Science of the Total Environment 822 (2022) 153268

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

The impacts of COVID-19 lockdown on wildlife in Deccan Plateau, India

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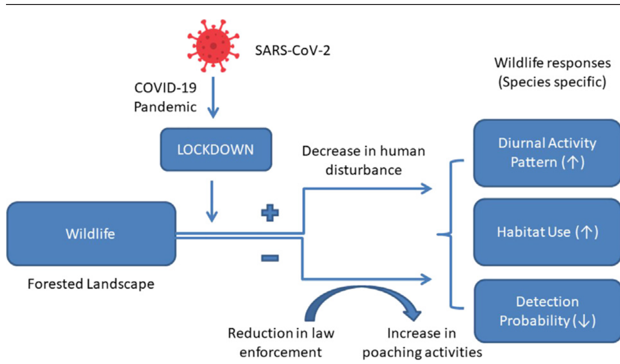
HIGHLIGHTS

- The COVID-19 lockdown has both positive and negative impact on wildlife.
- Reduced human activities led wildlife to increase their diurnal activities.
- Rise in illegal wildlife activities was observed during lockdown.
- Species-specific increase of habitat use was observed during lockdown.
- Reduced detection probabilities of species during lockdown

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 9 October 2021
Received in revised form 14 January 2022
Accepted 15 January 2022
Available online 22 January 2022

Editor: Rafael Mateo Soria

Keywords:
Activity pattern
Camera trap
COVID-19
Detection
Lockdown
Occupancy
Wildlife

ABSTRACT

The outbreak of the COVID-19 pandemic brought unprecedented changes in human activity via extensive lockdowns worldwide. Large-scale shifts in human activities bestowed both positive and negative impacts on wildlife. Unforeseen reduction in the activities of people allowed wildlife to venture outside of forested areas to exploit newfound habitats and increase their diurnal activities. While on a negative note, a reduction in forest-related law enforcement led to substantial increase in illegal activities such as poaching. We conducted mammal surveys in forested and nearby farmland of a fragmented landscape under two distinct scenarios: pre-lockdown and lockdown. An increase in poaching activities observed during the lockdown period in our study area provided us an opportunity to investigate the impact of the lockdown on wildlife. Camera trapping data of four highly poached mammalian species, namely black-naped hare *Lepus nigricollis*, wild pig *Sus scrofa*, four-horned antelope *Tetracerus quadricornis* and leopard *Panthera pardus* were considered to investigate activity patterns and habitat use, to understand the effect of lockdown. The pre-lockdown period was used as a baseline to compare any changes in trends of activity patterns, habitat use and detection probabilities of targeted species. Species-specific changes in activity patterns of study species were observed, with an increment in daytime activity during lockdown. The results showed species-specific increase in the habitat use of study species during lockdown. Reduction in the detection probability of all study species was witnessed. This is the first study to highlight the effect of the COVID-19 lockdown on the responses of wildlife by considering the changes in their temporal and spatial use before and during lockdown. The knowledge gained on wildlife during reduced human mobility because of the pandemic aid in understanding the effect of human disturbances and developing future conservation strategies in the shared space, to manage both wildlife and humans.

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http://dx.doi.org/10.1016/j.scitotenv.2022.153268

1. Introduction

Almost 2 years ago, the coronavirus pandemic, also known as the COVID-19 pandemic took over the world almost instantaneously. It is one of the deadliest pandemics in history as it challenged almost every nation globally and has claimed more than 5.32 million lives as of 13th December 2021 (CSSE (Center for Systems Science and Engineering), 2021; WHO, 2020). Its etiologic agent, SARS-CoV-2 virus spreads mainly through the air and via contaminated surfaces, and its rapid spread enormously affected public health systems and people's daily lives (Baloch et al., 2020; Nuñez et al., 2020). To control the spread of the pandemic, authorities worldwide responded by implementing lockdowns, curfews, travel restrictions and quarantines (Arnon et al., 2020). Research and case studies have shown that lockdowns effectively reduce the spread of COVID-19 (Perra, 2021; UNESCO, 2020). Reduction in human activities across the globe affected the environment in a positive manner with reductions in air and water pollution, and decreased greenhouse gas emissions (Arora et al., 2020; Chowdhury et al., 2021; Dutheil et al., 2020; Sharma et al., 2020).

Human presence and activities considerably influence the distribution, abundance, and behaviour of wildlife (Dirzo et al., 2014; Gaynor et al., 2018; Tucker et al., 2018). Certain studies suggest that rapid large-scale decline in human disturbance has led to changes in the 'landscape of fear' induced by humans through infrastructures, activities and widespread presence (Bleicher, 2017; Lodberg-Holm et al., 2019). According to media reports, the sudden halt in human activities and movements because of lockdown appeared to have triggered wildlife to emerge from their limited habitats to exploit the newly found habitat opportunities and increase their daily activities (Manenti et al., 2020; Silva-Rodríguez et al., 2021). Although, a few wild species have learned to benefit from anthropogenic resources (Castañeda et al., 2020; Newsome et al., 2015), the majority of the wild species generally avoid human-built areas (Dorresteijn et al., 2015).

The onset of the COVID-19 pandemic brought about major changes to human dynamics on a global scale with large-scale shifts in human activities. Besides having these positive impacts, this sudden reduced human activity had some negative effects on wildlife (Bates et al., 2020; Corlett et al., 2020; Manenti et al., 2020; Rutz et al., 2020; Zellmer et al., 2020). During the lockdown, imposed restrictions on movement reduced patrolling and monitoring from law enforcers, researchers, and hikers in large parts of natural areas (Corlett et al., 2020; Manenti et al., 2020), which fostered opportunities for illegal hunting of wildlife species by poachers. The lockdown has created economic insecurity in rural areas because of businesses closures, which may have compelled humans to support themselves through poaching and fishing (Badola, 2020). An abrupt halt in ecotourism, weakened management and law enforcement as lockdown and movement restrictions lowered local revenue, enforcement staffing and funding to enforce poaching restrictions all affected wildlife management (Spenceley et al., 2021; Waithaka et al., 2021). Different NGOs worldwide underlined that the poaching of wild animals more than doubled during lockdowns in both African and Asian countries (Athumani, 2020; Badola, 2020).

