PROXIMATE DRIVERS OF HUMAN-TIGER INTERFACE AND CONFLICT IN SARISKA AND PANNA TIGER RESERVES, INDIA

A THESIS
Submitted by

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for the award of the Degree of

DOCTOR OF PHILOSOPHY

IN

WILDLIFE SCIENCE

Under the guidance of

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DECLARATION

I hereby declare that the work conducted under the thesis titled **“Proximate drivers of human-tiger interface and conflict in Sariska and Panna Tiger Reserves, India”**, is a record of original and independent research work done by me and submitted for the award of the degree of **Doctor of Philosophy in Wildlife Science** to the **Saurashtra University, Rajkot, Gujarat**. This research work has been carried out under the guidance and supervision of Dr. K. Ramesh, Scientist-E and co-supervision of Dr. K. Sankar, Scientist (Retd.), Wildlife Institute of India, Dehradun. The work has not formed the basis for the award of any other degree, diploma or any other qualification. I also declare that the thesis embodies my work, analysis, observation, understanding and the particulars given in it are true to the best of my knowledge.

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CERTIFICATE

This is to certify that the thesis by **Ms. Manjari Malviya** titled "**Proximate drivers of human-tiger interface and conflict in Sariska and Panna Tiger Reserves, India**" is an original and independent research work submitted to the **Saurashtra University, Rajkot, Gujarat**, for the award of the degree of Doctor of Philosophy in Wildlife Science.

Ms. Manjari Malviya has put in more than six terms of research work embedded in this thesis under my guidance and supervision. The work presented in this thesis has not been submitted to any other University or Institute for the award of any degree, diploma or distinction.

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I certify that the research work was appreciated by all who were present, and the comments made by the faculty and researchers have been appropriately included in the thesis.

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List of Abbreviations

HWI:	Human-Wildlife Interactions/Interface
PAs:	Protected Area
HWC:	Human-Wildlife Conflict
HCC:	Human-Carnivore Conflict
HTC:	Human-Tiger Conflict
HTI:	Human-Tiger Interaction/Interface
STR:	Sariska Tiger Reserve
PTR:	Panna Tiger Reserve
CTH:	Critical Tiger Habitat
SES:	Social-Ecological Systems
CDM:	Conflict Determinant Model
LULC:	Land Use Land Cover
ER:	Encounter Rate
NDVI:	Normalized Difference Vegetation Index
NDWI:	Normalized Difference Water Index
DEM:	Digital Elevation Model
TRI:	Terrain Ruggedness Index
PD:	Patch Density
LPI:	Largest Patch Index
CLUMPY:	Clumpiness Index
SD:	Standard Deviation
SK:	Simple Kriging
OK:	Ordinary Kriging
EBK:	Empirical Bayesian Kriging

HH:	Household
HFC:	Household Facing Conflict
AUC:	Area Under the Curve
ROC:	Receiver Operating Characteristic

Abstract

Human-wildlife conflict poses the most complex challenge to achieving ‘coexistence’. It has resulted in the decline of many species globally. Tigers are one of the three most conflict-prone large-bodied felids in the world. In some of its range states, about 50% of tiger deaths have reportedly occurred due to retaliatory killing by humans in response to domestic cattle depredation. Because of the implications of human-tiger conflict (HTC) on the persistence of tiger especially in human-dominated landscapes, management of HTC is of great conservation importance. However, efficient management steps can only be taken when the reasons for conflict are exposed. For this purpose, we need to identify and understand the factors operating in a conflict that determines its occurrence in a certain place and certain time i.e., the drivers of HTC.

This study thus introduces an analytical framework, the conflict determinant model, to study human-carnivore conflict aimed at identifying various socio-ecological factors linked with conflict and model these factors to understand the mechanism and dynamics of HTC in the two study sites, viz. Sariska Tiger Reserve (STR), Rajasthan and Panna Tiger Reserve (PTR), Madhya Pradesh, India, with the goal to help design effective mitigation measures. Both these reserves suffered local extinction in 2005-2009, and as a result, tigers were reintroduced from other western and central Indian tiger reserves. Since the original tiger populations in both these reserves were lost to anthropogenic causes, study of human-tiger interface/interactions (HTI) and resulting HTC would be of great consequence for the ongoing reintroduction programs at these reserves.

To identify ecological drivers of HTC, data was collected on key habitat parameters for tigers i.e., prey, cover, water, and anthropogenic disturbance using line transect, circular plots, camera traps, and GIS. Additionally, to identify biological drivers, data on biological parameters of the tigers involved in conflict, viz. ID, sex, age, home range, and physiological stress were also collected. To understand the socio-economic drivers of HTC, a semi-structured questionnaire was administered to a total of 361 households from 32 villages in STR and 330 households from 25 villages in PTR. Data on livestock kill location with details of tigers involved in the conflict was procured from forest departments, for understanding the magnitude of conflict, as well as, to carry out spatial Generalized Additive Modelling (GAM) for identifying ecological drivers of conflict. Based on which livestock predation risk maps were produced. Similarly, livestock losses reported by respondents were modelled against several socio-economic factors, using GAM to understand the sociological drivers of HTC.

HTI was found to be high in both Sariska and Panna Tiger Reserves, however, grazing pressure was higher in Sariska, due to higher livestock dependence of communities. Severity of HTC seems to be higher in STR as compared to PTR both in terms of higher monetary loss to people, as well as, higher physiological stress lowering the reproductive potential of tigers. Modelling the ecological variables at multiple scales against livestock kill, revealed that, in Sariska, tigers occupy areas with high wild prey and flatter terrain where prey might be more vulnerable. In such areas if livestock is also in high numbers, tigers may depredate them because wild prey change their habitat use in response to predators whilst livestock, due to the loss of most of their anti-predator behaviour, may become easy kill. And in case of Panna, if prey availability is low at fine-scale within tiger occupied habitat, domestic livestock availability is high, and ambush cover is available, the odds of tiger depredating domestic livestock becomes high. Livestock kill by tiger is, thus, a culmination of predator choice and foraging tactics, and, prey vulnerability and defence mechanism.

Examination of the biological correlates of HTC indicate that certain tigers are more prone to conflict, male tigers owing to their large home range sizes, and younger individuals because they are trying to establish territories or occupying sub-optimal habitats, may depredate more livestock. And quality of home range is associated with livestock depredation, with tigers occupying high cover and wild prey habitat depredating less livestock, while, those occupying habitats with less cover and high anthropogenic disturbance, depredating more livestock. And finally, the socio-economic drivers, illuminated that livestock venture into the reserve forest to graze, because of high dependence of local communities on these forests for fodder. This dependence is more severe in Sariska, because the major community residing within the reserve i.e., Gujjars are pastoral and have very large livestock holdings. And the factor that contributes the most to the increased vulnerability of these livestock to depredation by tiger, is the practice of leaving livestock inside the forest to graze unaccompanied at night.

Applying these results for mitigating HTC in STR and PTR, it is suggested that based on predation risk map, high-risk areas (range, beats, and villages) should be focussed upon, to improve tiger habitat by improving cover, prey and reducing anthropogenic pressure, especially home range of tigers that are more frequently depredating livestock, and, approaching livestock husbandry dependent communities like Gujjars in case of STR and Yadavs in case of PTR, to improve their husbandry practices. And to manage negative attitudes towards tiger, education especially that of rural women, and improving people-park relationships, is suggested.

Chapter 1. Introduction

1.1. Background

As the habitats shrink, wildlife is forced to utilize human-dominated landscapes, leading to increased human-wildlife interface/interactions (HWI) which more often than not, turn negative. This has made 'coexistence' the biggest conservation challenge that we face today (Gross et al., 2021). Populous countries like India with increasing demands of land and at the same time increased focus on wildlife conservation, struggle with balancing conservation and development. Due to dedicated wildlife protection laws and conservation efforts, we have been able to conserve our biodiversity and bring back many species from the brink of extinction by creating protected areas (PAs) across the country. However, these PAs are also home to India's forest-dwelling and dependent communities that depend on these forests for their lives and livelihood, which are facilitated by legislations like the Forest Rights Act (2006). Such overlap in the usage of these PAs by both humans and wildlife results in high HWI. Given that traditional hunting practices have been criminalized by legislations such as Wildlife Protection Act (1972), the forest-dwelling communities draw little direct benefit from the existence of wildlife in these forests, which results in most of these HWI being negative in the form of loss of life, livestock or crop faced by humans, and retaliatory killing, assisted poaching or general reduced welfare faced by wildlife, what has been traditionally called 'human-wildlife conflict' (HWC).

HWC is defined as 'struggles that emerge when the presence or behaviour of wildlife poses actual or perceived, direct and recurring threat to human interests or needs, leading to disagreements between groups of people and negative impacts on people and/ or wildlife' (IUCN SSC Human-Wildlife Conflict Task Force) (IUCN, 2020)

HWC has resulted in the decline of many species globally (Babrgir et al., 2017; Woodroffe & Ginsberg, 1998). Retaliatory killing has resulted in the decline of almost 75% of the world's felid species (Gross et al., 2021). In India, almost 88 species are facing HWC across the country (Anand & Radhakrishna, 2017). HWC has far-reaching impact on not only the persistence of the wildlife involved but also the social and economic well-being of the people involved.

Although evidence suggests that losses caused by herbivores are more widespread and have higher economic costs (Karanth & Kudalkar, 2017), people perceive carnivores to be more dangerous, and even a single case of carnivore attack on a human has a far more devastating effect on human-wildlife relationship, as compared to frequent crop-raiding by herbivores (Devaiah, 2021; Patnaik, 2018). Because of the implications of carnivore attack on psyche of the masses, for persistence of wildlife in human-dominated landscapes, management of human-carnivore conflict (HCC) is of great conservation importance. However, efficient management steps can only be taken when the reasons for conflict are exposed because it is of utmost importance to understand the issue before we attempt to manage it. For this purpose, we need to identify and understand the factors operating in a conflict that determines its occurrence in a certain place and certain time i.e., the drivers of HCC.

1.2. Factors associated with human-carnivore conflicts

Several studies have recently focused on understanding factors associated with HWC to unravel the mechanism behind these negative HWI. Studies have focused on both ecological and social factors linked to conflict. In case of HCC, studies have found that several environmental/habitat factors, as well as, prey and predator ecology and biology play a role. Some of the key environmental and biological factors associated with conflict as found by previous studies are:

1.2.1. Tree cover, forest/vegetation types and forest area: Tree cover (Abade et al., 2014; Amirkhiz et al., 2018; Bradley, 2004; Bradley & Pletscher 2005; Kissling et al., 2009; Michalski et al., 2006; Soto, 2008; Zarco-gonzalez et al., 2013), forest/vegetation types (Eshete et al., 2018; Naha et al., 2018; Treves et al., 2004; Wilson et al., 2005; Zarco-gonzalez et al., 2013) and forest area (Zarco-Gonzalez et al., 2018) have been frequently associated with HCC. Dense forests and certain vegetation types provide cover to ambush predators, influencing their success rate (Cresswell et al., 2010; Murray et al., 1995; Wilson, 2007). For example, in case of livestock predation by jaguar (*Panthera onca*) and puma (*Puma concolor*) in Mexico**,** Zarco-gonzalez et al. (2013) found that cover is positively related to predation events by jaguar, while presence of arid vegetation is negatively related. In case of puma, higher forest cover particularly pine-oak forest was related to predation risk. In another study, they found that ranches experiencing livestock loss due to felids in Mexico had more water sources and forest area as compared to ranches with no predation (Zarco-Gonzalez et al., 2018). Amirkhiz et al. (2018) also considered various spatial factors to explain cattle depredation by wolves (*Canis lupus*) in Mexico and found that among other variables, increased risk of depredation was linked to higher canopy cover variation. Naha et al. (2018) found human - leopard (*Panthera pardus*) conflicts in North Bengal (part of eastern Himalayas) were associated with open forests and scrublands.

In a long-term study conducted by Treves et al. (2004) in Wisconsin and Minnesota, USA, to predict spatial factors linked with livestock depredation by wolves, they found that conflict incidences at townships level were linked with high proportions of pasture, low proportion of croplands, coniferous forest, herbaceous wetlands, and open water. Similarly, Bradley (2004) and Bradley and Pletscher (2005) studied the factors that make some cattle ranches more vulnerable to depredation by wolves in Montana and Idaho. They found that presence of vegetation cover was associated with depredation.

1.2.2. Distance or proximity to forest, protected area/reserve, predator occupied habitat, water, settlement, and road: Distance to forest (Azevedo & Murray, 2007; Michalski et al., 2006; Soto, 2008; Stahl et al., 2002; Treves et al., 2011) or PA/reserve (Äärilä, 2017; Behdarvand et al., 2014; Broekhuis et al., 2017; Karanth et al., 2013; Meena et al., 2014; Newmark et al., 1994; Schiess-Meier et al. 2007), predator occupied habitat (Bradley, 2004; Bradley & Pletscher, 2005; Kissling et al., 2009; Treves et al., 2011), water (Abade et al., 2014; Azevedo & Murray, 2007; Behdarvand et al., 2014; Soto, 2008; Treves et al., 2004; Wilson et al., 2005; Zarco-Gonzalez et al., 2018), settlement (Amirkhiz et al., 2018; Behdarvand et al., 2014; Mbiba et al., 2018; Mech et al., 2000; Steinberg, 2013) and road (Amirkhiz et al., 2018) has been frequently linked with HCC. PAs or reserve act as wildlife refuges and are often preferred by predators because it meets their need for cover and water, as well as, are characterized by less disturbance, since there are no or fewer settlements and roads (Stolton et al., 2015; Watson et al., 2014). Consequently, humans venturing into or livestock grazing in these areas, are more vulnerable to predator attacks (Kuiper et al., 2015; Morehouse & Boyce et al., 2011). In a study investigating HCC in Guatemala, Soto (2008) inferred that the best predictor of conflict were landscape variables, viz. forest cover, distance to forest, and rivers. Similarly, Thorn et al. (2012) studied HCC in South Africa and found that the key drivers were dense cover, increasing distance from PAs, and land use. They also found that social and environmental factors rather than economic loss fuelled carnivore persecution and conflict in the landscape. Broekhuis et al. (2017) identified hotspots of human-carnivore conflict in Maasai Mara and found that they were characterized by high proportion of closed habitat and PAs. In Tanzania, Abade et al. (2014) evaluated landscape and husbandry factors to explain depredation risk by large carnivores, and again found that proximity to river, low elevation, and tree cover was associated with predation risk. When mapped, 40% of the landscape was found to be at risk.

Behdarvand et al. (2014) found that the proportion of irrigated farms was the most important predictor for wolf attack on humans in Iran, followed by wolf denning probability and distance to water. As for wolf attacks on livestock, distance to settlement, distance to PA, denning probability, the proportion of dry farms, and distance to water were found to be important predictors. Likewise, Azevedo and Murray (2007) also studied increased mortality risk of cattle due to wolves and related certain habitat parameters with the elevated risks to certain cattle herds. They suggested that it is associated with age of the cattle, distance of cattle movement from forest edge, and water body. Wilson et al. (2005) studied conflict hotspots of grizzly bears (*Ursus arctos*) in Montana and found that conflict locations were characterized by proximity to river, riparian vegetation, sheep lambing areas, and fall sheep pastures. In another study investigating sheep depredation, Stahl et al. (2002) found that the factors characterizing pastures with high frequency of sheep depredation by Eurasian lynx (*Lynx lynx*) were distance to forest, absence of human settlements, abundance of roe deer, and the presence of other attacked pastures in their vicinity. Mbiba et al. (2018) found the factor that predicts livestock depredation by spotted hyaenas (*Crocuta crocuta*) was the distance from homesteads. Amirkhiz et al. (2018) found that among other variables, cattle depredation by wolves in Mexico was associated with distance from roads and settlements. In a study done on wolves in Wisconsin, Treves et al. (2011) found that livestock were at higher risks in open habitats, farther from forest, and closer to ranges of wolf packs. Bradley (2004) and Bradley and Pletscher (2005) found that cattle ranches closer to wolf dens were more vulnerable to depredation by wolves in Montana and Idaho. Kissling et al. (2009) also evaluated paddock characteristics in ranches to assess the risk of livestock predation by pumas in Patagonia, Argentina using rule-based habitat modelling. They found that puma presence was affected by paddock topography, woody vegetation cover, and proximity to puma habitat.

Äärilä (2017) carried out species distribution modelling to explain the conflict of humans with different species in Kenya. He deduced that drivers of conflict differed across species. However, distance to PA was the common explanatory variable across most conflicts. In India, Meena et al. (2014) found that cattle depredations by Asiatic lions were associated with proximity to Gir PA. Karanth et al. (2013) studied patterns of human-wildlife conflicts in Western Ghats and concluded that distance to PA and employment of mitigation measures were linked to lower depredation, however, unlike other studies they did not find any correlation of conflict with water sources.

1.2.3. Predator and cattle density: Studies have found that HCC is not only linked with the presence of predator and livestock in the same habitat but also their respective densities. Silveira et al. (2008) mapped major human-jaguar conflict zones in Brazil by overlaying jaguar distribution over cattle abundance and concluded that areas with both high jaguar and high cattle presence were potential conflict zones. Kaartinen et al. (2009) also found that in Norway, sheep farms that were surrounded by areas with a higher density of wolves were more vulnerable to depredation.

1.2.4. Wild prey abundance and availability: Apart from the density of predator and livestock, the density of wild/natural prey of the predator also influence the rate of livestock depredation in an area. Analyzing metadata from peer-reviewed publications worldwide Khorozyan et al. (2015) concluded that big cats predate upon livestock when wild prey abundance crosses a minimum threshold. In Mongolia, Davie et al. (2014) mapped the factors linked to livestock predation by wolves and concluded that predation risk is influenced by the abundance and availability of wild prey of the wolves. Amirkhiz et al. (2018) also found that cattle depredation by wolves in Mexico was linked to the relative abundance of elk (*Cervus elaphus*). Similarly, Bradley (2004) and Bradley and Pletscher (2005) also found that livestock depredation by wolves in Montana and Idaho was correlated to the presence of elk in the pastures. In the study conducted by Treves et al. (2004) in Wisconsin and Minnesota on wolves, they found that conflict incidences by wolves at the township level was also linked with deer density. The absence or paucity of wild prey has been discussed as a reason for HCC by others as well (Fritts et al. 2003; Francis, 2004).

Chetri et al. (2019) found that depredation by carnivores in central Himalaya was lower in areas with high wild prey and lower livestock density. However, they found that depredation was high in areas where density of both wild prey and livestock was high. Hence, they concluded that the relationship between wild prey density and livestock depredation was context-dependent, and as such it cannot be suggested that increasing wild prey would reduce HCC.

1.2.5. Human settlement and road densities: HCC has been found to be linked with not only proximity to human settlement and road but also their densities (Newmark et al., 1994). Behdarvand et al. (2014) found that among the most important predictor for wolf attack on humans in Iran, was also human population density. In the long-term study conducted by Treves et al. (2004) in USA towns to predict factors linked with livestock depredation by wolves, they found that at the farm level, predation risk was associated with road density and farm size.

1.2.6. Topography/terrain, elevation, and slope: Other habitat characteristics like terrain, elevation, and slope especially in hilly areas, have been found to be correlated to HCC. In the Himalayas, studies done on snow leopard (*Uncia uncia*), as well as, common leopard, suggest that livestock kill sites are characterized by high elevation (Naha et al., 2018; Steinberg, 2013). Steinberg (2013) found that livestock predation by snow leopard in trans-Himalaya was also associated with gentle slope, apart from high elevation. Amirkhiz et al. (2018) in the aforementioned study on cattle depredation by wolves in Mexico found that terrain was also associated with HCC. Similarly, Behdarvand et al. (2014) found that wolf attacks on humans in Iran was also associated with terrain roughness.

1.2.7. Temperature and precipitation: Apart from habitat characteristics, environmental variables like temperature and precipitation, have also been found to have bearing on conflict incidents involving carnivores. For e.g., In India, Naha et al. (2018) found precipitation and temperature to be the drivers of human-leopard conflict in Pauri Garhwal (part of western Himalayan region). In the western Himalayas lying in Pakistan, Dar et al. (2009) also observed that depredation events by leopard were highly correlated to temperature but not rainfall. Äärilä (2017) deduced that apart from habitat and species-specific factors, most conflicts involving carnivores in Africa were linked with annual average precipitation.

1.2.8. Season and time: Several studies have also focussed on seasonal variation in conflict incidences, and found that the frequency of depredation events by carnivores change temporally. Mazzolli et al. (2002) studied the temporal pattern of livestock depredation by mountain lion and concluded that depredation was higher at night (as also found by Yirga et al., 2012) and during bad weather conditions. Cavalcanti et al. (2010) discussed the seasonality of jaguar-livestock conflict in Brazil and stated that due to certain locality factors that reduce the availability of wild prey species, domestic cattle become more vulnerable to depredation during summer. Mbiba et al. (2018) found that livestock depredation by spotted hyaenas occurred more frequently during the wet season even though more households accompanied their livestock during the wet season, as compared to dry.

1.2.9. Predator personality, sex, social status, and pack size: Some studies have focused on individuals that frequently get into conflict and termed them 'problem animals'. Linnell et al. (1999) argued that certain individuals because of their intrinsic behaviour predate upon livestock. Lamichhane et al. (2017) said that transient or physically impaired animals are more likely to be involved in conflict. Odden et al. (2002) have studied depredation of domestic sheep by lynx in Norway to find out if there were any problem individuals and concluded that there was a 'problem sex' because males killed sheep more frequently than females. Wydeven et al. (2004) concluded from their study that, not all wolf packs that have access to domestic animals predate upon them, only certain wolf packs become 'problem'. The characteristic of packs depredating on guard dogs was that they were large with a greater number of pups, while the ones depredating on livestock were smaller. Woodroffe and Frank (2005) observed that certain African lions (*Panthera leo*) are habitual depredators and found that mortality was higher in these individuals because farmers in northern Kenya usually shoot them to protect their cattle. In another study, Mattisson et al. (2011) found that though all the lynx in northern Scandinavia were involved in the depredation of semi-domestic reindeer (*Rangifer tarandus*), the kill rate of individual lynx differed and was observed to be affected by sex and social status.

In addition to these ecological factors discussed above, certain sociological and economic factors have also been linked to HCC. Some of these factors have been briefly discussed below:

1.2.10. Herd and ranch/farm size and characteristics: Larger size of the herd/livestock owned and farm or ranch, has been frequently associated with higher likelihood of depredation by carnivores. A study done in South Gobi, Mongolia, reported that livestock loss by snow leopard and wolf was correlated to the number of livestock owned and the frequency with which camp sites were changed (Mijiddorj et al., 2018). Chetri et al. (2019) also reported the same from central Himalayas lying in Nepal. They found that chances of depredation by snow leopard and wolves increase with an increase in herd size and stock body size i.e., households that own more horses or yaks were more vulnerable to carnivore attacks. Another study done in Nepal, also reported the same i.e., larger stock in a flock and larger size of the flock, are associated with higher chances of predation by leopard (Adhikari et al., 2020). Similarly, in the western Himalayas in Pakistan, Dar et al. (2009) observed that among other factors, depredation events by leopard were correlated to herd size. Bradley (2004) and Bradley and Pletscher (2005) found that the number of cattle and location of grazing pasture were associated with depredation by wolves in Montana and Idaho. Mech et al. (2000) in a similar study attempted to identify habitat variables and husbandry practices that make ranches in Minnesota vulnerable to depredation by wolves. They concluded, that the large size of farms, large stocks of cattle, and grazing away from human settlements, made ranches vulnerable. Although in Ethiopia wolves and humans have coexisted peacefully for a long time, the recent rise in conflict incidences led Eshete et al. (2018) to study the associated factors. They concluded that households with large herds, closer to Afroalpine habitats, and using Afroalpine pastures were more vulnerable to depredation by wolves.

1.2.11. Husbandry practices and livestock characteristics: Livestock husbandry practices like grazing during the day, presence of shepherds and guard dogs, and housing in enclosures at night have been observed to reduce the chances of livestock predation by large carnivores in Iran (Behmanesh et al., 2019). Broekhuis, et al. (2017) observed that Bomas that were more likely to be depredated by carnivores in Maasai Mara were structurally weak and had fewer guard dogs. Ogada et al. (2003) observed that predation of livestock by large carnivores is affected by the livestock husbandry practices followed, with herding during the day, corralling at night, and using guard dogs, translating to lower losses. The colour, age, and sex of depredated cattle have also been reported to influence the likelihood of their predation by felids (Khorozyan et al., 2018).

1.2.12. Risky human behaviours: Penteriani et al. (2016) found that certain risky human behaviours were responsible for triggering large carnivore attacks, such as leaving children unattended, walking dogs unleashed, and carrying out activities in predator habitat at night.

1.2.13. Electricity supply: In the aforementioned study in Pakistan, Dar et al. (2009) observed that depredation events by leopard in the Himalayas were highly correlated to electricity supply in villages.

1.2.14. Socio-ecological factors:

Although in recent times many studies have called for integrating sociology and ecology to study HWC, and formulating interdisciplinary adaptive management strategies, (Dickman, 2010; Nyhus, 2016; Redpath et al., 2013), very few have actually taken that approach. A significant study in this regard was undertaken by Kolowski and Holekamp (2006) that tried to establish relations between various socio-ecological factors (rainfall, prey abundance, jaguar home range, livestock husbandry) and human-large carnivore conflict to conclude upon the villages and cattle enclosures vulnerable to spotted hyena and other large carnivores. They concluded that the high rate of depredation depended upon the livestock species and herding practices. But the temporal fluctuation in depredation could not be related to either rain or prey abundance. Atwood and Breck (2012) identified land cover classes and other spatial variables that are linked to bear movement, then using attitude-related data made a cost surface to identify the corridors in the landscape. Graham et al. (2005) surveyed available literature to find out the ecological and social factors largely common to HCC. They found livestock depredation is negatively associated with net primary productivity and home range size of carnivores. However, they found no relation of livestock depredation with predator density, husbandry, and human density. They concluded that insufficient data might have biased their results and affected their capability to identify important factors. Saberwal et al. (1994) studied the spatial, temporal, and social factors related to the conflict between local communities and lion (*Panther leo persica*) in Gir Sanctuary, Gujarat. They found that drought and forest edges affected the conflict incidences. They also identified lions that frequently depredate upon livestock, and discussed the attitude and herding practices followed by people. Such integrations of sociology and ecology in scientific studies are rare because they are difficult to carry out but imperative to gain a comprehensive understanding of HCC.

To summarize, the common ecological factors that studies have linked with HCC are tree cover, forest/vegetation types, distance to forest/PA/reserve, proximity to predator occupied habitat and water, distance to settlement and road, predator, prey, and livestock densities, topography, elevation, temperature, precipitation, season, time and predator personality and pack size. The common sociological factors/household characteristics most frequently linked with conflict are ranch/farm/herd size and husbandry practices.

1.3. Human-tiger conflict

Tiger (*Panthera tigris*) is a critically endangered species, reduced to 0.5% of its historical range (Morell, 2007; Sanderson et al., 2006; Walston et al., 2010). It is also one of the three most conflict-prone large-bodied felid in the world (Inskip & Zimmermann, 2009), on account of its large home range size, dispersal behaviour, and diet selection (Macdonald & Sillero-Zubiri, 2002). Tiger population declines have been attributed to human-tiger conflict (HTC) across its range (Norris, 2005). In some of its range states like Russia, about 50% of tiger deaths have reportedly occurred due to retaliatory killing by humans in response to domestic cattle depredation (Inskip & Zimmermann, 2009; Miquelle et al., 2005). Experts attribute the extinction of Bali (*Panthera tigris balica*) and Javan (*Panthera tigris sondaica*) tigers to HTC (Seidensticker, 1987). In India, dedicated protection and management efforts have resulted in tiger numbers steadily increasing from 1,411 in 2006 to 2,967 in 2018 (Jhala et al., 2019). However, to sustain the growth of tigers in a developing populous country like India, it is not only important to bring more area under the tiger reserve network but ensure the survival and persistence of tigers inside and outside these PAs, in multiple-use forests. However, with a reported approx. 45 human deaths occurring annually due to tigers, the psychological impact of tiger attack on the victims and their families, and sustained loss to the rural economy in form of livestock depredation, HTC poses the biggest challenge to this goal (Chowdhury et al., 2016; PTI, 2019). Moreover, almost 40% of tiger deaths in India have been attributed to anthropogenic causes, of which 69% were due to poaching (Nigam et al., 2016). Most (58%) of the poaching incidents were caused by poisoning (Nigam et al., 2016). Although in most cases it is difficult to establish the motive behind poisoning, it is known that poisoning is not used by poachers alone but also by local communities to retaliate against cattle loss (Chouksey & Singh 2018; Johnson et al., 2006; Kashyap, 2020; Moreto et al., 2019; Pinjarkar, 2019). Thus, HTC directly contributes to tiger mortality in the country. Given the impact that HTC has on human-tiger coexistence, its resolution becomes key to the persistence of tigers globally, more so for India that holds 70% of their population (Jhala et al., 2019).

1.4. Correlates of human-tiger conflict

HTC has been studied in almost all tiger range countries, viz. Nepal (Bhattarai & Fischer, 2014; Gurung et al., 2008; Lamichhane et al., 2017), Bhutan (Rostro-Garcia et al., 2016; Sangay & Vernes, 2008; Wang & Macdonald, 2006), Bangladesh (Barlow, 2009; Inskip et al., 2013; Neumann-Denzau & Denzau, 2010; Reza et al., 2002), China (Li et al., 2009; Soh et al., 2014), Indonesia (Nugraha & Sugardjito, 2009; Nyhus &

Tilson, 2004; Struebig et al., 2018), Lao PDR (Johnson et al., 2006), Russia (Goodrich et al., 2011; Tkachenko, 2012) and India (Bargali & Ahmed, 2018; Karanth & Gopal, 2005; Miller et al., 2015; Mukherjee, 2003; Naha et al., 2014; Pandit, 2014; Ramesh et al., 2019). However, as compared to wolves, puma, jaguar, and lion (as discussed above), very few studies have attempted to identify the predictors/drivers of conflict with tigers. Most of them focusing on understanding the costs (economics and human loss) of conflict, people's perception, and mitigation measures. Even though, identifying drivers and predicting conflict risk employing these drivers, is the most important tool for the management of HTC.

Soh et al. (2014) studied factors correlated with the depredation of livestock by Amur tigers (*Panthera tigris altaica*) in China. They found predation probability increased with proximity to rivers and reserve forest, distance to road, and higher tree cover. Li et al. (2009) also studied livestock depredation by Amur tigers in the same landscape and reported that attacks occurred more frequently on southern and eastern aspects, lower altitudes, gentler slopes, denser canopy, closer to villages and rivers, and farther from roads. Similar landscape variables were reported to be linked to livestock predation risk by Sumatran tigers (*Panthera tigris sumatrae*); namely, proximity to rivers, distant from road, and greater tree cover (Struebig et al., 2018). They also found that combining the ecological risk factors with social factors is better at predicting tolerance towards tigers, as compared to only social models. Ahmed et al. (2012) studied the depredation of livestock by large carnivores (including tiger) and concluded that the highest cattle depredation occurred in monsoons and the highest number of attacks on humans occurred in winter. Rostro-Garcia et al. (2016) identified and tested predictors of conflict at different scales in Bhutan. From their multiscale model, they concluded that density of settlements and roads, and tree cover were the major explanatory variables for livestock kill by both tiger and leopard. In India, Miller et al. (2015) identified factors linked to livestock kills by tiger in Central India to predict risk, employing resource selection function. They surmised that risk was greater near dense forest and park boundary, specifically 1.2 km from roads, 1.1 km from villages, and 8.0 km from scrubland. At a fine scale, they found that kill sites had denser, patchier, and more complex vegetation with lower visibility than random sites. Ramesh et al. (2020) while examining predation risk by carnivores in Eastern and Western Ghats found that livestock predation risk by tiger was best explained by the abundance of cattle, resource dependence of people, proximity to water, distance to forest boundaries, elevation, and location of the village with respect to PA boundary.

To summarize, in the case of tigers, the factors that have been reported to be linked to livestock depredation are tree cover, distance to road, proximity to water, proximity to reserve forest, distance to and location of village, density of livestock, settlements and roads, aspect, altitude/elevation, slope, and, dependence of people on forest.

However, all these studies either talk about environmental variables or socio-economic variables, rarely bringing the two of them together. Even rarer is the examination of scale at which these conflict-related factors are studied.

1.5. Multiple dimensions and scales

HWC is a complicated issue thus it needs to be examined from every angle. Just understanding the ecological or biological perspective of HCC is looking at only one facet of the issue, since humans constitute the other half. Therefore, one also needs to study the factors that dictate their conflict vulnerability. Hence, we need to conduct multi-disciplinary studies of HCC. Moreover, since all the factors associated with HCC are neither linearly related to kill occurrence nor come into play at the same scale, scale must be considered when modelling habitat correlates of HCC.

Scale: Most ecological relationships are complex and involve several factors. And because these factors range from macro to microhabitat/environmental covariates, all of them cannot be expected to operate at and influence the relationship at the same scale. Thus, ecological relationships are scale-dependent, such that when examined at different spatio-temporal scales the relationship and its interpretation are subject to change (McGarigal et al., 2016). Therefore, when identifying the factors related to a process or phenomenon they need to be examined at multiple scales, to identify the meaningful scale and make ecologically sound inferences. In the absence of such a multi-scale approach, misleading conclusions may be drawn. Even if we are able to successfully identify the causal factors of a problem, we would not know at which level to intervene, without understanding the scale at which these causal factors are influencing the problem. In which case, selection of the scale at which the variables are meaningfully correlated with the issue becomes as important as, the selection of variables themselves (Mateo Sánchez et al., 2013). Thus, coupled with variable selection, scale optimization should be the first step to predictive modelling.

Multiscale models have been proven to perform better than single-scale models at identifying and predicting relationships between environmental variables and the phenomenon/process under study (Mateo Sánchez et al., 2013; Timm et al. 2016). Thus, multiscale modelling has become an important tool for studying a myriad of ecological and biological processes/problems/groupings including community ecology (Dray et al., 2012), ecological niche modelling/niche/resource partitioning (Hearn et al., 2018; Khosravi et al., 2019; Vergara et al., 2016), habitat selection (Mateo Sánchez et al., 2013)/ habitat suitability modelling (Khosravi et al., 2019; Kittle et al., 2018; Rather et al. 2020; Store & Jokimäki, 2003; Vergara et al., 2016), predicting indicator species hotspots (Grand et al., 2004) and predicting carnivore dispersal (Krishnamurthy et al., 2016). Even though HWC often involves different variables and complex interactions, very few studies have tried to examine the factors determining HWC at multiple scales. In one of the earliest studies, Sitati et al. (2003) while modelling spatial correlates of human-elephant conflicts (HEC) in Masai Mara concluded that coarse spatial data can be utilized to examine HEC, and found that certain spatial variables are more relevant at broader scales as compared to fine-scale. Wilson et al. (2005) examined attacks of grizzly bear on humans, to identify the conflict hotspots, carrying out the analysis at three spatial scales. They found that among the attractants, unprotected beehives were associated with conflict locations at 3.2 km and 4.2 km scales. Davie et al. (2014) while mapping the landscape factors linked to livestock predation by wolves in Mongolia concluded that the scale at which wolves respond to their habitat is 500m radius around a potential kill site and not a larger (1000m) or a smaller (100m) area. And thus, scale influences livestock predation risk. Broekhuis et al. (2017) carried out a multiscale analysis to identify human-carnivore conflict hotspots in Maasai Mara, Kenya. They found that certain habitat factors like closed vegetation were influencing livestock depredation at a broad scale (2880m), as compared to fine scale. Wynn Grant et al. (2018) modelled mortality risk of black bear due to anthropogenic causes in Nevada USA, and found that environmental variables such as distance to forest and density of forest were good predictors of bear mortality risk at coarse spatial resolutions while anthropogenic variables like distance to and density of recreation site, best predicted mortality risk when measured at fine spatial resolutions. Thus, they concluded that scale must be considered when modelling mortality risk of carnivores.

Miller et al. (2015) to model livestock predation risk by tigers in India, measured vegetation structure at 3 spatial scales (20m, 100m, and 200m), to find out the optimum scale at which the variables respond to predation of livestock by tigers. They found that the fine-scale model (20m) performed the best and concluded that fine spatial grain risk models are more accurate in predicting human-carnivore conflict. Oppositely, Rostro-Garcia et al. (2016) while examining livestock depredation by tiger and leopard in Bhutan tested all their variables at five scales and found that vegetation cover was more influential at a broader scale (2000m). They also compared their multiscale model with a single-scale model and concluded that scale optimization improves modelling results.

However, I could not find any studies that examine HTC from multiple socio-ecological dimensions and on multiple scales, to understand the phenomenon in a comprehensive manner.

1.6. Local context: tiger extinction and reintroduction

As discussed previously there are several challenges tiger conservation in India faces in terms of habitat availability and protection. In 2005, Sariska Tiger Reserve (STR), a popular reserve in Rajasthan, lost all its tigers to poaching (Narain et al., 2005). As a response to the tiger extinction in STR, the Prime Minister of India set up a high-level committee the 'Tiger Task Force' which took a detailed account of the tiger crisis in the country and suggested strategic actions. In order to restore tiger population in STR, re-introduction of tigers from other close populations was suggested (Narain et al., 2005). To implement this, a species recovery plan was developed and one male ST-1 and two females ST-2 and ST-3 were initially translocated from Ranthambhore Tiger Reserve (RTR) to STR between 2008 and 2009 (Sankar et al., 2010). Meanwhile, in 2009, tiger population in Panna Tiger Reserve (PTR) in the neighbouring state of Madhya Pradesh was also declared functionally extinct when the reserve was reported to have no females and the only remaining male tiger also could not be traced for months (Wildlife Institute of India, 2009). In March 2009, the reintroduction program was launched in PTR by the Madhya Pradesh Forest Department, in collaboration with Wildlife Institute of India and National Tiger Conservation Authority, and two female tigers T-1 and T-2 were translocated from Bandhavgarh and Kanha Tiger Reserves, respectively. A species recovery plan was subsequently developed and a full-fledged reintroduction program was implemented, with further translocation of one male tiger named T-3 from Pench Tiger Reserve in November 2009. Subsequently STR received eight founders between 2008-2013 and PTR seven between 2009-2015 (Sankar et al., 2013; Sarkar et al., 2016). However, the first reintroduced tiger fell prey to Human–

Tiger Conflict (HTC) shortly after reintroduction, when it was poisoned by villagers in STR, reportedly in response to livestock depredation (Sankar et al., 2013). Thus, exposing the precarious relationship that humans and tigers share in these reserves and highlighting the importance of resolving HTC for the persistence of these reintroduced populations.

