Community, conflict and conservation: response of mammalian fauna to ecological and anthropological correlates in a critical habitat in Indo-Bhutan transboundary landscape urges multiagency cooperation

Anukul Nath (✉ anukulwii@gmail.com)

Wildlife Institute of India

Bibhuti P Lahkar

Aaranyak

Namita Brahma

Tata Institute of Social Sciences

Pranjit Sarmah

Aaranyak

Arup Kr Das

Aaranyak

Subhashish Das

Assam Forest Department

Thunu Basumatary

Green Forest Conservation Society

Rajual Islary

Green Forest Conservation Society

Anindya Swargiary

Assam Forest Department

Research Article

Keywords: multi-species, occupancy, spatial-dependence, social unrest, Raimona, Ripu

Posted Date: November 23rd, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-1099973/v1>

License: This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Community, conflict and conservation: response of mammalian fauna to ecological and anthropological correlates – a critical habitat in Indo-Bhutan transboundary landscape urges multiagency cooperation

Anukul Nath^{1,2*}, Bibhuti P Lahkar¹, Namita Brahma^{1,3}, Pranjit Sarma¹, Arup Kr Das¹, Subhashish Das⁴, Thunu Basumatary⁵, Rajual Islary⁵, and Anindya Swargiary⁴

1: Aaranyak, Guwahati, Assam, India

2: Wildlife Institute of India, Dehradun, Uttarakhand, India

3: Tata Institute of Social Sciences, Guwahati, Assam, India

4. Assam Forest Department, Kokrajhar, Assam, India

5: Green Forest Conservation Society, Kokrajhar, Assam, India

* Corresponding author: anucool.nath5@gmail.com/ ORCID: 0000-0003-3668-2640

Abstract

The impacts of conflict on nature are devastatingly adverse but differ widely in different socio-political regimes. Armed conflict often facilitates illegal plunder and unsustainable use of natural resources, variously by rebel groups and impoverished or displaced people challenged with limited subsistence options. We studied the response of mammals in Ripu Reserve Forest (Assam) that suffers prolonged anthropogenic pressure due to armed conflict instigated by social unrest. We used standard single-season (spatial-dependence) occupancy models using sign survey to assess the factors affecting the space use of mammals and subsequently build capacity of conservation volunteers for long-term sustenance of Ripu. Our study revealed that Ripu has a high proportion of occupied area by prey species of large carnivores. Asian elephant, barking deer, and wild pig occupied most of the habitat, whereas gaur, sambar and spotted deer restricted themselves to selected patches within the Ripu. Common leopards found to be positively associated with prey occupancy. The studied mammals responded variably to different ecological and anthropological covariates and urge for species-specific management alongside landscape scale conservation approach. Our ground effort to strengthen community patrolling and operational execution of various alternative livelihood has helped to empower the economic condition of patrolling staff. Strategic implementation of law enforcement could support

dispersal of tigers from Phibsoo WLS (Bhutan), potentially linked with the larger tiger and elephant landscape far west (Buxa Tiger Reserve) in the Terai region of India. Community-based conservation initiatives required continuous support from various agencies, including national, international, and local bodies, to restore this critical habitat.

Key words: multi-species, occupancy, spatial-dependence, social unrest, Raimona, Ripu

Introduction

The imperative of conserving natural resources and mitigating conflict is codified as three (Life on land, Life below water, and Peace, justice and strong institutions) of the seventeen United Nations Sustainable Development Goals (IUCN 2021). Although there is a long history and policy attention to the interlinkages between war and the environment in general, explicit connections concerning armed conflict and biodiversity conservation have received diminutive attention. Forty percent of civil wars between 1950 and 2010 were associated with natural resources and armed conflicts (IUCN 2021). However, the links amongst conflict, nature, and natural resources differ and remain usually debated and imperfectly understood. Globally, the number of armed conflicts has risen over the past 30 years, and more than 7000 armed conflict events have been reported since 2014. The majority of these armed conflicts occurred in Africa, West Asia, South, and South Asia. UN Permanent Forum on Indigenous issues highlighted that indigenous peoples have been frequently impacted and remain vulnerable to armed conflict (United Nations Permanent Forum on Indigenous Issues 2016). The present-day conflicts often relate to indigenous lands, territories, and belongings, as tenure insecurity disputes are time and again particularly acute for indigenous people. Conflicts also impact the civil, political, cultural, social, economic and spiritual rights of indigenous people (United Nations Permanent Forum on Indigenous Issues 2016), including biodiversity of the region (Hanson et al. 2009). Across the globe, large overlap of biodiversity hotspots with areas undergoing high levels of sociopolitical and ethnic conflicts, make the impact of such actions a precarious factor for the long-term preservation of biodiversity in these regions (Hanson et al. 2009).

In India, many forested lands, including protected areas, undergo erratic conflicts due to copious convoluted issues ranging from cultural identity to socio-political and environmental security (Dutta 2020). These conflicts act as foremost obstacles in monitoring, protection, and management in the biodiversity-rich areas and lead to exploitation of wildlife and their habitat by conflict parties in the absence of sufficient protection and monitoring forces (Dutta 2020). In the northeastern region of India, cultural differences among ethnic groups, differences in resource

endowments, migration followed by land scarcity coupled with discriminatory policies have initiated the armed conflict in the region (Brahmachari 2019). Assam in Northeast India has witnessed armed conflict over ethnolinguistic and religious lines since the 1980s (Baruah 1999). Historically, in the western Assam, the Bodo's are the largest plain tribe of northeast India, and they consider themselves to be the autochthons of the region (Dutta 2020). However, large-scale immigration took place during colonial times from Bengal and Bengali Muslim peasants were settled in western Assam. Besides, Adivasis (Santhal, Orao and Munda) tribes were also transported to work in the expanding tea plantations and build the railways (Brahmachari 2019). Furthermore, some tribes were employed by the British forest administration to work in definite forest zones in timber plantations. Immigration and complex land policies and the commoditization of forests and the implantation of tea estates initiated the ethnic violation followed by armed conflict in the western Assam zone (Vandekerckhove and Suykens 2010). The violence caused large-scale damage to the forested areas (including wildlife and habitat) of western Assam, including Manas National Park, Manas Reserve Forest, and the entire Kachugaon and Haltugaon Forest Division (Ripu RF, Chirang RF, and Kachugaon RF). The conflict resulted in 0.25 million refugees primarily along the National highway-37 south of the Kachugaon, Ripu and Chirang Reserve Forest (Horwich et al. 2013). These factors led to the destruction of 50% of western Assam's forest. Major deforestation occurred due to illegal logging (in Ripu and Chirang RF) and rampant fuelwood collection for sales were the driving factors that caused forest degradation (Horwich et al. 2013).

The Ripu Reserve Forest is part of the buffer zone of Manas Tiger Reserve (MTR) and the forests of Ripu are contiguous with those of Buxa Tiger Reserve in West Bengal and Phibsoo Wildlife Sanctuary in Bhutan. Ripu and adjoining forests have India's largest known population of the endangered golden langur *Trachypithecus geei* (Horwich et al. 2013). Apart from that, long-ranging mammals such as Asian elephant (*Elephas maximus*), Royal Bengal tiger (*Panthera tigris*) and gaur (*Bos gaurus*), Asiatic black bear (*Ursus thibetanus*), Asiatic wild dog (*Cuon alpinus*) had shared a common home range in Bhutan, West Bengal and Assam (Olivier 1978; Tiwari et al. 2017). This forest belt also served as the migratory passageway of the faunal species from Himalaya, Indo-Chinese and Indo-Malayan realms towards west and Peninsular Indian realm species to the east (Nath et al. 2008). However, the impact due to the conflict has completely devastated the infrastructure of the region and further troubled the protection and management activities suffered immensely since late 1990s. The political stability was initiated in 2003 with the formation of the Bodoland Territorial Council (BTC), which in turn has stimulated scientific research and management

in the region (Nath et al. 2008). Yet, in recent times, several incidents of ethnic conflict continued in the region that emphasized the fragile socio-political environment around Ripu RF.

Resource availability and habitat utilization by animals within a complex and dynamic landscape is a central theme in conservation ecology (Hull et al. 2016). Understanding distribution and habitat use of wildlife species are critical for setting applicable wildlife management goals, monitoring usefulness of management interventions, informing policymakers and other associated stakeholders. The information on space use by terrestrial mammals becomes crucial for a site like Ripu since this site has suffered prolonged anthropogenic activity of all kinds (ethnic violation led to encroachment, deforestation, habitat degradation, hunting and excessive resource extraction). Apart from mega herbivores like elephant and gaur, wild ungulates (>15 kg body mass) are an important faunal assemblage of terrestrial ecosystem. They play critical role in sustaining terrestrial ecosystem with their impact on plant communities and nutrient recycling (Hobbs 1996; Ritchie et al. 1998; Moe and Wegge 2008). They also represent the essential prey base for carnivores and regulate carnivore density and habitat use (Carbone and Gittleman 2002). Since the end of ethno-political conflict in 2003, conservation measures such as reintroduction (One-horned Rhino, Swamp deer), strengthening of law enforcement, population and habitat monitoring, community engagement and transboundary initiatives have been initiated within the western Assam zone although restricted to Manas National Park (World Heritage Site) (Borah et al. 2014; Barman et al. 2014; Nath et al. 2019a). On the other hand, certain areas of MTR, specifically the reserve forests, did not get considerable attention in terms of research monitoring, management, and conservation. Therefore, in the present study, we used the occupancy modeling approach that accounts for imperfect detection to assess ecological and anthropogenic correlates of mammals site use in Ripu RF.

Occupancy models applied to varied spatial scales, with both fine-scale and landscape-scale predictors, have revealed to be effective in addressing conservation needs (Scott et al. 2002) and have been used explicitly to help inform conservation strategies of multiple species (Wikramanayake et al. 2011). Standard occupancy models require replicated, independent, detection occasions which are usually replicated temporally (MacKenzie et al. 2006). On the other hand, spatial replication can be used, provided that occupancy is inferred applicably as being confounded by availability for detection within each spatial replicate, and survey locations are selected randomly with replacement within sites (Kendall and White 2009). However, due to logistical constraints and costs associated with surveying random sites and sometimes difficult to implement. Hines et al. (2010) addressed spatial correlation/dependence among adjacent segments on trails by modelling correlated detection probability or probability of presence as

Markovian processes. In recent years, spatially replicated correlated detection occupancy surveys have primarily been applied to track surveys covering medium to large size carnivores and herbivores (Hines et al. 2010; Wibisono et al. 2011; Thorn et al. 2011; Lakshminarayanan et al. 2016; Thapa et al. 2019; Jornburom et al. 2020; Lamichhane et al. 2020). In addition, it was already well established that spatial replication in occupancy studies useful for assessments of species habitat relationship (Srivathsa et al. 2018).

We used detection and non-detection data collected from sign surveys of mammals within an occupancy modelling frame work to assess the habitat use and simultaneously build capacity of conservation volunteers further to strengthen the monitoring and protection of Ripu RF. Our specific objectives were (a) to determine the proportion of Ripu occupied and investigate factors affecting the probability of occupancy and habitat use of elephant (*Elephas maximus*), gaur (*Bos garus*), sambar (*Rusa unicolor*), spotted deer (*Axis axis*), barking deer (*Muntiacus muntjak*), and wild pig (*Sus scrofa*), leopard (*Panther pardus*) (b) to develop predictive habitat use maps based on the spatially explicit occupancy models (c) to build capacity of conservation volunteers for the long-term monitoring and protection of Ripu RF. Here, we examined the influence of the proportion of different forest types, water availability, and anthropogenic activities on the site use pattern of the above-mentioned mammalian species. We hypothesized that these species would differ in their site use responses given their different habitat requirements. The findings of this study would be useful in informing management activities to conserve herbivore population and support large carnivore's recovery goals in this transboundary landscape.

Study Area

The Ripu Reserve Forest (RF) is one of the three reserve forests of Kachugaon Forest Division in the Kokrajhar district of BTAD (Bodoland Territorial Area Districts) in western Assam (Fig 1). The Indo-Bhutan boundary forms the northern boundary of the Ripu from the Sonkosh river on the west to Saralbhangra river on the east comprising 605.27 sq. km. The Buxa Tiger Reserve of West Bengal is located on the west and the Phibsoo Wild Life Sanctuary and Namgyal Wangchuk Wild Life Sanctuary of Bhutan are located on the north and Chirang RF in the east. The Ripu RF is one of the important westernmost buffer of Manas Tiger Reserve (2,837 sq. km) notified in 1973, Biosphere Reserve (1989) and as a Chirang-Ripu Elephant Reserve (2,600 sq. km) in 2003 under the umbrella of "Project Elephant" by Government of India. The Chirang-Ripu ER is also an essential part of Buxa-Ripu Elephant Corridor at Sankosh that connects Buxa Tiger Reserve in West Bengal with the Ripu Reserve Forest of Kachugaon Forest Division in Assam (Tiwari et al. 2017). Except for Sonkosh and Saralbhangra other rivers and several rivulets and streams

remains waterless in the dry season. The general topography of the region is low lying and more or less flat, except few undulating stumpy foothills that slope gently towards the south. The climate is warm and humid characterized by sub-tropical with pronounced monsoon with three distinct seasons, viz., winter, summer and monsoon (Borthakur, 1986). The mean annual rainfall is 3000 mm with an average temperature range between 06°C to 37°C. The study area falls under the Bhabar zone and the forest type is dominated by Moist-mixed deciduous and semi evergreen forest. A total of 136 trees, 53 shrubs and 61 herb species recorded from Ripu-Chirang area (Menon et al. 2008). *Albizia amara*, *Dillenia pentagyna* and *Terminalia arjuna* are found to be associated with the sal dominated areas within the study area. Moist deciduous miscellaneous forest represented by *Dillenia pentagyna*, *Lagerstroemia parviflora*, *Castanopsis indica*. The evergreen forests primarily include *Mesua ferea* and *Moringa angustifolia*. Besides, 270 species of birds have been reported (Menon et al. 2008) from the area which include the critically endangered White Bellied Heron (*Ardea insignis*). The forest division is also rich in mammalian fauna, previous study reported 24 species of mammals which includes threatened species like elephant, tiger, Asiatic wild dog, Golden langur, gaur, leopard, Chinese pangolin (Hilaluddin and Sharma 2008). The hunting and poaching of wildlife along with smuggling of timber in the study area have been reported to be frequent. The tree species targeted in the region are as follows- *Shorea robusta*, *Pterospermum personatum*, *Terminalia* sp, *Schliochera oleosa*, *Diptereocarpus* sp. Apart from timber, locals also heavily extracted fuel wood and other NTFP on regular basis (Menon et al. 2008).