In India, a nationwide lockdown was strictly imposed on 24th March 2020 with a public curfew, as a preventive measure against the pandemic (Gettleman and Schultz, 2020; Ministry of Home Affairs, 2020; UN News, 2020). The lockdown restricted the movement of people outside of their homes (PIB (Press Information Bureau)-Delhi, 2020). All transport services (road, air and rail), educational institutions, industrial establishments and hospitality services were also suspended (Ministry of Home Affairs, 2020). A complete ban of recreational, tourism, and non-essential economic activities was implemented during the lockdown (Gettleman and Schultz, 2020; Negi, 2020).

Understanding the impact of such disruption of normal human activities on wild animals necessitates the investigation of the influence of anthropogenic-related habitat determinants on their distribution and behaviour. This provides scope for ecologists and conservationists to understand ecological effects on the distribution of wildlife species. To explore the extent and scale of the impact of lockdown on wildlife, we conducted mammal surveys in forested and nearby farmland areas of a fragmented landscape under anthropogenic pressure using a systematic camera trapping framework. A lot of illegal activities such as wildlife poaching were observed in the study area during COVID-19 lockdown. Hence, we used this opportunity to test the effect of habitat measures believed to be associated and proxy of poaching activities on wildlife response during lockdown. A camera-trapping survey of four mammalian species, namely black-naped hare *Lepus nigricollis*, Indian wild pig *Sus scrofa*, four-horned antelope *Tetracerus quadricornis* and leopard *Panthera pardus* was undertaken to investigate changes in their activity patterns and habitat use before and during lockdown to understand the effect of lockdown. These four species were chosen for the study as they are widely distributed and are among the India's highly poached mammalian species (Keuling and Leus, 2019; IUCN SSC Antelope Specialist Group, 2017; Nameer and Smith, 2019; Stein et al., 2020).

We considered the term occupancy as habitat use because the home range of each study species is larger than the sampling grid size used, and the same individuals could use multiple sampling units within a short survey duration. Therefore, we infer our results as sites used (i.e., habitat use), and not area occupied (Occupancy), at each sampling unit. We explored whether the temporal pattern of study species varied across the two scenarios associated with different levels of human disturbances. We studied changes in habitat use and detection probabilities of focal species using a suite of habitat measures associated with illegal hunting activities to answer the following questions: 1) Did the COVID-19 lockdown impact the activity patterns of the wild mammalian species studies? 2) To what degree were habitat use and detection probabilities of mammalian species affected by lockdown?. We predicted that the diurnal activity and habitat use patterns of mammals to increase with reduced human disturbance during lockdown.

2. Material and methods

2.1. Study area

Our study, a part of a landscape level project, was conducted within the jurisdictional area of Ballari territorial forest division that forms a part of the Deccan Peninsula of India (Fig. 1). Camera-trapping data were collected from the forest areas of Sandur- North, Sandur- South and Kudligi territorial ranges covering Reserved Forests (RFs) and the adjoining fringe mosaic farmland areas up to 1 km from RF boundaries. We conducted the study between 10th March 2020 and 7th April 2020, in the forest patches and adjoining fringe mosaic farmland areas (Coordinates: between 14° 55′ 41″ and 15° 11′ 35″ north latitude and 76° 25′ 4″ and 76° 43′ 4″ east longitude). The general elevation of the study area is between 550 m and 750 m a.m.s.l. The average annual temperature ranges from 20 °C to 40 °C. Sandur North range is located at the central part of the district, comprising of tropical dry deciduous forest whereas the Kudligi territorial range and southern part of Sandur range, with sparse vegetation represents dry thorn forest (Champion and Seth, 1968). The terrain varies from open plains to undulating landscapes with some patches of rugged hills. Sandur ranges received relatively higher rainfall than the southern part with the average annual rainfall of the district being 574.9 mm (Meena, 2013). The study area is prone to heavy mining activities, land-use changes, over-grazing, forest land encroachment and illegal resource extraction. This district is one of the most economically vulnerable districts in the country and its economy is based predominantly on agrarian and associated activities. The local people have large cattle populations for the sustenance/economic prosperity and are highly dependent on Non-timber Forest Product (NTFP) collection (Meena, 2013). Forest land encroachment for farming is putting additional pressure on the remaining forest patches. All these human-related interferences constitute the fragmentation of natural forests. The district is endowed with rich deposits of minerals of economic importance like iron and manganese (Meena, 2013). Presently, over 50 km^2 of forest land is used for mining activities, and majority of the mines are situated within the forested land of Sandur range. Furthermore, large numbers of migratory

