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Looking beyond protected areas: Identifying conservation compatible landscapes in agro-forest mosaics in north-eastern India

Aritra Kshettry [a, b, c, d, e, *], Srinivas Vaidyanathan [f], Raman Sukumar [e], Vidya Athreya [c]

[a] INSPIRE-Fellow, Department of Science and Technology, Government of India, Technology Bhavan, New Mehrauli Road, New Delhi, 110016, India
[b] Manipal Academy of Higher Education, Manipal, 576104, India
[c] Wildlife Conservation Society-India, 551, 7th Main Road, 2nd Stage, Rajiv Gandhi Nagar, Kodigehalli, Bengaluru, Karnataka, 560097, India
[d] Centre for Wildlife Studies, 37/5, Yellappa Chetty Layout, Ulsoor Road, Bengaluru, 560042, Karnataka, India
[e] Centre for Ecological Sciences, Indian Institute of Science, Third Floor, New Biological Sciences Building, Indian Institute of Science, Bengaluru, Karnataka, 560012, India
[f] Foundation for Ecological Research, Advocacy and Learning, 170/3 Morrattandi, Auroville Post, Tamil Nadu, 605101, India

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ABSTRACT

Small-sized protected areas face increasing pressures from developmental activities and are often rendered inadequate and isolated to conserve wide-ranging species. However, in situations where wildlife persists outside protected areas, conservation goals may be met by aligning the ecological needs of wildlife with the socio-economic needs of local communities and offsetting losses arising due to shared spaces. We explore the potential of a tea-plantation dominated landscape of multiple land-use in north-eastern India to conserve the Asian elephant and the Indian leopard. We assess conservation potential by identifying predictors of species use of particular habitats using species distribution models and identify challenges by reviewing the available literature. Elephants used ~680 km^2 of this 1200 km^2 non-forested landscape; within this area, habitats with a higher proportion of deciduous forest patches were favored. Leopards were found to be ubiquitous in tea-plantation and used ~950 km^2 of the study area, with the proportion of tea cover being the single best predictor of leopard habitat-use. With more than 30 human deaths and 100 injuries per year caused by these two species in the study area alone, the high frequency of human casualties and economic losses remain the prime hurdles to long-term conservation efforts. We discuss specific mitigation measures to reduce human casualties and call for the inclusion of important stakeholders in the mitigation process. The study provides a template for identifying conservation-compatible landscapes outside protected areas and a framework for identifying challenges and potential to mitigate current or future conservation conflicts.

* Corresponding author. Address: 55, Harish Mukherjee Road, Kolkata, P.O: 700025, West Bengal, India.
E-mail address: aritra.kshettry@gmail.com (A. Kshettry).

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1. Introduction

Protected areas (PAs) have been the cornerstone of terrestrial wildlife conservation globally, but current PA networks are often inadequate to conserve all species (Chape et al., 2005). This is especially true for large-bodied and wide-ranging species which require vast stretches of land to fulfill their ecological needs (Sukumar, 2003; Ripple et al., 2014). Land under PAs is especially low in densely-populated countries where wildlife conservation is often pitted against development goals and food security (Rodrigues et al., 2004). Land sharing between people and wildlife is a commonly advocated approach in areas where the existing PA network is insufficient to meet conservation targets (Jiang et al., 2017). Adopting land sharing strategies in broader landscapes warrants knowledge of multiple disciplines from the social sciences to economics, as well as ecological studies on wildlife outside of 'wilderness' areas. While human dimensions of sharing space with wildlife have been explored in some cases, it is still a nascent discipline of research (Jalais, 2007; Barua et al., 2013; Barua, 2014). On the other hand, a lot of research has focused on understanding species requirements through long term ecological research focusing on charismatic taxa (Karanth and Sunquist, 1995; Wittemyer and Getz, 2007; Wasser et al., 2011; Fattebert et al., 2013). However, since these studies are mostly conducted within protected areas, the results may not be applicable to poorly studied systems such as human-use areas (Ghosal et al., 2013; Kshettry et al., 2017).

Ecological studies on large wildlife outside PAs are slowly gaining ground with researchers realizing the variation in the ecological adaptations of even 'potentially dangerous' species (Fernando et al., 2008b; Gehrt et al., 2010; Athreya et al., 2013; Navya et al., 2014; Odden et al., 2014; Vickers et al., 2015; Kshettry et al., 2018; Srinivasaiah et al., 2019). Although shared spaces appear to be the norm since historical times, there is now a greater need for understanding the ecology of large carnivores and megaherbivores persisting outside PAs or using areas outside wilderness zones to mitigate negative impacts of these shared spaces. In countries with high human densities, this presents challenges as well as opportunities to conserve wildlife species over larger human-use landscapes. While the opportunities include the conservation potential of certain human-use landscapes for the persistence of wide ranging species, economic losses, human casualties and wildlife mortality present significant conservation challenges (Treves and Karanth, 2003; Palmeira et al., 2015; Penteriani et al., 2016; Kshettry et al., 2018). In order to conserve large-bodied, wide-ranging species across human-use areas in a land-sharing model, identifying suitable habitats as well as minimizing existing or potential conservation conflicts is essential (Woodroffe et al., 2005). Landscapes where large wildlife conservation goals are made compatible with local livelihoods and human safety may be the way forward in the face of limited protected area network (land sparing) and wide-ranging habits of such species. However, such landscapes are rarely considered in species conservation programmes since the dominant focus is still on protected area networks as arks of wildlife persistence (Chape et al., 2005).

Even in conservation prioritization, the focus is still largely on so-called "pristine wilderness" in mega-diverse areas, biodiversity hotspots and areas with endemic species, where the focus is on the vulnerability rather than conservation opportunity of species and habitats (Brooks et al., 2006). To illustrate the current potential of conservation compatible landscapes in wildlife conservation, we highlight some systems where space sharing exists between people and even potentially damage-causing wildlife. Puma (*Puma concolor*), jaguar (*Panthera onca*), leopard (*Panthera pardus*), Asian elephant (*Elephas maximus*), African elephant (*Loxodonta africana* and *L. cyclotis*), brown bear (*Ursus arctos*), wolf (*Canis lupus*), Asiatic lion (*Panthera leo*) and many other globally threatened species persist in significant numbers outside protected area boundaries in human-inhabited areas (Singh and Gibson, 2011; Morell, 2013; Chapron et al., 2014; Ripple et al., 2014; Athreya et al., 2015; Madhusudan et al., 2015). Wolves have re-colonized parts of America and Europe after the cessation of years of extermination (Chapron et al., 2014; Olson et al., 2015). Today, wolves are found in human-use areas across much of their range where they exist in close proximity to people (Jhala and Giles, 1991; Chavez et al., 2005; Majgaonkar et al., 2019). The leopard is another such species which persists in close proximity to people across some of its range especially in densely populated countries of South-East Asia (Jacobson et al., 2016). The Asiatic lion has also made a remarkable comeback and have expanded their range considerably close to human-use areas (Singh and Gibson, 2011). Even large herbivores such as elephants persist outside protected spaces and are found close to human settlements and even depend on anthropogenic food sources (Sukumar, 1990; Fernando et al., 2008b; Madhusudan et al., 2015; Krishnan et al., 2019).