The reintroductions of tigers in STR and PTR are some of the first successful tiger reintroduction programs anywhere in the world. However, such reintroduction programs and especially the ones that involve a large carnivore are always under the scanner and threatened by many adverse factors including the ones that might have initially resulted in the extermination of that species in the landscape (Johnsingh & Madhusudan, 2009). There are evidences to this argument, such as the case of white rhinoceros (*Ceratotherium simum*) re-extinction from Limpopo National Park in Mozambique due to poaching, where they were reintroduced in 2002-03, after they went extinct due to the same reason, in the 1950s (Dunham, 2004; Liang, 2013). Since tiger populations at both STR and PTR were lost to anthropogenic causes, the success of these projects depends on the behavioural adaptation of both the reintroduced tigers and the human population with a stake in these reserves. Although the primary cause of tiger extinction in these reserves i.e., 'poaching' is mostly driven by economic gains to a few (Jorge et al., 2013; Liu et al., 2011), however, evidence suggest that at least in STR, local people harboured poachers, even invited them to hunt crop-raiding livestock, who went on to poach tigers (Narain et al., 2005). Thus, integration of people support would provide immense help in curtailing illegal practices within the reserves.

People's support for conservation is lost due to conflict which may affect heavily the landscape level tiger conservation initiatives (Tilson & Nyhus, 1998). Moreover, the problem of carnivore depredation on livestock appears to be more in an area where the carnivore population has surged after a period of absence (Linnell et al., 1999). Furthermore, due to the likelihood of retaliatory killing, conflict with local people is an important direct threat to tiger populations as evidenced by poisoning of ST1 in STR. Therefore, management of any kind of conflict between the people and tiger is of pivotal importance for the long-term establishment of the reintroduced and recovered tiger populations in these PAs.

The communities living in and around these PAs interact with carnivores at different spatial and temporal scales, but not every human-tiger interaction/interface (HTI) can be termed as 'conflict'. It is therefore of importance to understand which are the factors that contribute to HTI becoming HTC. It is in this background that this study gains importance and needs to be undertaken to understand the extent of HTI and resultant HTC, more so in these two reserves where great efforts have been made to re-establish the tiger population. It would be a major setback for tiger conservation in India, if these costly tigers were lost to anthropogenic causes, again.

1.7. Human-tiger conflict studies in Sariska and Panna Tiger Reserves

Sekhar (1998) studied human-animal conflict in STR looking into socio-economic linkages. They have reported that tiger prey upon large-bodied livestock which results in a large amount of money being spent by villagers in guarding their livestock. The study also pointed out that despite facing losses, people are tolerant towards wildlife because of the benefits that they get from the forest and their social and religious beliefs. Recently, Doubleday (2018) examined the hidden dimensions/costs of HTI, from a social science perspective. They found that women bear the cost of HTI in Sariska, suggesting that it has an additive effect on the various reasons already existing in rural society (linked with patriarchy) that fuel domestic abuse faced by them. In their other publications further exploring the subject, it was found that women had negative perceptions towards tigers because they are the ones risking their lives going into the forest for fuelwood and fodder collection (Doubleday & Adam, 2020; Rubino & Doubleday, 2021). This sense of vulnerability is augmented by their already vulnerable position in the patriarchal Indian household (Doubleday, 2020).

Kolipaka et al. (2015) studied the tolerance and attitude towards tiger by pastoralists residing in the buffer zone of PTR. They found that people are tolerant towards tiger because of their religious and social belief systems that promote coexistence so that even though they face frequent losses there are no retaliatory killings of tiger and other large carnivores. However, in another study, they found that reintroduced tigers in buffer area killed more livestock than wild prey, due to their easy availability (Kolipaka et al., 2017). They inferred that this could lead to more negative attitudes. In a related study, they reported that tiger use of the buffer area was not only influenced by tiger-specific factors, viz. sex and age and season/time, but also anthropogenic factors (Kolipaka et al., 2017). They found livestock husbandry practices and human activities affected tiger behaviour and hence are crucial in shaping HTC in the area. Therefore, easy availability of livestock due to poor husbandry practices is leading to livestock predation by tiger in buffer area, but the severity of conflict is checked by the fact that people are tolerant on account of their social and religious beliefs. However, continued depredation of livestock might make people more negative, which would in turn adversely affect the persistence of the reintroduced and recovered tiger population in this landscape.

However, there has not been any multidimensional study to understand the various factors that are determining the livestock loss by tiger in both these reserves.

1.8. Rationale of the study

It is recognized from the review of existing studies that drivers of conflict are scenario specific and of the many drivers of human-carnivore conflicts, it is difficult to generalize any factors for tiger-related conflicts in tropical landscapes. Moreover, there are very few studies on carnivores globally that have identified social, biological, and ecological factors associated with conflict on multiple scales and none on tigers in India. Therefore, there is a need to bring together all the factors that are plausibly linked to the depredation of livestock by tigers and draw a holistic picture. Holistic studies are vital to understanding the predictors of conflict because if all possible factors are not considered the results would be biased and inaccurate, risk maps/prediction maps created based on such incomplete knowledge may be misleading and result in inefficient management practices.

This study thus introduces an analytical framework to study human-carnivore conflict aimed at identifying various socio-eco-biological factors linked with conflict and model these factors to understand the mechanism and dynamics of human-tiger conflicts in the two study sites, with the goal to help design effective mitigation measures.

1.9. Aim of the study and usage of the term Human-tiger conflict

This study aims to highlight livestock losses faced by local communities due to tiger, and expose the causal factors. Since in the absence of attacks on humans, this is the major form of HTC in these reserves, and have had serious ramifications for the tiger population in the past (it led to the poisoning and death of the first reintroduced tiger). Hence, the term 'HTC' has been used to indicate livestock loss due to tiger. However, losses suffered by humans are only one side of the coin, the other side i.e., the losses suffered by tigers, as indicated above, should also be highlighted. Thus, the negative impact of HTI on tigers in these reserves (both direct and indirect) and the factors that would determine the persistence of tigers in these landscapes have also been briefly discussed.

1.10. Objectives

1. To discern the key life requisites (prey, cover and water) and social dynamics of tiger that potentially mediate human-tiger interactions.

2. To undertake quantitative analyses of forest dependency, economic activity and spatial pattern of anthropogenic activities that potentially mediates human-tiger interactions.

3. To establish the key drivers and estimate the threshold of interactions resulting into conflict and dynamics of human-tiger conflicts across ecological and socio-economic units.

1.11. Thesis structure

The thesis is organized into chapters. Chapter 1 is Introduction that sets the background for the thesis, discussing past studies, relevant concepts, and the need for this study. Chapter 2 is Study Area that describes the natural and anthropological history and challenges of the two study sites. Chapter 3 discusses very briefly a novel analytical framework, i.e., the conflict determinant model. Chapters 4 and 5, address the first objective, establishing the intensity and spatio-temporal pattern of HTC in these reserves and deal with the ecological and biological determinants of HTC, respectively. These chapters detail how various relevant ecological and biological factors were measured and modelled against livestock kill locations to isolate the ecological and biological drivers of HTC. Chapter 6 addresses the second objective and explores the sociological determinants of conflict, discussing the relevant socio-economic variables that were studied at the household level to understand HTI and modelled against perceived livestock loss to understand the sociological drivers of HTC. Chapter 7 addresses the effect of negative HTI, on the tiger population in these reserves. Chapter 8 summarizes the HTI in these reserves and addresses the third objective by bringing together the results from the study of ecological, biological, and sociological drivers and identifying the overall determinants of HTC. Finally, within this chapter, the management implications of the study outcomes are also discussed.

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Chapter 2. Study area

2.1. Sariska Tiger Reserve

2.1.1. Location, area, and administration

STR (27°5′N to 27°33′N and 76°17′E to 76°34′E) covering an area of 1203.33 km^2 is situated in Alwar district of Rajasthan in western India (Figure 2.1). The Critical Tiger Habitat (CTH) of STR covers an area of 881.11 km^2, of which 492 km^2 is a wildlife sanctuary (Rajasthan Forest Department, 2007). The buffer of the reserve is 334 km^2 (Rajasthan Forest Department, 2012).

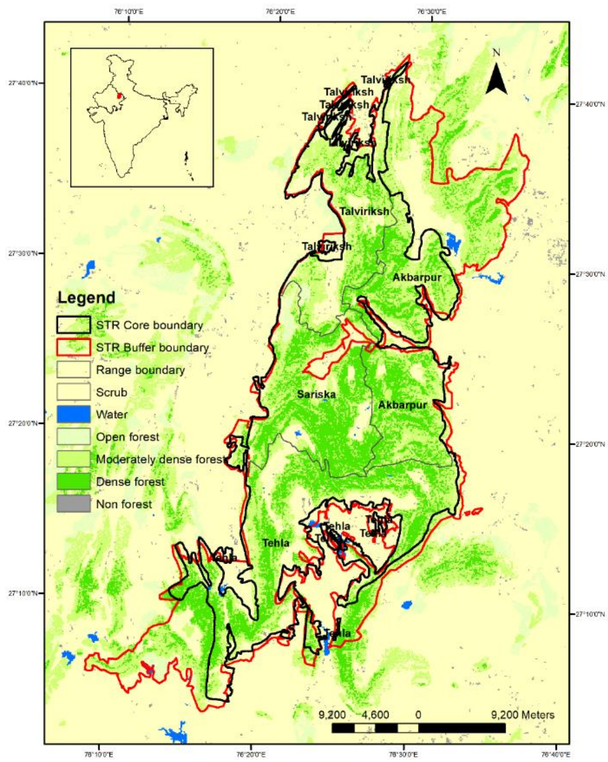

Figure 2. 1: Map showing the location and extent of Sariska Tiger Reserve

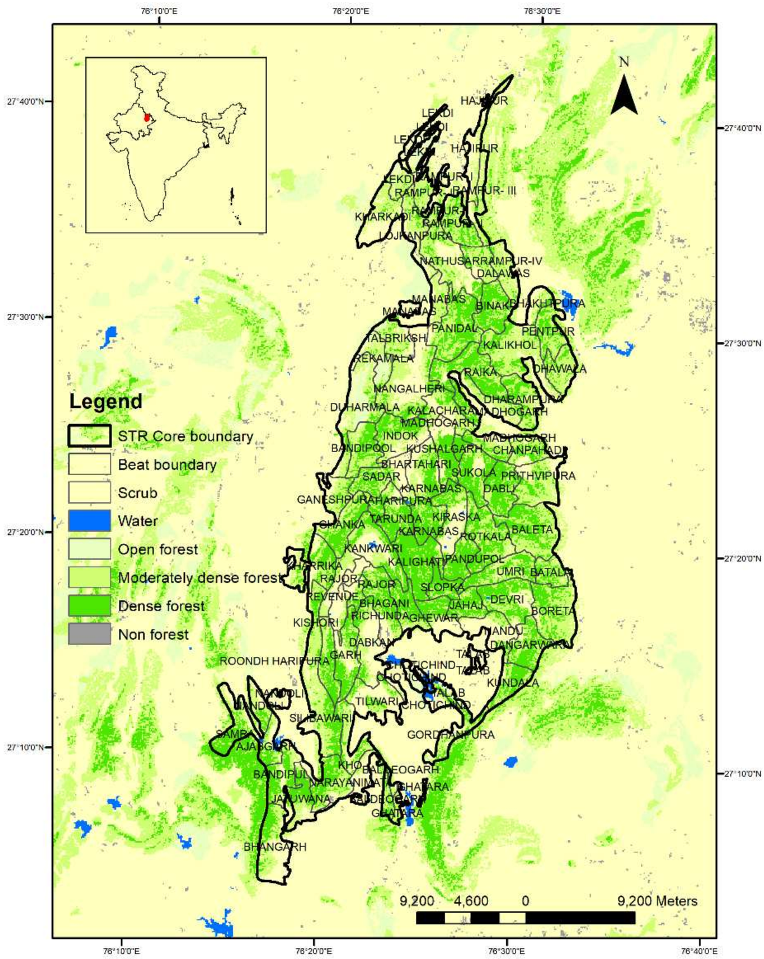

Figure 2. 2: Map showing the beats within Critical Tiger Habitat of Sariska Tiger Reserve

Pre-independence much of the forest that comprises STR was a hunting reserve of Alwar princely state (Dang, 2005). In 1955, Sariska Wildlife Sanctuary was established, and then in 1982, some part of the sanctuary and adjoining forests were preliminarily notified as national park (Rajasthan Forest Department, 1955, 1982). Since the rights of forest villages inside the national park area have not yet been settled, Sariska has not been declared a national park, with the final notification still pending. However, when Sariska was brought under the ambit of Project Tiger in 1978, it became a tiger reserve, its core area was carved out of Sariska Wildlife Sanctuary, Sariska National Park, and adjoining forests of Alwar, Rajgarh, and Sariska Forest Ranges (Rajasthan Forest Department, 2007; Shekhawat, 2014). And much later in 2012, the buffer was carved out of Jamuwaramgarh Sanctuary and parts of Alwar territorial forest division (Rajasthan Forest Department, 2012). The CTH of the reserve comprises of four ranges, viz. Tehla, Akbarpur, Sadar and Talvriksh. The buffer comprises of two ranges Ajabgarh and Alwar buffer. The current study focused on the CTH of the reserve, comprised of 75 beats (Figure 2.2).

2.1.2. Topography, geology and climate

STR is the only large forest patch left in the Northern Aravalli Hills. It has an altitude ranging between 540 and 777m a.s.l. The CTH is comprised of two major plateaus, Kankwari and Kiraska, with the important Sariska-Kalighati-Pandupole valley between them. Plateaus in Sariska are made of flat-topped Alwar quartzite and conglomerates, and valleys mostly of Ajaibgarh phyllites, limestone, and schists (Dang, 2005; Shekhwat, 2014).

STR has a subtropical dry climate. It receives an annual rainfall of around 600mm and suffers from frequent droughts (Rodgers & Panwar, 1988). Moreover, Sariska doesn’t have many perennial sources of water. Therefore, the reserve suffers from seasonal water scarcity. The only river, River Ruparel, that originates near the reserve in Udainath hills, ceased to be perennial in the 1970s (Down To Earth, 1998; Ground Water Department, Rajasthan, 2013). However, due to local efforts and organizations such as Tarun Bharat Sangh, the river once again became perennial in the 1990s (Down To Earth, 1998). It flows for about 20-25km within STR (Shekhwat, 2014). Sariska also has some small perennial springs like Algual and Pandupol (Rodgers, 1990; Shahabuddin et al., 2006). Other major sources of water in the region are the reservoirs and canals that were constructed by erstwhile Alwar state, prominent among them is the Siliserh Lake constructed by Maharaja Vinay Singh, the canals running from this lake waters the Alwar city (Mody, 2017). Other important reservoirs within the reserve are Karnakawas, Kankwari, Mangalsar, Mansarovar, and Siliberi (Figure 2.3) (Shekhwat, 2014). During the dry summer months, the wildlife is mainly dependent on these reservoirs and artificial water holes constructed by the forest department (Dang, 2005).

2.1.3. Vegetation/flora

According to the biogeographic classification, STR lies in Zone 4 B - 'Semi-Arid - Gujarat-Rajwara' (Rodgers & Panwar, 1988). According to Champion and Seth (1968), the major forest types here are tropical dry deciduous forest (Group 5) and tropical thorn forest (Group 6), with the major vegetation being *Anogeissus pendula* (Figure 2.4). Parmar (1985) has classified the forest of STR into the following types:

1. *Anogeissus pendula* forest
2. Boswellia serrata forest
3. Acacia catechu forest
4. Miscellaneous forest with three sub categories:
    a. *Butea monosperma* forest
    b. Forests along nallahs (riverine forest)

c. Scrub forest

A total of 403 plant species have been reported from the reserve including pteridophytes and gymnosperms (Parmar, 1985). 82 herbaceous species have also been reported from the reserve (Yadav & Gupta, 2007). The reserve also houses a diversity of medicinal plants, with a reported 99 species (Dashahre et al., 2014).

2.1.4. Fauna

The major faunal community in the reserve is comprised of the two large felids, tiger (*Panthera tigris*) and leopard (*Panthera pardus*), other carnivores, viz. striped hyena (*Hyaena hyaena*), jackal (*Canis aureus*), jungle cat (*Felis chaus*), Indian grey mongoose or common mongoose (*Herpestes edwardsi*), small Indian mongoose (*H. javanicus auropunctatus*), ruddy mongoose (*H. smithii*), Asian palm civet (*Paradoxurus hermaphroditus*), small Indian civet (*Viverricula indica*), and honey badger or ratel (*Mellivora capensis*); herbivores, viz. chital (*Axis axis*), sambar (*Rusa unicolor*), nilgai (*Boselaphus tragocamelus*), wild pig (*Sus scrofa*) and Indian hare (*Lepus nigricollis ruficaudatus*) and primates, viz. hanuman or common langur (*Semnopithecus entellus*) and rhesus macaque (*Macaca mulatta*) (Figure 2.5) (Chaurasia, 2015; Gupta, 2011; Ross & Srivastava, 1994; Sankar, 1994; Sankar et al., 2010). The elusive and threatened desert cat (*Felis silvestris ornate*) has also been recorded from STR (Gupta et al., 2009). Eleven species of small rodents and three species of bats have also been recorded from the reserve (Gupta et al., 2013; Joshi et al., 2015).

Apart from these, large populations of Indian crested porcupine (*Hystrix indica*) and Indian peafowl (*Pavo cristatus*) exist in the reserve (Avinandan et al., 2006; Sankar et al., 2010; Kidwai et al., 2011). In addition, 374 species of birds, including seven globally threatened species have been recorded from STR, due to which it has been accorded the status of Important Bird Area (IBA) (Kidwai et al., 2011; Sankar et al., 1993; Shahabuddin et al., 2006; Shekhawat, 2014; Sultana, 2013). A few fish species and mugger crocodile are also found inside the park water bodies (Kumar & Sankar, 1993; Shekhawat, 2014). 38 species of butterflies have also been recorded from the reserve (Rani & Ahmed, 2021).

2.1.5. Cultural and historical value

Several temples and forts of cultural and historical importance are located within STR. Pandupol Hanuman temple is the most famous temple within the reserve, located in the heart of the national park area (Dang, 2005). It is believed to be connected to the story of migration of Pandavas to heaven, in the Mahabharat. Another famous temple, the Bhartrihari temple build after the sage king Bhartrihari, attracts lakhs of visitors every year and holds an annual fair (Dang, 2005). Besides these two other temples, Narayani Mataji and Parasarji are also located within the core area (Shekhawat, 2014). Other temples of historical significance are the ruins of Neelkantha Mahadev temple complex, with both Hindu and Jain temples, built between 8^{th} to 12^{th} century (Dang, 2005). Some other temples of local significance are Naldeshwar, Naharsati Mata, Narayaniji Mata, Sarsa Mata, Ganga Mata, Garbaji, and Udainath, all located within the reserve (Shekhawat, 2014).

Figure 2. 3: Karnkawas reservoir in STR not only provides water to wildlife residing within the reserve but also attracts several migratory birds during winter

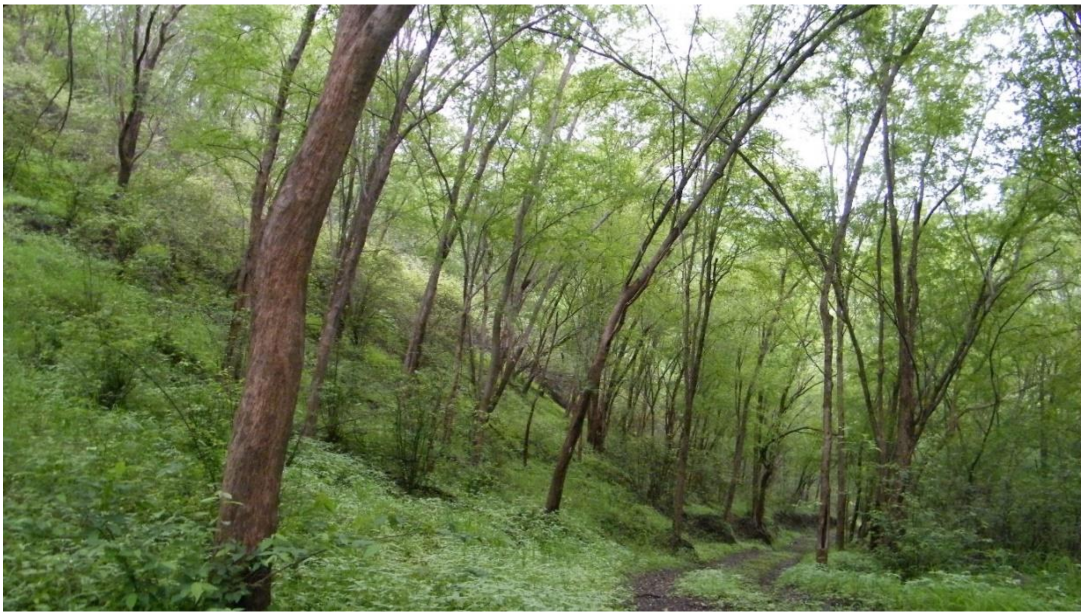

Figure 2. 4: Anogeissus pendula forests within STR

Figure 2. 5: Tiger and prey species in Sariska Tiger Reserve

Before the region was brought under Mughal rule by Babur, it was part of Mewat and Narukhand, mostly under the rule of local landholders (Haynes, 1978). During Akbar's reign, the region came under the subah of Agra (Haynes, 1978). Later, Aurangzeb granted Alwar as jagir to Maharaja Sewai Jai Singh of Jaipur. The legacy of this period is most prominently depicted by Kankwari fort, which was built by Maharaja Jai Singh II of Amber in the 16th century and where Aurangzeb famously imprisoned his brother Dara Shikoh in the 17th century (Figure 2.6) (Dang, 2005; Lalwani, 2015). But with the death of Aurnagzeb in the 18th century, the region came under the complete control of Rajputana, when Pratap Singh created the state of Alwar in 1775 (Haynes, 1978). The Sariska Palace was built by the fourth king of Alwar state, Maharaja Jai Singh in 1892, to house prominent British officials and other royal guests visiting the Sariska forests for *shikar* (Figure 2.7) (Lalwani, 2015). Another prominent palace in the reserve is the Siliserh Lake Palace, build in 1845 by Maharaja Vinay Singh (Lalwani, 2015). Several other forts and their ruins are scattered across the reserve like Bhangarh, Ajabgarh, Tehla, Madhogarh, Kushalgarh, and Pratapgarh (Lalwani, 2015).

2.1.6. Village settlements and forest-dwelling communities

There are 26 villages inside CTH, nine of which are within the notified national park area (Figure 2.8, 2.9, 2.10). The buffer of the reserve has 146 villages. The dominant communities are Gujjars followed by Meena (Shahabuddin et al., 2007). Gujjars are pastoral, while Meenas are agro-pastoral. And because of the traditional livelihood strategies of these communities the entire reserve is exploited for fuelwood, fodder, and grazing, putting a lot of anthropogenic pressure (Dular, 2015; Jain & Sajjad, 2016; Tiwari & Sharma, 2018).

Figure 2. 6: Kankwari Fort within STR

Figure 2. 7: Sariska Palace in STR

Figure 2. 8: Haripura village within STR

Figure 2. 9: Locals visit many temples within the reserve creating disturbance and potential protection issues

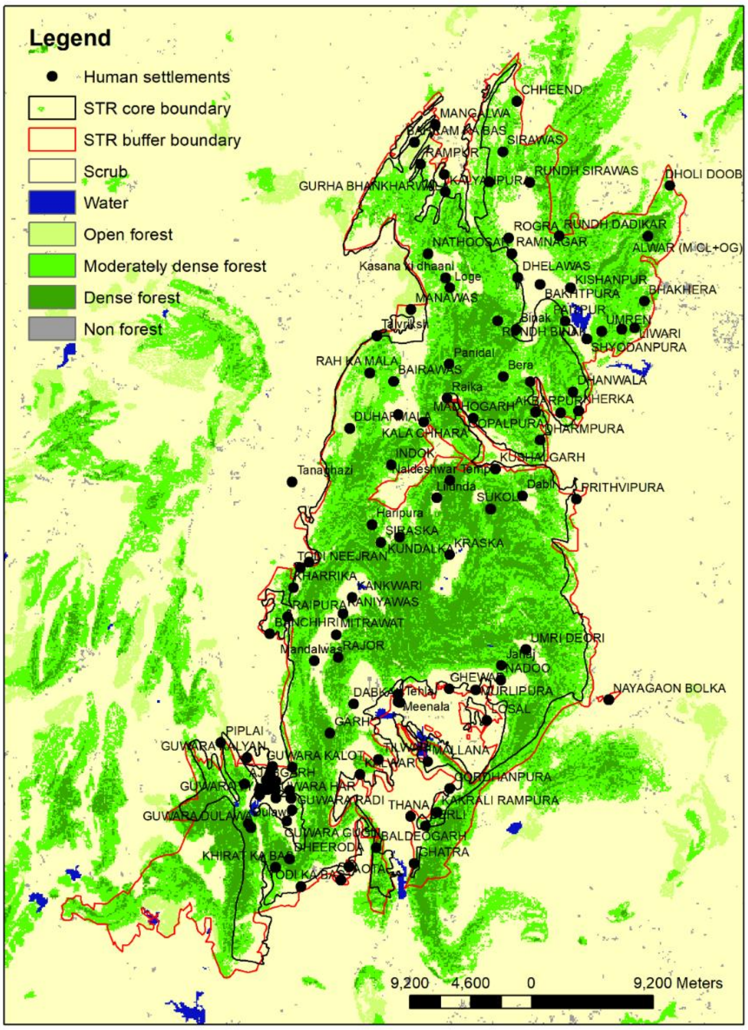

Figure 2. 10: Map depicting the location of human settlements within Sariska Tiger Reserve

Local communities owing to their traditional knowledge of plants also collect medicinal plants for both themselves and their livestock (Goyal & Jeyabalan, 2020; Upadhyay et al., 2011). Besides this, some minor forest produce is also collected from the reserve forest like fruits and seeds of some plants and leaves for roof thatching.

Although concerted efforts have increased forest cover since the 1980s, the presence of these villages, along with temples and roads has resulted in forest fragmentation within STR (Jain et al., 2016). The disturbance caused by fuelwood collection and grazing in Sariska has resulted in changes in vegetation structure and composition, with vegetation richness being lower in disturbed habitats (Kumar & Shahabuddin, 2005; Yadav & Gupta, 2006, 2007). This has impacted the biodiversity of the area, with disturbed habitats reporting less bird species diversity and less utilization by other arboreal species like Hanuman langur (Ross & Srivastava, 1994; Shahabuddin & Kumar, 2007). Weeds like *Cassia tora* that come up where anthropogenic disturbance is high, threaten the regeneration of native species in STR (Gupta & Yadav, 2007).

2.1.7. Other anthropogenic pressures

Mines and quarries

Despite the ban on mining and quarrying activities inside or even within 10km of the reserve by the Hon'ble Supreme court and NGT, several marble, dolomite, and limestone mines are still operating around the reserve, some even possibly inside Tehla Range (Nityendra Manav v. Union of India, 2018; Tarun Bharat Sangh, Alwar v. Union of India & Ors, 1993; Mazoomdar 2014). The mining mafia has refuted Supreme Court orders, intimidated authorities, and NGOs and recently even murdered a home guard (Budhwar & Sharma, 2020).

State highways

The reserve is also threatened by two state highways 13 (Alwar-Sariska-Jaipur) and 29A (Sariska -Tehla-Dausa) passing through the CTH. These highways receive a lot of traffic, especially highway no. 13, on which almost 3000 vehicles ply every day

(Shekhawat, 2014). However, by the Hon’ble Supreme Court’s order, the state highway 29A is closed for traffic, except for visitors to STR or Pandupole temple within STR (Godhawarman Trimulpad v. Union of India & Ors, 2009). The status of a stretch of state highway 13 that was frequently utilized by tigers, was converted into Ordinary District Road (ODR), and movement of heavy traffic was diverted to a bypass road and night time plying stopped. In 2015, the state highway 13 was proposed to become a new national highway NH248A (Bhardwaj, 2015; Mishra, 2015; Sharma, 2015), although it did not receive clearance from National Board for Wildlife, Rajasthan Forest Department, or NTCA (Bhardwaj, 2015; Mishra, 2015).

Apart from direct mortality as roadkill, the presence of these roads has been reported to have caused heavy metal contamination in the reserve environment, including everything from wildlife, vegetation, soil to water (Gruisen 1998; Gupta & Bakre, 2012).

Tourism

Due to its proximity to Delhi and because it falls amid the golden triangle, Sariska receives on an average 39000 wildlife/eco-tourists each year (Shekhawat, 2014). However, of greater concern is religious tourism; lakhs of tourists visit the temples located in the national park area, every year (Plate 4b). Especially on Tuesday, Saturday, and full moon days when the SH-29 leading to Pandupole temple is open to all, including private vehicles, a lot of disturbance is created in the CTH. According to STR management records, from mid-2011 to mid-2014, a total of 77794 vehicles entered through one of the gates of Sariska national park area. Within this period, more than 131000 visitors entered the designated national park area. Of these, 89827 were eco-tourists and 41178 were pilgrims.

Apart from this, huge fairs or *melas* are also organized annually at both Pandupol and Bharthtrihari Temples that attract 8-10 lakh tourists, putting immense pressure on this fragile ecosystem (Shekhawat, 2014).

2.2. Panna Tiger Reserve

2.2.1. Location, area, and administration

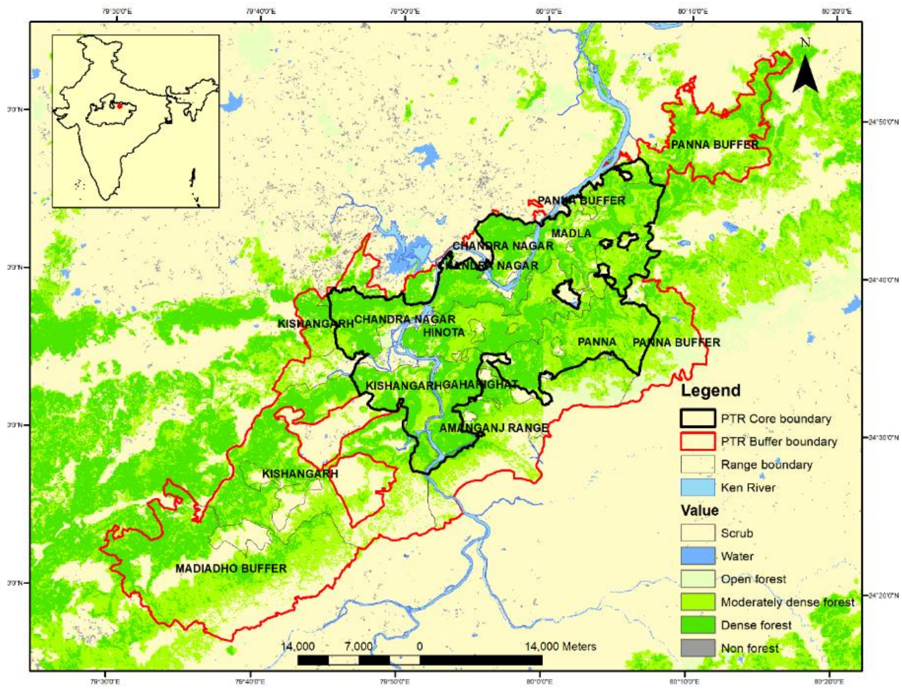

Figure 2. 11: Map showing the location and extent of Panna Tiger Reserve

PTR (24°16′N to 24°42′N and 79°29′E to 80°16′E) covering an area of 1598.10 km² is situated in Panna and Chhatarpur districts of Madhya Pradesh in central India. Some parts of the buffer also lie in the Damoh district. The CTH or core of PTR is composed of Panna National Park and Gangau Wildlife Sanctuary covering an area of 576.13

km^2 (Madhya Pradesh Forest Department, 2007), and the buffer covers an area of about 1,021.97 km^2 (Madhya Pradesh Forest Department, 2012) (Figure 2.11).

Panna was a division within Rewa circle (Bhil, 1976) until 1975 when several ranges of Panna and Chhatarpur forest division were declared as Gangau Game Sanctuary. In 1981, the area was declared as Panna National Park (Madhya Pradesh Forest Department, 1982), which later became the core of PTR (Madhya Pradesh Forest Department, 2007). In 2020, PTR along with parts of North Panna Forest Division was given the designation of Biosphere Reserve by UNESCO (UNESCO, 2020).

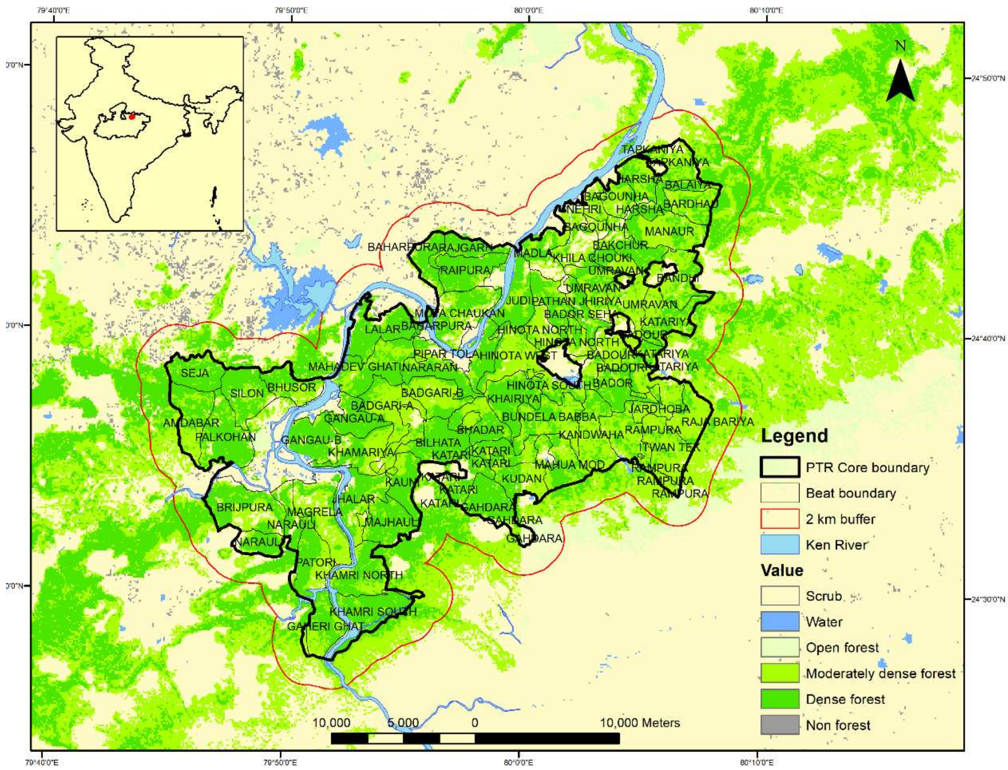

Figure 2. 12: Map showing the beats within Critical Tiger Habitat of Panna Tiger Reserve, along with the buffer considered for this study

Administratively there are seven ranges in the CTH, five lying within Panna District, viz. Panna, Hinauta, Gehrighat, Madla, and Gangau, and two within Chhatarpur District, viz. Chandranagar and Kishangarh. The buffer comprises of mainly four ranges, Panna Buffer, Kishangarh Buffer, Amanganj, and Madiadho, and a smaller range Chandranagar Buffer (consisting of three beats of Chandranagar Range). Ken Ghariyal Wildlife Sanctuary is also under PTR administration, however, it is not connected with the rest of the TR. The current study was focussed on the CTH and 2 km natural buffer around it (Figure 2.12).

2.2.2. Topography, geology and climate

PTR lies in Vindhyan hills, its altitude ranging between 330 and 540 m a.s.l. (Chawdhry, 1996; Rodgers et al., 2002). The reserve is divided into two by the Ken River, which flows from South to North. It has a tabletop/bench topography, characterized by plateaus and gorges (Chawdhry, 1996; Gopal et al., 2010). The CTH is mainly comprised of three geological features, the upper Talgaon Plateau, middle Hinauta Plateau, and the Ken River valley, which are separated from each other by high escarpments (Chundawat et al., 1999). The reserve has mostly three types of soil, lateritic soil (which is the dominant type), black cotton soil, and loamy soil (Chawdhry, 1996). It has an average annual humidity of 86% and temperature ranges from 5 to 45°C (Chawdhry, 1996; Chundawat et al., 1999; Gopal et al., 2010; Karanth et al., 2004).

Lying within the Bundelkhand region, the reserve is vulnerable to drought which is a combination of meteorological and hydrological factors, viz. late arrival of rain, weak or failure of monsoon, poor recharge of groundwater and above-ground reservoirs (Gupta et al., 2014). Although PTR receives an annual rainfall of approx. 1100-1200 mm, most of it falls during the months of July-September (Chawdhry, 1996). Both monsoon and winter are short, thus, the climate is mostly hot and dry. In PTR, water scarcity stems from the short wet season, steep topography, and basement rock/strata that does not hold water (Chawdhry, 1996; Karanth et al., 2004). Even Ken River, which is considered the lifeline of Panna, exhibits high seasonal fluctuation in its discharge (carrying almost 800 cu of water during monsoon, which reduces to 300 by winter), increases the water insecurity in the region (Gupta et al., 2014).