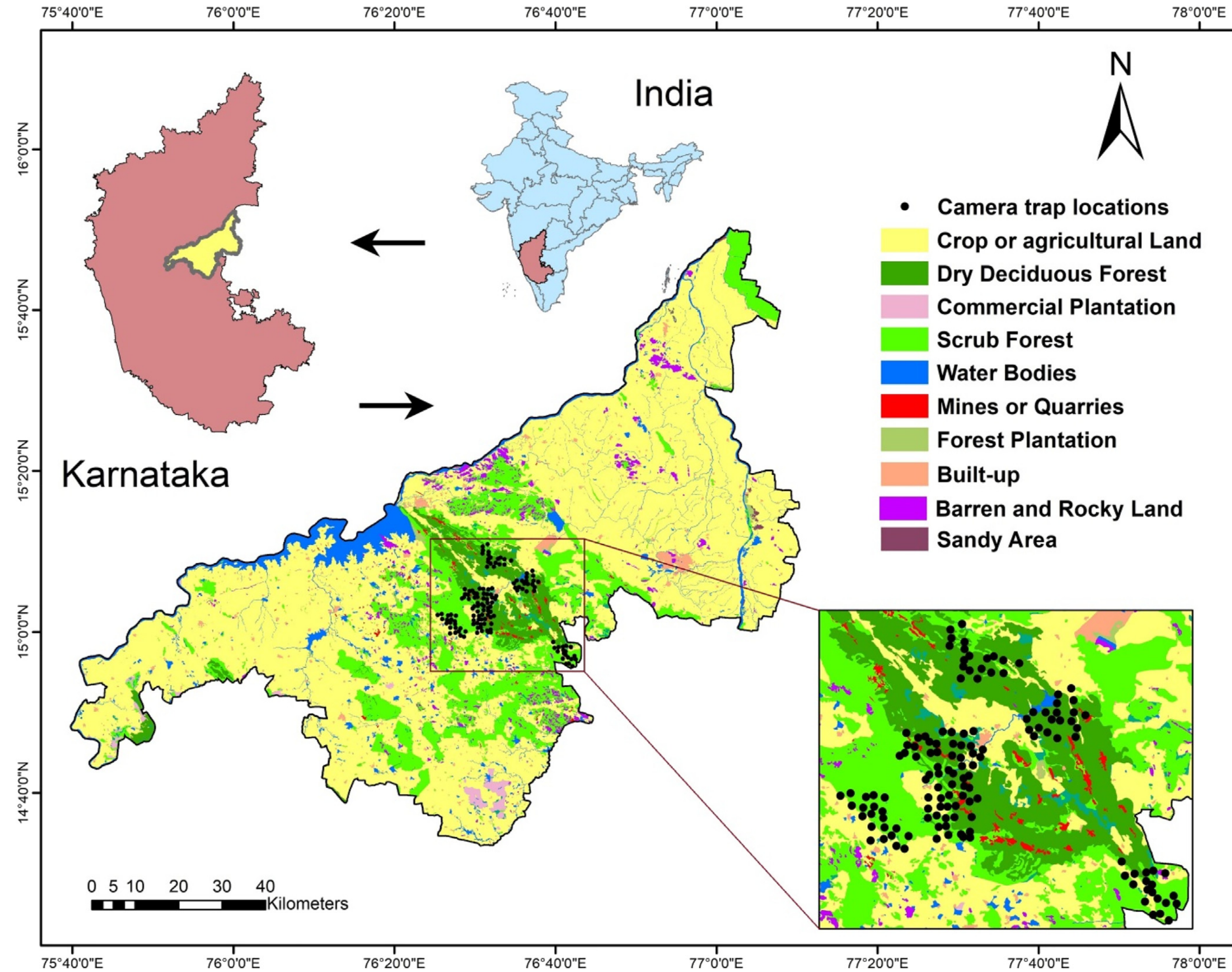

Fig. 1. Camera trap locations of the survey area in Bellary district, Karnataka.

labourers from different parts of the country are engaged in these mines and steel plants. When India went into complete lockdown in 2020, halting of mining-related activities resulted in thousands of labourers losing their livelihood. This may be a driving cause of the resulting poaching of wild animals. The COVID-19 outbreak left many people destitute and without any back-up from the government, many poor and vulnerable people were left with the only option of exploiting natural resources (Abd Rabou, 2020).

2.2. Data collection and analyses

Camera-trap data presented here were 'by-catch' from our landscape level project with the primary objective to study the landscape level patterns of mammalian assemblages in Ballari district, Karnataka. Pre-lockdown considers 7 days of data of focal species just before the implementation of lockdown i.e., from 17th March 2020 to 23rd March 2020 and the lockdown period comprised 7 days of data after 1 week from the implementation of lockdown, i.e., from 31st March 2020 to 6th April 2020. We ignored the initial week of the lockdown as the study area mostly falls in rural areas and we operate under the assumption that strict implementation of lockdown guidelines took more time than in urban areas. Before initiating the study, we overlaid 1×1 km^2 grids throughout the entire study area using ArcGIS 10.1 (Environmental Systems Research Institute Inc., Redlands, CA, USA). We considered a small systematic grid size of 1 km^2 as the sampling unit, to capture the distribution of all mammalian species. The land cover layer obtained from Karnataka Forest Department was laid at the background to identify the gradient of land cover types in the study area. A total of 145 camera trapping-grids were sampled, covering an area of 145 km^2. In each grid, mammalian sign surveys were conducted by walking for at least 1 km around the centroid of each grid to identify the best potential camera sites based on sign evidence (sightings, scats/pellet and tracks of mammals) and existing database/information from local field forest staff for placement of single passive-infrared digital camera traps: Cuddeback digital, Blue series (Jhala et al., 2008; Kalle et al., 2013; Karanth and Nichols, 2002; Ramesh et al., 2012). Camera trapping has been instrumental in determining abundance, occupancy and habitat use of wild animals, even in areas with access difficulties (Carbone et al., 2001; Ramesh and Downs, 2013; Tobler et al., 2008; Trolliet et al., 2014). A single camera trap was deployed in each grid to record photographs of passing mammals. Camera traps were operated at an inter-trap distance of ca. 500 m, simultaneously for 22 days. We assumed that within this camera trap survey duration, it was unlikely that the focal species' site occupancy would change. Camera traps were placed along dirt roads, animal trails, river and streambeds, near water holes, trees, etc. at 25–30 cm above the ground and left to operate for 24 h every day. We placed them at this height to photo-capture a wide spectrum of species from rodents to large mammals. We removed vegetation within the range of view of cameras was removed to avoid false capture. No bait was used during survey. Camera traps were checked once in 2 days and data were collected from camera traps on a weekly basis. We measured the distance to water sources, existing mines, roads, settlements, nearest farmland, and nearest hunting site detected in the camera traps at each camera location from the available land use map of Karnataka Forest Department and verified these with Google Earth using the Euclidean distance tool in ArcMap 10.3 (Table 1.). Percentage of canopy coverage was estimated visually in each circular plot of radius 20 m, keeping the camera trap location at the centre (Ehlers Smith et al., 2017). Percentage mining coverage was calculated by using the 'add polygon' tool on Google Earth Pro after overlaying the land cover layer obtained from Karnataka Forest Department. Using the same land cover layer, land-use types (Reserved Forest or farmland) of the camera site were determined in ArcMap 10.3 (ESRI, 2011).

Before analyses, we determined correlation coefficients between all predictor variables using the Pearson's correlation coefficient (Supplementary Fig. S1). To avoid multi-collinearity problems, correlations among independent variables were tested (Graham, 2003) using package "corrplot" in program R v4.0.5 and highly correlated variables ($r > 0.60$) were not used in the same model (Wei and Simko, 2021). In the case of highly correlated variables, we retained ecologically important variables for further modelling. As the study area is a place associated with water scarcity, the majority of species depend on temporary water sources like water holes and water puddles situated in the mining areas. Roads located within the study were categorised into two types: 1) Public roads, comprised of highways, village roads and mining roads, or 2) Management roads, used by Forest department staff for forest management purposes. During lockdown, all the mining related activities ceased with no vehicular movements. The movement of people outside of their premises was drastically reduced for the initial 2 weeks of the lockdown. Patrolling and monitoring from forest law enforcers was weakened that led poaching activities to flourish. All these changes during lockdown may influence the occurrence of species, leading to a variation in habitat use and detection probabilities. A more detailed description about of model parameters is explained in Table 1. The variables used in the analysis are proxy variables measuring the effect of illegal hunting activities by explaining the impact of lockdown associated with different levels of human disturbances on wildlife in the study area.