The aim of this study is to explore the conservation potential and prioritization of non-protected spaces (such as tea-plantations) without undermining the importance of protected areas (National Parks, Wildlife Sanctuaries, Reserve Forests in the Indian context) in species conservation. India has the largest global population of the Asian elephant and approximately 80% of the current range of the species in India lies outside protected areas (Sukumar, 2006; Goswami et al., 2014). However, the current focus of managing the elephant is still largely centered on protected areas while non-forested areas are often outside the purview of proactive conservation efforts, in spite of the flagship conservation programme, Project Elephant, emphasizing a landscape approach (RS personal observation). The leopard is another species which is commonly found in human-use areas across its range in India, yet assessments of its habitat usage, interactions with people as well as its conservation outside protected spaces is rarely explored (Ghosal et al., 2013; Kshettry et al., 2017).

To highlight the conservation potential of shared spaces, we focused on a landscape where both species, the leopard and the elephant co-occur along with high density of people in North-Eastern India. To understand the ecological basis of shared spaces and the opportunities in the landscape for species conservation, we attempted to understand the correlates of habitat usage of these two species when they occur outside protected areas. Our primary hypothesis was that these two species would use habitats much larger that the PA network which is currently allocated for wildlife conservation. Further, we hypothesized that elephant habitat use in non-protected spaces would be higher along corridor areas and areas with higher canopy cover since elephants use such areas to rest during the day and move during the night. We also hypothesized that leopard habitat use outside the protected areas would be largely determined by the presence of tea-bushes since prior studies in the landscape indicate that tea-plantations are suitable leopard habitats (Kshettry et al., 2017). Furthermore, we also draw from literature and our previous studies on the impacts these species have on the lives and livelihoods of the local communities to identify the conservation challenges and opportunities of this landscape. We also provide a framework for interventions which may be applicable to mitigate the challenges and thereby promote long term and sustained local conservation support. We selected this landscape since elephants and leopards are both found here and there is a history of ecological research on these species in the region. Furthermore, challenges to conserving these species outside protected areas is nowhere greater that this landscape due to the high frequency of human casualties due to elephants and leopards which is one of the highest in the world (Sukumar, 1989; Sitati et al., 2003; Kioko et al., 2006; Athreya et al., 2011; Ramkumar et al., 2014; Pant et al., 2016; Packer et al., 2019). In this study we look at the opportunities as well as challenges for the conservation of potentially dangerous charismatic wildlife species such as elephant and leopard outside of designated protected areas in a densely populated landscape.

2. Methods

2.1. Study area

The Indian subcontinent presents several opportunities to identify conservation landscapes for a variety of reasons. First, despite the high density of people, India still retains all its charismatic mega-fauna with the exception of the Asiatic cheetah (*Acinonyx jubatus venaticus*) and Sumatran rhino (*Dicerorhinus sumatrensis*); the mammalian fauna of the Indian subcontinent has persisted almost intact over the past 200,000 years in spite of substantial ecological pressures (Roberts et al., 2014). Furthermore, existing laws accord high levels of protection to large wildlife species even if they exist outside protected areas. We focus this study in a landscape dominated by tea (*Camellia sinensis*) plantations in north-eastern India. The region comprises of the states of West Bengal and Assam with a combined tea-plantation cover of ~4000 km^2, one-third of which lies in West Bengal (https://www.indiatea.org/tea_growing_regions accessed on October 8th, 2018). The landscape is a mosaic of tea-plantations interspersed between forest fragments of various sizes (Fig. 1a). The region is also part of the Indo-Myanmar Biodiversity Hotspot (Myers et al., 2000) and is rich in faunal and floristic diversity including the Asian elephant, Greater one-horned rhino (*Rhinoceros unicornis*), tiger (*Panthera tigris*) (in some parts only), leopard and a host of other wildlife species (Kshettry et al., 2017). The region also has high human density with 700 people per km^2 in the intensive study area of approximately 2000 km^2 (Fig. 1b) on the West Bengal side (Kshettry et al., 2017). The study area has an average annual rainfall of about 3000 mm with elevation of 100 m a.s.l to 500 m a.s.l and is flanked by the densely-forested foothills of the Himalaya in the north (Fig. 2a). Agricultural areas typically mark the southern boundary of the study area without patches of forest or tea-estates (Fig. 2a). The eastern side of the study area has similar fragments of tea-plantations and forest patches (Jaldapara National Park and Buxa Tiger Reserve). The western side of the area is represented by the perennial Teesta river which marks a natural boundary for restricting animal movement. However, elephants are known to cross the river further downstream to move into the forest patches on the Western side which includes the Mahananda Wildlife Sanctuary (Fig. 3a).

Historically, the landscape comprised of tropical moist deciduous forests dominated by Sal (*Shorea robusta*) and silk cotton (*Bombax ceiba)* along with riverine grasslands. Large stretches of these forests were cleared to set up tea-estates in the late 1800s during British rule and this land-use has remained largely unchanged since then (Chatterjee, 2001). The workforce (entirely tribal people) for these estates was brought from the dry and arid Chotanagpur Plateau which lies to the southwest of the region in east-central India (Chatterjee, 2001; Moxham, 2003). There have been reports of leopard presence in these areas since colonial times (Daniel, 1996), while elephants also have been part of the landscape before the tea-plantations were set up (Sivaramakrishnan, 1999). Presently, the tea-estates are embedded in a larger matrix of agricultural lands, human-habitations as well as forest fragments. The persistence of leopards in these tea-estates and its usage by elephants has also led to high number of human casualties and economic losses in the region (Kshettry et al., 2017; Roy, 2018). However, despite the high quantum of losses, the attitudes of people towards these wildlife species are often positive with a high acceptance towards wildlife in the region due to cultural, social and legal factors (Sivaramakrishnan, 1999; Bhattacharjee and Parthasarathy, 2013; Naha et al., 2018; Naha et al., 2019). The people who share space with these species are mostly the tea-estate workers of tribal origin who are extremely impoverished and marginalized with an average daily wage of less than 3 USD. Poverty and under-nutrition is widespread with many tea-estates being shut down for intermittent periods resulting in even more hardships and social disruptions (Chatterjee, 2001).

