey badger. This could be due to resource scarcity inside the sanctuary during winter for bears and badgers, while availability of guaranteed resources near villages (bee farms, crops, etc.) may have attracted them. Therefore, it is likely that, in winter, the activity of sloth bears and honey badgers will be less inside the sanctuary and more concentrated near the villages, resulting in fewer photo-captures of bears in 2024 (winter) compared to 2022 (summer). However, this needs to be investigated in a detailed manner to understand this dynamic system.

The temporal activity patterns among the carnivores, showing nocturnal or crepuscular activity peaks, suggest an avoidance strategy from anthropogenic interference. By adopting this strategy, the large carnivores adjust themselves in the human-dominated landscape.

Apart from the large carnivores, Kumbhalgarh also harbors a diverse community of smaller carnivores (Table 1). The jungle cat and rusty-spotted cat capture rates increased in 2024 compared to 2022; however, their spatial distribution remained similar. The capture rate of golden jackals increased in 2024 compared to 2022, which is likely to have caused a decline in the capture rate of Indian foxes in 2024 (Table 1). It's interesting that the relative abundance of small and meso-carnivores is lower in comparison to Ranthambore (Latafat et al. 2023), most likely due to the higher presence of leopards and hyenas in the sanctuary. However, detailed research needs to be conducted to understand such intricacies.

The projected prey density of sambar, wild pig, and nilgai remained stable between 2022 and 2024, which is a positive sign. However, in these hilly forest patches, chital is absent. Creating suitable habitat for chital is challenging in this landscape due to the unavailability of valley/flat areas with intact grassland ecosystems. Nonetheless, it is important to nurture at least a few pockets of suitable chital habitat before reintroducing tigers in Kumbhalgarh.

Kumbhalgarh Wildlife Sanctuary is one of the last remnants of forests left in the Aravalli range and is rich in biodiversity. The high density of leopards underscores the importance of Kumbhalgarh with respect to large carnivore conservation. Our findings indicated a sizable population of leopards, striped hyenas, and sloth bears in the sanctuary. A detailed study using radio telemetry, intensive, and long-term camera trapping would provide interesting insights into the demography, resource selection, interactions, and behavior of these elusive carnivores in the Kumbhalgarh landscape.



References

Borchers, D. L., & Efford, M. G. (2008). Spatially explicit maximum likelihood methods for capture–recapture studies. *Biometrics*, *64*(2), 377-385.

Buckland, S. T., Anderson, D. R., Burnham, K. P., Laake, J. L., Borchers, D. L., & Thomas, L. (Eds.). (2004). *Advanced distance sampling: estimating abundance of biological populations*. OUP Oxford.

Burton, A. C., Neilson, E., Moreira, D., Ladle, A., Steenweg, R., Fisher, J. T., ... & Boutin, S. (2015). Wildlife camera trapping: a review and recommendations for linking surveys to ecological processes. *Journal of applied ecology*, *52*(3), 675-685.

Carbone, C., Christie, S., Conforti, K., Coulson, T., Franklin, N., Ginsberg, J. R., ... & Shahruddin, W. W. (2001, February). The use of photographic rates to estimate densities of tigers and other cryptic mammals. In *Animal Conservation forum* (Vol. 4, No. 1, pp. 75-79). Cambridge University Press.

Champion, H. G. (1968). A revised survey of the forest types of India. *Government of India Publication*.

Cohen, I., Huang, Y., Chen, J., Benesty, J., Benesty, J., Chen, J., ... & Cohen, I. (2009). Pearson correlation coefficient. *Noise reduction in speech processing*, 1-4.

Dirzo, R., Young, H. S., Galetti, M., Ceballos, G., Isaac, N. J., & Collen, B. (2014). Defaunation in the Anthropocene. *science*, *345*(6195), 401-406.

Efford, M. G. (2012). secr: Spatially explicit capture-reapture models. R package version 2.3. 2. http://CRAN.R-project.org/package=secr.

Efford, M. G., Borchers, D. L., & Byrom, A. E. (2009). Density estimation by spatially explicit capture–recapture: likelihood-based methods. *Modeling demographic processes in marked populations*, 255-269.