2.2.1. Procedures for temporal use analysis

To evaluate the temporal overlap between the two scenarios of the four study species, we considered an independent photograph of a species regardless of multiple photographs recorded within 5 min at the same camera trap location. We considered two sampling periods: "Pre-lockdown" and "Lockdown" as explained earlier, and accordingly, photographs were segregated for further analyses. The kernel density estimates of activity patterns of temporal overlap between different scenarios of species were measured using the coefficient of overlap (Meredith and Ridout, 2016; Ridout and Linkie, 2009). We conducted temporal overlap analysis in Program R (R Core Team, 2020) using package overlap (Meredith and Ridout, 2016).

2.2.2. Procedures for determining habitat use and detection probability

Each camera trap site and sampling occasion was treated as an independent site and a temporal repeat of the survey, respectively. In our analyses, the habitat use of an individual species was assumed to be independent of other species. We developed matrices for each species spanning 24-h survey (00:00–23:59) in columns and rows consisting of camera numbers. We designated a '1', '0' or 'NA' for each observation where '1' indicated one or multiple occurrences within the particular 24-h period, '0' indicated no detection and 'NA' indicated malfunction of the camera trap (Otis et al., 1978). Multiple photo-captures in 24 h were considered to be a single detection. This was done for successive days. Species presence has been used as a surrogate for species abundance or its population size (MacKenzie, 2005). The occupancy modelling framework enabled us to estimate the probability of occurrence of a species among sampled sites, while exploring hypotheses about associated habitat characteristics assumed to influence the species' occurrence. It was also developed to account for imperfect detection (MacKenzie et al., 2006). Single-season occupancy model was used to estimate site occupancy (Ψ) and detection probability (p) of the study species. We used the program R (R Core Team, 2020) using package "unmarked" (Fiske and Chandler, 2011) to model site occupancy and detection probability with its covariates as a measure of anthropogenic activities. All the continuous site covariates were standardized to Z scores (Cooch and White, 2005) prior to modelling. Camera trap data were used to determine species' occupancy as a function of the various habitat variables associated with hunting activities predicted to influence its probability of occupancy (habitat use) and detection in the study area during lockdown. Models were ranked using AICc (Akaike information criterion adjusted for small sample size) because the ratio of sample sizes (n) to the maximum number of estimated parameters (k) was <40 in both pre-lockdown and lockdown scenario of all four species. We followed stepwise model selection procedures and the goodness of fit for model selection as described in Burnham and Anderson (2002). Models with the lowest AIC values ($\Delta AIC \leq 2$) were considered as best descriptors of species habitat use and detection probability among candidate models (Burnham and Anderson, 2002).

3. Results

3.1. Temporal use

We observed an increase in poaching activities because of lockdown during field data collection as poachers were photographically recorded in many camera trap locations (Fig. 2). We recorded 19 species of wild mammals from 1898 camera trap-nights. In total 73, 59, 36, and 20 independent photographs of black-naped hare, wild pig, four-horned antelope and leopard, respectively were recorded during the pre-lockdown phase.

Table 1
List of habitat covariates used for modelling.

Sl. No.	Covariates	Abbreviation	Predicted relationship		Source
			Pre-lockdown	Lockdown	
1	Proximity to the nearest village (m)	vildist	−	−	Land-cover map obtained from Karnataka Forest Department and Google Earth
2	Proximity to the nearest mine (m)	minedist	−	+	Google Earth
3	Proximity to the nearest public road (m)	roadpub	−	+/−	Google Earth
4	Proximity to the nearest management road (m)	roadman	−	−	Google Earth
5	Land use type either Reserved Forest' or 'Farmland' (RF = 0, Farmland = 1)	rorf	−	−	Land-cover map obtained from Karnataka Forest Department
6	Proximity to the nearest farmland (m)	farmdist	−	+	Land-cover map obtained from Karnataka Forest Department and Google Earth
7	Proximity to the nearest water body (m)	waterbody	+	+	Land-cover map obtained from Karnataka Forest Department and Google Earth
8	Canopy coverage (%)	canopyco	+	+	Field data
9	Proximity to the nearest hunting site detected (m)	huntdist	−	−	Field data
10	Mining coverage (%)	mineper	−	−	Google Earth

Scale: m = in meter; % = in percentage.

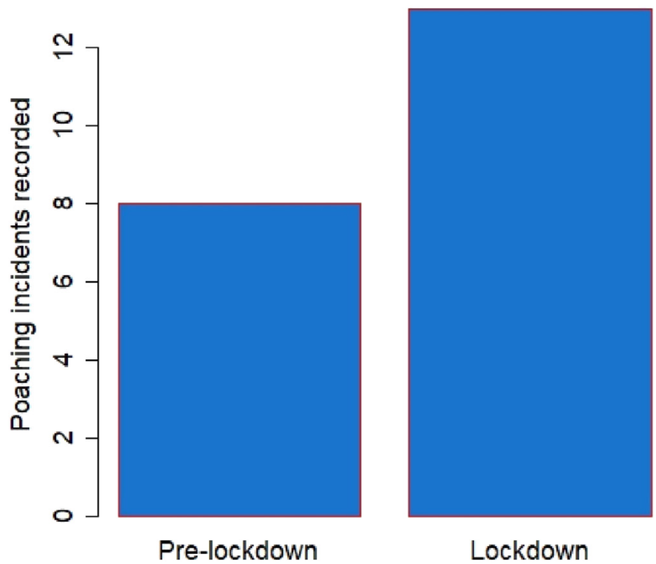

Fig. 2. Graph showing increase in poaching activities recorded during lockdown in camera traps during study period.