Methodology

Occupancy survey and sampling design

We employed a single season occupancy framework (MacKenzie et al. 2002; MacKenzie et al. 2006) to statistically assess the occupancy/habitat use of elephant, gaur, sambar, spotted deer, barking deer, wild pig and leopard using sign-survey data while explicitly addressing the concern of imperfect detection (Duangchantrasiri et al. 2015). We created a grids ($n = 144$) across the Ripu RF with each grid cell of size (2×2) 4 km² and investigated it in 75 grid cells to examine ecological and anthropogenic factors influencing site use pattern (Fig. 2). Our sampled grid cells covered 300 km² (~50%) of the available 605 km² of the study area. To infer the true occupancy, the area of a sampling unit should generally be larger than the average home range size of species so that assumption of geographic closure and independent sampling sites can be maintained (MacKenzie et al. 2002). Except for elephant, gaur, and leopard, the studied species in our study have small home ranges (less than 4 km²). Additionally, this grid cell size

circumscribes the expected daily ungulate movement based on home range size and movement rates reported at other field sites (see McShea et al. 2011; Thapa and Kelly 2017). For elephant, gaur, and leopard with larger home ranges than our 4 km² grid cells, occupancy models can be used to describe habitat-use at finer spatial scales rather than true occupancy [e.g. within home range habitat use, see tigers: Sunarto et al. (2012) and dholes: Srivathsa et al. (2014)]. At this finer scale, “probability of occupancy” is a measure of habitat use or the habitat that an animal selects relative to the habitat available within a home range (Johnson 1980). For mammals, modeling habitat use is key because it helps categorize the positive and negative ecological and anthropomorphic correlates that determine their home range or third-order habitat selection (Johnson 1980). This information is vital for achieving straightforward understanding of habitat use and making management decisions.

The sign survey was carried out by five different teams (each team consisting of 4-6 conservation volunteers and forest guards) simultaneously in different areas (Sanfan, Athiabari and Raimona Range) within the Ripu RF. Skilled personnel among the conservation volunteers were mixed in each team since sign surveys are prone to observation error (Royle and Lin 2006; Shea et al. 2011; Thapa and Kelly 2017). We searched for signs along the trails following probable animal travel routes, including all types of forest paths, stream beds, and riverbanks, which were considered to have a high likelihood of finding signs (Barber-Meyer et al. 2013). We assume that sign availability was similar across the study area, though studies have previously noted that occupancy estimation based on signs is subject to the decay rates of signs (Rhodes et al. 2011). Only fresh dung, pellet, track, other signs, and direct sightings of animals were recorded to avoid other biases that may arise from decay signs (Rhodes et al. 2011; Hedges 2012). We conducted the surveys in winter/dry seasons (January to April 2014) to make sure that sign persistence was consistent (Barnes 2001; Hedges et al. 2012) and to reduce heterogeneity in detection probability induced by rainfall variation (Royle and Nichols 2003). We spent ample time to verify signs and only recorded signs that were unambiguously identified. Specifically, for leopard, to avoid misidentification of signs, tracks and scrapes were identified using a combination of size and shape, while scats (tiger scat usually is less coiled compared to leopard scat; Wang and Macdonald 2009) were identified based on their size and the presence of secondary evidence at the site (Harihar 2012). On several occasions, we photographed tracks and signs and verified them later with experts. To further minimize the bias from the movement of animals from the surrounding grid cells, each grid cell was surveyed between 4-5 hours. The starting point of the trail was randomly selected within the grid for the sign survey. The effort of the sign survey ranged from 0.9 km of walk-in grid cells to 3.6 km with a mean of 2.37 km. The variation in the

effort occurred due to several factors, including percent forest cover in the grid cell, the encounter of major illegal activities (on-field encounter with hunter, substantial logging), and the movement of rebels and armed forces. The sign detection data were collected for each 100-m segment on the trail as either detected (1) or not detected (0).

Selection of ecological and anthropogenic variables

We selected plausible ecological and anthropogenic variables relevant to the ecology of the species and management intervention of the study area (Table 1). We collected variables both at the landscape scale using remote sensing & GIS and during the field survey. For the landscape-scale variables, we obtained Landsat image (30 m resolution; <https://earthexplorer.usgs.gov/>) of the previous year (i.e., 2013) for the classification forest types and land use land cover of Ripu and its adjoining area. We classified seven land cover classes – (i) semi-evergreen mixed with moist deciduous forest (SE-MMD), (ii) secondary degraded forest (SDF), (iii) scrub (mostly degraded areas dominated by invasive like *Chromolaena odoratum*, *Perthenium* sp. and *Ageratum conyzoides*) (SC) (iv) water body (v) agriculture (vi) settlement (built-up areas, all types of road and home gardens) and (vii) sand (river banks & stream beds) (Fig. 2, Table S1 and Fig. S1). The landscape-level variables to determine the probability of habitat use across the grid cells included – elevation (ELE), distance to human settlement (DHS), distance to water sources (DWS), and remotely sensed vegetation types mentioned above. The elevation data was computed using a 90 m SRTM dataset (Jarvis et al. 2008), and we assumed that the different species might respond differently with varied elevation gradients. However, the study site is comparatively low-lying areas except the northern part bordering Bhutan hills. The land use class agriculture and settlement were used to generate variable– distance to human settlement (DHS) through the Euclidean distance tool in ArcGIS 10.4. We hypothesized that distance to human settlement would act as a major anthropogenic factor that would influence the habitat use of species (Jathanna et al. 2015). This variable is an alternative measure of prolonged disturbance faced by Ripu RF in the last two decades, including cattle grazing, hunting, and all kinds of resource extraction (majorly fuel wood) (Gray and Phan 2011). In contrast, distance to water sources is expected to positively impact elephant habitat use (Lakshminarayanan et al. 2016) and the abundance of wild ungulates (Lamichhane et al. 2020). Subsequently, the proportion of different vegetation types (SE-MMD, SDF and SC) may influence the habitat use of animals. All these continuous variables were extracted for each pixel within the 4 km² grid cell using Spatial Analyst Tools- Zonal Statistics in ArcGIS 10.4. Additionally, for leopard we used

summed occupancy probability of prey (sambar, spotted deer, barking deer and wild pig) species in the study area along with other covariates mentioned above.

We also recorded on-field evidence of logs and/carts, tree felling, looping and cutting brunches, hunting signs (hunters seen, snares, axes, and wildlife carcasses), and fresh fire signs along 100 m segments. In addition, detection of the sign was believed to be associated with the substrate (SUB) condition, livestock (LS) presence, and effort (EF) in terms of trail length in each 4 km² grid cell. Substrate conditions noted were recorded as a categorical variable: soft soil (muddy areas, river & stream beds= 1), hard soil (forest paths with dry loose soil) = 2, and 3 for leaf litter. The presence of domestic animals, too, could influence detection since domestic animals can obliterate tracks of wild ungulates (pers. obs; Jornburom et al. 2020). The presence/absence of domestic livestock was noted as a binary variable coded as “0” for absence and “1” for presence in every 100 m replicate.

Capacity building of conservation volunteers and community awareness

The study began with a series of community consultations in the Kachugaon Forest Division in coordination with Green Forest Conservation NGO. This organization is one of the Community Forest Protection Forces in Bodoland Territorial Council to boost the forest protection forces in the Ripu RF. In recent years, the impact of community forces in reducing illegal logging and hunting has been encouraging in BTAD (Howrich et al. 2010). The Green Forest Conservation has around 100 conservation volunteers, of which few receive a small salary from the Bodoland Territorial Council (Howrich et al. 2010). To further strengthen the capacity of the conservation volunteers and their families, we provided training on biodiversity monitoring, supported with alternate livelihood options including hands-on training, and exposure-trip to give them ideas on the role of community protection, the scope of ecotourism followed by formation of village development committee (VDC) in the region. Apart from that, we encouraged conservation volunteers to participate actively in patrolling along with the forest department to regulate the anthropogenic activity in the study area.

Data Analysis

We used standard single-season occupancy models (MacKenzie et al. 2006) to estimate the occupancy and detectability of species using a sign survey. For the species with home range <4 km², spatial autocorrelation models (Hines et al. 2010) were used to determine the smallest segment length at which spatial dependence could be considered negligible following Throne et al. (2011) and McHenry et al. (2016). To allow estimation of detection

probabilities for trail segments of different length, a suite of 12 sets of detection histories were constructed from the sign survey data, with each set using a different segment length (0.1–1.2 km). Detection histories were imported into *RPresence* for analysis of occupancy models. The single-season occupancy (null) models assuming constant detection probability, $p(\cdot)$, and occupancy, $\psi(\cdot)$, (MacKenzie et al. 2002) were generated for each set (0.1–1.2 km) of detection histories to determine the effect of segment length on the detection probability of species of interest (for details see McHenry et al. 2016). Parameters estimated from standard occupancy models using adjacent spatial sampling units may be biased by autocorrelation in availability for detection between replicated observations—this spatial dependence model recompenses for lack of independence by modeling the spatial autocorrelation among segments. The spatial dependence is captured by parameters θ , representing the probability that the species is present locally, given the species was not present in the previous segment; θ' representing the probability that a species is present locally, given it was present in the previous segment, and θ^π representing the probability of local presence in the first segment where no prior information on local occupancy is available. Bias due to autocorrelation between adjacent observations can be considered negligible when model selection by AIC (at the level of $\Delta AIC < 2$) favours the null model over the spatial autocorrelation model and $\theta' \approx \theta$ (Thorn et al. 2011; McHenry et al. 2016; Lamichhane et al. 2020). We applied this model to the sets of standard detection histories for each segment length to test for between-segment spatial dependence.

For Asian elephant and leopard (having larger home range $>4 \text{ km}^2$), we used a spatial, first-order Markovian model (parameterized by θ , θ' , and θ^π , Hines et al., 2010) to check the spatial dependence and then estimate the intensive habitat use probability. We modeled probabilities of habitat use (ψ) at 600 m (Thapa et al. 2019) as a function of the above-mentioned covariates using logit link function (MacKenzie et al. 2002). For these models, we used a constant model for θ , θ' and θ^π (Sunarto et al. 2012; Duangchantrasiri et al. 2015). Furthermore, detection histories were collapsed to 600 m segment length, generating replicates suitable for use with standard PRESENCE models. We aggregated substrate quality values using the *mode* of values in the collapsed segments. The field measured covariate and landscape-level covariates (extracted using GIS) were used to investigate the detection and occupancy/habitat use probabilities across the Ripu RF. All the covariates were screened for multi-collinearity (Table S2). Covariates with $r \leq 0.75$ were either removed or not used in combination within the same model. For example: distance from the human settlement and elevation were not used in combination due to high correlation between the variables ($r = 0.90$). Similarly, the proportion of SE-MMD and SC forest type were not used in the combination during model building.

We retained the variables that better explained the parameter of interest based on: ecological relevance, correspondence with earlier studies, ease in data collection across the study areas, and simplest in explanation of the model outcomes (parsimony). Prior to modelling, all continuous site covariates were scaled, $(x - \bar{x})/SDx$, to facilitate estimation of parameters using numerical optimization techniques and to make estimates comparable between parameters (Sunarto et al. 2012; Nath et al. 2019b; Jornburom et al. 2020).

We used package *RPresence* (that explicitly took spatial autocorrelation into account) and *unmarked* in R v. 4.0.2 to carry out the analysis. The spatial dependence models estimate four parameters, even without covariates (Hines et al. 2010), and given our sample size, we considered it likely that models containing covariates might fail to converge. Therefore, we fitted the spatial-autocorrelation model without the covariates and used the results to determine the cumulative segment length at which detection of the focal species ceased to be dependent on the preceding segment as mentioned above. In model building, first, we modeled detection probability (p) by varying candidate detection models. We explored covariate (substrate, presence of livestock, and effort) effects on detectability while holding the site covariates for occupancy constant. Using the best-fitted detection probability model, we modeled site use probability based on the information-theoretic approach (or a priori hypothesis) by varying combinations of covariates. We only used combinations of covariates as additive effects in the models. Interaction models were not used due to the complexity of general covariates to model different species without prior information on their distribution (Thapa and Kelly 2017). Finally, we ranked all models using Akaike's Information Criterion (AIC) and selected the best model based on the lowest AIC values. We considered all models with $\Delta AIC < 2$ as competing models (Burnham and Anderson 2002) and examined the β coefficient and model averaged β estimates of the covariates to test the significance of their effect on detection and occupancy probability.

The low detection of gaur (600 m replicates following Thapa and Kelly 2017) in our studied sampling (naïve occupancy = 0.13; presence noted on 10 grids out of 75 samples) grids has resulted in numerically unstable measures. Previously this issue was well addressed for detection/occupancy probability is small or when the number of sites and number of visits per site is small (Moreno and Lele 2010). Hence, for gaur specifically, we used the Bayesian approach to estimate occupied habitat since the results using maximum likelihood estimators were numerically unstable. We conducted all computationally intensive model fitting necessary for Bayesian inference using MCMC sampling via packages *R2jags* and *rjags* in R statistical software to run the occupancy models (Plummer 2003, Su and Yajima 2012). We used the uniform priors for probability of detection $p \sim \beta(1,1)$ and occupancy probability $\psi \sim \beta(1,1)$.

Uninformative-uniform priors are defined by the log-odds interval $[-5, 5]$ for all parameter distributions with three chains of 10,000 iterations each. As we are working on the logit scale and we have standardized the predictors (site covariates) to have $SD = 1$, therefore it would be highly unlikely if coefficients were outside the range ± 5 . Further, based on the calculation, we assessed model convergence using the $\hat{R}$ value (closer to 1.0, indicating a more plausible convergence) and from a visual inspection of chain trace plots (Link et al. 2012; see Fig. S2). We selected the final model based on the lowest DIC value since DIC has been widely used to rank hierarchical models based on their anticipated predictive performance, and it remains one of the most commonly used approaches for ranking models in the Bayesian context (Gelman et al. 2014; Barker and Link 2015; Hooten and Hobbs 2015). In addition, comparisons of Bayesian model selection methods for hierarchical models often include DIC, despite its limitations (e.g., Hooten and Hobbs 2015).

Finally, we estimated (projected for 144 grids= 576 km²) occupancy for all the ungulate species and intensive habitat use maps of elephant, gaur, and leopard based on inferences made from the model (with lowest AIC and DIC value) outputs in ArcGIS 10.4. To estimate the overall occupancy and habitat use of studied species within the Ripu RF (144 grids), we weighed the cell-specific occupancy estimates within each grid cell (4 km²) (Thapa and Kelly 2017). Further, to evaluate the status of illegal activities, we compared the number of confiscated materials and reports of hunting and poaching activities taken place in the previous years with the present effort.