Efford, M. G., Dawson, D. K., & Borchers, D. L. (2009). Population density estimated from locations of individuals on a passive detector array. Ecology, 90(10), 2676-2682.

ESRI (2016) ArcGIS for Desktop 10.5. Environmental Systems Research Institute, Redlands.

Woodroffe, R., & Ginsberg, J. R. (1998). Edge effects and the extinction of populations inside protected areas. Science, 280(5372), 2126-2128.

Hayward, M. W., O'Brien, J., & Kerley, G. I. (2007). Carrying capacity of large African predators: predictions and tests. *Biological Conservation*, *139*(1-2), 219-229.

Hiby, L., Lovell, P., Patil, N., Kumar, N. S., Gopalaswamy, A. M., & Karanth, K. U. (2009). A tiger cannot change its stripes: using a three-dimensional model to match images of living tigers and tiger skins. *Biology letters*, *5*(3), 383-386.

Hines, J. E. (2006). PRESENCE2: Software to estimate patch occupancy and related parameters. USGS-PWRC. *http://www. mbr-pwrc. usgs. gov/software/presence. html.*

Karanth, K. U., Nichols, J. D., Seidenstricker, J., Dinerstein, E., Smith, J. L. D., McDougal, C., ... & Thapar, V. (2003, May). Science deficiency in conservation practice: the monitoring of tiger populations in India. In *Animal Conservation forum* (Vol. 6, No. 2, pp. 141-146). Cambridge University Press.

Khan, J. A., Chellam, R., Rodgers, W. A., & Johnsingh, A. J. T. (1996). Ungulate densities and biomass in the tropical dry deciduous forests of Gir, Gujarat, India. *Journal of Tropical Ecology*, *12*(1), 149-162.

Kinnaird, M. F., & O'brien, T. G. (2012). Effects of private-land use, livestock management, and human tolerance on diversity, distribution, and abundance of large African mammals. *Conservation Biology*, *26*(6), 1026-1039.

Latafat, K., Sadhu, A., Qureshi, Q., & Jhala, Y. V. (2023). Abundance and activity of carnivores in two protected areas of semi-arid western India with varying top predator density and human impacts. European Journal of Wildlife Research, 69(1), 15.

MacKenzie, D. I., Nichols, J. D., Lachman, G. B., Droege, S., Andrew Royle, J., & Langtimm, C. A. (2002). Estimating site occupancy rates when detection probabilities are less than one. *Ecology*, *83*(8), 2248-2255.

Meredith, M., & Ridout, M. (2014). Overview of the overlap package. *R. Proj*, 1-9..

Mlavec, J. (2010). *Locus Map* (Version 4.0) [Mobile app]. Asamm Software. https://www.locusmap.app

O'brien, T. G. (2008). On the use of automated cameras to estimate species richness for large- and medium-sized rainforest mammals. *Animal Conservation*, *11*(3).

O'Brien, T. G., Kinnaird, M. F., & Wibisono, H. T. (2003, May). Crouching tigers, hidden prey: Sumatran tiger and prey populations in a tropical forest landscape. In *Animal Conservation Forum* (Vol. 6, No. 2, pp. 131-139). Cambridge University Press.

O'Connell, A. F., Nichols, J. D., & Karanth, K. U. (2011). *Camera traps in animal ecology: methods and analyses* (Vol. 271). New York: Springer.

Qureshi, Q., Jhala, Y. V., Yadav, S. P., Tiwari, V. R., Garawad, R., & Mallick, A. (2024). Status of Leopards in India, 2022. *National Tiger Conservation Authority, Government of India, New Delhi, and Wildlife Institute of India, Dehradun*.

Shehzad, W., Nawaz, M. A., Pompanon, F., Coissac, E., Riaz, T., Shah, S. A., & Taberlet, P. (2015). Forest without prey: livestock sustain a leopard Panthera pardus population in Pakistan. *Oryx*, *49*(2), 248-253.

Singh, P., & Reddy, G. V. (2016). Lost Tigers Plundered Forests: A report tracing the decline of the Tiger across the state of Rajasthan (1900 to Present). *WWF India, New Delhi, 131pp*.

Williams, B. K., Nichols, J. D., & Conroy, M. J. (2002). *Analysis and management of animal populations*. Academic press