2.2.3. Vegetation/flora

According to the biogeographic classification, PTR lies in Zone 6 E- 'Deccan Peninsula – Central Highland' (Rodgers & Panwar, 1988). The major forest type here is dry deciduous forest with teak (*Tectona grandis*) as the most dominant flora (Champion & Seth, 1968; Meher-Homji 1990). According to Champion & Seth (1968) classification, the following forest types are found within the CTH:

1. Southern Tropical Dry Deciduous Dry Teak Forest (5 A/C1b): Occupies mainly Ken River valley with deep loamy soil. Teak as mentioned is the dominant species, comprising 25-65% of the vegetation (Chawdhry, 1996). The associated species are Dhaora (*Anogeissus latifolia*), Saja (*Terminalia tomentosa*), Tendu (*Dyospyros melanoxylon*), Lendia (*Lagerstroemia parviflora*), Amla (*Emblica officinalis*), Tinsa (*Ougenia ooginensis*), Bija (*Pterocarpus marsupium*), Moyan (*Lannea coromandelica*), Salai (*Boswellia serrata*), Achar (*Buchanania lanzan*), Kari (*Saccopetalum tomentosum*), Papra (*Gardinia latifolia*), Bel (*Aegle marmelos*), Dudhi (*Holorrhena

antidysentrica), Amaltas (*Cassia fistula*), Khair (*Acacia catechu*), Ghont (*Zizyphus xylopyra*).

2. Northern Tropical Dry Deciduous Mixed Forest (5 B/C2): The common tree species include Saja, Dhaora (*Anogeissus latifolia*), Seja (*Lagerstroemia parviflora*), Tendu, Mahua (*Madhuca indica*), Haldu (*Haldina cordifolia*), Rohan (*Soymida febrifuga*), Kaim (*Mitragyna parvifolia*), Moyan, Ghont Salai, Jamun (*Syzygium cumini*), Kusum (*Schleichera oleosa*) and some teak. The underwood consists of Amla, Achar, Kari, Khair, Amaltas, Kardhai (*Anogeissus pendulla*), Bamboo (*Dendrocalamus strictus*), Jamras (*Cassine glauca*), Ghont, Papra, Reonjha (*Acacia leucophloea*), and Palas (*Butea monosperma*).

3. Dry Deciduous Scrub Forest (5/S1): These are degraded teak and mixed forest, occupying areas near village and cultivation. Occurring on flat or gentle slope in plateaus. Palash is a common tree in these types of forest (Chawdhry, 1996).

4. Boswellia Forest (5/E2): Occupies upper slopes of hills, where soil is stony and shallow. As the names suggests, *Boswellia serrata* or Salai are the dominant trees. Associates are Kaim, Moyan, Dhaora, Saja, Seja, Dhoban (*Dalbergia lanceolaria*), Tendu, Tinsa (*Desmodium oojeinense*), Amla, Rohan, Ghont, Dudhi, Papra, Amaltas, Achar, Khair, etc.

5. Dry Bamboo Brakes (5/E9): Characterized by *Dendrocalamus strictus* growing on hill slopes or along water bodies.

6. *Anogeissus pendula* Forest (5/E1): Occupy mainly foothills from Pipartola to Gangau dam along Ken River on both the banks (Chawdhry, 1996). As the name suggests *Anogeissus pendula* is the main species, interspersed with some teak.

2.2.4. Fauna

The major faunal community comprises of the carnivores, viz. tiger (*Panthera tigris*), sloth bear (*Melursus ursinus*), leopard (*Panthera pardus*), striped hyena (*Hyaena hyaena*), wild dog (*Cuon alpinus*), golden jackal (*Canis aureus*), Bengal fox (*Vulpes bengalensis*) and jungle cat (*Felis chaus*); herbivores, viz. sambar (*Cervus duvauceli*), chital (*Axis axis*), nilgai (*Boselaphus tragocamelus*), chinkara (*Gazella bennetti*), four-horned antelope (*Tetraceros quadricornis*) and wild pig (*Sus scrofa*) and primates, viz. hanuman or common langur (*Semnopithecus entellus*) and rhesus macaque (*Macaca mullata*) (Gopal et al., 2010) (Figure 2.13). Apart from these, over 150 species of birds and 15 species of amphibians have been recorded in PTR (Prasad et al., 2020). Ken river is home to mugger crocodiles (*Crocodylus palustris*) and a few gharials (*Gavialis gangeticus*). Even after several attempts to reintroduce gharials in the Ken River since the 1980s, the gharial population has failed to establish (Nair & Katdare, 2013). Ken river is also rich in fish diversity with 50 species reported from PTR, including several fish species of importance like mahaseer (*Tor tor*) (Johnson et al., 2012).

Tiger habitat: Habitat suitability modelling suggests, that about 83% of the core and 47% of buffer of the reserve is suitable tiger habitat (Sarkar et al., 2017). Bamboo mixed forest is the most preferred forest type followed by riverine forest, and the teak forest (which is the dominant forest) (Figure 2.13); least preferred are mixed forest (Sarkar et al., 2017).

Figure 2. 13: Tiger habitat and prey species in Panna National Park

2.2.5. Cultural and historical value

Apart from being rich in biodiversity, PTR also has a rich cultural history**.** The famous Khajuraho temples in Chhatarpur lie within 25 km from PTR. The city of Panna is also famous for its numerous temples, the most famous of which is Pran Nath ji temple built by Maharaja Chhatrasal.

Rock paintings at several sites in and around PTR show that the area was always occupied by tribes (Figure 2.14). Gonds are considered to be the indigenous people of the region (Mehta, 1984). The region was ruled by several dynasties from Chedis in 600 AD to Mauryas, Sungas, Kalchuris, Nagas, Vakataks, Guptas, Abhirs, and Gujar-Pratihars, all bringing their unique style of art and architecture, but the region gained cultural and religious prominence during the rules of Chandelas and Bundelas (Gupta, 1990; Khan, 2012; Singh, 2015).

Chandelas ruled the region from the middle of 10th century, that came to be called 'Jaijakbhukti' after the second Chandela ruler Jeja or Jejak (Gupta, 1990; Singh, 2015). They built the Khajuraho temples between 950 AD and 1050 AD (Figure 2.15) (Khan, 2012). This period is often referred to as the 'golden age' of the region (Gupta, 1990). Chandela rule ended in 1563 AD with the death of Kiratsingh Chandel in 1545 AD (Gupta, 1990). Bundelas, a Rajput tribe ruled Panna and Chattarpur during the 17th and 18th centuries, because of which the region came to be known as 'Bundelkhand' (Gupta, 1990; Jain, 2002). Panna separated from the parent Orchha Bundela Kingdom in 1657 AD, and the foundation of Panna Kingdom was laid by Maharaja Chhatrasal (Jain, 2002). Chattarpur was founded by a Panwar Rajput retainer in 1785 AD, and named after Maharaja Chhatrasal (Jain, 2002). Like Chandelas, Bundelas also built numerous forts, temples, gardens, water reservoirs and gave patronage to renowned poets and philosophers (Gupta, 1990; Singh, 2015; Sharma et al. 2019). During this period a unique style of painting known as 'Bundeli Kalam' became widely popular (Gupta, 1990). All throughout this period, the Bundela were under the suzerainty of Mughals, although they paid *Khiraj* a kind of protection tax to Jehangir and later

Moguls, they enjoyed almost complete autonomy within the region (Jain, 2002). Before the death of Chhatrasal in 1734 AD, large parts of his territory were granted to the Marathas for helping win a war against Bangash Nawabs of Farrukabad in 1729 AD; which after Treaty of Basein in 1802, passed to the British Rule (Jain, 2002).

2.2.6. Village settlements and forest-dwelling communities

Although 13 villages have been relocated outside the Panna National Park, as per official records, there are still three villages within Panna National Park, 49 within buffer, and seven within Gangau WLS (Figure 2.16). Inhabited by several ethnic groups, the most prominent of which are Gond and Khairuas among tribes, and Yadav, Basor, Kushwahas, and Dimar among other backward communities (Chawdhry, 1996). These villages depend upon the reserve forest for wood (for construction purposes), fuelwood, fodder, and NTFPs like Amla, Achar, Tendu, and Mahua (Chawdhry, 1996). Many of the communities are agro-pastoral and graze their livestock within the reserve forest, including the core area (Figure 2.17). Illegal timber felling also happens in the peripheral areas. Panna has a past of hunting. Occasional poaching by forest-dwelling tribes is still reported (Murthy, 2018). Illegal fishing by some communities like Kushwahas and Dimar is frequently reported in parts of reserve forest falling within Chattarpur district (Chawdhry, 1996).

Figure 2. 144: Rock art at Chandrakala inside Panna National Park

Figure 2. 15: Khajuraho temple complex built by Chandelas in Chattarpur

Figure 2. 15: Revenue village inside core area of PTR

Figure 2. 16: Grazing inside core area of PTR

2.2.7. Other anthropogenic pressures

Highways

National highway 75 (Panna-Chattarpur) and State highway no. 6 (Chattarpur-Rewa) pass through the reserve, causing loss of several animals as roadkill. Recently a tiger cub also died when it was run over on the highway within PTR buffer (TNN, 2020).

Mines and quarries

The only working commercial diamond mine in India, is situated within PTR, in Majhgawan near Hinouta range. Apart from commercial mining done by NMDC, small-scale and artisanal mining are also done by locals in the periphery of the reserve (Chowdhury & Lahiri-Dutt, 2019). Some stone quarries are also situated along the reserve boundary (Chawdhry, 1996).

2.3. Tiger population status

Since reintroduction, tiger population in PTR registered rapid growth while STR experienced staggered growth (Figure 2.18, 2.19). As of December 2020, the tiger population in PTR stands at approx. 60, with around 30 tigers having dispersed outside. As for STR, the population stands at 20 individuals.

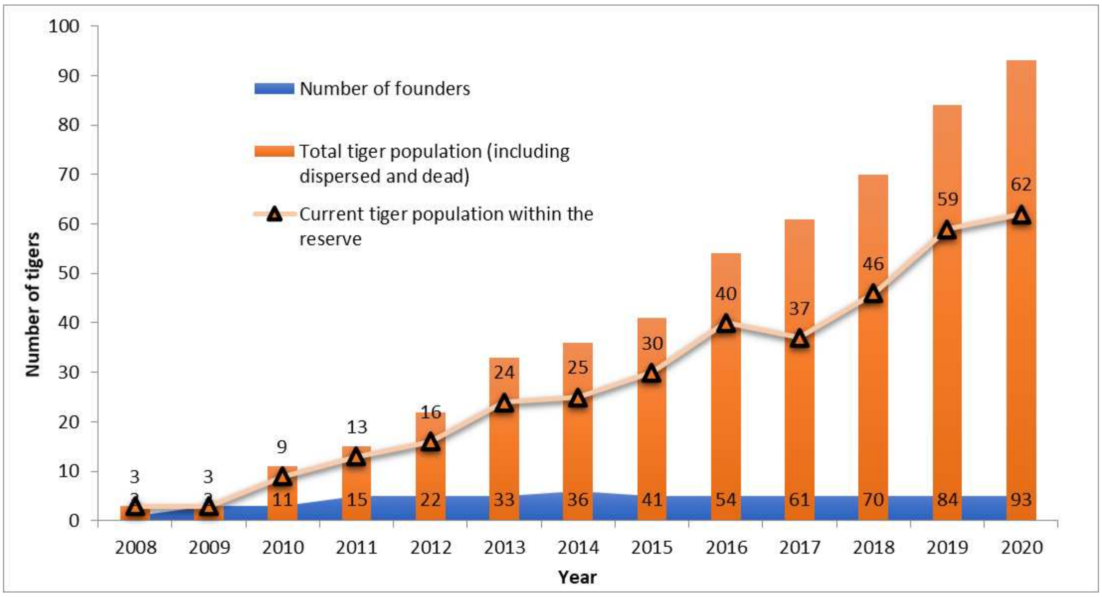

Figure 2. 17: Graph showing tiger population trend in Panna Tiger Reserve

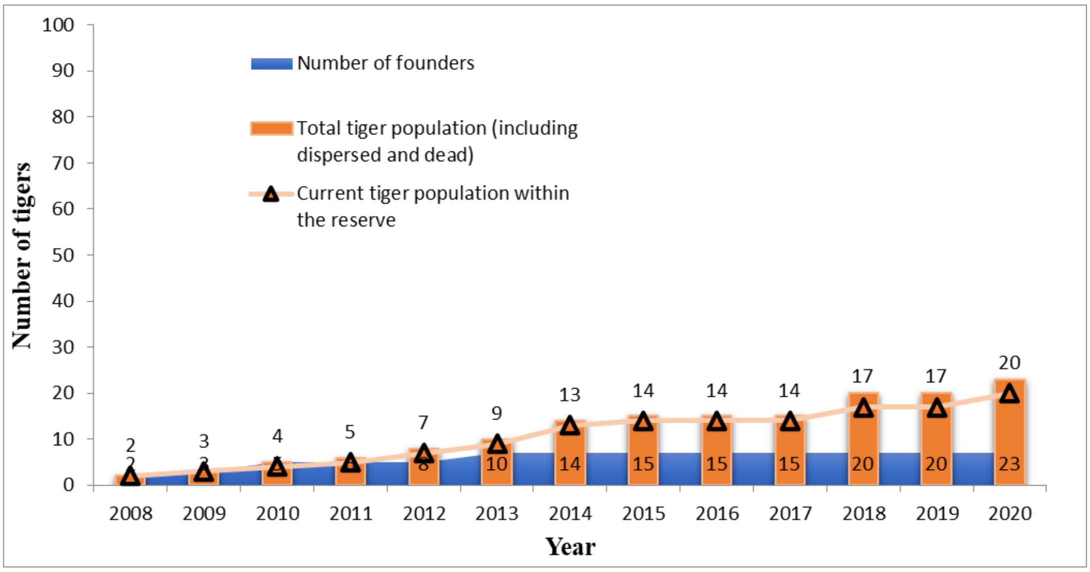

Figure 2. 18: Graph showing tiger population trend in Sariska Tiger Reserve

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Chapter 3. Theoretical Framework

3.1. Conflict Determinant Model

HWI are complicated and multidimensional and any study focusing on them require a comprehensive framework, especially those on HWC. Moreover, even though HWI are complex, managers handling HWC often rely on simple SOPs and require heuristic frameworks for understanding the issue and planning mitigation strategies. HWI fall under what are termed as social-ecological systems (SES), coupled human-environment system or coupled human and natural systems or coupled social-ecological systems (Carter et al., 2014; Morzillo et al., 2014; Redman et al., 2004; Turner et al., 2003). Various frameworks for analyzing such SES have been proposed by researchers in the past which are either analysis-oriented or action-oriented (Binder et al., 2013). However, most of these frameworks have either an anthropocentric or ecocentric view of the issue and do not represent the two systems in equal depth. At the same time, many of these frameworks lack scale consideration, conceptualizing SES only at the macro scale. Despite their drawbacks, such frameworks are necessary for understanding complex systems requiring an interdisciplinary approach. Therefore, such SES frameworks have been employed to propose conceptual models for studying HWC (Lischka et al., 2018; Mosimane et al., 2013).

White et al. (2009) developed a conceptual framework for understanding biodiversity conflicts. In the framework, they presented conflict indicators as a function of economic, ecological, and social factors. The indicators are the attitudes that determine actions (behaviour) of the various actors and the consequences of those actions, which in turn affect/feedback into the factors. Patana et al. (2018) applied the mathematical approach of system thinking, to understand HWC as a system with different interacting components. They identified the factors involved in HWC and drew a conceptual framework to resolve HWC in Leuser Landscape employing Multi-criteria Decision Making. Lischka et al. (2018) proposed a conceptual SES approach to understand internal and external factors within these systems that drive human and animal behaviours responsible for HWI. Within the ecological system, they identified interactions of an animal in a hierarchical manner starting with ecosystem level, to community and population level which are termed as external factors, and individual behaviours which are such attributes as age, sex, reproductive status, and past experiences, termed as internal factors. Similarly, within the social system, interactions of an individual start at the broadest level with society, then institutions, and groups which are termed as external factors and individual behaviours which are such attributes as age, sex, past experiences, and emotions which are termed as internal factors. Applying this model to human-black bear conflict in Colorado they learned that human and animal behaviours are proximate drivers of HWI and key for conservation but are themselves driven by social and ecological systems, thus, social science should be integrated with wildlife sciences throughout the research process. Although they have identified the hierarchical nature of the factors driving HWI, and call for aligning the scale of social and ecological data, they have failed to mention that many processes operate at multiple levels, and hence, one needs to identify the scale at which these factors are relevant. At the same time for immediate and focused conservation or management actions to mitigate HCC, such analytical frameworks are too broad, exhaustive, and elaborate. Instead based on past researches we have to break down the drivers of conflict into comprehensible units as a manager or conservationist sees them and narrow them down to fit the wildlife under study. However, there are very few such models, and conceptual study of HCC to frame heuristic models largely remain unexplored.

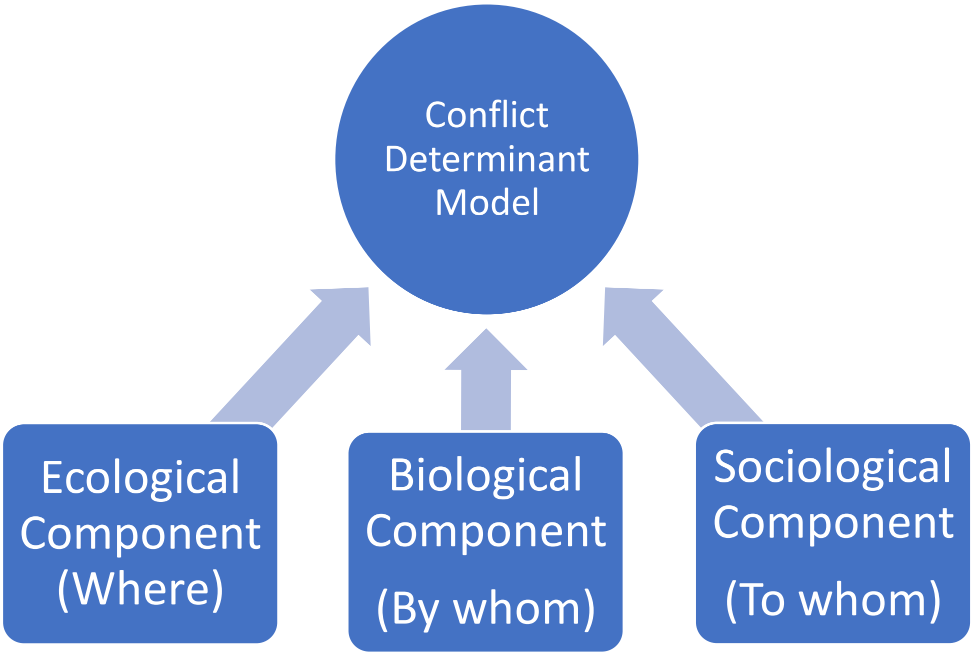

Figure 3. 1: Simple representation of Conflict Determinant Model

To plug this analytical gap, drawing inspiration from existing frameworks I propose the Conflict Determinant Model (CDM), a novel theoretical framework to identify key drivers of HCC (Figure 3.1).

A study of any case of carnivore attack on livestock raises three questions or reveals three facts. First, where? i.e., the location where the kill has occurred and by extension the environmental factors associated with the conflict incident, viz.

topography, land use, forest cover, etc. Second, by whom? i.e., the identity of the carnivore that has depredated the livestock and by extension the biological factors associated with the conflict incident, viz. sex, age, and distribution. Third, to whom? i.e., the identity of the human who has lost the livestock and by extension the socio-economic factors associated with the conflict incident, viz. community/social class, economic class, livelihood strategy, village distance from the kill site, husbandry practice. Therefore, by collecting information on these factors one can observe the pattern and frequency of their occurrence across such conflict incidences, for e.g. We can learn from summarizing data related to livestock kills that the distance to human settlement at which kills are occurring ranges from 3-6 km. However, that doesn't necessarily reveal that the 'distance to human settlement' is 'determining whether the conflict would occur or not'. Thus, to understand which of these ecological, socio-economic, or biological factors actually determine conflict occurrence we need to model these factors against livestock kill (presence/ absence or loss/no loss).

3.2. Components of CDM

Thus, there are three main components to the CDM (Figure 3.1, 3.2). These are, firstly, habitat or ecological drivers that would include habitat-related factors like prey, cover, terrain, and water. Secondly, socio-economic or people/community-related drivers like proximity to predator habitat, livelihood strategies, husbandry practices, socio-cultural norms, and attitudes. Thirdly, if the manager or conservationists have the luxury and tools to identify the individual animals that are involved in the conflict, biological drivers i.e. biology and behaviour of an individual that make them vulnerable to conflict for e.g. their sex, age (dispersing individual), reproductive status (animal looking for a mate or accompanied by cubs), physiological parameters (stress); and if possible, however, extremely difficult to establish in *in-situ* conditions, the personality or temperament of the animal. CDM is not only multidisciplinary but also multiscale. It proposes that each of the spatial ecological variables should be tested on multiple scales to determine the scale at which that factor drives HCC. Thus, CDM is a comprehensive, multidisciplinary, multiscale analytical framework to identify the drivers of HCC.

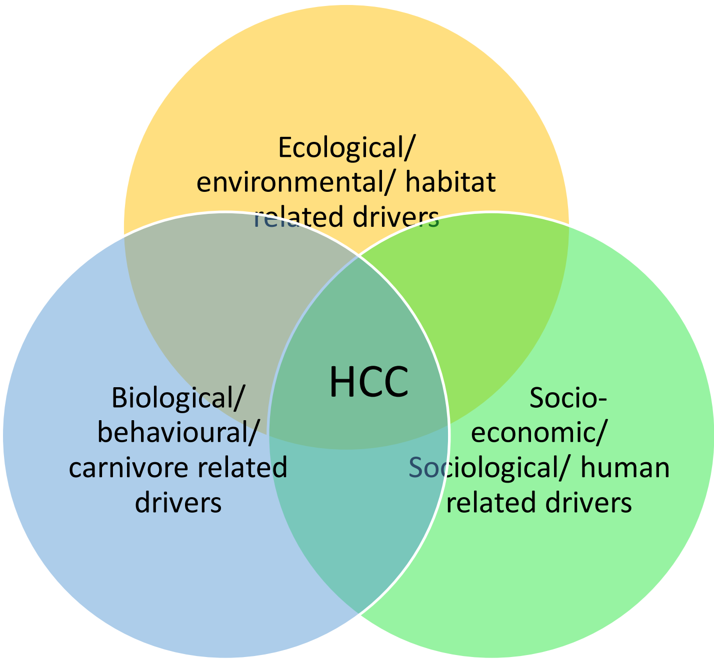

Figure 3. 2: Chart showing the drivers of human-carnivore conflict that together form the conflict determinant model

The purpose of CDM is not limited to only livestock loss by carnivores but can be applied to attacks on humans by carnivores and the process also identifies if the carnivore involved is vulnerable to direct loss in form of retaliatory killing and or indirect loss like increased physiological stress.

3.3. Dynamics in CDM: feedback loops

Dynamism is the inherent property of such complex systems as HCC, such that changing one factor within one component may lead to changes in another factor in another component, thus, affecting the entire system. Hence, feedback loops have also been identified in CDM (Figure 3.3). For e.g., habitat disturbance which is a driver classified within the ecological component is directly influenced by the forest dependence of communities, which is an expression of livelihood strategies of the communities, a driver classified within the sociological component of the system. Although, in this example, the flow is from only socio-economic component to ecological component, but there are other interactions that are reciprocal in nature, for e.g. land use land cover (LULC) driver of ecological component is influenced by the activities of the community living in the region, however, under their influence/utilization pressure the existing LULC may change, such change in LULC can, in turn, bring about change in the livelihood strategies and community structure. Such feedback loops can also be seen among various natural processes like the prey-predator relationship which is depicted in CDM as the interaction between carnivore diet and prey abundance and prey preference.

This analytical framework has been applied on the two study sites STR and PTR, to identify the drivers of negative HTI and understand the real-world applicability of CDM and its lacunas. Individual components of the system shall thus be discussed in greater detail in the succeeding chapters.

Although the framework presented here is analysis-oriented, after applying the framework on studying HTC in the two study sites, I hope to come up with an action-oriented framework to manage HTC in these reserves, and by extension in all tiger reserves of the country.

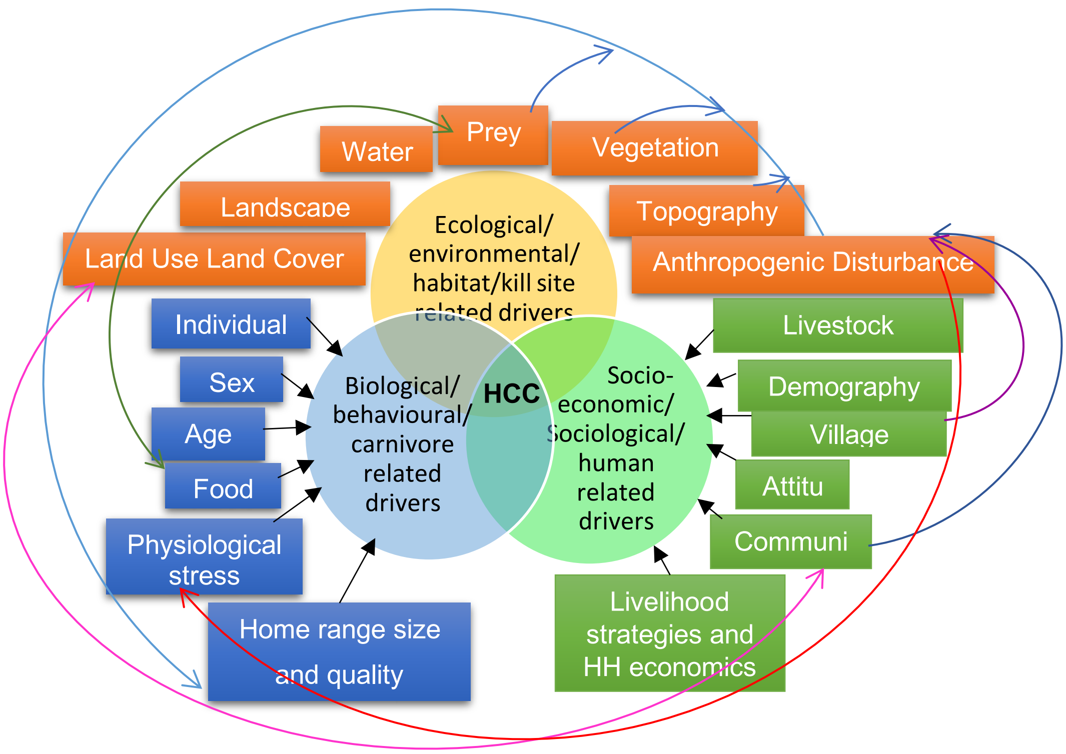

Figure 3. 3: Flow diagram depicting the interaction of the major drivers of human-carnivore conflict and feedbacks loops in the system

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Chapter 4. Ecological determinants of human-tiger conflict

4.1. Background

Habitat factors that structure the carnivore use of an area are likely to dictate livestock kill by the carnivore and, thereby, HCC. Preferred habitat parameters for tiger have been identified mainly as high prey density, forest contiguity, thick understory, high altitude, steep slopes, proximity to water, and low human disturbance (Karanth & Sunquist, 2000; Miquelle et al., 1999; Sunarto et al., 2012; Takahata et al., 2014). Among these, past studies have linked HTC with tree cover, elevation/altitude, slope, aspect, proximity to reserve forest, proximity to water, distance to village, distance to road, and density of livestock, settlements, and roads (Ahmed et al., 2012; Li et al., 2009; Miller et al., 2015; Ramesh et al., 2020; Rostro-Garcia et al., 2016; Soh et al., 2014; Struebig et al., 2018). These habitat/ecological factors can be modelled to reveal the ecological drivers of HTC, the first component of CDM, and understand where it is occurring or may occur.

Spatial modelling of conflict or predictive risk modelling has become one of the major tools to understand HCC (Amirkhiz et al., 2018; Edge et al., 2011; Kaartinen et al., 2009; Kissling et al., 2009; Marucco & McIntire, 2010; Mbiba et al., 2018; Rostro-Garcia et al., 2016; Soh et al., 2014; Treves et al., 2004; Treves et al., 2011; Wilson et al., 2005; Zarco-gonzalez et al., 2013). It helps managers identify vulnerable habitats, communities, and species. And because it is such a great tool there has been a surge in publications employing different ecological concepts whether it be resource selection function (selected vs. available) (Hebblewhite et al., 2005; Miller et al., 2015; Wynn Grant et al., 2018), density surface modelling (Wilson et al., 2005) or species distribution modelling (presence vs. absence) (Äärilä, 2017; Abade et al., 2014; Mateo-tomas et al., 2012; Recio et al., 2018) to produce predictive/risk maps. There are two kinds of studies dealing with mapping conflict risk. The first, aims to identify the current distribution based on conflict intensity/cluster and map 'conflict hotspots' (Bargali & Ahmed, 2018; Baruch-Mordo et al., 2008; Karanth et al., 2012, 2013; Meena et al., 2014). The second attempts to reveal the factors determining conflict and based on the factors, model HCC distribution and map risk/conflict hotspots (Amirkhiz et al., 2018; Behdarvand et al., 2014; Broekhuis et al., 2017; Davie et al., 2014; Kaartinen et al., 2009; Mateo-tomas et al., 2012; Soh et al., 2014; Treves et al., 2011). The former can be done based merely on existing location of the carnivore kill sites and is essentially about mapping where those kill sites are concentrating. The latter, on the other hand, is more labour intensive and requires statistical modelling to not only isolate the factors that are related to depredation events, occurring where it is occurring, but also predict its distribution where it might not be occurring at the movement i.e., extrapolating to similar areas and predicting future conflict risk (Behdarvand et al., 2014; Broekhuis et al., 2017; Kaartinen et al., 2009; Rostro-Garcia et al., 2016; Treves et al., 2004). Therefore, to understand the ecological correlates of HTC and predict predation risk, livestock kill was modelled as a function of various tiger relevant ecological variables, viz. prey, cover, water, and anthropogenic disturbance, at multiple scales, in both STR and PTR.

4.2 Methodology

4.2.1. Livestock kill quantification and kill site location

In case of STR, livestock kill information was obtained from compensation records maintained by the forest department and Sariska Tiger Foundation, which revealed the intensity of HTC in STR. For handing out compensation it is necessary that the range officer visits and verifies the kill at the site and record relevant information including its GPS location. Thus, 402 kill locations were obtained from the compensation data for the period 2011-2016 (Figure 4.1).

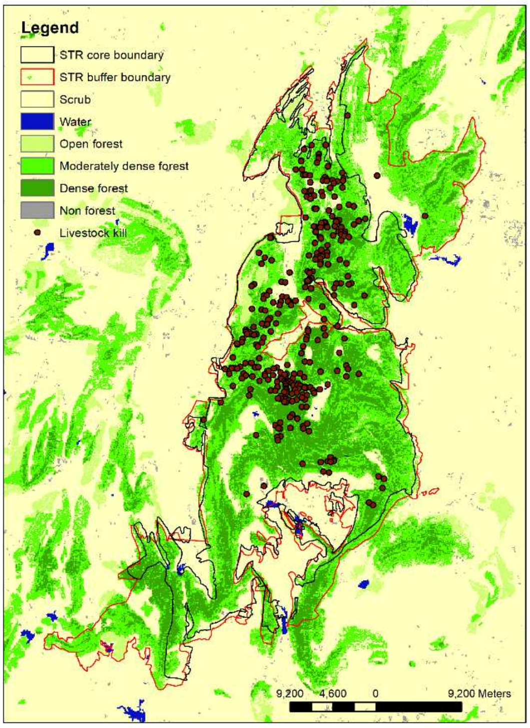

Figure 4. 1: Map showing distribution of livestock kill by tiger in STR between 2011-2016

In case of PTR, compensation data was collected from forest department to understand the intensity of HTC in PTR. But the compensation data was not geo tagged, hence kill data was also collected from forest department. The livestock kill locations were obtained from tiger monitoring registers, which are maintained for all tigers, for the period 2009-2016 (Figure 4.2). Since in case of PTR, there are several feral livestock, and no distinction is made between feral and domestic livestock in the kill records; kill and compensation data were matched, to obtain reliable locations for conflict incidence. Thus, 156 locations were matched for the period 2011-2016.

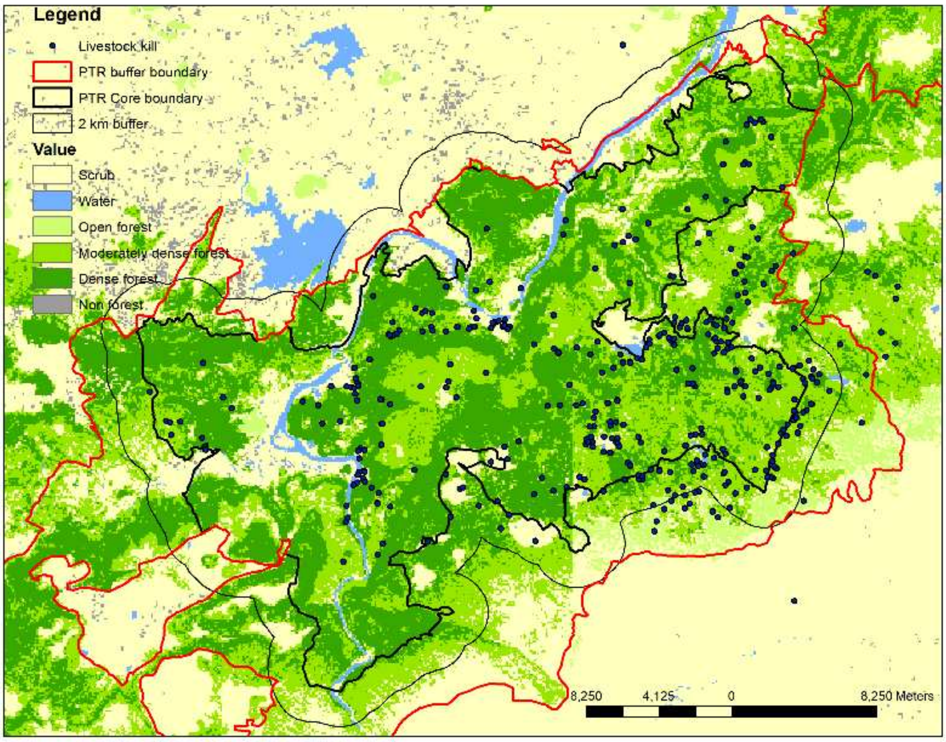

Figure 4. 2: Map showing distribution of livestock kills made by tigers in PTR between 2009-2016

4.2.2. Spatio-temporal patterns of HTC: Mapping existing conflict hotspots

The livestock kill data collected from forest department in case of PTR and livestock kill information obtained from compensation records in case of STR, were analysed to understand the spatio-temporal pattern of HTC and map it. Season-wise summary statistics were calculated to understand the temporal distribution of the intensity of livestock kill by tigers. Beat wise intensity of livestock kill was calculated and mapped, to understand the spatial distribution of HTC, across the basic management unit. To map the hotspots of conflict, the data was further subjected to spatial analyses. Initially, the kernel density estimator tool in ArcMap 10.4 was used to locate the spots where density of conflict locations was high (ESRI, 2016a; Wand & Jones, 1995). However, kernel density estimate only gives us clusters of conflict, and to make management-related decisions it is important to know whether these clusters are statistically significant hotspots or not. For this reason, 'optimized hotspot mapping' tool in ArcMap 10.4 was used which employs Getis-Ord Gi* statistic (ESRI, 2016a; Getis & Ord, 1992). To be a statistically significant hotspot, a feature will have a high value and be surrounded by other features with high values as well. What Getis-Ord Gi* statistic does is that it compares proportionally the local sum for a feature and its neighbours to the sum of all features; when the local sum is very different from the expected local sum, and when that difference is too large to be the result of random chance, a statistically significant z-score is generated (ESRI, 2016b). So, areas with red spots are statistically significant hotspots, blue are statistically significant cold spots and all else are non-significant. These maps were overlaid with village location and tiger home range MCP to help identify the villages and tigers that are facing conflict. Furthermore, to identify the forest beats which are facing higher livestock attack, the forest beat and ranges were overlaid on the hotspot maps.

4.2.3. Multivariate multiscale predictive modelling to identify ecological drivers and map predation risk

Various statistical tools have been applied to model the relationship between habitat variables and livestock kill, most of the times as presence vs absence (or classification into kill or no kill) using linear parametric models for e.g. discriminant function analysis (Edge et al., 2011; Treves et al., 2004), binary logistic regression or generalized linear model (GLM) with logit link function and binomial error distribution (Alsamadisi, 2015; Broekhuis et al., 2017; Karanth et al., 2012, 2013; Kissling et al., 2009; Michalski et al., 2006; Miller et al., 2015; Steinberg, 2013; Thorn et al., 2012); or when modelling the frequency of occurrence of kills (count data), then negative binomial distribution (Penteriani et al., 2016) or if kill events are rare, then zero-inflated negative binomial model (Soh et al., 2014), zero altered negative binomial model (Chen et al., 2016) or rare event model in a binary logistic regression (Naha et al., 2018). However, classical statistical tools like parametric models have several assumptions relating to data distribution and linearity, even though in the real world most of the relationships are not linear and most of the data does not have a gaussian distribution (Chambers & Dinsmore, 2014; Mahmoud, 2021). Thus, in recent times, machine learning algorithms are being increasingly used to generate accurate predictions without having to worry about the data distributions, a priori (Kuhn & Johnson, 2013). Some of the most frequently used machine learning algorithms to model conflict/predation risk are Maxent, Artificial Neural Network (ANN), Genetic Algorithm for Rule Set Production (GARP), Support Vector Machines (SVM), Ecological Niche Factor Analysis (ENFA), Maximum entropy and Random Forest

(Abade et al., 2014; Amirkhiz et al., 2018; Behdarvand et al., 2014; Braunisch et al., 2011; Mateo-tomas et al., 2012; Mbiba et al., 2018; Rostro-Garcia et al., 2016; Zarco-gonzalez et al., 2013). Many studies have even combined several of these models to generate ensemble models that produce more robust predictions (Äärilä, 2017; Struebig et al., 2018). Although the machine learning algorithms may perform better than classical statistical models when it comes to giving more accurate predictions, but if the purpose is to draw inference about the relationship between variables, they are not very interpretable (Stewart, 2019).