Results

Spatial independence

Ungulate species < 4 km² home range, we compared the standard MacKenzie et al. (2002) occupancy model with the Hines et al. (2010) model that explicitly addresses spatial dependence of sign detections made along adjacent (0.1-1.2 km) spatial replicates. We found negligible evidence for spatial dependence of sign detections using 500 m spatial replicates for sambar [$\hat{\theta}=0.154$ (SE 0.048, 0.081-0.274 at 95% CI) and $\hat{\theta}'=0.341$ (SE 0.074, 0.213-0.497)] and spotted deer [$\hat{\theta}=0.056$ (SE 0.026, 0.021-0.137) and $\hat{\theta}'=0.659$ (SE 0.185, 0.276-0.907 at 95% CI)], and 800 m spatial replicates for barking deer [$\hat{\theta}=0.157$ (SE 0.152, 0.019-0.639 at 95% CI) and $\hat{\theta}=0.845$ (SE 0.082, 0.612-0.950 at 95% CI)] (Table S3). Instead, wild pigs were found to have a high degree of overlap in all the different adjacent segments (Table S3). Therefore, the model was built with 600 m [$\hat{\theta}=0.686$ (SE 0.190, 0.278-0.925 at 95% CI) and $\hat{\theta}'=1$ (SE 2.4×10^{-5} , 0-1 at 95% CI)] replicates (following Thapa and Kelly 2017) using the spatial dependence model of Hines et al. 2010.

On the other hand, for the large-ranging mammals (elephant and leopard) we carried out a spatial dependence model (Hines et al. 2010) at 600 m spatial replicates and compared it with the null model (MacKenzie et al. 2002). The estimates of the Hines et al. (2010) model demonstrated a high degree of spatial dependence between replicates (Table S3) for elephant [$\hat{\theta}=1$ (0-1 at 95% CI) and $\hat{\theta}'=0.930$ (SE 0.053, 0.729-0.984 at 95% CI)]. However, for leopard spatial dependence was minimal [$\hat{\theta}=0.137$ (SE 0.039, 0.076-0.234 at 95% CI) and $\hat{\theta}'=0.548$ (SE 0.249, 0.144-0.897 at 95% CI)]. Moreover, the range of detection probability measures using spatial dependence (null model, Hines et al. 2010) model was not stable (0.651 ± 0.329 , 0.097-0.969 at 95% CI) compared to standard (null model, MacKenzie et al. 2002) occupancy model (0.254 ± 0.046 , 0.173-0.357 at 95% CI). Therefore, for leopard we used standard occupancy model and for elephant we performed further analyses using the Hines et al. (2010) model to assess the intensive habitat use.

Detection Probability

Sign detection probabilities were found to vary for leopard, spotted deer, barking deer and to some extent for elephant either due to the presence of livestock or substrate condition. Whereas, varying efforts (in km) made on each grid to record signs had no influence on detectability on the studied species (Table S4). Spotted deer sign detection probability was found to be significantly affected by the presence of livestock (Fig. 3). The probability of detection drops to $\hat{p} = 0.0468 \pm 0.0465$ (SE) in the presence of livestock compared to its absence $\hat{p} = 0.29 \pm 0.05$ (SE).. Similarly, the presence of cattle also had negative impact on the detection of elephant [presence of livestock, $\hat{p} = 0.75 \pm 0.08$ (SE); absence of livestock, $\hat{p} = 0.86 \pm 0.05$ (SE)] and leopard [presence of livestock, $\hat{p} = 0.09 \pm 0.05$ (SE); absence of livestock, $\hat{p} = 0.29 \pm 0.05$ (SE)]. We reasoned a priori that sign detection probabilities could be low in grid cells with more livestock presence, as opposed to grid cells with minimal livestock activity. In contrast, the probability of sign detection of barking deer [$\hat{p} = 0.76 \pm 0.12$ (SE)] was high on substrate bearing leaf litters and significantly low for leopard signs [$\hat{p} = 0.073 \pm 0.074$ (SE)] compared to other substrates (Fig. 3). Therefore, we used the effect of livestock presence on detection probability to examine habitat occupancy of spotted deer and elephant and substrate type on barking deer. Whereas, the additive effect of the sign detectability on the presence of livestock and substrate type for leopard. For all other studied species *viz.*, sambar, wild pig and gaur, we used constant detection $p(.)$ probability while building habitat occupancy models.

Influence of covariates on occupancy probability and habitat use

Using the best-fitted detection probability model, we modeled site use probability based on the information-theoretic approach. The best predictive models on occupancy and habitat use for each species, including a complete set of models and estimates of regression coefficients in these models, are found in tables 2- 4. The influence of covariates on occupancy probability of studied species shown in figures 4 & 5. The best model for sambar revealed that distance to human settlements (DHS) was the strongest (β estimate: 1.28 ± 0.44) ecological correlate predicting habitat use; probability of occupancy > 0.5 began at > 7 km from human settlements. The proportion of semi evergreen and moist-mixed deciduous (SE-MMD) had a positive [$p(.)\psi(\text{SE-MMD})$ β estimate: 0.73 ± 0.36] influence on the occurrence probability of sambar. However, the second rank model showed that grids near to human settlements even with a high proportion of SE-MMD had negative influence on the occurrence probability (β estimate: -0.21 ± 0.63).

For spotted deer, there was a single best model with 48% AIC weight. The strongest ecological correlate was a negative response to anthropogenic activity (AA β estimate: -0.88 ± 0.41) and quadratic effect (SDF² β estimate: -0.88 ± 0.48) proportion of secondary degraded forest. Initially, the probability of occupancy increases with the increase in the proportion of SDF, however, declines are marked once the proportion of SDF measures greater than 0.3. In case of barking deer, DHS was found to have a quadratic effect (DHS² β estimate: -1.15 ± 0.57) on the occurrence probability with 46% AIC weight. The second ranked model also showed positive response to the distance to human settlements. For Wild pig, the first top two best model showed negative response towards anthropogenic activity (AA β estimate: -0.64 ± 0.39) and distance from water sources (DWS β estimate: -0.55 ± 0.33). The cumulative AIC weight of first two model was 47%. On the other hand, proportion of SE-MMD was found to positively influence the habitat use of gaur in the study area. Whereas, for elephant habitat use DHS, DWS had positive and SDF had negative response. The cumulative best top three model had an AIC weight of 46%. However, all these covariates have very weak effect on habitat use.

For leopard, additive effects of prey occupancy and proportion of secondary degraded forest was the best model followed by proportion of semi evergreen and moist-mixed deciduous forest type. The first three top-ranked model ($\Delta\text{AIC}>2$) had cumulative AIC weight of 58%. Prey occupancy (PREY β estimate: 4.80 ± 3.20) and semi evergreen & moist-mixed deciduous forest (SE-MMD β estimate: 1.33 ± 0.67) had positive impact and proportion of secondary degraded forest (SDF β estimate: -1.19 ± 0.68) had negative impact on the habitat use probability of leopard.

In addition, grids with more than 50% of SE-MMD forest were also found to have leopard habitat probability of more than 50%.

Estimates of occupancy and habitat use probability

Ungulates with small to medium body size, in the sampled grids, Barking deer has the highest occupancy probability [$\hat{\psi}$ SE($\hat{\psi}$): 0.87 (0.008)] followed by wild pig [$\hat{\psi}$ SE($\hat{\psi}$): 0.53 (0.02)], Sambar [$\hat{\psi}$ SE($\hat{\psi}$): 0.45 (0.03) and spotted deer [$\hat{\psi}$ SE($\hat{\psi}$): 0.37 (0.02)] For all these four species the estimated occupancy probability is higher than the naïve estimates (Table 5). For the non-sampled grid cells, we used covariate information to draw inference using the best model. Except for spotted deer, the projected occupancy estimates produced lower but similar occupancy measures for other three species (Table 5). On the other hand, for large ranging mammals, the habitat use probability is very high for Asian elephant [$\hat{\psi}$ SE($\hat{\psi}$): 0.98 (0.002)] followed by leopard [$\hat{\psi}$ SE($\hat{\psi}$): 0.63 (0.02)] and Gaur [$\hat{\psi}$ SE($\hat{\psi}$): 0.13 (0.009)] and similar to non-sampled grids. Finally, we generated predicted occupancy map for the entire study area (Figs. 6 & 7).

Community patrol

Conservation volunteers actively participated in the patrolling alongside forest department to strengthen the protection measures. Apart from routine daily patrolling, conservation volunteers additionally carried out 1260 hrs. of night patrol, 400 hrs of day patrol when informed on particular anthropogenic activity in the study area. In addition, ~250 km of motor-bike patrolling was done in the Athiabari Range and 300 km of patrolling made using four-wheeler vehicle along with the Forest department in the Central range of Ripu. The specific outcome of the patrolling effort was as follows- a total of 225 logs (mostly Sal), 36 bicycles, 25 bullock carts, and four vehicles were seized loaded with logs; two poachers caught with guns and five hunting machan was damaged during patrolling (Table S5, Fig S3). We also noted that the majority of the fuel-wood extraction had occurred in the western part of the Ripu R.F. and logging activities were seen to be scattered due to selective logging of sal trees.

Community development

Conservation volunteers get a nominal amount from the forest department as remuneration which was not adequate to incur their family expenses. Additional under this study, conservation volunteers (n= 100) were also provided with daily wages for a year during the study period (total of 200000 INR). As mentioned here since they were supported

only for a year, for long term sustenance we decided to support their family members through sustainable income generating livelihood activities based on the skills they possess. So in order to initiate the process we constituted three Village Development Committee (VDC) in Kachugaon, Raimona and Jambuguri area in the southern boundary of the study site. Subsequently, we conducted a consultation workshop in order to assess the skill and their willingness for preferred livelihood activities of the family members of conservation volunteers. Based on the information gathered, livestock rearing was found to be the preferred livelihood activity. We could assess that since 90% of the families were indigenous tribes who traditionally have the skills to rear livestock they expressed their willingness for piggery and dairy. So, to further enhance their skills, we had conducted six training programme on piggery and dairy farming with the help of professionals. In order to enhance the livelihood of the conservation volunteers, 29 members were provided with Dairy (one heifer each), 71 members provided with piggery (two piglets each). At the beginning the families of conservation volunteers were earning around ~2000 INR month⁻¹ but now after our intervention in 2014 their monthly income had gradually increased to on an average ~11000 INR month⁻¹ (9-10 liter day⁻¹ milking cow⁻¹) beneficiaries associated with dairy as per our assessment in 2018 and it is still continuing. In case of beneficiaries associated with the piggery earned ~44000 INR year⁻¹. Furthermore, to boost their motivation, an exposure trips to Khonoma, Nagaland and Sijusa, Arunachal Pradesh (India) was organized for conservation volunteers to educate and sensitize them on the role of local communities in the protection and conservation of forest. As both these sites in northeastern part of India has gained appreciation for community conservation practices and sustainable tourism. Apart from handheld GPS training, the members were also provided with camera, binocular and field guides (on butterflies, birds, reptiles and mammals) to generate awareness on biodiversity monitoring, protection and conservation.

Discussion

Understanding species-habitat relationships and impacts of anthropogenic factors on species site use patterns is a key to prioritize conservation actions. In Ripu, for the first time, we used the statistically robust occupancy modelling approach to examine site occupancy and intensive habitat use of mammals. We were able to document that Ripu has the potential to hold primary prey for large carnivores like tigers and leopards along with mega-herbivores like gaur and elephant. As hypothesized, studied mammalian fauna showed varied but species-specific responses to ecological and anthropogenic factors. Species responded variably to different covariates, indicating a need to consider

management actions according to the relative importance of species as per conservation requirements. This implies that although conservation paradigm has shifted towards landscape-level conservation (Bhattarai et al. 2017), species conservation approach is equally vital and consideration of species-specific habitat requirements is paramount to successful conservation planning.

The present study used tracks and sign detection for occupancy survey. Therefore, the underlying ecological processes that regulate distribution and habitat associations of ungulates and predator species can be unnoticed without estimating detection probability, especially when surveys are conducted using animal signs. Had we not modeled sign detection, we would have underestimated the negative impact of livestock on spotted deer, leopard and to some extent elephant on detection probability. Similarly, as expected, substrate type influenced the detectability of leopard signs and detection probability was low where substrate dominated by leaf litter. In the case of barking deer, the high probability of detection in leaf litter is associated with the preference towards dense vegetation, and this species avoids open areas like river beds for their movement. Henceforth, by estimating detection, we increased our estimate of occupancy for most of the studied species and reduced bias in predicting occupancy (Tyre et al. 2003; Rota et al. 2011; Lahoz-Monfort et al. 2014). Our occupancy estimate revealed that barking deer was the most widely distributed medium-sized prey in Ripu habitat followed by wild pig, sambar, and spotted deer. As expected, high human activities in the forest edges bordering human settlements have a low occurrence probability of sambar and barking deer. Both of these species prefer dense vegetation (Chapman et al. 1994; McCullough et al. 2000), and majority of the degraded areas are adjacent to human settlements in our study area. The forest areas adjacent to human settlements experience prolonged pressure from various anthropogenic activities (grazing, resource extraction, hunting) compared to areas bordering Phibsoo WLS in the north. Previous studies also showed that sambar increased with increasing distance to human settlements, supporting our findings that the species is sensitive to disturbance (Kushwaha et al. 2004).

Spotted deer are habitat generalists (Schaller 1967). Their distribution in Ripu is associated with the initial increase in proportion of secondary degraded forest and negative response with an increase in anthropogenic pressure within grid cells. However, it was also observed that the probability of occupancy declines in the grid cells where proportions of secondary degraded forests measure doubles. Previous studies from Terai (Chauria, Nepal) region showed mixed-moist deciduous forests limit the distribution of this species (Thapa and Kelly 2017). However, the majority of wild ungulate density in Indian forests is contributed by spotted deer (Khan 1995; Sankar 1994; Bagchi et al. 2003). The species limit its distribution in the western Assam, and last remaining population was Ripu & Chirang

RF, and recently photographic evidence was also found from further east in Panbari, Manas National Park (Bhatt 2018). Though this species is a key prey for large predators like the tiger, leopard, and dhole (Schaller 1967), we witnessed frequent hunting incidents (Fig. S3). The wild pig is a generalist species (Bratton 1975) with a highly plastic diet contributing to their wide distribution (Ballari and Barrios-García 2014). The positive association with water bodies in our study area could be associated with vegetation it feeds on. During winter, above-ground resources may get scarce, and pigs might rely on rooting, which can be more easily accessible to nearby water bodies. Hunting wild pigs using snares and other accessories are common in the region (pers. obs.), and the meat has high demand in this belt of India. Hence, wild pigs' occupancy estimate is negatively associated with the anthropogenic activity in the study area. However, studies also stated that the species is particularly resilient to hunting pressure due to its high reproduction rate (Choquenot et al. 1996; Pepin et al. 2017).

As expected, the leopard habitat use was governed by the cumulative prey occupancy and proportion of available SE-MMD forest types. Though leopard is a broadly distributed large carnivore adapted to a multitude of habitats and to some extent lenient to human-induced anthropogenic pressure (Athreya et al. [2016](#)). In Ripu, the species showed a negative response towards degraded forest adjacent to human settlement and predictive occupancy probability showed that the species were mostly confined to areas bordering Phibsoo WLS. Besides our study, a camera trapping exercise carried out in Phibsoo WLS in the same year (2014) reported that leopard was one of the most common out of six species of felids they recorded (Anonymous 2018). The study also recorded tigers on nine occasions at six camera trapping stations of Phibsoo. Most of these captures were from bordering Ripu RF in the lower and middle foothills zone. In Terai region, mainly in the foot-hills of the Himalayas, leopards coexist with tigers in the protected and buffer zone areas. In the absence of a tiger, the positive influence of prey has indicated the importance of wild ungulates in minimizing human-leopard conflict. Despite the high adaptability of leopards, they require a comparatively large area with abundant prey for survival, thus, threatened by prey depletion, poaching, landscape fragmentation, and conflict with humans (Athreya et al. [2011](#); Crdillo et al. [2005](#); Kissui [2008](#)).

