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continued on the back inside cover

Cover: Nilgiri Large Burrowing Spider *Haploclastus nilgirinus*. Acrylic on canvas. © Aakanksha Komanduri.

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ARTICLE

Evaluating wildlife activity and corridor functionality: a study of underpasses in and around Rajaji National Park, India

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Abstract: Habitat fragmentation threatens biodiversity, making wildlife corridors vital for maintaining ecological connectivity. This study evaluated the functionality of three corridors—Chilla-Motichur, Teenpani, and Laltappar—in and around Rajaji National Park, Uttarakhand, India. We deployed camera traps at these corridors and surrounding forest areas for 8,198 trap nights to monitor the wildlife use of the corridors. We recorded 17 species of wild animals in the connected forested area and nine within the corridors. The Wild Pig *Sus scrofa* and Sambar *Rusa unicolor* were the most frequently captured species, with the highest Relative Abundance Index (RAI) in the Teenpani corridor. Activity patterns of wild species showed changes in the corridor compared to forest areas. Chital *Axis axis* exhibited continuous activity in corridors but an early-morning peak in forests (Δ = 0.68). Asiatic Elephant *Elephas maximus* shifted from daytime activity in forests to nocturnal peaks in corridors, likely avoiding human presence (Δ = 0.48). Sambar avoided daytime activity in the corridor compared to activity in the forest (Δ = 0.55), while Wild Pig maintained nocturnal peaks across both habitats (Δ = 0.71). Human activity, primarily diurnal, overlapped with Chital (Δ = 0.61) and increased potential encounters with Elephants and Leopards during evening hours (Δ = 0.25 and 0.39, respectively). Mitigation measures, such as habitat restoration and managing anthropogenic activities, are crucial for strengthening corridor functionality. The recent reintroduction of tigers in western Rajaji underscores the importance of these corridors for species connectivity and genetic exchange. This study provides valuable insights into managing wildlife corridors in human-dominated landscapes, highlighting their role in biodiversity conservation.

Keywords: Asiatic Elephant, camera trapping, conservation monitoring, habitat connectivity, human disturbance, infrastructure mitigation, species activity patterns.

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Author details and **Author contributions:** Nishant Verma (APCCF, Uttarakhand Forest Department) conceptualised the study, conducted fieldwork, analysed data, and wrote the first draft. Saket Badola (former director, Rajaji Tiger Reserve) assisted with data collection and manuscript preparation. Samrat Mondol (scientist, Wildlife Institute of India) contributed to the study design and reviewed the manuscript.

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INTRODUCTION

The rapid expansion of human activities has led to significant alterations in natural landscapes. Habitat loss and fragmentation are two main contributors to biodiversity decline (Haddad et al. 2015). Anthropogenic habitat loss occurs when natural areas are converted for human activities such as agriculture, horticulture, infrastructure development, and urban expansion. Roads, railways, and urban expansion fragment once-continuous landscapes, thus impeding wildlife movement, disrupting ecological processes, and increasing the risk of local extinctions (Laurance et al. 2014; van der Ree et al. 2015). These processes disrupt habitat connectivity, impacting the movement, dispersal, and genetic exchange of wildlife populations (e.g., Callens et al. 2011; Napolitano et al. 2015). Such disruptions can have profound consequences, including population decline and loss of ecosystem functionality. Therefore, connecting natural habitats through ecological corridors is crucial for maintaining gene flow and population viability in the wild (Holderegger & Di Giulio 2010).

Wildlife corridors, composed of native vegetation, link larger habitat patches and facilitate animal movement (Burkart et al. 2016). By mitigating the effects of habitat loss and fragmentation, these corridors help sustain healthy animal populations and preserve biodiversity. In human-dominated landscapes, corridors are essential conservation tools, enabling wildlife to navigate fragmented habitats and reducing the risks of isolation and local extinctions.

