



# Spatio-Temporal Patterns and Source-Dispersion Modeling Towards Sloth Bear–Human Conflict Management in Central India

Sankarshan Chaudhuri<sup>1\*</sup>, Meghna Bandyopadhyay<sup>1</sup>, Rajasekar Rajaraman<sup>1</sup>, Sankar Kalyanasundaram<sup>2</sup>, Sathyakumar Sambandam<sup>3</sup> and Ramesh Krishnamurthy<sup>1,4\*</sup>

<sup>1</sup> Department of Landscape Level Planning and Management, Wildlife Institute of India, Dehradun, India, <sup>2</sup> Ministry of Environment, Forest and Climate Change, Government of India, Salim Ali Centre for Ornithology and Natural History, Coimbatore, India, <sup>3</sup> Department of Endangered Species Management, Wildlife Institute of India, Dehradun, India, <sup>4</sup> Faculty of Forestry, University of British Columbia, Vancouver, BC, Canada

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### \*Correspondence:

Ramesh Krishnamurthy  
ramesh@wii.gov.in  
Sankarshan Chaudhuri  
chaudhursankarshan@gmail.com

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The impact of humans on biodiversity, in the form of the spatially extensive occurrence of humans and subsequent habitat degradation, leads to negative interactions between humans and native wildlife. However, knowledge of the spatial and temporal interface between humans and wildlife is necessary to understand the root cause of such negative interactions, yet considerably understudied in the context of human-dominated landscapes in south and south-eastern Asia. We took this opportunity, gaining insights on seasonal spatial interaction and spatio-temporal overlap between sloth bears (*Melursus ursinus*) and humans, and subsequently predicted the conflict source sites and dispersion (i.e., hotspots) based on the robust geographic profiling (GP) method in the Sanjay Tiger Reserve (STR), a human-dominated landscape of central India. Detection data of sloth bear and human were obtained from camera trap survey conducted for two years (2017–2018) and records of conflict incidents (2009–2019) were collected from forest department. We found that sloth bears can co-occur with humans independently of seasons, based on occupancy models. However, during summer, higher temporal overlap ( $\Delta_4 = 0.46$ ) and lower spatial overlap (0.31) were observed between sloth bears and humans. Contrastingly, lower temporal overlap ( $\Delta_4 = 0.29$ ) and higher spatial overlap (0.44) were observed between the same two during winter. The activity patterns of sloth bears and humans differed significantly across seasons and within the same species in different seasons. Our findings indicated that significant changes in human activity, especially during summer, increased the likelihood of sloth bear-human interaction and subsequent conflict incidents. The mapping of conflict source and dispersion (with high accuracy) also predicted a greater probability of conflict during summer, compared to winter, and thus showed the successful application of GP models in this field. Also,

camera trap data alone were able to predict the occurrence of hotspots, demonstrating the use of camera trap records in the successful prediction of source-dispersion of conflict. This study would be useful for decision-makers to alleviate sloth bear–human conflict based on insights on seasonal variation of spatio-temporal overlap between the two and direct conservation efforts accordingly.

**Keywords:** camera trap survey, human-dominated landscape, interaction, conflict hotspot, *Melursus ursinus*, geographic profiling

## 1 INTRODUCTION

The ever-expanding human population and the resultant degradation and fragmentation of habitat have inadvertently affected wildlife and increased the proximity-driven interaction between humans and wildlife (Messmer, 2000; Messmer, 2009; Inskip and Zimmermann, 2009; Elfström et al., 2014; Joshi et al., 2016). Often, these human–wildlife interactions pose challenges to conservation initiatives due to the significant damage in the form of livestock depredation, human-mauling, crop loss, and retaliatory killing of the concerned species (Rajpurohit and Krausman, 2000; Madhusudan, 2003; Treves and Karanth, 2003; Bargali et al., 2005; Karanth et al., 2012). However, the identification of underlying reasons behind such conflict scenarios is necessary to address human–wildlife conflict (Sutherland et al., 2009). Among other species of wildlife, conflict with large carnivores (including bears) has a significant impact on the health and livelihood of humans worldwide (Treves and Karanth, 2003; Chapron et al., 2014). Human–carnivore interaction has been studied widely to understand the nature and extent of conflict and draw inferences on possible conflict mitigation (Redpath et al., 2013; Nyhus, 2016).

The expansion of anthropogenic activities has affected the global distribution of carnivores as well as their temporal and spatial use of the habitat, globally (Dirzo et al., 2014; Gaynor et al., 2018; Tucker et al., 2018). Also, humans impact directly or indirectly on the mortality and physiological fitness of carnivores (Rode et al., 2007; Darimont et al., 2015). However, it was observed that human–wildlife interaction could be quite complex and dependent on several factors (Tablado and Jenni, 2017). Wild animals, especially carnivores, can respond to increased or persistent anthropogenic activities in a variety of ways (Ordiz et al., 2011; Carter et al., 2012; Elfström et al., 2014; Tablado and Jenni, 2017; Suraci et al., 2019b), including strong fear responses (Suraci et al., 2019a). The response of carnivores towards human occurrences may be governed by the spatial extent and intensity of the anthropogenic pressure prevailing in the concerned landscape. In a human-dominated landscape, especially with year-round high occurrence of humans can affect the space use pattern of carnivores, leading to avoidance of areas where human disturbance is high (Chi and Gilbert, 1999; Fortin et al., 2016). Many wildlife species, including bears, consider humans as a perceived threat or predator as they elicit similar responses in the presence of natural predators (Joshi et al., 1999; Frid and Dill, 2002; Ciuti et al., 2012). However, bears were also found to be frequently attracted to

human settlements for opportunistic foraging, especially crop raiding, livestock depredation, and feeding on garbage (food wastes) (Charoo et al., 2011; Morales-González et al., 2020; Prajapati et al., 2021). Despite these exceptions, it is likely that animals will avoid places where human pressure persists (Dröge et al., 2017). Similarly, if the temporal pattern of human occurrence is more predictable to the animals, it is also possible that animals would segregate their movement by increasing the time of activity when humans are least active (Suraci et al., 2019b), instead of avoiding spatially (Nickel et al., 2020), which would in turn facilitate co-existence (Fagen and Fagen, 1994; Fortin et al., 2016; Srivastava et al., 2020).

It is expected that human–wildlife conflict is a direct outcome of the high degree of human–wildlife interface (Pack et al., 2013). However, unlike in Europe and North American countries, in South and South-east Asian regions, the prevalence of human–wildlife conflict is primarily due to rich and endangered biodiversity and associated developmental activities in and around forest areas (Madhusudan and Karanth, 2002; Sodhi et al., 2010). A high degree of dependence on natural resources driven by poverty and an expanding human population impacts adversely on biodiversity (Sodhi et al., 2010; Chao, 2012) and subsequently increases conflict scenarios due to highly overlapping resource use (Treves et al., 2006). In this view, there is a paucity of studies that take into consideration the spatio-temporal interactions between humans and carnivores with global distribution, such as Asian bear species, to address the issues of conflict more effectively (Can et al., 2014; Anand and Radhakrishna, 2017).