The overall occurrence probability of gaur was low in the study area and mostly confined to areas in which proportion of semi-evergreen and moist-mixed deciduous forest was high. Compared to all other studied species, the probability of detection was also very low in our study area. Previous studies from the adjacent landscape stated that proximity to human settlement negatively influences the occurrence probability of gaur (Zangmo et al. 2018). Observations of senior forest frontline staffs indicated that gaur was indeed widespread in the Ripu and adjacent areas

before insurgency (pers. com.). Habitats in our study area vary in terms of vegetation type and intensity of anthropogenic pressure. The habitat use of elephants is much more complex than we observed. Although elephants used all the available habitats (naïve occupancy = 96%) in the study area, detection probability was low in grids, where cattle presence is high. Fine-scale habitat use parameters are vital to individual protected area managers seeking to recover habitat conditions for elephants (Buij et al. 2007; Lakshminarayanan et al. 2016). Irrespective of high anthropogenic pressure, the elephants were bound to use the forest of Ripu since the northern side (Phibsoo WLS, Bhutan) has rugged mountainous terrain, and the eastern part of the land highly encroached. Permanently bifurcates Chirang and Manas RF. Our current study and other studies elsewhere specify that Asian elephants are sensitive to human activities (Goswami et al. 2014; Jathanna et al. 2015). However, there were reports of crop-raiding (mostly paddy) of elephants, during winter months: October to December.

Sign-based occupancy survey is the only practical assessment strategy found applicable since anthropogenic activity is too high and movement of people is not restricted in the study area. The site also lacks permanent anti-poaching camps/guard camps inside, unlike the core of the Tiger Reserve (i.e., Manas National Park) to monitor cameras regularly. Although, monitoring programs are often criticised for a dearth of scientific rigour, arising out of poor design or insufficiently robust statistical analysis (Mattfeldt et al. 2009). Our current study specifically accounts for both imperfect detection and robust spatial autocorrelation measures at different segment lengths. However, we could not address false positive detection for leopard signs (only for scats) since a study (Naha et al. 2020) claimed that scat identified in the field has an error rate of 50–80%. Moreover, species identification using genetic analysis was beyond the scope of the study since resources were limited. Therefore, in future, we recommend systematic camera trap studies to identify elusive and nocturnal mammals in the study area. However, field observations and personal communications with forest frontline staff revealed 25 species mammals from Ripu RF (Table S6). We would also like to highlight a few limitations: the species-specific responses we observed could thus be different during the summer season when forage quality and quantity are generally abundant for ungulates, and water is not a limiting factor. Studies looking at seasonal responses to ecological factors would improve our understanding of habitat use of these species.

Like most other societal challenges, conserving natural resources during conflict (insurgency) is complex and case-specific. In the case of Ripu, biodiversity suffers from the general breakdown in both law and infrastructure that facilitated various anthropogenic activities. Along with the cattle grazing, fuel wood collection and poaching,

selective logging of sal trees was one of the key illegal activities in the study area. Prior to 1992 no logs were sized by the Assam Forest Department. It was all started after the formation of Bodoland Protection Force, and subsequently, they confiscated all the materials associated with illegal activities. The estimated value of these materials was of USD 100,000 (for details, see Howrich et al. 2010). In the present study (Jan 2014 to June 2015), the number of confiscated materials was low compared to previously reported during Nov 2006 to 2008. Looking at this massive destruction, apart from community vigilance, forest department needs to take immediate action to set up anti-poaching camps in strategic locations to ensure security for wildlife and its habitat.

Conservation Implications

In recent years, the government of India has encouraged community participation in the conservation process (Pathak, 2002). Therefore, community co-management can be the solution to involve communities as influential partners in protecting wildlife and its habitat, which is being searched for by various governments and NGOs (Borrini-Feyerabend et al. 2004). Prohibiting cattle grazing within the Ripu would decrease forage competition and increase habitats for wildlife. Our community-based conservation initiatives could encourage stall feeding of livestock and address illegal activities in RF, but such programs require continuous government incentives. Similarly, our approach towards alternative livelihood support (piggery and dairy farming) can only be effective if the government and other agencies continue to generate funds and encourage locals till they self-sustain. Other anthropogenic activities, such as the collection of NTFPs, especially fuelwood, are often linked to fishing and hunting. To engage more people, ecotourism was thought to be one sector that was not well explored due to ethnic violation in the region. However, we provided exposure to the youths and tried to motivate them for sustainable tourism activities in the region as an alternative livelihood opportunity. Another option would be to include more local villagers as a part of an effort to strengthen and broaden GPS-patrolling in the region. Given that Ripu-Chirang Elephant Reserve is the viable source population of elephants in mainland Southeast Asia, combining the current top-down approach of GPS patrol with bottom-up community participation appears to be a hopeful strategy for elephant, tiger, co-predator, and prey's recovery across the region. In India, National Tiger Conservation Authority (NTCA) have already implemented M-STripES (an app-based platform to assist effective patrolling, evaluate ecological status and mitigate human-wildlife conflict in and around tiger reserves). We recommend that Assam Forest Department actively implement the same in Ripu to ease decision-making and adaptive management. Moreover, the Indian Government Border Security Force has already established camps in Kachugaon, Ripu, and Chirang Reserve Forests. The Security Force is an armed central

government paramilitary force whose command is to control illegal activities in the Indian border areas. They helped forest department to intercept illegal logging in areas around their camps and in future joint patrolling can help further regulating the illegal activities in Ripu.

Ripu is on the road to recovery, and recently (June 5, 2021), a major portion (422 km²) of the reserve forest was declared as Raimona National Park. This extended favourable social and political climate and widespread support for conservation activities would help secure the biodiversity of this region, and the local community may benefit from the same. Our study revealed that Ripu has a high proportion of occupied area by prey species of large carnivores. Recently (February 2020), a tiger has been camera trapped in Ripu bordering Phibsoo WLS (Goswami 2020). Additionally, tiger and elephant harboring in Bhutan (Phibsoo WLS), West Bengal (Buxa Tiger Reserve), and Assam (Chirang RF) are interconnected by Ripu, which provides continuous forest cover at the landscape scale for elephant, tigers, and other ungulates. The contiguous land cover patches of the Ripu also likely to provide a hospitable habitat for dispersing among source sites (Manas and Royal Manas NP) and recovery sites (Buxa Tiger Reserve) within Tiger Conservation Landscape India and Bhutan. It is worth noting that the year-long tiger estimation process carried out in 2018-19 by National Tiger Conservation Authority (NTCA) did not record any presence of the tiger in Buxa TR (Jhala et al. 2019). On the other hand, to resolve insurgency, the Indian government signed a “peace” accord on January 27, 2020, with all the factions of rebels running in the BTAD region of Western Assam. The accord reportedly incorporated a number of political and economic actions designed to strengthen the autonomy of the Bodoland Territorial Area District (BTAD), now renamed as Bodoland Territorial Region (BTR). Besides, 1,615 rebels across the Bodo factions formally surrendered. Subsequently, collective efforts of Assam Forest Department, Bodoland Territorial Council, regional to international organizations, educational institutes, and local communities with stakeholders at a number of levels need to bridge the gap for the long-term conservation of Ripu. In the meantime, activities like education and outreach initiatives can play a vital role in promoting positive attitudes among various communities living adjacent to the area. Livelihood is also a major issue in this conflict driven landscape. There are not much livelihood opportunities for local communities other than daily wage earning or extracting resources from the forest and agricultural land being limited. Thus it is very important to address the livelihood issue in order to boost conservation actions and enhance community participation. Hence, activities that encourage community participation and further strengthen forest officials and conservation volunteers would be the key to securing the threatened habitat of Ripu.

Acknowledgment

We would like to thank Assam Forest Department for their immense support to carry this work and US Fish & Wildlife Service for the funding. We are thankful to the members of the Green Forest Conservation NGO, Kachugaon for their support in the field. Our sincere thanks to all the members of Aaranyk for their support in the overall implementation of the study. The first author is thankful to Ranjana Pal (Wildlife Institute of India) and Arundhooity Mohanty (Central Zoo Authority, India) for their comments and suggestions on the final draft.

References

- Anonymous (2018) Biodiversity Baseline Assessment: Phibsoo Wildlife Sanctuary in Bhutan. ISBN 978-92-9261-374-7 (print), 978-92-9261-375-4 (electronic) Publication Stock No. TCS189223 DOI: <http://dx.doi.org/10.22617/TCS189223>
- Athreya V, Odden M, Linnell JDC, Karanth KU (2011) Translocation as a tool for mitigating conflict with leopards in human-dominated landscapes of India. *Conserv Biol* 25:133–141
- Athreya V, Odden M, Linnell JDC, Krishnaswamy J, Karanth KU (2016) A cat among the dogs: Leopard (*Panthera pardus*) diet in a human-dominated landscape in western Maharashtra, India. *Oryx* 50:156–162
- Bagchi S, Goyal SP, Sankar K (2003) Prey abundance and prey selection by tigers (*Panthera tigris*) in semiarid dry deciduous forest in Western India. *J Zool* 260(3):285–290
- Ballari S, Barrios-Gracia M (2014) A review of wild boar *Sus scrofa* diet and factors affecting food selection in native and introduced ranges. *Mamm Rev* 44: 124-134
- Barber-Meyer SM, Jnawali SR, Karki JB, Khanal P et al (2013) Influence of prey depletion and human disturbance on tiger occupancy in Nepal. *J Zool* 289:10–18
- Barker RJ, Link WA (2015) Truth, models, model sets, and multimodel inference: a Bayesian perspective. *J Wildl Manage* 79:730–738

- Barman R, Choudhury B, Asraf NVK, Menon V (2014) Rehabilitation of greater one-horned rhinoceros calves in Manas National Park, a World Heritage Site in India. *Pachyderm* 55:78–88
- Barnes RFW (2001) How reliable are dung counts for estimating elephant numbers? *Afr J Ecol* 39:1–9
- Baruah S (1999) *India Against Itself: Assam and The Politics of Nationality*, Oxford University Press, New Delhi
- Bhatt UM, Habib B, Lyngdoh S (2018) Chital: Photographic evidence of *Axis axis* after two decades in Manas National Park, Assam, India. *Zoo's Print* 33(8):5–8
- Bhattarai S, Pant B, Timalisina N (2017) Conservation without Participation: Detrimental Effects of Escaping People's Participation in Protected Area Management in Nepal. In Mukul SA, Rashid AZMM “Protected Areas: Policies, Management, and Future Directions (pp.83–103)”.
- Borah J, Sharma T, Das D, Rabha N, Kakati N, Basumatray A, Ahmed MF, Vattakaven J (2014) Abundance and density estimates for common leopard *Panthera pardus* and clouded leopard *Neofelis nebulosa* in Manas National Park, Assam, India. *Oryx* 48(1):149–155. DOI:[10.1017/S0030605312000373](https://doi.org/10.1017/S0030605312000373)
- Borrini F, Eyarabend G, Pimbert M, Farvar MT, Othari K, Renard Y (2004) *Sharing Power: Learning by Doing in Co-management of Natural Resources Throughout the World*. IIED and IUCN/CMWG, Cenesta, Tehran, Iran.
- Borthakur M (1986) Weather and Climate of North East India. *North-Eastern Geographer* 18 (1&2):20–27
- Brahmachari D (2019) Ethnicity and Violent Conflicts in Northeast India: Analysing the Trends. *Strategic Analysis* 43(4):278–296. DOI: [10.1080/09700161.2019.1623497](https://doi.org/10.1080/09700161.2019.1623497)
- Bratton SP (1975) The effect of the European Wild Boar, *Sus scrofa*, on Gray Beech Forest in the Great Smoky Mountains. *Ecology* 56(6):1356–1366
- Buij R, McShea WJ, Campbell P, Lee ME, Dallmeier F, et al (2007) Patch-occupancy models indicate human activity as major determinant of forest elephant *Loxodonta cyclotis* seasonal distribution in an industrial corridor in Gabon. *Biol Conserv* 135:189–201
- Burnham KP, Anderson DR (2002) *Model selection and multimodel inference: a practical informationtheoretic approach*, 2nd edn. Springer, New York

Carbone C, Gittleman JL (2002) A common rule for scaling of carnivore density. *Science* 295(5563): 2273–2276.

DOI: 10.1126/science.1067994

Chaiyarat R, Srikosamatara S (2009) Populations of domesticated cattle and buffalo in the Western Forest Complex of Thailand and their possible impacts on the wildlife community. *Journal of environmental management* 90(3):1448–1453

Chapman N, Harris S, Stanford A (1994) Reeves' Muntjac *Muntiacus reevesi* in Britain: their history, spread, habitat selection, and the role of human intervention in accelerating their dispersal. *Mamm Rev* 24:113–160

Chapman N, Harris S, Stanford A (1994) Reeves' Muntjac *Muntiacus reevesi* in Britain: their history, spread, habitat selection, and the role of human intervention in accelerating their dispersal. *Mamm Rev* 24:113–160

Choquenot D, McIlroy J, Korn T (1996) Managing vertebrate pests: Feral pigs. Bureau of Resource Sciences, Australian Government Publishing Service, Canberra.

