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Wildlife Institute of India

LANDSCAPES RECONNECTED

First Evidence of Wildlife Movement across the World's Largest Animal Viaduct on NH-72 (Asarori-Ganeshpur), Delhi-Dehradun Expressway

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Landscapes Reconnected

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(Asarori–Ganeshpur),
Delhi–Dehradun Expressway

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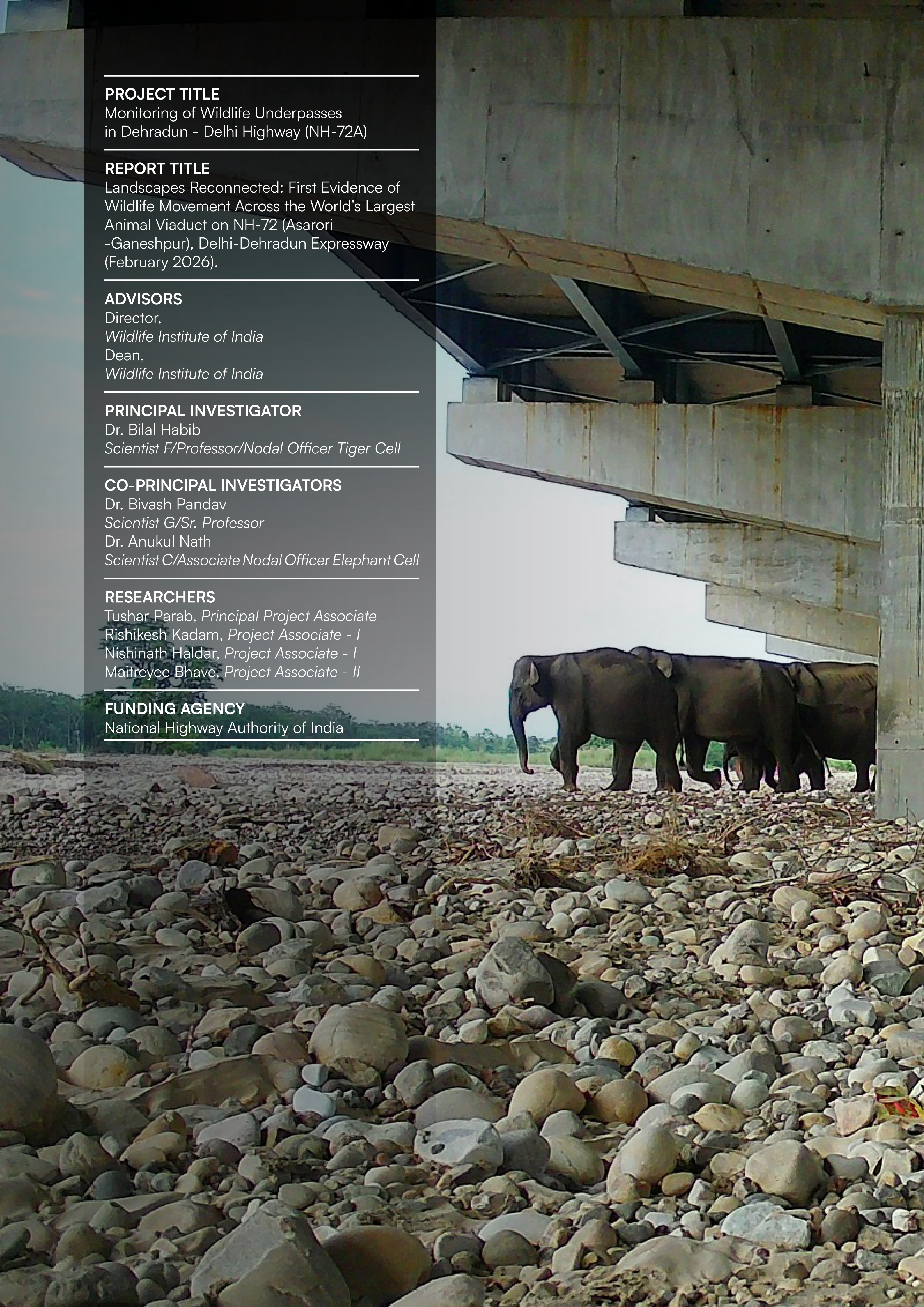

PROJECT TITLE
Monitoring of Wildlife Underpasses in Dehradun - Delhi Highway (NH-72A)

REPORT TITLE
Landscapes Reconnected: First Evidence of Wildlife Movement Across the World's Largest Animal Viaduct on NH-72 (Asarori -Ganeshpur), Delhi-Dehradun Expressway (February 2026).

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01 Introduction

Roads are important for the socio-economic development of a country, ultimately improving the livelihood of people. Although once constructed, roads are a permanent entity in the landscape, and the wrong road at the wrong place may have long-term impacts on the ecosystem (Van Der Ree *et al.*, 2015), including habitat loss, degradation (Eigenbrod *et al.*, 2008) and mortality during construction due to collisions with vehicles (Trombulak *et al.*, 2000). These roads also act as barriers that lead to the isolation of populations in pockets, ultimately prone to extinction (Shepard *et al.*, 2008). Other impacts include the change in animal behavior (Shannon *et al.*, 2014) and the threat of species invasion (Deeley & Petrovskaya., 2022). The traffic volume and width of the road cause a major impact on animal movement (Taylor & Goldingay., 2010; Sáenz-de-Santa-María & Tellería., 2015). Apart from this, the road passing through the forested areas also provides access to the poachers and hunters (Van Der Ree *et al.*, 2015).

Reasonably therefore, numerous efforts have been undertaken to mitigate the impacts of roads in different landscapes worldwide. Mitigation measures, including crossing structures (underpasses and overpasses) (Van Der Ree *et al.*, 2015; Mata *et al.*, 2015), wildlife fencing (Huijser *et al.*, 2016), and automatic detection systems to alert both the animals and humans to prevent accidents (Huijser *et al.*, 2015), have been implemented by infrastructure planners and conservation professionals in response to the extensive impacts of roads on wildlife. The crossing structures, like underpasses, are bridge-like structures that help wild animals cross roads while vehicles drive above grade and are one of the most widely used strategies to reduce the number of wildlife-vehicle collisions and make wildlife corridors more permeable (Sugiarto W., 2023). Dimensions, distance from human settlements or human presence, availability of natural drainage, etc., are some of the variables that affect an underpass's performance (Jackson and Griffith, 2000). Understanding the significance of these aspects in the utilization of crossing structures is crucial. Research in this area can help with planning future crossing structures, identifying mitigation needs for animals or species groups, and finding ways to modify current structures to make them more permeable.

Along with the more apparent roads, the wildlife is adversely affected by vehicular noise (Vidya T. N. C. & Thuppil V, 2010), ultimately affecting their habitat occupancy, vigilance, spatial utilization, predation efficiency, predator avoidance behavior, and various other behaviors, including communication (Bowles A, 1995; Duquette *et al.*, 2021). These effects are reported to vary among animal species, resulting in a diverse range of reactions within wildlife communities, which may impact their trophic and other interactions. Ware *et al.* (2015) and McClure *et al.* (2017) experimented by introducing vehicle noise into roadless areas and demonstrated behavioral and other effects (migratory birds as study species). This was the first direct evidence of vehicle noise itself being the cause of disturbance. This effect is known as a "phantom road." To gather audio data more efficiently and to understand its effects, 'Audiomoth' has emerged as a cost-effective and reliable device for monitoring wildlife at the edge of roads. These recordings give deeper insights into the road and associated effects (Levik *et al.*, 2025; Bradfer-Lawrence *et al.*, 2019). The collection and analysis of acoustic data while monitoring the underpasses together is of paramount importance, especially when it is targeted in a developing country like India.

In India, protected areas (PAs) contain approximately 4.7% of the total geographic area. Additionally, the majority of the PAs are tiny and isolated patches (National Forest Commission, 2006). To exacerbate the situation, approximately 20,000 kilometers of roads traverse our forested regions (Annual Report 2012-2013, Ministry of Road, Transport & Highways, Govt. of India), and the construction and upgrading of around 200,000 km of roads are planned under various government initiatives until 2022 (Ministry of Road Transport & Highways, Government of India). India is also experiencing a period of rapid road network expansion. Because of the far-reaching impacts it can have on animal populations, developing linear infrastructure, especially roadways, is a difficult task. (Jackson S., 2000; Ghent C., 2018). This impact is said to be quadrupled on the larger, continuous landscapes.

The Terai Arc Landscape (TAL) includes the Shivalik hills in the outer Himalayan range and the Terai regions of northwestern India and southern Nepal. This 5 million ha area stretches from the Bagmati River in Nepal to the Yamuna River in India and includes protected areas, including the well-known tiger reserves of Corbett and Rajaji. This landscape has also been recognized as one of the regions with the highest potential for long-term tiger conservation in the country and is home to rich biodiversity within and outside of the protected area network. In addition to the tiger, this landscape harbors other flagship species, such as the one-horned rhinoceros (*Rhinoceros unicornis*) and Asian elephant (*Elephas maximus*) (Umariya *et al.*, 2021). This area is a mega-biodiversity hotspot and a geo-ecological asset that provides ecosystem services (water, food, and energy) to over 240 million people (Sharma *et al.*, 2019). Several roads pass through these forested tracts (for instance, Rajaji Tiger Reserve), threatening the viability of long-term conservation goals (Yadav *et al.*, 2022).

The existing National Highway 72 connects Delhi and Dehradun and is subjected to heavy vehicular traffic. The highway is critical for connecting Delhi to Dehradun, as well as major urban and commercial centers along the north-south transportation corridor. However, the section of the highway also cuts through the Rajaji and neighboring Dehradun and Shivalik forest divisions. Considering the wildlife value of the area, the National Highway Authority of India (NHAI) approached the Wildlife Institute of India (WII) to carry out a rapid assessment of the wildlife use of this road and suggest mitigation measures to avoid negative impact of this road on wildlife of the area. Based on that, the report has been submitted to NHAI entitled, "Rapid assessment of wildlife and suggested mitigation measures for development of Delhi-Dehradun highway in the Shivalik hills."

With the suggested mitigations, the underpass of 10.978 km (out of the 20 Km road segment) was developed in all three Zones.

Table 1

Zone	Total length	WII recommended structure length	Constructed elevated structure length	Avg. Height (in m)
Zone I (UP)	4.90 Km	3.50 Km	4.168 Km	7
Zone II (UP and UK)	13.30 Km	6.80 Km	6.41 Km	7
Zone III (UK)	1.80 Km	0.400 Km	0.400 Km	6
Total	20 Km	10.700 Km	10.978 Km	

As post-monitoring becomes important in terms of understanding the use of crossing structures by animals, the project entitled “Monitoring wildlife underpasses on Dehradun-Delhi Highway (NH-72 A)” funded by the National Highways Authority of India (NHAI) set out with the following objectives:

01

To assess the patterns of underpass use by wildlife, we ask

- Do species characteristics affect variation in underpass use?
- Is there any variation of underpass use by different age and sex classes? and
- Does temporal activity at the underpass differ from natural activity of wildlife?

02

To assess the factors affecting the use of underpasses by different wild species, we ask

- what road-related, structure-related, and environmental factors influence the use and effectiveness of wildlife underpasses, and
- Do habitat characteristics of forest patches adjacent to underpasses, *viz.*, presence of trails, tree/shrub cover, and drainage/water bodies, affect underpass use?

03

To assess the effectiveness of underpasses, we ask if

- The presence of mitigation measures reduces occurrences of roadkill? and
- Does wildlife road crossing frequency vary between mitigated and unmitigated sections of the highways?

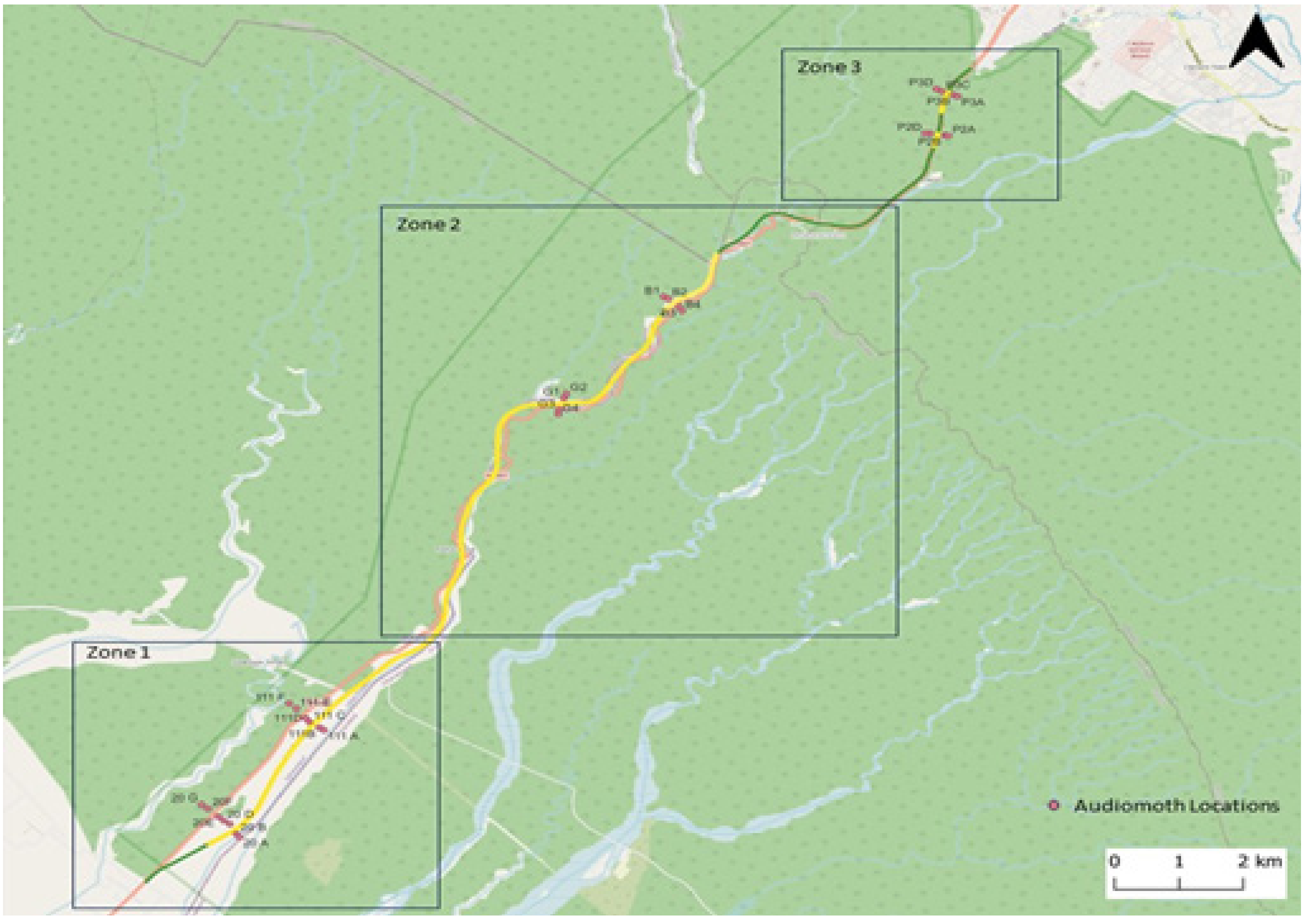
02 Study Area

The study was conducted along an 18 km stretch of NH72 A between Ganeshpur (UP) at 30 008' N latitude and 77 0 52' E longitude and Dehradun (UK) at 30 015' latitude and 77 058' longitude, India. This place falls in the Terai arc landscape, one of the crucial landscapes to be conserved in the country. This contiguous belt of forest has to be the westernmost limit of the distribution of some of the endangered species such as tigers, elephants, greater hornbills and king cobras (Johnsingh *et al*. 2004). The stretch of this expressway passes through the Shivalik elephant corridor (Elephant Corridors of India, 2023 (Edition — 1/2023)) in Shivalik forest division, which is a wildlife-rich forested habitat and the Rajaji Tiger Reserve (along the westernmost edge), and the Dehradun Forest Division of Uttarakhand. The area lies within the Gangetic Plains biogeographic zone and upper Gangetic Plains (Rodgers *et al*., 2002). The major portion of the area is dominated by tropical moist deciduous forest with dominant tree species that are found here: *Shorea robusta* (Sal), *Mallotus phillipinensis* (Kamala), *Haldina cordifolia* (Haldu), *Crataeva religiosa*, *Garuga pinnata* (kharpat), *Toona ciliate* (Indian Mahogany), *Terminalia tomentosa* (Anjan Tree), *T. bellerica* (Bahera), *Hymenodictyon excelsum* (Kala bachnag), and *Ficus benghalensis* (Banyan tree). Also certain areas are dominated by Teak (*Tectona grandis*) plantations and extensive riverine vegetation such as *Acacia catechu* and *Holoptelea integrifolia*. The highway of 18 km stretch will serve as a primary arterial route connecting the Doon valley to the plains of northern India to support high traffic load, and based on its covered area, this road can be broadly classified into three distinguished sections based on their geographical features (Fig. 1).