The sloth bear (*Melursus ursinus*) is one of the four bear species found in the Indian subcontinent and endemic to this region (Prater, 1965; Johnsingh, 2003; Sathyakumar et al., 2012). Most of the sloth bear populations are restricted to the moist and dry deciduous forests of the Western Ghats and central Indian landscape (Yoganand et al., 2006). The sloth bear is a myrmecophagous (ant and termite eating) ursid, which is notably involved in conflict with humans in some parts of its distributional range, especially human-dominated landscapes (Rajpurohit and Krausman, 2000; Bargali et al., 2005; Akhtar and Chauhan, 2008; Garcia et al., 2016; Debata et al., 2017; Dhamorikar et al., 2017; Singh et al., 2018; Sharp et al., 2020; Prajapati et al., 2021). However, except for a few anecdotal evidences, attacks on humans by sloth bears are mostly defensive, rather than intentional or predatory in nature, as they perceive humans as threats or predators (Sharp et al., 2020). In human-dominated forests of central India, it was

found that most of the victims belonged to tribal communities with high natural resource dependency and were attacked inside the forest while collecting non-timber forest produce (NTFP) (Dhamorikar et al., 2017), as well as adjacent to the village peripheries and agricultural lands (Dhamorikar et al., 2017; Singh et al., 2018). The seasonal and temporal patterns of these attacks varied between different landscapes (Bargali et al., 2005; Dhamorikar et al., 2017; Singh et al., 2018). Sloth bears are mainly nocturnal and crepuscular in activity (Yoganand, 2005; Bargali et al., 2012; Ramesh et al., 2013) but could be active throughout the daylight hours in some parts of its distribution (Joshi et al., 1999). It was believed that the majority of the conflict cases happened due to the overlapped activity between sloth bears and humans during the crepuscular period (Akhtar et al., 2004; Bargali et al., 2005). However, there is a shortfall of studies which describe the fine-scale interaction and overlap (spatial and temporal) between sloth bears and humans utilizing the spatially independent point locations (such as camera traps) in a human-dominated landscape. Also, to our knowledge, no research work has been conducted to predict probable conflict sources and hotspots based on occurrence records of sloth bears and humans.

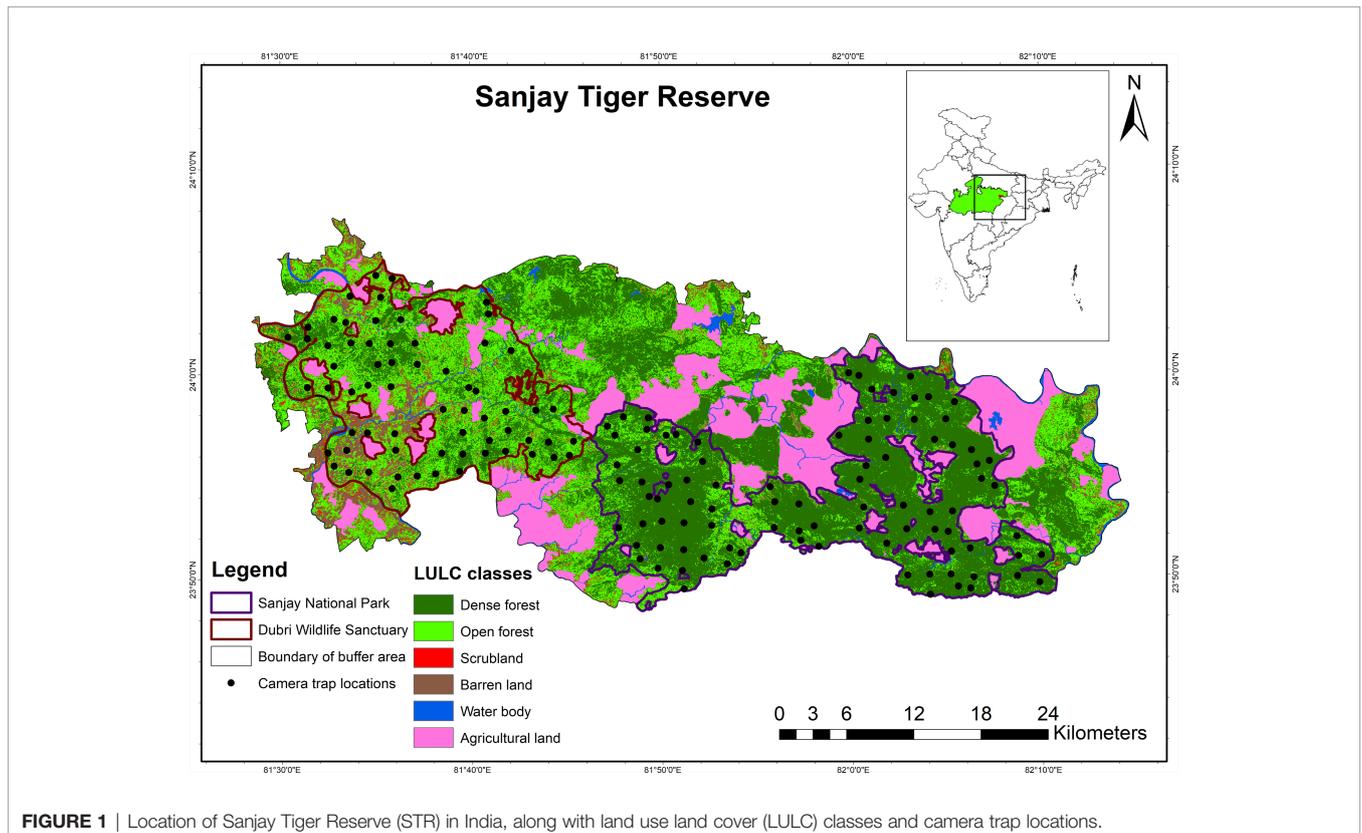
In this study, we used the season-specific detection records of sloth bears and humans, obtained from a camera trap survey conducted in the Sanjay Tiger Reserve (STR), central India, to understand the interaction between sloth bears and humans. Firstly, based on detection and non-detection data of sloth bears and humans, two-species occupancy models (Richmond et al., 2010) were developed to assess the species interaction in terms of

association or segregation. Furthermore, the extent of spatial and temporal overlap was estimated using the relative abundance index (RAI) (O'Brien et al., 2003; Rovero and Marshall, 2009) of sloth bears and humans. We expected that sloth bears would avoid humans spatially regardless of seasons, as evident from other studies (Paudel et al., 2022; Pokharel et al., 2022). However, we also assumed that sloth bears would be more nocturnal in disturbed habitats to avoid human encounters during daylight hours. Finally, we used geographic profiling/geo-profiling (GP) to identify conflict sources and dispersion (i.e., hotspots), a novel approach to tackle wildlife crime and predict conflict hotspots (Faulkner et al., 2018; Struebig et al., 2018), which was earlier only restricted to criminology (Rossmo, 2000). With this background, we aimed to understand the seasonal spatial interaction and spatiotemporal overlap between sloth bears and humans in the context of a human-dominated landscape. Subsequently, we also attempted to identify probable conflict source sites and hotspots that can serve as a basis for implementing sloth bear–human conflict mitigation strategies.

## 2 MATERIALS AND METHODS

### 2.1 Study Area

This study was conducted at the Sanjay Tiger Reserve (STR), which is spread over two districts, i.e., Sidhi and Shahdol, in the Indian state of Madhya Pradesh, central India (**Figure 1**). As per the biogeographic classification of India by Rodgers & Panwar (1988),



STR comes under the “Central Highlands.” Sanjay National Park (SNP) and Dubri Wildlife Sanctuary (DWLS) together constitute the core area (831.25 km<sup>2</sup>) of STR. Surrounding the core, an additional area of 812.58 km<sup>2</sup> was demarcated as a buffer zone for STR.