Crdillo M, Mace GM, Jones KE, Bieby J, Bininda-Emonds OFP, et al (2005) Multiple Causes of High Extinction Risk in Large Mammal Species. *Science* 309(5738):1239–41

Dinerstein E (1980) An ecological survey of the Royal Bardia Wildlife Reserve, Nepal. Part III: Ungulate Populations. *Biol Conserv* 18:5–38

Duangchantrasiri S, Umponjan M, Simcharoen S, Pattanavibool A, et al (2015) Dynamics of a low-density tiger population in Southeast Asia in the context of improved law enforcement. *Conserv Biol* 30(3):639–648.
doi.org/10.1111/cobi.12655

Dutta A (2020) Forest becomes frontline: Conservation and counter-insurgency in a space of violent conflict in Assam, Northeast India. *Polit Geogr*:102117

food selection in native and introduced ranges

Gelman A, Hwang J, Vehtari A (2014) Understanding predictive information criteria for Bayesian models. *Stat Comput* 14:997–1016

Goswami R (2020) Royal Bengal tiger sighted in Ripu reserve forest. *The Telegraph*

<https://www.telegraphindia.com/north-east/royal-bengal-tiger-sighted-in-ripu-reserve-forest/cid/1749254>

Goswami VR, Vasudev D, Oli MK (2014) The importance of conflict-induced mortality for conservation planning in areas of human–elephant co-occurrence. *Biol Conserv* 176:191–198

Gray TN, Phan C (2011) Habitat preferences and activity patterns of the larger mammal community in Phnom Prich Wildlife Sanctuary, Cambodia. *Raffles Bull Zool* 59(2):311–318

Hanson T, Brooks TM, Fonseca GABD et al (2009) Warfare in Biodiversity Hotspots. *Conserv Biol* 23(3):578–587

Harihar A, Pandav B (2012) Influence of Connectivity, Wild Prey and Disturbance on Occupancy of Tigers in the Human-Dominated Western Terai Arc Landscape. *PLoS ONE* 7(7): e40105. doi:10.1371/journal.pone.0040105

Hedges S (2012) Estimating elephant population density and abundance from dung pile density: theoretical concepts. In: Hedges, S (Ed). *Monitoring elephants and Assessing Threats: A Manual for Researchers, Managers and Conservationists*. University Press (India) Private Limited, Himayatnagar, India

Hilaluddin, Sharma K (2008) Survey of three divisions of Bodoland Territorial Council for addition into protected area network. In V. Menon, R. Kaul, R. Dutta, NVK. Ashraf & P. Sarkar (Eds). *Bringing Back Manas-Conserving the forest and wildlife of Bodoland Territorial Council*. Pp. 66-84. New Delhi, Wildlife Trust of India.

Hines JE, Nichols JD, Royle JA, MacKenzie DI, Gopalaswamy AM, Samba Kumar N, Karanth KU (2010) Tigers on trails: occupancy modelling for cluster sampling. *Ecol Appl* 20:1456–1466

Hobbs NT (1996) Modification of ecosystems by ungulates. *J Wildl Manag* 60:695–713

Hooten MB, Hobbs NT (2015) A guide to Bayesian model selection for ecologists. *Ecol Mongr* 85:3–28

Horwich, R. H., R. Islari, A. Bose, B. Dey, M. Moshahary, N.K. Dey, R. Das, J Lyon 2010. Community protection of the Manas Biosphere Reserve in Assam, India, and the endangered golden langur *Trachypithecus geei*. *Oryx* 44(2): 252–260

Horwich RH, Das R, Bose A (2013) Conservation and the Current Status of the Golden Langur in Assam, India, with Reference to Bhutan. *Primate Conservation* 27:77-83. DOI: <http://dx.doi.org/10.1896/052.027.0104>

Hull V, Zhang J, Huang J et al (2016). Habitat use and selection by giant pandas. *PLoS One* 11: e0162266

IUCN (2021) Conflict and conservation. Nature in a Globalised World Report No.1. Gland, Switzerland: IUCN. ISBN: 978-2-8317-2115-6 (PDF) DOI: <https://doi.org/10.2305/IUCN.CH.2021.NGW.1.en>

Jarvis A, Reuter HI, Nelson A, Guevara E (2008) Hole-filled seamless SRTM data V4, International Centre for Tropical Agriculture (CIAT), available from <http://srtm.csi.cgiar.org>.

Jathanna D, Karanth KU, Kumar NS, Karanth KK, Goswami V R (2015) Patterns and Determinants of Habitat Occupancy by the Asian Elephant in the Western Ghats of Karnataka, India. PLoS ONE 10(7):e0133233

Jathanna D, Karanth KU, Kumar NS, Karanth KK, Goswami VR (2015) Patterns and Determinants of Habitat Occupancy by the Asian Elephant in the Western Ghats of Karnataka, India. PLoS ONE 10(7): e0133233. doi:10.1371/journal.pone.0133233

Jhala YV, Qureshi Q, Nayak AK (2019) Status of tigers, co-predators and prey in India 2018. Summary Report. National Tiger Conservation Authority, Government of India, New Delhi & Wildlife Institute of India, Dehradun. TR No./2019/05

Johnson DH (1980) The comparison of usage and availability measurements for evaluating resource preference. Ecology 61:65–71

Jornburom P, Duangchantrasiri S, Jinamoy S, Pattanavibool A, Hines JE, et al. (2020) Habitat use by tiger prey in Thailand's Western Forest Complex: What will it take to fill a half-full tiger landscape? J Nat Conserv 58:125896

Karanth KU, Sunquist ME (1992) Population Structure, density and biomass of large herbivore in the tropical forests of Nagarhole, India. J Trop Ecol 8:21–35

Kendall WL, White GC (2009) A cautionary note on substituting spatial subunits for repeated temporal sampling in studies of site occupancy. J Appl Ecol 46:1182–1188

Khan S (1995) Study on Sympatric Herbivores (Sambhar, Chital and Nilgai) with Special Reference to Conservation Strategies in Darrah Wildlife Sanctuary, Rajasthan, India. Ph.D. thesis, University of Kota, Kota. 229 pages.

Kissui BM (2008) Livestock Predation by Lions, Leopards, Spotted Hyenas and Their Vulnerability to Retaliatory Killing in the Maasai Steppe, Tanzania. Anim Conserv 11:422-432. doi.org/10.1111/j.1469-1795.2008.00199.x

Kushwaha SPS, Khan A, Habib B, Quadri A, Singh A (2004) Evaluation of sambar and muntjak habitats using geostatistical modelling. *Curr Sci* 86:1390–1400

Lahoz-Monfort JA, Guillera-Arroita G, Wintle BA (2014) Imperfect detection impacts the performance of species distribution models. *Global Ecol Biogeogr* 23: 504–515

Lakshminarayanan N, Karanth KK, Goswami VR, Vaidyanathan S, Karanth KU (2016) Determinants of dry season habitat use by Asian elephants in the Western Ghats of India. *J Zool* 298:169–177. doi:10.1111/jzo.12298

Lamichhane S, Khanal G, Karki JB, Aryal C, Acharya S (2020) Natural and anthropogenic correlates of habitat use by wild ungulates in Shuklaphanta National Park, Nepal. *Glob Ecol Conserv* 24:e01338. doi.org/10.1016/j.gecco.2020.e01338

Link WA, Eaton MJ (2012) On thinning of chains in MCMC. *Methods Ecol Evol* 3 (1):112–115. doi:10.1111/j.2041-210X.2011.00131.x.

MacKenzie DI, Nichols JD, Lachman GB, Droege S, Royle JA, Langtimm CA (2002) Estimating site occupancy rates when detection probabilities are less than one. *Ecology* 83:2248–2255

MacKenzie DI, Nichols JD, Royle JA, Pollock KH, Bailey LL, et al. (2006) Occupancy estimation and modeling: inferring patterns and dynamics of species occurrence. Academic Press. 324 p

Mattfeldt SD, Bailey LL, Grant EHC (2009) Monitoring multiple species: estimating state variables and exploring the efficacy of a monitoring program. *Biol Conserv* 142:720–737

McCullough DR, Pei KC, Wang Y (2000) Home range, activity patterns, and habitat relations of Reeves' muntjacs in Taiwan. *J Wildl Manage* 64:430–441

McHenry E, O'Reilly C, Sheerin E, Kortland K, Lambin S (2016) Strong inference from transect sign surveys: combining spatial autocorrelation and misclassification occupancy models to quantify the detectability of a recovering carnivore. *Wildlife Biol* 22:209–216

McShea WJ, Davies SJ, Bhumpakphan N (2011) The ecology and conservation of seasonally dry forests in Asia. Smithsonian Institution Scholarly Press, Washington DC

Menon V, Kaul R, Dutta R, Ashraf NVK, Sarkar P (2008) Bringing back Manas. Conserving the forest and wildlife of the Bodoland Territorial Council. Wildlife Trust of India. 267pp. https://wti.org.in/wp-content/uploads/2017/03/pub_bringing_back_manas.pdf

Moe SR, Wegge P (1994) Spacing behavior and seasonal habitat preferences of axis deer (*Axis axis*) in Royal Bardia National Park, Nepal. *Can J Zool* 72:1735–1744

Moreno M, Lele SR (2010) Improved estimation of site occupancy using penalized likelihood. *Ecology* 91:341–346

Naha, D., Dash, S.K. and Sathyakumar, S., 2020. Inaccurate methods and erroneous conclusions drawn on human-leopard coexistence in India—Response to Puri et al., 2020 “The balancing act: Maintaining leopard–wild prey equilibrium could offer economic benefits to people in a shared forest landscape of central India”. *Ecological Indicators*, 117, p.106632.

Nath N, Singha H, Das JP, Brahma N, Dey S, Lahkar BP, Ahmed F (2008) Checklist of birds of Chirang-Ripu Reserve Forests, Assam, India. *Newsletter for Birdwatchers* 48 (3):33–36

Nath A, Sinha A, Lahkar BP, Brahma N (2019a) In search of Aliens: Factors influencing the distribution of *Chromolaena odorata* L. and *Mikania micrantha* Kunth in the Terai grasslands of Manas National Park, India, *Ecol Eng* 131:16–26. <https://doi.org/10.1016/j.ecoleng.2019.02.012>

Nath A, Singha H, Haque M, Lahakar BP (2019b) Sparrows in urban complexity: macro and micro-scale habitat use of sympatric sparrows in Guwahati City, India. *Urban Ecosyst* 22:1047–1060 (2019). <https://doi.org/10.1007/s11252-019-00876-4>

Olivier RCD (1978) Distribution and status of the Asian elephant. *Oryx* 14: 379–424

Pathak N (2002) Implications of existing and proposed laws and policies on community forestry initiatives in India. *Inform* 2:5–11

Pepin KM, Davis AJ, Cunningham FL, VerCauteren KC, Eckery DC (2017) Potential effects of incorporating fertility control into typical culling regimes in wild pig populations. PLoS ONE 12(8): e0183441.

<https://doi.org/10.1371/journal.pone.0183441>

Phumanee W, Steinmetz R, Phoonjampa R, Bejraburnin T, Grainger M, Savini T (2020) Occupancy based monitoring of ungulate prey species in Thailand indicates population stability, but limited recovery. Ecosphere 11(9):e03208. 10.1002/ecs2.3208

Plummer M (2003) JAGS: a program for analysis of Bayesian graphical models using Gibbs sampling. Proceedings of the 3rd International Workshop on Distributed Statistical Computing: Vienna, Austria

Rhodes JR, Lunney D, Moon C, Matthews A, McAlpine CA (2011) The consequences of using indirect signs that decay to determine species' occupancy. Ecography 34:141–150

Ritchie ME, Tilman D, Knops JMH (1998) Herbivore effects on plant and nitrogen dynamics in Oak Savanna. Ecology 79(1):165–177

Rota, C. T., Fletcher, R. J., Evans, J. M., & Hutto, R. L. (2011). Does accounting for imperfect detection improve species distribution models?. Ecography 34(4): 659–670

Royle JA, Lin WA (2006) Generalized occupancy models allowing false positive and false negative errors. Ecology 87(4):835-841

Royle JA, Nichols JD (2003). Estimating abundance from repeated presence absence data or point counts. Ecology 84(3):777–790

Sankar K (1994) The Ecology of Three Large Sympatric Herbivores (Chital, Sambhar and Nilgai) with Special Reference for Reserve Management in Sariska Tiger Reserve, Rajasthan. Ph.D. thesis, University of Rajasthan Jaipur.

Schaller GB (1967) The deer and the tiger—a study of wildlife in India. The University of Chicago Press, Chicago

Scott JM, Heglund PJ, Morrison ML (2002) Predicting species occurrences: issues of accuracy and scale. Island Press, Washington

- Shea CP, Peterson JT, Wisniewski JM, Johnson NA (2011) Misidentification of freshwater mussel species (Bivalvia: Unionidae): contributing factors, management implications, and potential solutions. *J N Am Benthol Soc* 30:446–458
- Srivathsa A, Puri M, Samba Kumara N, Jathana D, Karanth KU (2018) Substituting space for time: Empirical evaluation of spatial replication as a surrogate for temporal replication in occupancy modelling. *J Appl Ecol* 55:754–765
- Su YS, Yajima M (2015) R2jags: a Package for Running jags from R. R package version 0.5-7. <http://CRAN.R-project.org/package=R2jags>
- Sunarto S, Kelly MJ, Parakkasi K, Klenzendorf S, Septayuda E, Kurniawan H (2012) Tigers need cover: multi-scale occupancy study of the big cat in Sumatran forest and plantation landscapes. *PLoS ONE*. doi:10.1371/journal.pone.0030859
- Thapa K, Kelly MJ (2017) Prey and tigers on the forgotten trail: high prey occupancy and tiger habitat use reveal the importance of the understudied Churia habitat of Nepal. *Biodivers Conserv* 26:593–616. DOI 10.1007/s10531-016-1260-1
- Thapa K, Kelly MJ, Pradhan NMB (2019) Elephant (*Elephas maximus*) temporal activity, distribution, and habitat use patterns on the tiger's forgotten trails across the seasonally dry, subtropical, hilly Churia forests of Nepal. *PLoS ONE* 14(5): e0216504. <https://doi.org/10.1371/journal.pone.0216504>
- Thorn M, Green M, Bateman PW, Waite S, Scott DM (2011) Brown hyenas on roads: estimating carnivore occupancy and abundance using spatially auto-correlated sign survey replicates. *Biol Conserv* 144:1799–1807
- Tiwari SK, Poddar A, Ramkumar K (2017) Elephant Corridors of Northern West Bengal. In: Right of Passage: Elephant Corridors of India [2nd Edition]. Menon, V., Tiwari, S. K., Ramkumar, K., Kyarong, S., Ganguly, U. & Sukumar, R. (Eds.). Conservation Reference Series No. 3. Wildlife Trust of India, New Delhi.
- Tyre AJ, Tenhumberg B, Field SA, Niejalke D, Parris K, Possingham HP (2003) Improving precision and reducing bias in biological surveys: estimating false-negative error rates. *Ecol Appl* 13(6):1790–1801

United Nations Permanent Forum on Indigenous Issues (2016). Document available at: <https://www.un.org/esa/socdev/unpfii/documents/2016/Docs-updates/backgrounderC1.pdf>; Frayer and Martin (eds.) (2014). ISBN: 9781134385379; Keeley (1996). ISBN: 9780195119121; Bamforth (1994), DOI: <https://doi.org/10.2307/2803512>

Vandekerckhove N, Suykens B (2008) ‘The Liberation of Bodoland’: Tea, Forestry and Tribal Entrapment in Western Assam, South Asia: *J Southeast Asian Stud* 31(3): 450–471. DOI: [10.1080/00856400802441961](https://doi.org/10.1080/00856400802441961)

Vinitpornsawan S (2013) Population and spatial ecology of Tigers and Leopards relative to prey availability and human activity in Thung Yai Naresuan (East) Wildlife Sanctuary, Thailand. Ph.D. Thesis. University of Massachusetts

Wang SW, Macdonald DW (2009) Feeding habits and niche partitioning in a predator guild composed of tigers, leopards and dholes in a temperate ecosystem in central Bhutan. *J Zool* 277:275-283. doi:10.1111/j.1469-7998.2008.00537.x

Wibisono HT, Linkie M, Guillera-Aroita G, Smith JA, Sunarto, et al. (2011) Population Status of a Cryptic Top Predator: An Island-Wide Assessment of Tigers in Sumatran Rainforests. *PLoS ONE* 6(11): e25931. doi:10.1371/journal.pone.0025931.