The Generalized Additive Model (GAM) while retaining the interpretability of GLM have the flexibility of machine learning models, because it does not assume a linear relationship between dependent and independent variables (Hastie & Tibshirani, 1990; Larsen, 2015). GAM is, as the name suggests, a generalization of the linear model, in which the linear function of the covariate is replaced with a smooth function (Hastie & Tibshirani, 1990). Because of their semiparametric nature, GAMs are much more sensitive to unique data distribution than GLM, allowing for modelling of nonlinear relationships by deriving predictor functions during model building (Härdle & Turlach, 1992; Larsen, 2015). At the same time to avoid overfitting, one can control the smoothness or 'wiggliness' of the predictor function (Larsen, 2015). Despite their versatility, GAM has not been explored as much as linear or machine learning models to understand the relationship between livestock depredation by carnivores and the environmental factors (Kaartinen et al., 2009). Given that the data for this study does not fit the assumptions of linear models, and the primary aim is to not merely get accurate prediction but identify the drivers of HTC, GAM was selected, to model livestock kill locations as a function of various tiger relevant habitat factors (after determining appropriate scale) (Wood, 2017). Since hotspot map revealed that there was no apparent shift in conflict incidences with season, the model was not run separately for different seasons.

Data preparation for multiscale modelling: For the purpose of modelling, livestock kill data was treated as presence, while random absence data was generated in GIS. A 42m buffer (average drag distance) was created around each kill location, which were then overlayed over the random points to make sure that none overlapped with kill location (using erase tool in analysis toolbox in ArcMap 10.4). In both, the study areas livestock kill data for the period 2011-2015 was used for training the model and 2016 data was used for testing the model.

Measuring ecological variables: A total of 27 variables were considered for ecological driver modelling, which can be grouped under the following heads:

- Prey: Wild prey encounter rate (ER), livestock ER, all prey ER
- Vegetation Cover: Canopy cover, tree abundance, shrub abundance, Normalized Difference Vegetation Index (NDVI)
- Water: Euclidean distance to water source (waterhole, perennial water source), Normalized Difference Water Index (NDWI)
- Topographic variables: Slope, slope standard deviation, elevation, terrain ruggedness
- Land use: Land use land cover

- Landscape metrics (FRAGSTATS): Patch density, Largest patch index, Clumpiness index
- Disturbance variables: Lopping intensity, cutting intensity, human ER, livestock ER, vehicle ER, Human footprint data, population census, Euclidean distance to road and village/human settlement

I. Prey

Distance sampling technique was used for tiger prey species population estimation (Buckland et al., 2001). A total of 41 and 48 line transects each up to 2 km in length were surveyed in PTR and STR respectively, during winter 2012-13 and 2013-14 (Figure 4.3, 4.4). All the line transects at both the reserves were walked in a replicate of three. Data for the entire study period were combined and prey ER for each transect, calculated. Further analysis was done using 'conventional distance sampling engine' in the software Distance 6.2 (Thomas et al., 2010). Suitable truncation distances were selected to achieve better model fit of the data. Models were selected on the basis of quantile-quantile plot, Chi-square goodness of fit test p-value and lowest value of Akaike information criteria (Buckland et al., 2001; Thomas et al., 2010).

II. Cover

Vegetation: Vegetation indices, viz. canopy cover and shrub abundance were quantified in 15m circular plots laid at every 400 m on the line transects (Figure 4.3, 4.4) (Jhala et al., 2009). A total of 235 and 234 circular plots were laid in STR and PTR, respectively. Within the plots, ocular estimation of canopy cover was made and shrub cover was scored according to its abundance (0-4).

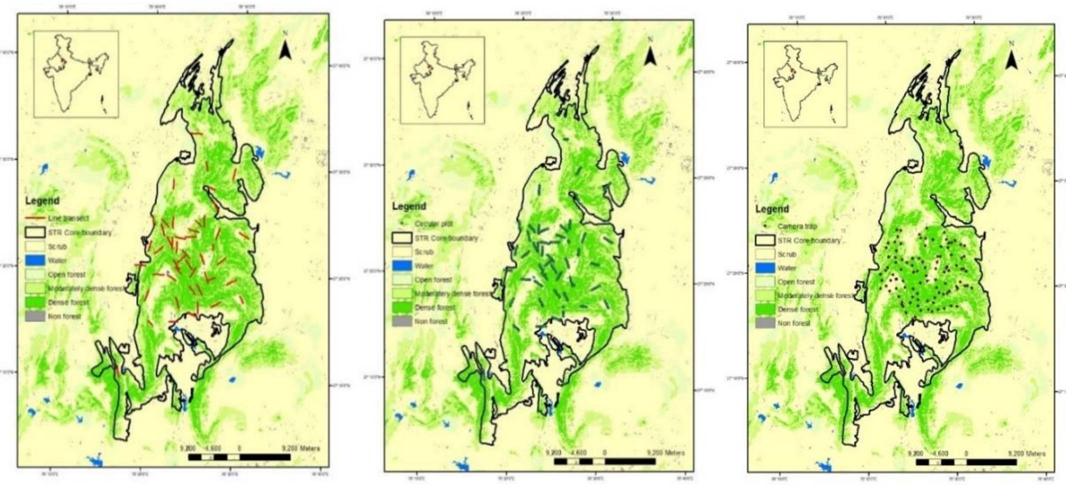

Figure 4. 3: Map showing sampling locations of line transect, circular (vegetation and disturbance) plot and camera trap in STR

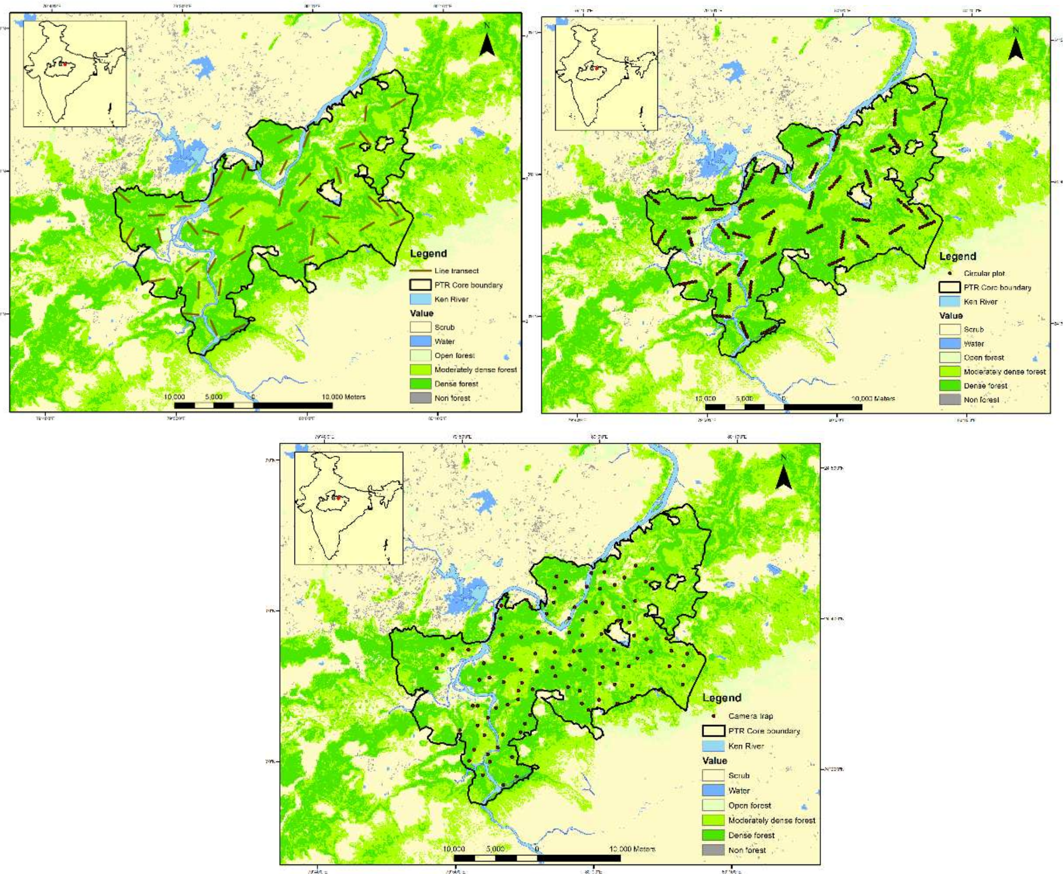

Figure 4. 4: Map showing sampling locations of line transect, circular (vegetation and disturbance) plot and camera trap in PTR

For further understanding the vegetation cover of the tiger reserves, LANDSAT 8 (OLI/TIRS) scenes were downloaded from USGS website for STR for the month of May (LANDSAT SCENE ID = LC81470412013140LGN01; Download date = 24 December 2014) and December (LANDSAT SCENE ID = LC81470412013348LGN01; Download date = 7 December 2020); and PTR for the month of April 2013 (LANDSAT SCENE ID = LC81440432013119LGN01; Download date = 20 April 2015) and November 2013 (LANDSAT SCENE ID = LC81440432013327LGN01; Download date = 15 December 2020). NDVI (Rouse et al., 1974) was calculated for both reserves based on these scenes, using Raster calculator in ArcGIS 10.1 (ESRI, 2012) by the formula: NDVI = (Near Infrared - Red)/ (Near Infrared + Red).

Terrain: Since terrain features also act as cover for tiger, especially breeding animals, topographic data (elevation, slope, and terrain ruggedness) were also derived from satellite data. ASTER Global Digital Elevation Model (DEM) data was downloaded from USGS Global Visualization Viewer website, for both the sites. Slope tool in spatial analyst in ArcGIS 10.1 was used to calculate slope from DEM layers (ESRI, 2012). Additionally, topographic ruggedness index or terrain ruggedness index (TRI) that measures elevation difference between a cell and mean of its eight neighbouring cells (Riley et al., 1999) was calculated for both the reserves. Raster calculator in ArcGIS 10.1 (ESRI, 2012) was used to calculate TRI by the formula (Cooley, 2016): TRI = SquareRoot (Abs((Square(“3x3max”)-Square (“3x3min”)))).

LULC and forest contiguity: LULC prepared by Forest Survey of India for the entire country at 98m resolution for the year 2009 was procured (FSI, 2009). Landscape characteristics and patterns, particularly habitat connectivity, were studied using multiple indices in program FRAGSTATS (ver. 4.2) for both the reserves. FRAGSTAT analyses was run using the FSI LULC, and various landscape-level metrics and three class-level metrics were calculated: Patch density (PD), Largest Patch Index (percentage of total landscape area comprised by the largest patch) (LPI), and Clumpiness index (CLUMPY) (a measure of fragmentation). LPI is a simple measure of dominance. And CLUMPY that ranges from -1 (patch type is maximally disaggregated) to 1 (patch type is maximally clumped) provides an index of fragmentation of the focal class that is not affected by changes in class area (McGarigal, 2015).

III. Water

The scenes used for calculating NDVI were also used to calculate NDWI (McFeeters, 1996) with raster calculator in ArcGIS 10.1 (ESRI, 2012) by the formula: NDWI = (Green-Near Infrared)/ (Green+Near Infrared). Additionally, drainage and water source data for PTR and STR were obtained from respective forest departments and Euclidean distance raster created using Euclidean Distance tool in spatial analyst toolbox in ArcMap 10.4 (ESRI, 2016a). In case of PTR, Euclidean distance rasters were also created for Ken River and its tributaries, and water sources tagged perennial.

IV. Disturbance

Anthropogenic disturbance indices were quantified in the circular plots (as discussed earlier under section II), at both the sites (Figure 4.3, 4.4). In each plot, all the lopped (only branches were cut) and cut (cut to stump) trees were counted and weed abundance ranked. Additionally, camera trap data was obtained from independent tiger monitoring teams at both sites. Camera trapping (Cuddeback Attack pairs) was done in 2x2 km grids within tiger-occupied area in both STR and PTR (Figure 4.3, 4.4). In PTR, camera traps were deployed in 109 locations accounting for 7459 trap nights, in STR, camera traps were deployed in 104 locations accounting for 1827 trap nights. The number of tigers, livestock, humans, and vehicles captured in each camera trap was then manually counted and encounter rates (total no. of captures/total trap nights) calculated. The camera trap data also suggested the extent of overlap between habitat use of the area by tigers and humans, giving us a preliminary understanding of HTI in these reserves.

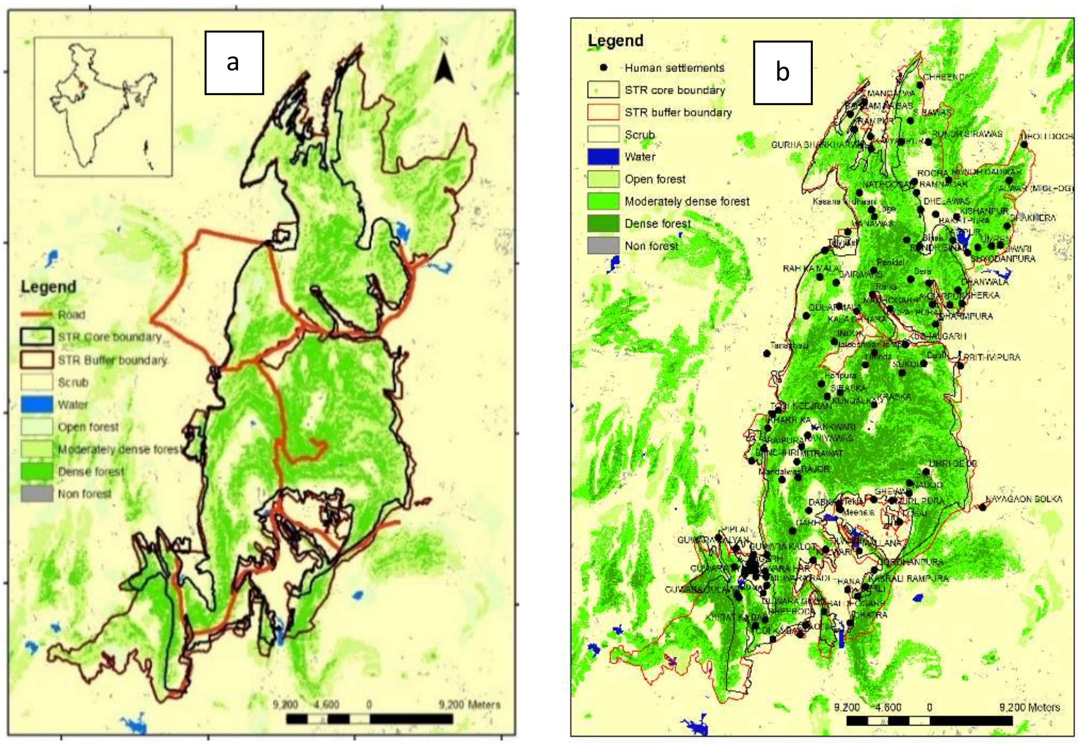

Figure 4. 5: Maps showing location of: a) Major roads; b) Human settlements, within STR

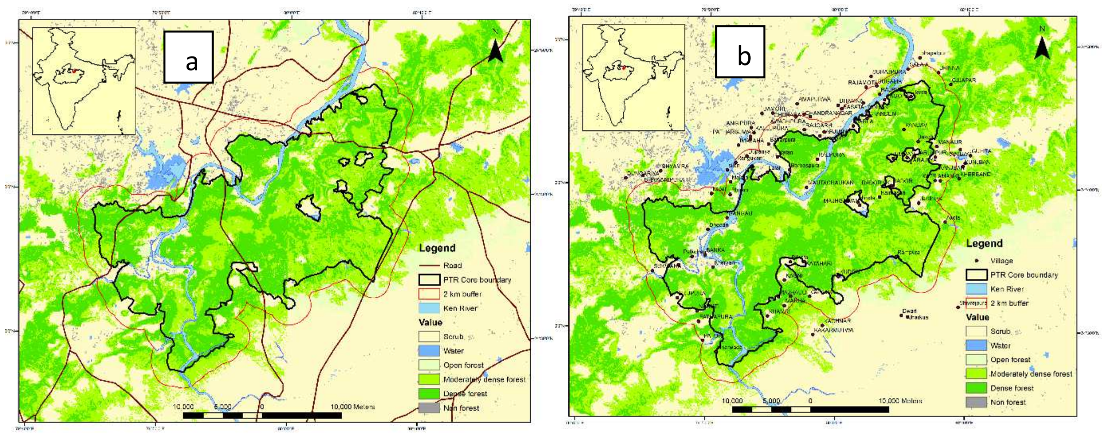

Figure 4. 6: Maps showing location of: a) Major roads; b) Human settlements, within PTR

Village and road location data were also obtained from the forest department and Euclidean distance raster, calculated (Figure 4.5, 4.6). The average distances of villages from tiger home range centers were also calculated to understand the HTI. Additionally, human footprint data was downloaded from Socio Economic Data and Application Centre (SEDAC) website for the year 2009 (Sanderson et al., 2002; Venter et al., 2018). Population census data for 2011 was also downloaded from SEDAC (Balk et al., 2020).

Geostatistical modelling to create rasters: Rasters, viz. NDVI, NDWI, DEM, Slope, and TRI, were masked with STR and PTR boundary polygons using ArcMap's extract by mask tool (ESRI, 2009). Means and standard deviations (SD) of all the listed variables were then obtained from these rasters for both the reserves. Canopy cover, prey, human, livestock, and vehicle ER, cutting and lopping intensity rates, as well as their SDs were interpolated to create rasters, using the Geostatistical wizard in ArcMap

10.4 (Cressie, 2015; De Smith et al., 2007; ESRI, 2016a). Before interpolation looking at the histogram complete outliers were removed. Four interpolation tools were considered for the purpose: Inverse Distance Weighing, Simple Kriging (SK), Ordinary Kriging (OK), and Empirical Bayesian Kriging (EBK). In case of plot data, declustering and data transformation were performed when employing SK. Statistical measures of correctness (mean prediction error, root-mean-square error, standardized root-mean-square error, average standard error) from the cross-validation were used to compare the kriging algorithms. The best model was considered the one that has the smallest root-mean-squared prediction error (RMSE), standardized mean nearest to zero, the average standard error nearest the root-mean-squared prediction error, and the standardized root-mean-squared prediction error nearest to 1 (ESRI, 2016c). Also, unless there was a huge difference in the RMSE among kriging methods, EBK was preferred over other kriging methods, because it gives more robust prediction errors, given that it considers not one but several semivariograms when building the model (Table 4.1).

Table 4. 1: Interpolation model selection summary for all ecological variables for both PTR and STR

Variable	**PTR**		**STR**	
	Selected model	**Selection criteria**	**Selected model**	**Selection criteria**
Tree abundance	EBK	EBK has the lowest RMSE and SM is closest to zero	SK	SK has the lowest RMSE, other parameters are similar across models

Livestock encounter rate (camera trap)	EBK	The ASE of EBK is nearest to the RMSE, SM is closest to zero and RMSS is closest to 1. And although OK has the lowest RMSE, EBK is very close.	OK	OK performing best on all parameters
Cutting	EBK	EBK has SM closest to zero and RMSS closest to 1	EBK	The ASE of EBK is nearest to the RMSE. And although OK has the lowest RMSE, EBK is very close.
Lopping	OK	The ASE of OK is nearest to the RMSE and RMSS is closest to 1.	EBK	The ASE of EBK is nearest to the RMSE. And although SK has the lowest RMSE, EBK is very close.
Vehicle encounter rate	OK	The ASE of EBK is nearest to the RMSE, SM is closest to zero and RMSS is closest to 1. And although EBK has the lowest RMSE, OK is very close.	EBK	The ASE of EBK is nearest to the RMSE and SM is closest to zero. And although SK has the lowest RMSE, EBK is very close.
Human encounter rate	OK	OK has the lowest RMSE, the ASE is nearest to the RMSE, and RMSS is closest to 1.	EBK	The ASE of EBK is nearest to the RMSE and RMSS is closest to 1. And although SK has the lowest RMSE, EBK is very close.
Prey encounter rate	EBK	EBK has RMSS closest to 1, and ASE nearest to the RMSE. And although SK has the lowest RMSE, EBK is very close.	EBK	The ASE of EBK is nearest to the RMSE and RMSS is closest to 1. And although SK has the lowest RMSE, EBK is very close.

Canopy cover	OK	OK is doing best on all parameters	EBK	The ASE of EBK is nearest to the RMSE and RMSS is closest to 1. And although SK has the lowest RMSE, EBK is very close.
Shrub abundance	EBK	EBK has the lowest RMSE and SM is closest to zero	SK	The ASE of SK is nearest to the RMSE and RMSS is closest to 1. And although EBK has the lowest RMSE, SK has almost the same.
Wild prey encounter rate	EBK	Output of EBK has some variance across the area, other models are showing very little variance i.e. wild prey encounter rate is changing across the area when using EBK but is more or less homogenous when using other interpolation tools.	OK	The ASE of OK is nearest to the RMSE and RMSS is closest to 1. And although SK has the lowest RMSE, OK is very close.
Livestock encounter rate (line transect)	OK	SM of OK is closest to zero. And although SK has the lowest RMSE, OK is very close and much lower than EBK.	OK	The ASE of OK is nearest to the RMSE and RMSS is closest to 1. And although SK has the lowest RMSE, OK is very close.

SM: Standardized Mean; RMSS: Root Mean Square Standardized; ASE: Average Standard Error; RMSE: Root Mean Square Error; OK: Ordinary Kriging; SK: Simple Kriging; EBK: Empirical Bayesian Kriging

Multiple scales: To construct a multiscale model, each of these variables (except human footprint, and FRAGSTATS variable) were resampled at five scales: 30m (the highest resolution available), 50m (average kill drag distance for tiger, as indicated by literature (Karanth & Sunquist, 2000; Miller et al., 2015)), 100m (midpoint between fine and coarse resolution), 350m (maximum kill drag distance from literature), 1200m (coarsest resolution used by us and at which most global environmental data is available) using the Resample tool in data management toolbox of ArcMap 10.4. Thus, in total there were 118 variables. All the variables were then extracted for each of the presence/absence points using the 'Extract Multi Values to Point' tool in the Spatial Analyst toolbox of ArcMap 10.4.

Scale and variable selection using univariate models and information value: For scale and feature selection, firstly, univariate logistic regressions were run, after performing Box-Tidwell procedure to test for logistic regression linearity assumption i.e., logit transformation of the dependent variable and continuous independent variables have a linear relationship (Shin & Ying, 1994; Wuensch, 2016). Secondly, univariate GAMs were run to understand how much r square/deviance was explained by each of the predictors at each of the scales. The scale at which the variable was best explaining the response was selected. Additionally, Information Value and Weight of evidence were employed for feature selection (Good & Osteyee, 1974). Results of univariate logistic regression, univariate GAM, and Information value were studied to select the explanatory variables at appropriate scales for constructing the predictive models. The data was then checked for spatial autocorrelation and multicollinearity. To check for multicollinearity among the selected variables, appropriate tests of association were run (for continuous vs continuous and continuous vs ordinal variables, Kendall's tau b; for categorical vs continuous variables, logistic regression; and for categorical vs categorical variables, Cramer's V). Among the correlated variables, selection for inclusion in the model was made based on which variable was better explaining the response. In case of PTR, all prey (wild prey plus livestock) was highly correlated to wild prey ER (r=0.812). Since all prey ER was explaining higher deviance of dependent variable, it was selected. Similarly, NDVI and NDWI were moderately correlated (r=0.636), since NDVI was explaining higher deviance, it was selected. In case of STR, slope variance was highly correlated to TRI (r=0.784), since TRI was explaining higher deviance, it was selected. And LULC was correlated to several variables that were explaining better deviance, hence, it was dropped.

So after variable selection, the predictive modelling for Sariska was done on these 16 variables: Wild prey ER (350m), livestock ER (lt) (1200m), all prey ER (350m), slope (30m), elevation (30m), TRI (100m), NDVI (50m), tree abundance (100m), shrub abundance (350m), canopy cover (350m), NDWI (30m), distance to water hole (350m), cutting (1200m), lopping (100m), livestock ER (ct) (50m), vehicle ER (350m), human ER (350m), distance to road (1200m), distance to village (1200m), human footprint, human population (1200m) (Figure 4.7).

The global model in case of PTR consisted of the following 12 variables at these scales: All prey ER (50m), slope (50m), elevation (1200m), slope deviation (100m), NDVI (100m), shrub abundance (50m), canopy cover (30m), distance to water hole (1200m), livestock ER (ct) (50m), human ER (1200m), distance to road (100m), distance to village (100m) (Figure 4.8).

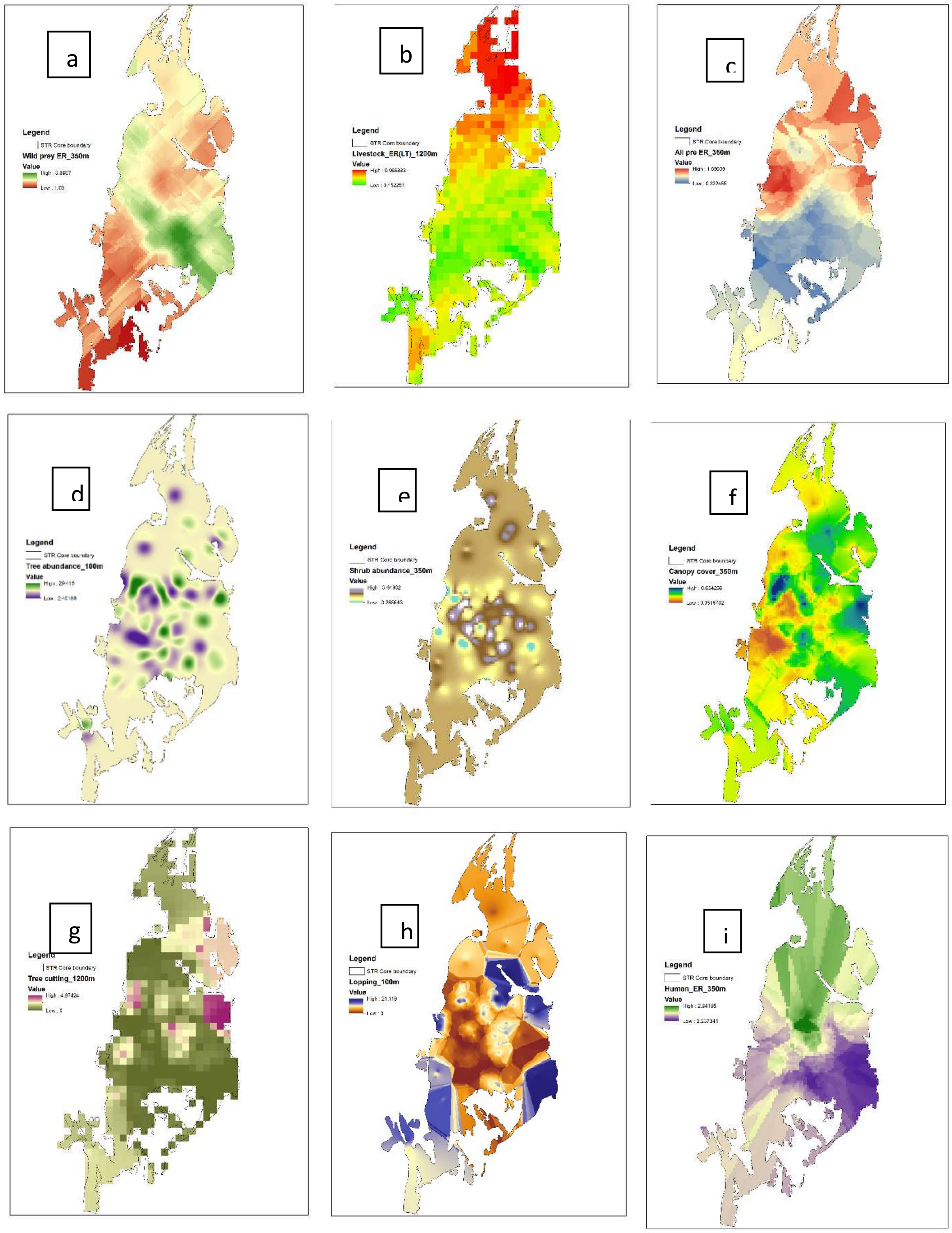

Figure 4. 7: Maps depicting interpolated layers of various variables in STR at selected scale: a) Wild prey encounter rate (ER) (350m), b) livestock ER (lt) (1200m), c) all prey ER (350m), d) tree abundance (100m), e) shrub abundance (350m), f) canopy cover (350m),

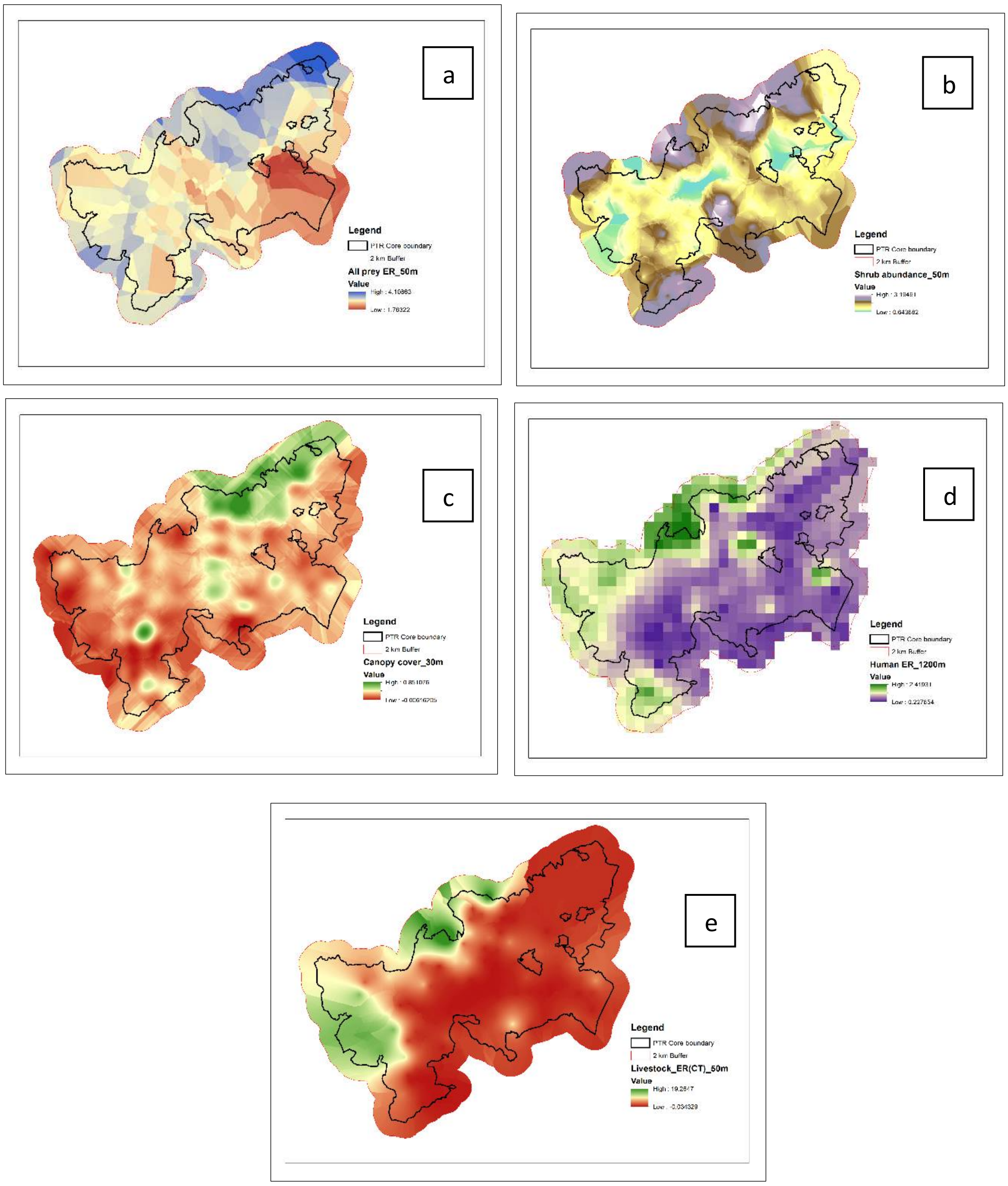

Figure 4. 8: Maps depicting interpolated layers of various variables in PTR at selected scale: a) All prey ER (50m), b) shrub abundance (50m), c) canopy cover (30m), d) human ER (1200m), e) livestock ER (ct) (50m)

Spatial GAM: Since most ecological variables exhibit a certain degree of spatial autocorrelation, therefore, it is important to account for the spatial nature of the data (Griffith, 1992; Legendre, 1993), when modelling predation risk by carnivores. In absence of which, ‘independence of data points’, a common assumption across most statistical models, is violated, leading to unreliable model outcomes (Dale & Fortin, 2002; Legendre, 1993). Spatial autocorrelation was checked among independent variables using Moran’s I statistic and it was found that many variables were spatially autocorrelated (Getis, 2007; Moran, 1950).

To account for the spatial autocorrelation in the data, instead of the regular GAM, spatial GAM model was constructed using geoGAM package in R ver. 3.6.3. (Nussbaum & Papritz, 2017). It’s a procedure to build parsimonious model based on gradient boosting, smoothing splines and a smooth spatial surface to account for the spatial structure. The GAM for spatial data or geoaddtive model in its full generality is represented by

$$\mathrm{g}\left(\mu\big(\mathrm{x}(\mathrm{s})\big)\right) = \nu + \mathrm{f}\big(\mathrm{x}(\mathrm{s})\big) =$$
$$\nu + \sum_{u} f_{j_u}(x_{j_u}(\mathrm{s})) + \sum_{v} f_{j_v}(x_{j_v}(\mathrm{s})) \,.\, f_{k_v}(x_{k_v}(\mathrm{s}))$$
$$+ \sum_{w} f_{s_w}(\mathrm{s}). f_{j_w}(x_{j_w}(\mathrm{s})) + f_s(\mathrm{s})$$

Where, $f_s(\mathrm{s})$ is a smooth function of spatial coordinates, which accounts for residual autocorrelation.

Since the response variables in this case is binary, Bernoulli distribution is assumed and logit link used

$$\mathrm{g}\left(\mu\big(\mathrm{x}(\mathrm{s})\big)\right) = \log\left(\frac{\mu\big(\mathrm{x}(\mathrm{s})\big)}{1 - \mu\big(\mathrm{x}(\mathrm{s})\big)}\right)$$

where,

$$\mu\big(x(s)\big) = \mathrm{Prob}[Y(s) = 1 \,|\, x(s)] = \frac{\exp(\nu + f(x(s)))}{1+\exp(\nu + f(x(s)))}$$

For building parsimonious model geoGAM automatically selects factors, covariates and spatial effects using gradient boosting, following which model is further reduced using cross validation (Nussbaum & Papritz, 2017).

The final model so selected was run on test data, to get model performance measures, area under the curve (AUC) and true skill statistic.

Risk map: A raster with 42m cell size was created and masked to the reserve boundary. It was then converted into points using the raster to point tool in the conversion toolbox of ArcMap 10.4. Now for each of these points, values for all variables were extracted. The final model was then run on this data to predict predation risk probability for each of these points. The points were then converted back to raster, using the point to raster tool in the conversion toolbox of ArcMap 10.4. Finally, risk predictions were assigned as the value of the raster, to create HTC risk maps for both reserves.

4.3. Results

4.3.1. Status of human-tiger interaction: The analyses of camera trap data revealed that in STR out of the 104 camera trap grids, tigers were captured in 36, and 32 of these tiger occupied grids also registered the presence of either human, livestock, or vehicle, and 27 grids had all of them. In 32 of the tiger-occupied grids, humans and livestock were also captured, and in 26 of the tiger-occupied grids, vehicles were also captured. In PTR, out of the 109 camera trap grids, tigers were captured in 21 grids, and all of these tiger-occupied grids also registered the presence of either humans, livestock, or vehicles. In all of the tiger-occupied grids, humans and vehicles were also captured, and in 14 of the tiger-occupied grids, livestock were also captured. Therefore, in both the reserves there is a high overlap of human and tiger use of the CTH. It may seem that since PTR has the presence of humans and vehicles in all tiger-occupied habitats, it has probably higher HTI. However, a deeper examination of the data revealed that people frequently captured in PTR were forest department staff, carrying out various management related activities in and around the roads, in contrast, in STR, the people captured were mostly villagers moving inside the reserve to collect fuelwood and fodder or grazing livestock, infiltrating the forest irrespective of the presence of roads and trails. Thus, even though a similar number of people may be moving inside these reserves, the manner in which they are moving and the purpose of their movement are different. Further, in STR, villages are located within smaller distance of tiger home ranges (average distance of villages from tiger home range centers was 12.5 km) as compared to PTR, where villages are located outside or in the fringe area of tiger habitats (average distance of villages from tiger home range centers was 17.04 km).

4.3.2. Status of human-tiger conflict: In STR, livestock compensation records reveal that a total of 217 livestock have been lost to tiger, between mid-2011 to December 2014. For the same period in PTR, livestock compensation records reveal that a total of 224 livestock have been lost to tiger. However, it should be noted that between this period PTR population grew from 13 to 25 individuals, while STR population grew from 5 to 13. So even though total livestock loss was higher in PTR, in STR similar amount of loss was caused by a much smaller number of tigers. Hence, severity of HTC seems to be higher in STR as compared to PTR.

4.3.3. Spatio-temporal pattern of human-tiger conflict:

Analysis of compensation data for both PTR and STR revealed the spatio-temporal pattern of HTC in the past. The season in which most of livestock were depredated by tiger in STR (N=208) was winter (n=96), closely followed by monsoon (n=74), and least in summer (n=38). In case of PTR (N=224) also it was winter (n=104), closely followed by monsoon (n=82) and least in summer (n=38).