In Zone 1 (5.43 km) of the corridor, it stands between Ganeshpur and Mohand and passes through flat terrain along the riverbed. It is primarily located in the Shivalik forest division (UP). Ecologically, it abuts the Rajaji Tiger Reserve (Mohand range).
Zone 2 (9.80 km) marks the section starting from the Mohand settlement and extending all the way up to the Asarodi police check post. This part goes through the hilly terrain of the area.
Zone 3 (3.14 km) starts from the Asarodi police checkpost and extends up to the edge of the Mohabewala settlement in the Doon valley. The road in this zone passes through mixed stretches of sal forest.

Figure 1

The map showing the audiomoth locations in all three zones, i.e., 13 in Zone 1, 8 in Zone 2, and 8 in Zone 3. The distance between two sets in each zone was 3 Km except in zone III.



ZONE 1

Figure 2

The map showing the camera trap locations in Zone I of NH-72A (Delhi-Dehradun highway). There were 150 camera traps deployed in this stretch of road.

The one major elephant underpass (EUP) with the average height of 7 m covers, apparently, zones I and II and two EUPs with the average height of 6 m and length of 200 m each are present in zone III at the location of Location I (N30°15'07.76" E77°58'35.80") and Location II (N30°15'25.41" E77°58'39.76").

03 Methodology

Data collection included a mixed-method approach using camera traps and Audiomoth recorders, with the objective of capturing a broad range of faunal species and assessing the influence of highway on species distribution and activity patterns.

Camera traps

A total of 150 camera traps (CTs) were systematically deployed along underpasses within Zone I of the designated road segment (refer to Fig. 2), spanning from Mohand village in the northeast to Ganeshpur in the southwest. Each CT unit was installed on one side of the structural pillars at a height of 40—50 cm above ground level to ensure detection of a broad spectrum of terrestrial fauna, ranging from small to large-bodied species. For secure placement, 15 × 8 cm cages were drilled into the pillars and Zeiss Secacam 7 cameras were placed within the protective cages. The deployment started on 16 May 2025 and cameras were retrieved on 24 June 2025, meaning a 40-day sampling period. Post retrival, data were downloaded, corrected for data and time in Exif pro image viewer software, and sorted into species-wise folders (including humans, wild and domestic/feral animals) using Timelapse software (Greenberg *et al.*, 2019). A comprehensive record table was generated, documenting camera ID, species identity, and timestamp of each capture event. To account for temporal independence of detections, a 30-minute interval threshold (Δt) was applied using the camtrapR package (Niedballa *et al.*, 2016) in R (R Core Team, 2021).

a. Pattern of species-wise use of crossing structures

The record table was compiled to summarize the number of captures per species. All capture-related plots were created from the package ggplot2 (Wickham H., 2016) in R. The timing of initial detections of each species was estimated using the "time to first capture" metric (Habib *et al.*, 2020). The Relative abundance index (RAI) was calculated to show the number of independent captures per camera trap day (i.e., number of cameras times number of days operational) (Palmer *et al.*, 2018). It shows the abundance of species at the underpasses. It was assumed that species photographed at the underpasses are likely to utilize the structures (Verma *et al.*, 2025). The RAI was calculated for all the species.

$$RAI = \frac{No. of captures}{Trap\ nights} \times 100$$

Where, No. of captures = number of photocaptures of an individual, Trap nights = number of camera trap days

b. Identification of species-specific crossing areas

To visualize the species-specific utilization of crossing structure, RAI values were mapped as RAI heat map. The analysis was carried out using ArcGIS Pro (vX.X, ESRI, Redlands, USA), and the estimated RAI values were linked to the GPS coordinates of each camera trap location. Heat map symbology was applied to represent point data, enabling the depiction of relative abundance patterns. In ArcGIS, the heat map symbology specifies warmer colors for points with greater RAI values, with visual intensity determined by both the RAI magnitude and proximity of adjacent high values. This method visualizes the distribution of animal activities spatially without requiring statistical interpolation.

c. Characterization of wildlife activity beneath underpasses

We plotted the activity pattern for each species with the group disturbance, including vehicles, humans, and cattle.Temporal overlap analyses were conducted using the "acitivityOverlap" function from the overlap package in R (Meredith *et al.*, 2014). The resulting plots were visualized using the ggplot2 package (Wickham, 2016), facilitating comparative assessments of species activity in disturbed versus undisturbed contexts.

Table 2

Animal and other groups considered for analysis for the present study.

Group	Species	Scientific name	Count of captures
Large Carnivores	Common leopard	*Panthera pardus*	25
Lesser Carnivores	Golden Jackal	*Canis aureus*	4812
	Small Indian civet	*Viverricula indica*	85
	Common Palm Civet	*Paradoxurus hermaphroditus*	13
	Monitor Lizard	*Varanus bengalensis*	9
	Grey Mongoose	*Herpestes edwardsii*	14
	Rusty spotted cat	*Prionailurus rubiginosus*	6
Small mammalian herbivores	Indian porcupine	*Hystrix indica*	83
	Indian Hare	*Lepus nigricollis*	2577
Ungulates	Spotted deer	*Axis axis*	8015
	Wild boar	*Sus scrofa*	193
	Sambar	*Rusa unicolor*	10534
	Nilgai	*Boselaphus tragocamelus*	12432
Pheasants	Indian peafowl	*Pavo cristatus*	250
	Red Junglefowl	*Gallus gallus*	2
Primates	Terai Grey langur	*Semnopithecus hector*	53
	Rhesus macaque	*Macaca mulatta*	834
Large herbivores	Indian elephant	*Elephas maximus indicus*	300
Others	Domestic Cat	*Felis catus*	22
	Domestic Cattle	*NA*	9552
	Person	*NA*	30610
	Domestic Dog	*Canis lupus familiaris*	2133
	Birds	*NA*	201
	Unidentified	*NA*	187
	Domestic goat	*NA*	589

Audiomoth

The traffic noise was recorded using AudioMoth acoustic recorder (version 1.10.1) which is a cost-effective, lightweight, and energy efficient acoustic recording device. The device is open-source and programmable, with many applications for capturing animal vocalizations or human activities at sampling rates of upto 384 kHz (Hill *et al.*, 2018). Audiomoths record the acoustic recordings and store them in the format of WAV files.

A series of Audiomoth recorders was strategically deployed perpendicular to a national highway to assess the impact of vehicular noise on animals. Each device recorded audio files of one hour for one time subset, meaning 4 files for one day and 28 files for 7 days duration. Two sets of recorders were deployed in each zone to maximize spatial coverage. The standard inter-set distance was 3 km, except in Zone 3, where proximity between underpasses necessitated a reduced spacing of 700 m (Fig. 1). Each set bisects the road horizontally. The distance between the recorder and road was based on the terrain and forest cover. Zone I comprises flat terrain with forested and open areas of river channel. Here, the existing and newly constructed roads run parallel to each other, and the distance between them varies with the location. So, the location of a single set and the number of recorders vary accordingly. In the first set, 7 recorders (5 in the forest and 2 in the open area) were horizontally aligned and covered both the roads. Given the higher acoustic attenuation in forested environments compared to open areas (Yip *et al.*, 2017), inter-recorder spacing was set at 100 m in forested zones and 50 m in open areas. In the second set, 6 devices (4 in forest and 2 in open areas) were deployed, maintaining 100 m distance in forest and 50 m in open areas. In zones 2 and 3, the number of recorders was 4 and 3, respectively. In zone 2, the terrain is hilly. The recorders were placed at a distance of 75 m in two sets. Subsequently in zone 3, The area is forested, and the recorders were deployed at 50 m in one set and 75 m in another.

Figure 3

AudioMoth

Recorders were configured to collect the data for a minimum of 7 days and a maximum of 10 days. Each device was configured to collect the recordings in the morning (5-6 AM), afternoon (10-11 AM), evening (5-6 PM), and night (11-11) for 1 hour. A total of 905 recordings of 1 hour duration were collected and analyzed. The audacity (Audacity Development Team 2010) software was used to process the soundfiles.

Table 3

Showing the zone wise audiomoth locations and their distance from newly constructed roads.

Zones	Set	Device ID	Location		Distance From newly constructed road (m)
			Latitude	Longitude	
Zone 1	1	20A	30.151483	77.883758	100
		20B	30.151881	77.883444	50
		20C	30.153303	77.882517	100
		20D	30.153821	77.881670	200
		20E	30.154391	77.880973	300
		20F	30.155521	77.879630	470
		20G	30.156083	77.878817	570
	2	111A	30.166737	77.894983	100
		111B	30.167055	77.894410	50
		111C	30.167946	77.893109	100
		111D	30.168440	77.892568	175
		111E	30.169757	77.891306	335
		111F	30.170479	77.890381	435
Zone 2	1	G1	30.214753	77.927181	150
		G2	30.214084	77.926840	75
		G3	30.212377	77.926147	75
		G4	30.211792	77.926096	150
	2	B1	30.228535	77.940056	150
		B2	30.228290	77.940690	75
		B3	30.227159	77.942226	75
		B4	30.226582	77.942495	150
Zone 3	1	P2A	30.251520	77.977880	150
		P2B	30.251562	77.977390	75
		P2C	30.252193	77.975745	75
		P2D	30.252523	77.975082	150
	2	P3A	30.257183	77.979103	100
		P3B	30.257361	77.978521	50
		P3C	30.258002	77.977304	50
		P3D	30.258204	77.976854	100

Computation of acoustic indices

We analyzed the acoustic data using the R programming language (version R 4.4.1) (R Core Team, 2021). Six indices, ACI, BI, ADI, AEI, H, and NDSI were calculated utilizing the multiple_sounds function within the soundecology package (Villanueva-Rivera *et al.*, 2011) (Table 4). For indices where we could set limits for minimum and maximum frequency within the function, such as ACI and BI, we calculated the indices for the specified frequency range. 0-800 Hz, as significant anthropophony occurs within this frequency range. and 800-8000 Hz, as a significant fraction of avian vocalizations occur within this frequency range (Kuehne *et al.*, 2013). We obtained the index values for ADI, AEI, H, and NDSI within the default frequency range.

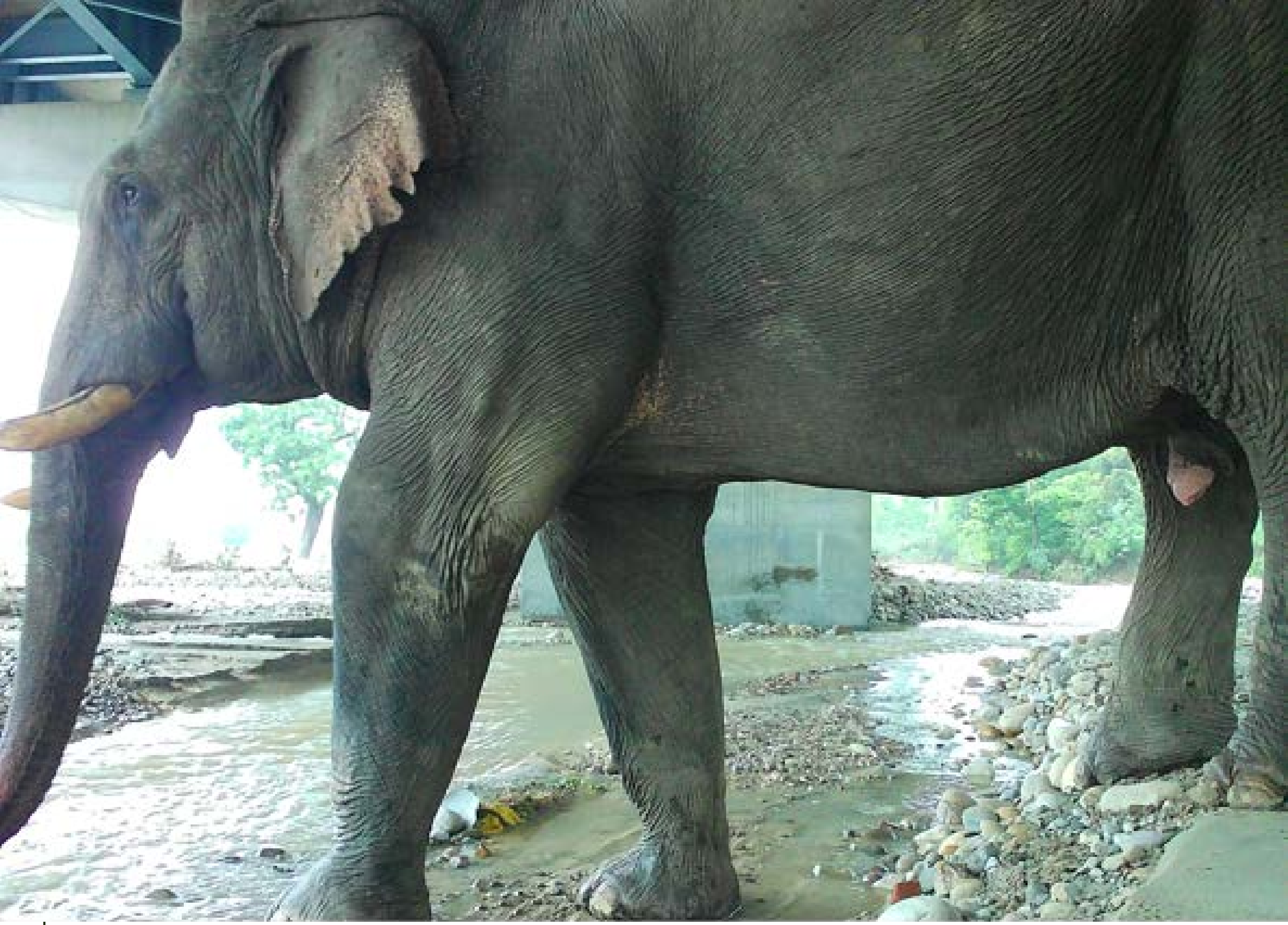
After extracting the index values, we arranged the data in the file containing the F_band which contains 11 distance categories ranging from 50 meters to 570 meters. The predominant class is 75 m (192 recordings), followed by 100 m, 50 m, and 150 m. Only a few recordings were made at 335 m, 435 m, and 570 m. Even the recordings were further divided into weekends and weekdays with timings such as Morning, Afternoon, Evening, and Night. Each category comprises around 215 to 232 recordings.