Wikramanayake E, Dinerstein E, Seidensticker J, Lumpkin S, Pandav B, et al. (2011) A landscape-based conservation strategy to double the wild tiger population. *Conserv Lett* 4:219–227. doi:10.1111/j.1755-263X.2010.00162.x

Zangmo P, Gurung DB, Letro L, Wangmo S (2018) Distribution, Abundance and Occupancy of Gaur (*Bos gaurus* Smith) in the Royal Manas National Park, Bhutan. *BJNRD* 5(1):1–12

Statements & Declarations

Funding

This work was supported by US Fish & Wildlife Services Grant numbers Grant # F13AP00755

Competing Interests

The authors have no relevant financial or non-financial interests to disclose

Author Contributions

Conceptualization: [Bibhuti P Lahkar, Subhashish Das, Namita Brahma]; Methodology: [Anukul Nath]; Formal analysis [Anukul Nath] and investigation: [Anukul Nath, Pranjit Sarma, Thunu Basumatray, Rajual Islary, Arup Kr Das]; Writing - original draft preparation: [Anukul Nath]; review and editing: [Namita Brahma, Bibhuti P Lahkar, Subhashis Das]; Funding acquisition: [Bibhuti P Lahkar, Namita Brahma], Supervision: [Bibhuti P Lahkar, Subhashis Das, Anindya Swargiary]

Data Availability

Data and codes will be provided on request.

Consent to participate: We give our consent to participate in the publication process.

Consent for publication: We give our consent for the publication of submitted manuscript

Table 1. Factors hypothesized to influence patterns of occupancy (ψ)/habitat use (4 km²) and detection probability (p) of mammals in Ripu Reserve Forest, Assam, India.

Covariates	Description	Justification of selection of covariate	<i>A priori hypothesis</i>	
			p	ψ
Distance to water sources (DWS)	Generated a surface by calculating the Euclidean distance from rivers, streams (both permanent and seasonal) and stagnant water bodies	The presence of water bodies is expected to have positive impact on abundance and hence on the site use of elephants and other wild ungulates under study (Lakshminarayanan et al. 2016)		+
Elevation (ELE)	Computed using the SRTM digital elevation model-90m	Elevation can both positively and negatively influence the habitat use of the studied species (Thapa and Kelly 2017, Phumanee et al. 2020)		+ /–
Semi-evergreen and mixed-moist deciduous forest (SE-MMD)	Proportion of intact semi-evergreen and Mixed-Moist Deciduous forest extracted from LULC map prepared for the study area	Different vegetation structure associated with forest types could influence the habitat use of studied mammalian species.		+ /–
Secondary degraded forest (SDF)	Proportion of secondary degraded forest with canopy openings extracted from LULC map prepared for the study area	Previous studies from western Terai stated that barking deer prefer dense vegetation (Chapman et al. 1994), sambar prefer mixed deciduous forest (Karanth and Sunquist 1992) and spotted deer prefer open grassland intermixed with forest (Dinerstein 1980).		+ /–
Scrub (SC)	Proportion of scrub forest extracted from LULC map prepared for the study area			+ /–
Distance to nearest human settlement (DHS)	Generated a surface by calculating the Euclidean distance from agriculture, settlements, built-up areas and roads	DHS is used as a surrogate measure of prolonged disturbance in the study site associated with the human activity such as grazing, hunting and resource extraction. (Vinitpornawan 2013, Thapa and Kelly 2017).		–
Anthropogenic activity (AA)	Encounter rate of anthropogenic activities including, logging, wood cutting, fire and hunting	Due to socio-political unrest in the region, all these mentioned anthropogenic activities could negatively impact habitat use and population of mammals in the study area (Thapa and Kelly 2017, Joraburom et al. 2020, Phumanee et al. 2020)		–
Livestock encounter rate (LSER)	Encounter rate of cattle's and their signs	Livestock raising is common in villages adjacent to study area, and their presence was likely to negatively impact the ungulate populations through competition for forage (Chaiyarat & Srikosamata 2009; Jathanna et al. 2016, Thapa and Kelly 2017).		
Effort (EF)	Total km of search paths walked during the sign-survey in each of 4 km ² grid cells.	Detection of sign would be influenced by survey effort (Harihar and Pandav 2012).	+	
Substrate (SUB)	Subjective grading of substrate quality for detecting tracks. 1= Soft soil, 2 = Hard soil, 3 = Leaf litter	Soft soil expected to increase the detection probability of animal tracks compared to hard soil and leaf litter (Lamichhane et al. 2020). Further, presence of leaf litter on the trail can influence the detectability of pellet and scat of animals.		+ /–
Livestock (LS)	Presence of domestic animals (1,0) 1= Presence, 0 = Absence	Presence of domestic animals was expected to influence detection probability as it would lower abundance directly through competition for forage and indirectly through human-induced impacts (Royle and Nichols 2003, Joraburom et al. 2020). Furthermore, a herd of cattle can also influence the sign detected on the forest floor		–

Table 2. Results of model selection to identify ecological and anthropogenic covariates influencing probability of habitat use of mammals in Ripu Reserve Forest, Assam, India. Number of parameters (K), Akaike information criterion (AIC), Akaike weights (ω_i).

Sambar	K	AIC	ΔAIC	ω_i	Spotted deer	K	AIC	ΔAIC	ω_i
$p(.)\psi(DHS)$	3	260.88	0	0.600	$p(LS)\psi(SDF+I(SDF^2)+AA)$	6	210.61	0	0.486
$p(.)\psi(DHS+SE-MMD)$	4	262.74	1.86	0.236	$p(LS)\psi(SDF+I(SDF^2))$	5	213.23	2.62	0.131
$p(.)\psi(DHS+SE-MMD+SDF)$	5	264.31	3.42	0.108	$p(LS)\psi(DWS)$	4	213.57	2.95	0.110
$p(.)\psi(DHS+SE-MMD+SDF+AA)$	6	265.99	5.11	0.046	$p(LS)\psi(AA)$	4	214.35	3.74	0.074
$p(.)\psi(SE-MMD)$	3	272.28	11.39	0.002	$p(LS)\psi(DHS+SE-MMD+SDF+AA+DWS)$	8	215.02	4.41	0.053
$p(.)\psi(DWS)$	3	272.41	11.52	0.001	$p(LS)\psi(DHS)$	4	215.89	5.28	0.034
$p(.)\psi(SE-MMD+AA)$	4	273.06	12.18	0.001	$p(LS)\psi(SE-MMD)$	4	216.22	5.60	0.029
$p(.)\psi(SDF)$	3	273.64	12.75	0.001	$p(LS)\psi(DWS+SE-MMD+DHS)$	6	216.51	5.89	0.025
$p(.)\psi(SC)$	3	273.87	12.98	0.0009	$p(LS)\psi(LS)$	4	217.24	6.63	0.017
$p(.)\psi(.)$	2	274.81	13.92	0.0005	$p(LS)\psi(SDF)$	4	217.39	6.77	0.016
$p(.)\psi(SDF+AA)$	4	274.88	13.99	0.0005	$p(LS)\psi(SC)$	4	217.46	6.85	0.015
$p(.)\psi(AA)$	3	276.11	15.23	0.0002	$p(.)\psi(.)$	2	220.54	9.93	0.003
Barking deer	K	AIC	ΔAIC	ω_i	Wild pig	K	AIC	ΔAIC	ω_i
$p(SUB)\psi(DHS+I(DHS^2))$	6	325.44	0	0.46	$\psi(AA + DWS) \theta(.)p(.)\theta'(.)\theta^{\#}(.)$	6	276.16	0	0.329
$p(SUB)\psi(DHS)$	5	328.54	3.09	0.09	$\psi(AA) \theta(.)p(.)\theta'(.)\theta^{\#}(.)$	5	277.87	1.71	0.140
$p(SUB)\psi(DHS+I(DHS^2)+SE-MMD)$	8	328.94	3.49	0.08	$\psi(DWS) \theta(.)p(.)\theta'(.)\theta^{\#}(.)$	5	278.16	2	0.121
$p(SUB)\psi(DHS+I(DHS^2)+SE-MMD+AA)$	8	328.94	3.49	0.08	$\psi(.) \theta(.)p(.)\theta'(.)\theta^{\#}(.)$	4	279.03	2.87	0.078
$p(SUB)\psi(SDF)$	5	329.39	3.94	0.06	$\psi(AA + SC) \theta(.)p(.)\theta'(.)\theta^{\#}(.)$	6	279.18	3.02	0.072
$p(SUB)\psi(SE-MMD)$	5	329.58	4.13	0.05	$\psi(SE-MMD) \theta(.)p(.)\theta'(.)\theta^{\#}(.)$	5	279.67	3.51	0.056
$p(SUB)\psi(DWS)$	5	330.50	5.05	0.03	$\psi(AA + SC + DHS) \theta(.)p(.)\theta'(.)\theta^{\#}(.)$	7	280.39	4.23	0.039
$p(SUB)\psi(SC)$	5	330.52	5.07	0.03	$\psi(SDF) \theta(.)p(.)\theta'(.)\theta^{\#}(.)$	5	280.60	4.44	0.035
$p(SUB)\psi(AA)$	5	330.92	5.47	0.03	$\psi(DHS) \theta(.)p(.)\theta'(.)\theta^{\#}(.)$	5	280.74	4.58	0.033
$p(SUB)\psi(SE-MMD+I(SE-MMD^2))$	6	330.99	5.54	0.02	$\psi(AA + DWS + SE-MMD + SDF + DHS) \theta(.)p(.)\theta'(.)\theta^{\#}(.)$	9	281.27	5.11	0.025
$p(.)\psi(.)$	2	333.63	8.18	0.007	$\psi(SDF + I(SDF^2)) \theta(.)p(.)\theta'(.)\theta^{\#}(.)$	6	281.54	5.38	0.022
					$\psi(SE-MMD + SDF) \theta(.)p(.)\theta'(.)\theta^{\#}(.)$	6	281.66	5.5	0.021
					$\psi(DHS + I(DHS^2)) \theta(.)p(.)\theta'(.)\theta^{\#}(.)$	6	282.14	5.98	0.016
					$\psi(SE-MMD + SDF + DHS) \theta(.)p(.)\theta'(.)\theta^{\#}(.)$	7	283.65	7.49	0.007
Leopard	K	AIC	ΔAIC	ω_i	Elephant	K	AIC	ΔAIC	ω_i
$p(LS+SUB)\psi(PREY+SDF)$	7	250.36	0	0.215	$\psi(DHS+SDF+DWS) \theta(.)p(LS) \theta'(.)\theta^{\#}(.)$	8	380.82	0	0.305
$p(LS+SUB)\psi(SDF)$	6	250.54	0.17	0.197	$\psi(DHS) \theta(.)p(LS) \theta'(.)\theta^{\#}(.)$	6	382.43	1.61	0.136
$p(LS+SUB)\psi(SE-MMD)$	6	250.80	0.44	0.172	$\psi(SDF) \theta(.)p(LS) \theta'(.)\theta^{\#}(.)$	6	382.70	1.88	0.119
$p(LS+SUB)\psi(AA+SDF+DWS)$	8	252.62	2.26	0.069	$\psi(SE-MMD) \theta(.)p(LS) \theta'(.)\theta^{\#}(.)$	6	382.90	2.08	0.108
$p(LS+SUB)\psi(PREY)$	6	252.95	2.59	0.058	$\psi(DWS) \theta(.)p(LS) \theta'(.)\theta^{\#}(.)$	6	382.90	2.08	0.108
$p(LS+SUB)\psi(SDF+SE-MMD+PREY+DWS+DHS)$	10	253.00	2.63	0.057	$\psi(AA) \theta(.)p(LS) \theta'(.)\theta^{\#}(.)$	6	382.90	2.08	0.108
$p(LS+SUB)\psi(SDF+I(SDF^2)+DWS)$	8	253.27	2.91	0.050	$\psi(DHS+AA) \theta(.)p(LS) \theta'(.)\theta^{\#}(.)$	7	383.62	2.8	0.075
$p(LS+SUB)\psi(AA+SE-MMD+DHS)$	8	253.68	3.31	0.040	$\psi(DHS+SDF+SE-MMD) \theta(.)p(LS) \theta'(.)\theta^{\#}(.)$	8	385.01	4.19	0.037
$p(LS+SUB)\psi(SDF+SE-MMD+PREY+AA+DWS)$	10	253.70	3.33	0.040	$\psi(.)\theta(.)p(.)\theta'(.)\theta^{\#}(.)$	4	394.37	13.55	0.0003
$p(LS+SUB)\psi(DHS)$	6	253.77	3.412	0.039	$\psi(DHS+SDF+I(SDF^2)) \theta(.)p(LS) \theta'(.)\theta^{\#}(.)$	8	394.77	13.95	0.0003
$p(LS+SUB)\psi(DHS+I(DHS^2))$	7	254.23	3.874	0.031	$\psi(SDF+I(SDF^2)) \theta(.)p(LS) \theta'(.)\theta^{\#}(.)$	7	395.24	14.42	0.0002
$p(LS+SUB)\psi(AA)$	6	255.12	4.765	0.019	$\psi(DHS+I(DHS^2)+DWS+SE-MMD) \theta(.)p(LS) \theta'(.)\theta^{\#}(.)$	9	395.68	14.86	0.0002
$p(LS+SUB)\psi(DWS)$	6	257.41	7.051	0.006	$\psi(DWS+I(DWS^2)) \theta(.)p(LS) \theta'(.)\theta^{\#}(.)$	7	397.34	16.52	0.0001
$p(.)\psi(.)$	2	261.56	11.19	0.0007					

Table 3. Estimates of β coefficient values (standard errors, SE) of mammals site-use probability for different individual and model average covariates based on the models $\Delta AIC > 2$. *indicate statistical significance as defined by $\beta \pm 1.96 \times SE$ not overlapping 0.

Species	Covariate	β Estimate	SE
Barking deer	DHS	1.53	0.82
	DHS ² *	-1.15	0.57
Spotted deer	SDF	0.64	0.48
	SDF ² *	-0.88	0.41
	AA	-0.88	0.48
Sambar	DHS*	1.28	0.44
	SE-MMD	-0.22	0.63
Wild pig	AA	-0.64	0.39
	DWS	-0.55	0.33
Elephant	DHS	9.43	16.96
	SDF	-8.08	14.38
	DWS	8.16	14.53
Leopard	PREY	4.80	3.20
	SDF	-1.19	0.68
	SE-MMD*	1.33	0.67

Table 4. Factors affecting the intensive habitat use of gaur using Bayesian approach in Ripu RF, Assam, India. Successful convergence based on Rhat values (all < 1.1). Rhat is the potential scale reduction factor (at convergence, Rhat=1). Overlap0 checks if 0 falls in the parameter's 95% credible interval. Deviance information criterion (DIC).