The Terai Arc Landscape (TAL), spanning the Himalayan foothills in India and Nepal, is among the world's 200 globally significant ecoregions (Olson & Dinerstein 1998). This landscape harbours flagship species such as the Royal Bengal Tiger *Panthera tigris* and the Asiatic Elephant *Elephas maximus*, which require large, connected habitats for survival (Jhala et al. 2015). TAL is also a human-dominated landscape, facing significant challenges from expanding settlements, agriculture, and transportation infrastructure (Harihar & Pandav 2012). Corridors within this landscape are critical for maintaining connectivity between protected areas, yet many have become degraded due to anthropogenic pressures.

Rajaji National Park (RNP), spanning 820 km² within the western TAL, is a key protected area for Tigers, elephants, and other large mammals. This park is bifurcated into eastern and western sections by the Ganges River (Johnsingh et al. 2004). Additionally, highways and railway lines connecting Haridwar and Dehradun, two of Uttarakhand's most populated cities, create significant movement barriers for wildlife between protected areas and surrounding patches of reserve forests. Particularly, the connectivity between the Barkot Range of the territorial forest and the Kansrao Range of RNP is critical for elephant movement in this landscape (Johnsingh et al. 2004). Historically, the erstwhile Chilla-Motichur corridor played a crucial role in facilitating wildlife movement across both banks of the Ganges. This 3-km long and 1-km wide stretch of forest land that connects the Chilla Forest range on the eastern part of the Ganga to the Motichur Range on the west bank, is the only functional link between the eastern and western parts of RNP. While roads, railways, and irrigation channels hinder wildlife movement, roads pose the greatest barrier due to a continuous traffic flow. To address these challenges, three wildlife underpasses—Chilla-Motichur, Teenpani, and Laltappar—were constructed on the highway to provide connectivity between forested habitats within and around the park in 2021 (Nigam et al. 2022).

In this study, the current functionality of these three corridors were accessed in facilitating wildlife movement. Using camera-trap data, the activity patterns of key species — Leopard *Panthera pardus*, Asiatic Elephant, Spotted Deer or Chital *Axis axis*, Sambar *Rusa unicolor*, and Wild Boar *Sus scrofa*—were compared within the corridors and nearby forest ranges. It was also examined how human activities influence wildlife behaviour and corridor usage. By assessing corridor effectiveness, this study provides data-driven insights for enhancing connectivity and informing conservation planning in RNP and the broader TAL.

MATERIAL AND METHODS

Study Area

The study was conducted in the western part of Rajaji National Park (RNP), situated in Uttarakhand, India (30.248–29.850 ^{0}N & 77.878–78.444 ^{0}E), within the Terai Arc Landscape (TAL). The study focused on three wildlife corridors—Chilla-Motichur, Teenpani, and Laltappar—which have been established to connect fragmented forest patches of the Chilla, Motichur, & Kansrao ranges of RNP, and Barkot & Rishikesh ranges of the Dehradun Forest Division (Image 1). These corridors are intersected by major highways and railways, with underpasses designed to mitigate barriers to wildlife movement. The Chilla-Motichur underpass is 900 m