Table 4

Acoustic indices, including their technical specifications, ecological applications, parameters, references, and associated R packages with functions. All indices were computed based on a one-hour sound file.

Index	Name	Description	Application	Frequency range	References	R Implementation
ACI	Acoustic complexity index	Measures soundscape complexity by quantifying amplitude variations across frequency bins at various temporal intervals in the sound recordings.	Useful to measure biotic activity from avian species, mammals, and invertebrates (Fairbrass *et al.*, 2017).	Frequency range: Anthropophony (0-800 Hz) and Biophony (800-8000 Hz).	Pieretti *et al.*, 2011	Package: soundecology Function: acoustic_complexity()
BI	Bioacoustic index	Measures soundscape complexity by quantifying the change in signal amplitude within the recordings.	Useful for bird species richness and help to assess the biodiversity (Boelman *et al.*, 2007; Budka *et al.*, 2023)	Frequency range: anthrophony (0-800 Hz) and Biophony (800-8000 Hz).	Boelman *et al.*, 2007	Package: soundecology Function: bioacoustic_index()
NDSI	Normalized difference soundscape index	Quantifies the components of the soundscape biophony and anthrophony by determining a ratio between mid-frequency biophony and low-frequency anthrophony.	Used to show the anthropogenic presence and avian diversity (Doser *et al.*, 2020)	Default frequency range, anthrophony: 1— 2 kHz, biophony: 2—8 kHz	Kasten *et al.*, 2012	Package: Soundecology Function: ndsi()
ADI	Acoustic diversity index	Measures the evenness of the soundscape by assessing the distribution of acoustic energy across the frequency bands in the recordings.	Developed to assess acoustic diversity within a soundscape (Villanueva-Rivera *et al.*, 2011)	Minimum frequency: default (0 Hz), maximum frequency: default (10,000 Hz), frequency band size: 1000 Hz	Villanueva-Rivera *et al.*, 2011	Package: Soundecology Function: acoustic _diversity()
AEI	Acoustic evenness	Measures the evenness of the soundscape in the recording.	Developed to measure the acoustic diversity in a soundscape (Villanueva-Rivera *et al.*, 2011)	Minimum frequency: default (0 Hz), maximum frequency: default (10,000 Hz), frequency band size: 1000 Hz	Villanueva-Rivera *et al.*, 2011	Package: Soundecology Function: acoustic _evenness()
H	Total entropy	Quantifies soundscape evenness by assessing a uniformity of amplitude across the frequency band.	Used to determine the bird species' richness (Sueur *et al.*, 2008).	Minimum frequency: default (0 Hz), maximum frequency: default (24,000 Hz)	Sueur *et al.*, 2008	Package: seewave function: H()

A structured dataset in .csv format was prepared with columns representing multiple distance categories from the road (50 m, 75 m, 100 m, 150 m, 175 m, 200 m, 300 m, 335 m, 435 m, 470 m, and 570 m), along with temporal variables including day type (weekday vs. weekend) and time of day (morning, afternoon, evening, and night). The dataset was analyzed using R statistical software (R Core Team, 2021). Box whisker plots were generated using the ggplot2 package (Wickham, 2016) to visualize variations in acoustic indices across distances and time periods. A correlation matrix was constructed to the relationship between acoustic indices and distance from the road, serving as a proxy for frequency band variation. To assess the association between Relative Abundance Index (RAI) values and acoustic indices, Pearson correlation heatmaps and scatter plots were developed. All analyses were conducted within the R environment.



04 Results

Camera trap analysis

A total of 150 camera traps were deployed in Zone 1 of NH 72-A, covering a distance of 3.54 kilometers over a period of 40 days, yielding 5960 trap days. We acquired a total of 111,234 images of humans, domestic animals, and wildlife. Among these, 40,444 were attributed to 18 unique wild species.

a) Pattern of species-wise use of crossing structures

The highest captures at the underpasses were human associated species with high disturbance levels (Fig. 4). The golden jackal contributed to the largest number of captures (1204) (Fig. 5), with an RAI value of 21.04895105, surpassing the lesser carnivores, even a small Indian civet. Ungulates, specifically nilgai (16.76573427) and sambar (15.06993007), along with spotted deer (RAI = 7.727272727), showed significantly high captures among all species. The Indian hare exhibited the highest capture frequency among small mammalian herbivores, with a 9.965034965, RAI value. The Asian elephant, classified as a mega-herbivore, had a capture of 60 (Fig. 5) with the RAI of (1.048951049) (Fig. 6, Table 5).

Figure 4

Total captures around the sampled area of NH-72A, including wild species and human disturbance.

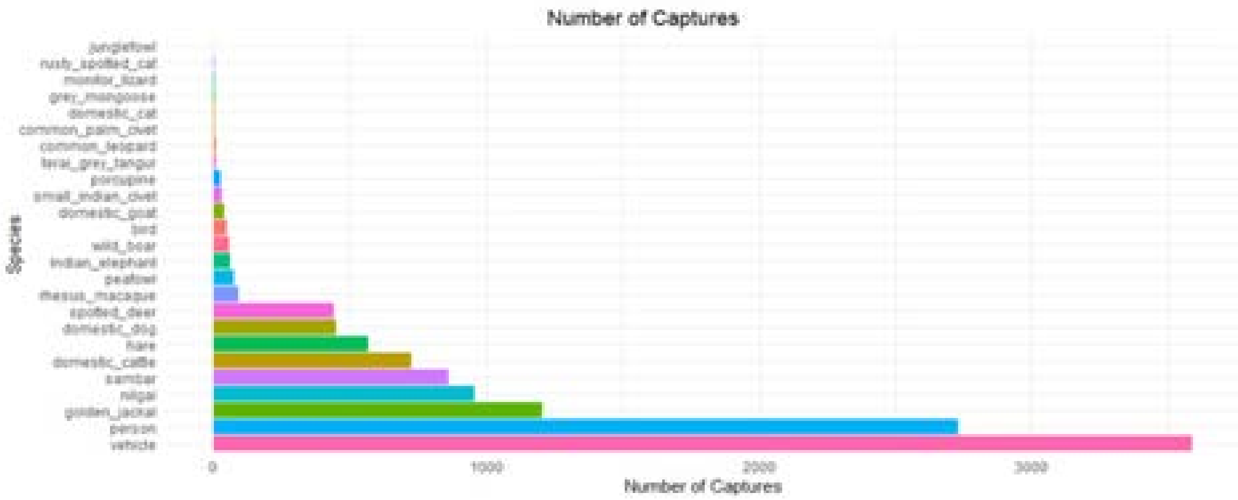


Figure 5

Total captures of all the species around the sampled stretch of NH-72A including human-associated species.

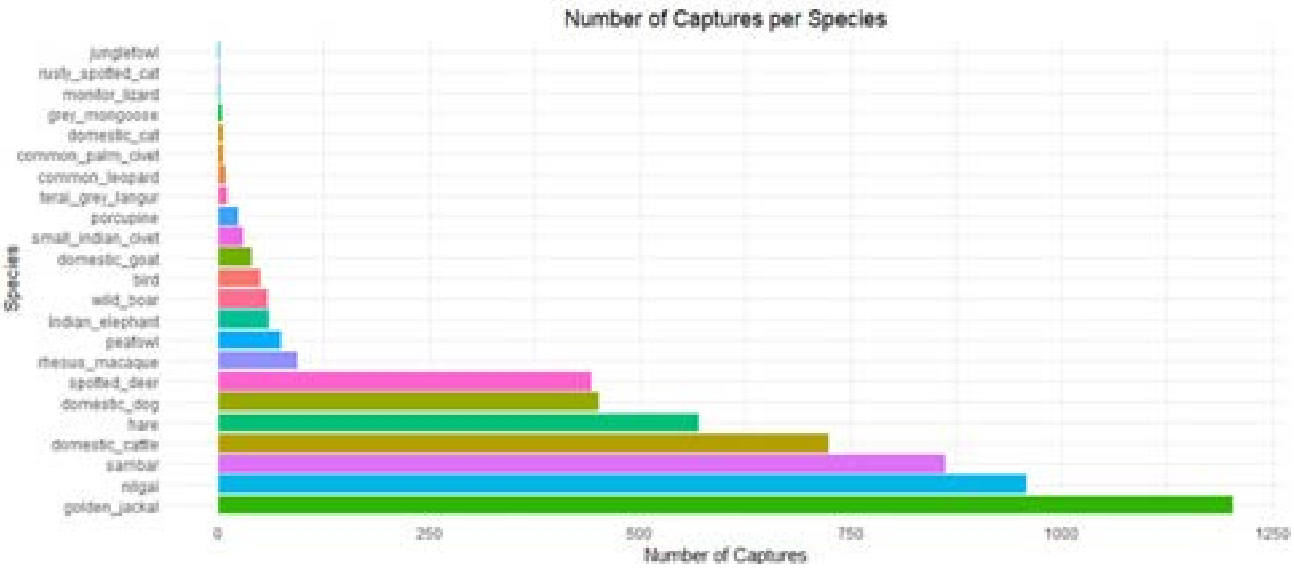


Figure 6

Relative abundance index of all the species.

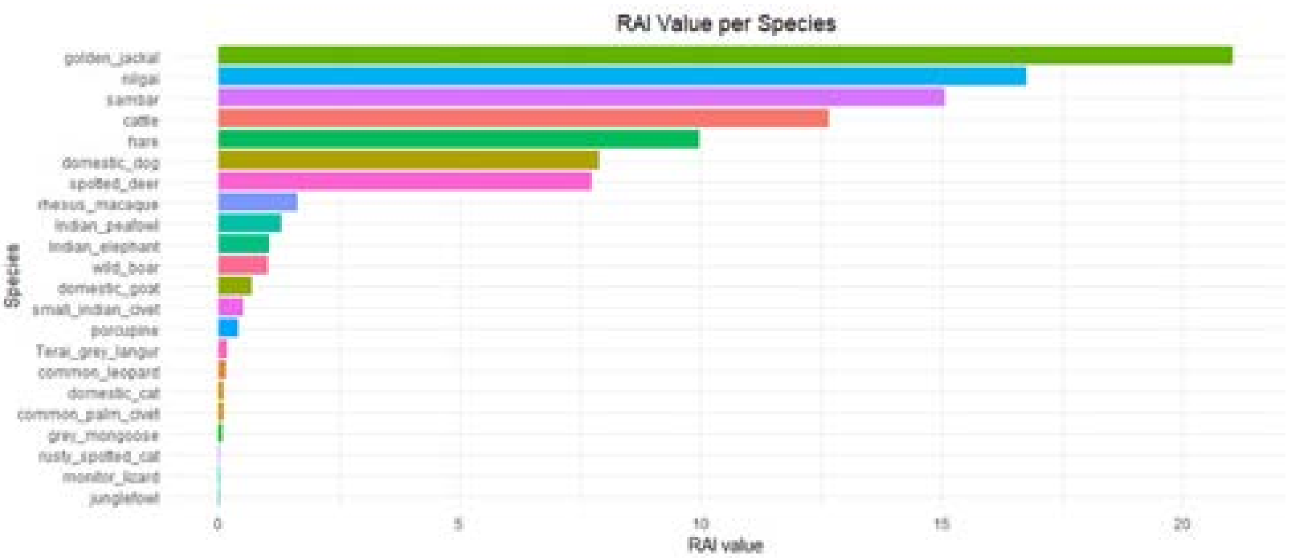


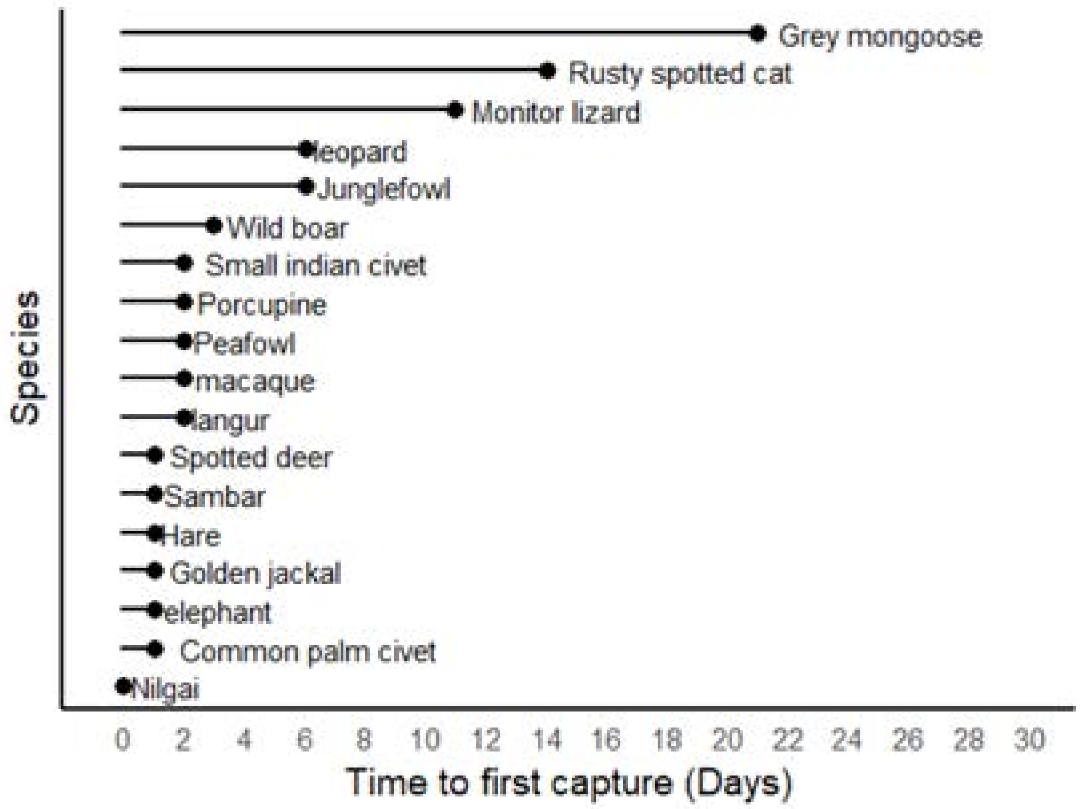
Table 5

RAI values for all the wild species found around the NH72A.

Sr. no	Species	RAI
1	Golden Jackal	21.04895105
2	Nilgai	16.76573427
3	Sambar	15.06993007
4	Indian hare	9.965034965
5	Spotted deer	7.727272727
6	Rhesus Macaque	1.625874126
7	Indian Peafowl	1.311188811
8	Indian Elephant	1.048951049
9	Wild boar	1.013986014
10	Small Indian Civet	0.506993007
11	Porcupine	0.41958042
12	Terai grey langur	0.174825175
13	Common leopard	0.13986014
14	Common Palm civet	0.104895105
15	Grey mongoose	0.087412587
16	Monitor lizard	0.034965035
17	Rusty spotted cat	0.034965035
18	Red Junglefowl	0.017482517

Figure 7

Time of first capture of different wild animal species to use the crossing structures on NH-72A.



Habituation to the underpasses and capture frequency of species varied based on the local abundance and behavior of species (Fig. 6). This is evident by the timing of initial detections and the frequency of structure usage. Nilgai are one of the initial species to be captured and are frequently captured utilizing the underpasses (Fig. 7). Other species, such as the common palm civet, elephant, golden jackal, hare, sambar, and spotted deer, were among the initial users of the underpasses, documented within five days of monitoring having started, whereas species like the common leopard, Rusty spotted cat, and Grey mongoose were recorded significantly later in the monitoring period.