Model	Parameter	Mean	SD	2.50%	50%	97.50%	Overlap0	Rhat	DIC
ψ (SE-MMD) $p(.)$	β_{SE-MMD}	1.721	0.789	0.446	1.632	3.607	FALSE	1.002	86.5
ψ (SE-MMD+SDF+DHS+DWS+AA) $p(.)$	β_{SE-MMD}	2.647	1.78	-1.62	3.006	4.914	TRUE	1.009	87.58
	β_{SDF}	-1.528	1.997	-4.778	-1.616	2.673	TRUE	1.018	
	β_{DHS}	2.826	1.504	-0.229	3.06	4.915	TRUE	1.007	
	β_{DWS}	0.958	1.852	-2.283	0.677	4.638	TRUE	1.001	
ψ (SDF) $p(.)$	β_{SDF}	-1.044	0.539	-2.231	-1	-0.118	FALSE	1.000	87.99
ψ (SE-MMD+DHS) $p(.)$	β_{SE-MMD}	1.847	1.123	0.088	1.66	4.545	FALSE	1.006	90.96
	β_{DHS}	1.193	1.21	-0.456	0.882	4.282	TRUE	1.004	
ψ (SE-MMD+SDF+DHS) $p(.)$	β_{SE-MMD}	2.292	1.477	-0.538	2.254	4.827	TRUE	1.001	96.26
	β_{SDF}	-0.606	1.73	-4.516	-0.289	2.169	TRUE	1.002	
	β_{DHS}	1.864	1.444	-0.342	1.653	4.707	TRUE	1.003	

Table 5. Summary of detection probability, naïve occupancy, site use (occupancy) probability of sampled (n= 75) and predicted (n= 144) grids of mammals in Ripu Reserve Forest, Assam, India.

Species	Proportion with detections (Naïve ψ occupancy)	Detection probability ($\hat{p}(SE[\hat{p}])$)	Occupancy-Sampled grid ($\hat{\psi}(SE[\hat{\psi}])$)	Occupancy-Overall grid (predicted) ($\hat{\psi}(SE[\hat{\psi}])$)
Sambar	0.34	0.26 (0.04)	0.45 (0.03)	0.37 (0.02)
Spotted Deer	0.29	Presence of livestock: 0.0468 (0.0465)	0.37 (0.02)	0.16 (0.007)
		Absence of livestock: 0.75 (0.08)		
Barking deer	0.80	Soft soil: 0.48 (0.05); hard soil: 0.67 (0.06); leaf litter: 0.76 (0.12)	0.87 (0.008)	0.83 (0.01)
Wild pig	0.41	0.38 (0.24)	0.53 (0.02)	0.40 (0.009)
Gaur	0.13	0.26 (0.009)	0.13 (0.009)	0.20 (0.01)
Elephant	0.96	Presence of livestock: 0.75 (0.08)	0.98 (0.002)	0.97 (0.009)
		Absence of livestock: 0.86 (0.05)		
Leopard	0.38	Presence of livestock: 0.09 (0.05)	0.63 (0.02)	0.59 (0.01)
		Absence of livestock: 0.29 (0.05)		
		Soft soil: 0.17 (0.04); hard soil: 0.33 (0.06); leaf-litter: 0.07 (0.07)

Fig. 1. Map showing the study area – Ripu Reserve Forest in Assam, India

Fig. 2. Classified land cover map of Ripu Reserve Forest and adjacent areas showing sampled grids (4 km²) for sign survey of mammals.

Sambar

Spotted deer

Barking deer

Gaur

Figure 4. Association between the highly influential covariates (based on estimates of regression parameters (β) and 95 % CI from the best models) and the probability of sambar, spotted deer, barking deer and gaur occupancy in Ripu Reserve Forest, Assam, India.

Wild Boar

Leopard

Fig. 5. Association between the highly influential covariates (based on estimates of regression parameters (β) and 95 % CI from the best models) and the probability of wild boar and leopard occupancy in Ripu Reserve Forest of Assam, India.

Fig. 6. Barking deer, spotted deer, sambar, wild pig, and leopard site use across the Ripu Reserve Forest in Assam, India.

Fig 7. Gaur and Asian elephant site use across the Ripu Reserve Forest in Assam, India.

Supplementary Information

Community, conflict and conservation: response of mammalian fauna to ecological and anthropological correlates – a critical habitat in Indo-Bhutan transboundary landscape urges multiagency cooperation

Anukul Nath^{1,2*}, Bibhuti P Lahkar¹, Namita Brahma^{1,3}, Pranjit Sarma¹, Arup Kr Das¹, Subhashish Das⁴, Thunu Basumatary⁵, Rajual Islary⁵, and Anindya Swargiary⁴

Fig. S1. Flow chart for image classification of Ripu and Chirang Reserve Forest, Assam, India.

Table S1. Accuracy assessment of classified image

Land cover	SE-MMD	SDF	SC	Settlement	Agriculture	Water	Sand	Row total	User's Accuracy (%)
Semi-evergreen & moist-mixed deciduous forest (SE-MMD)	35	3						38	92.10
Secondary degraded forest (SDF)	3	34	3					40	82.92
Scrub (SC)		2	26	1	1		1	31	83.87
Settlement	1	1	1	31	1	2		37	83.78
Agriculture	1			4	33	2	2	42	78.57
Water				3	3	26	2	34	78.78
Sand				1	2		25	28	89.28
Column total	40	40	30	40	40	30	30	250	
Producer's Accuracy (%)	87.5	85	87	77.5	82.5	86.66	83.3		
Overall Accuracy (%)	84%								

Table S2. Results of correlation coefficient (r) among different variables hypothesized to influence the occupancy of mammalian fauna in Ripu Reserve Forest, Assam, India [$r > 0.75$ shown in bold].

Covariate	SE_MMD	SDF	SC	DWS	DHS	ELE	EF	AA
SDF	-0.62440							
SC	-0.80935	0.32207						
DWS	0.39787	0.02145	-0.30220					
DHS	0.54306	-0.44105	-0.32154	0.13810				
ELE	0.61901	-0.49315	-0.42288	0.07979	0.90941			
EF	0.04137	0.03634	-0.12557	-0.02923	-0.02131	-0.02942		
AA	0.11223	-0.00498	-0.07615	-0.11747	-0.08632	-0.05621	0.16818	
LSER	0.015915	0.00882	-0.03327	-0.20067	-0.12803	-0.10394	0.16058	0.77581

Table S3. Comparison of parameter estimates for spatial dependence occupancy models based on detection histories using different segment lengths of trail. θ is the probability that the species is present locally, given the species was not present in the previous segment and θ' is the probability that a species is present locally, given it was present in the previous segment. Δ AIC is the difference between spatial autocorrelation occupancy models [Hines et al. 2010 ($\psi(\cdot)\theta(\cdot)p(\cdot)\theta'(\cdot)\theta^p(\cdot)$) represented as H in the table] relative to simple models assuming no spatial dependence [MacKenzie et al. 2002 ($p(\cdot)\psi(\cdot)$) represented as M in the table] for that trail length.

Species	Segment	θ	SE (θ)	95% CI (θ)	θ'	SE (θ')	95% CI (θ')	Δ AIC	H	M
Sambar	1.2	0.152	0.137	0.021-0.589	0.522	0.104	0.324-0.712	2.468	181.557	179.089
	1.1	1.000		0.000-1.000	0.750	0.203	0.263-0.961	4.946	193.718	188.772
	1	0.095	0.131	0.005-0.673	0.806	0.294	0.094-0.993	5.536	197.372	191.836
	0.9	0.122	0.056	0.047-0.278	0.708	0.196	0.274-0.939	3.413	207.190	210.602
	0.8	0.115	0.047	0.055-0.243	0.654	0.187	0.271-0.905	2.377	215.199	212.822
	0.7	0.203	0.063	0.106-0.354	0.303	0.063	0.195-0.437	4.128	237.236	233.108
	0.6	0.076	0.038	0.027-0.191	0.798	0.124	0.465-0.947	1.967	256.756	254.789
	0.5	0.155	0.048	0.081-0.274	0.341	0.074	0.213-0.497	1.387	274.815	273.428
	0.4	0.127	0.036	0.071-0.216	0.326	0.071	0.203-0.477	4.533	304.422	299.889
	0.3	0.104	0.048	0.041-0.240	0.593	0.166	0.274-0.848	10.285	352.564	342.279
	0.2	0.096	0.037	0.044-0.196	0.628	0.133	0.356-0.837	11.632	412.548	400.916
	0.1	0.104	0.057	0.070-0.152	0.080	0.039	0.030-0.194	5.692	403.499	397.807
Segment		θ	SE (θ)	95% CI (θ)	θ'	SE (θ')	95% CI (θ')	Δ AIC	H	M
Spotted Deer	1.2	0.032	0.142	3.774493e-06 - 0.996	0.625	0.302	1.181796e-01 - 0.954	2.663	155.492	152.828
	1.1	0.081	0.173	0.0009-0.89	0.583	0.480	0.028-0.985	3.267	159.900	156.633
	1	0.087	0.028	0.045-0.157	0.294	0.111	0.128-0.541	2.851	161.014	158.162
	0.9	0.000		0-1	0.774	0.122	0.465-0.930	27.418	179.772	207.190
	0.8	0.042	0.099	0.0003-0.849	0.780	0.281	0.125-0.988	4.882	186.588	181.706
	0.7	0.059	0.041	0.014-0.209	0.633	0.208	0.229-0.908	2.774	196.760	193.986
	0.6	0.155	0.090	0.045-0.415	0.400	0.089	0.243-0.580	2.607	213.232	210.625
	0.5	0.056	0.027	0.021-0.137	0.659	0.186	0.276-0.907	1.236	221.902	220.667
	0.4	0.032	0.035	0.003-0.228	0.861	0.138	0.391-0.983	4.758	247.365	242.607
	0.3	0.027	0.024	0.004-0.141	0.867	0.102	0.535-0.973	3.460	272.625	269.166
	0.2	0.109	0.277	0.0004-0.970	0.208	0.612	0.0001-0.997	2.920	307.775	304.855
	0.1	0.862	0.767	2.024238e-05 - 0.999	0.471	0.651	5.288308e-03 - 0.993	5.005	370.414	365.409
Segment		θ	SE (θ)	95% CI (θ)	θ'	SE (θ')	95% CI (θ')	Δ AIC	H	M
Barking deer	1.2	0.21	0.32	0.006 - 0.91	0.81	0.15	0.37 - 0.96	1.75	245.07	243.33
	1.1	0.15	0.26	0.003 - 0.90	0.81	0.12	0.47 - 0.95	2.19	262.73	260.54
	1	0.27	0.24	0.032 - 0.79	0.77	0.19	0.30-0.96	0.26	273.26	273.00
	0.9	0.10	0.18	0.002 - 0.83	0.85	0.07	0.65 - 0.94	2.03	320.37	318.34
	0.8	0.16	0.15	0.019 - 0.63	0.85	0.08	0.61 - 0.95	0.04	333.67	333.64
	0.7	0.22	0.09	0.09 - 0.45	0.77	0.10	0.52 - 0.90	8.59	387.21	378.62
	0.6	0.24	0.10	0.10 - 0.47	0.79	0.11	0.50 - 0.93	4.56	440.58	436.03
	0.5	0.20	0.08	0.08 - 0.40	0.83	0.07	0.64 - 0.93	6.94	501.67	494.73
	0.4	0.21	0.27	0.010 - 0.86	0.83	0.19	0.24 - 0.98	7.06	597.77	590.71
	0.3	0.17	0.20	0.01 - 0.77	0.85	0.16	0.31 - 0.98	15.88	738.53	722.65
	0.2	0.13	0.04	0.072 - 0.22	0.88	0.05	0.72 - 0.95	37.06	961.97	924.91

	0.1	0.07	0.06	0.012 - 0.29	0.95	0.04	0.79 - 0.98	45.37	1358.05	1312.67
	Segment	θ	SE (θ)	95% CI (θ)	θ'	SE (θ')	95% CI (θ')	Δ AIC	H	M
Wild pig	1.2	0.765	0.164	0.352-0.950	0.360	0.096	0.199-0.560	2.983	192.980	189.997
	1.1	0.909	0.198	0.083-0.999	1.000	0.004	0.000-1.000	5.777	207.700	201.923
	1	0.358	0.137	0.147-0.642	0.533	0.091	0.358-0.700	4.785	213.211	208.426
	0.9	0.581	0.551	0.016-0.991	0.848	0.593	0.0006-0.99	3.116	230.211	227.095
				1.474236e-						
	0.8	0.691	0.797	03-0.999	0.969	0.826	0.000-1.000	4.381	231.303	235.684
	0.7	0.424	0.096	0.254-0.614	0.307	0.054	0.211-0.422	4.515	259.731	255.216
	0.6	0.687	0.190	0.278-0.925	1.000	0.000	0-1	3.898	279.032	275.134
	0.5	0.548	0.332	0.080-0.943	0.916	0.306	0.004-0.999	3.518	304.993	301.475
	0.4	0.280	0.208	0.192-0.387	0.208	0.059	0.115-0.345	4.858	334.032	329.175
	0.3	0.196	0.036	0.135-0.275	0.189	0.042	0.119-0.284	5.981	376.101	370.120
	0.2	0.392	0.176	0.132-0.732	1.000	0.000	0.000-1.000	3.389	434.951	431.562
	0.1	0.199	0.148	0.038-0.604	0.514	0.599	0.009-0.991	2.819	557.355	554.536
	Segment	θ	SE (θ)	95% CI (θ)	θ'	SE (θ')	95% CI (θ')	Δ AIC	H	M
Asian elephant	1.2	1.00		0-1	1.00		0-1	6.00	172.56	166.56
	1.1	1.00		0-1	1.00		0-1	6.00	194.11	188.11
	1	1.00		0-1	0.86	0.05	0.72- 0.93	0.47	197.06	196.60
	0.9	1.00		0-1	0.81	0.06	0.67- 0.89	1.92	261.83	263.75
	0.8	1.00		0-1	0.89	0.06	0.71- 0.95	2.69	273.42	270.73
	0.7	1.00		0-1	1.00		0-1	6.00	338.50	332.50
	0.6	1.00		0-1	0.93	0.05	0.72- 0.98	4.49	394.37	389.88
	0.5	1.00		0-1	0.92	0.06	0.70- 0.98	4.37	487.94	483.57
	0.4	0.32	0.15	0.11- 0.63	0.90	0.06	0.72- 0.96	9.09	625.73	634.81
	0.3	0.20	0.12	0.05- 0.51	0.95	0.04	0.79- 0.98	10.50	837.78	848.28
	0.2	0.13	0.07	0.03- 0.35	0.97	0.02	0.89- 0.99	8.09	1200.95	1209.04
	0.1	0.87	0.30	0.03- 0.99	0.65	0.23	0.20- 0.92	3.20	1884.10	1880.91
	Segment	θ	SE (θ)	95% CI (θ)	θ'	SE (θ')	95% CI (θ')	Δ AIC	H	M
Leopard	1.2	0.16	0.04	0.09 - 0.26	0.39	0.09	0.23 - 0.58	4.21	195.43	191.22
	1.1	1.00		0-1	0.63	0.32	0.10 - 0.96	6.07	203.47	197.40
	1	1.00		0-1	0.68	0.20	0.25 - 0.93	5.65	208.63	202.98
	0.9	0.00		0-1	0.91	0.11	0.43 - 0.99	5.44	225.98	220.54
	0.8	0.16	0.06	0.07 - 0.32	0.70	0.28	0.14 - 0.97	4.58	233.73	229.15
	0.7	0.15	0.08	0.05 - 0.37	0.36	0.08	0.22 - 0.51	2.54	251.02	248.48
	0.6	0.14	0.04	0.07 - 0.23	0.55	0.25	0.14 - 0.89	1.22	270.52	269.30
	0.5	1.00		0-1	0.54	0.19	0.20- 0.84	5.19	293.93	288.74
	0.4	0.79	0.48	0.01 - 0.99	0.37	0.26	0.06- 0.84	3.81	313.87	310.06
	0.3	1.00		0-1	0.56	0.19	0.21 - 0.85	5.22	362.45	357.23
	0.2	0.10	0.02	0.07 - 0.15	0.08	0.04	0.03 - 0.19	5.69	403.50	397.81
	0.1	0.72	0.69	0.002 - 0.99	0.29	0.32	0.01 - 0.89	5.66	487.78	482.13

Table S4. Factors affecting the detection probability studied mammal species in Ripu RF, Assam, India. *indicate statistical significance as defined by $\beta \pm 1.96 \times SE$ not overlapping 0.