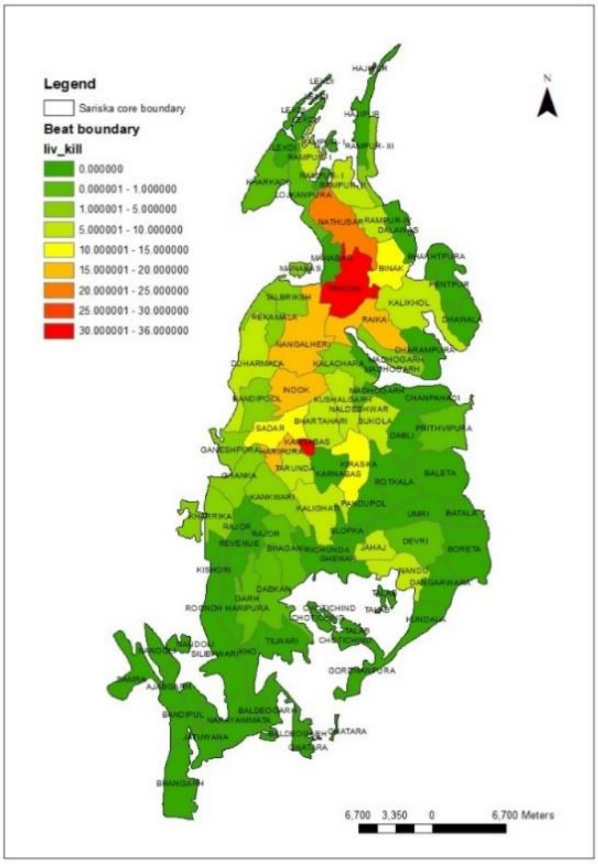

Figure 4. 9: Thematic map presenting the intensity of livestock kill by tiger in STR, across beats

Upon mapping the livestock kill beat wise, it was revealed that in case of STR certain beats like Panidhal and Karnakawas were experiencing high livestock loss, while several beats especially those in the south of the reserve are experiencing almost no livestock loss due to tigers (Figure 4.9).

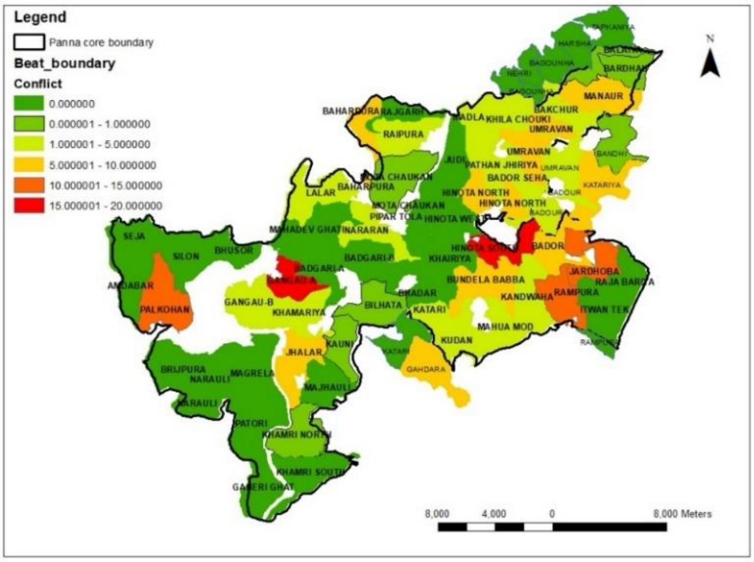

Figure 4. 10: Thematic map presenting the intensity of livestock kill by tiger in PTR, across beats

In case of PTR, it was found that Hinota south, Gangau A, Jardhoba, Rampura, Palkohan were experiencing high conflict, and certain beats in the west of the national park like Magrela and Khamri South were experiencing low livestock loss (Figure 4.10). To further understand the spatial and temporal pattern of HTC in both the reserves the kernel density estimates and getis-ord gi hotspot maps were analysed.

In STR, kernel density estimation reveals higher density of livestock kill was in sanctuary area, with beats Karnakawas and Kiraska experiencing more livestock kills (Figure 4.11).

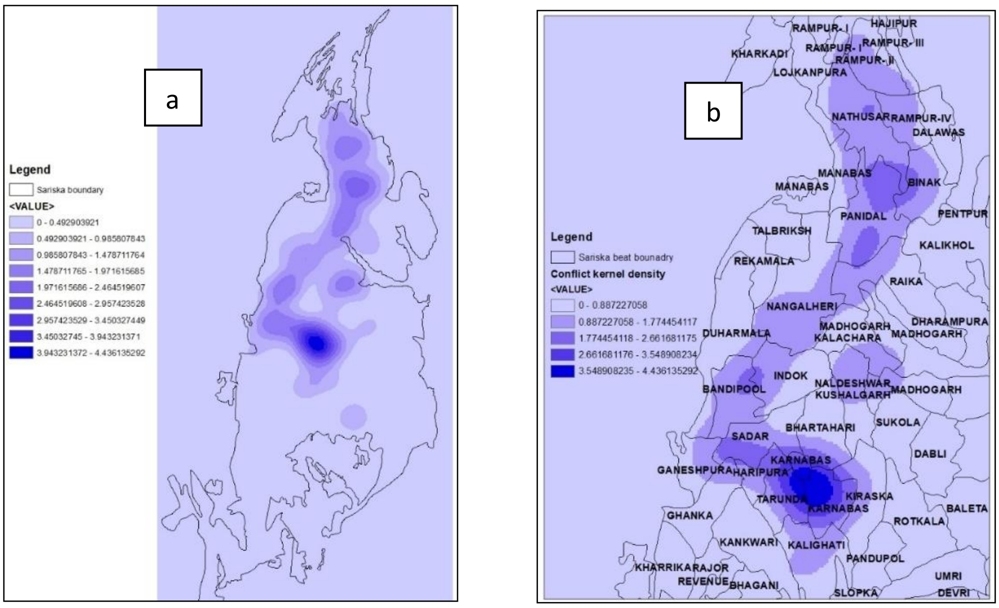

Figure 4. 11: Maps showing kernel density estimate for: a) hotspots of livestock kill in STR core b) forest beats falling within conflict hotpots in STR

Optimized hotspot mapping reveals that statistically significant conflict hotspots were centred in Sariska, Talvriksh and parts of Akbarpur Ranges, while cold spots were in Tehla Range (Figure 4.12 a, b). Overlaying MCPs of collared tigers revealed that all sampled tigers were occupying livestock kill hotspots (Figure 4.12c). Overlaying village location revealed that many villages occupying tiger reserve core like Haripura, Kiraska, Kankwadi, Indok, Sukola, Kushalgarh, Panidhal, Loge, Nathusar, and Nangalhedi among others, were falling within hotspots (Figure 4.12d). Again, overlaying both tiger MCP and village location, revealed that most of the conflict hotpot lay where the two overlapped (Figure 4.12e). A comparison of the seasonal hotspot maps revealed that there was no significant shift in conflict incidences with season in Sariska (Figure 4.13).

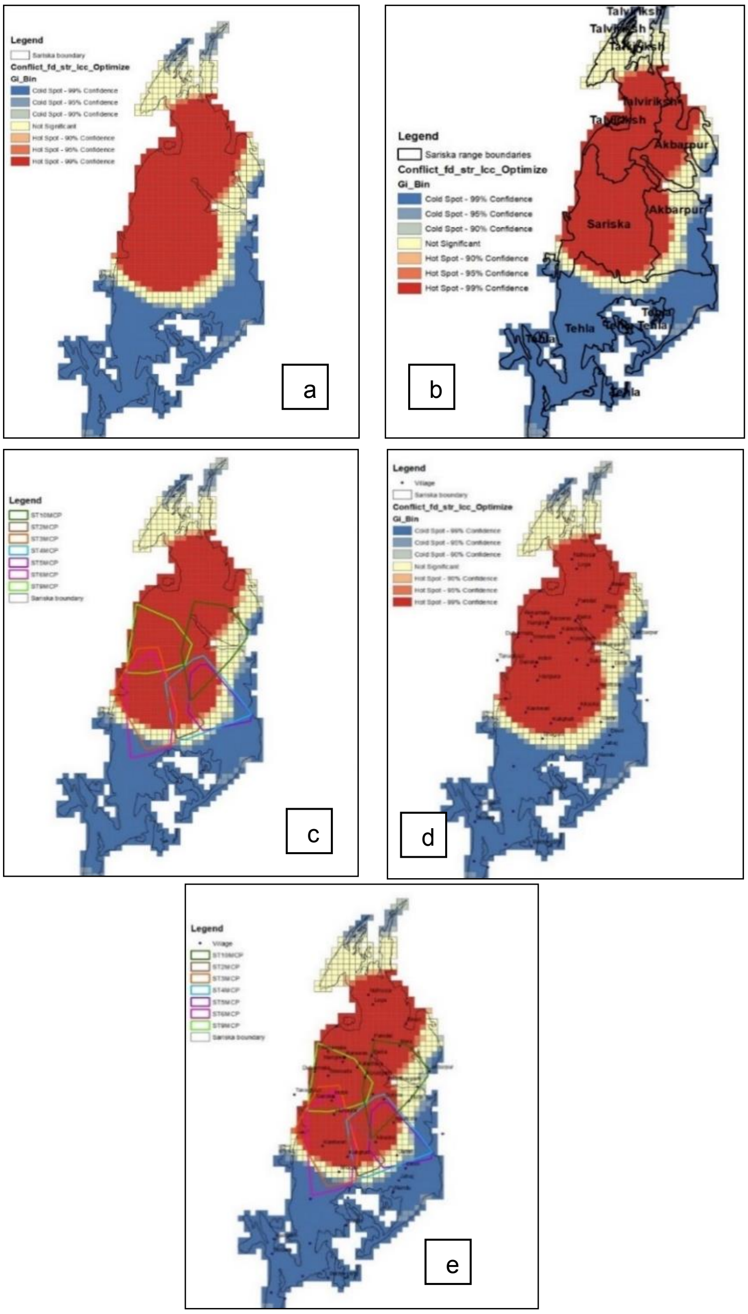

Figure 4. 12: Getis-Ord Gi* statistic hotspot map of: a) livestock kill by tiger in STR core; b) forest ranges falling within conflict hotpots in STR; c) tiger home ranges falling within conflict hotpots in STR; d) villages (present, as well as, relocated) falling within conflict hotpots in STR; e) tiger home ranges and village locations overlapping in conflict hotpots in STR

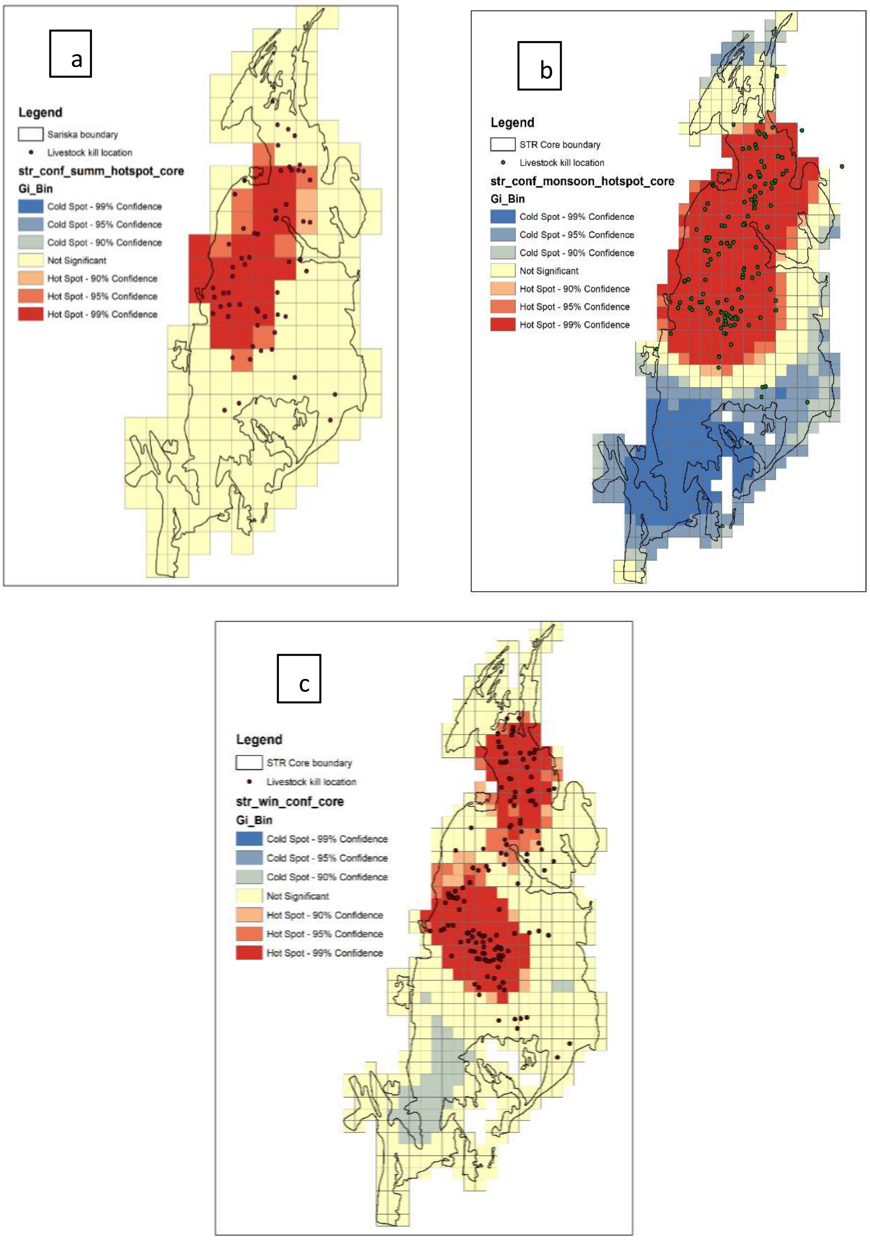

Figure 4. 13: Getis-Ord Gi* statistic seasonal hotspot map of livestock kills by tiger in STR core: a) Summer b) Monsoon c) Winter

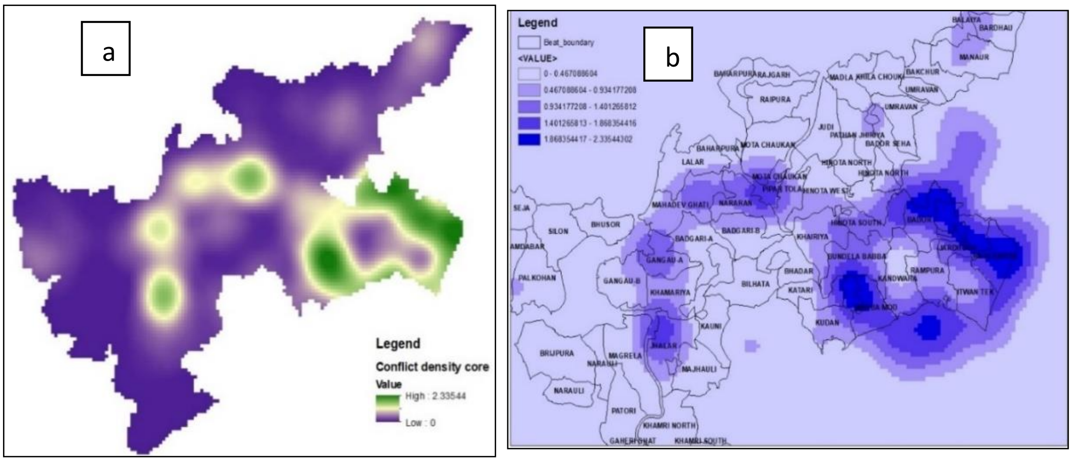

Figure 4. 14: Maps showing kernel density estimate for: a) hotspots of livestock kill in PTR core b) forest beats falling within conflict hotpots in PTR

In PTR, the kernel density estimation reveals that higher density of livestock kill was in beats like Bador, Hinota south, Bundela Baba, and Pipartola (Figure 4.14 a, b).

Optimized hotspot mapping reveals that statistically significant hotspots mostly lie in Panna Range, and parts of Hinota and Gharighat ranges (Figure 4.15 a, b), PTR does not have statistically significant cold spots (Figure 15a). Overlaying MCPs of collared tigers revealed that barring T4 all tigers were occupying high conflict locations (Figure 4.15c). Overlaying village location revealed that among the existing villages Hinota, Akola, Jardhova, Bador, and Rampura were falling within hotspots (Figure 15d). Overlaying both tiger MCP and village location, it was found that most of the hotspots lay where the two overlapped (Figure 4.15e). However, the results should be interpreted with caution, since it is based only on livestock kill information of radio-collared tigers.

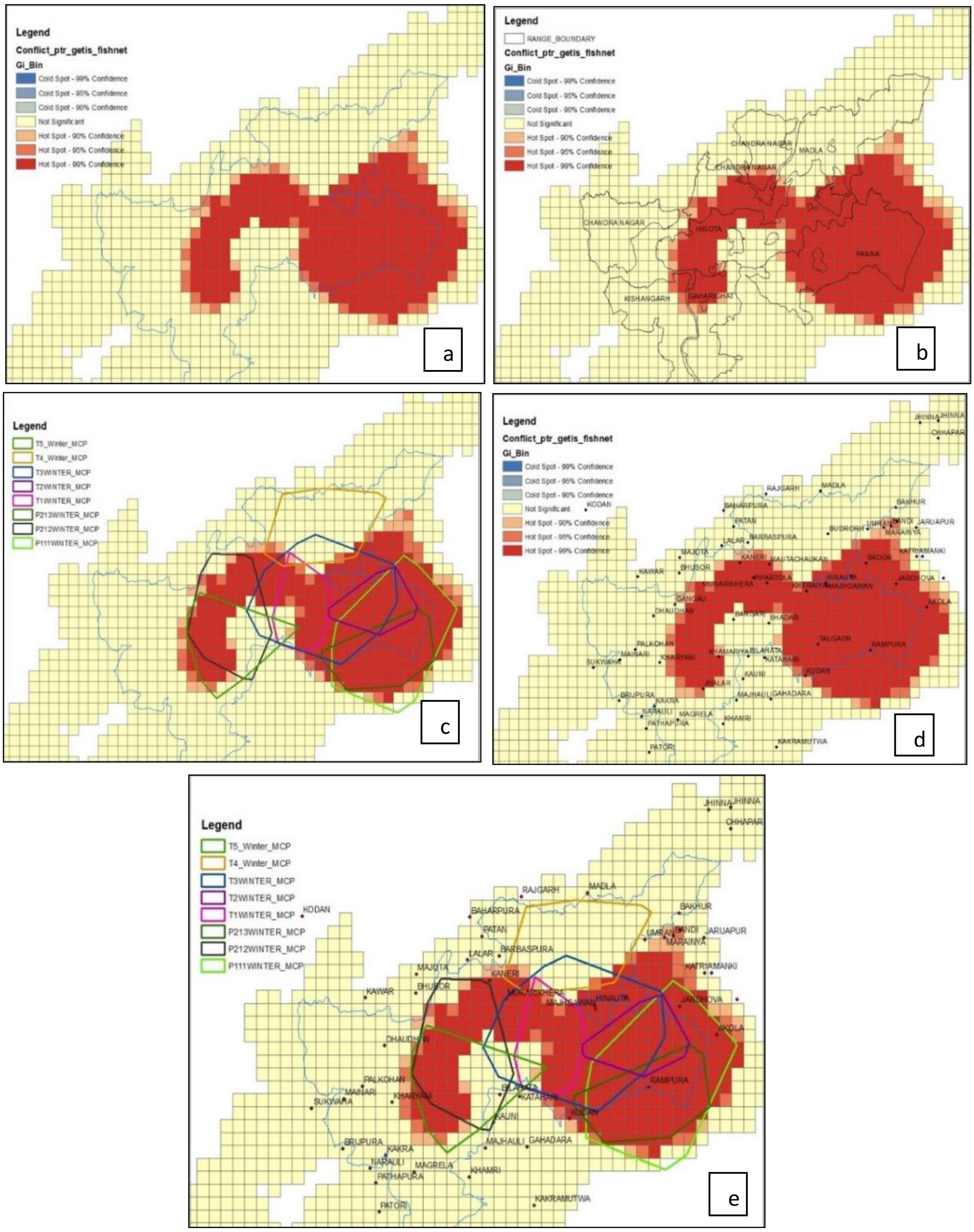

Figure 4. 15: Getis-Ord Gi* statistic hotspot map of: a) livestock kill by tiger in PTR; b) forest ranges falling within conflict hotpots in PTR core; c) tiger home ranges falling within conflict hotpots in PTR; d) villages (present, as well as, relocated) falling within conflict hotpots in PTR; e) tiger home ranges and village locations overlapping in conflict hotpots in PTR

Since all livestock depredation by tiger (especially in case of PTR) is not recorded, these hotspot maps might be giving us an incomplete picture. This is where it becomes necessary to model the distribution of HTC using habitat correlates.

4.3.3 Ecological drivers of human-tiger conflict:

Prey: Prey density estimates (including livestock) were 199.50 ± 12.30 n/km^2 in STR and 52.80 ± 7.10 n/km^2 in PTR, for both winters combined (Table 4.2). Wild ungulate prey density in STR was 35.99 ± 4.94 n/km^2 and in PTR 27.78 ± 2.61 n/km^2. Livestock density in STR was 85.20 ± 11.90 n/km^2 while in PTR it was 39.80 ± 10.90 n/km^2.

Table 4. 2: Prey density estimate in Panna and Sariska tiger reserves (2012-14)

Species	Panna Tiger Reserve		Sariska Tiger Reserve	
	Estimated individual density (N/Km^2)	**CV %**	**Estimated individual density (N/Km^2)**	**CV %**
Sambar	6.2	18.1	8.7	20.0
Chital	8.7	31.8	10.4	35.7
Nilgai	8.8	12.7	9.7	17.2
Wild pig	2.8	25.3	7.2	41.5
Langur	13.5	16.5	8.2	34.3
Peafowl	3.5	22.8	98.1	7.5
Livestock	39.8	29.8	85.2	14.0

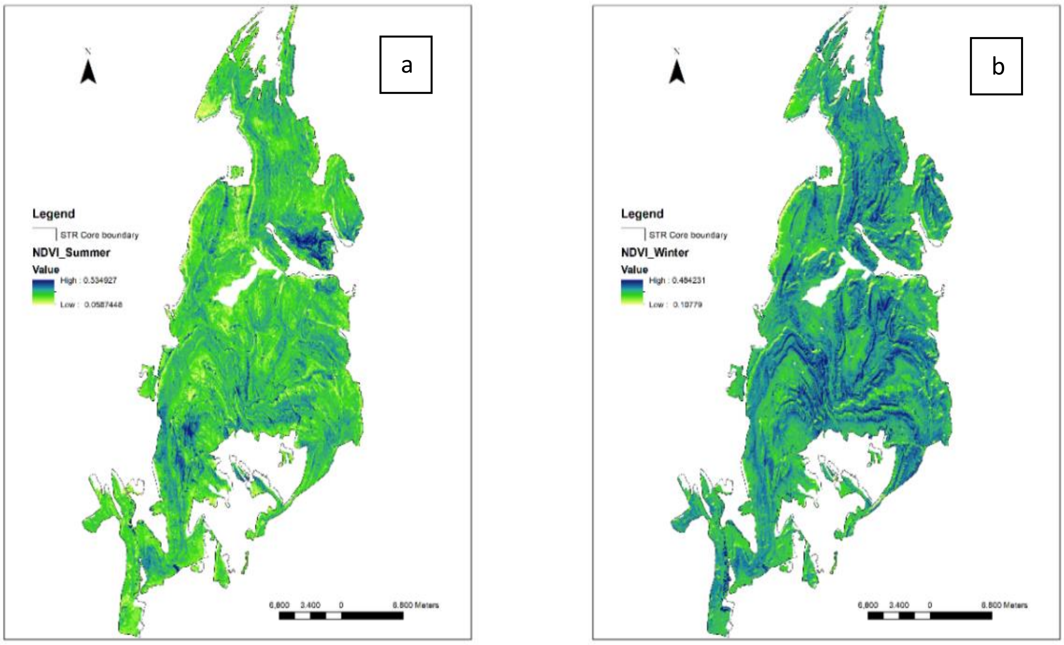

Figure 4. 16: Normalized Difference Vegetation Index (NDVI) of STR for a) Summer, b) Winter

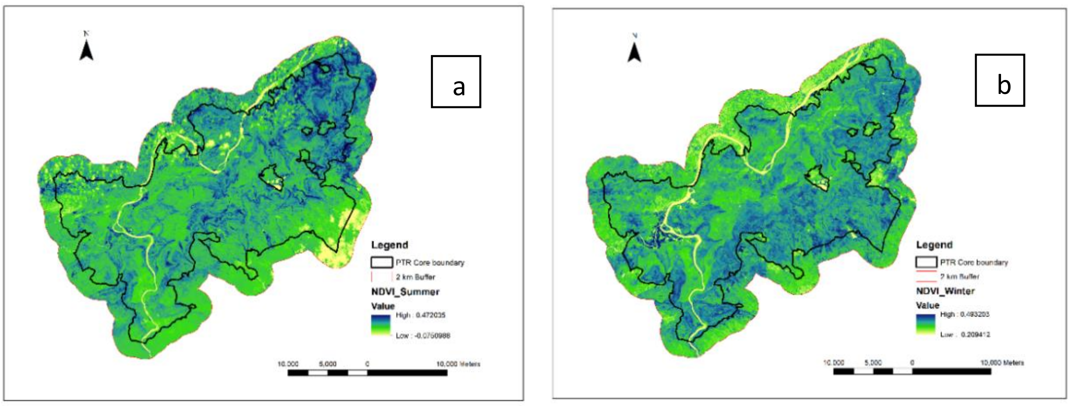

Figure 4. 17: Normalized Difference Vegetation Index (NDVI) of PTR for a) Summer, b) Winter

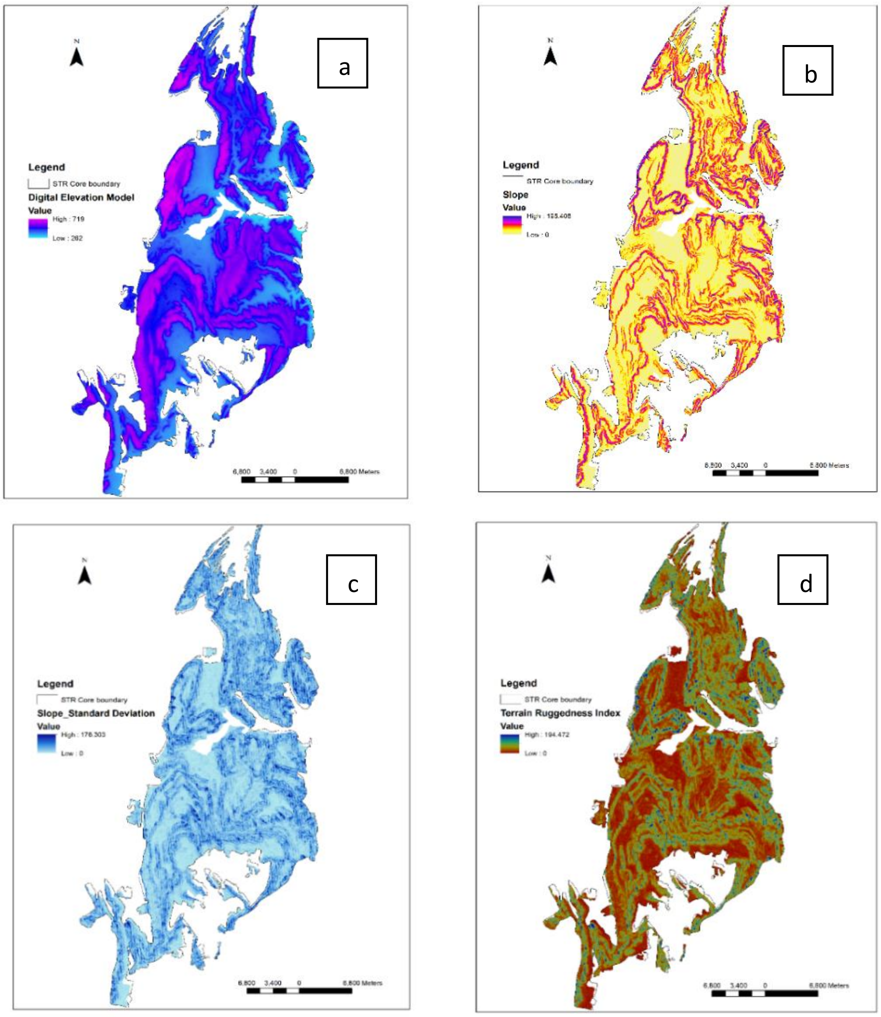

Figure 4. 18: Maps depicting terrain features of STR: a) Elevation (DEM); b) Slope; c) Slope standard deviation; d) Terrain ruggedness

Cover: Average canopy cover and shrub abundance for STR, were 0.29 and 1.72, respectively. For PTR, canopy cover was 0.33 and shrub abundance 1.81. The mean value of NDVI for STR during summer was 0.18 ± 0.03 and during winter 0.20 ± 0.05 (Figure 4.16). For PTR, NDVI was 0.15 ± 0.03 during summer and 0.22 ± 0.06 during winter (Figure 4.17).

Mean elevation and slope (%) for STR were 481.22±96.38 and 21.4±18.65, respectively (Figure 4.18 a, b, c). For PTR mean elevation was 350.69±83.84 and slope was 9.58±9.93 (Figure 19 a, b, c). The TRI value for STR was 22.43±17.08 and for PTR was 63.68 ±32.82 (Figure 4.18, 19 d).

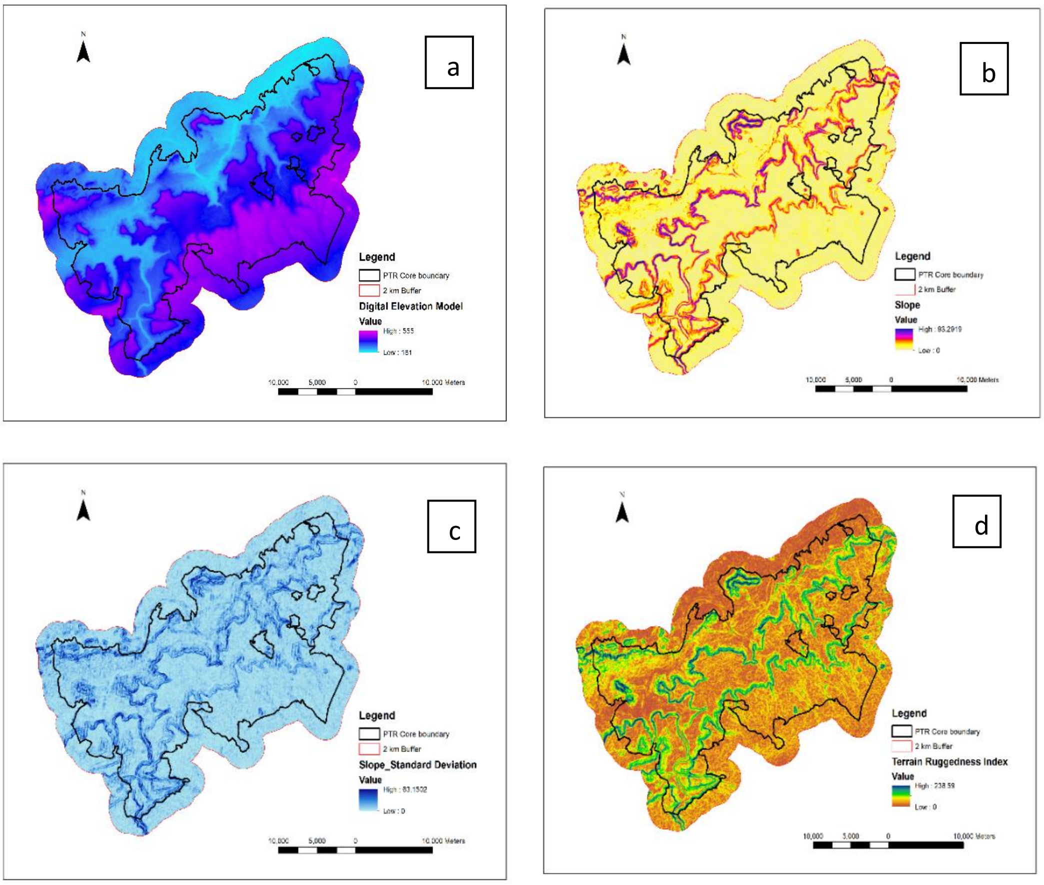

Figure 4. 19: Maps depicting terrain features of PTR: a) Elevation (DEM); b) Slope; c) Slope standard deviation; d) Terrain ruggedness

As for FRAGSTATS metrices, both size of the patch (AREA_MN) and extensiveness of the patch (GYRATE_MN) are more for Sariska than Panna, therefore Sariska seems to be more contiguous (Table 3). Patch size variability is more for Panna than Sariska suggesting that, difference in patch sizes among patches in Panna is more than Sariska (Table 4.3). The spatial heterogeneity of the landscape as reflected by edge density was similar for the two reserves. LSI for both the reserves suggests that patch shape complexity was comparable (Table 4.3). Aggregation metrics (both measures of interspersion and dispersion, as well as, isolation) suggest that habitat fragmentation is similar in the two reserves. Patch richness is low for both the reserves (Table 4.3). When compared patch richness density is lower for Panna than Sariska indicating that Panna has a lower number of patch types (Table 4.3).

As for class-level metrics, PD was highest for open forest in PTR, and very dense forest in STR (Table 4.4). LPI was highest for moderately dense forest in PTR and for open forest in STR. As for fragmentation, in case of both STR and PTR there was not much difference in CLUMPY among classes (Table 4.4). In STR clumpiness was highest for moderately dense forest and lowest for open forest. In PTR, surprisingly clumpiness was highest for non-forest class and lowest for scrub.

Table 4. 3: Selected landscape level metrices quantified using FRAGSTAT for Panna and Sariska tiger reserves

Landscape level metrices		**Name of the reserve**	
		Panna	**Sariska**
Area and edge metrics	Patch density	2.67	2.00
	Edge density	44.28	43.87
	Patch area (AREA_MN)	37.50	49.99

	Patch area CV	1750.82	863.15
	Radius of Gyration (GYRATE_MN)	146.99	194.86
	Radius of Gyration CV	273.06	207.86
Shape metrics	Landscape shape index (LSI)	49.82	42.27
Aggregation metrics	Euclidean Nearest Neighbour Distance (ENN_AM)	242.66	245.42
	Euclidean Nearest Neighbour Distance CV	117.07	103.28
	Contagion (CONTAG)	38.44	42.60
	Proportion of like adjacencies (PLAD)	75.04	74.49
	Interspersion Juxtaposition Index (IJI)	67.25	51.05
Diversity metrics	Patch richness density (PRD)	0.0034	0.053

Table 4. 4: Selected class level metrices quantified using FRAGSTAT for Panna and Sariska Tiger Reserves

Class	Panna Tiger Reserve			Sariska Tiger Reserve		
	PD	LPI	CLUMPY	PD	LPI	CLUMPY
Non-Forest	0.49	11.93	0.76	0.07	0.31	0.69

Moderately Dense Forest	0.44	20.17	0.67	0.02	0.22	0.82
Open Forest	1.04	6.35	0.59	0.64	12.92	0.57
Very Dense Forest	0.37	2.00	0.62	0.73	8.98	0.62
Scrub	0.26	0.26	0.53	0.09	0.63	0.72
Water	0.07	0.34	0.63	0.46	4.16	0.73

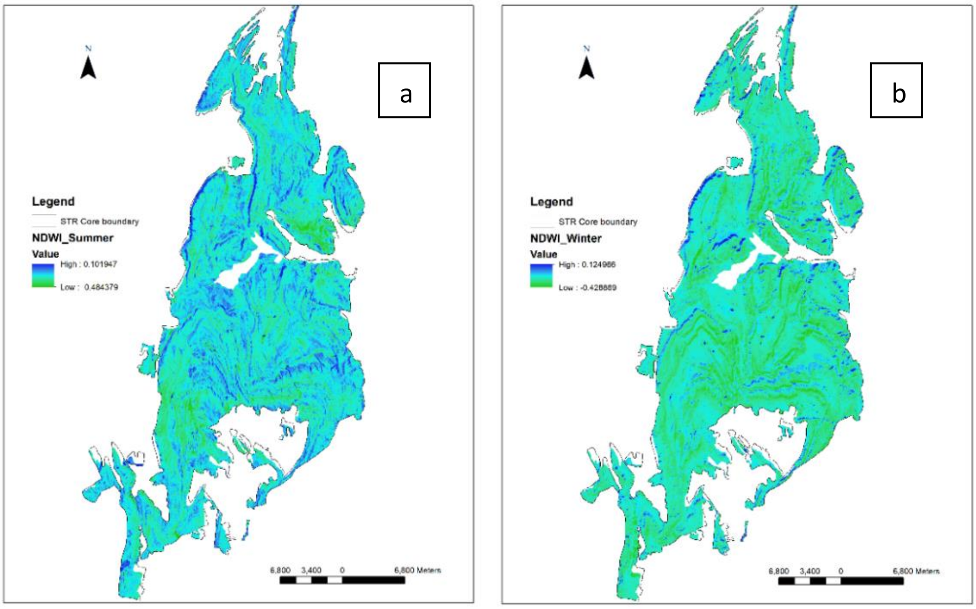

Figure 4. 20: Normalized Difference Water Index (NDWI) of STR for a) Summer, b) Winter

Water: In STR, mean NDWI during summer was -0.21±0.02 and during winter -0.19±0.05 (Figure 4.20). For PTR, NDWI during summer was -0.09±0.04, and during winter 0.01±0.07 (Figure 4.21). Mean Euclidean distance to water hole in case of STR at the resolution of 350m was 925.87m± 525.02 (Figure 4.22 a). In case of PTR, Euclidean distance to water source including ponds and water falls but excluding river at 1200m resolution was 1378.21m±906.25 (Figure 4.22 b). Mean distance to river (at 30m resolution) was 4339.78m±3655.48.