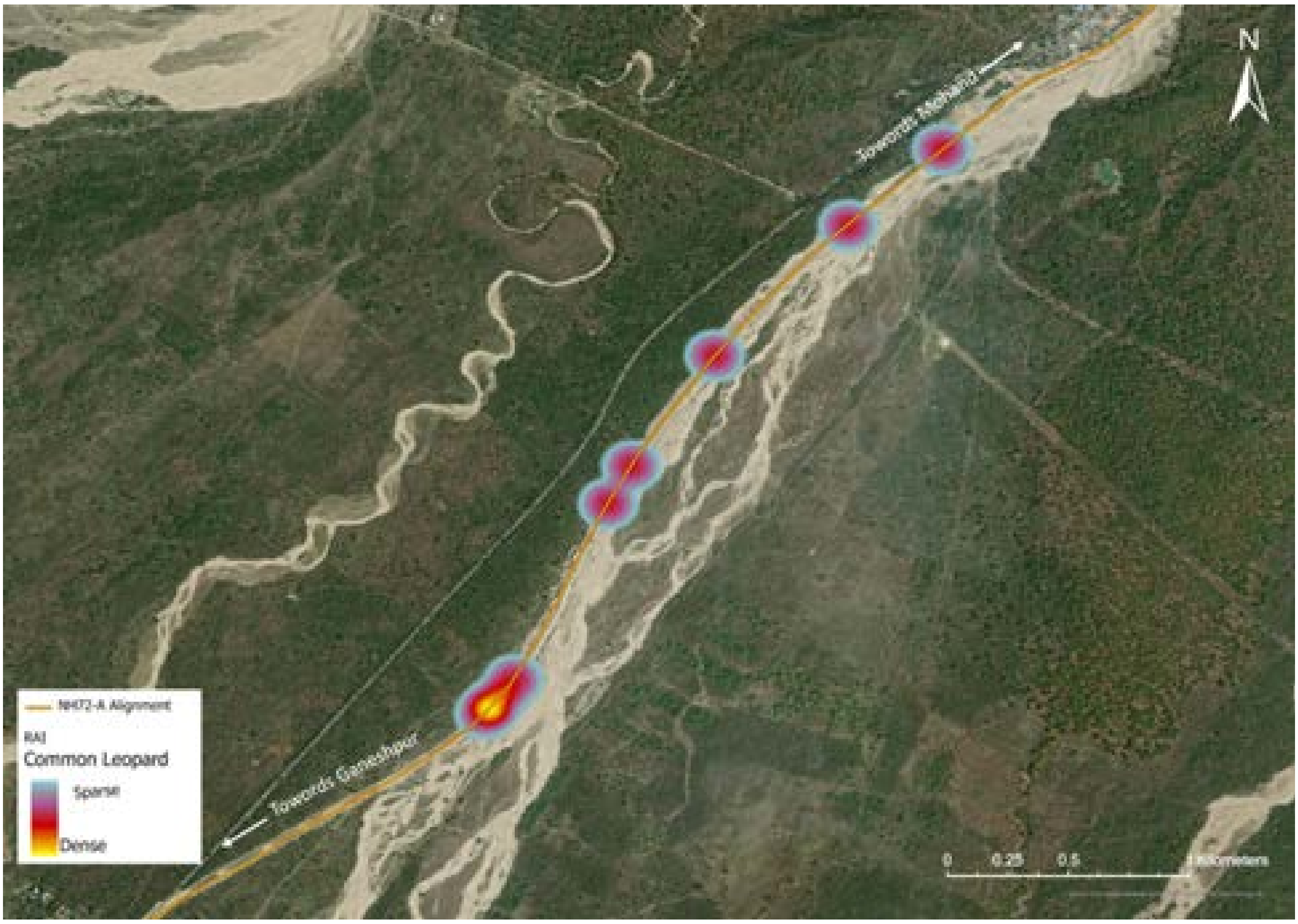
Identification of species-specific crossing areas

- ***Large carnivores (common Leopard)***

Camera trap data along NH72-A revealed spatial variation in leopard activity as represented by Relative Abundance Index (RAI) values. Heat maps indicate that leopard detections were not uniformly distributed along the road. Highest leopard captures were obtained from the southern end of the alignment, particularly towards Ganeshpur, suggesting frequent underpass use by leopards in this segment. In contrast, captures were relatively low in the central and northern portions of the road alignment (Fig. 8)

Figure 8

Relative abundance index (RAI)-based heat maps show intensity of captures of Common leopards on road zones I on NH 72 between Ganeshpur and Mohand.



- ***Small mammalian herbivores (Indian hare, porcupine)***

Figure 9

RAI based heat maps show the intensity of captures of small mammalian herbivores ((a) Indian hare and (b) porcupine) in road zone I on NH 72 between Ganeshpur and Mohand.

For small herbivores, heat maps showcase the detections were not uniformly distributed along the road. Highest captures of Indian hare were obtained from the southern end of the alignment, specifically towards Ganeshpur, and were sparser towards the Mohand village (Fig. 9 (a)). For the Indian porcupine, the highest number of captures was found near the Mohand village, indicating the highest porcupine activity in this segment of the underpass. However, the central and southern portions of the alignment exhibited reduced capture frequencies (Fig. 9 (b)).

- ***Ungulates (Spotted deer, Sambar, Nilgai)***

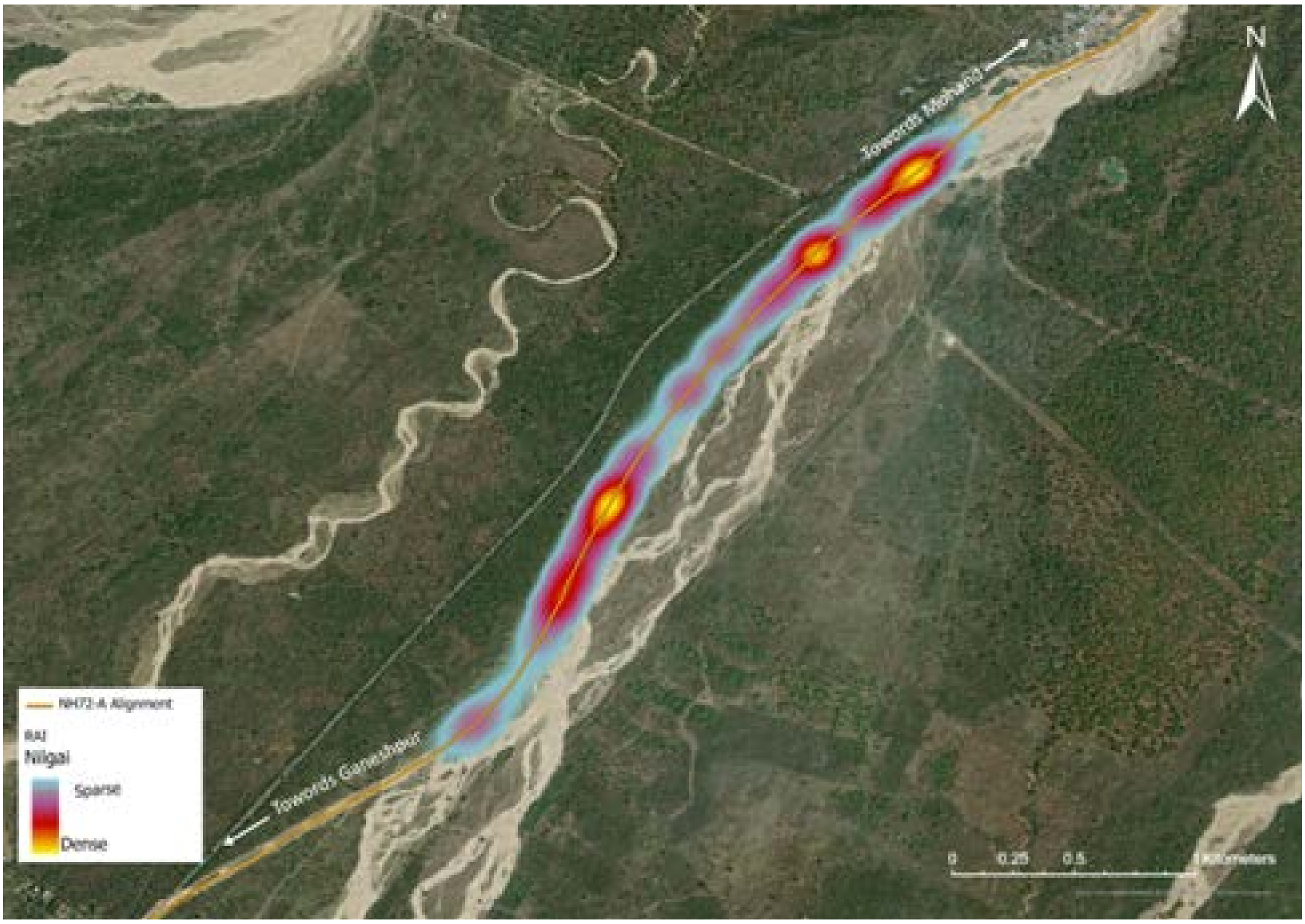
Figure 10

RAI based heat maps show the intensity of captures of Ungulates ((a) Spotted deer and (b) Sambar) in road zone I on NH 72 between Ganeshpur and Mohand.

The heat maps for ungulates show the increased number of detections of spotted deer near Mohand and the relatively lower number of detections at the center and the slight increase towards Ganeshpur, indicating the uniform use of underpass by spotted deer (Fig. 10 (a)). Sambar activity, as depicted in the plot, reveals the highest number of captures near Mohand and the lowest near Ganeshpur and a moderate number of captures in the central area (Fig. 10 (b)).

Figure 11

RAI based heat maps show the intensity of captures of Ungulates (Nilgai) in road zone I on NH 72 between Ganeshpur and Mohand.



Regarding Nilgai, the heat map demonstrates a larger number of captures near the Mohand and the central part of the underpass, with fewer captures at the south near Ganeshpur (Fig. 11).

- ***Primates (Terai grey langur, Rhesus macaque)***

Figure 12

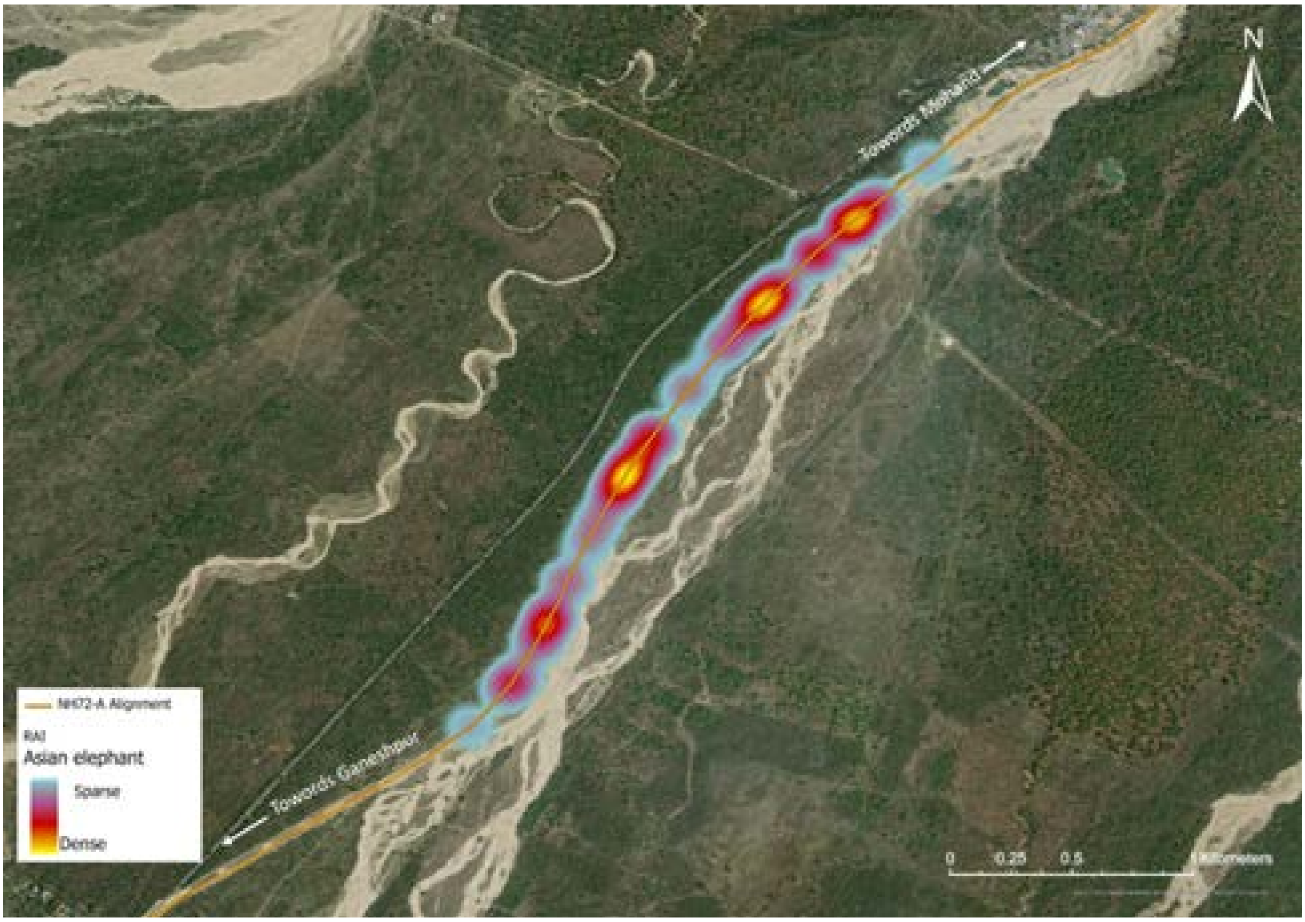
RAI based heat maps show the intensity of captures of Primates ((a) Terai grey langur, (b) Rhesus macaque) in road zone I on NH 72 between Ganeshpur and Mohand.

In the case of the Terai grey langur and rhesus macaque, the graph illustrates that the medium value of abundance near the Mohand village and captures will increase in the central part of the segment (Fig. 12 (a)). The capture declines towards the south. The same with the rhesus macaque, with the highest captures near the Mohand village (Fig. 12 (b)).

- ***Megaherbivore (Elephant)***

Figure 13

RAI based heat maps show the intensity of captures of megaherbivores (elephants) in road zone I on NH 72 between Ganeshpur and Mohand.



For Elephants, the RAI value in heat maps shows the detection at the center of the road segment and a decline towards Mohand and Ganeshpur village. The heatmap shows that elephant presence is not uniform but clustered at specific locations, with high-density zones (red and yellow heat) interspersed by sparse-use areas (blue). These hotspots likely represent preferred crossing points across the alignment of NH72 A (Fig. 13).

Characterization of wildlife activity beneath underpasses

To understand species-specific responses to anthropogenic disturbances, temporal activity overlaps were assessed. The coefficient of overlap (Dhat) was used to quantify the extent of temporal intersection between activity patterns.

The overlap between the activity of common leopard and cattle was minimal (Dhat = 0.05), with leopards exhibiting nocturnal activity peaks, whereas cattle were exclusively diurnal, with activity focused during daytime. A comparable pattern was noted with the humans who exhibited the lowest overlap (Dhat = 0.07), although both species showed limited overlapping activity during early morning hours. Human activity was observed to be restricted to daylight hours, exhibiting minimal intersection with the leopard's nocturnal activity. Comparable findings were seen for the vehicles. Most of the vehicular activity occurred during midday, exhibiting a diurnal pattern contrary to that of the leopards (Dhat = 0.05) (Fig. 14).

The activity overlap between Golden jackals and cattle was negligible (Dhat = 0.49), with jackals demonstrating significant activity peaks during daylight and after sunset, exhibiting restricted activity at night. whereas cattle were strictly diurnal. The activity of cattle peaks during midday. Similarly, jackals have a degree of overlap (Dhat = 0.5) with humans, primarily from the afternoon till dusk. A significant temporal overlap with the vehicle (Dhat = 0.54) corresponded with peak activity at dusk (Fig. 15).