While during the lockdown, 56, 49, 27 and 18 independent photographs of black-naped hare, wild pig, four-horned antelope, and leopard were recorded, respectively. The mean kernel density temporal overlap coefficient estimates (Dhat1) with 10,000 smoothed bootstraps were found to be high in the case of black-naped hare (0.80; CI [basic0]: 0.67–0.91), wild pig (0.79; CI: 0.69–0.93) and four-horned antelope (0.76; CI: 0.68–0.97), while it was low for leopard (0.60; CI: 0.43–0.84), for pre-lockdown versus lockdown (Fig. 3). All the focal species were observed to have increased their day-time activity during lockdown because of less disturbances (Fig. 3).

3.2. Habitat use

The naïve occupancy of the black-naped hare were 0.20 and 0.27 during pre-lockdown and lockdown, respectively. Similarly, we observed the naïve occupancy of other study species: wild pig (0.22; 0.24), four-horned antelope (0.11; 0.12) and leopard (0.09; 0.11) during pre-lockdown and lockdown, respectively. All species showed an increase in their habitat use during the lockdown as predicted but it was not uniform across species (Table 2). A significant increase in the habitat use of wild pig and leopard were observed during the lockdown in and around forested landscapes (Figure 4b & 4d, Supplementary Tables S3, S4, S7 & S8). While we found only a slight increase in habitat use of black-naped hare and four-horned antelope (Figure 4a & 4c, Supplementary Tables S1, S2, S5 & S6). Habitat use of the black-naped hare increased with proximity to mines during lockdown (Table 3). Higher habitat use was found to be associated with the availability of reserved forest (0.27 ± 0.06) than farmland (0.22 ± 0.06) in lockdown period. While the habitat covariate, proximity to water body negatively influenced black-naped hare's habitat use during both periods (Table 3). The best model for the wild pig during lockdown indicated that the habitat use was independent of any habitat covariate effect, while before lockdown it was influenced positively by proximity to mine and negatively by proximity to public roads (Table 3). In the case of the four-horned antelope, no significant increase in habitat use was observed. Before lockdown, its habitat use was highly associated with availability of natural habitat (Reserved Forest = 0.31 ± 0.09 and farmland = 0.07 ± 0.06). Habitat use of leopard increased with increase in canopy coverage as it increased its daytime activity spread during the lockdown. During pre-lockdown, its habitat use was associated with proximity of mines (Table 3).

3.3. Detection probability

We observed species-specific variation in detection probability during the lockdown phase (Fig. 5). A significant reduction in the probability of detection of the wild pig was influenced by distance to mines and public roads in negative and positive ways, respectively (Table 3). A slight drop in the detection probabilities of the four-horned antelope and leopard were apparent. In the case of four-horned antelope it was a positive function of the increase in the availability of canopy coverage and proximity to mines, whereas for the leopard, proximity to mine affected the detection positively (Table 3). Detection of the black-naped hare was almost unaffected by lockdown.

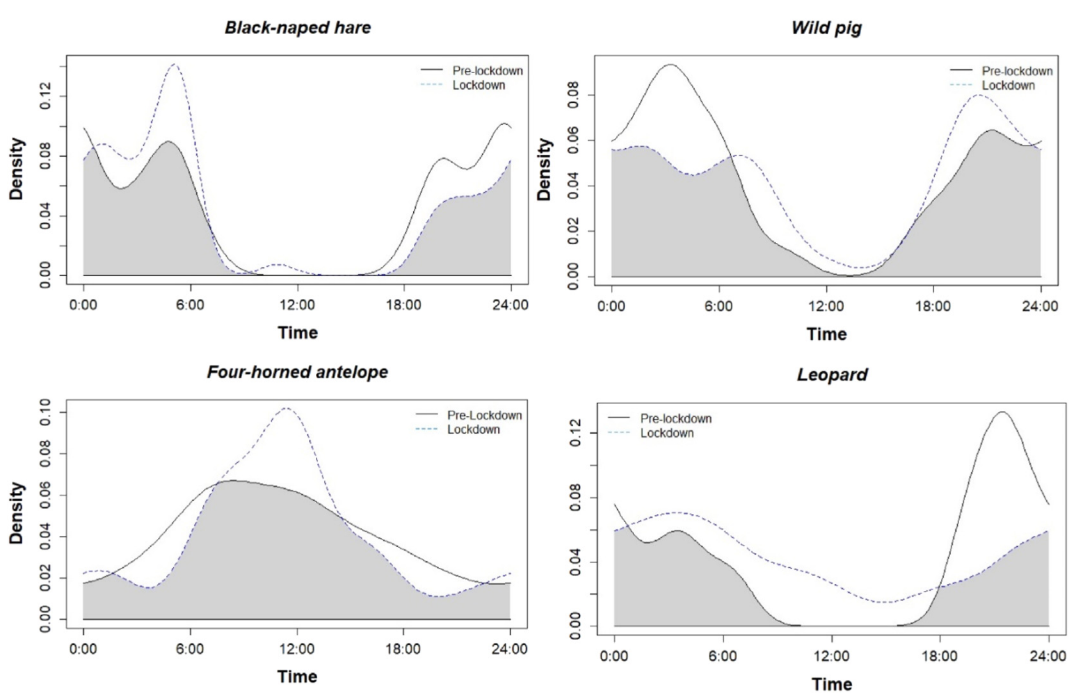

Fig. 3. Kernel density estimates of activity patterns of focal species during pre-lockdown and lockdown. The coefficient of overlapping equals the area below both curves, *shaded gray* in this diagram.

Table 2
Model selection parameters for comparing two scenarios: pre-lockdown and lockdown, from the top-ranking models (≤ 2 ΔAIC).

Species	Scenario	Naïve occupancy	Best model	AICc	AICc Weight	nPars	logLik
Black-napped hare	Pre-lockdown	0.201	rorf + canopyco + farmdist ~waterbody	345.89	0.44	6	−166.63
	Lockdown	0.266	farmdist + rorf ~minedist + waterbody + rorf	372.30	0.35	7	−178.72
Wild pig	Pre-lockdown	0.223	huntdist + canopyco ~roadpub + minedist	349.90	0.47	6	−168.63
	Lockdown	0.244	waterbody + minedist + roadpub ~1	356.99	0.46	5	−173.27
Four-horned antelope	Pre-lockdown	0.115	canopyco + roadpub ~rorf	193.81	0.57	5	−90.59
	Lockdown	0.122	minedist + canopyco ~huntdist + farmdist	203.91	0.70	6	−95.64
Leopard	Pre-lockdown	0.093	farmdist + canopyco ~minedist	146.21	0.43	5	−67.88
	Lockdown	0.100	minedist ~canopyco	147.90	0.57	4	−69.80

AICc = corrected Akaike Information Criterion; AICc Weight = Akaike weight; nPars = number of parameters; logLik = Log-likelihood.