The forest type of STR is dominated by *Shorea robusta* (Sal). It falls under the sub-group “North Indian moist deciduous forests”, with subtype “Moist sal-bearing forest” and subdivision “Moist peninsular sal forest”, according to the revised classification by Champion & Seth (1968). Other major tree species found in STR include *Buchanania cochinchinensis* (Char), *Diospyros melanoxylon* (Tendu), *Madhuca longifolia*, (Mahua), *Lagerstroemia parviflora* (Sedha), and *Cassia fistula* (Amaltas). Land use land cover types of STR are categorized into six classes, i.e., dense forest, open forest, scrubland, barren land, water bodies, and agricultural land (Figure 1). The elevation of the STR varied from 239 to 770 m. The topography is generally undulating and hilly in the eastern part and moderately sloped to flat terrain in the western part with varying slopes, ranging from 0° to 61°. Temperature varies between 7.4 and 41.8°C with distinct seasonal variation viz. summer (March to June), monsoon (July to October), and winter (November to February). The mean annual precipitation in STR is 1,303 mm. Apart from sloth bear, STR harbors diverse mammal species such as the *Panthera tigris* (Tiger), *Panthera pardus* (Leopard), *Hyaena hyaena* (Striped hyena), *Canis lupus* (Indian wolf) *Cuon alpinus* (Asiatic wild dog), *Axis axis* (Chital), *Rusa unicorn* (Sambar), *Tetracerus quadricornis* (Four-horned antelope), etc. There are thirty-nine villages inside the core area of the Tiger Reserve. People living in these villages, along with their substantial livestock population, are highly dependent on forest resources, which pose immense anthropogenic pressure on the core habitat of STR.

## 2.2 Camera Trap Survey

Systematic camera trapping exercises were conducted over two consecutive years, from December 2016 to April 2017 (henceforth, 2017) and January 2018 to April 2018, in the core area of STR. The core area was gridded into 4 km<sup>2</sup> blocks (henceforth, sites), following the Indian tiger estimation protocol (Jhala et al., 2015). A total of 143 and 144 sites were selected for the deployment of camera traps during 2017 and 2018, respectively. Due to logistical constraints, we divided the core area into two blocks, viz., SNP (466.6 km<sup>2</sup>) and DWLS (364.6 km<sup>2</sup>) for the deployment of camera traps. First, we deployed camera traps at 86 sites during winter 2017, i.e., December 2016 to February 2017 in SNP, followed by 57 sites in DWLS during summer 2017, i.e., March 2017 to April 2017. During winter 2018 (January to February) and summer 2018 (March to April), camera traps were deployed in 57 sites in DWLS and 87 sites in SNP, respectively.

Double-sided automated camera traps (Cuddeback C1 and Cuddeback Ambush) were placed preferably on dirt roads, dry riverbeds, and animal trails to maximize the detectability of large carnivores (Karanth et al., 2011), including sloth bears, at a height of 30–40 cm above the ground. Furthermore, the placement of double-sided camera traps, opposite to each other, at each site would preferably increase the detection

probability of animals (Pease et al., 2016). Each camera trap was set to take photographs at a 15-second interval upon detection of the animals. The survey duration of camera traps at each block was continued for 45 days, and camera traps were active on a 24 × 7 basis. However, in 2017, due to rampant forest fires at DWLS during summer, camera traps were active for an average period of 36 days. Each camera trap location was recorded using Garmin e-Trex handheld GPS units (Garmin Inc.).

After retrieving the camera trap data, detections of sloth bears and humans were considered independent events (or independent photographs) if two consecutive photographs of each species were taken at a ≥30-minute interval, to limit the risk of pseudoreplication (O’Brien et al., 2003; Xiao et al., 2018; Haswell et al., 2020). We chose a 30-minute interval for humans as we expected a substantial number of repeated photo-captures of the same individual (single and groups) within a short period, due to the curiosity of people detecting camera traps. The entire survey duration (45 days) was collapsed into 15 temporal replicates per site by considering each three days as a single temporal replicate and pooling the detection–nondetection records of species accordingly. Collapsing the survey duration into a smaller number of temporal replicates facilitated the reduction of overdispersion (variance > mean) and increased the temporal independence of each detection (Penjor et al., 2019). Lastly, we used camera trap data from two summers and two winters obtained from two blocks representing the entire core area of STR for each season (overall winter and summer).

## 2.3 Spatial Interaction

In the first step, we used two-species conditional occupancy models (Richmond et al., 2010) to assess if sloth bears show any spatial avoidance toward human occurrence in two different seasons (winter and summer). The two-species occupancy model estimates the conditional probability of occupancy and detectability of a less dominant species in the presence of a dominant species (Richmond et al., 2010). We interpreted the “probability of occupancy” of a species as the probability of “use” since we believed that the size of the site would potentially violate the closure assumption and independence between sites (MacKenzie et al., 2017, p447). If species A and B are to co-occur and A is dominant over B, the following parameters are estimated in the two-species model:

- i.  $\Psi^A$  (Probability of occupancy of A)
- ii.  $\Psi^{Ba}$  (Probability of occupancy of B when A is absent)
- iii.  $\Psi^{BA}$  (Probability of occupancy of B when A is present)
- iv.  $p^A$  (Detection probability of A when B is absent)
- v.  $p^B$  (Detection probability of B when A is absent)
- vi.  $r^A$  (Detection probability of A when both A and B were present)
- vii.  $r^{BA}$  (Detection probability of B when A was present and detected)
- viii.  $r^{Ba}$  (Detection probability of B when A is present but not detected).

In this study, we assumed that human (species A) activity does not depend on the occurrence of sloth bear (species B). Sloth bears probably perceive humans as a threat equivalent to predators (tigers and leopards), with which they are sympatric (Laurie and Seidensticker, 1977; Yoganand, 2005). Given the extensive anthropogenic pressure in STR, it is very likely that sloth bears would adjust their space use in accordance with human occurrence. In this view, we assumed sloth bears to be a subordinate species in the two-species occupancy model. However, considering humans as the dominant species in two-species occupancy models was not common [but see Parsons et al. (2016)], our intention was to assess the degree of spatial avoidance of sloth bears in response to the extensive occurrence of a perceived threat (i.e., humans) in the context of the human-dominated landscape.

The species interaction factor (henceforth, SIF) is a derived parameter estimated from the two-species occupancy model. A value of SIF >1 shows the degree of species aggregation rather than avoidance, and an SIF value <1 indicates spatial avoidance or segregation, where two species are less likely to occur with each other than expected under the hypothesis of species independence. An SIF value of ~1 indicates that both species can occur independently. Following Richmond et al. (2010), SIF can be calculated as:

$$SIF = \frac{\Psi^A \Psi^{BA}}{\Psi^A [\Psi^A \Psi^{BA} + (1 - \Psi^A) \Psi^{Ba}]}$$

We calculated SIF and compared it between seasons to assess the avoidance of space used by sloth bears in the presence of humans. We also carefully inspected the values of other parameter estimates ( $\Psi^{Ba}$ ,  $\Psi^{BA}$ ,  $p^B$ ,  $r^{BA}$  and  $r^{Ba}$ ), and compared them between seasons. Model comparison and selection were based on Akaike's Information Criterion (AIC) (Burnham and Anderson, 2002). We used the program Presence (Version 2.13.11) (Hines and USGS-PWRC, 2006) to estimate occupancy and related parameters of the two species.

## 2.4 Spatial and Temporal Overlap

### 2.4.1 Spatial Overlap

In the second step, the extent of spatial overlap between sloth bears and humans was estimated for summer and winter as we were interested in assessing the interaction on a finer scale, which might not always be discernible from occupancy models. In order to do so, the relative abundance index (RAI; O'Brien et al., 2003; Rovero & Marshall, 2009) was calculated at each camera trap location for both species using the following formula:

RAI = (No. of independent photographs/total no. of days during which each camera trap was operating) × 100.