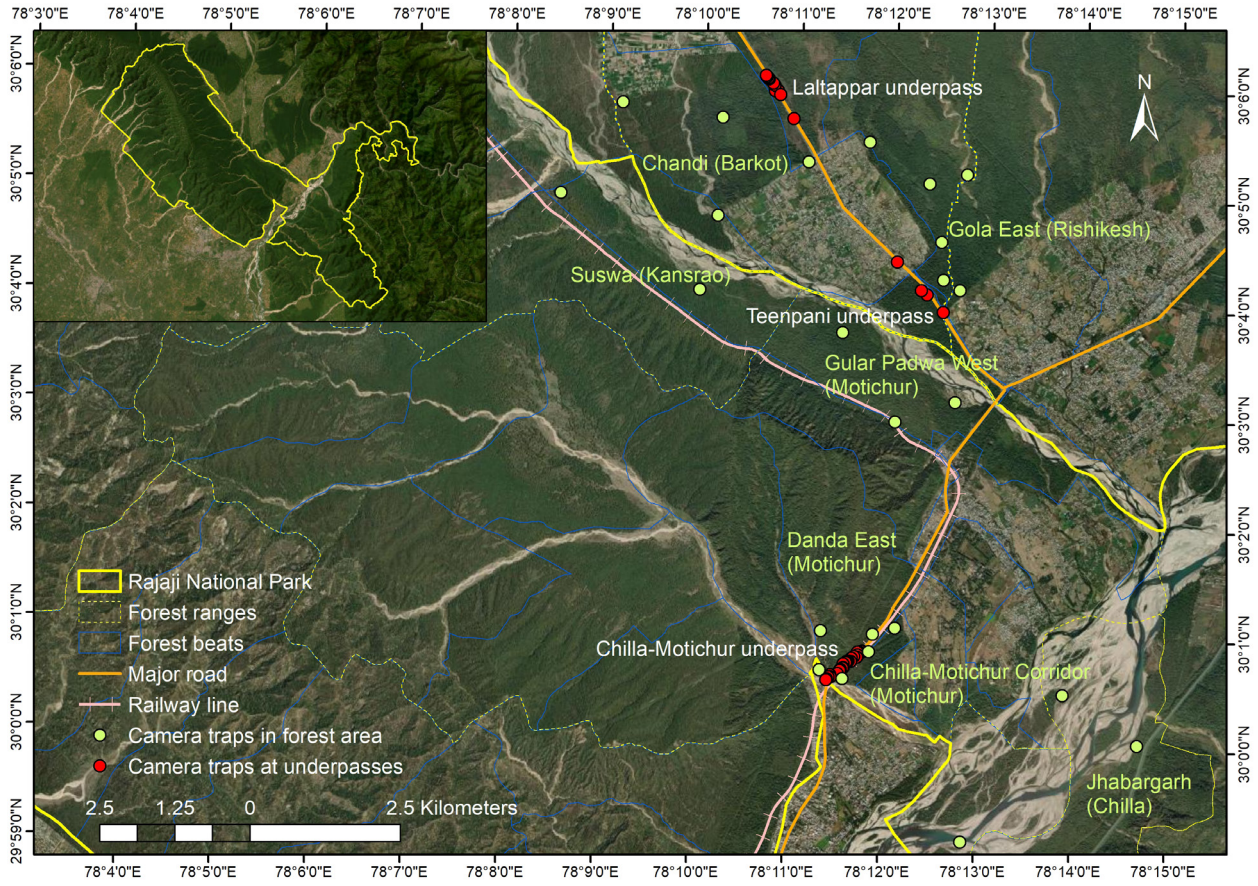

Image 1. Location of the three corridors — Laltappar, Teenpani, and Chilla-Motichur — at the boundary of the western Rajaji National Park. All three corridors are traversed by road, and wildlife underpasses are built on all three roads. Sampled forest beats are mentioned in green text.

long, while the Teenpani and Laltappar underpasses are each approximately 500 m in length. These underpasses provide critical connectivity between forested habitats in the park and adjacent territorial forests (Nigam et al. 2022).

The vegetation of RNP is primarily tropical moist and dry deciduous forests (Champion & Seth 1968), dominated by Sal *Shorea robusta*. Riverine forests and scrublands are also present. The region supports diverse wildlife, including flagship species such as the Tiger, Asiatic Elephant, and Leopard. It also harbours a rich diversity of avifauna and herpetofauna.