2.1.1. Assessing conservation opportunity: sampling design

We attempted to understand the ecological and anthropogenic correlates which enable the persistence of elephants and leopards in human-use spaces using species distribution models based on sign surveys across this landscape (Goswami et al., 2014; Kshettry et al., 2017). We hypothesized that elephant and leopard presence in the landscape would be determined by ecological as well as anthropogenic covariates (Table 1). This understanding would enable us to prioritize areas in the landscape for long term conservation of these species as well as identify areas to focus conservation-conflict mitigation efforts. We focused on a two-species, large herbivore-carnivore system since conservation prioritization may differ substantially between large herbivores and large carnivores due to varying ecological needs.

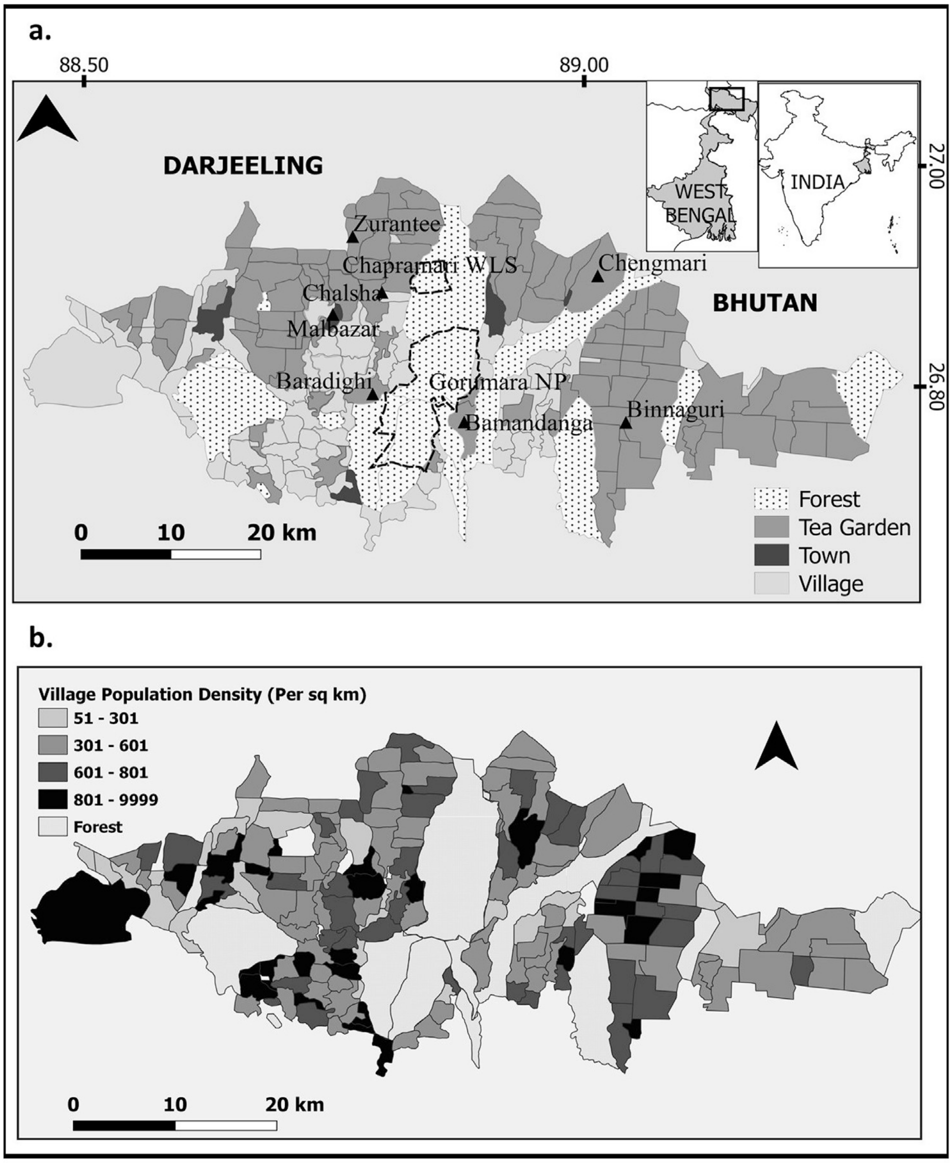

Fig. 1. Maps showing **a.** location of the study area and broad land-use categories and **b.** variation in human population density across the study area.

We sampled ~1200 km^2 of non-forested areas comprising of tea-estates, human habitations and agriculture fields. We left out forested areas and PAs from this study since these are already available for wildlife conservation, and the primary aim of our study was to understand habitat use outside these areas. We adopted a systematic sampling framework where the entire study area was divided into 4 km^2 grid cells (Goswami et al., 2014; Kshettry et al., 2017). Trained researchers surveyed trails in each grid for a minimum of 2 km while ensuring spatial coverage of the entire grid cell by subdividing each cell into four sub-cells and walking in each of the sub-cells. Signs of elephants (dung, footprint, feeding signs) and leopards (scat, scrape, kill, pugmark) were recorded for every 200 m segment. Each 200 m segment along the trail was treated as a spatial replicate (Hines et al., 2010).

The data were analyzed in an occupancy modeling framework where detection or non-detection of signs of these species in each grid cell was recorded, and their presence or absence inferred after accounting for imperfect detection (MacKenzie et al., 2002). The presence or absence of these species was then regressed against ecological and anthropogenic covariates in a logistic regression framework using the software PRESENCE (Hines, 2006). The covariates used for each species and the *a priori* expected relationships have been provided in Table 1. The methods used to derive the covariates have been provided in Supplementary Material. Program R (Version 3.5.0) was used to extract the covariates using packages GGPLOT2, rGDAL, Raster, MAPTOOLS (R Core Team, 2013; Wickham and Chang, 2014). Since the grid sizes were small and the habitat variables could be spatially auto-correlated, we also included the mean covariate value from the first order neighbouring cells as an