Considering each location of the camera trap as spatially independent of other locations, we calculated the spatial overlap by applying Pianka's overlap index (Pianka, 1974). This method takes account of the proportion of RAI values of a pair of species with respect to different camera trap locations. The output value (estimate of overlap) ranges between 0, i.e., no overlap and 1 or complete overlap. Although it was developed initially to estimate the niche overlap, several studies have applied Pianka's index to

estimate spatial overlap between co-occurring species and human activities (Ramesh et al., 2012b; Yang et al., 2019; Mori et al., 2020; Zhao et al., 2020). We also estimated 95% confidence interval (CI) of the spatial overlap estimate from 10,000 bootstrapped replicates. All analyses related to spatial overlap estimation were carried out in R (R Core Team, 2019) using the package "spaa" (Zhang et al., 2013).

### 2.4.2 Temporal Overlap

To assess the activity pattern of sloth bears and humans for summer and winter, we considered the same camera trap locations that were used to compute the spatial overlap. Following the methodology described by Ridout & Linkie (2009), a non-parametric kernel density function was fitted to the circular time data obtained from the camera trap photographs of both species, which would produce the pairwise (sloth bear–human) activity patterns. Then, the coefficient of overlap ( $\Delta$ ) was estimated from the area under the curve of two different density functions (sloth bear and human). Values of  $\Delta$  ranged between 0 and 1, where 0 denotes no overlap and 1 denotes complete overlap (Linkie & Ridout, 2011; Meredith & Ridout, 2014). We calculated  $\Delta_4$  when the number of independent events of both sloth bear and human, were >75, except for one season (winter 2018), when, number of sloth bear photographs was <75 and hence,  $\Delta_1$  was calculated, as mentioned by Linkie & Ridout (2011). The 95% CI was generated by 10,000 bootstrapped samples of overlap coefficient to check the precision of the estimates (Linkie and Ridout, 2011). Analyses regarding the estimation of overlap coefficient were carried out in the package "overlap" (Meredith and Ridout, 2021), implemented in R (R Core Team, 2019).

One-sample Watson's  $U^2$  test (Watson, 1961) is a goodness of fit test, which was performed to determine whether the distribution of detection time of each species significantly deviated from the uniform distribution of activity. Similarly, we performed two-sample Watson's  $U^2$  tests (Watson, 1962) to assess if the activity distributions of sloth bears and humans were significantly different from each other between summer and winter. We also tested for the difference in activity of sloth bears and humans separately between seasons through two-sample Watson's  $U^2$  tests. Both one-sample and two-sample Watson's  $U^2$  tests were performed using the software "Oriana" (Kovach, 2011).

## 2.5 Geographic Profiling for Sloth Bear–Human Conflict

### 2.5.1 Sloth Bear–Human Conflict Incidents

Records of conflict incidents between sloth bears and humans in the form of human injuries and deaths were obtained from the forest department of STR for 10 years (2009–2019). We retained the records only for the core area of the STR, as our camera trapping exercise was conducted in the core area only. However, GPS locations of these incidents were generally not recorded by the forest department; only the name of the concerned forest beat and compartment was mentioned. As compartments are the smallest (average size of 2.12 km<sup>2</sup>) administrative units of our

study area (and all other Tiger Reserves), we generated centroids of compartments of forest beats where conflict incidents occurred and used this information for further analysis.

## 2.5.2 Geographic Profiling

Geographic profiling (GP) is a technique used to estimate the probable sources of spatial encounters (human–sloth bear encounters in this case) when the sources are unknown (villages or sloth bear territories). It works on the Bayesian framework based on a distance decay process (Verity et al., 2014). We used the Dirichlet process mixture (DPM) (Verity et al., 2014; Faulkner et al., 2017) model to produce a geographic profile of sloth bear–human encounters using the package Rgeoprofile 2.1.0 in R (<https://github.com/bobverity/Rgeoprofile>). GP has been proven to be advantageous over conventionally used prediction models such as kernel density and ensemble modeling for mapping of invasive species as well as conflict or risk assessment (Stevenson et al., 2012; Struebig et al., 2018). The process consists of two parts: the incident locations where the conflict occurred and the source locations from where the conflict might have arisen. The model divides the incident locations into “n” clusters. Then the source sites are predicted using the Gibbs sampler (Geman and Geman, 1984) within a Markov Chain Monte Carlo framework until it converges on the posterior distribution of sigma ( $\sigma$ ). Sigma ( $\sigma$ ) is the standard deviation of the dispersion distribution, and it means how far we expect the sources to travel from the incident sites. There are two approaches to testing the model efficiency: one is by using the hit score percentage (HS%, ranging from 0 to 100%), and the second is using the Gini coefficient (G, ranging from 0 to 1) (Gini, 1921; Faulkner et al., 2018). The GP model provides an optimal search process of the source locations or anchor points. The hit score percentage (i.e., the proportion of the area covered by the “conflict/encounter” divided by the total area) was used to test the efficiency of the model, with a lower hit score value depicting more accuracy of the search process. The Gini coefficient was used to assess the model performance; the higher the Gini coefficient, the more accurate the geographic profile (Faulkner et al., 2018).

We produced a geographic profile of sloth bear–human encounters using a) conflict data of sloth bear attacks on humans and b) camera trap data where both the sloth bears and humans were detected together (but at different times). We used the compartment centroids for the conflict data and camera trap data consisting of only sloth bears or humans were excluded. Duplicate points were removed from the data as the DPM model tends to fit very low sigma values with repeated locations (Struebig et al., 2018). The mean sigma ( $\sigma$ ) used for the analysis was 2 km [assuming 87% of the dispersal events occur within 2 km of the source; following Faulkner et al. (2017)] and we ran the full data set with locations of conflict and camera trap, using 10 chains with a burn-in of 10,000. Firstly, the resultant model will identify the probable conflict source sites, followed by conflict hotspots or dispersion around the source sites. Next, we compared any seasonal shift in the conflict-probable areas in STR using the summer and winter camera trap locations separately, where sloth bear and human both were detected. In this study, we assumed the camera trap data where both the sloth

bears and humans were detected to be a probable conflict site. Therefore, to test the efficacy of camera trap data ( $n = 88$ ) alone to predict the future probable conflict areas, model validation was conducted. We generated a geographic profile based solely on camera trap data (where both sloth bears and humans were detected). Sloth bear attack sites ( $n = 57$ ) were then overlaid on the geographic profile layer to check whether the conflict sites were falling over the predicted probable conflict areas generated by the camera trap data.

## 3 RESULTS

A total of 179 and 311 independent detections of sloth bears were obtained from camera traps in winter and summer, respectively, during the entire survey period of 12,430 trap-nights (winter = 6,435 trap-nights; summer = 5,995 trap-nights). Detection of sloth bears was substantially higher in SNP (winter = 122; summer = 235) than in DWLS (winter = 57; summer = 76), irrespective of the season (**Figure 2**). Similarly, the detection of humans was found to be higher in SNP (winter = 3,396; summer = 2,565) than in DWLS (summer = 1,749; winter = 1,862) (**Figure 2**).

### 3.1 Spatial Interaction

During winter and summer, SIF values (SIF value  $\pm$  Standard Error) were found to be  $0.98 \pm 0.007$  (95% CI: 0.97–0.99) and  $1.00 \pm 0.03$  (95% CI: 0.93–1.07), respectively (**Table 1**). Thus, no difference in species interaction was observed between seasons. The closeness of the SIF value toward 1 indicated no distinguishable pattern of spatial avoidance shown by sloth bears toward human occurrences. The probability of use of sites by sloth bears in the presence of humans was found to be less [ $\Psi^{BA}$  (SE) = 0.71 (0.04)] than when humans are absent [ $\Psi^{Ba}$  (SE) = 1.00 (0.00)] during winter. However, during summer, the probability of use of sites by sloth bears did not differ much [ $\Psi^{BA}$  (SE) = 0.79 (0.04);  $\Psi^{Ba}$  (SE) = 0.77 (0.17)] in the presence or absence of humans.