The small Indian civet demonstrated negligible temporal overlap with human-induced disturbances, with Dhat values of 0.07 for both cattle and humans, and 0.08 for vehicles (Fig. 16). Spotted deer primarily exhibited nocturnal activity, with limited diurnal overlap with cattle (Dhat = 0.31). The majority of human activity beneath the underpasses occurred during the day (Dhat = 0.32). the vehicles exhibited peak activity between morning and evening, with some overlap observed with the spotted deer at dusk (Dhat = 0.36) (Fig. 17).

Similarly, the sambar exhibited minimal overlap with humans (Dhat = 0.07) and cattle (Dhat = 0.09); however, there was a degree of overlap with vehicular activity during nightfall (Dhat = 0.13) (Fig. 18). The same pattern was found for nilgai. The Activity overlap for nilgai at the underpasses involves cattle (Dhat = 0.22), humans (Dhat = 0.24), and vehicles (Dhat = 0.26) (Fig. 19). Elephant activity patterns beneath the road exhibited two peaks: one at midnight and another in the morning, coinciding with the absence of cattle (Dhat = 0.22), humans (Dhat = 0.24), or vehicles (Dhat = 0.27) (Fig. 20). Table 6 shows Dhat value of overlap for the species with respect to the human-associated disturbance.

Common Leopard Vs Human Associated Disturbance

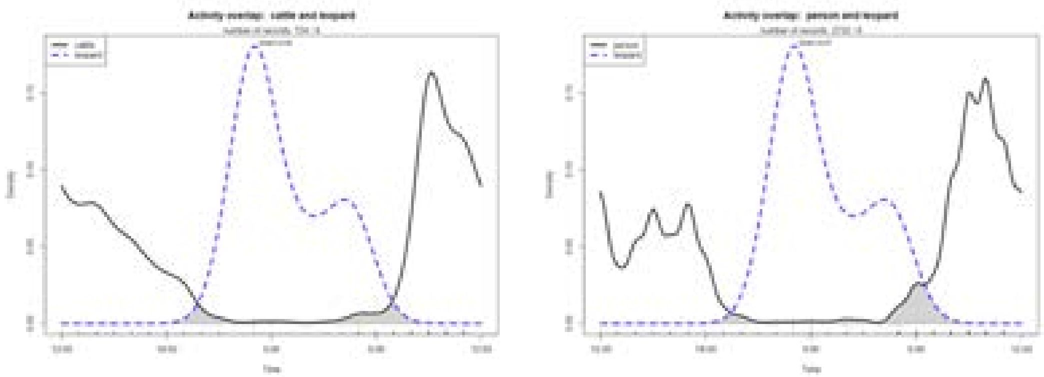
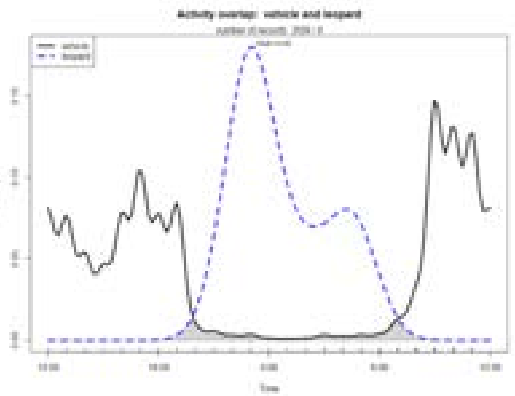
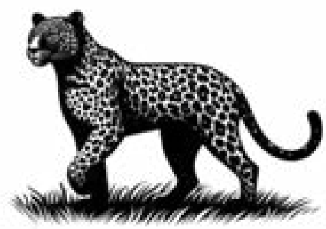


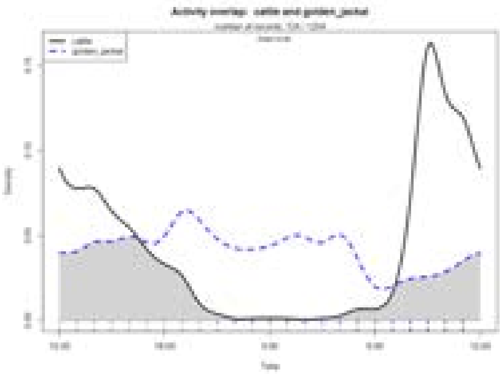
Figure 14

Temporal overlap between Leopard and various human-induced disturbances (Human, cattle and vehicle). Dashed line represents Leopard activity; solid line represents each animal's activity. The shaded area indicates the overlap in activity. Dhat values indicate the degree of overlap (0 = No overlap, 1 = complete overlap).





Golden Jackal Vs Human Associated Disturbance



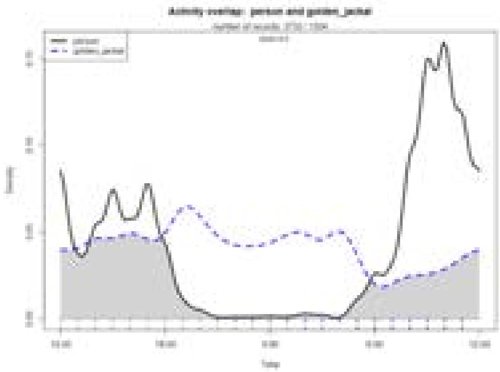
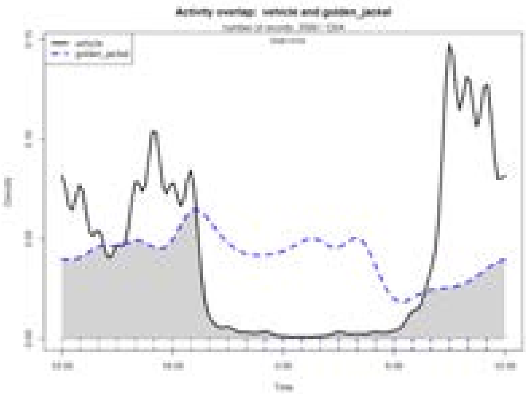
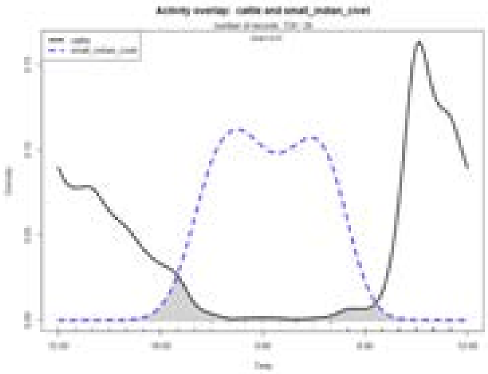


Figure 15

Temporal overlap between golden jackal and various human-induced disturbances (Human, cattle, and vehicle). Dashed line represents Leopard activity; solid line represents each animal's activity. The shaded area indicates the overlap in activity. Dhat values indicate the degree of overlap (0 = No overlap, 1 = complete overlap).



Small Indian Civet Vs Human associated Disturbance



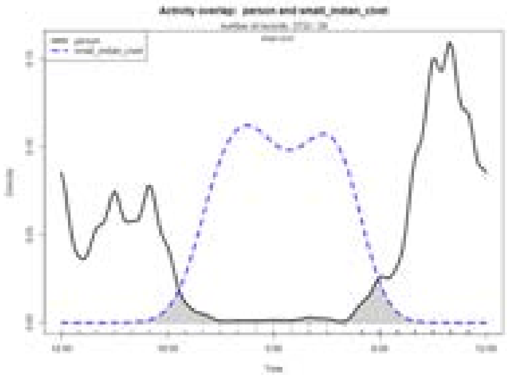
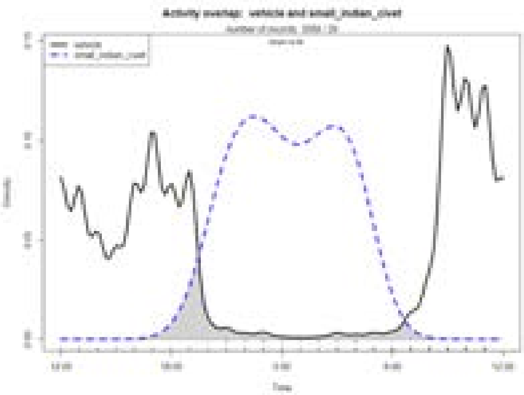
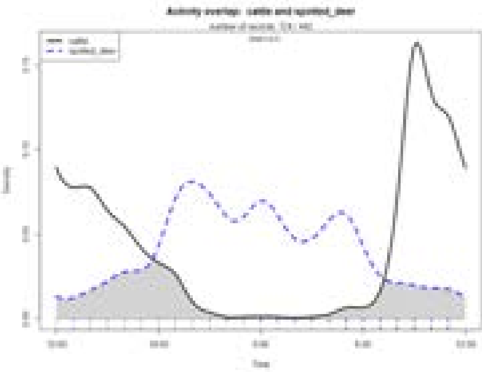


Figure 16

Temporal overlap between Small Indian civet and various human-induced disturbances (Human, cattle, and vehicle). Dashed line represents Leopard activity; solid line represents each animal's activity. The shaded area indicates the overlap in activity. Dhat values indicate the degree of overlap (0 = No overlap, 1 = complete overlap).



Spotted deer Vs Human Associated Disturbance



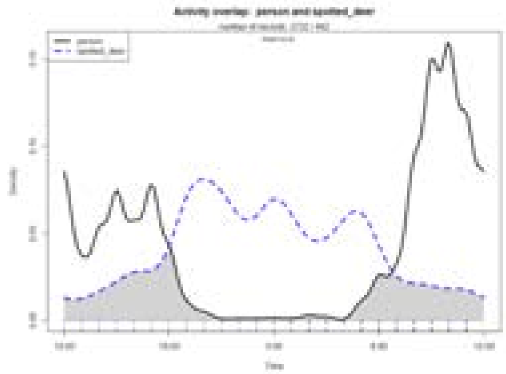
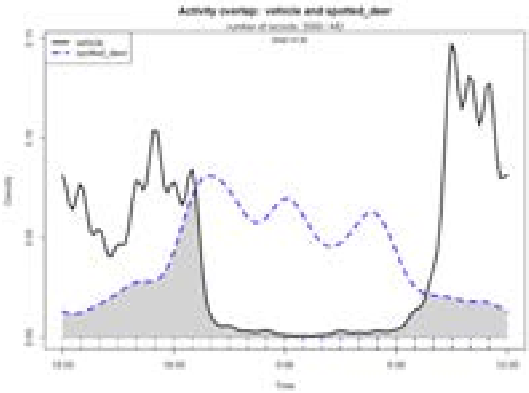
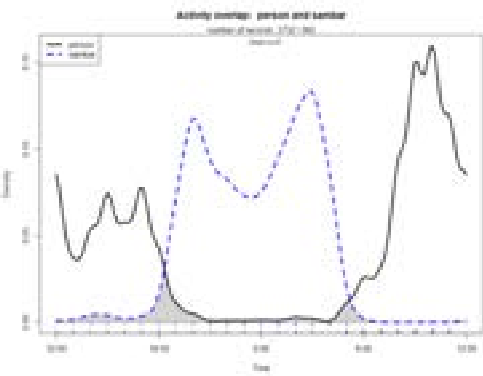


Figure 17

Temporal overlap between Spotted deer and various human-induced disturbances (Human, cattle, and vehicle). Dashed line represents Leopard activity; solid line represents each animal's activity. The shaded area indicates the overlap in activity. Dhat values indicate the degree of overlap (0 = No overlap, 1 = complete overlap).



Sambar Vs Human Associated Disturbance



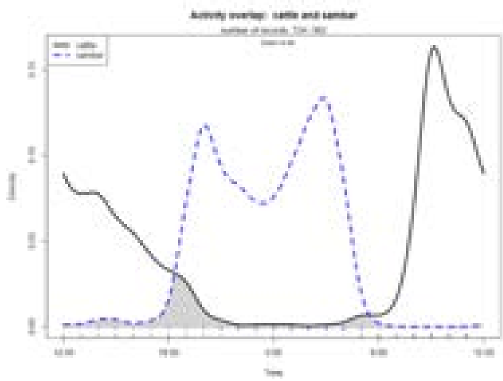
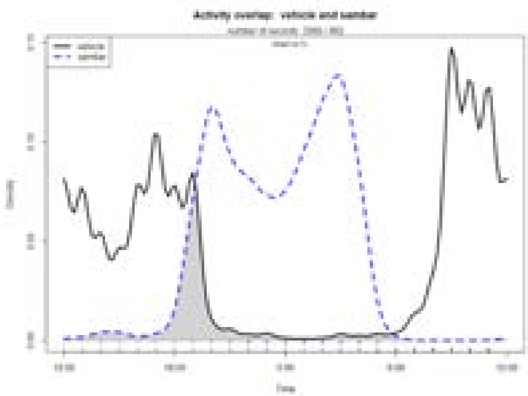
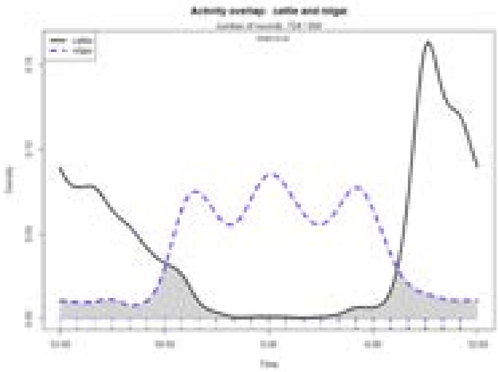


Figure 18

Temporal overlap between Sambar and various human-induced disturbances (Human, cattle, and vehicle). Dashed line represents Leopard activity; solid line represents each animal's activity. The shaded area indicates the overlap in activity. Dhat values indicate the degree of overlap (0 = No overlap, 1 = complete overlap).



Nilgai Vs Human associated Disturbance



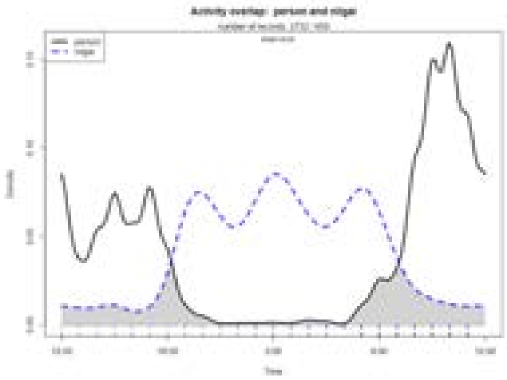
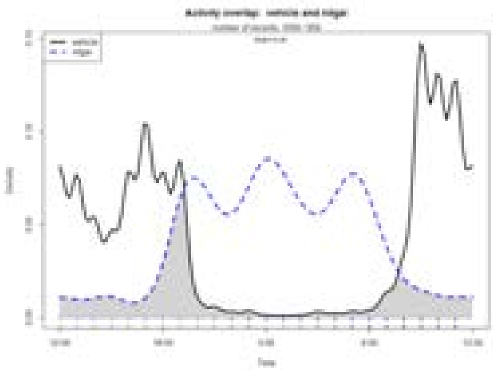
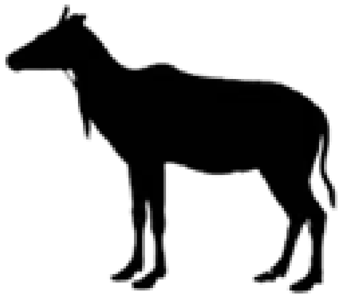


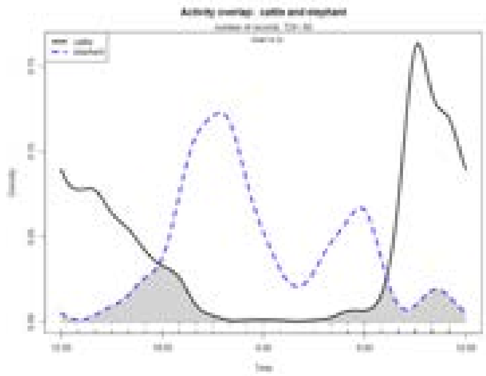
Figure 19

Temporal overlap between Nilgai and various human-induced disturbances (Human, cattle, and vehicle). Dashed line represents Leopard activity; solid line represents each animal's activity. The shaded area indicates the overlap in activity. Dhat values indicate the degree of overlap (0 = No overlap, 1 = complete overlap).