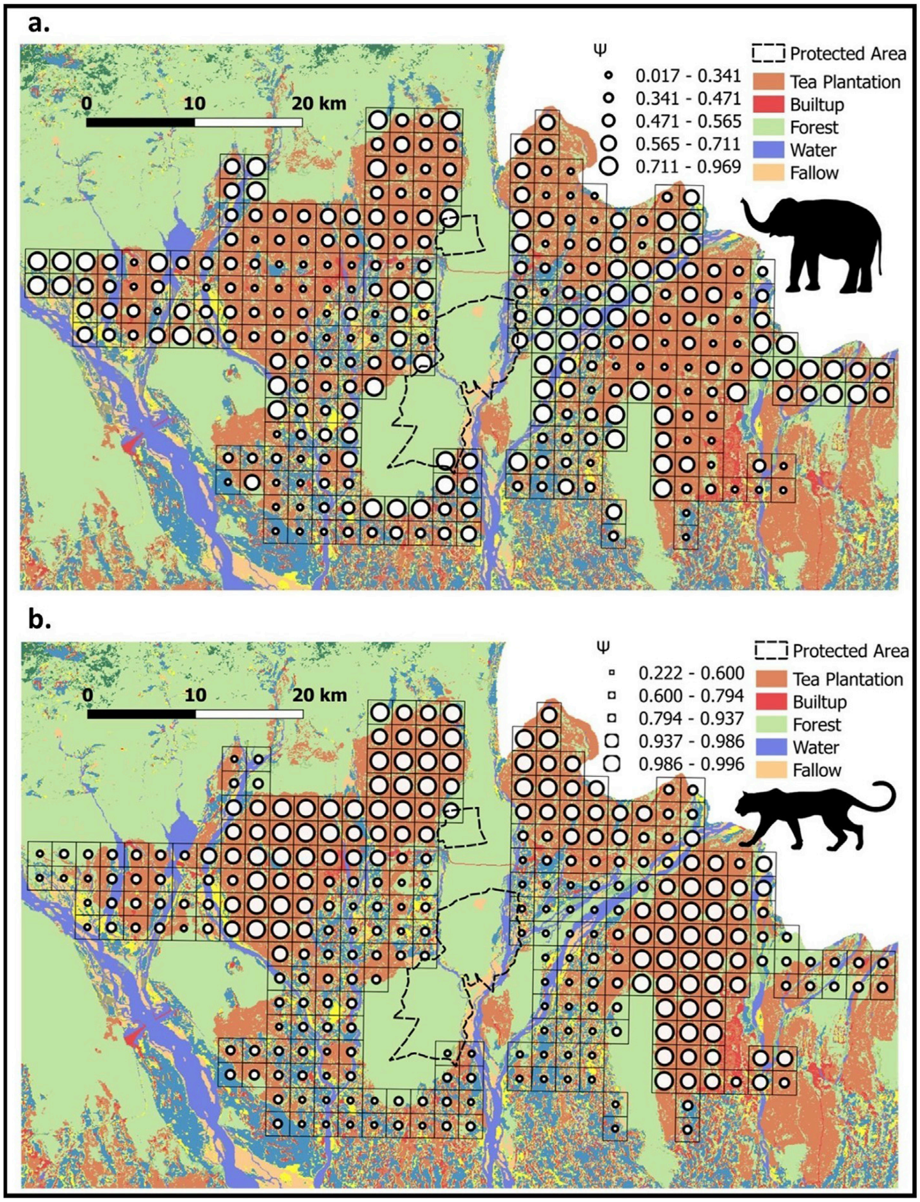

Fig. 2. Maps showing **a.** variation in probability of site-use by elephants and land cover types of the study area and adjoining areas and **b**. variation in probability of site-use by leopard and land cover types of the study area and adjoining areas in northern West Bengal, India.

additional covariate for the focal cell to account for this possible spatial correlation. The predictors were checked for correlation and over dispersion and only non-correlated ($r< |0.7|$) predictors were used in the final analysis after centering to Z-scores for scaling.

The parameter of interest in the model was the probability of habitat-use (Ψ) and probability of detecting the species in a replicate (p_t), given that the species is present in the replicate. The model building approach was similar to that described in Kshettry et al. (2017) where models with variables influencing the probability of detecting a species was first fixed while maintaining a global model for probability of habitat-use. Subsequently, the model for detection probability was kept constant while building the models for probability of habitat use.

2.2. Evaluating conservation challenges: literature review and stakeholder mapping

We carried out a review of the legal framework for the conservation of these species, local attitudes, losses faced by people as well as relationships between local people and large wildlife (elephant and leopard) in the region. We used a Web of