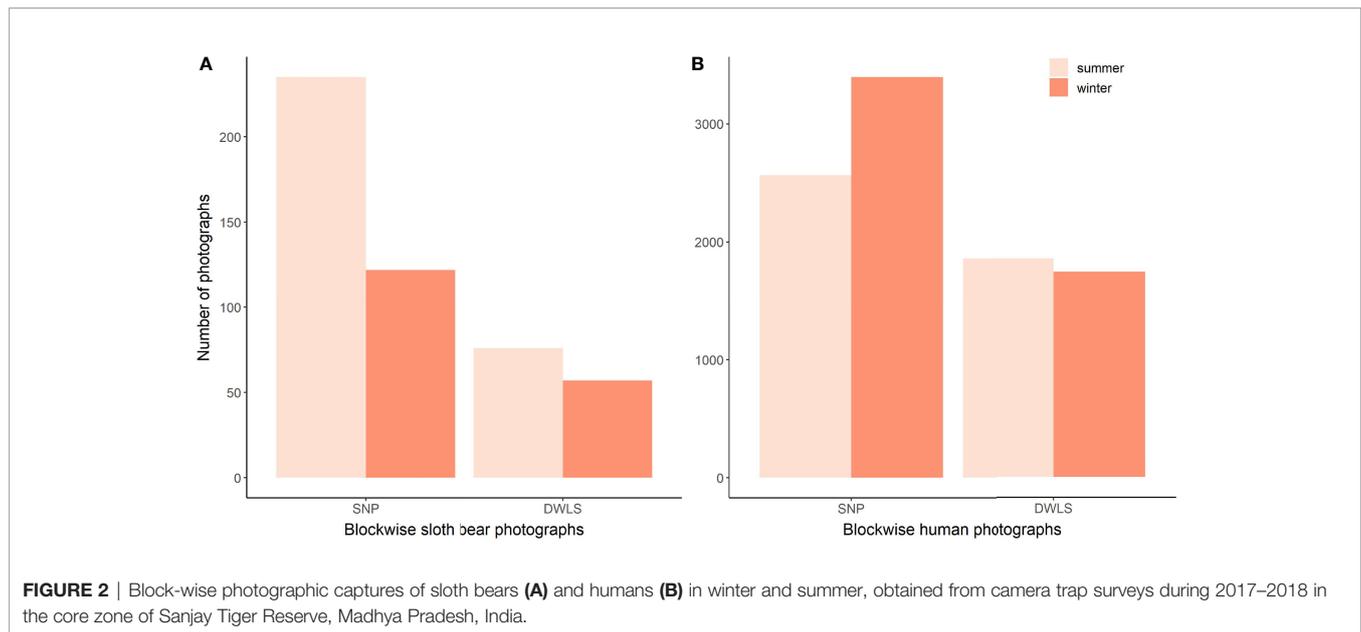
### 3.2 Spatial and Temporal Overlap

#### 3.2.1 Spatial Overlap

A higher spatial overlap (0.44) between sloth bears and humans was observed during winter than in summer (0.31). A high variation in spatial overlap between sloth bears and humans was observed between seasons in DWLS compared to SNP (**Table 2**).

#### 3.2.2 Temporal Overlap

It was found that, during summer, the temporal overlap between sloth bears and humans was higher in comparison to winter (**Table 3; Figure 3**). Sloth bears were found to be more crepuscular and nocturnal (Watson’s  $U^2 = 0.09$ ;  $p < 0.05$  for winter; Watson’s  $U^2 = 0.51$ ;  $p < 0.005$  for summer) irrespective of the seasons, whereas human activity was found to be primarily diurnal (Watson’s  $U^2 = 2.25$ ;  $p < 0.005$  for winter; Watson’s  $U^2 = 3.85$ ;  $p < 0.005$  for summer; **Table 4**). During summer, the activity of humans started before 06:00 and extended as long as 22:00 (**Figure 3**). However, during winter, human activities mostly started after 07:00 and continued till 20:00 (**Figure 3**). Watson’s



**TABLE 1 |** Values of species interaction factor (SIF), probability of use ( $\Psi^{BA}$ ) of sites by sloth bears (denoted as “B”) in the presence of humans (denoted as “A”), probability of use ( $\Psi^{Ba}$ ) of sites by sloth bears in the absence of humans (denoted as “a”) and detection SIF (delta,  $\delta$ ), along with associated standard error (SE), calculated for two seasons (winter and summer) in the Sanjay Tiger Reserve, Madhya Pradesh, India, during 2017–2018.

Season	SIF $\pm$ SE	$\Psi^{BA} \pm$ SE	$\Psi^{Ba} \pm$ SE	$\delta \pm$ SE
Overall winter (2017 & 2018)	0.98 $\pm$ 0.007	0.71 $\pm$ 0.04	1.00 $\pm$ 0.00	1.05 $\pm$ 0.06
Overall summer (2017 & 2018)	1.00 $\pm$ 0.03	0.79 $\pm$ 0.04	0.77 $\pm$ 0.17	1.06 $\pm$ 0.07

**TABLE 2 |** Spatial overlap index values of species pair (sloth bear and human), with associated 95% confidence interval (CI), during 2017–2018 in the Sanjay Tiger Reserve, Madhya Pradesh, India.

Season	Area	Spatial overlap between sloth bear and human with 95% CI
Winter 2017	SNP	0.41 (0.21–0.68)
Summer 2017	DWLS	0.17 (0.10–0.33)
Winter 2018	DWLS	0.51 (0.24–0.78)
Summer 2018	SNP	0.38 (0.18–0.62)
Overall winter (2017 & 2018)	SNP + DWLS	0.44 (0.27–0.65)
Overall summer (2017 & 2018)	SNP + DWLS	0.31 (0.16–0.49)

two-sample  $U^2$  test revealed that sloth bear and human activity patterns significantly differed (Watson’s  $U^2 = 9.84$ ,  $p < 0.001$  for winter; Watson’s  $U^2 = 11.13$ ,  $p < 0.001$  during summer; **Table 4**) from each other for both the seasons. However, between seasons, the activity of sloth bears and humans also differed significantly ( $U^2 = 0.22$ ,  $p < 0.05$  for sloth bears;  $U^2 = 19.61$ ,  $p < 0.001$  for humans).

### 3.3 Sloth Bear–Human Conflict Prediction Through Geographic Profiling

#### 3.3.1 Sloth Bear–Human Conflict Incidents

A total of 57 records of attacks on humans by sloth bears occurred in the core area of STR from 2009 to 2019. Centroids of compartments were generated for 57 conflict incidents.