4. Discussion

COVID-19 impacted humanity in an unprecedented manner at an unexpected magnitude. To break the chain of infection most countries around the world implemented lockdown that brought a period of unusually reduced human activity and mobility. Initially, it was perceived as beneficial consequences to the environment as there was reduction in Greenhouse gas emission and in air and water pollution (Dutheil et al., 2020; Mahato et al., 2020; Mantur, 2020; MeghnaDhankhar et al., 2021). Unusual animal sightings like roe deers (*Capreolus capreolus*) on a near-empty sidewalk in Poland, dolphins (*Tursiops* spp.) near the shoreline in Turkey, pumas (*Puma concolor*) on the street of Santiago, etc. were reported (Chalasani, 2020; Silva-Rodríguez et al., 2021). Social media worldwide claimed this as an indication that many animals were exploiting the new favourable environment (BBC News, 2020; Paital, 2020; Rutz et al., 2020). Concurrently, a reduction in law enforcement and human presence potentially exposed many wild animals to the increased risk of poaching (Buckley, 2020). Some studies reported a significant increment in poaching of wild animals during lockdown (Badola, 2020; Mendiratta et al., 2021) that shares consensus with our field observation and results. Thus, the impact of lockdown on the natural environment is complex with a mixture of both positive and negative effects. Our study attempted to fill this knowledge gap and substantiates previous research on impacts of lockdown on wildlife (Manenti et al., 2020; Rutz et al., 2020; Silva-Rodríguez et al., 2021). We found species-specific changes in the activity and habitat use patterns of study species, with increased diurnal activities of study species during lockdown. Overall, all study species showed an increase in habitat use during lockdown. The increased habitat use of the wild pig and leopard were significant while a minor increase was observed for the black-naped hare and four-horned antelope. Species-specific decreases in probability of detection was also observed during the lockdown phase. The outcome of this study will help in understanding the complexity of the effect of COVID-19 lockdown on the behaviour and distribution of wildlife that would help in wildlife conservation planning and effective enforcement of wildlife laws to improve human-wildlife coexistence.

The expansion of human activity and its resulting disturbances at the global level has several profound consequences for wildlife (Dirzo et al., 2014). The presence of humans instils a strong sense of fear in wild animals

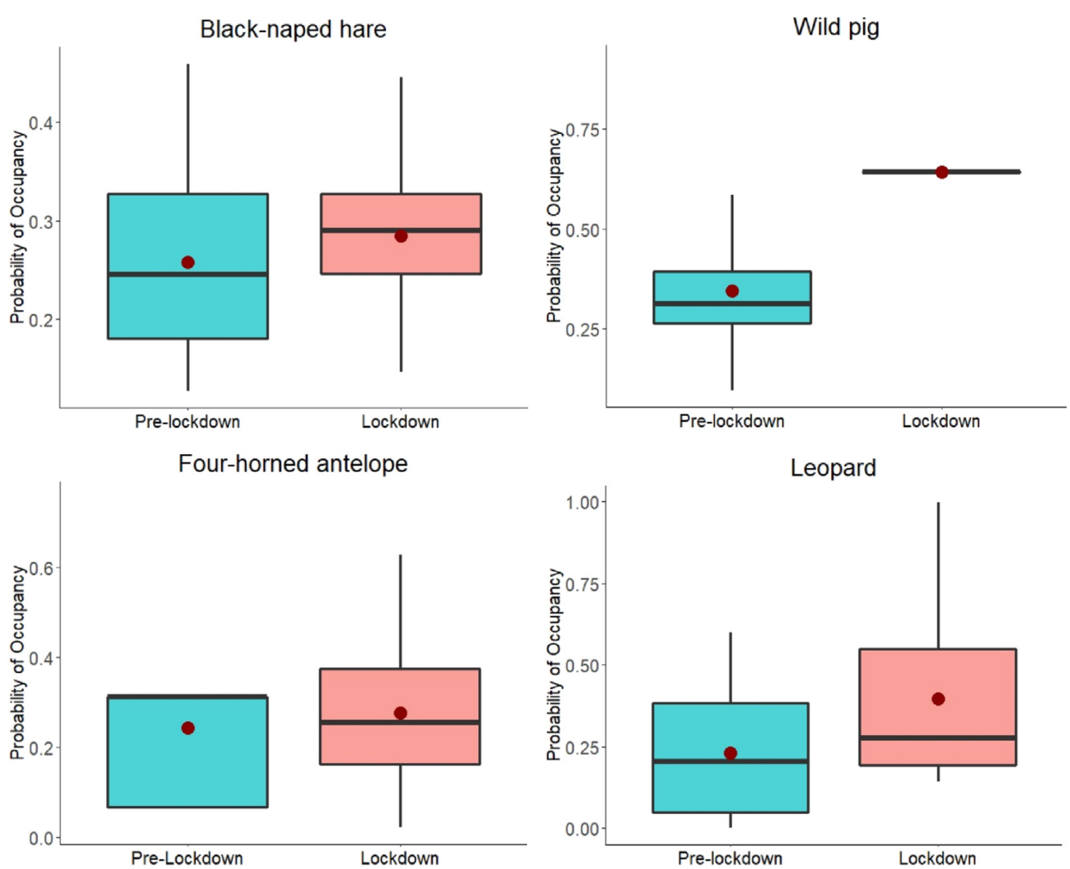

Fig. 4. Boxplots showing the occupancy (habitat use) of focal species during pre-lockdown and lockdown period.

Table 3
Log-transformed parameter estimates of explanatory variables from the top-ranking occupancy and detection models during pre-lockdown and lockdown.