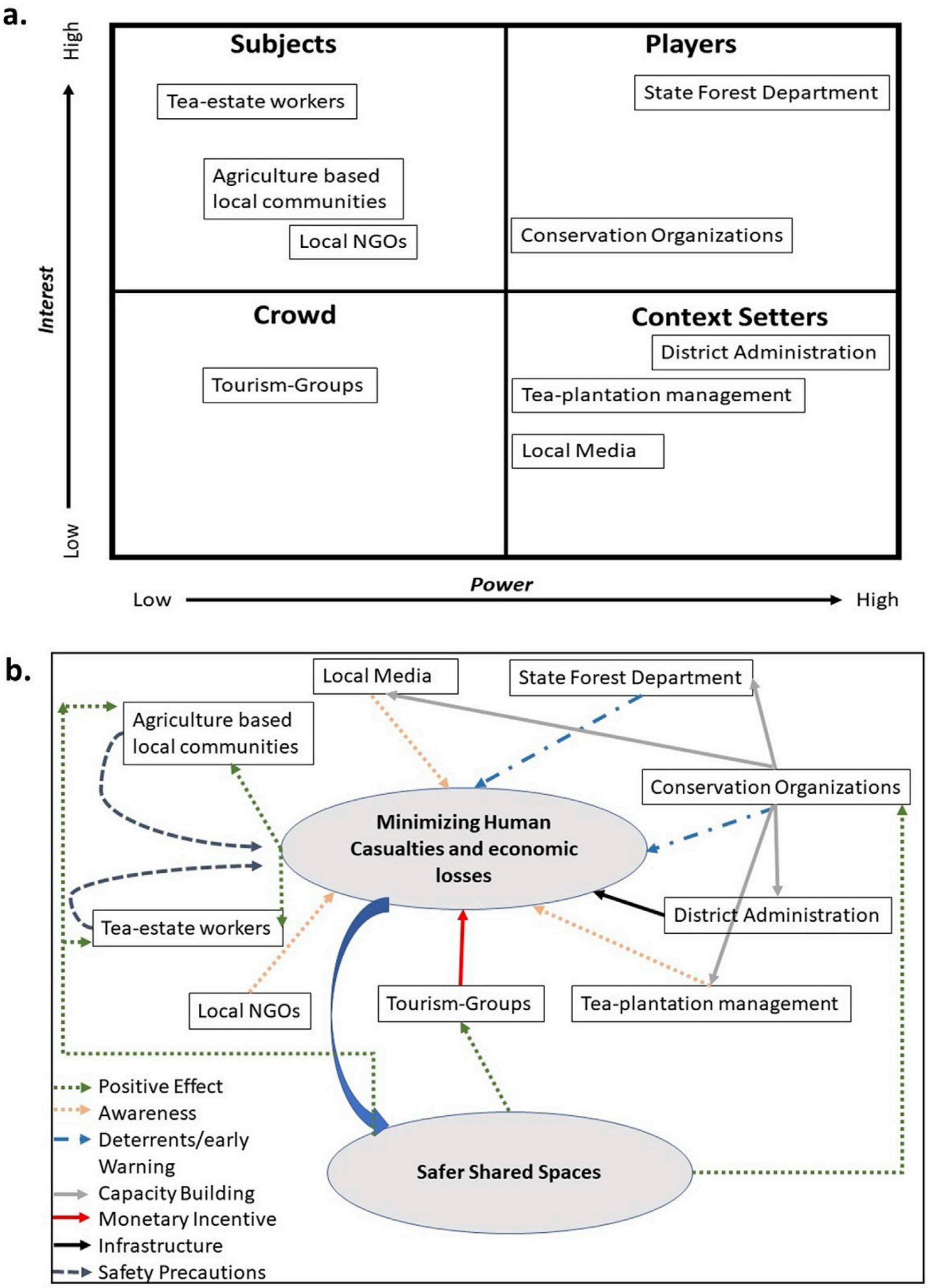

Fig. 3. **a**. Power versus interest grid mapping they key stakeholders in the region and **b**. Potential role of the various stakeholders in minimizing negative impacts of wildlife on people.

Science (https://login.webofknowledge.com accessed on October 15th˒ 2018) search with the keywords ‘leopard’ AND ‘bengal’, ‘elephant’ AND ‘bengal’. We also carried out a Google search for secondary literature with the keywords ‘Elephant, Leopard, Research, Bengal, Report ‘. Furthermore, we also attempted to interpret existing wildlife laws in the state to understand the protection status of these species both inside and outside protected areas. Based on the available literature and our experience of working in the same landscape for more than 5 years, we identified the major stakeholders and mapped them according to the power versus interest axis (Eden and Ackermann, 2013). We also outlined the potential role each of the key stakeholders can play to minimize the negative impacts of shared spaces in the landscape. We draw heavily on

Table 1
Covariates used in the models and the *a priori* relations.

Species	Covariates	Expected Relationship	References
Elephant	Proportion of agriculture area	+ve	Srinivasaiah et al. (2019)
	Proportion of tea-plantation	+/−	NA
	Proportion of deciduous forest	+ ve	Jathanna et al. (2015)
	Distance to forest	- ve	NA
	Density of habitations	-ve	NA
Leopard	Encounter rate of prey	+ve	Kshettry et al. (2018)
	Proportion of tea-plantation	+ve	Kshettry et al. (2017)
	Proportion of agriculture	-ve	Kshettry et al. (2017)
	Density of habitations	-ve	Kshettry et al. (2017)
	Distance to forest	+/-	

stakeholder theory to develop the framework on identifying the key players, their current roles and potential contributions to mitigate conflicts in the region (Phillips et al., 2003). For each paper/report/book reviewed, we noted the year of publication, theme of the study, framework for analyses (key methods), data source, key results, recommendations (if any), key stakeholders (focus groups/respondents) and if any social aspects such as local attitudes/behaviour towards the focal wildlife species have been studied or not. Further, we also noted from the paper any mention of the agencies/interest groups/stakeholders who are affected by the issue or can enable positive change to minimize negative interactions.

3. Results

3.1. Habitat-use patterns: conservation opportunities

The survey covered 295 grid cells (1180 km^2) with a walk effort of 663 km. The mean walk effort per 4 km^2 cell was 2.2 (±0.01 SE) km. Elephant signs were recorded in 33% of all cells and leopard signs recorded in 31% of all cells. However, after accounting for imperfect detections, 57% of all sites were determined as being used by elephants (Fig. 2a) whereas 79% of the study area was used by leopards (Fig. 2b). The area used by elephants in the non-forested space added to 684 km^2 whereas 932 km^2 in this human-use area was also used by leopards.

3.1.1. Elephant

There was no single top model for elephant habitat use; the top three models which were within delta AIC of 2 comprised of four predictors, distance to forests, density of human habitations, proportion of deciduous forest patches and proportion deciduous of forest patches in neighbouring cells (Table 2). Increasing distance to forests ($\beta = -0.26$, ±0.12) and higher number of human habitations ($\beta = -0.002$, ±0.0007) decreased the probability of habitat use in elephants. Increased proportion of deciduous forest patches ($\beta = 0.75$, ±0.59) increased the probability of habitat use in elephants, the proportion of forest patches in neighbouring cells also increased ($\beta = 0.83$, ±0.75) habitat use in elephants. While elephants were found in the tea-plantation areas, habitat use in other land-use types was also high. Habitat use was distinctly higher in cells located in between two adjoining forest patches (Fig. 2a) indicating that elephants use this landscape to move between forested areas. Fifty-seven percent of the study area had evidence of elephant-use which means that elephants are using over 670 km^2 in the areas outside the PA within the 1200 km^2 study area. Currently, only 88 km^2 has been assigned to conservation under the protected area paradigm.

Table 2
Top models explaining the habitat-use patterns of elephant in the study area.

Model	AIC	Delta AIC	AIC wgt	Model Likelihood	no.Par.	−2*LogLike
psi (building, forest.dist, deciduous),thta0 (.),thta1 (.),p (.),pi (.)	1282.56	0.00	0.50	1.00	8.00	1266.56
psi (building, forest.dist, deciduous,deciduous_1 order),thta0 (.),thta1 (.),p (.),pi (.)	1283.42	0.86	0.33	0.65	9.00	1265.42
psi (building, deciduous),thta0 (.),thta1 (.),p (.),pi (.)	1285.17	2.61	0.14	0.27	7.00	1271.17
psi (buildings),thta0 (.),thta1 (.),p (.),pi (.)	1289.64	7.08	0.01	0.03	6.00	1277.64
psi (forest.dist),thta0 (.),thta1 (.),p (.),pi (.)	1290.81	8.25	0.01	0.02	5.00	1280.81
psi (forest.dist, agriculture, deciduous,deciduous_1 order),thta0 (.),thta1 (.),p (.),pi (.)	1291.45	8.89	0.01	0.01	9.00	1273.45
psi (forest.dist, deciduous),thta0 (.),thta1 (.),p (.),pi (.)	1291.74	9.18	0.01	0.01	7.00	1277.74
psi (forest distance_1 order),thta0 (.),thta1 (.),p (.),pi (.)	1296.79	14.23	0.00	0.00	6.00	1284.79
psi (agriculture),thta0 (.),thta1 (.),p (.),pi (.)	1299.52	16.96	0.00	0.00	6.00	1287.52
psi (deciduous),thta0 (.),thta1 (.),p (.),pi (.)	1302.63	20.07	0.00	0.00	6.00	1290.63
psi (decidious.1 order),thta0 (.),thta1 (.),p (.),pi (.)	1303.35	20.79	0.00	0.00	6.00	1291.35
psi,thta0 (.),thta1 (.),p (.),pi (.)	1303.77	21.21	0.00	0.00	5.00	1293.77