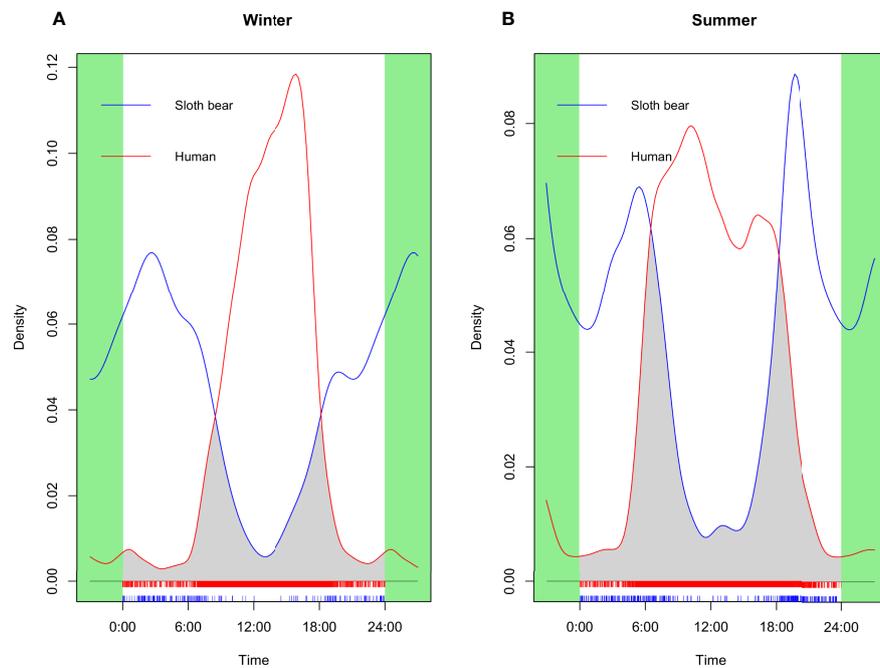
#### 3.3.2 Geographic Profiling for Conflict

The first model was run to produce the overall geographic profile of sloth bear–human encounters in STR using locations ( $n = 57$ ) of bear attacks on humans and 88 camera trap locations that detected both sloth bears and humans. The top 10% of the probable source sites ( $n = 8$ ) are mentioned in **Table 5** and **Figure 4**. The Gini coefficient of the model was 0.97. For the second model, the seasonal shift in the probable conflict sites was assessed using 81 and 66 camera trap locations for summer and winter, respectively. The model identified 9 sites and 5 sites as probable sources of conflict in summer and winter, respectively, details of which are provided in the supplementary material (**Supplementary Table 1; Supplementary Figures 1, 2**). The Gini coefficient for the summer and winter models was 0.90 and 0.99, respectively.

**TABLE 3** | Estimates of temporal overlap ( $\Delta_4$ ) between sloth bear and human, with associated 95% confidence interval (CI), during 2017–2018 in the Sanjay Tiger Reserve, Madhya Pradesh, India.

Season	Area	Temporal overlap ( $\Delta_4$ ) between sloth bear and human with 95% CI
Winter 2017	SNP	0.343 (0.282–0.404)
Summer 2017	DWLS	0.402 (0.323–0.483)
Winter 2018	DWLS	0.183 (0.110–0.262)*
Summer 2018	SNP	0.460 (0.405–0.515)
Overall winter (2017 & 2018)	SNP + DWLS	0.288 (0.238–0.337)
Overall summer (2017 & 2018)	SNP + DWLS	0.459 (0.414–0.505)

\*due to less number of detections (< 75) of sloth bears,  $\Delta_1$  was calculated instead of  $\Delta_4$ .

**FIGURE 3** | Activity overlap and overlap coefficient ( $\Delta_4$ ), i.e., gray shaded area, between sloth bear (blue solid line) and human (red solid line) for overall winter (A) and summer (B) in the Sanjay Tiger Reserve, Madhya Pradesh, India, during 2017–2018.

A third model was run using 88 camera trap locations where sloth bears and humans were detected together, to test the efficacy of camera trap data for conflict prediction (Figure 5). A profile based on camera trap data alone produced a similar conflict prediction and could identify 21% of the sloth bear attacks on humans (12 attack sites out of 57) by searching less than 10% of the study area and 50% of these conflicts (29 attack sites out of 57) by searching just 20% of the study area (Supplementary Table 2). Thus, it validated the model performance (Gini coefficient = 0.91).

## 4 DISCUSSION

We reported spatial interaction and spatio-temporal overlap between sloth bears and humans with respect to seasons, i.e., winter and summer, in STR. Sloth bears independently co-occurred with humans in terms of space use, which was in

contradiction to our expectations. However, distinct seasonal variation of spatial and temporal overlap between sloth bears and humans was observed at a finer scale, which, we believe, perhaps enables sloth bears to co-exist with humans in a human-dominated landscape. Finally, in the context of extensive human activities in sloth bear habitat and resultant conflict incidents, we identified the probable conflict source sites and hotspots in STR based on available conflict records and detections of sloth bears and humans from camera traps.

### 4.1 Spatial Interaction and Spatio-Temporal Overlap Between Sloth Bears and Humans

Two-species occupancy models showed that sloth bears could independently occur with humans irrespective of seasons, which, to our knowledge, is not an entirely novel situation. In Mudumalai Tiger Reserve, the occupancy of sloth bears was uninfluenced by the distance to the nearest human settlements

**TABLE 4** | Circular statistics (include one-sample and multi-sample tests) of seasonal patterns of temporal activity of sloth bears and humans during 2017–2018 in the Sanjay Tiger Reserve, Madhya Pradesh, India.

Season	Variables	Sloth bear	Human
Winter	Mean vector	01:45	13:40
	95% confidence interval	12:48–02:42	13:35–13:46
	Watson's $U^2$ one-sample (p-value)	0.09 ( $p < 0.05$ )	2.25 ( $p < 0.005$ )
	Watson's $U^2$ two-sample (p-value)		9.84 ( $p < 0.001$ )
Summer	Mean vector	00:18	12:09
	95% confidence interval	11:23–01:13	11:59–12:19
	Watson's $U^2$ one-sample (p-value)	0.51 ( $p < 0.005$ )	3.85 ( $p < 0.005$ )
	Watson's $U^2$ two-sample (p-value)		11.13 ( $p < 0.001$ )

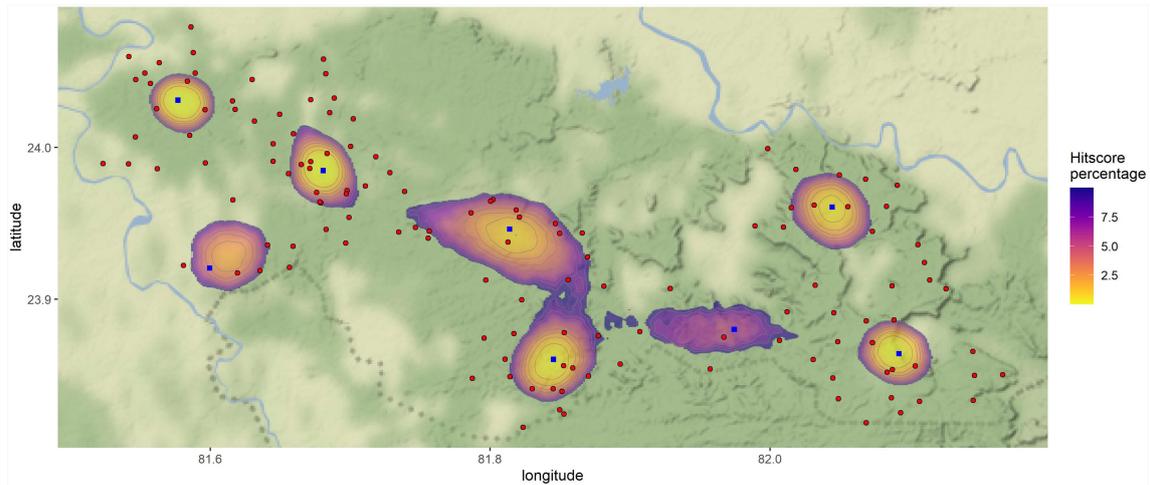
**TABLE 5** | Hit score percentages of the probable source locations estimated from the Dirichlet Process Mixture (DPM) modeling using conflict (sloth bear attacks on humans from 2009 to 2019) and camera trap locations (where sloth bears and humans were both photo-captured) as incident sites in the Sanjay Tiger Reserve, Madhya Pradesh, India, during 2017–2018.