Camera-trapping

Camera traps were deployed between April and November 2022 across the corridors and adjacent forest ranges (Table 1). Sixty-four motion-triggered digital cameras (Cuddeback Model C1) were installed, yielding a total of 8,198 trap nights. Cameras were single-sided and mounted approximately 30–40 cm above ground level. Under the flyovers, the cameras were placed at a minimum of 25 m to a maximum of 100 m distance from each other along the flyover, so that any animal crossing the flyover would not be missed out. The Chilla-Motichur corridor was monitored by 24 cameras, whereas the Teenpani and Laltappar corridors each had eight cameras. Eight adjacent forest beats in five ranges of RNP and the Dehradun Forest division were sampled to understand the presence of wildlife. Three camera traps were deployed in each of the beats, except for six cameras in the Chandi beat of Barkot Range as it was relatively larger (Image 1, Table 1). Camera traps were strategically placed along trails, riverbanks, and other linear features to maximize the detection of medium- and large-sized mammals, which commonly use these pathways (Jhala et al. 2015). All the camera traps were active 24 h and monitored every fortnight to check the battery status and retrieve the data.

Data analyses

Species identification was conducted manually for each photograph by a single observer and verified by a

Table 1. Details of the survey effort during camera trapping at the corridors and adjacent forest ranges in and around the western Rajaji National Park.

Sites	Start date	End date	Total cameras	Total trap nights	Sampling coverage
Corridors					**Length (m)**
Laltappar	12.iv.2022	05.xi.2022	8	1656	500
Teenpani	10.vi.2022	05.xi.2022	8	1184	500
Chilla-Motichur	25.iv.2022	26.xi.2022	24	4485	900
Forest beats (ranges)					**Area (Km^2)**
Chandi (Barkot)	04.iii.2022	21.iv.2022	6	288	14.83
Jhabargarh (Chilla)	13.iii.2022	16.iv.2022	3	102	11.60
Suswa (Kansrow)	19.iii.2022	04.v.2022	3	138	6.14
Gola East (Rishikesh)	13.iii.2022	22.iv.2022	3	120	10.57
Chilla-Motichur Corridor (Motichur)	01.iv.2022	18.iv.2022	3	54	2.20
Danda East (Motichur)	16.iii.2022	19.iv.2022	3	102	6.12
Gular Parwa West (Motichur)	16.iii.2022	08.iv.2022	3	69	6.40

second observer. The date and time of each photograph were recorded from the image metadata, maintaining a time interval of 1 min for independent capture events. Wildlife presence in the connected forest areas and corridor underpasses was quantified using the relative abundance index (RAI), defined as the number of independent detections per 1,000 trap nights (O'Brien 2011). Comparative analyses of species activity patterns in forests and corridors, as well as their temporal overlap with humans, were conducted using the camtrapR package (version 2.3.0; Niedballa et al. 2016) in R (version 4.4.0; R Core Team 2024). Temporal overlap was estimated by the overlap coefficient Δ, which ranges from 0 (no overlap) to 1 (complete overlap) and is calculated using kernel density functions fitted to the time data of capture incidents of two species (Ridout & Linkie 2009).

RESULTS

Over 8,198 trap nights, camera traps recorded 17 species in the forest areas and nine in the corridors. Among the corridors, Chilla-Motichur and Laltappar had the highest species richness (seven species each), while Teenpani recorded six species (Image 2, Table 2). Teenpani had the highest relative abundance index (RAI) for Wild Boar (227.2) and Sambar (123.31) among the corridors, whereas Chilla-Motichur and Laltappar exhibited lower RAIs for most species (Table 2). In contrast, adjacent forest areas exhibited higher RAIs across all species, indicating a preference for less-disturbed habitats (Wilcoxon test: V = 0, p <0.001).

Species exhibited distinct activity patterns between corridors and forest areas (Figure 1). Chital, the only diurnal species, exhibited activity throughout the 24-hour period in corridors, whereas it displayed a distinct early-morning peak inside the forest (Δ = 0.68). Leopards were uniformly active throughout the day in the forest but showed slightly reduced daytime activity in corridors (Δ = 0.71). Elephants exhibited contrasting activity patterns, with a daytime activity peak in forest ranges and a night-time peak in corridors (Δ = 0.48). Sambar displayed an early-morning activity peak in corridors, avoiding the daytime, while in the forest, it maintained activity throughout the day with increased movement during morning and evening hours (Δ = 0.55). Wild Pig activity remained consistent across both habitats, with peaks at night and reduced activity during the day (Δ = 0.71).