Asian Elephant Vs Human Associated Disturbance



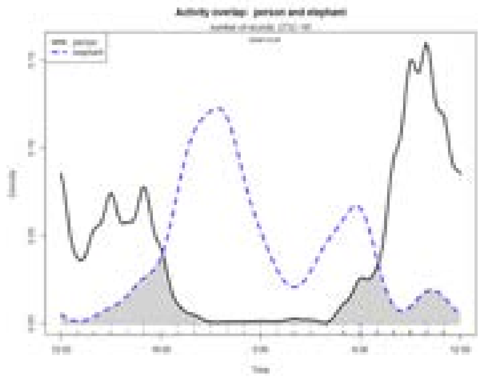
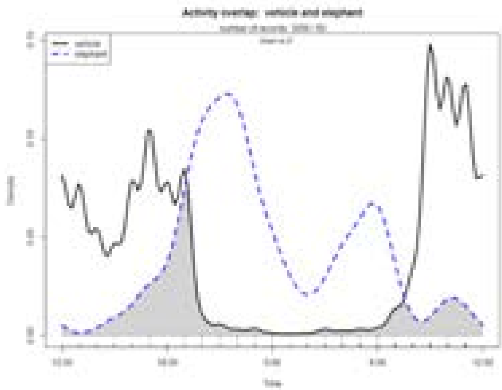


Figure 20

Temporal overlap between Asian elephants and various human-induced disturbances (humans, cattle, and vehicles). Dashed line represents Leopard activity; solid line represents each animal's activity. The shaded area indicates the overlap in activity. Dhat values indicate the degree of overlap (0 = No overlap, 1 = complete overlap).



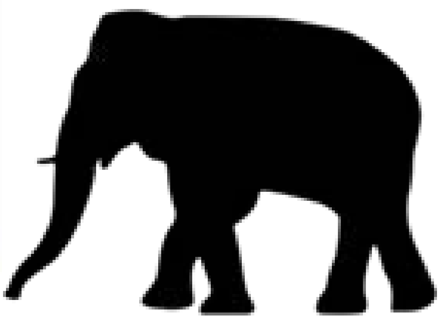


Table 6

Showing the Dhat value of temporal overlap between species and Human-associated disturbances

Species	Human-associated disturbances		
	Cattle	Humans	Vehicle
Common leopard	0.05	0.07	0.05
Golden Jackal	0.49	0.5	0.54
Small Indian Civet	0.07	0.07	0.08
Spotted deer	0.31	0.32	0.36
Sambar	0.09	0.07	0.13
Nilgai	0.22	0.24	0.26
Asian elephant	0.22	0.24	0.27

Audiomoth data analysis

A total of 29 acoustic recorders were deployed along the NH 72-A, including 13 in zone 1, 8 in zone 2 and zone 3 containing a total of 905 acoustic recordings of 1 hour. The value of all the indices was calculated with its standard deviation (Table 7).

Table 7

Showing the mean of all the acoustic indices with SD and overall range.

Index	Mean ± SD	Range
Acoustic complexity index (ACI) (0-800 Hz)	10.73 ± 0.72	9.99 — 123.90
Acoustic complexity index (ACI) (800-8000 Hz)	1.51 ± 0.35	0.64 — 2.85
Bioacoustic Index (BI) (0-800 Hz)	1.61 ± 0.54	0.38 — 5.42
Bioacoustic Index (BI) (800-8000 Hz)	3.46 ± 0.76	0.78 — 6.55
Acoustic Diversity (ADI)	1.70 ± 0.23	1.18 — 2.33
Acoustic Evenness (AEI)	0.56 ± 0.10	0.32 — 0.93
Normalized Difference soundscape index (NDSI)	—0.25 ± 0.09	—0.57 — 0.07
Total Entropy (H)	0.80 ± 0.06	0.67 — 0.95
Number of peaks (NP)	15.38 ± 5.21	2 — 39

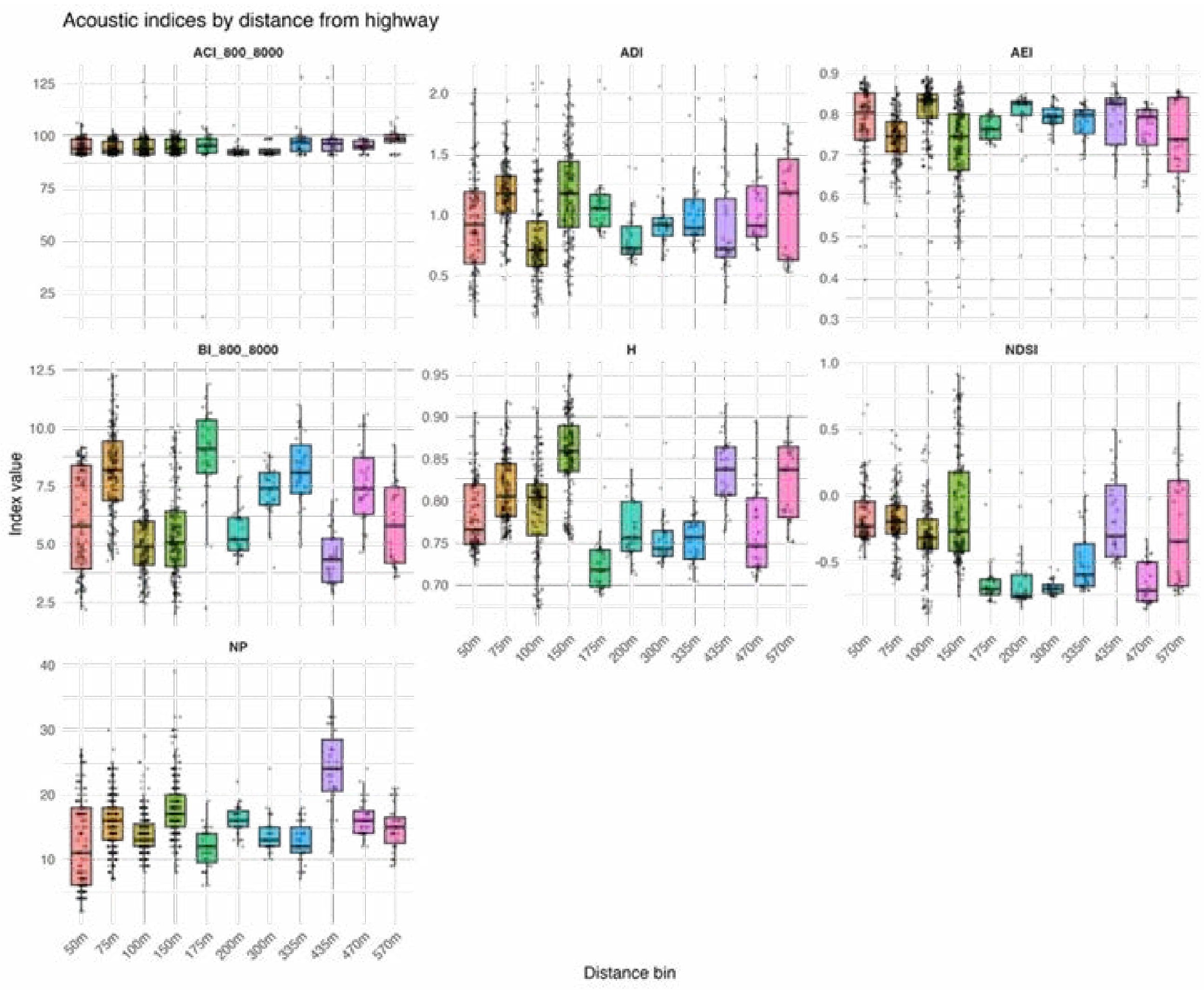
The NDSI is negative for all recordings, showing that anthropogenic sounds (vehicle noise) predominantly exceeded biological sounds throughout the study area.

Patterns of sound across distance

The acoustic complexity index (ACI) and diversity index (ADI) exhibit relative stability across various distances. The absence of a distinct correlation with distance indicates that biological activity might be evenly distributed along the set. BI (0—800 Hz) declines with distance, indicating that low-frequency biological activity is more prominent in the vicinity to the highway. In contrast, BI (800—8000 Hz) remains rather constant regardless of distance. The NDSI is negative at all distances due to a low ratio of biophony to anthrophony. The minor reduction with distance suggests that anthropogenic noise exists even at 570 m. The Total entropy (H) and the Acoustic evenness index (AEI) exhibit minimal variation with distance. These indicators seem unaffected by the variation in traffic noise within the observed range. A slight increase in NP with distance was also found (shown in Fig. 21).

Figure 21

The box plot showcases the variation in the acoustic indices against the varying distances from the road

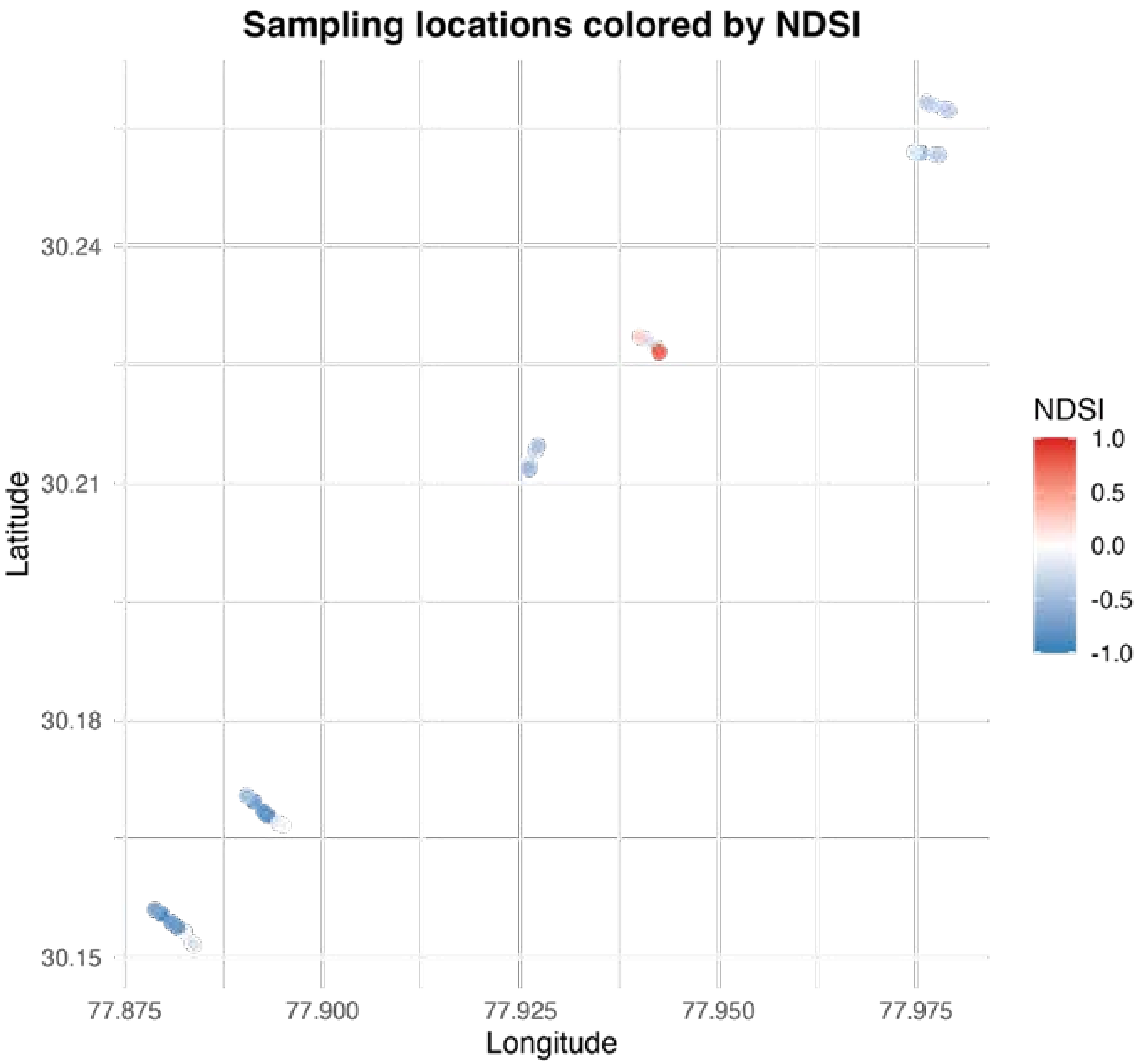


Spatial patterns of Normalized Difference Soundscape Index (NDSI)

Zone 1 exhibited notably higher NDSI values near to the existing road, whereas lower values were found in devices situated in open areas near the newly constructed road (Fig. 22). In zone 2, a high NDSI value was observed at 75m from the road, while a lower value was recorded at a distance of 150m from the road. Notably, the other set has an opposite pattern. Despite the cover of thick forests, both sets in zone 3 exhibit relatively mixed patterns.

Figure 22

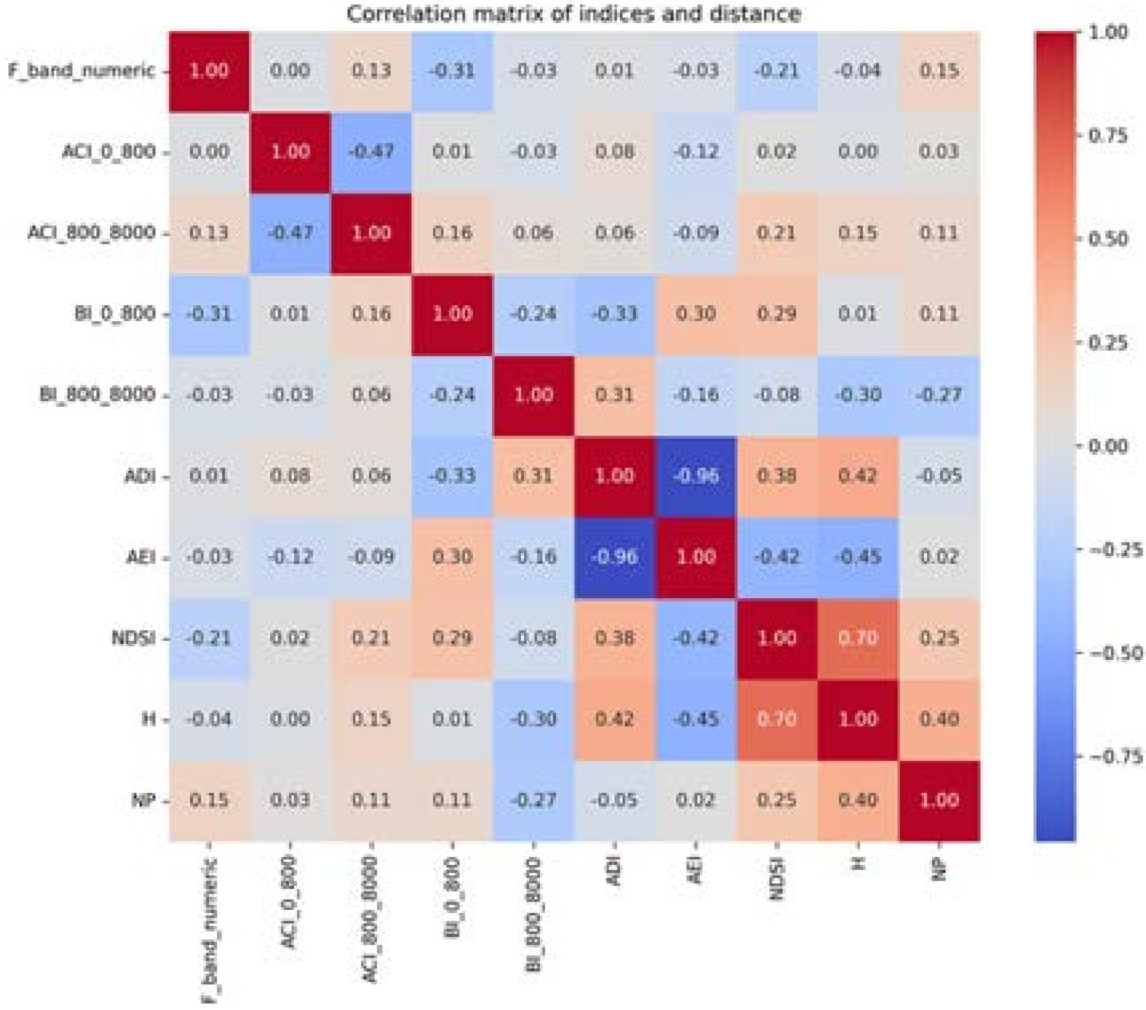
Shows the sampling locations coloured by their Normalized Difference Soundscape Index (NDSI). Warmer colours (towards red) indicate recordings with less negative NDSI means a higher proportion of biophony, while cool colours (blue) denote recordings heavily dominated by traffic noise. The devices were deployed along the stretch of NH72A.