Psi: Probability of habitat-use, thta0,thta1: Spatial dependence parameters, p: replicate level detection probability given replicate is occupied, building: number of buildings in cell, forest.dst: distance to nearest forest patch, deciduous: Area under deciduous forests, deciduous_1 order: Mean area under deciduous forests in 1st order neighbouring cells, agriculture: Area un agriculture.

3.1.2. Leopard

The mean probability of habitat use in the top model was 0.79 (range 0.22–0.99) and the mean standard error was 0.08 (Range 0.01–0.14). The top model for predicting leopard habitat-use was the proportion of large tea-plantation patches (proportion of tea in first order neighbours) (β 1.94 $\pm$ 0.92), the proportion of tea-plantations in the focal cells was also important predictor and was the second best model within a delta AIC of 2 (β 1.15 $\pm$ 0.06) (Table 3). Predictors such as encounter rate of prey and distance to forest had no significant influence on habitat-use by leopards. The leopard distribution map (Fig. 2b) reveals distinct patterns where leopards are ubiquitous in the tea-estates covering the entire northern half of the study area and also the eastern side. The habitat-use map also illustrates that leopards are not using the agricultural landscapes in this area. Seventy-nine percent of the non-forested areas in our study area supports leopard presence which totals 948 km^2.

3.2. Conservation challenges: Status of conservation conflicts

Our literature search resulted in 13 peer-reviewed publications, one book chapter, one conference paper and two reports on these two species from outside protected areas in this landscape (S1 Supplementary material). While five of these papers focused on leopards and their interactions with people, 10 focused on elephant-human interactions while two studies looked at both species. Majority of the studies (8 out of 17) only compiled secondary records on human casualties, economic losses and wildlife mortality from available government records while some studies (6 out of 17) combined secondary records and field interviews and spatial mapping of locations where negative interactions have occurred. Only three studies were based entirely on primary field data. Only two (out of 17) papers investigated human perceptions using structured questionnaire surveys and report contrasting results despite being conducted in the same forest division as our current study area and interviewing local tea-estate workers. The first study published in 2013 on human-leopard encounters and perceptions towards leopards report widespread fear of leopards among the respondents (60% respondents reported that leopards aroused fear and animosity) and was regarded as an 'automatic' enemy (Bhattacharjee and Parthasarathy, 2013). On the other hand, a study published in 2018 found that 75% of the respondents reported positive attitude towards leopards (Naha et al., 2018).

In the study area alone, a total of 108 human deaths due to elephants were reported between 2009 and 2013 in a single forest division (Gorumara Wildlife Division) with an average of 22 cases per year (Roy, 2018). There were 476 human fatalities due to elephants between 2006 and 2016 with an annual average of 47 cases in the entire northern Bengal region comprising eight forest divisions (Naha et al., 2019). Hence, one particular forest division accounts for 46% of all human deaths in the region. The region also witnesses a high frequency of human injuries due to elephants with more than 160 non-fatal cases per year on an average (Naha et al., 2019). Only one study has investigated the circumstances behind human casualties and found that 36% of the cases involved inebriated men trying to chase elephants, 20% were 'accidental' encounters while people were moving at night, seven percent were inside forests during the day and eight percent of the cases were due to house breakage by elephants to access stored food (Naha et al., 2019). Crop damage and damage to buildings is the next major aspect to be explored for human-elephant co-habitation in the study area. Between 2009 and 2013, the study area (Gorumara Forest Division) reported 250 ha of crop damage by elephants (56 ha per year on average) while the entire northern West Bengal region reported more than 18,000 ha of crop fields affected by elephants (4500 ha damage per year on average) during the same period (Das, 2013; Roy, 2018).

Between 2001 and 2008, 243 incidents of human injury by leopards were reported from the study area (34 cases per year on average) which increased to 56 cases per year between 2009 and 2018 (West Bengal Forest Department Records) (Bhattacharjee and Parthasarathy, 2013). However, it is not clear if this merely reflects better reporting or an actual increase in the number of leopard attacks on people. Majority of these incidents (93%) occur within tea-plantations which have been found to be suitable habitats for leopards in previous studies as well as the present study (Kshettry et al., 2017). The incidents occurred predominantly during the day when people were engaged in tea-estate related activities (Kshettry et al., 2017). However, despite high losses faced by local communities, retaliation towards these species are quite low, which could be explained by the legal framework protecting these species in addition to the cultural acceptance towards wildlife.

Table 3
Top models explaining the habitat-use patterns of leopard in the study area.

Model	AIC	Delta AIC	AIC wt	Model Likelihood	no.Par.	-logLik
psi (tea_1st Order),thta0 (.),thta1 (.),p (.),pi (.)	1150.16	0	0.4368	1	6	1138.16
psi (tea),thta0 (.),thta1 (.),p (.),pi (.)	1151.54	1.38	0.2191	0.5016	6	1139.54
psi (frst.dst),thta0 (.),thta1 (.),p (.),pi (.)	1152.48	2.32	0.1369	0.3135	6	1140.48
psi (goat),thta0 (.),thta1 (.),p (.),pi (.)	1152.98	2.82	0.1066	0.2441	6	1140.98
psi (dog),thta0 (.),thta1 (.),p (.),pi (.)	1155.68	5.52	0.0276	0.0633	6	1143.68
psi (frst.dst.1),thta0 (.),thta1 (.),p (.),pi (.)	1156.15	5.99	0.0219	0.05	6	1144.15
psi,thta0 (.),thta1 (.),p (.),pi (.)	1157.38	7.22	0.0118	0.0271	5	1147.38

Psi: Probability of habitat-use, thta0,thta1: Spatial dependence parameters, p: replicate level detection probability given replicate is occupied, tea-1stOrder:Mean area under tea in 1st order neighbouring cells, tea: Area under tea plantation, frst.dst: distance to nearest forest patch, goat: Encounter rate of goats. Dog: encounter rate of dogs, frst.dst.1: Mean distance from nearest forest patch for 1st order neighbouring cells.