Sambar	K	AIC	Δ AIC	oi	Covariate	β Estimate	SE
$p(.)\psi(.)$	2	274.81	0	0.46			
$p(EF)\psi(.)$	3	276.56	1.75	0.19	EF	0.13	0.248
$p(LS)\psi(.)$	3	276.8	1.98	0.17	LS	-0.0925	0.669
$p(SUB)\psi(.)$	4	277.23	2.42	0.14	SUB2	-0.5325	0.431
					SUB3	-0.0568	0.828
$p(LS+SUB)\psi(.)$	5	279.23	4.41	0.05	LS	-0.0445	0.677
					SUB2	-0.5308	0.432
					SUB3	-0.0619	0.828
Spotted Deer	K	AIC	Δ AIC	oi	Covariate	β Estimate	SE
$p(LS)\psi(.)$	3	215.5	0	0.474	LS*	-2.139	1.056
$p(LS+SUB)\psi(.)$	5	215.85	0.35	0.399	SUB2	-0.11	0.489
					SUB3	-9.45	63.241
					LS*	-2.142	1.059
$p(EF)\psi(.)$	3	219.77	4.27	0.056	EF	-0.403	0.248
$p(.)\psi(.)$	2	220.55	5.05	0.038			
$p(SUB)\psi(.)$	4	220.8	5.3	0.033	SUB2	-0.283	0.472
					SUB3	-8.954	50.617
Barking deer	K	AIC	Δ AIC	oi	Covariate	β Estimate	SE

$p(\text{SUB})\psi(\cdot)$	4	329.59	0	0.564	SUB2*	0.793	0.335
					SUB3	1.254	0.697
$p(\text{LS}+\text{SUB})\psi(\cdot)$	5	330.9	1.31	0.293	SUB2	0.793	0.336
					SUB3	1.284	0.705
					LS	-0.306	0.369
$p(\cdot)\psi(\cdot)$	2	333.64	4.05	0.075			
$p(\text{LS})\psi(\cdot)$	3	335.01	5.42	0.038	LS	-0.288	0.362
$p(\text{EF})\psi(\cdot)$	3	335.43	5.84	0.03	EF	0.076	0.165
Wild boar	K	AIC	ΔAIC	ωi	Covariate	βEstimate	SE
$\psi(\cdot)\theta(\cdot)p(\text{LS})\theta'(\cdot)\theta^{\text{F}}(\cdot)$	5	279.03	0	0.353	LS	-0.824	0.574
$\psi(\cdot)\theta(\cdot)p(\cdot)\theta'(\cdot)\theta^{\text{F}}(\cdot)$	4	279.21	0.18	0.322			
$\psi(\cdot)\theta(\cdot)p(\text{EF})\theta'(\cdot)\theta^{\text{F}}(\cdot)$	5	280.29	1.26	0.188	EF	0.202	0.210
$\psi(\cdot)\theta(\cdot)p(\text{SUB})\theta'(\cdot)\theta^{\text{F}}(\cdot)$	6	282.19	3.16	0.073	SUB2	0.011	0.446
					SUB3	0.219	0.812
$\psi(\cdot)\theta(\cdot)p(\text{SUB}+\text{LS})\theta'(\cdot)\theta^{\text{F}}(\cdot)$	7	282.43	3.4	0.064	SUB2	0.060	0.450
					SUB3	0.196	0.785
					LS	-0.760	0.585
Elephant	K	AIC	ΔAIC	ωi	Covariate	βEstimate	SE
$\psi(\cdot)\theta(\cdot)p(\text{LS})\theta'(\cdot)\theta^{\text{F}}(\cdot)$	5	368.905	0	0.628	LS	-0.757	0.484
$\psi(\cdot)\theta(\cdot)p(\text{EF})\theta'(\cdot)\theta^{\text{F}}(\cdot)$	5	371.305	2.4	0.189	EF	0.026	0.270
$\psi(\cdot)\theta(\cdot)p(\text{SUB})\theta'(\cdot)\theta^{\text{F}}(\cdot)$	6	371.385	2.48	0.181	SUB2	-0.661	0.517
					SUB3	-0.165	1.018
$\psi(\cdot)\theta(\cdot)p(\cdot)\theta'(\cdot)\theta^{\text{F}}(\cdot)$	4	382.375	13.47	0.0007			
$\psi(\cdot)\theta(\cdot)p(\text{SUB}+\text{LS})\theta'(\cdot)\theta^{\text{F}}(\cdot)$	7	385.455	16.55	0.0002	SUB2	0.147	0.350
					SUB3	0.568	0.726
					LS	-0.612	0.379
Leopard	K	AIC	ΔAIC	ωi	Covariate	βEstimate	SE
$p(\text{LS}+\text{SUB})\psi(\cdot)$	5	255.57	0	0.594	SUB2*	0.878	0.405
					SUB3	-0.868	1.113
					LS*	-1.265	0.646
$p(\text{LS})\psi(\cdot)$	3	257.55	1.98	0.221	LS*	-1.39	0.647
$p(\text{SUB})\psi(\cdot)$	4	258.47	2.9	0.139	SUB2*	0.916	0.39
					SUB3	-0.954	1.101
$p(\cdot)\psi(\cdot)$	2	261.56	6	0.03			
$p(\text{EF})\psi(\cdot)$	3	262.7	7.14	0.017	EF	0.186	0.201

Fig. S2. McMc output diagnostic plot (top) and marginal probabilities (below) showing the model fit and positive influence of proportion of semi-evergreen and moist-mixed deciduous forest in the site use probability of gaur.

Table S5. List of confiscated materials and illegal activities recorded by forest department along with conservation volunteers in Ripu Reserve Forest during January 2014 to September 2015.

Sl. No.	Date	Locality	Illegal activities/Confiscated articles
1	11.01.2014	Jirampur	Seized 18 logs
2	22.01.2014	Ride No. 8	Seized seven logs
3	02.02.2014	Near Sankosh river	Hunting machan damaged
4	10.02.2014	Lungsubil, Nilwundobha, Ride No. 9	Bicycle & hunting machan damaged
5	03.03.2014	Ballamjhora	Eight buffalo-cart with logs seized
6	07.03.2014	Ride No. 6	One buffalo-cart damaged
7	10.03.2014	Bamuni Nala 10 Ride No.	28 logs seized
8	11.03.2014	Maulakhola, Ride No. 1	Three logs seized
9	13.03.2014	Bhaoramunda, Ride No. 6	Three bicycle damaged
10	15.03.2014	Ride No. 6, Ranga Block	Seized seven logs; three bicycle and one pull cart damaged
11	28.03.2014	Zamduar SSB camp Ride No. 9	Poacher caught with local-made guns and a spotted deer
12	01.04.2014	Near Zamduar SSB camp	Poacher caught with local-made guns with a spotted deer
13	03.04.2014	Ride No. 9, Sindrinala	Three bicycle seized
14	08.04.2014	Ride No. 4, Janaligaon	Three bicycle seized
15	14.04.2014	Timijhora near plantation area	Seized eight logs and eight bicycle
16	20.04.2014	Boroghpa, Sonkosh River	Seized two logs
17	26.04.2014	Ballamjhora via Kusumbil Road	Six bicycle damaged
18	06.05.2014	Dudekhola, Ride No. 5	13 logs seized
19	16.05.2014	Ride No. 5, Nearby Ranga River	Four logs seized
20	17.05.2014	Ride No. 6	Seven logs seized
21	02.12.2014	Sialmari	Two logged pull-cart seized
22	23.03.2015	Sanfan Range, Ride No. 1 to 5	11 pull-cart was seized and damaged
23	23.03.2015	Jalashri to Nobinnagar	Four Pull-cart with Logs was seized
24	24.03.2015	Ride No.4 to 7, Central Range	One Bi- cycle and Three Pull- Cart Seize
25	26.03.2015	Ride No. 2 to 7, Sanfan Range	Four pull-cart with logs seized
26	26.03.2015	Sanfan Range	One Pull-cart was seized
27	28.03.2015	Ride No. 2 to 7	Three tyre vehicle and 10 Pull-cart with logs seized
28	31.03.2015	Central Range, Ride No. 4 to 9	Three logging pull-cart was damaged
29	01.04.2015	Central Range, Ride No. 3 to 10	Three truck with logs seized
30	10.04.2015	Sanfan Range	Four pull cart and two of bi-cycle seized with logs
31	10.04.2015	Ride No. 10, Central Range	Seven logs with pull cart seized
32	13.04.2015	Ride No. 4 to 10, Central Range	Six buffalo cart and seven Pull cart with logs seized
33	13.04.2015	Ride No 3 to 10, Sanfan Range	Three pull cart and one bi-cycle with logs seized
34	22.04.2015	Sanfan Range	Two pull cart with logs was seized
35	25.04.2015	Central Range	Four Buffalo cart and two vehicle with logs seized
36	28.04.2015	Ride No. 2	One logging pull cart seized and damaged
37	30.04.2015	Sanfan Range	One pull cart with logs seized
38	04.05.2015	Ride No. 9 to 10 Central and Sanfan Range	Six pull cart with logs and eight Buffalo cart with logs, one Bolero-camper vehicle with full of logs seized
39	08.05.2015	Sanfan and central Range	Six pull cart with logs was seized

40	13.05.2015	Ride No. 6, Sanfan Range	Three pull cart with logs was seized and damaged
41	14.05.2015	Ride No. 4 to 7, Central and Sanfan Range	Six pull cart with full of logs was seized
42	18.05.2015	Sanfan Range	Four pull cart was seized with logs
43	23.05.2015	Sanfan and central range	One bi-cycle with logs was seized
44	02.06.2015	Sanfan Range	Seven pull cart and two bi-cycle with full of logs seized
45	13.06.2015	Sanfan Range	D.L. Safari car with full of logs seized
46	10.06.2015	Sanfan Range	Four pull cart with logs seized
47	15.06.2015	Ride No. 5 to 6	Five Tractor and four pull cart with logs seized
48	16.06.2015	Sanfan and Central Range	Three pull cart and two bi-cycle seized
49	17.06.2015	Sanfan Range	Three Bi-cycle was damaged
50	17.06.2015	Sanfan Range	Tata Magic with full of logs was seized
51	19.06.2015	Central Range	Two pull cart damaged
52	19.06.2015	Central and Sanfan Range	One Mini-Truck with logs seized
53	21.06.2015	Sanfan Range	Two pull cart was damaged with logs
54	26.06.2015	Sanfan and Central Range	Three pull cart was seized with logs
55	18.07.2015	Sanfan Range	Two Tractor, three Bi-Cycle with logs was seized

Table S6. List of mammalian species encountered (photographed, direct sighting, interviewed conservation volunteers) in Ripu Reserve Forest, Assam, India.

Sl. No.	Common Name	Scientific Name	IUCN Status
1	Barking deer	<i>Muntiacus muntjak</i>	Least Concern
2	Spotted deer	<i>Axis axis</i>	Least Concern
3	Sambar deer	<i>Rusa unicolor</i>	Vulnerable
4	Gaur	<i>Bos gaurus</i>	Vulnerable
5	Wild pig	<i>Sus scrofa</i>	Least Concern
6	Asian elephant	<i>Elephas maximus</i>	Endangered
7	Asiatic Black bear	<i>Ursus thibetanus</i>	Least Concern
8	Common leopard	<i>Panthera pardus</i>	Vulnerable
9	Jungle cat	<i>Felis chaus</i>	Least Concern
10	Leopard cat	<i>Prionailurus bengalensis</i>	Least Concern
11	Wild dog	<i>Cuon alpinus</i>	Endangered
12	Crab eating mongoose	<i>Herpestes urva</i>	Least Concern
13	Grey mongoose	<i>Herpestes edwardsii</i>	Least Concern
14	Common Palm civet	<i>Paradoxurus hermaphroditus</i>	Least Concern
15	Small Indian civet	<i>Viverricula indica</i>	Least Concern
16	Large Indian civet	<i>Viverra zibetha</i>	Least Concern
17	Yellow throated marten	<i>Martes flavigula</i>	Least Concern
18	Indian hare	<i>Lepus nigricollis</i>	Least Concern
19	Indian Crested Porcupine	<i>Hystrix indica</i>	Least Concern
20	Malayan Giant Squirrel	<i>Ratufa bicolor</i>	Near Threatened
21	Hoary-bellied Squirrel	<i>Callosciurus pygerythrus</i>	Least Concern
22	Himalayan Striped Squirrel	<i>Tamias mccllellandii</i>	Least Concern
23	Chinese Pangolin	<i>Manis pentadactyla</i>	Endangered
24	Rhesus Macaque	<i>Macaca mulatta</i>	Least Concern
25	Golden langur	<i>Trachypithecus geei</i>	Endangered

Fig S3. Patrolling effort and glimpses of anthropogenic activity recorded in Ripu RF during 2014-2015. Poached barking deer (A & B), spotted deer (C & D), gaur (E); hunting machan (F, G, H); Poachers along with guns and buffalo and logs (I); Bicycle sized by forest department and conservation volunteers (J); Logging activity in Ripu (K, L, M, N, O); sign survey and patrolling team (P, Q, R).