Human activity occurred exclusively during the daytime across all corridors, significantly overlapping with Chital (Δ = 0.61, Figure 1). Other species avoided times of peak human activity. The Leopard (Δ = 0.39) and the elephant (Δ = 0.25), both species frequently involved in negative human-wildlife interactions, showed increased overlap with human activity in the evening hours.

Image 2. Some of the wildlife species captured by camera traps at the corridors; top left to right: Asiatic Elephant, Sambar, Chital, and Barking Deer; bottom left to right: Leopard, Striped Hyena, and Wild Boar. © Uttarakhand Forest Deparment.

DISCUSSION

This study highlights both the significance and challenges of wildlife corridors in maintaining connectivity for species within fragmented habitats. The lower species richness observed in corridors (nine species) compared to forested areas (17 species) reflects the impact of disturbance and habitat fragmentation in human-dominated landscapes, a pattern consistent with global studies (Benítez-López et al. 2010; van der Ree et al. 2015).

Species activity patterns exhibited significant shifts within corridors compared to forest areas (Figure 1). Chital exhibited continuous activity throughout the daytime in corridors, whereas, in forests, its activity peaked during the early morning hours. Chital is primarily a diurnal species, with peak activity occurring at dawn and dusk. They spend most of their time feeding, followed by resting and social activities. This diurnal pattern is consistent across various habitats, including those with high human activity, where they may alter their behaviour to avoid disturbances (Rajawat & Chandra 2020; Dahya et al. 2023; Kumar et al. 2023). Leopards, known for their cathemeral activity (Palei et al. 2021; Dahya et al. 2023), exhibited uniform activity in forests but reduced daytime activity in corridors, possibly avoiding human activity. Elephants shifted their activity from a daytime peak in forests to a nocturnal peak in corridors, demonstrating their adaptability to avoid human encounters (Chakraborty et al. 2021). Sambar, predominantly nocturnal in other studies (Kumar et al. 2023), showed early-morning peaks in corridors, likely due to lower human presence at that time. Wild Boars maintained their nocturnal peaks across both habitats, consistent with findings from Dahya et al. (2023).

Human activity in corridors was predominantly diurnal, significantly overlapping with Chital activity, while other species mostly avoided peak human activity times. The overlap of Leopards and Elephants with human activity during evening hours is concerning, given

Table 2. Relative abundance index (per 1,000 trap nights) of the wildlife species, livestock, and humans captured at three corridors and adjacent forest areas in and around the western Rajaji National Park.

Species	Laltappar	Teenpani	Chilla-Motichur	Forest area
Barking Deer *Muntiacus muntjak*	0.6	-	0.22	12.9
Chital *Axis axis*	50.12	-	8.03	1363.44
Sambar *Rusa unicolor*	99.64	123.31	7.8	993.55
Nilgai *Boselaphus tragocamelus*	-	-	-	15.05
Asiatic Elephant *Elephas maximus*	19.93	2.53	0.89	172.04
Wild Boar *Sus scrofa*	13.89	227.2	22.07	223.66
Rhesus Macaque *Macaca mulatta*	1.81	-	1.34	43.01
Central Indian Langur *Semnopithecus entellus*	-	0.84	-	25.81
Indian Hare *Lepus nigricollis*	-	-	-	49.46
Indian Crested Porcupine *Hystrix indica*	-	3.38	-	49.46
Indian Peafowl *Pavo cristatus*	-	-	-	329.03
Indian Pangolin *Manis crassicaudata*	-	-	-	4.3
Leopard *Panthera pardus*	12.08	15.2	4.01	215.05
Tiger *Panthera tigris*	-	-	-	4.3
Striped Hyena *Hyaena hyaena*	-	-	-	21.51
Golden Jackal *Canis aureus*	-	-	-	4.3
Small Indian Civet *Viverricula indica*	-	-	-	17.2
Livestock	397.34	333.61	108.58	531.18
Human	752.42	26094.59	2360.98	206.45

the elevated risk of human-wildlife encounters (Figure 1). Such patterns, particularly involving species known to cause damage or pose danger in shared spaces, highlight the need for targeted management strategies.