No. of source sites	Latitude	Longitude	Hit score %
1	23.98	81.68	0.00
2	24.03	81.58	0.05
3	23.87	82.09	0.17
4	23.86	81.85	0.25
5	23.96	82.04	0.54
6	23.95	81.81	1.06
7	23.92	81.60	3.93
8	23.88	81.95	6.57

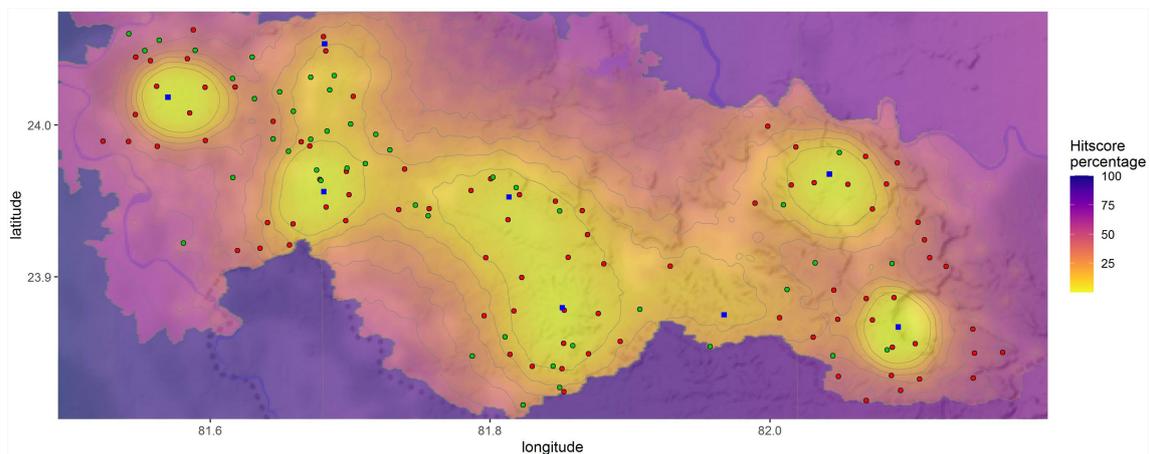
(Ramesh et al., 2012a). Sloth bears can be habituated to persistent human presence and are attracted to human settlements in search of abundant seasonal fruits (*Ziziphus mauritiana*, *Syzygium cumini*), cultivated crops (groundnut, maize), and even garbage (food wastes) (Akhtar et al., 2004; Palei et al., 2020; Prajapati et al., 2021), which also increased the sloth bear–human conflict (Bargali et al., 2005; Prajapati et al., 2021). However, increased human activity or encounter with humans would facilitate the shifting of temporal activities of many mammalian species, including carnivores (Gaynor et al., 2018), instead of spatial avoidance (Nickel et al., 2020), or could induce habituation towards human activity (Albert and Bowyer, 1991; Barnes and Wilker, 2000; Elfström et al., 2014). On the other hand, bears show strong avoidance of human activities both spatially and temporally (Chi and Gilbert, 1999; Tollefson et al., 2005; Ladle et al., 2018). We believe the spatial distribution of humans or anthropogenic activities could be the governing factor of such spatial avoidance or spatial co-occurrence. In the human-dominated landscape, it is not always possible to avoid humans spatially as it would cost to miss out on potential resource-rich areas, which would negatively affect the foraging success and overall fitness of the animal. In STR, human occurrence and livestock grazing in sloth bear habitat are extensive. We found high occupancy ( $\Psi^A = 0.96 \pm 0.02$  in winter;  $\Psi^A = 0.84 \pm 0.03$  in summer) of humans in STR, which indicated the substantial level of anthropogenic pressure throughout the study area, regardless of seasons. Despite this extensive human pressure, the probability of use of sites by sloth bears was also found to be high ( $\Psi^{BA} = 0.71 \pm 0.04$  in winter;  $\Psi^{BA} = 0.79 \pm 0.04$  in summer; **Table 2**), which indicated that irrespective of seasons, sloth bears are utilizing sites independently of humans. It was also found

that detection SIF (delta,  $\delta$ ) was slightly higher than 1 ( $\delta = 1.05 \pm 0.06$  in winter;  $\delta = 1.06 \pm 0.07$  in summer; **Table 2**), indicating some sort of association in detection between sloth bears and humans. It could be attributed to the relatively high preference for trail use by wide-ranging carnivores (Harmsen et al., 2010; Karanth et al., 2011; Kays et al., 2017; Nickel et al., 2020), apart from humans, which would facilitate animals to cover a larger distance in an energetically efficient way (Dickie et al., 2017).

However, spatial overlap estimation based on Pianka's overlap index (Pianka, 1974) revealed seasonal variation between sloth bears and humans. The intensity of space use by sloth bears was lower (0.31) during summer than during winter (0.44), which indicated that bears used sites less frequently during summer in the presence of humans than in winter. Given the widespread distribution of human activities during winter and summer, it was expected to have more overlapped areas between the two without any seasonal variation. Less spatial overlap between sloth bears and humans during the summer season could be attributed to comparatively higher temporal overlap during summer with respect to winter (see **Table 4**). In STR, human activities were found to be primarily diurnal regardless of seasons. However, during summer, the activities of humans started well before 06:00 o'clock in the morning and continued till late evening hours, which substantially overlapped with the crepuscular activity of sloth bears (Yoganand, 2005; Bargali et al., 2012; Ramesh et al., 2013). Increased human activity in the early morning and crepuscular hours during summer (especially from March to the first half of April) is primarily associated with the collection of flowers of Mahua, which is used to prepare alcoholic beverages (Kumar and Rao, 2007; Mewada, 2012). The selling of dry Mahua flowers



**FIGURE 4** | Map showing the top 10% of the probable sloth bear–human conflict areas (probable source sites and dispersion or hotspots around source sites) in the Sanjay Tiger Reserve, Madhya Pradesh, India, based on locations of sloth bear attacks on humans (from 2009 to 2019) and camera trap surveys (locations where sloth bears and humans were both photo-captured) conducted during 2017–2018; blue square points ( $n = 8$ ) were probable source locations (or anchor points) of conflict; red points were the camera trap locations which photo-captured both sloth bears and humans; lighter color shade indicated high conflict probabilities.



**FIGURE 5** | Prediction of the source-dispersion of sloth bear–human conflict using camera trap surveys conducted in the Sanjay Tiger Reserve during 2017–2018, Madhya Pradesh, India; the lighter shade areas indicate high conflict probable areas and the blue squared points were the probable source sites ( $n = 8$ ) of conflict hotspots; light green points were the conflict sites where attacks on humans by sloth bears occurred between 2009 and 2019; red points were the camera trap locations which photo-captured both sloth bears and humans; twenty-nine conflict sites fall within <20% of the search area and 12 conflict sites within <10%, thus validating the model performance.

significantly helps in the income generation of indigenous people (Islam and Quli, 2017). Hence, it is widely considered an important livelihood option for indigenous people in India (Kumar et al., 2018; Mishra and Poonia, 2019). The Mahua flowers also significantly contributed to the diet of sloth bears during the onset of summer (Bargali et al., 2004; Yoganand, 2005), which, coupled with its crepuscular activity, increased the interaction between sloth bears and humans (Akhtar et al., 2004). In STR, based on our camera trap survey, it was found that the

frequency of occurrence of sloth bears and humans at per hour intervals was high during the early morning (05:00–07:00) and evening (19:00–20:00) in summer (**Supplementary Figure 3**). To avoid human encounters during the crepuscular period, it is possible that sloth bears used sites less intensively where chances of human encounters were high. Contrastingly, during winter, high spatial overlap could be associated with low temporal overlap between sloth bears and humans. In winter, human activities remained more concentrated during broad daylight

hours for a comparatively short span of time, but did not start in the early morning hours, like summer (see **Figure 3**). In line with this, the morning (07:00–08:00) and early evening hours (15:00–16:00) showed the maximum frequency of occurrence of sloth bears and humans per hour interval, although the magnitude of the frequency of occurrence was less in winter compared to summer (**Supplementary Figure 3**).