Species	Scenario	Occupancy			Detection		
		Covariates	Estimates	Standard error	Covariates	Estimates	Standard error
Black napped hare	Pre-lockdown	waterbody	0.467	0.242	rorf	1.132	0.591
					canopyco	−0.028	0.027
					farmdist	0.358	0.292
	Lockdown	minedist	−0.239	0.273	farmdist	0.566	0.224
		waterbody	0.18	0.248	rorf	0.993	0.582
		rorf	0.466	0.595			
Wild pig	Pre-lockdown	roadpub	0.682	0.421	huntdist	0.4151	0.177
		minedist	−0.395	0.331	canopyco	0.036	0.024
	Lockdown	NA	NA	NA	waterbody	0.539	0.197
					minedist	−0.682	0.271
					roadpub	0.477	0.212
Four horned antelope	Pre-lockdown	rorf	−1.847	1.102	roadpub	−1.662	0.598
					canopyco	0.115	0.027
	Lockdown	huntdist	−0.854	0.451	minedist	−1.781	0.772
		farmdist	0.599	0.356	canopyco	0.065	0.028
Leopard	Pre-lockdown	minedist	−2.51	1.72	farmdist	0.628	0.319
					canopyco	0.064	0.033
	Lockdown	canopyco	0.184	0.103	minedist	−1.24	0.740

creating a landscape a fear among wild animals that may compel them to adjust their activity to avoid contact with humans (Frid and Dill, 2002; Kitchen et al., 2000; Ramesh and Downs, 2013). All species are not equally affected by anthropogenic activities and functional traits like wide habitat tolerance, nocturnal activity and small body mass etc., promote behavioural flexibility to human activities (Gaynor et al., 2019; Šálek et al., 2015). During the COVID-19 lockdown, reduced human presence and activity, along with increased poaching activities shifted the human-induced landscape of fear among wild mammals. Our results indicated species-specific alteration in the activity patterns, with an increase in diurnal activity spread of all study species, thus supporting previous studies on the effect of human disturbance on wildlife (Gaynor et al., 2018; Ladle et al., 2018; Lima et al., 2020).

Leopards are the apex mammalian predators in our study area and the major threats posed to them are from human-induced changes (Henschel et al., 2011; Jacobson et al., 2016); therefore, they were observed to have the maximum activity pattern shift with lockdown. Decreases in general human presence and increased presence of poachers at night have led to a significant increase in diurnal activities of leopards (Carter et al., 2015). With predominantly diurnal habits, four-horned antelope prefer higher elevated areas in dry deciduous forests and at a greater distance from human habitations (Baskaran et al., 2011). In our study area, the location of

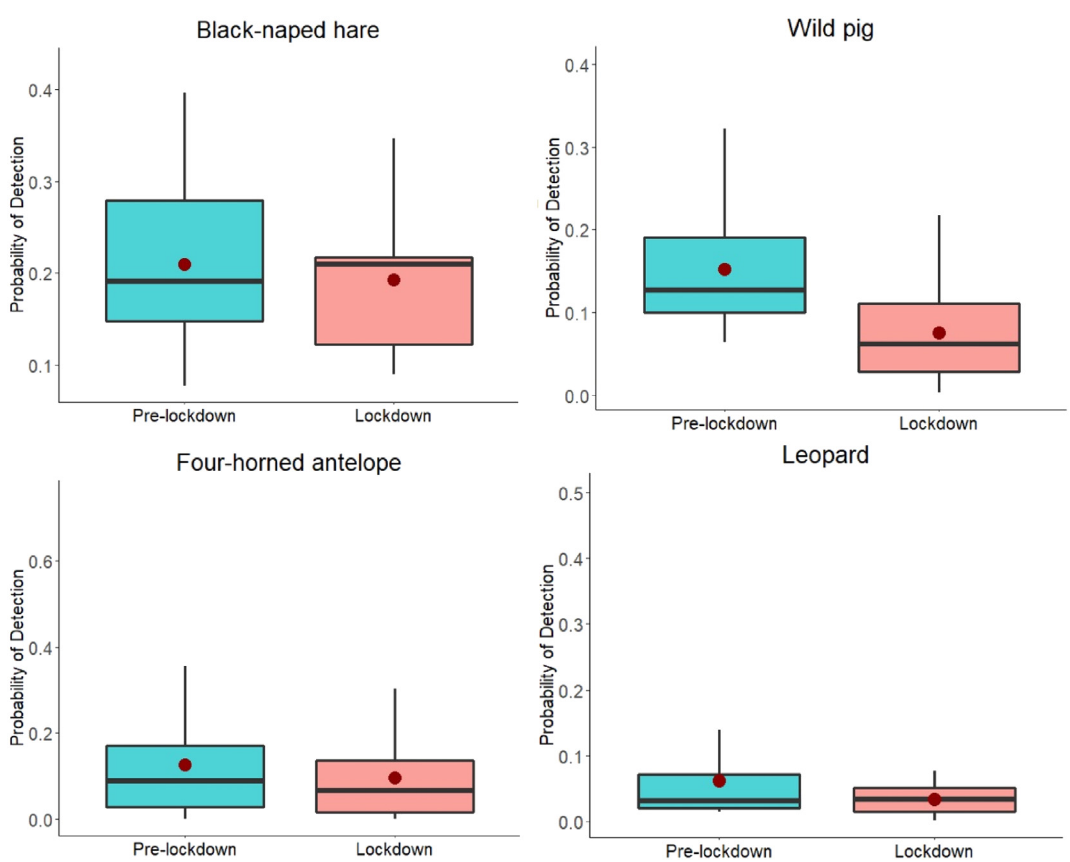

Fig. 5. Boxplots showing the probability of detection of focal species during pre-lockdown and lockdown.

mines and mining activities overlapped with the forest areas that are the ideal habitat of the four-horned antelope (Sharma et al., 2009), so the halt in mining activities because of lockdown allowed it to increase its diurnal activities. Wild pig may be found in all habitats including agricultural fields. A reduction in human outdoor activities and mobility resulted in a shift in the activity spread of the wild pig towards daytime, supporting an earlier study (Keuling et al., 2008). The black-naped hare is a small-sized mammal, which is generally crepuscular to nocturnal, thus the increase in activity spread was different from the other study species (Krishnan et al., 2018). An increased peak in the activity pattern during twilight could result from reduced agricultural activities during lockdown. Consequently, our results supported our hypothesis regarding wildlife altering their activity pattern by widening the window of day-time activity. There is a need to study the magnitude of this effect and its consequences for individual fitness, species interactions, and natural selection. Systematic approaches to understanding and managing temporal interactions between humans and wildlife may highlight new domains for wildlife conservation.