The study also underscores the importance of infrastructure like underpasses in enhancing corridor functionality. Although highway underpasses support wildlife movement, parallel railway lines may act as significant barriers, particularly for elephants, necessitating targeted mitigation measures (Carvalho et al. 2017; Gilhooly et al. 2019). Additionally, debris from underpass construction, garbage dumping, and the use of old roads below the flyover at Teenpani exacerbate habitat degradation (Oro et al. 2013; Katlam et al. 2018). Habitat restoration, particularly in the Chilla-Motichur corridor, and increasing forested cover are crucial for improving corridor effectiveness (Dutta et al. 2018).

The translocation of four Tigers from Corbett Tiger Reserve to western Rajaji National Park (2021–2024) reinforces the importance of maintaining functional corridors (Times of India 2024, director, Rajaji Tiger Reserve pers. comm. 20.iii.2025). In 2022, a male Tiger was photo-captured in camera traps moving from the Chilla Range in the east to the Motichur Range in the western Rajaji using the reclaimed corridor under the Chilla-Motichur flyover. This observation signifies the successful restoration of historical connectivity between the eastern and western RNP. Furthermore, it highlights the critical role of the Chilla-Motichur corridor in Tiger conservation in this landscape. As Tigers recolonise the western TAL, maintaining and monitoring these corridors will be vital for their survival and genetic exchange. The corridor, is yet to be fully restored as an existing ammunition depot of the Indian army cuts through it leaving little space for unrestricted movement of wild animals.

The current study was limited in scope due to a smaller sample size, a lack of a more systematic sampling design, and coverage of only limited areas around the flyovers. Using more camera traps in a grid design could yield more information on the spatial use and abundance of wildlife populations in the landscape. Therefore, the analyses were restricted to RAI as an indicator of site use intensity. Interpreting RAI as abundance may be incorrect as the number of captures may be affected by habitat quality, disturbances, individual behaviour and camera placement (O'Brien 2011). Temporal activity may also be affected by similar biases in captures. Therefore,