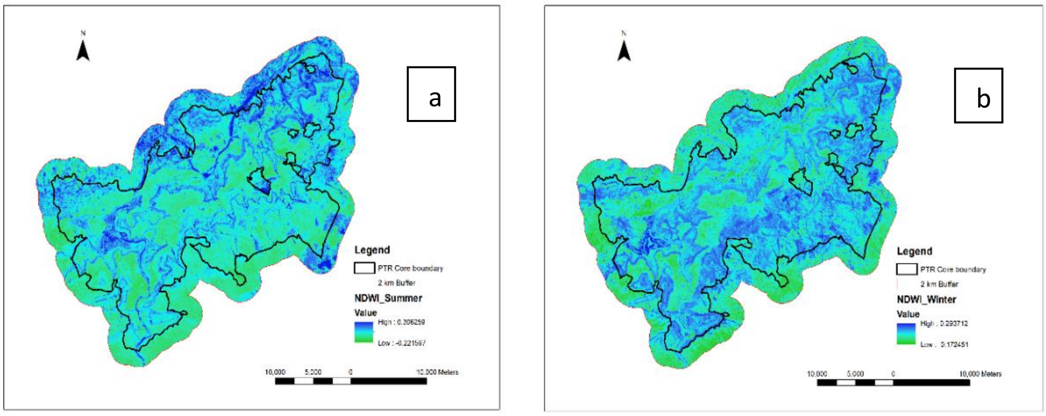

Figure 4. 21: Normalized Difference Water Index (NDWI) of PTR for a) Summer, b) Winter

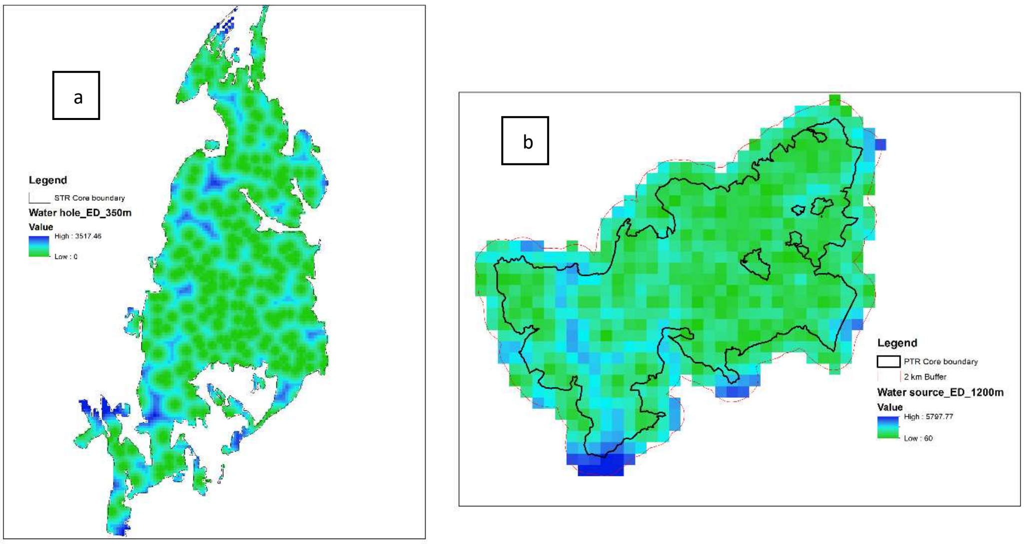

Figure 4. 22: Map depicting Euclidean distance to water hole/source in a) STR; b) PTR

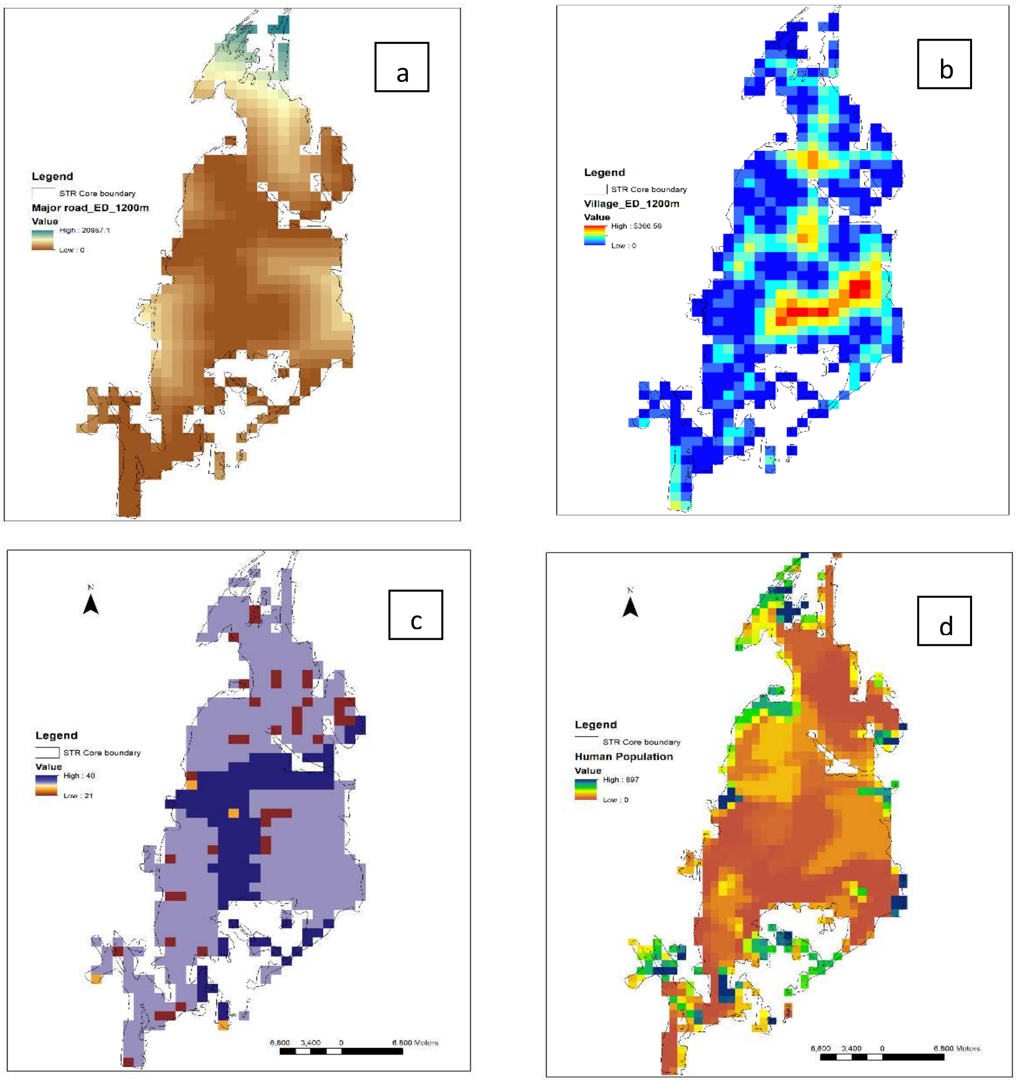

Figure 4. 23: Maps depicting anthropogenic disturbance within STR: a) Euclidean distance to major roads; b) Euclidean distance to human settlements; c) Human footprint; d) Human population (census)

Disturbance: In STR, lopping, woodcutting, and weed presences were recorded in 67%, 31%, and 91% plots, respectively. Mean lopping was calculated to be 6.37 ± 8.19, and mean woodcutting was 1.06 ± 2.11. In PTR lopping, woodcutting and weed presences were recorded in 22%, 40%, and 71% plots, respectively. Mean lopping was calculated to be 0.60 ± 1.50, and mean woodcutting was 1.39 ± 3.28. Mean livestock

ER for STR was 4.09 ± 5.94, for PTR it was 3.19 ± 9.6. Vehicle ER in PTR was 4.57 ± 7.72 and for STR was 0.50 ± 1.20. As for human ER, it was 1.40 ± 1.97 and 1.02 ± 1.20 for STR and PTR, respectively.

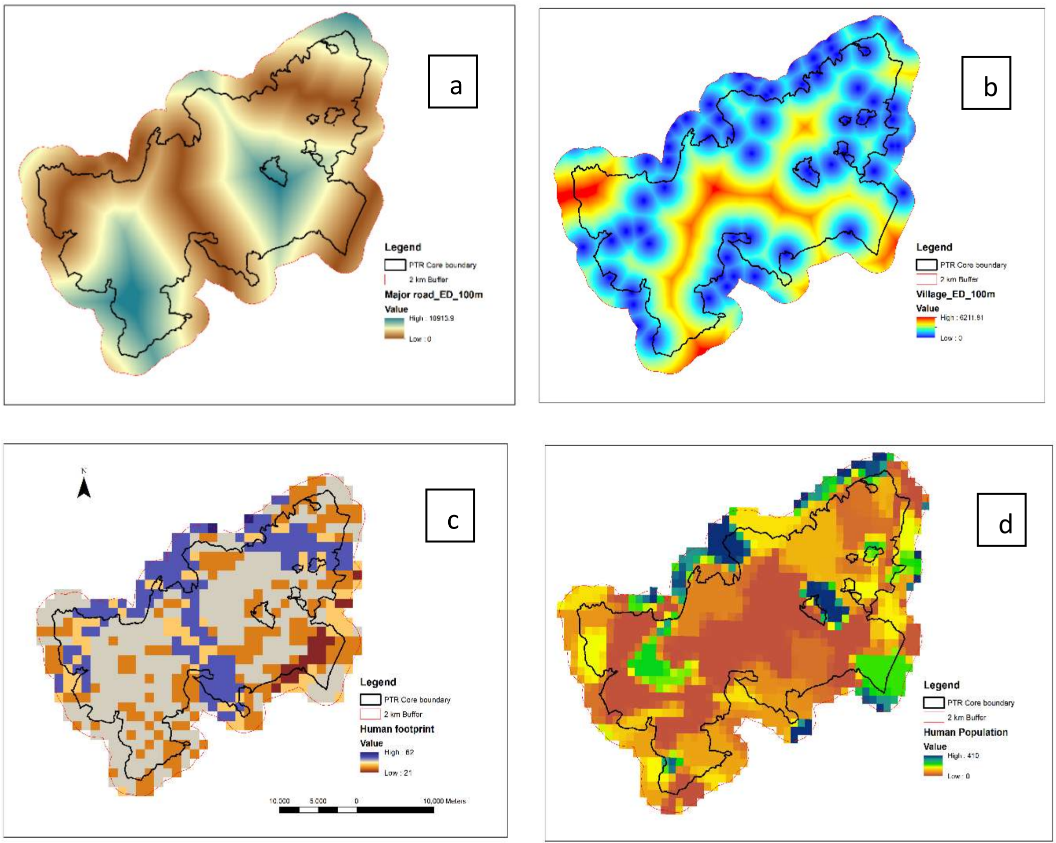

Figure 4. 24: Maps depicting anthropogenic disturbance within PTR: a) Euclidean distance to major roads; b) Euclidean distance to human settlements; c) Human footprint; d) Human population (census)

Mean Euclidean distance to road was 3531.75m ± 3268.66 in STR (1200m) and 4064.82m ± 2524.38 in PTR (100m) (Figure 4.23, 4.24 a). Mean distance to human settlement was 1863.69m ± 1065.68 in STR (1200m) and 2252.61m ± 1279.18 in PTR (100m) (Figure 4.23, 4.24 b). Comparison of human footprint maps indicates that overall disturbance was similar in PTR (μ=37.14±6.95) and STR (μ=34.33±4.42)

(Figure 4.23, 4.24 c). However, human population was very low in both the reserves (Figure 4.23, 4.24 d).

4.3.4. Results for geoGAM

Sariska Tiger Reserve

The variables selected to be included in the final geoGAM model for STR were, wild prey ER (350m), slope (30m), elevation (30m), NDVI (50m), canopy cover (350), NDWI (30m), human ER (350m), and distance to road (1200m). All smooth terms except NDWI were significant at α=0.05 level (Table 4.5).

Table 4. 5: Approximate significance of smooth terms of final geoGAM model for STR

Smooth terms	edf	Ref.df	Chi.sq	p-value
s(lt_wp_350)	2.748	3.423	23.405	5.95E-05
s(slope_30)	3.483	4.257	32.655	2.37E-06
s(road_1200)	3.027	3.745	18.893	0.000507
s(ndvi_50)	3.157	3.898	15.867	0.003109
s(cc_ebk_350)	3.277	4.021	11.309	0.023875
s(hum_ebk350)	3.369	4.14	29.888	6.18E-06
s(ndwi_30)	3.294	4.016	7.487	0.116696
s(dem_30)	3.487	4.281	24.517	7.05E-05

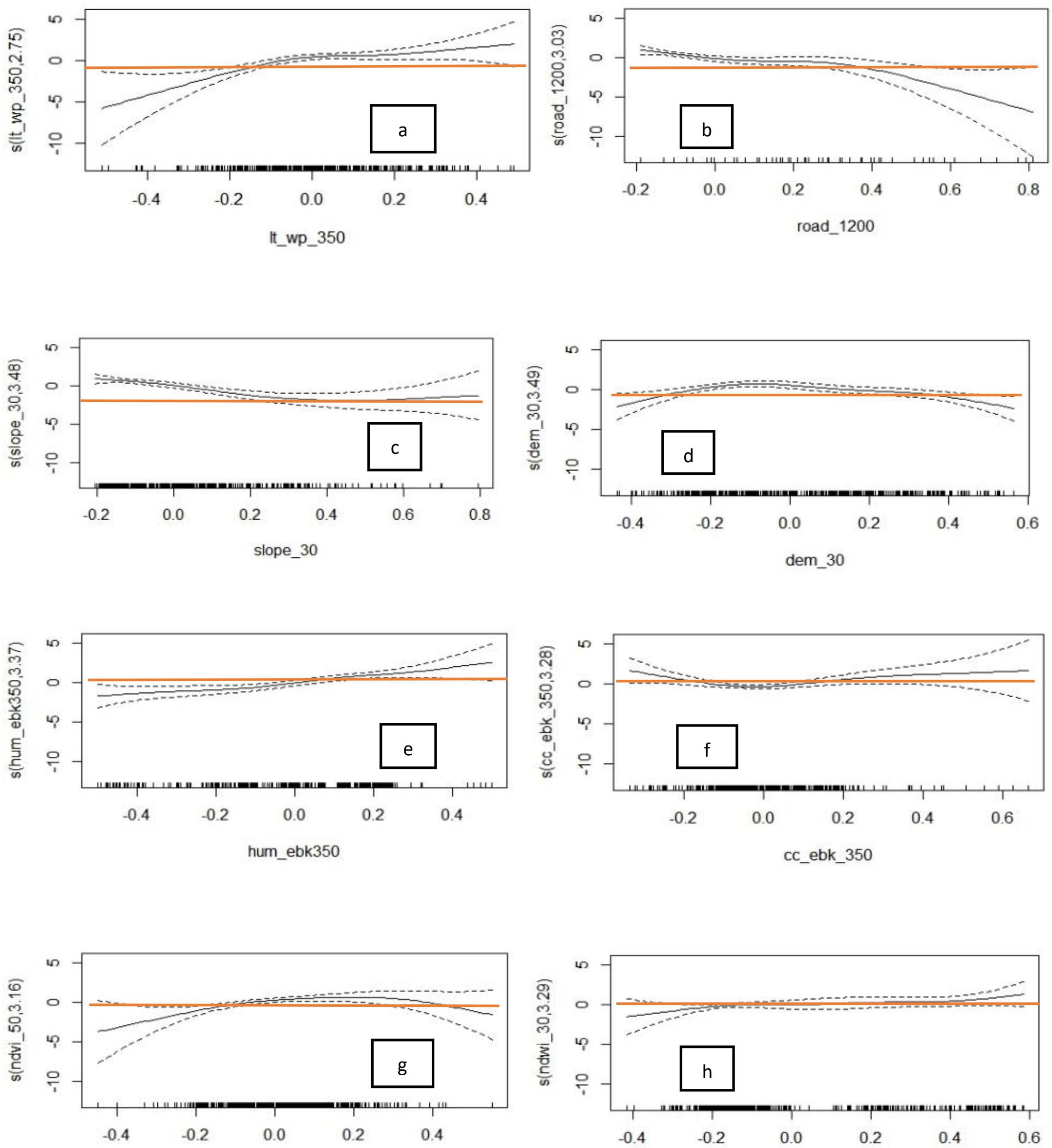

Figure 4. 25: Partial effect plots for livestock kill by tiger in STR: a) wild prey ER (350m), b) distance to road (1200m), c) slope (30m), d) elevation (30m), e) human ER (350m), f) canopy cover (350), g) NDVI (50m), h) NDWI (30m). The dashed line represents 95% confidence interval and the lines on x axis represent the frequency of data

The effective degree of freedom (edf) is higher than 3 for most of the smooth terms, indicating that the wiggliness is high, and relationships, nonlinear (Table 4.5). Even more is revealed by examining the partial effect plots of smooth terms also called rug plots (where the data points are put on the x-axis, and by looking at their density, it can be determined how reliable that particular part of the plot is). A partial effect plot shows the effect of an explanatory variable on the response variable after accounting for the effects of all the other variables included in the model. By a simple rule of thumb, a smooth term is significant if you can't draw a horizontal line through the 95% confidence interval (Ross, n.d.).

In the rug plot for wild prey ER, it seems that there is a gradual increase in the log odds of livestock kill with increase in wild prey encounter (Figure 4.25 a). In case of distance to road, the relationship seems to be inverse, such that lesser the distance from road, higher the log odds of livestock kill or higher the distance from road higher the odds of livestock not getting killed (Figure 4.25 b). Similarly, in case of slope the odds of kill seem to be more when the slope is less (Figure 4.25 c). In case of human ER, canopy cover, elevation and NDVI, although the smooth terms have very small chi sq. p value, the plots seem to be quite flat such that the horizontal line is almost passing through them, thus the relationships cannot be assumed to be significant (Figure 4.25 d, e, f).

The deviance explained by the model was 44.1% and AUC of the model was 0.91. When run on test dataset the model accuracy was calculated to be 0.81 (Table 4.6) and AUC was found to be 0.89, indicating that the model has good prediction capability.

Table 4. 6: True skill statistic of final geoGAM model for STR run on test dataset

Accuracy	0.8136
95% CI	0.7483-0.8681
Kappa	0.6268
Sensitivity	0.8333
Specificity	0.7931
Positive Predicted Value	0.8065
Negative Predicted Value	0.8214
Prevalence	0.5085
Detection Rate	0.4237
Detection Prevalence	0.5254
Balanced Accuracy	0.8132

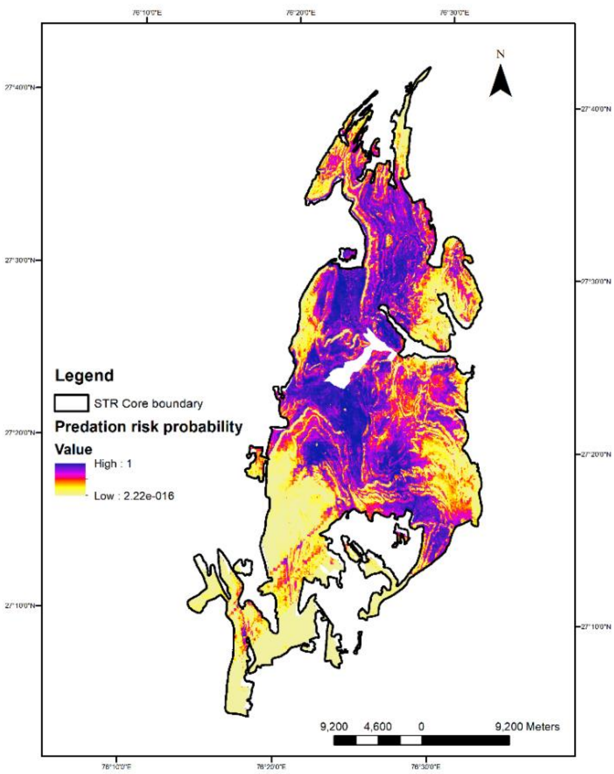

Figure 4. 26: Risk map depicting probability of livestock kill by tiger in STR, predicted employing geoGAM model

The risk map produced using this model shows that the risk was high in the central and northern parts of the reserve, while the southern part of the reserve is relatively low risk (Figure 4.26). Upon laying tiger home ranges (2013) it was observed that most of the tigers are occupying the high-risk area (Figure 4.27).

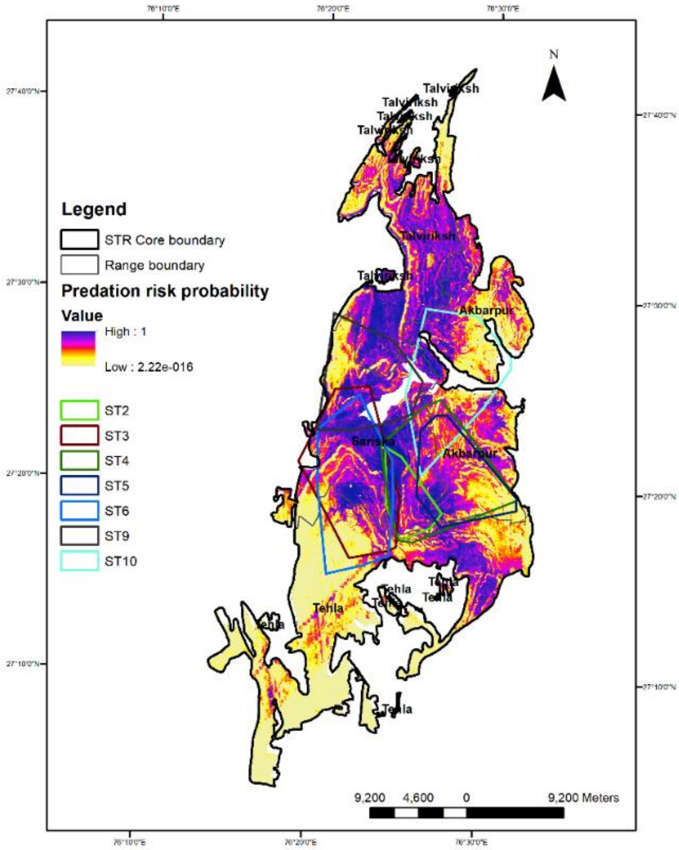

Figure 4. 27: Home ranges of radio-collared tigers in STR overlaid on livestock predation risk map

Panna Tiger Reserve

The variables selected to be included in the final geoGAM model for PTR were, all prey ER (50m), elevation (1200m), NDVI (100m), shrub abundance (50m), and human ER (1200m). Among these smooth terms, all prey ER and shrub abundance were significant at α=0.05 level, and elevation was significant at α=0.1 level (Table 4.7). Again, the effective degree of freedom is higher than 3 for all the smooth terms, indicating that the wiggliness is high, and relationships, nonlinear.

Table 4. 7: Approximate significance of smooth terms of final geoGAM model for PTR

Smooth terms	edf	Ref.df	Chi.sq	p-value
s(lt_all_50)	3.174	3.847	16.653	0.00172
s(sa_ebk_50)	3.232	3.974	10.95	0.0246
s(hum_1200)	3.261	4.023	6.46	0.16992
s(ndvi_100)	3.18	3.947	5.721	0.1903
s(dem_1200)	3.405	4.125	9.368	0.08898

Upon examination of the partial effect plots it was found that all prey ER has an inverse relationship with log odd of livestock kill i.e., the odds of livestock kill by tiger are higher when prey is low (Figure 4.28 a). In case of shrub abundance, a unique trend was observed, log odds of livestock kill increases with shrub abundance but only till it reaches a certain mark, after which increase in shrub abundance seems to reduce odds of livestock kill (Figure 4.28 b). In case of NDVI, human ER and elevation, as also indicated by their chi square p values, doesn't seem to have a significant relationship with odds of livestock kill (Figure 4.28 c, d, e).

The deviance explained by the model was 44.4% and AUC of the model was 0.91. When run on test dataset the model accuracy was calculated to be 0.65 (Table 4.8) and AUC was found to be 0.70, indicating that the model had fair amount of prediction capability.

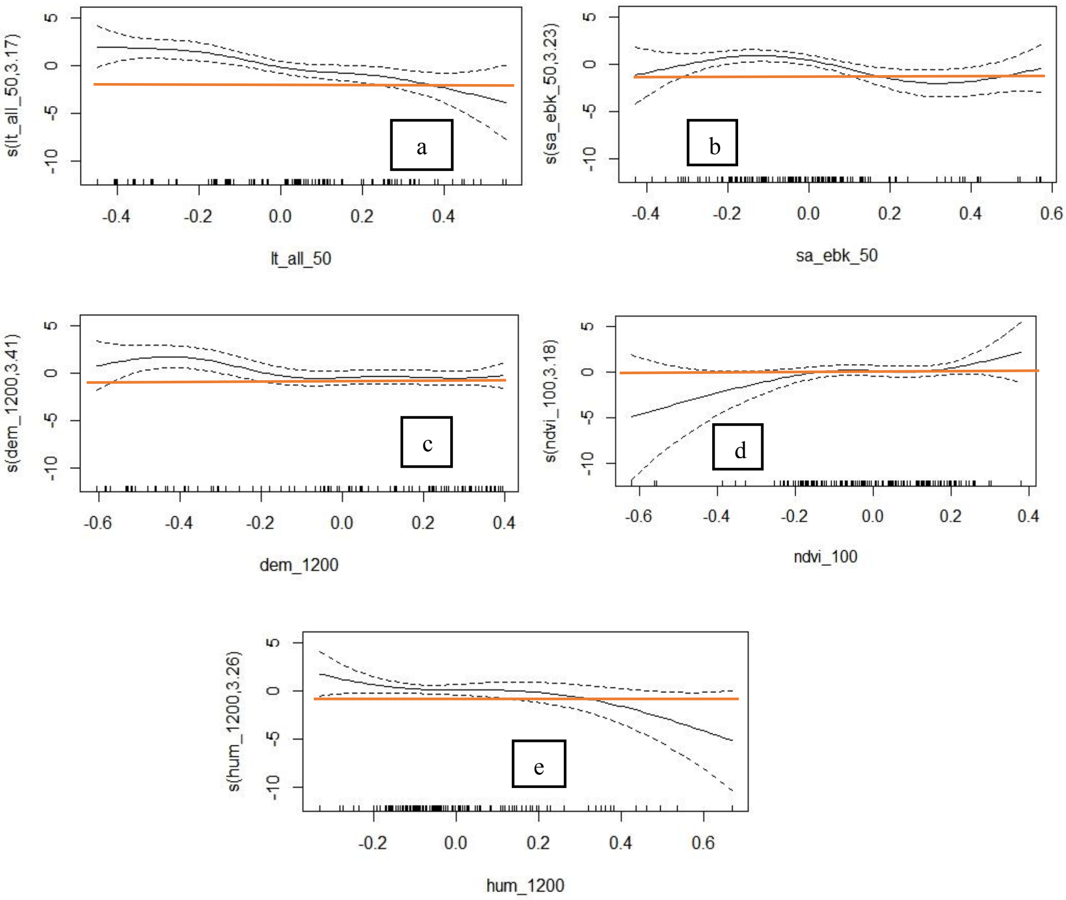

Figure 4. 28: Partial effect plots for livestock kill by tiger in PTR: a) all prey ER (50m), b) shrub abundance (50m), c) elevation (1200m), d) NDVI (100m), e) human ER (1200m). The dashed line represents 95% confidence interval and the lines on x axis represent the frequency of data

Table 4. 8: True skill statistic of final geoGAM model for PTR run on test dataset

Accuracy	0.6508
95% CI	0.5203-0.7666
Kappa	0.3007
Sensitivity	0.6129

Specificity	0.6875
Positive Predicted Value	0.6552
Negative Predicted Value	0.6471
Prevalence	0.4921
Detection Rate	0.3016
Detection Prevalence	0.4603
Balanced Accuracy	0.6502

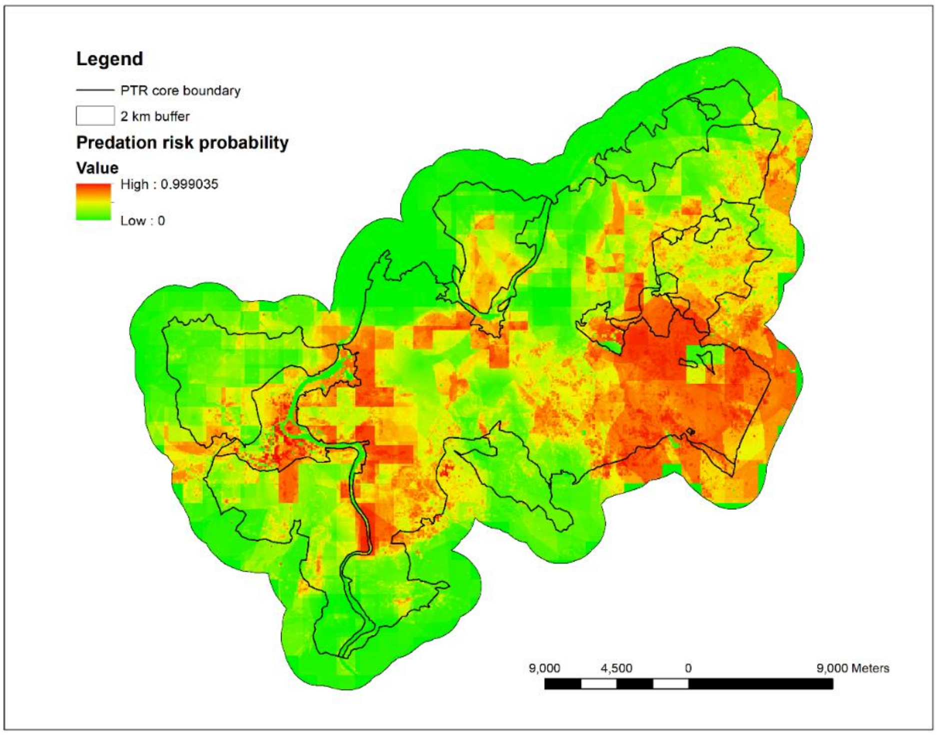

Figure 4. 29: Risk map depicting probability of livestock kill by tiger in PTR, predicted employing geoGAM model

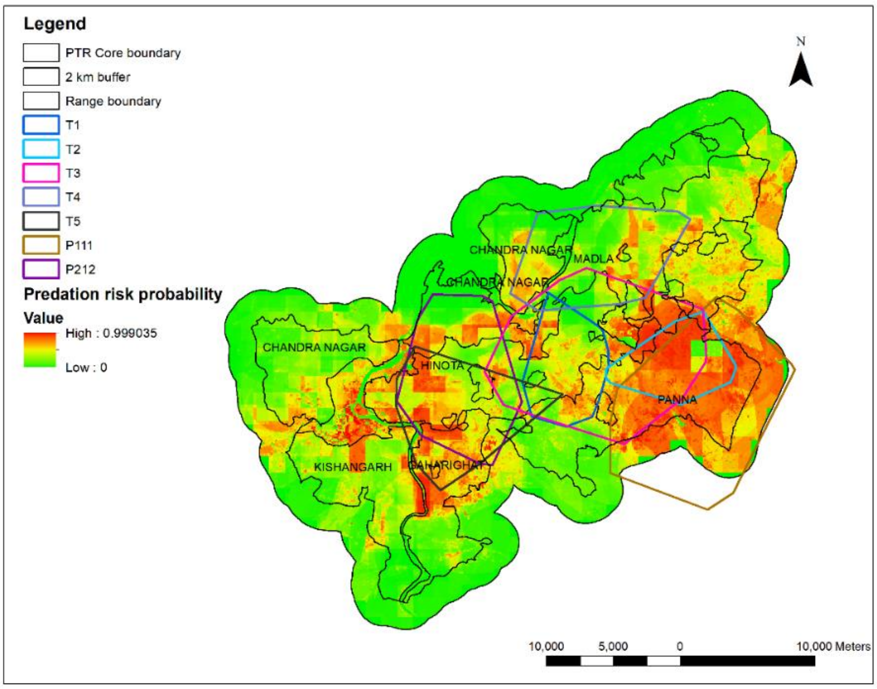

Figure 4. 30: Home ranges of radio collared tigers in PTR overlaid on livestock predation risk map

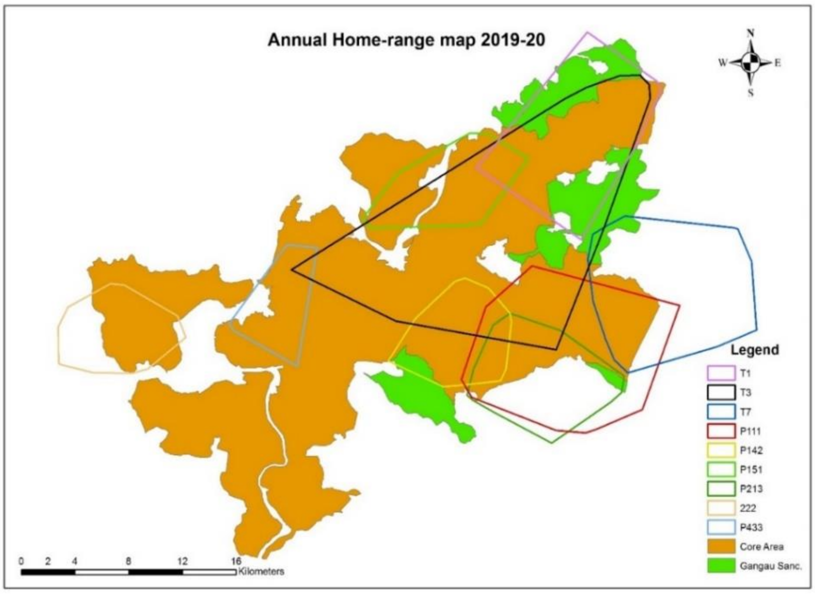

Figure 4. 31: Annual home range of radio-collared tigers in PTR 2019-20

Source: Tiger Reintroduction and Recovery Program in Panna Tiger Reserve and the Landscape Complex, Madhya Pradesh: Phase II Annual Progress Report 2019-20

The risk map produced using this model shows that the risk was higher in the south eastern part of the reserve (Figure 4.29). Upon laying tiger home ranges (2013 and 2019-20) it was observed that most of the radio collared tigers are occupying high risk area, which is falling within the Panna Range of PTR (Figure 4.30, 4.31).

4.4. Discussion

Spatial modelling of HCC has enabled conservationists to visualize where the risk of conflict is high and requires mitigation (Amirkhiz et al., 2018; Broekhuis et al., 2017; Kaartinen et al., 2009; Treves et al., 2011; Zarco-González et al., 2013). Potential habitat/environmental factors identified as drivers of conflict risk can help reduce conflict potential and design targeted mitigation measures (Behdarvand et al., 2014). We employed multivariate multiscale spatial modelling to reveal the drivers of HTC in two tiger reserves in India.

HTI was found to be high in both the reserves, however, the severity of HTC seems to be higher in STR as compared to PTR, which could be attributed to the high overlap of habitat use by tiger and humans and their livestock in Sariska, as compared to Panna. As for the temporal pattern, in both the reserves, the season in which the greatest number of depredation events occurred was winter, closely followed by monsoon and least in summer. As also observed by other studies done in PTR (Kolipaka et al., 2017). This could be because breeding of tiger is known to peak during monsoon-winter season, when they disperse widely in search of mate (Sankhala, 1967; Singh et al., 2014). Especially, in case of dry deciduous (like PTR) or semi-arid (like STR) forests, where winter and monsoon are the only optimal seasons with higher availability of water, cover, and homogeneous distribution of prey.

Tigers in search of mate and a tigress that has cubs to feed, would also have higher energy requirements in these seasons (Miller et al., 2014). At the same time due to the higher availability of forage during monsoon-winter, livestock are also more likely to venture into the forest, resulting in high overlap between tiger and livestock habitat use.

Examining the spatially explicit hotspots of livestock kill by tiger, it was found that in case of Sariska the hotspot lay in the central and northern part of the reserve, while most of the southern part was found to be coldspot, indicating almost no livestock depredation by tiger in this part of the reserve. In case of PTR, the Panna range and part of buffer in the south eastern part of the reserve were found to be livestock depredation hotspots, although there were no statistically significant coldspots within PTR. However, since the hotspot analysis was based on incomplete livestock kill information it was necessary to statistically model the livestock depredation to get more reliable estimates of risk. And most importantly to reveal the reasons behind such spatial patterns of HTC.

Ecological drivers of HTC

The first component of CDM i.e., the potential ecological drivers of livestock depredation by tigers in Sariska and Panna tiger reserves, as revealed by geoGAM modelling were prey, slope, shrub, and distance to road, albeit at different scales.

In case of both Sariska and Panna, prey encounter rate is an important explanatory factor, although in Sariska it is more or less positively associated with livestock depredation, while in Panna the association was negative. However, the distinction is in the kind of prey, the scale at which they are selected, and also the unique characteristics of each of these habitats. In case of Sariska, livestock depredation is high where wild prey encounter rate is high. It is because in Sariska areas with high wild prey encounter rate represents suitable tiger habitat as indicated by the broader scale of 350m. Studies done on wolves in North America have found that presence of wild prey like elk or deer, is associated with livestock depredation by wolves, because they dictate the distribution of wolves (Amirkhiz et al., 2018; Bradley, 2004; Bradley & Pletscher, 2005). Amur tigers establish their home range where their primary prey is most vulnerable and utilize patches on the periphery of their home ranges where prey density is high (Petrunenko et al., 2016). In Sariska also, the distribution of tiger home ranges is in valley areas that have flatter terrain where prey is most vulnerable but the home range encompasses areas with higher terrain complexity where prey encounter rate is high.

However, within these tiger-occupied habitats, cattle from villages located inside and bordering the CTH, directly compete with wild prey. Studies have indicated that when wild prey is high and livestock density is low, livestock depredation by carnivores is low, however, if both wild prey and livestock are in high density, livestock predation is also high (Chetri et al., 2019). Which is similar to what was found in Sariska, where both wild prey and livestock density are high. Thus, high wild prey encounter rate is associated with livestock kill because wild prey attracts predators, which may also depredate on livestock if they are readily available in the same habitat.

Prey, however, should not be seen in isolation, since its relationship with livestock kill should be interpreted in conjunction with other variables in the model. Other habitat factors which seem to have a bearing on livestock depredation by tigers in Sariska are slope at fine scale (30m) and distance to road at a very broad scale (1200m). Much of the aforementioned prey-rich but disturbed habitat in Sariska lies in valleys, because valleys have better grazing grounds due to the higher availability of water and fertile soil. Apart from the overlap of livestock with wild prey in valley areas, which increases the chance of their depredation by tiger, it might be easier for tigers to make a kill in flatter terrain as compared to steep slopes. Other studies have also found that in mountainous region, predators depredate on livestock where the slope is gentle (Amirkhiz et al., 2018; Steinberg, 2013). In response to presence of predator, prey use rugged and steep terrain, an anti-predator behaviour observed in wild ungulates but found to be absent in livestock (Laporte et al., 2010). Thus, slope and prey together increase the vulnerability of livestock in predator habitat, because predators occupy not only prey rich areas but also flatter terrain where their prey is vulnerable, and if livestock ventures into this habitat, they might become easier prey because unlike wild prey, they lack appropriate anti-predator response.