The legal framework for wildlife conservation as reflected by Central and State government laws provides for the strict protection of these species even outside protected areas. Currently, the methods adopted to deal with the presence of these species in these landscapes, outside the protected areas are; a. trapping and translocation of leopards; b. driving away elephants from human habitations and c. payment of ex-gratia compensation and compassionate payments for injury, life loss or property damage (Wildlife (Protection) Act 1972, West Bengal Forest Department Sources).

3.3. Key Stakeholders

Stakeholder theory deals with groups of people whose inputs lead to decision-making and groups who are affected by the outcomes of such decisions (Phillips et al., 2003). Based on this premise, the available literature from the study area and our five years of experience in the landscape, we have identified the following primary stakeholders for the study area who would be part of the process to enable safer shared spaces between people and large wildlife in the region: a. tea-plantation workers, b. tea-plantation management, c. State forest department, d. Local/Regional Non-Governmental Organizations (NGOs), e. National/International Conservation Organizations/researchers, f. District Administration, g. Media, h. Agriculture based local communities, and i. Tourism based income groups. Based on the power versus interest grid proposed by Eden and Ackermann (2013), we classified the stakeholders into four primary categories i. Subjects, with high interest but low power, ii. Crowd with low power and low interest, iii. Players with high powers and high interest and iv. Context Setters with high power but low interest (Eden and Ackermann, 2013).

The roles of the stakeholders are summarily mapped in Fig. 3. In the study area, the decision making with respect to wildlife management and conflict mitigation is almost entirely led by the state forest and wildlife department. However, the people that are seriously and directly affected by the damage caused by leopards and elephants are the tea-estate workers and agriculture-based communities as seen in other tea-dominated landscapes of India (Margulies, 2019). Local media is an important interest group since articles in print and digital media can have a direct impact on the attitudes of local people towards wildlife (Bhatia et al., 2013). The district administration and tea-estate administration have high power in minimizing negative impacts by providing infrastructure support such as power fences and solar lights within the tea-estate colonies. The tea-administration could play a key role in minimizing illegal alcohol brewing which is one of the key reasons behind human encounters with elephants (Naha et al., 2019). Local NGOs active in the area could mediate dialogue between the interest groups with power asymmetry. Tourism-related agencies could incentivise shared spaces between wildlife and local communities since tourism is a major industry in the region (Karmakar, 2011).

4. Discussion

Our study assessed the wildlife conservation potential of non-forested landscapes using the Asian elephant and the Indian leopard as flagship species. Elephant habitat-use in the study area was related to the presence of deciduous forest patches in this multi-use landscape. This result is consistent with recent studies where elephants use plantation habitats extensively in the absence of sufficiently large protected areas (Madhusudan et al., 2015; Krishnan et al., 2019). Such habitats provide these large bodied herbivores with cover to rest during the day as well as connectivity to elephant populations since elephants use these habitats to move between forested patches. The obliteration of such patches, conversion to other land uses and/or excluding elephants from these areas would entail significant consequences to population connectivity. On the other hand, preservation and growth of tree cover within strategically located tea-plantations may also help reduce human losses, by providing easy passage to elephants and resting places during the day. Such cover may also enhance local biodiversity, carbon stocks and also lead to increased soil fertility thereby leading to better production of economically important species such as tea (Anand et al., 2010).

Our observations suggest that elephants are currently using 56% (680 km^2) of this non-protected landscape but administrative conservation and management focus is restricted to the 88 km^2 protected area in the region. Our results also indicate that elephants avoid human-habitations at the scale of our study area which has implications for conflict management. Elephant entry into tea-plantation housing colonies is a serious problem in the landscape, however, our results show that the elephants, by and large, avoid proximity to dense human habitation. This could indicate that only certain individual bull elephants may be predisposed to enter housing areas to gain nutritional benefits and would need targeted management actions (Sukumar, 1991; Pokharel et al., 2018). The primary challenges to elephant persistence in these shared landscapes seem to be the high quantum of economic losses as well as unacceptable levels of human casualties (Roy, 2018). The negative interactions, in absence of effective proactive interventions by the relevant stakeholders, could escalate and seriously undermine conservation attitudes among local communities.

Studies on the circumstances of human injuries point to the fact that many such incidents could be avoided as they occur largely due to lack of safety practices, high alcoholism among local people especially the men in the household and a general lack of awareness among people regarding elephant behaviour (Roy, 2018; Naha et al., 2019). Therefore, a significant proportion of these negative incidents should be reduced by targeted conservation awareness, education and safety practices which need to be taken up by the relevant stakeholders in the region. Economic losses may be offset by timely and fair compensation paid by the government (forest department), crop insurance and proactive measures such as active guarding and solar-fences to protect crops, as well as changes in cultivation patterns where relevant (Fernando et al., 2008a; Hoare, 2012). Economic losses from crop and house damage are already compensated by the forest department; however, the process is usually time consuming and disparate with the actual quantum of losses, as a result, only a small proportion of people who face losses apply for compensation (AK personal observation). Crop insurance programmes may be planned by conservation organizations working in the area and infrastructure inputs such as solar-fences and solar lights may be installed with financial support from the district administration and relevant state welfare schemes.

The leopard is a widely distributed large felid whose range overlap with human spaces throughout many parts of its geographic distribution especially in S-E Asia (Athreya et al., 2015; Jacobson et al., 2016). The large cat is also widely hunted for the illegal trade of its body parts and also in retaliation to economic losses (Raza et al., 2010). The increasing threats to leopard populations throughout its distribution has led to the up-gradation of its vulnerability status as per IUCN from Least Concern in 2002 to Near Threatened in 2008 to Vulnerable in 2016 (Stein et al., 2016).

In our study area, leopard habitat-use was positively influenced by tea-plantations and probability of use was also higher in larger contiguous patches of tea-plantations. Studies in the same landscape have found that leopards also avoid human habitations at a finer scale in the tea-plantations (Kshettry et al., 2017). Availability of prey and ground vegetation cover seem to be conducive for leopard persistence in these tea-dominated landscapes (Kshettry et al., 2017, 2018). The tea landscape extends to the eastern state of Assam, too, which has a similar terrain and climate thereby offering tremendous conservation potential for this charismatic felid. In our study area alone, the leopard used a 948 km^2 area (out of ~1200 km^2 sampled area) which dwarfs the small 88 km^2 protected area currently assigned to leopard conservation and management. The main challenge to leopard presence in this particular landscape is the high number of human injuries in the region. Research suggests that these incidents are accidental in nature when people and leopard accidently come face to face in the close confines of tea-bushes leading to injuries to the tea-plantation workers (Kshettry et al., 2017). Hence, targeted mitigation measures within these plantations such as making noise to scare off leopards and careful inspection of plantation area before start of work may be practised to reduce these encounters (Bhattacharjee and Parthasarathy, 2013; Kshettry et al., 2017). The problem of livestock loss may be negated by adopting better livestock protection regimes and livestock insurance programs by interested conservation agencies (Mishra et al., 2003).