The correlation matrix demonstrates a weak positive correlation between ACI (800-8000) at different frequency bands (r = 0.127) (Fig. 23). Bioacoustic indices (0—800) at different bands exhibit a moderate negative correlation (r = -0.313). This indicates that near-road recordings contain higher low-frequency bioacoustic energy. The NDSI Shows a moderate negative correlation (r = -0.210) suggesting a decline in NDSI values with increasing distance from the road. Additionally, a weak positive correlation between frequency bands and the number of acoustic peaks (r = +0.153) implies that recordings captured at greater distances from the road tend to exhibit more distinct acoustic events.

Figure 23

A correlation matrix of the acoustic indices and distance reveals the relationships among the different metrics. F_band_numeric indicates the varied distances at which the devices have been deployed from the road.



Variations on Day and Time

The acoustic indices exhibit little variation between weekdays and weekends. The distributions of each index for weekday and weekend recordings significantly overlap (Fig. 24). The Bioacoustic Index (BI_0_800) during weekends is moderately high, indicating increased low-frequency noise, whereas the overall NDSI on weekends is more negative, showing a greater proportion of anthropophony. In contrast, the BI_800_8000 and ACI_800_8000 exhibit no change on weekends. Acoustic Diversity Index (ADI) shows a gradual decrease at the end of week while there is a slight rise in evenness index (AEI) and entropy (H). Overall differences in the weekdays and weekends are minimal indicating that human induced disturbances such as traffic noise, persist on weekends much at the same extent as on weekdays.

Figure 24

The box whisker plot shows the distributions of acoustic index values on weekdays and weekends. Each box (median and interquartile range) for one index, comparing recordings from Weekdays (blue) and Weekends (orange). For NDSI, the median NDSI is about -0.30 on weekends vs. -0.29 on weekdays, both relatively negative.

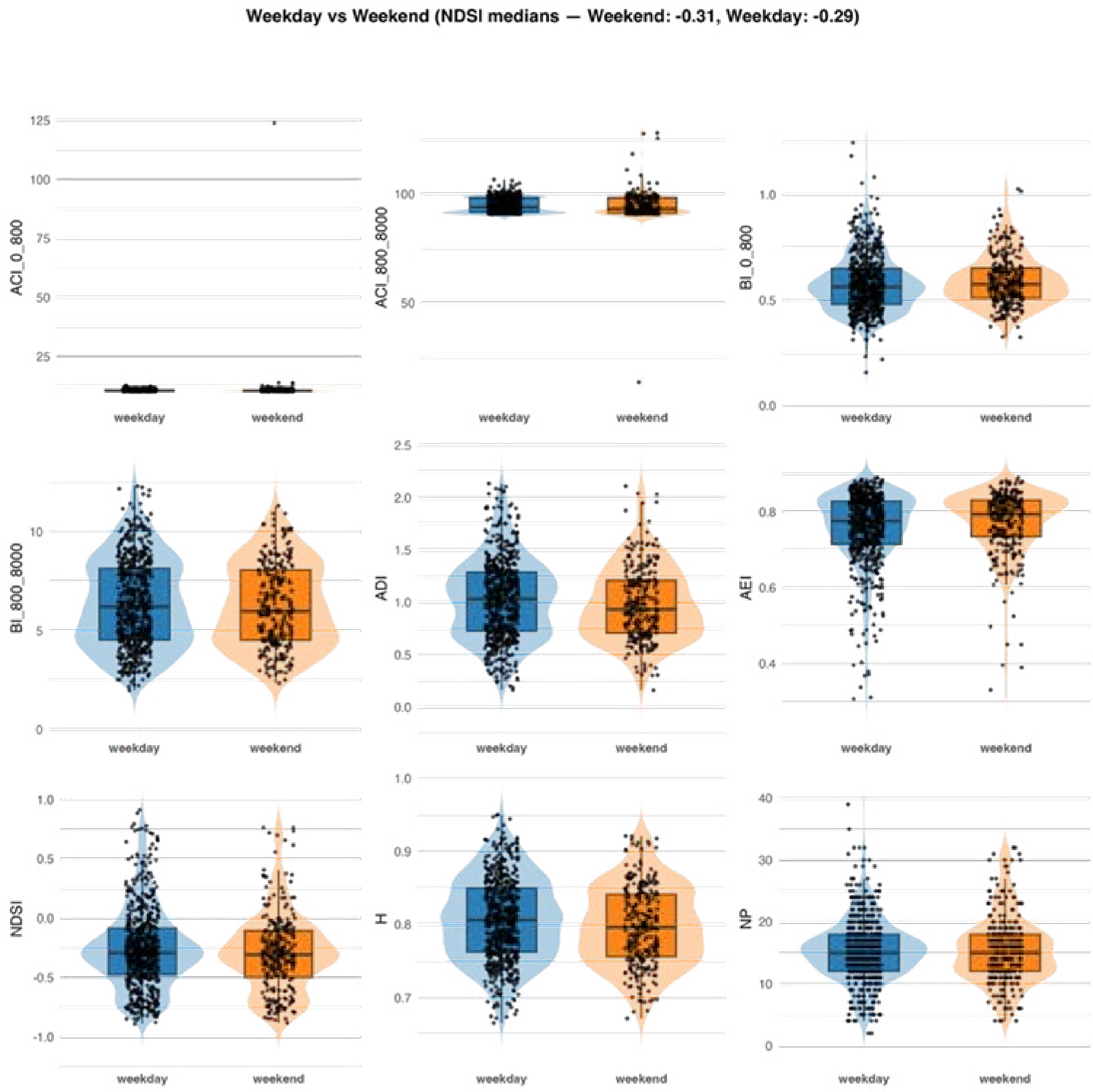
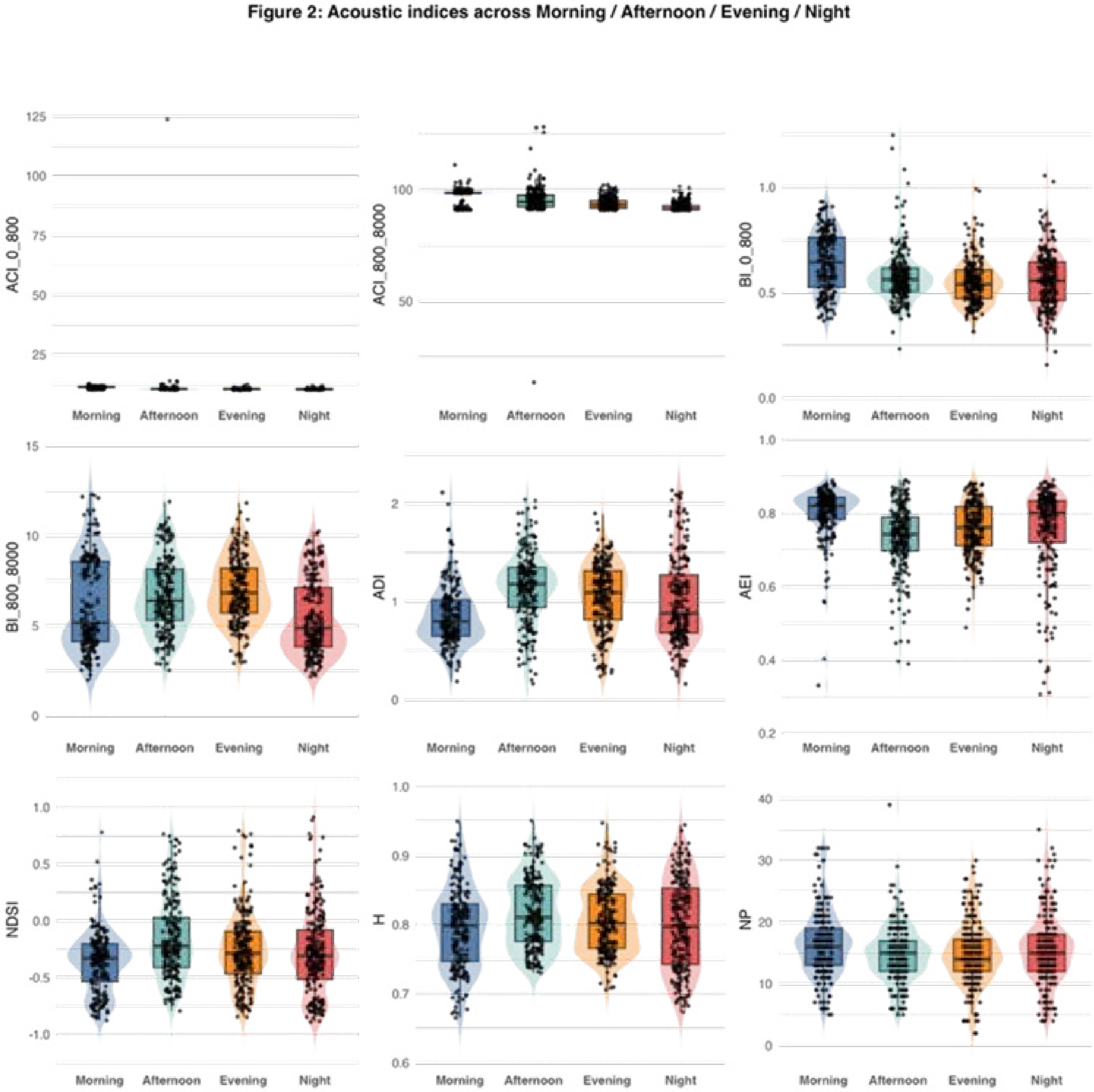


Figure 25

The box whisker plot shows distributions of acoustic indices across four times of day: Morning, Afternoon, Evening, and Night. Each box indicates the interquartile range of that time of day. The central line depicts the meridian value.



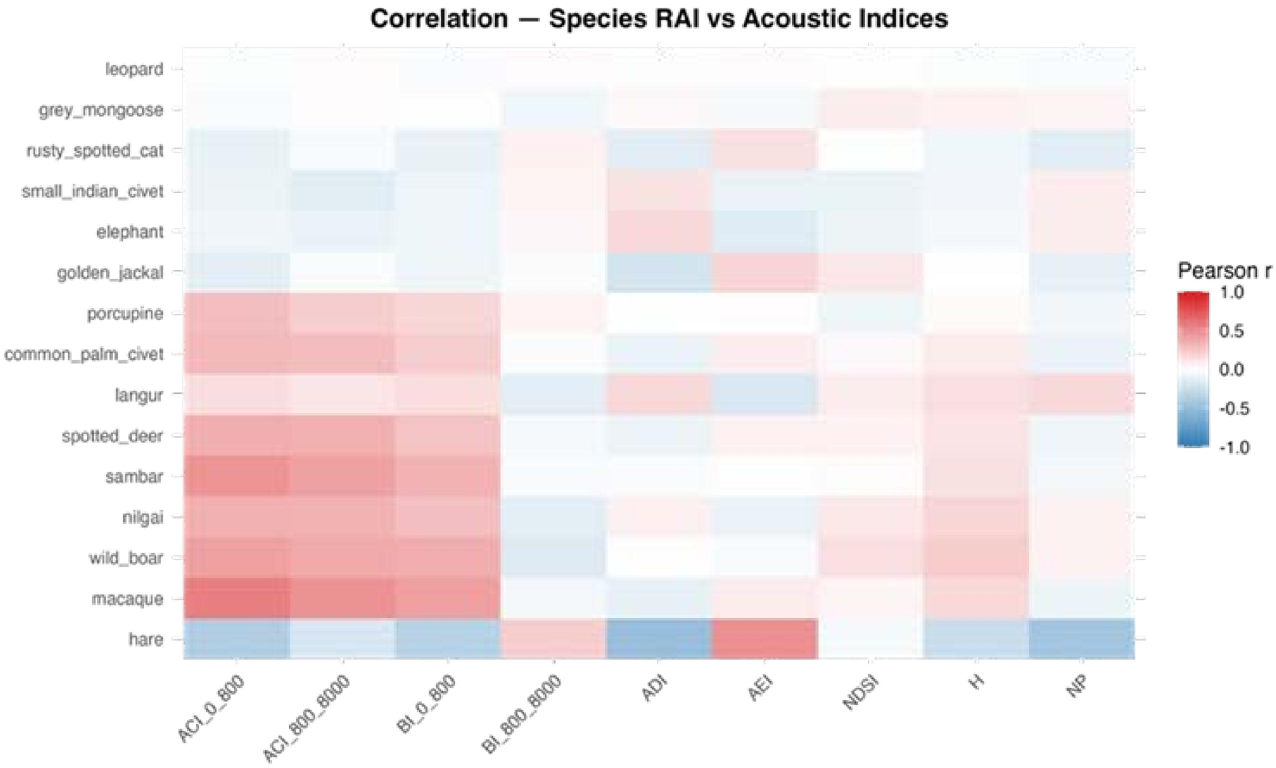
The morning hours exhibit the most prominent values of anthropophony. Most low-frequency signals reach their peak in the morning, the BI_0_800 values are elevated in morning recordings, and the morning ACI_0_800 is similarly greater, suggesting increased complexity in low-frequency fluctuations (Fig. 25). Consequently, the NDSI is lowest in the morning (with a median of -0.33). In the afternoon, NDSI values were comparatively less negative (approximately —0.16), and BI_0_800 values declined, suggesting reduced anthropophony. Evening recordings exhibited the lowest BI_0_800 values across all time periods, and NDSI values were less negative than those observed during morning and night, potentially attributable to heightened biological activity contributing to high-frequency sound energy. The night hours exhibit relatively low anthropogenic activity, the NDSI remains moderately negative (about -0.29 median). The ADI shows the elevated peaks in the morning and evening and drops at night, while AEI was found highest at night. The entropy was found highest in the night and lowest in the evening and the number of peaks was found similar in morning and night.