As for road density, although studies have indicated that livestock depredation risk is higher in areas with lower road density (Amirkhiz et al., 2018), in case of Sariska, the road density is higher in valley areas with the presence of state highways and Sariska-Kalighti-Pandupol road to cater to pilgrims visiting the Hanuman temple. Additionally, livestock when moving from their villages into the forest traverse using these roads. Therefore, as far as, Sariska is concerned major roads pass through tiger habitat which are utilized by livestock to venture into the reserve, thus increasing the odds of livestock kill near the roads. Hence, the ecological drivers of HTC in STR, indicated that in tiger habitats where prey is high but so is the livestock presence, livestock is depredated in areas with less slope and proximate to roads.

In case of Panna, the prey ER determining livestock kill includes both wild prey, as well as, livestock. This is because, Panna has a sizable population of feral cattle which were left behind by villages relocated outside the reserve, and these livestock have become a part of tiger's diet (as indicated by tiger diet analyses, discussed in detail in the next chapter). Moreover, wild prey density was found to be lower in Panna as compared to Sariska. Earlier studies have also highlighted that there is low availability of wild prey in Panna as compared to livestock (Chundawat et al., 1999). Our spatial modelling result suggests that when prey encounter is low at fine scale (50m), i.e., tiger encounters less prey, it is more likely to predate upon domestic livestock. Thus, in Panna livestock form an important part of tiger's diet due to the presence of a large number of feral cattle and low wild prey density. And tiger would depredate domestic livestock in areas where density of both wild prey and feral livestock is particularly low and there is an influx of domestic livestock. Other studies have also linked low availability of prey with livestock depredation by carnivores including tiger (Bhattarai & Fischer, 2014; Fritts et al., 2003; Francis, 2004; Khorozyan et al., 2015). Vulnerability of prey influences predator choice (Cresswell et al., 2010; Greene, 1986; Onkonburi, & Formanowicz' Jr, 1997; Provost et al., 2006), predators select a kill which is easier to catch (Lang & Gsödl, 2001; Mueller, 1977; Weise et al., 2020). Livestock have lost most of their anti-predator behaviour during the domestication process such that in the absence of human herders they are vulnerable to becoming easy prey for predators (Flörcke, & Grandin, 2013; Linnell et al., 1999; Laporte et al., 2010; Weise et al., 2020). Thus, in predator-occupied habitats where there is low availability of wild prey, domestic prey becomes vulnerable due to lack of anti-predator defence mechanisms.

The second explanatory variable in case of PTR is shrub abundance, which is also selected at the same scale (50m) as prey. Shrub abundance seems to have a unique relationship with livestock kill, resulting in increase of livestock kill up to a certain point after which increase in shrub abundance is actually decreasing the odds of livestock kill. Although it is difficult to explain such a complex relationship, but it can be examined in the light of predation technique of tigers. Tiger is an ambush predator, therefore in areas where there is very low cover, it might be very difficult to make a kill, but in areas where cover is high the chances of success may improve (Greene, 1986; Karanth & Sunquist, 2000; Murray et al., 1995; Sunquist, 2010). Studies done on tiger and other carnivores have also found that livestock predation risk was higher in habitats with high shrub density, because it provides cover for these predators (Davie et al., 2014; Miller et al., 2015). However, if the cover is too dense it is also less likely for grazers like livestock to venture into such patches because they would be devoid of grasses. Thus, making the relationship curve between livestock kill and shrub cover, bell-shaped.

Hence the study of ecological drivers of HTC in PTR, revealed that the chances of livestock kill increases in an area that has suitable ambush cover but low availability of prey.

Predation risk map

Predation risk maps produced as a result of modelling have revealed the areas where livestock are at high risk of getting depredated upon by tigers. Most of which lies within prime tiger habitat. In case of Sariska, the risk map shows that the predation probability was higher in the central part of the reserve where lies the Sariska-Kalighati-Pandupole valley and towards the northern part of the reserve. The southern part of the reserve is relatively low risk, as also indicated by hotspot mapping. Home range distribution of radio-collared tigers in STR as observed in 2013, indicate that movement of most of the tigers was restricted to these high-risk areas, much of which is the notified national park falling in the Sariska Range. Latest studies indicate that not only are these tigers continuing to occupy the Sariska Range, but the northern part of the reserve falling in Talvriksh Range, which was unoccupied in 2013, but predicted as high risk by our modelling, has been occupied by tigers in recent times; whilst the southern part of the reserve, i.e., Tehla Range, which is predicted as low risk in our model remains largely unoccupied (Bhardwaj et al., 2021).

In Panna, the high-risk area mostly lies in and around the Panna Range and parts of Gehrighat Range. As in case of Sariska Range in STR, Panna Range is where most of the home ranges of radio-collared tigers in PTR overlap (in 2013, as well as, 2020). Thus, in case of both Sariska and Panna livestock predation risk seems to be closely linked to suitable habitat for tigers. This could be because unlike leopards, tigers are known to not venture outside their habitat to predate on livestock (Malviya & Ramesh, 2015). In both these reserves, it is the livestock that are venturing into tiger habitat and getting depredated.

Therefore, from examining the predation risk map it was found that when livestock venture into predator habitat they are vulnerable to getting depredated. And the study of ecological drivers helped us understand the ecological/landscape features which are responsible for this pattern. To summarize, the first component of CDM i.e., the ecological drivers of HCC have revealed that predators occupy areas with high wild prey, and flatter terrain where prey might be more vulnerable. In such areas if livestock is also in high numbers, predators may depredate them because wild prey change their habitat use in response to predators whilst livestock, due to the loss of most of their anti-predator behaviour, may become easy kill. And in predator-occupied habitat if prey availability is low at fine scale, domestic livestock availability is high and ambush cover is available, the odds of predator depredating livestock become high. Livestock kill by tiger is thus a culmination of predator choice and foraging tactics, and, prey vulnerability and defence mechanism.

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Chapter 5. Biological determinants of human-tiger conflict

5.1. Background

Biological factors like sex, age, and personality/social status of individual tigers are also likely to affect their chances of getting into conflict with humans (Mattisson et al., 2011; Odden et al., 2002). It is also possible that just like social or sexual conflict leads to stress in animals (Sapolsky, 2004), conflict with humans can lead to higher stress in tigers, or inversely, stressed tigers might be more prone to livestock depredation. Therefore, biological parameters of tigers, viz. ID, age, sex, and physiological stress were quantified for both PTR and STR and correlated with livestock kill, to reveal the potential biological drivers of HTC.

5.2. Methodology

5.2.1. Livestock kill quantification

As discussed in the last chapter, livestock kill information was obtained from compensation records and kill data maintained by forest department in both STR and PTR. Since these compensation and livestock kill records contain information on tiger ID, livestock loss caused by individual tigers could be quantified. In case of Sariska, livestock kill data for seven tigers and in case of Panna eleven tigers, were summarized and compared against different biological variables.

5.2.2. Measuring biological variables

Following variables were considered for determining biological drivers:

- Tiger id

- Sex
- Age
- Food habit
- Physiological stress
- Home range size and quality (prey, cover, disturbance)

I. Tiger ID, sex and age

As stated before, the compensation/kill data obtained from forest departments also provided the identity of the tiger involved. And since all the tigers in the two populations are closely monitored their life history including sex and age are known.

II. Food habit

For reconstructing tiger diet and establishing prey preference, especially to understand if livestock was a preferred prey, tiger scats were analysed. A total of 231 tiger scats from STR and 120 scats from PTR were collected and analysed. According to Sankar et al. (2013), a minimum of 100 scat samples were adequate to understand the food habits of tigers; therefore, the obtained sample sizes for both the sites were expected to give accurate results. Scats that could be identified to individuals were given IDs accordingly and used to conclusively discuss about individual's prey preference. The scats were washed and dried, prey species were identified on the basis of micro-histological structure of hairs (Mukherjee et al., 1994) and their percentage frequency of occurrence was calculated. The proportion of prey biomass intake per scat was estimated using Ackerman's equation (Ackerman et al., 1984). Preference of certain prey species over others was established by comparing predation of a species with its availability (prey density). The number of scats from kill of a particular species was estimated using the equation given by Link and Karanth (1994); expected proportion of scat were then calculated based on nonselective predation, using multinomial likelihood ratio test (Avinandan et al., 2008; Biswas & Sankar, 2002; Karanth & Sunquist, 1995; Link & Karanth, 1994). Sensitivity analysis and parametric bootstrapping were done to increase the reliability of the results (Link & Karanth, 1994). All the analyses were done using SCATMAN (Hines & Link, 1995).

III. Physiological stress

Sample collection: Tiger scat samples were collected from STR and PTR with the assistance of tiger monitoring teams. Search efforts were focused on the home range of tigers and specifically around kill sites. Since most of the tigers were radio-collared they were monitored 24 hours a day, seven days a week. As such, it was possible to match faecal samples to individual tigers based on monitoring data, including inspection of kill sites. Freshness of samples was visually estimated, and only samples that were considered fresh were collected. A total of 103 wild tiger scat samples were collected from STR, and 144 from PTR, between January 2013 and May 2014 for analyses of FGM concentrations. Each sample was catalogued with its location (latitude and longitude), ID of the individual, date of collection and freshness. A total of 119 scat samples from PTR and all 103 from STR, were identified to individual tiger by correlating theirs and that of their kill's GPS location with that of scat, by tiger monitoring teams. Thereby, a total of nine individual tigers in PTR (of which five were founders and four were F1) and seven in STR (all founders), were sampled. The scat samples were oven dried at 80°C for 48 hours. This sample was then sent to Laboratory for the Conservation of Endangered Species (LaCONES) at the Centre for Cellular and Molecular Biology (CCMB) for hormone metabolites extraction and Enzyme Immunoassay (EIA).

Faecal glucocorticoid hormone metabolite (FGM) extraction and measurement procedure: Faecal steroid metabolites were extracted according to previously published protocols (Brown et al.,1994; Umapathy et al., 2013). 0.2–0.3 g of the dried, mixed and pulverized faecal sample was boiled in 5 ml of 90 % aqueous ethanol for 20 min. After centrifugation at 500 gf for 10 min, supernatant was recovered and the pellet re-suspended in 5 ml of 90% aqueous ethanol, which was vortexed for one minute and re-centrifuged to recover the supernatant. Both the ethanol supernatants were then combined, dried (in an oven at 40º C), re-suspended in 1 ml of absolute methanol, vortexed for one minute and sonicated for 30 seconds (Branson Ultrasonics 250, CT, USA) to free particles adhering to the wall of the test tube. Samples were then stored at - 20° C until hormone assay. Extraction efficiency of protocols was examined by adding known amount of radio labelled hormones in randomly selected samples before extraction. Extraction efficiencies were calculated as percentage of the amount of labelled hormones observed relative to the amount expected; they ranged between 85.2 and 93.4% (n = 22).

FGM concentration was measured by cortisol enzyme immunoassay (EIA) (C. Munro, University of California, Davis), which has been successfully validated in various mammals, including tigers (Bhattacharjee et al., 2015; Narayan et al. 2013; Young et al. 2004). The cortisol polyclonal antibody (R4866) was diluted to 1:9000, HRP-conjugated cortisol 1: 250000 and cortisol standards (1000-1.95 pg/well). The cross-reactivity of cortisol antibody with cortisol was 100%, prednisolone 9.90%, prednisone 6.30%, cortisone 5%, and <1% with corticosterone, desoxycorticosterone, 21 desoxycortisone, testosterone, androstenedione, androsterone, and 11-desoxycortisol (Young et al., 2004). Assay sensitivity was calculated at 90% binding and found to be 1.95 pg/well. To calculate inter and intra assay coefficients we pooled the faecal extracts and divided these into high (spiked with standards) and low (not spiked) quality controls, and used these on each EIA plate (n=10). The intra and inter coefficient of variation (CV) were 5.30% (n=10) and 9.60% (n=10) respectively. The cortisol EIA demonstrated parallel displacement curves between pooled serial dilutions of faecal samples and standards. The EIA procedure was performed as described previously (Kumar et al., 2014; Umapathy et al., 2015; Young et al., 2004).

Statistical Analyses: Pearson's correlation was run to test relationship between total livestock killed by a tiger and its mean FGM level; to establish whether tigers with chronic stress are more prone to conflict.

IV. Home range size and quality

To estimate the home range of radio-collared tigers, Minimum Convex Polygon (MCP) (100%) of each radio-collared tiger was prepared using GPS point location (secondary) data collected using radio telemetry (by independent tiger monitoring project teams at each of the sites) for the year 2013, using Hawth's tool in ArcGIS 9.3 (ESRI, 2009). Line transects falling within the home range of each sampled tiger were pooled and analysed in Distance 6.2 (as discussed in last chapter), to obtain independent prey abundance estimates for each sampled tiger. Similarly, vegetation plots and camera traps falling within home ranges of each sampled tiger in the two populations were pooled and analysed (as discussed in last chapter), to obtain canopy cover, shrub abundance, and anthropogenic disturbance estimates for each individual's home range.

5.3. Results

5.3.1. Tigers involved in human-tiger conflict:

STR: Among the tigers in STR (n=7), ST10 (female) made the highest number of livestock kills on an average in a year (n/year=22.5), closely followed by ST9 (female) (n/year=17.5), and least by ST2 (female) (n/year=2.3) and ST5 (female) (n/year=2.7) (Figure 5.1).

PTR: Among the sampled collared tigers in PTR (n=11), T7 (male) made the highest number of livestock kills on an average in a year (n/year=33), closely followed by P111 (male) (n/year=30.7), and least by T1 (female) (n/year=3.5) (Figure 5.2).

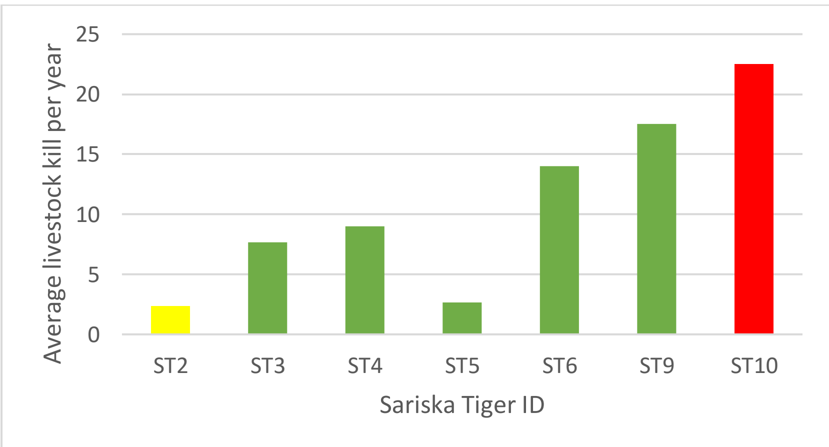

Figure 5. 1: Bar graph representing the intensity of livestock kill by individual tigers in STR

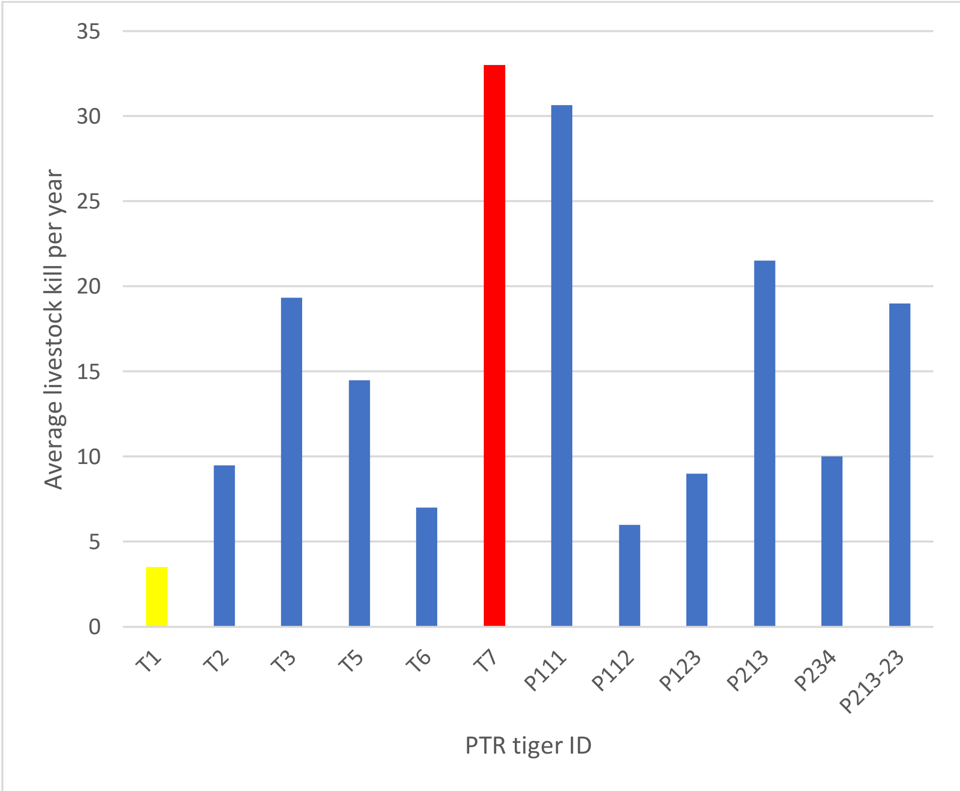

Figure 5. 2: Bar graph representing the intensity of livestock kill by individual tigers in PTR

5.3.2. Sex of tigers involved in human-tiger conflict: Since there were more adult females (n=9) in the STR population than males (n=4), livestock depredation was also mostly due to females (n=280), than males (n=140). However, the average livestock depredation by females was 10.5±9.1 kill/year, while for male tigers it was 11.5±3.5 kill/year. Thus, in STR, there is no significant difference between the rate of livestock kill between sexes. In PTR, although among the radio-collared tiger there were five males as compared to six females, total livestock depredation by males (n=259) was more than females (230). Thus, on average male tigers (19.6±12.2 kill/year) were depredating more livestock than females (12.1±6.5 kill/year).

5.3.3. Age: In case of STR the number of livestock depredated in 2014 by individual tigers was compared to their age in that particular year. It was found that age was inversely correlated to livestock depredation (r=-0.79; p=0.035), with younger individuals killing livestock more frequently than older individuals (Figure 5.3).

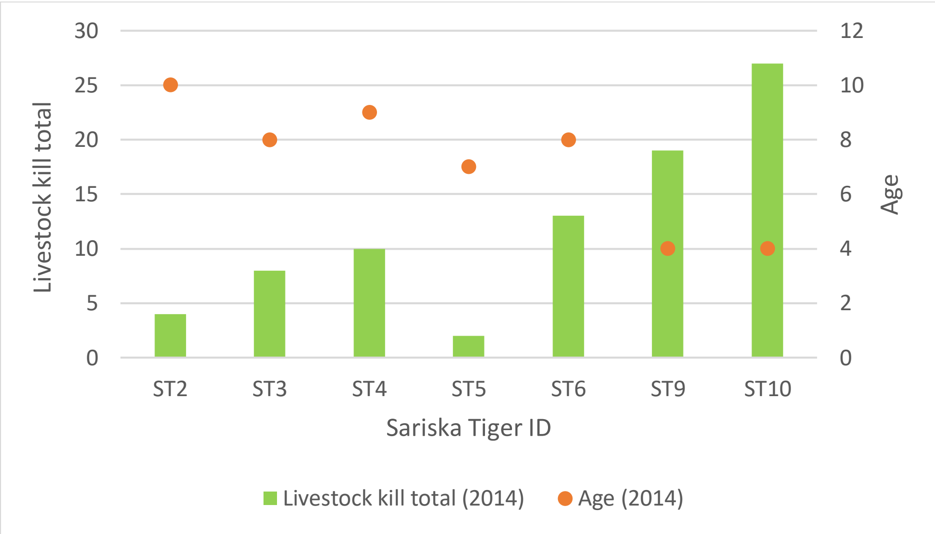

Figure 5. 3: Graph comparing age of tigers to the number of livestock killed by them in STR in 2014

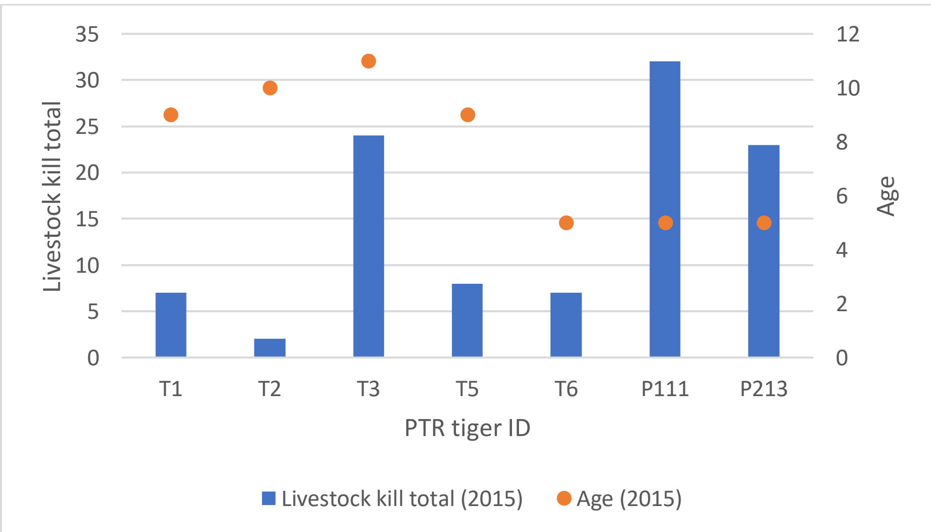

Figure 5. 4: Graph comparing age of tigers to the number of livestock killed by them in PTR in 2015

Similar in case of PTR, the number of livestock depredated by individual tigers in 2015 was compared to their age. However, the two were not found to be significantly correlated ($r=-0.36$; $p=0.42$) (Figure 5.4).

5.3.4. Tiger food habit and prey preference: Scat analysis suggests that in STR sambar (61.57%) form the largest proportion of tiger's diet, followed by nilgai (11.03%), chital (9.86%), and wild pig (9.86%). Cattle formed a very small percentage of the diet at 6.41% followed by peafowl (1.07%). Sambar contributed 64.12% of relative biomass of prey consumed by tiger in STR (Table 5.1). It was the most preferred prey species, since it was consumed more than expected on basis of availability (Table 5.2). Livestock utilization was less than the availability (Table 5.2).

Table 5. 1: Frequency of occurrence of food items in tiger scats and contribution of different prey species in terms of biomass to the tiger diet in Sariska Tiger Reserve

Prey species	Body weight	Prey species remains (F=281)	Percent occurrence of prey species (n=228) (fi*100/n= %occurance)	Relative Occurance (R=fi*100/F)	Number of collectible scats produced per kill(Y)	Prey biomass (B=F*Y)	Percentage relative biomass of prey contribution (P=B*100/Bt)
Sambar	125	173	75.88	61.57	6.36	1099.42	64.12
Nilgai	180	31	13.60	11.03	8.28	256.68	14.97
Wild pig	38	28	12.28	9.96	3.31	92.68	5.41
Chital	45	28	12.28	9.96	3.56	99.54	5.81
Livestock	226.6	18	7.89	6.41	8.88	159.84	9.32
Peafowl	5	3	1.32	1.07	2.16	6.47	0.38
						1714.62	

Table 5. 2: Preference of prey species by tiger in Sariska Tiger Reserve based on availability of individuals and utilization

Species	Chi squared	Unadjusted p-value	Adjusted p-value 10% CV	Adjusted p-value 20% CV	Adjusted p-value 30% CV	Adjusted p-value 40% CV	Ivlev's electivity index
Sambar	1381.67	0.00	0.00	0.00	0.00	0.00	0.83
Nilgai	4.15	0.04	0.15	0.21	0.31	0.40	0.19
Wild pig	21.94	0.00	0.00	0.01	0.02	0.04	0.47
Chital	4.52	0.03	0.20	0.24	0.30	0.33	0.24
Livestock	440.72	0.00	0.00	0.00	0.00	0.01	-0.83
Peafowl	17.26	0.00	0.00	0.01	0.06	0.13	-0.85

In case of PTR, tiger scat analyses suggest that chital (25.2%) and cattle (25.2%) both form the largest proportion of its diet, followed by sambar (22.76%) and nilgai (22.76%). Rodent, langur, and wild pig were also recorded in tiger diet. Calculation of prey species contribution to biomass of tiger diet showed that livestock contributed largest proportion (34.28%) of relative biomass of prey consumed by tiger in PTR, followed by nilgai (Table 5.3). However, in PTR sambar and chital were preferred prey species, since, they were consumed more than expected on basis of availability (Table 5.4). And livestock utilization was less than the availability (Table 5.4).

Table 5. 3: Frequency of occurrence of food items in tiger scats and contribution of different prey species in terms of biomass to the tiger diet in Panna Tiger Reserve

Prey species	Body weight	Prey species remains (F=121)	Percent occurrence of prey species (n=109) (fi*100/n=% occurance)	Relative Occurance (R=fi*100/F)	Number of collectible scats produced per kill(Y)	Prey biomass (B=F*Y)	Percentage relative biomass of prey contribution (P=B*100/Bt)
Sambar	125	28	25.69	23.14	6.36	177.94	22.16
Nilgai	180	28	25.69	23.14	8.28	231.84	28.87
Wild pig	38	1	0.92	0.83	3.31	3.31	0.41
Chital	45	31	28.44	25.62	3.56	110.21	13.72
Livestock	226.6	31	28.44	25.62	8.88	275.28	34.28
Langur	8	2	1.83	1.65	2.26	4.52	0.56
						803.10	

Table 5. 4: Preference of prey species by tiger in Panna Tiger Reserve based on availability of individuals and utilization

Species	Chi squared	Unadjusted p-value	Adjusted p-value 10% CV	Adjusted p-value 20% CV	Adjusted p-value 30% CV	Adjusted p-value 40% CV	Ivlev's electivity index
Sambar	39.50	0.00	0.00	0.00	0.00	0.02	0.51
Nilgai	6.53	0.01	0.10	0.13	0.19	0.28	0.24
Wild pig	0.75	0.39	0.46	0.47	0.51	0.53	-0.39
Chital	55.56	0.00	0.00	0.00	0.00	0.02	0.56
Livestock	80.71	0.00	0.01	0.00	0.01	0.03	-0.44
Langur	0.60	0.44	0.50	0.53	0.56	0.60	-0.26

5.3.5. Physiological stress: The mean FGM concentration of tigers in the STR tiger population was 50.14 ± 42.84 ng/g and in the PTR population it was 20.29 ± 16.34 ng/g. Meaningful correlation was not found between total livestock killed by individual tigers and their FGM levels in both STR ($r=0.15$; $p=0.751$) and PTR ($r=-0.08$). Although, correlations of FGM levels were tested with total livestock killed during 2010-2016, as well as, livestock killed during 2013-14 (the period when stress levels were also monitored), but no relationships could be drawn (Table 5.5, 5.6; Figure 5.5, 5.6).

Table 5. 5: Table listing faecal glucocorticoid metabolites (FGM) concentration of tigers sampled in Sariska tiger reserve (STR)

S. No.	Tiger ID	Generation	Sex	No. of samples	FGM concentration (ng/g)	SD	Livestock kill total (2011-2016)	Livestock kill total (2013-2014)
1	ST2	Founder	Female	12	39.5	19.37	36	4
2	ST3	Founder	Female	25	55.01	54.75	36	16
3	ST4	Founder	Male	8	42.87	29.82	93	21
4	ST5	Founder	Female	14	52.95	37.50	9	6
5	ST6	Founder	Male	21	41.94	47.87	70	37
6	ST9	Founder	Female	15	63.42	45.24	55	31
7	ST10	Founder	Female	8	49.86	28.25	119	45

Table 5. 6: Table listing faecal glucocorticoid metabolites (FGM) concentration of tigers sampled in Panna tiger reserve (PTR)

S. No.	Tiger ID	Generation	Sex	No. of samples	FGM concentration (ng/g)	SD	Livestock kill total (2010-2016)	Livestock kill total (2013-2014)
1	T1	Founder	Female	16	26.13	13.98	21	11

2	T2	Founder	Female	28	25.81	21.89	67	21
3	T3	Founder	Male	16	18.73	17.63	116	62
4	T5	Founder	Female	7	13.26	13.57	59	25
5	P111	F1	Male	14	15.73	12.14	92	29
6	P112	F1	Male	4	19.72	12.97	6	6
7	P213	F1	Female	15	14.49	9.60	43	0

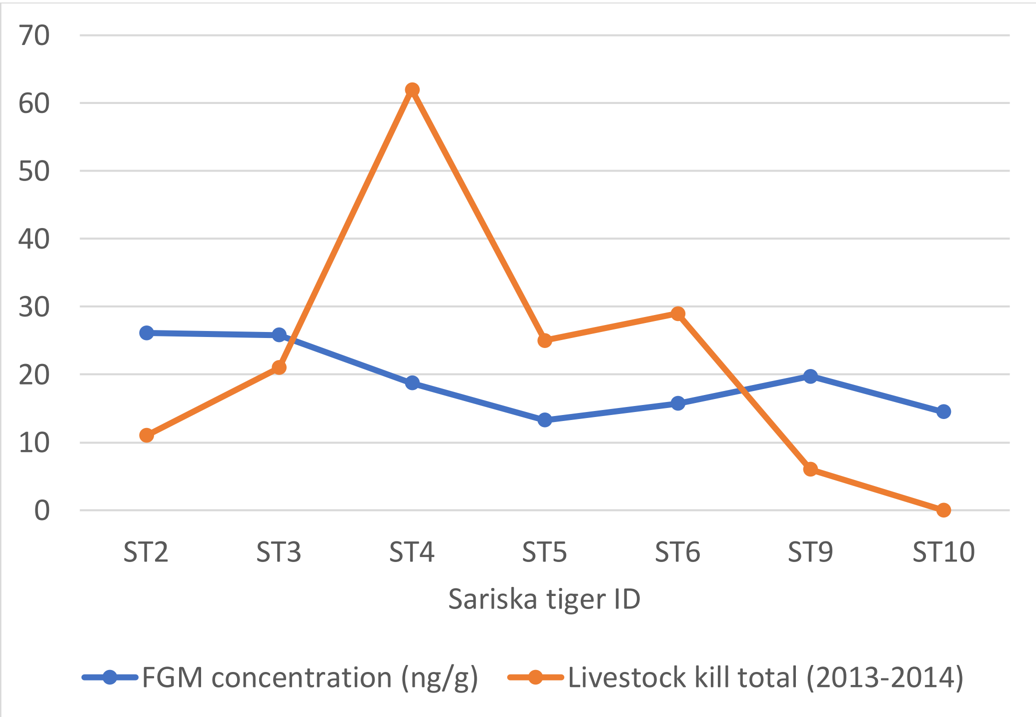

Figure 5. 5: Graph comparing mean FGM concentration of tigers in STR to the total livestock kill made by them

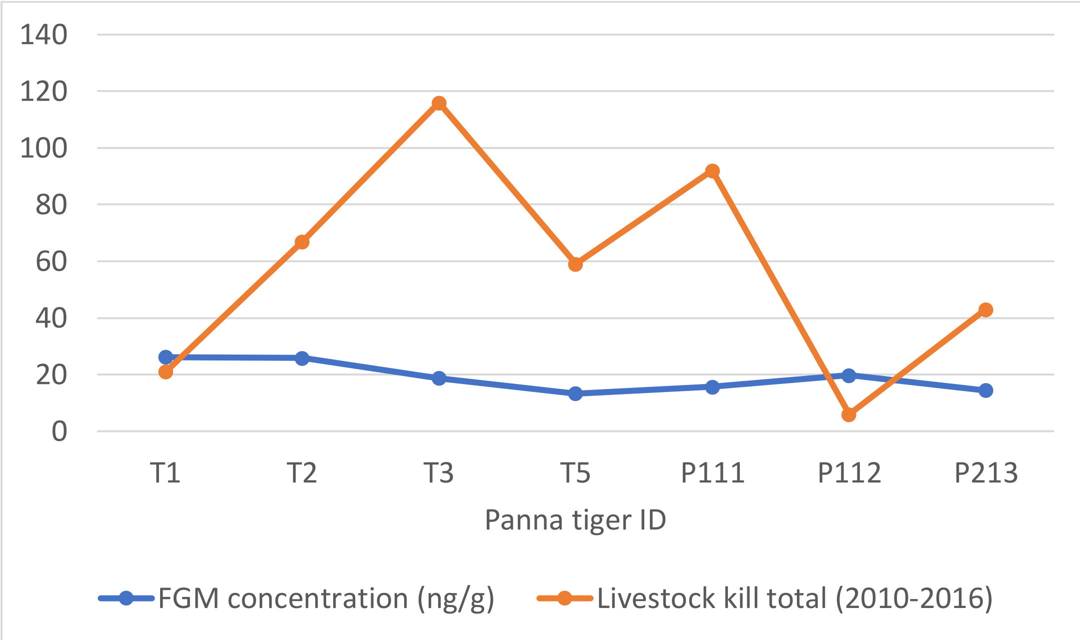

Figure 5. 6: Graph comparing mean FGM concentration of tigers in PTR to the total livestock kill made by them

5.3.6. Home range size: Home range size and livestock depredation were not found to be significantly correlated ($r=0.61$; $p=0.163$), in STR (Figure 5.7). However, in case of PTR a strong correlation (at $\alpha=0.1$) ($r=0.77$; $p=0.074$) was observed between home range size and livestock depredation i.e., larger the home range size, higher the livestock depredation by tiger (Figure 5.8).