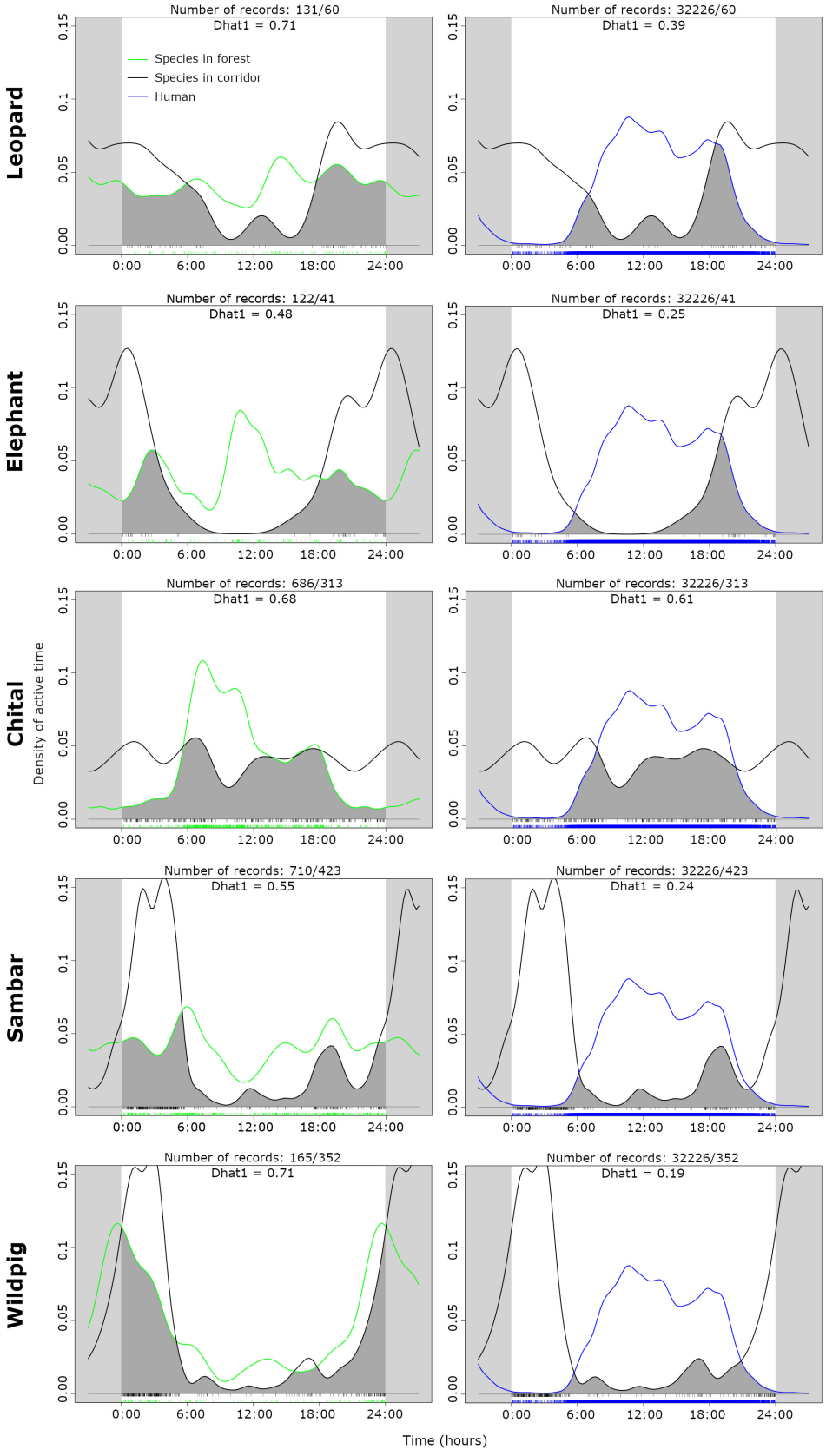

Figure 1. Comparison of the activity time of the five species frequently captured at the corridors around the western Rajaji National Park: Left—activity time of the species within the corridor and the forest ranges | right—activity overlap of the species with humans in the corridor. Dhat value represents the overlap coefficient.

temporal patterns were not analysed for all the captured species but focused only on the species with sufficient captures across the camera traps.

Nonetheless, this study provides valuable insights into the effectiveness of highway underpasses and the challenges of maintaining corridor functionality in human-dominated landscapes. Active measures are essential to enhance corridor utility, including habitat restoration to increase forest cover, shifting of the army's ammunition depot to fully restore the corridor, restricting human activity during critical wildlife movement times, ensuring proper disposal of construction debris and garbage, and implementing effective mitigation strategies for railways to facilitate safe crossings such as advance alert systems, improved braking systems in the trains, regular patrolling and crossing infrastructures (Carvalho et al. 2017). Continuous monitoring of corridor use is crucial, particularly with the recent reintroduction of Tigers, to support the long-term conservation of these apex predators and Elephants in the region.

The findings from this study offer broader conservation implications for wildlife corridors in other parts of the TAL and similarly fragmented habitats across India. The observed shifts in wildlife activity patterns and the influence of human presence highlight the urgent need for integrated infrastructure planning including road and rail barriers in preserving corridor functionality. These results can inform national-level policy on corridor identification, underpass design, and mitigation strategies, especially under frameworks such as India's Wildlife Action Plan (2017–2031), which prioritises connectivity conservation (MOECCF 2017). Furthermore, the study underscores the importance of long-term monitoring, offering a replicable approach for assessing corridor functionality in other Tiger and elephant landscapes.

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