The habitat-use patterns of leopards and elephants shows up stark contrasts which would also entail separate sets of conservation measures in the landscape. While leopards are ubiquitous in the tea-plantation dominated areas, the agricultural areas are devoid of their presence. In contrast, elephant presence is higher closer to the forested areas and in areas inbetween two adjacent forest patches. This indicates that the conservation efforts in certain parts of the landscape, irrespective of the land-use would be essential to ensure movement of elephants between forest patches. Despite the contrasting species and their habitat-usage, commonalities emerge on how both species are involved in negative interactions with people especially human injuries and also that these incidents are largely due to the lack of safety practices rather than 'attacks' by the species. These commonalities underscore the role of the various stakeholders in the region in addressing the critical issue of human safety to garner local support for wildlife conservation. The key interest groups such as those with high interest and low power and those with high power and low interest needs to find shared solutions to the problems and the process may be mediated by groups with high interest and moderate power such as National/International conservation organizations.

Elephants and leopards have distinct histories of relationship with people in tea-plantation landscapes of N-E India. Before the colonial era, the landscape comprised of intact stretches of Sal forest and riparian grasslands. With the advent of British rule, the region witnessed rapid transformation due to forestry practices adopted by the colonial rulers (Sivaramakrishnan, 1999). The elephant became an important symbol of forest management and economy as the animals were captured for logging and forestry activities and also killed for trophy hunting (Sanderson, 1912; Nongbri, 2003). Subsequently laws were enacted in the 1870s to protect the elephants as the species was viewed as an important resource by the British (Sivaramakrishnan, 1999). The late 1800s was also the time when the tea-plantations came up after forests were cleared for plantations thereby shrinking and fragmenting the forested elephant habitat. Elephants still persisted in the region and more recent laws such as the Indian Wildlife (Protection) Act, 1972, further reinforced elephant protection making their killing punishable within and outside protected forests (*THE INDIAN WILDLIFE (PROTECTION) ACT, 1972* n. d.).

Culturally, elephants have been venerated as gods (Sukumar, 2011) by a multitude of ethnic groups such as Rajbangshis and Adivasis, which has also favored the persistence of the species outside forested areas despite causing high damage to people (AK unpublished data). Such beliefs, if fostered and reinforced may be helpful in garnering positive support for the species in the landscape in the longer term among the other high interest-low power groups. Leopards, on the other hand seemed to have adapted to the tea-plantations since the tea-bushes provided suitable habitats for leopards as well as a diverse assemblage of domestic prey (Daniel, 2009; Kshettry et al., 2017, 2018). However, both species cause significant losses to life and property and hence, proactive mitigation measures are urgently needed in the landscape to prevent the erosion of tolerance towards these species.

The mitigation measures to promote safer shared spaces and reduce negative encounters will be successful only if carried out by all stakeholders in the landscape. Currently, the onus of preventing accidents in this region falls almost entirely with the Department of Forests and Wildlife, as is the case across India. However, other stakeholders such as tea-plantation management, local environment organizations and local administration need to collaborate in finding shared solutions to the conservation and conflict-management problems (Fig. 3). Such collaborations between relevant authorities and stakeholders are rarely seen in the real world and throws up interesting opportunities for conservation scientists and practitioners to affect positive change by mediating and catalyzing such processes (Davies et al., 2013; McMahon et al., 2017).

Our long-term presence in the landscape has also led to the initiation of one such project where multiple stakeholders are involved and the affected communities are enabled to better avoid encounters with elephants and leopards. The Co-Existence

Project (wwww.coexistenceproject.org) has been active in the region since 2013–14 provides a platform for multi-stakeholder interactions. The project may have had positive effect on the attitude of locals based on the increase in positive attitude towards leopards between (Bhattacharjee and Parthasarathy, 2013) and (Naha et al., 2018). However, the results could also be an artefact of non-comparable methods and protocols and not necessarily reflect any actual change in local attitudes towards the species.

Our work highlights the use of human-dominated landscapes by a large carnivore and a mega-herbivore in this north-east Indian landscape; published literature indicates the extremely high levels of damages incurred by the local people. We propose the term Conservation Compatible Landscapes (CCL) to denote regions with potential for large animal conservation in human-use areas where such space sharing is enabled by a host of social, cultural, economic and legal frameworks, concurrent with ecological adaptations (Odden et al., 2014; Srinivasaiah et al., 2019) of certain species of high conservation priority. These landscapes are present globally where several charismatic species such as large carnivores as well as large herbivores persist alongside people. The present study highlights only one such system with a forest-agriculture-tea plantation mosaic.

The first step would be to identify such landscapes based on habitat-use studies, analysis of existing laws and local support for the species and by negating any current or future conflicts that may arise. However, such an approach may only be applicable in landscapes where these species are already present and there is local acceptance towards these species (Majgaonkar et al., 2019). The next step would be engagement between the different stakeholders to focus on addressing the situation for both people and wildlife in the shared spaces and to incentivise such shared spaces for local communities. The incentives would have to be context specific and locally relevant. We argue that the protected area network in developing nations will saturate in the near future and considerable biological diversity will persist outside the confines of these reserves. Hence, policy and planning need to be focused urgently on shared landscapes to find solutions towards safer co-habitation. Currently, the dominant paradigm is that of conflict-mitigation which is largely reactive and not sufficiently proactive in planning and execution. Our study provides a template for identifying landscapes and species of high conservation value that are able to persist in human-use spaces or are dependent on human-modified landscapes, to ensure population connectivity and long-term persistence.

CRediT authorship contribution statement

Aritra Kshettry: Conceptualization, Formal analysis, Funding acquisition. **Srinivas Vaidyanathan:** Conceptualization, Formal analysis, Resources, Visualization, Writing - original draft, Writing - review & editing, Supervision, Validation. **Raman Sukumar:** Writing - original draft, Writing - review & editing, Funding acquisition, Conceptualization, Supervision, Validation. **Vidya Athreya:** Conceptualization, Resources, Visualization, Writing - original draft, Writing - review & editing, Supervision, Validation.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gecco.2020.e00905.

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