Comparison of wildlife underpass use with different noise levels

Pearson's correlation revealed that various species indicate varied relationships with sound data. Sambar (*Rusa unicolor*), spotted deer (*Axis axis*) and Asian elephants (*Elephas maximus*) exhibited a moderate negative correlation with NDSI (r = —0.36), indicating a preference for underpasses characterized by lower anthropogenic noise levels. In contrast, the Relative Abundance Index (RAI) of golden jackals (*Canis aureus*), nilgai (*Boselaphus tragocamelus*) and wild boar (*Sus scrofa*) showed a positive correlation with NDSI (r = +0.43), suggesting a higher frequency of detections in acoustically disturbed environments. Ultimately, the overall result showed that most wild ungulates and elephants except nilgai selectively use underpasses in low noise areas, whereas opportunistic carnivores generalist species, such as golden jackals may even prefer the underpasses with substantial noise level.

Figure 26

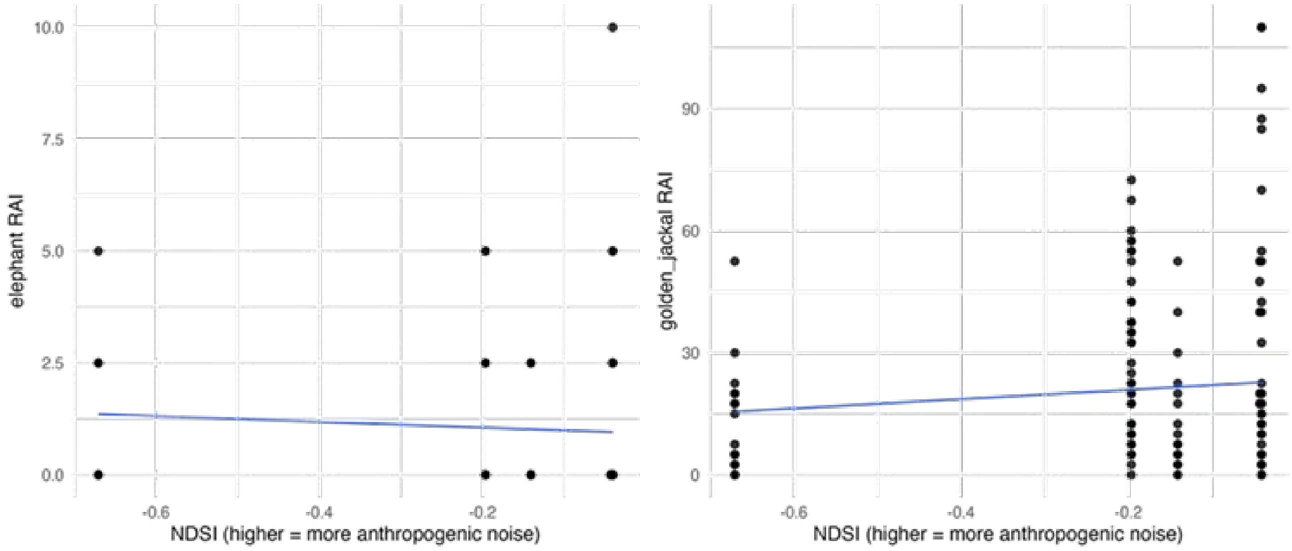
Pearson correlation heatmap between selected species relative abundance index (RAI) (rows) and acoustic indices (columns). The colour of each cell represents the Pearson correlation, blue tones indicate negative correlations and red tones positive.



The scatter plot (Fig. 27) shows that the Elephants were exclusively recorded at areas with a relatively low NDSI (> - 0.2), and their peak RAI was observed at the lowest anthropophony (NDSI = — 0.67). No elephants were observed at the places with the highest noise levels. Conversely, the scatter plot illustrates that golden jackals are distributed throughout the high noise underpass, demonstrating a high RAI at one of the most acoustically active underpass locations (NDSI = —0.1). Jackals were often observed even in areas with significant road noise. Both the species differ in noise tolerances.

Figure 27

Scatter plots of species RAI against NDSI. On the left side indicating the RAI value of Elephant against the NDSI. Elephants were primarily detected at sites with lower NDSI (low anthropophony) (—0.7 and —0.2), while no elephants were recorded in high-noise areas (NDSI < 0). Conversely, for Golden Jackals to showcase the opposite pattern, a significant jackal activity was observed even at the locations of high noise underpasses (NDSI = —0.1).

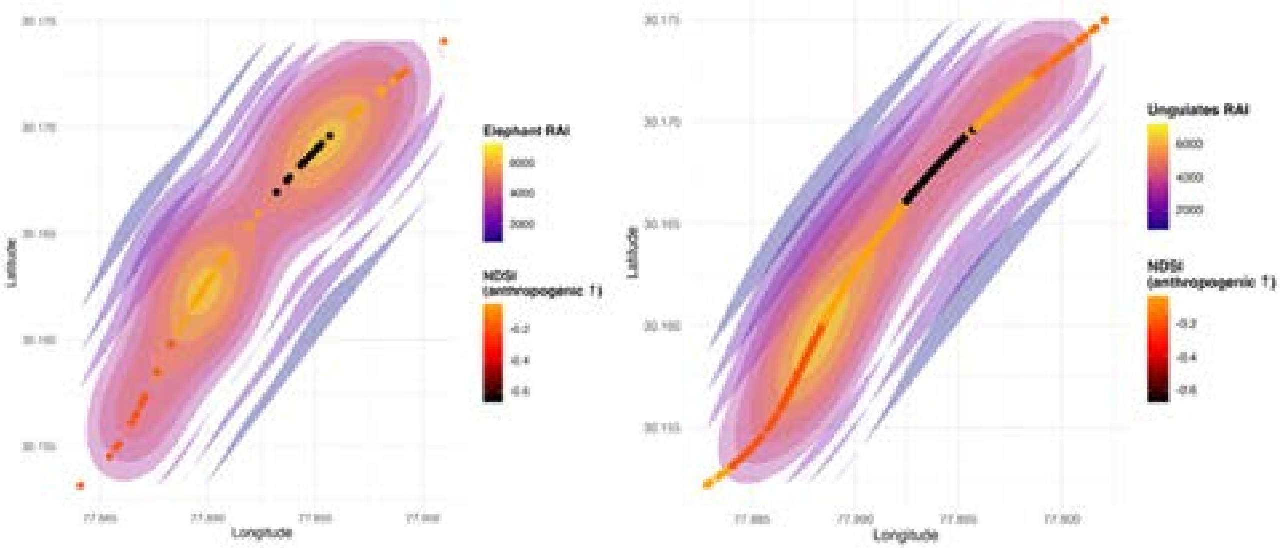


Spatial Patterns of Wildlife Activity and Noise

To visualize the spatial relationship of crossings with the noise levels, Fig. 28, shows the camera stations contiguous to the underpasses denote NDSI (anthropogenic noise level) and the clusters indicate the RAI value of elephants and ungulates includes aggregated sambar and spotted deer activity.

Figure 28

A map showing camera trap locations adjacent to two crossing sites in one continuous underpass, displaying animal Relative Abundance Index (RAI) in relation to noise levels. Two clusters of points correspond to one single underpass structure with two preferred crossing sites. Within each cluster, one side (blue points) had reduced traffic noise and displayed larger markers, indicating greater ungulate and elephant usage), while the points indicated increased roadway noise (red and orange) often presented smaller markers (indicating fewer ungulate crossings). This geographical pattern indicates that ungulates focused their movements towards the sites with low noise underpasses.



Spatial patterns of elephant crossings revealed two distinct clusters within a single continuous underpass, corresponding to preferred crossing sites. Within each cluster, one side of the underpass had increased traffic noise (marks in warm colour indicating higher NDSI), while the opposing side was comparatively less noisy (markers in cooler blue tones reflecting less negative NDSI). The cluster with blue points indicates the highest crossings of elephants while the small cluster with orange points exhibit low noise level. Among ungulates, crossing activity was predominantly concentrated in clusters associated with reduced anthropophony. Spotted deer (*Axis axis*) were notably absent from the noisier sections of the underpasses, but frequently recorded in quieter zones. Similarly, sambar (*Rusa unicolor*) exhibited greater utilization of underpass segments with lower NDSI values, reinforcing the pattern of noise-avoidance among these species.

05 Discussion

Camera trap data

Observations over a 40-day period show that a wide range of wildlife species actively use the underpasses along the NH72 corridor, indicating that these crossing structures perform as an effective mitigation strategy for maintaining natural movement patterns near the roadways. We identified 18 wild animal species utilizing the structures, demonstrating their acceptability by generalist wildlife species. But for some species, such as barking deer, there was not a single capture found by comparing the previous report (Pandav B. & Habib B., 2020) in Zone 1. The sporadic and delayed use of crossing structures can be related to their relative abundance within protected areas, as well as their closeness to these areas and vegetation cover (Jhala *et al.*, 2020), alongside species behavior (Saxena A. & Habib B., 2022). Infrequent sightings of species like the Rusty spotted cat, Grey mongoose, and Red junglefowl are consequences of their low population numbers, preference for undisturbed habitats, and elusive behavior.

Each species shows its distinct preferences for specific crossing zones. Animals typically select these areas based on disturbance from humans, predator avoidance (Araya-Gamboa D. & Salom-Pérez R., 2015; Prokopenko *et al.*, 2017), and noise (Collins *et al.*, 2022). According to findings, leopards primarily use the underpasses, located at sites spatially separated from nearby settlements, i.e., Ganeshpur and Mohand (Kshettry *et al.*, 2017; Chaudhary *et al.*, 2020). In the case of small herbivores, the Indian hare is more abundant towards Ganeshpur, and the Indian porcupine is more abundant towards Mohand village, mostly because of the availability of water near Mohand village in the dry season. Ungulates such as Spotted deer, Sambar, and Nilgai used the underpass often and at various locations; the highest captures for all these herbivores were near due to water availability in drier months. The other reason for these mammals to be captured mostly near the underpass in zone 1 is because that the underpass passes from an open riverbed (known as Rao in the local language). These animals, especially ungulates, rest in the dried riverbed, spotted deer in herds, sambar and nilgai in small groups (Author's personal observation). Many herbivores use open lands to rest at night to avoid predation risk, as also shown by Owen-Smith N. & Traill L (2017). De Jonge et. al. (2022), showed in their study that large grazers such as Wildebeest

(*Connochaetes taurinus*) and Zebra (*Equus quagga*) use the open land near the village for rest at night. Primates crossing mostly occur near Mohand village, and the availability of a permanent water source. The elephants avoid the disturbance near the village and cross mostly from the undisturbed underpass (Berti *et al.*, 2025).

Various human activities force wild animals to alter their daily activity patterns to avoid interaction (Lewis *et al.*, 2021). Additionally, human disturbances at crossing structures create a significant challenge (Wang J., 2014). Most species demonstrate temporal avoidance of human activity, except for wild boar, golden jackal, and other generalist species, which maintained consistent behaviors across varying levels of human presence. In the present study, leopards significantly minimize all the human-associated disturbances with the activity at dawn, nighttime and dusk. This marks the avoidance of peak human activity (Smyth *et al.*, 2025). In contrast, the golden jackal showed a significant overlap with human activity, probably due to easy food availability and the absence of predators (Mandal M, 2024). Small Indian civets clearly avoid humans, primarily because of their nocturnal habits and the increase in human activity during daylight hours. Another possible explanation is their preference for forested environments, which makes underpass use an irregular activity. Most activity of Spotted dear, Sambar, and Nilgai occurred at night because the anti-predator strategy of these ungulates force them to rest in the open habitats right in front of the camera to be captured (Creel *et al.*, 2014; Courbin *et al.*, 2019). Asian elephants were mostly recorded at dusk, dawn, and night when the human disturbances were minimal. It was a rare occasion where a male elephant was found crossing the underpass in the afternoon (Author's direct observation).

Acoustic indices

The use of Passive Acoustic Monitoring (PAM) has become increasingly accessible and beneficial for addressing ecological questions related to road studies (Ross *et al.*, 2023). It also provides the integrative indices for assessing the effects of road-induced noises on biological sounds (Wang *et al.*, 2025). In the present study, the Bioacoustic index (BI) of low frequency up to 0-800 Hz shows a decline with the distance. The (Ducay R. & Pease B., 2024) also showed in their study that Bioacoustic indices are impacted by distance from roads and vehicle traffic. A slight increase in the Number of peaks (NP) further suggests that more distinct Biophony can be detected farther from the road, whereas close to the road may result in vehicle noise suppressing low-frequency calls and reducing the number of detectable peaks. The Normalized Difference Soundscape Index (NDSI) exhibited negative values even up to 570 m, perhaps due to the open terrain facilitating the propagation of road noise. In contrast, in the hilly terrain, NDSI was found to be higher near the road but decreased significantly with distance, primarily because hills hinder the propagation of sound away from the road (Renterghem *et al.*, 2007).

The weak correlation observed between Acoustic Complexity Index (ACI; 800—8000 Hz) and various frequency bands suggests that acoustic complexity at higher frequencies increases slightly with greater distance from the highway (Guagliumi *et al.*, 2025). The Bioacoustic Index (BI;0-800) shows a moderately negative correlation with different bands of distances, mainly due to anthrophony (Traffic noise) overlapping with biophony (biological sounds). The reason for the weak positive correlation between the various frequency bands and Number of Peaks (NP) was possibly reflecting more diverse biological activity in less disturbed areas (Retamosa I. & Barrantes M., 2023). The noise level is found to be increased on weekends and shows a positive relation with indices. The pattern in the data indicates that weekends exhibit a considerable amount of vehicular activity, with weekend recordings reflecting equal or marginally elevated levels of vehicular noise (Ducay R. & Pease B., 2024). Variations have been observed at various times throughout the day. The morning hours display increased levels of anthropophony due to a lack of significant biological activity, and the same for the night, as numerous biological sounds decline during the night (Gage S. & Axel A., 2014; Chew Y. & Wu B., 2016). It implies that even a minor presence of traffic noise at night can disproportionately overpower the soundscape with the low noise.

The value of the Relative Abundance Index (RAI) and acoustic indices provides evidence that numerous wildlife species utilize underpasses more frequently when urban noise levels are reduced. Species such as leopards, herbivores including sambar, spotted deer, and mega-herbivores such as elephants exhibited increased activity in the low noise sections of the underpass, demonstrating correlation with NDSI and with significantly higher usage of low noise sections. These species are sensitive to noise and likely perceive loud traffic noise as a disturbance and causing physiological and behavioral responses, thereby restricting their ability to cross the noisy underpasses (Shilling *et al.*, 2018; Dawe G. & Goosem M., 2008). In contrast, generalist species such as the Golden jackal, Nilgai, and wild boar did not avoid, and may rather prefer, the noisier underpasses, potentially foraging along roadways or becoming habituated to human presence. A previous study of 19 underpasses in Spain revealed no consistent overall reduction in crossings due to noise, indicating that habitat characteristics were more significant than noise levels in influencing usage (Iglesias *et al.*, 2012). Noise may not regularly hinder all vertebrates; rather, it can substantially impact sensitive species. In the present study, the overall Relative Abundance Index (RAI) did not significantly decline due to noise, as tolerant species balanced; nevertheless, the composition changed, with ungulates and other shy species being comparatively scarce at the noisiest places and being replaced by resilient species, including humans and livestock (Ditmer *et al.*, 2021). This indicates that underpasses adjacent to high traffic may still exhibit wildlife activity. Mitigation measures may encompass noise abatement strategies, such as sound barriers to enhance the efficacy of underpasses for noise-sensitive species. For the entire stretch of NH72 A, sound barriers have been placed at all areas, especially above the underpasses, but in the areas, including zone 1, which is a major crossing area, are devoid of sound barriers. Which might deter the sensitive species (Sołowczuk A., 2020; Author's personal observation).

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