We found that the activity patterns of humans varied significantly between seasons, which was also the case for sloth bears. Our results indicated that sloth bears used sites more extensively during winter regardless of human occurrences, with a distinct temporal avoidance. Studies elsewhere have shown that carnivores could avoid human occurrences temporally (Tollefson et al., 2005), instead of avoiding them spatially, in a human-dominated landscape (Wang et al., 2015; Nickel et al., 2020). The marginal difference ( $p < 0.05$ ) in the activity of sloth bears between seasons indicated that sloth bears tended to avoid a more predictable pattern of human activity, despite already being strictly nocturnal and crepuscular in a human-dominated landscape (Bargali et al., 2012). Since human activity is not dependent on sloth bear activity, our study revealed that a significant shift in human activity between seasons influenced the likelihood of interaction between sloth bears and humans temporally and spatially.

However, despite distinct spatio-temporal avoidance, the conflict between sloth bears and humans in terms of human-mauling is prevalent in STR. It is attributed to the year-round existing immense anthropogenic pressure posed by human settlements inside the core area of STR. Similar observations were also made in the human-dominated landscapes of central India (Bargali et al., 2005; Dhamorikar et al., 2017) and elsewhere (Garcia et al., 2016; Debata et al., 2017; Singh et al., 2018). Based on our camera trap survey, we found that during summer, the number of detections of sloth bears and humans per hour interval was higher ( $n = 53$ ) than during winter ( $n = 33$ ), indicating that during summer, there is a relatively high probability of conflict incidents inside the forest, as reported by Dhamorikar et al. (2017). We assumed that sites where sloth bears and humans were detected more frequently within a specific bin (1 h in this case) of time are more prone to accidental encounters between them, while humans are engaged in different activities, especially in and around those sites. In previous studies, it has also been observed that most of the attacks occur during sudden close encounters with sloth bears (Dhamorikar et al., 2017; Singh et al., 2018), especially while collecting non-timber forest produce (NTFP) separately and silently inside the forest (Dhamorikar et al., 2017).

## 4.2 Identification of Existing and Future Conflict Hotspots

Finally, we have made an attempt to identify the conflict source sites and dispersion around source sites based on the present camera trap survey and records of conflict incidents obtained from the forest department. Our primary aim was to identify areas inside the forest where humans and sloth bears occurred more frequently, assuming that areas where sloth bears and humans were more likely to get exposed to each other, lead to conflict scenarios. Furthermore, records from the forest department were

used to validate our model and future conflict predictions. We found that, based on detections of sloth bears and humans obtained from camera traps and validating them with registered conflict records, the GP model produced a reasonably good prediction (Gini coefficient = 0.92) of conflict source and dispersion. The GP model was found to be especially robust when fewer data points are provided and can potentially outcompete any other spatial statistics used in different contexts and scenarios of model-based predictions (Stevenson et al., 2012). However, a distinct seasonal variation was observed in the current prediction of conflict hotspots. More probable source sites ( $n = 9$ ) of conflict were identified during summer, in comparison to winter ( $n = 5$ ), indicating a greater chance of conflict in forest areas during summer, which was also earlier reported in the central Indian landscape (Dhamorikar et al., 2017). It could be attributed to the much higher number of detections of sloth bears ( $n = 312$ ) during summer, in comparison to winter ( $n = 180$ , see **Table 1**), and associated high temporal overlap with humans. We found that seasonal variation in the temporal overlap between sloth bears and humans was also reflected in the predicted source-dispersion modeling of conflict in STR. As probable source sites and hotspots were mostly associated with villages' locations, it was evident that the probability of conflict was also higher in areas adjacent to villages. Relocation of villages from the core zone of STR, especially those situated around the probable source sites shown here, would be a primary step for managers to reduce conflict between sloth bears and humans. However, despite being a contentious and gradual process, voluntary relocation of villages from the core zone of Tiger Reserves was proved to be one of the successful means to restore wildlife population and its habitat (Lasgorceix and Kothari, 2009), with special reference to tiger conservation in India (Jhala et al., 2021). Also, elsewhere in India, communities living inside Tiger Reserves prefer to be relocated willingly due to the decreased productivity of forests, lack of basic amenities, and human–wildlife conflict (Harihar et al., 2014). Thus, we believe that the findings of geographic profiling could be one means for forest managers to identify the villages that need to be relocated on a priority basis or rationalize resources or techniques for conflict mitigation. However, in between the process of relocation, an effort could be made to make people living in conflict hotspots aware of the avoidance of conflict scenarios based on the findings of this study and studies carried out elsewhere in central India (Bargali et al., 2005; Dhamorikar et al., 2017; Dhamorikar et al., 2018). Although we could not identify the conflict sources and hotspots outside the core zone of STR, conducting awareness programs among the local people as mitigation measures is especially important in the buffer zone and other human-dominated forest areas outside the Tiger Reserve.

## 4.3 Caveats and Limitations

Our study had several limitations. Due to logistical constraints, we could not broaden our understanding of conflict prediction in the buffer zone of STR. Also, camera traps were not deployed in the monsoon, which restricted us to drawing inferences during this season. We have deployed camera traps on the trails and forest roads in order to maximize the capture of tiger and other co-predators, including sloth bears. Previous studies showed that

placement of camera traps on trails or forest roads significantly increased the detection of certain mammal species and bears as well (Wearn et al., 2013; Kolowski and Forrester, 2017; Tanwar et al., 2021). On the other hand, human activities inside the forest, such as the collection of NTFPs, are not restricted to the roads and trails but can be conducted anywhere in the forest depending upon resource availability and accessibility. In general, people do not walk alone on the forest roads or trails, especially during dark hours, as moving in groups would reduce the chance of being attacked by bears (Garrote et al., 2017). Despite knowing these facts, we assumed that in the locations where humans and bears were frequently detected, the chance of conflict could also be high in and around those locations. Although widely used, the efficacy of trail-based camera traps in estimating anthropogenic pressure has rarely been assessed. However, Miller et al. (2017) showed how wildlife monitoring cameras (on-trail) can also efficiently capture human activities and could be used for long-term wildlife–human interaction-based studies. Our study indicated fairly accurate conflict prediction through the GP model by using only camera trap data, although we recommend careful considerations while deploying camera traps (on-road and off-road) in future similar studies.

#### 4.4 Conclusion

This study revealed that the interaction between sloth bears and humans was primarily governed by the seasonal variation of spatio-temporal overlap, especially the significant changes in human activity between seasons. From the species perspective, fine scale segregation of temporal and spatial activity was observed to co-exist with humans. However, extensive anthropogenic pressure throughout STR exacerbated the situation and led to conflict scenarios. Therefore, radio-telemetry-based research, along with monitoring through camera traps, is recommended to understand the spatio-temporal activity of sloth bears in a human-dominated landscape. In this study, the application of novel methods like GP models provided an opportunity to predict the source-dispersion of conflict precisely, even using secondary data sets obtained from camera traps. It would be insightful for forest managers to reduce conflict incidents derived from sloth bear–human interface with a more area-specific targeted approach and promote coexistence in a human-dominated landscape.

#### DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/**Supplementary Material**.

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#### AUTHOR CONTRIBUTIONS

SK and RK conceived the project. RK, SK, SS, and SC designed the study. SC and RR collected the data. SC and RR carried out data preparation prior to analysis. SC and MB completed data analysis, prepared tables and figures and wrote the first draft of the manuscript. SS, RK, and SK supervised and critically reviewed the manuscript. All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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#### SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fcosc.2022.850309/full#supplementary-material>

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