We observed species-specific increases in the habitat use of all study species during lockdown that strongly concur with a prior study (Oberosler et al., 2017). A steady increment in the site habitat use of both wild pig and leopard were observed, whereas a slight increase of site habitat use by the black-naped hare and four-horned antelope were found. During lockdown, we found an increase in habitat use of black-naped hare with proximity to mines that indicated its utilisation of the newly available suitable habitat with reduced human disturbance as in other studies (Bhattarai and Kindlmann, 2013). The probability of detection of the black-naped hare almost remained unaffected by lockdown, inferring that its small body size is a functional trait to its behavioural plasticity to human activity (Larson et al., 2015). Although the increased habitat use of the wild pig was found to be independent of any habitat parameter during the lockdown, it was influenced positively by proximity to mines and negatively by public roads before lockdown. The impact of public roads is likely to be detrimental to most wildlife species movement, especially by the frequent vehicular movements of iron ore-laden vehicles on mining roads and highways, in addition to providing easy access to poachers (Haines et al., 2012). As our study period coincided with the dry season, most of the available water sources were water holes and puddles near mining sites, which could have influenced the wild pig's habitat use and detection probability near mining sites (Caley, 1997). Our results indicated an increase in habitat use of the four-horned antelope during lockdown thereby supporting prior findings (Baskaran et al., 2011; Swamy et al., 2020). The four-horned antelope is an elusive ungulate with its habitat use associated with the availability of undisturbed habitat. In our study area, its ideal habitat of undulating dry deciduous habitat coincides with the presence of many mines. Thus, a sudden halt in all mining activities allowed them to venture around mines, exploring new habitat with sufficient water supply, especially during daytime. The detection probability of the four-horned antelope was associated with the availability of canopy coverage that support its cryptic nature. A marked increase in the habitat use of leopard supports their nocturnal behaviour in disturbed and fragmented landscapes (Ngoprasert et al., 2007). Their occurrence and detection close to mining areas, suggested the availability of water and their major prey species, i.e., four-horned antelope and wild pig. Camera traps were placed in forested and nearby areas, so the decrease in detection probabilities of all study species suggests the species became increasingly widespread in the absence of human disturbances, which supports the reports of wildlife exploiting the suitable temporary habitat without anthropogenic activities (BBC News, 2020).

Our study provides important insights into the impact of humans on wildlife by quantifying the responses of four forest-associated mammalian species. Spatial habitat use and temporal patterns of the study species in response to the habitat measures used as proxies to the large-scale shifts of human activities and illegal hunting outlines the potential impact of lockdown on wild mammals. However, our study could not quantify the direct consequences of increased poaching activities because of lack in post-lockdown data. Our study focused on an area with a relatively small sample size because COVID-19 lockdown restrictions limited further sampling. The COVID-19 lockdown period has been asserted by field biologists as a once-in-a-lifetime opportunity for observation and data collection in a world devoid of anthropogenic disturbances. Thus, results from our study act as critical information to understand the response of wildlife during this global crisis, which would help in further wildlife conservation planning and effective enforcement of wildlife law. This study paves the way for further holistic studies, which would help in identifying vulnerable and endangered species that are negatively affected by human-induced habitat loss and fragmentation and are in dire need of protection. Outputs from our study will also aid in planning swift conservation actions for proactive and reactive wildlife management interventions during pandemics.

During lockdown, reverse migration of people from cities and towns to villages close to forest/wildlife areas and their unemployment has driven them to venture into forest areas illegally. Furthermore, during the lockdown period, the livelihood of the landless labourers, artisans and other small shop owners/traders/businessmen have been threatened seriously, which had an indirect bearing on the local wildlife, especially on small game and ungulates. Therefore, illegal entry into forest and illegal hunting of ungulates and small animals increased significantly during this lockdown period. Capture of poaching activities in many camera trap locations requires active participation and collaboration of researchers with different stakeholders like local law enforcers, local NGOs, and local people to join hands to strengthen efforts to protect wildlife. The COVID-19 crisis has exposed the existing potential threats facing the forest and wildlife, and the gap in the existing systems, thus opening up areas for improvement. This crisis has emphasised the connection between nature, climate change and humans that calls for restructuring present systems to reduce the risk of future crisis. Scientific knowledge gained during this crisis will allow us to develop innovative strategies for the coexistence of both wildlife and humans on this planet.

5. Conclusions

Lockdown was implemented in numerous countries to reduce the spread of the virus that causes COVID-19. Initially, there was a misconception that nature is restoring or “taking a break” from humans during the lockdown but later its negative effect on nature came to light. The COVID-19 lockdown has both positive and negative impacts on wildlife. Reduction of human disturbances led wildlife to exploit newfound habitats and increase their diurnal activities. Species specific increase in the habitat use of all study species during lockdown was observed because of reduced human activities. Concurrently, there was a rise in illegal wildlife activities because of reduced forest law enforcement, the reverse migration of people from cities and towns to villages near wildlife areas, the dependence of poor families on wild meat as their livelihood was seriously threatened and, the lack of tourism (Mendiratta et al., 2021). The COVID-19 crisis has exposed the loopholes in the existing systems, thus opening windows for improvement. So, the present study is the need of the hour through active collaboration of researchers with different forest-related stakeholders, NGOSs and local people to come together and strengthen efforts to protect wildlife.

CRediT authorship contribution statement

AKB, PRK, MMP, TR and RK conceptualized and designed the study. AKB collected and analyzed data, and wrote the draft manuscript. TR and RK provided input in the analysis. PRK, MMP, TR, and RK edited and provided input on the draft manuscript.

Declaration of competing interest

None.

Acknowledgement

We thank the Director SACON for providing necessary logistic support and permission to execute our work. We are grateful to Karnataka Forest

Department, Ballari Division for providing camera traps, necessary permits, and all logistic support. A special thanks to the staff of Karnataka Forest Department for helping in conducting camera trapping surveys and collecting data, without which this study would not have been possible. The study was carried out with support from Ballari Forest Division, Karnataka government and the INSPIRE Fellowship, Department of Science and Technology (DST/INSPIRE Fellowship/2028/IF180359) to A.K.B. A sincere thanks to Prof. Colleen T Downs and Dr. David A. Ehlers Smith for their diligent proofreading of this paper. We are most grateful for the constructive comments and suggestions of the editor and reviewers.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2022.153268.

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