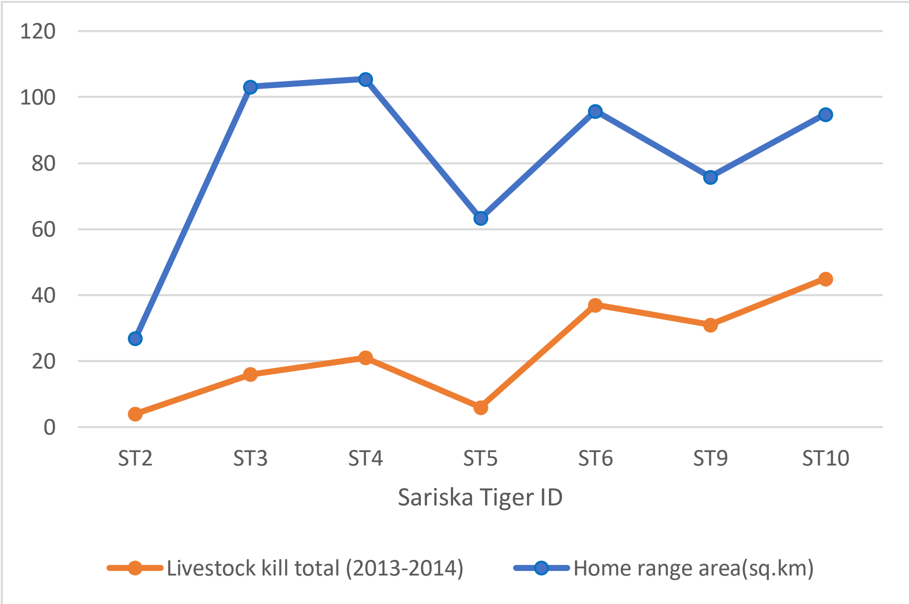

Figure 5. 7: Graph comparing home range size of tigers in STR to the total livestock kill made by them

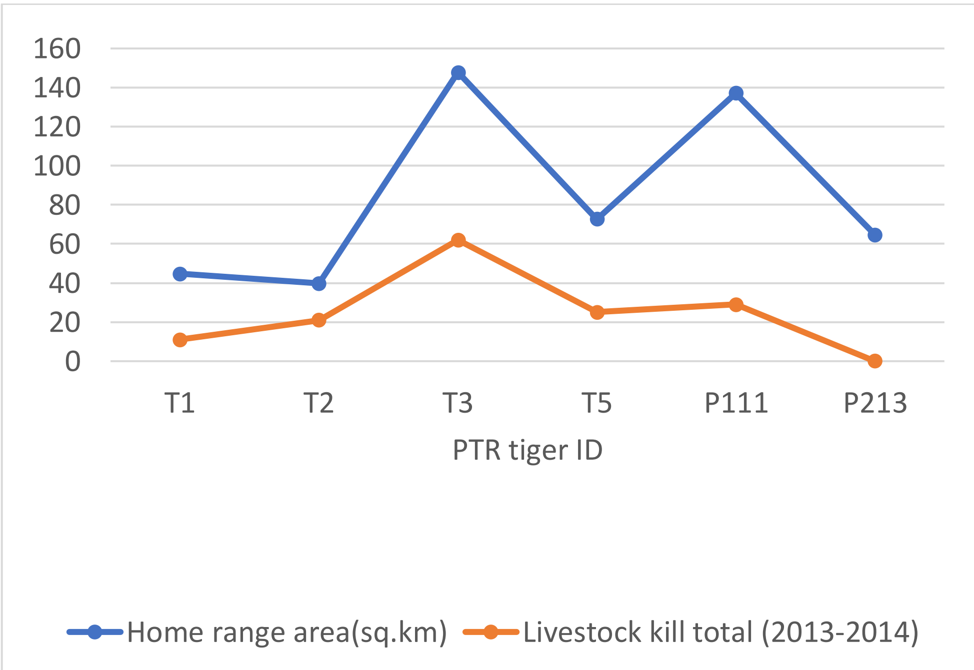

Figure 5. 8: Graph comparing home range size of tigers in PTR to the total livestock kill made by them

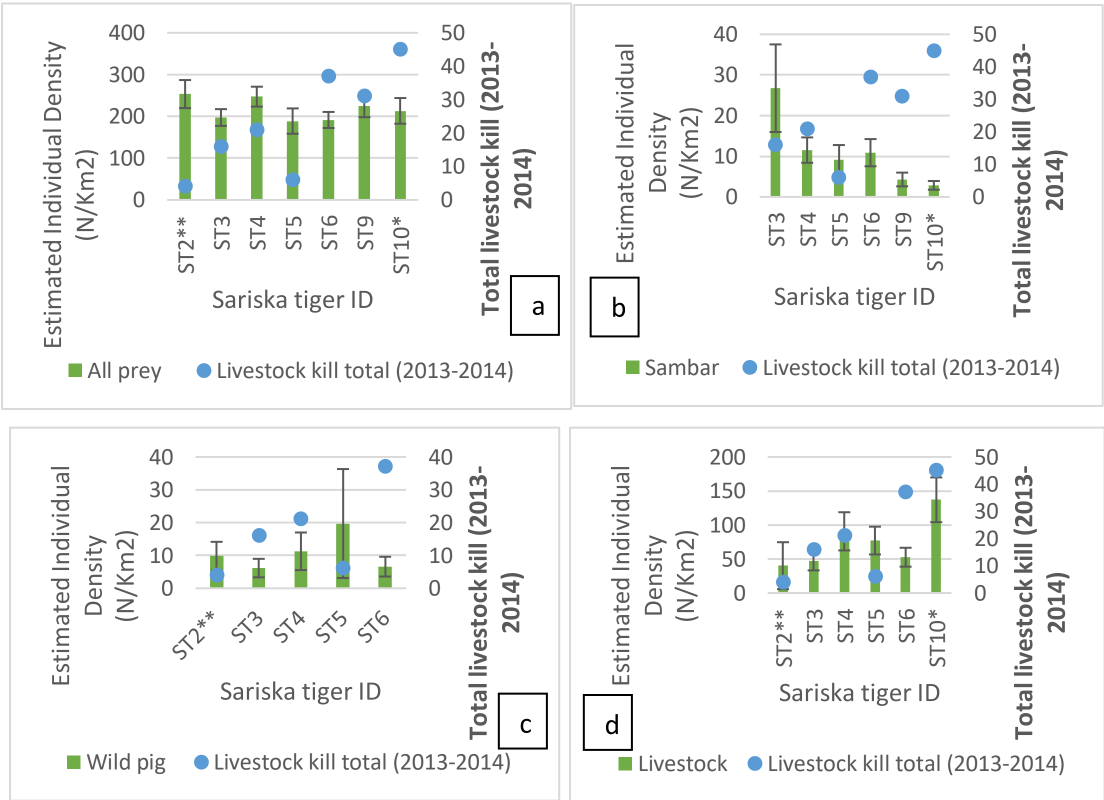

Figure 5. 9: Graph comparing prey within tiger home ranges in STR to the total livestock kill made by them: a) All prey, b) Sambar, c) Wild pig, d) Livestock

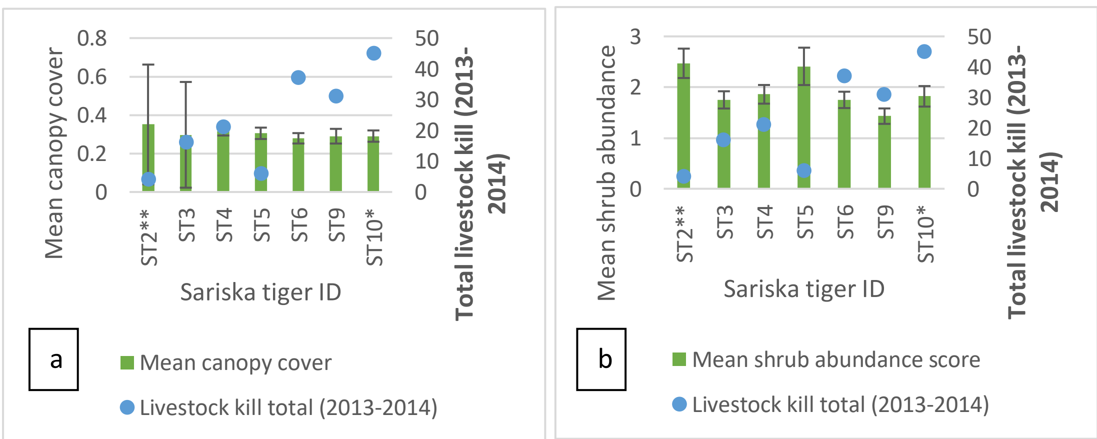

Figure 5. 10: Graph comparing vegetation cover within tiger home ranges in STR to the total livestock kill made by them: a) Canopy cover, b) Shrub abundance

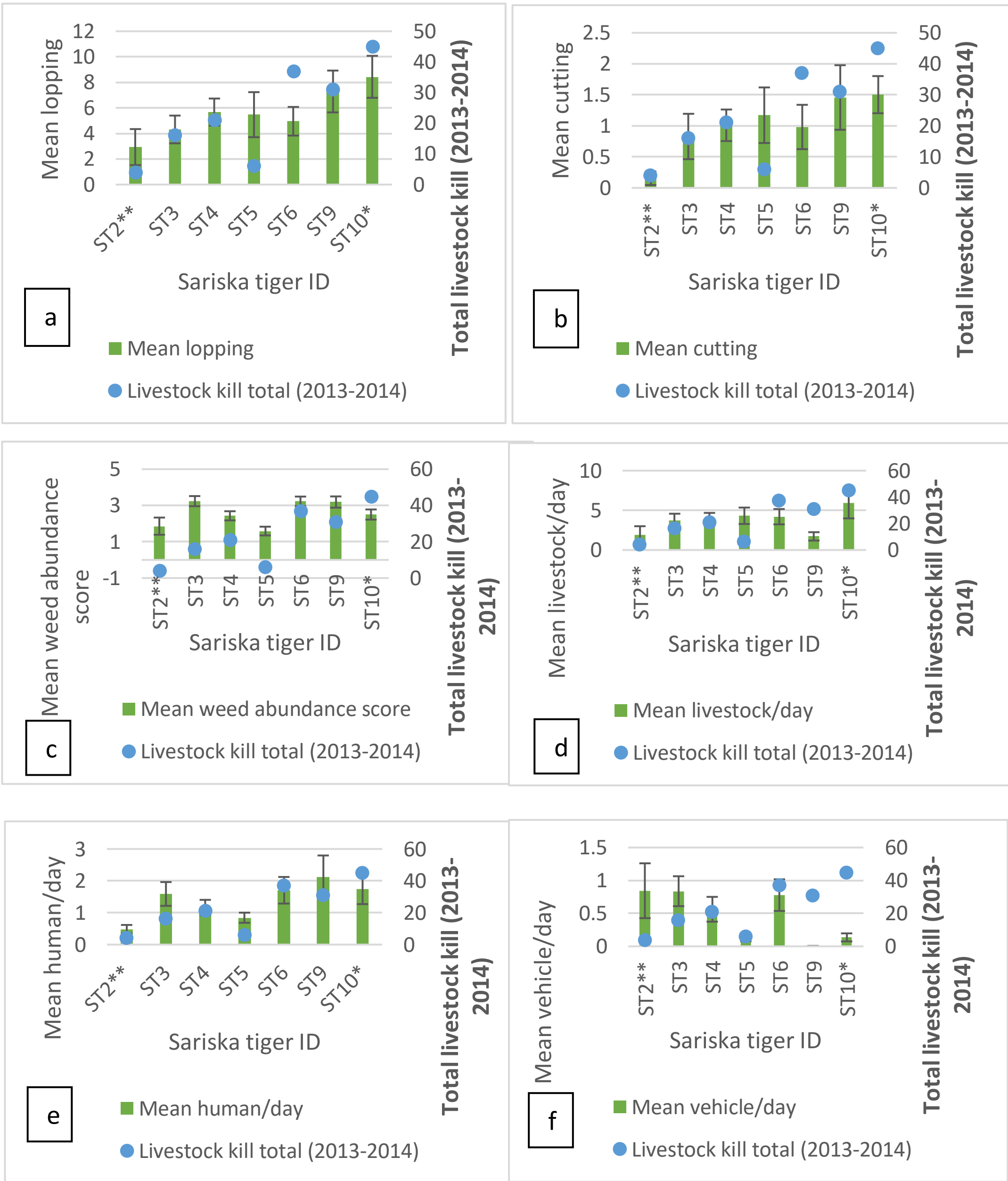

Figure 5. 11: Graph comparing anthropogenic disturbance within tiger home ranges in STR to the total livestock kill made by them: a) Lopping, b) Cutting, c) Weed abundance, d) Livestock encounter rate, e) Human encounter rate, f) Vehicle encounter rate

Home range quality: In STR, tiger whose home ranges have less cover (canopy and shrub) and high disturbance seem to be more prone to livestock depredation (Table 5.7, Figure 5.9, 5.10, 5.11). While in PTR higher abundance of chital within their home range is correlated to lesser livestock depredation by tiger (Table 5.8, Figure 5.12, 5.13, 5.14).

Table 5. 7: Correlation of various habitat factors within tiger home ranges with the number of livestock killed by the tigers in STR

Key habitat features	Variables assessed	Correlation with total livestock kill	p-value
Prey	All prey density (n/km2)	-0.20988	0.656
	Sambar density (n/km2)	-0.51194	0.254
	Wild pig density (n/km2)	-0.55882	0.206
	Livestock density (n/km2)	0.610459	0.160
Cover	Canopy cover (%)	**-0.74021**	**0.07**
	Shrub abundance score	**-0.73871**	**0.07**
Disturbance	Lopping	**0.753932**	**0.062**
	Cutting	0.681864	0.105
	Weed abundance score	0.608048	0.162
	Livestock encounter rate (n/day)	0.470832	0.299
	Human encounter rate (n/day)	**0.81477**	**0.035**
	Vehicle encounter rate (n/day)	-0.30458	0.514

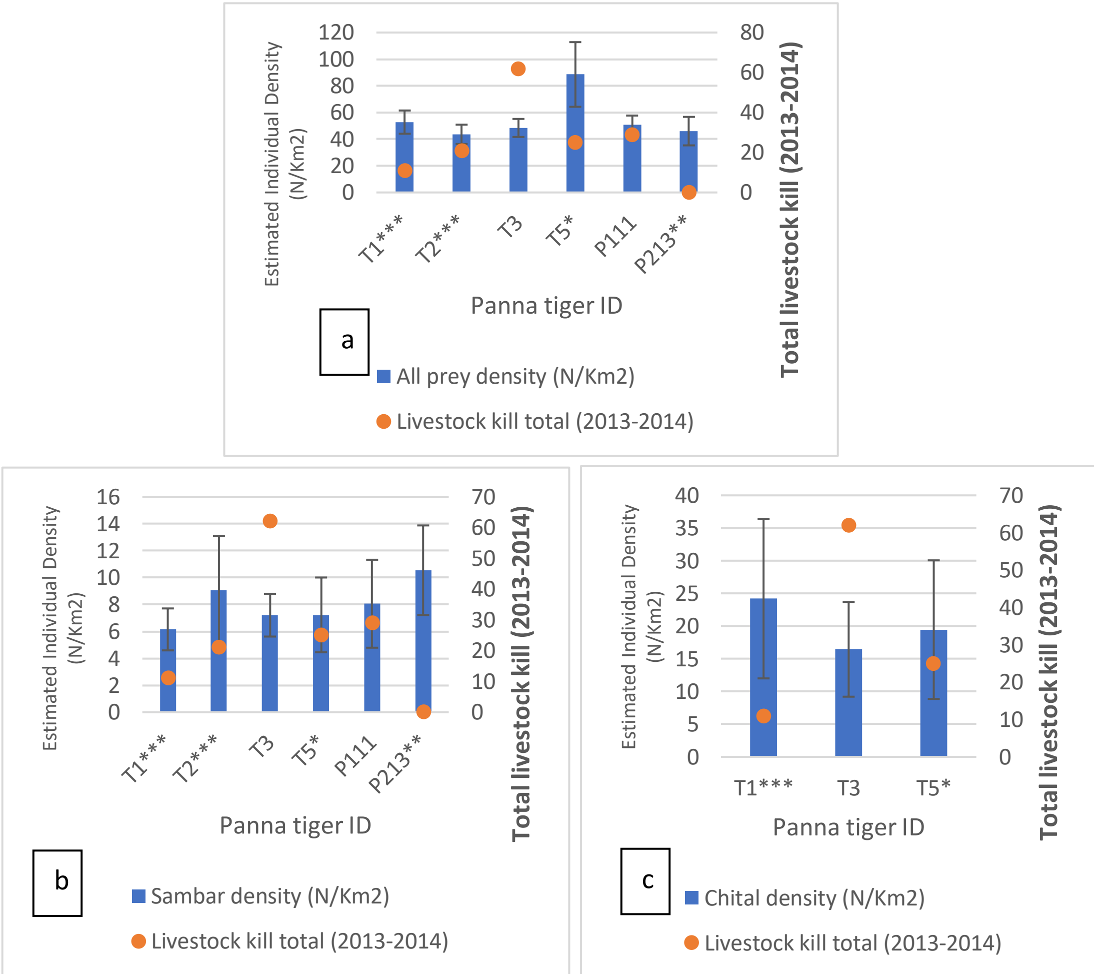

Figure 5. 12: Graph comparing prey within tiger home ranges in PTR to the total livestock kill made by them: a) All prey, b) Sambar, c) Chital

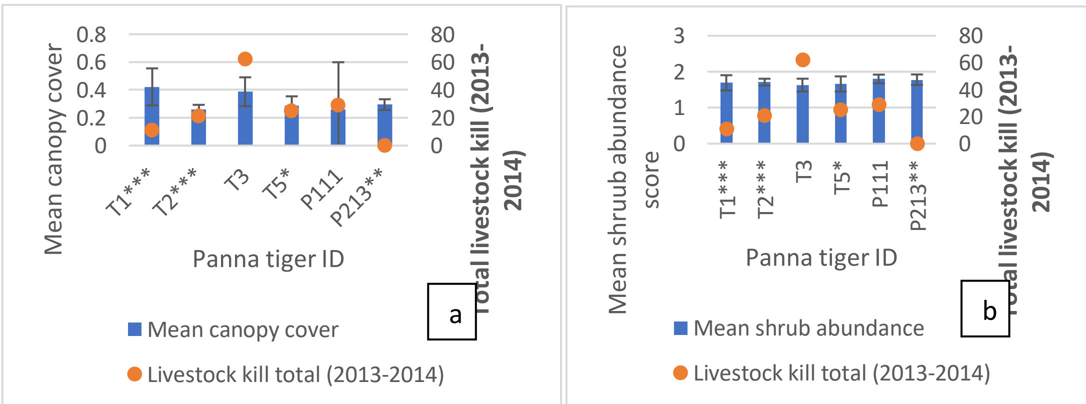

Figure 5. 13: Graph comparing vegetation cover within tiger home ranges in PTR to the total livestock kill made by them: a) Canopy cover, b) Shrub abundance

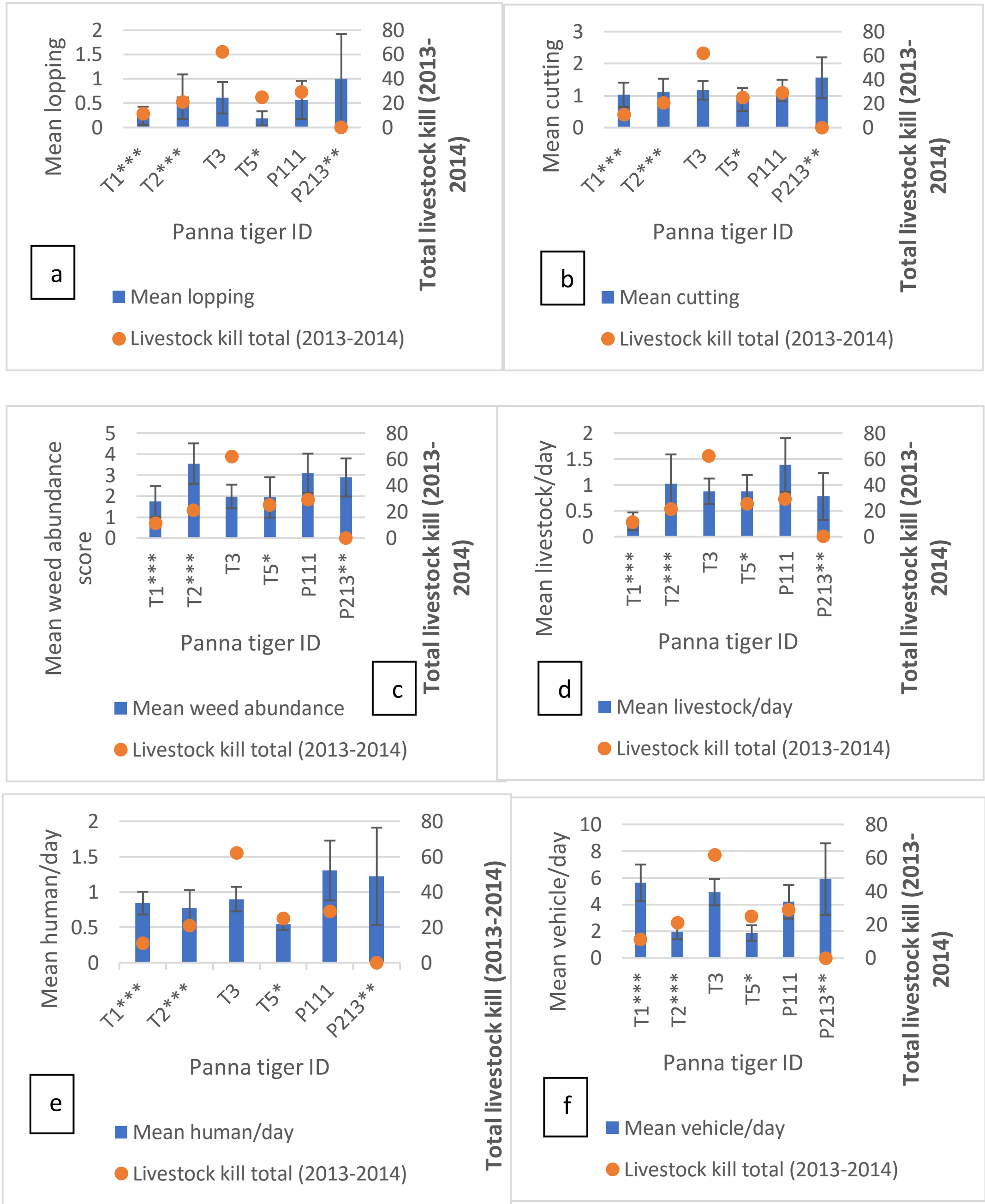

Figure 5. 14: Graph comparing anthropogenic disturbance within tiger home ranges in STR to the total livestock kill made by them: a) Lopping, b) Cutting, c) Weed abundance, d) Livestock encounter rate, e) Human encounter rate, f) Vehicle encounter rate

Table 5. 8: Correlation of various habitat factors within tiger home ranges with the number of livestock killed by the tigers in PTR

Key habitat features	Variables assessed	Correlation with total livestock kill	p-value
Prey	All prey density (n/km2)	0.022547	0.966
	Sambar density (n/km2)	0.429957	0.395
	Chital density (n/km2)	**-0.92738**	**0.008**
Cover	Canopy cover (%)	0.228295	0.664
	Shrub abundance score	-0.57515	0.232
Disturbance	Lopping	-0.15679	0.769
	Cutting	-0.31966	0.537
	Weed abundance score	-0.25676	0.623
	Livestock encounter rate (n/day)	0.322543	0.533
	Human encounter rate (n/day)	-0.16786	0.751
	Vehicle encounter rate (n/day)	-0.14373	0.786

5.4. Discussion

From the previous chapter it was learned that almost all tigers in STR and many radio-collared tigers in PTR, are occupying high-risk habitats, but are all tigers occupying high-risk habitat depredating livestock? Our results suggest that some individuals are causing significantly more livestock depredation and others significantly less. In STR, younger individuals were causing more livestock as compared to older. And tigers whose home ranges have less cover and high disturbance seem to be more prone to conflict. In PTR, male tigers and large home range size are positively correlated to livestock depredation. While high chital density within their home range in inversely correlated to livestock depredation.

Several studies have indicated that certain individuals, especially, males are more prone to HCC (Linnell et al., 1999; Mattisson et al., 2011; Odden et al., 2002; Woodroffe & Frank, 2005). Although this was not observed in case of STR, but in case of PTR, owing to large home ranges sizes of male tigers (Sarkar et al., 2016), which also often encompass areas outside CTH, male tigers were found to be depredating livestock more frequently as compared to females. A pattern, observed in the original Panna tiger population (Chundawat et al., 1999) and reported by earlier studies done on reintroduced tigers in Panna buffer, as well (Kolipaka et al., 2017). Younger tigers that are in the process of establishing their territories, may more frequently depredate livestock (Lamichhane, 2019). As in case of Sariska, where the older individuals, the ones that were reintroduced first, established their home ranges in prime tiger habitat like notified national park area, while younger individuals, or individuals that were translocated later, could not establish their territory in prime tiger habitat (because it was already occupied) and hence they occupied areas with higher anthropogenic disturbance, causing more livestock depredation.

As discussed in the last chapter, cover is an important habitat requisite for an ambush predator like tiger (Sunquist, 2010). In STR, it was found that tigers that have, on an average less cover within their home range, are depredating more livestock. This could be because, as discussed earlier, livestock are easier prey than wild herbivores owing to the lack of anti-predator response (Flörcke & Grandin, 2013), thus in absence of requisite cover, the chances of tiger successfully killing wild prey would be less, while chances of successfully depredating domestic livestock, would be better. In habitats with high anthropogenic disturbance, wild herbivore abundance would also be low while livestock availability would be high (Xiao et al., 2018). Therefore, in STR, tigers occupying home ranges with higher anthropogenic disturbance are depredating higher number of livestock. On the other hand, although overall physiological stress was higher in Sariska as compared to Panna, and overall livestock depredation is also higher in Sarsika, however, at individual level, physiological stress doesn't seem to be correlated to livestock depredation in both the reserves, i.e., stressed individuals are not more likely to depredate livestock, and inversely animals facing conflict are not necessarily more stressed as compared to their conspecifics.

Although IDs were attached to many of the scats analysed for food habit, tiger diets were not analysed individually, due to small sample size. However, examination of the overall food habit of tiger in both the places indicates that although livestock availability is high, it is not a preferred prey. In case of PTR, livestock has a major contribution to the prey biomass which could be due to the presence of high number of feral cattle in the reserve, however, livestock is still not the preferred prey and is utilized less than its availability. Instead, chital is the most preferred prey closely followed by sambar, as also observed in tiger diet at other places (Biswas & Sankar, 2002; Upadhyaya et al., 2018). And tiger occupying home ranges with high chital density were also depredating less livestock. In case of STR, the presence of livestock in tiger scat was particularly low even though livestock availability is very high.

Instead, sambar is the most preferred prey species and forms the major percentage of prey biomass. This resonates with earlier food habit studies done in STR (Avinandan et al., 2008; Mondal et al., 2012; Sankar et al., 2010). However, recent studies have reported high presence of livestock in tiger diet in Sariska (Bhardwaj et al., 2020). This trend needs to be closely monitored and studied.

Thus, the examination of biological associates of HTC indicates that certain tigers are more prone to conflict, male tigers owing to their large home range sizes, and younger individuals because they are trying to establish territories or occupying sub-optimal habitats, may depredate more livestock. And quality of home range is associated to livestock depredation, with tigers occupying high cover and high wild prey habitat depredating less livestock while, those occupying habitats with less cover and high anthropogenic disturbance, depredating more livestock.

However, since these correlations are drawn from very small data, results should be viewed with caution. And further research should aim to increase the sampled tiger population size to arrive at more concrete results.

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Chapter 6. Socio-economic determinants of human-tiger conflict

6.1. Background

Socio-economic parameters are important indicators of HWC (Dickman, 2010). Studies have found livestock husbandry practices, size of livestock holding and farm characteristics to be related with livestock depredation by carnivores (Adhikari et al., 2020; Bradley, 2004; Bradley & Pletscher, 2005; Dar et al., 2009; Eshete et al., 2018; Kolowski & Holekamp, 2006; Mech et al., 2000; Michalski et al., 2006; Mijiddorj et al., 2018; Ogada et al., 2003; Treves et al., 2004). Furthermore, the traditional livelihoods and household economics can also dictate the magnitude of loss faced by forest-dwelling communities. Local communities in both Sariska and Panna are highly dependent on these reserve forests (Chawdhry, 1996; Dular, 2015; Jain & Sajjad, 2016; Tiwari & Sharma, 2018) and face frequent losses due to tigers (Kolipaka et al., 2017; Sekhar et al., 1998). Therefore, to understand the sociological correlates of HTC, perceived livestock kill was modelled as a function of various HTI linked socio-economic variables, viz. demographics, community, resource dependence, livestock husbandry, economic status, at household level, in both STR and PTR.

6.2. Methodology

6.2.1 Survey design

Questionnaire surveys were carried out in selected villages within and around the reserves, in 2016–2017 (Bryman, 2012; De Vaus, 2002; Oppenheim, 2000; Presser et al., 2004; White et al., 2005). Village list and locations were obtained from the forest department of both the reserves, along with livestock compensation data. In case of STR all 27 villages within the CTH were sampled; additionally, 20% (n=5) of the conflict-facing villages outside the CTH were randomly sampled (Figure 6.1). In PTR, all villages inside the national park area plus two villages on the national park boundary were sampled (n=6). Additionally, villages within a 2 km buffer of the national park were stratified into high-, low-, and no-conflict villages and then randomly sampled (n=19) (Figure 6.2). Village sampling intensity was 50% for high conflict, and 20% for low and no conflict strata. Within villages, households (HH) were considered as the Primary Sampling Unit (PSU) and were selected randomly. To do so, electoral lists for particular villages were downloaded from the official websites of the chief electoral office of Rajasthan and Madhya Pradesh. HH numbers were obtained from these lists which were fed in MS-Excel. Random numbers equivalent to the desired sample size were generated, these numbers were treated as serial numbers associated with HH, HH numbers corresponding to the random serial numbers were then selected for sampling. The HH sample size was decided based on the number of HH in each village, in STR due to small village sizes, it was possible to sample 11-30% of the HH (Appendix 6.1). In case of PTR, HH in villages within core area and those experiencing high conflict, were sampled between 10-33%. But larger sizes of low and no conflict villages resulted in a sampling effort of 5-15% (Appendix 6.2). Thus, a total of 361 HH across 32 villages were sampled in STR, and in PTR 330 HH from 25 villages were sampled.

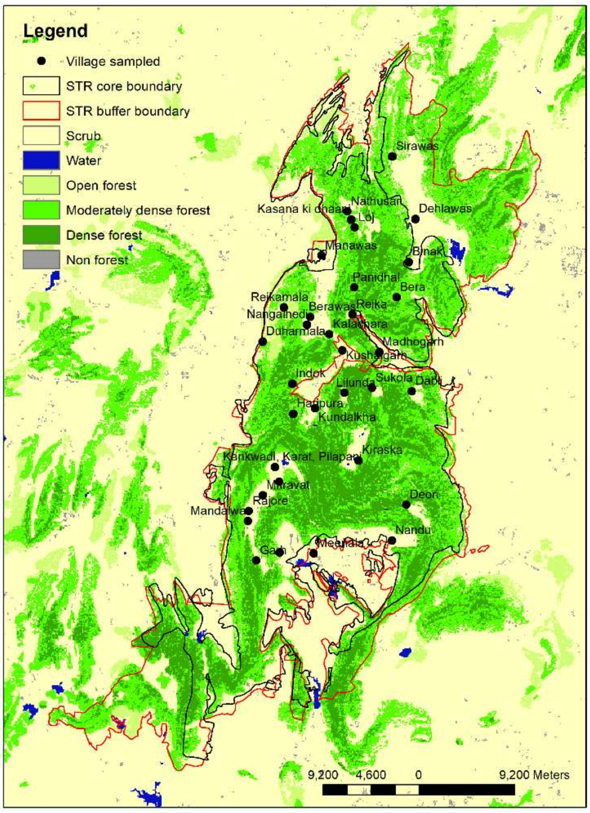

Figure 6. 1: Map showing sampled villages in Sariska Tiger Reserve

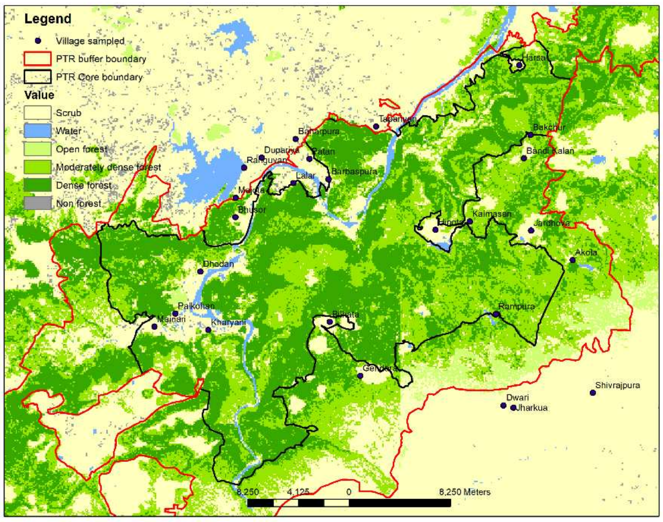

Figure 6. 2: Map showing sampled villages in Panna Tiger Reserve

The semi-structured questionnaire was aimed at understanding (Appendix 6.3):

1. HH demography, age, sex, caste/community, and education level of the respondent.
2. Resource dependencies of people, impressing upon the details of resources exploited and profit gained. The movement of people and cattle inside the reserve (how far from the village did they graze or went to collect NTFP & fuelwood) and the livestock husbandry practices followed.
3. Peoples' attitude towards tiger and re-introduction program in general. Additionally, opinion was also sought on village relocation.
4. Perceived livestock loss due to tiger: Such households were identified as the HH facing conflict (HFC) and were questioned in detail about the nature, time, and location of conflict. And also, the perceived monetary loss, compensation received, and satisfaction.
5. Threat perceived towards other carnivores and losses caused by herbivores.
6. Livelihood strategies and HH economics.

Questions were both closed (multiple choice type), as well as, open-ended. The questionnaire was tested on two trusted locals, at both the reserves. Based on their feedback, questions were edited. Help of trusted locals was also taken to understand resource use by people, rates of NTFP in local markets, profit made by standard HH by selling NTFP, cropping patterns, loss by herbivores, and profit and cost associated with agriculture and livestock rearing, in both the reserves. All the data were entered, coded, and summarized in MS-Excel. For all the explanatory variables descriptive statistics were calculated. Using box plot, outliers were identified and removed. Normality and linearity for all continuous variables were checked using Shapiro-Wilk test and scatterplot.

6.2.2. Perceived livestock loss quantification and economics of loss

Based on the details of the perceived livestock loss stated by the HFC (the number, age and species of the livestock), the quantum of loss in terms of monetary units was calculated for each household. Since not all households stated the cost of the lost livestock, the prices for each type of livestock (bullock, cow, buffalo, goat) were calculated by averaging the prices as stated by trusted locals, livestock trading websites, and the sampled households (Table 6.1).

Table 6. 1: Average livestock prices used to calculate the economics of loss faced by households in PTR and STR

Livestock	PTR		STR	
	INR	USD*	INR	USD*
Cow	24166.67	323.28	15875.00	212.36
Cow's calf	3750.00	50.16	4000.00	53.51
Buffalo	41666.67	557.38	49038.46	655.99
Buffalo's calf	4000.00	53.51	4000.00	53.51
Bullock	7666.67	102.56	7666.67	102.56
Goat	6625.00	88.62	5666.67	75.8

*Exchange rate: 1 USD = 74.76 INR

6.2.3. Spatio-temporal patterns of HTC

From the details obtained for the last livestock lost to tiger for each of the HFC, spatio-temporal patterns of livestock loss were studied, in both the reserves. The location of the livestock depredation incident was categorized into i) inside village or agricultural field, ii) between village and forest, iii) edge of forest, iv) inside forest. Season was recorded as winter (November-February), summer (March-June) and monsoon (July-October). And time of the incident was recorded as early morning (>4:00 am – 8:00 am), morning (>8:00 am – 12:00 pm), afternoon (>12:00 pm – 4:00 pm) evening (>4:00 pm – 8:00 pm), and night (>8:00 pm – 4:00 am). For each of the categories, percentages were calculated.

6.2.4. Multivariate statistical modelling to identify the socio-economic drivers of HTC

Statistical models were constructed to model socio-economic variables against livestock loss due to tiger (HH has reported livestock loss due to tiger [1] or not [0]), for both the reserves. A total of 25 variables were considered for socio-economic driver modelling, which can be grouped under the following heads:

- Village location: Inside or outside national park area
- Demography and social system: Gender, age, education, family size, community/caste
- Attitude: attitude towards tiger

- Livelihood strategies and HH economics: dependence on forest resources, distance travelled to collect forest resource, major income source, household income
- Livestock husbandry: total livestock owned, number of cow, buffalo and goat owned, major source(s) of fodder, dependence on reserve for fodder, complete/partial dependence, estimated cost of fodder procured from reserve forest, graze in reserve forest, grazing strategy, grazing time and season
- Agriculture and loss due to herbivores: size of agricultural land, whether farm or not, crop raided by herbivores or not

Calculation of income from NTFP and fuelwood collection: People were asked about the NTFP that they collected and how much. Although all HH shared the information on the types of NTFP that they are collecting and whether they are collecting fuelwood to sell or not, very few HHs could tell us how much did they collect or how much profit did they make? Therefore, the profits made from each of the NTFP, by each of the HH was calculated, assuming that all of the adult members of the household went for collection (based on information received from locals and respondents). I divided the total collection by a HH by the number of collectors from the HH. This way for each household I knew the average weight of the product collected per person (in kg). Now I took an average for all the HHs in a given class i.e., dependent (adivasis) and non-dependent (non-adivasis). By this, I got to know the average product collected per person for each class. Then I took an average of daily market price as indicated by government of India data (https://data.gov.in/) and as dictated by trusted locals to get the per kg price of the product. In the end, I just multiplied the collection per HH with the average price to get the average income from NTFP for each HH. Similarly for fuelwood, since it was known which were the HHs that were selling fuelwood, and the number of stacks collected, deducting one for the HH's personal usage, the rest were assumed to have been sold. The rate at which the fuelwood was assumed to be sold was the average of what some of the respondents stated and what the trusted locals told me.

Calculation of income from livestock rearing: During the interview, respondents stated not only the number of livestock belonging to each species and age class that they owned but also how many of them were milch and how many were non-milch. They also stated how much milk they sold and at what price. Since not all households shared this information, an average was calculated by dividing the amount of milk with the amount of milch cattle, for each of the households that did share this information. Again, this was further averaged with the estimates shared by the trusted locals, and websites giving information on livestock farming (Appendix 6.4; Goswami et al. 2013), to arrive at the income generated from milk by each livestock owning household. I also took into account the dry period and the lactation length for each cattle (as informed by trusted local and concerned websites) (Appendix 6.4; Goswami et al. 2013). Some of the households also stated that they did not sell the milk but made ghee or khoa out of the milk and sold that. I calculated the income generated from ghee/khoa per household in the same manner as I did for milk. Additionally, the average number of calves produced based on adult cattle owned by each HH and the interbirth interval reported by trusted locals and livestock rearing website, profits from the selling of calves were also calculated. Similarly, profits made from the selling of goats were also calculated (Appendix 6.4; Kumar, 2007; Kumar et al. 2010; Manohar et al., 2013). It should be noted that I also took into account the average mortality rate and average health care costs per cattle while calculating profits (Appendix 6.4; Dohare et al., 2013; Ershaduzzaman et al., 2007; Singh et al., 2009; Upadhyay et al., 2015).

Calculation of cost of fodder: For each of the households the cost of fodder was also calculated by averaging the information received from some of the respondents, the trusted locals, published research, and several websites imparting information on livestock rearing (Appendix 6.4; Goswami et al., 2013; Mishra et al., 2010). Since each of the household reported how much they depended on the forest for fodder (they stated partial (months or seasons) or complete dependence), I was able to calculate not only how much they were spending out of their pocket, which helped me calculate the profits from their livestock-related income, but also how much they were saving by depending on the forest for fodder.

Calculation of profits made from agriculture: Data on the types of crops grown and size of the farm along with percentage loss due to wildlife were shared by most respondents. It was assumed that different crops grown in a season would be sowed in equal area, therefore I simply divided the total farm area by the number of crops grown in each season, which was then multiplied by the per acre yield calculated for each crop. Which was calculated by averaging yields estimated by me from the data that was available, estimated by trusted locals, and as stated by various farming-related websites and government statistics for the district (Appendix 6.5; Commissionerate of Agriculture, 2017; Ranganathan, 2015). However, for cash crops like tobacco and vegetables, the area farmed was usually much smaller, and accordingly, calculations were made (FAO, 2003). For each of the sampled villages based on their location (near river higher yield or far away lesser yield, near forest higher loss to crop-raiding, far from forest lesser loss), yield was calculated for each category of household (small, medium, large), for each crop. Cost of cultivation of various crops was calculated based on published research and agro-farming websites (Appendix 6.5; Ahirwar et al. 2015; Gurjar & Varghese, 2005; Morale, 2010; Peer et al., 2013; Ranganathan, 2015; Singh, 2005; Singh et al., 2015; Verma et al., 2016). Selling price of all crops was calculated by averaging current MSP, average of market price for the past five years (as indicated by government reports), and the price estimated by our trusted locals (Appendix 6.5; Commissionerate of Agriculture, 2017; Peer et al., 2013). For those crops, for which MSP is not fixed and or average price for past years was not available, help was taken from trusted locals to estimate the price and current market price was checked online (Appendix 6.5). I also took into account household consumptions and based on literature assumed that small farmers (less than 1 ha or 2.5 acre) kept 30% of their produce for household consumption and as seed for next year, medium farmers 20% and large (more than 10ha or 25 acre) 10% (Department Of Agriculture, Cooperation & Farmers Welfare Ministry Of Agriculture & Farmers Welfare, 2020; IANS, 2015; Mahendra Dev, 2012; Nazli et al., 2014). Thus, profit from agricultural income was estimated for each household from each crop and summed to get total agriculture income per sampled household, for both the reserves.

Income from manual labour and other sources: Based on the information received from the respondent about whether they find work at villages or if they migrate for work to other cities and the number of days that they manage to find work, income from manual labour was calculated by multiplying the number of man-days with the minimum wage for that particular city. Similarly, rough estimates of income from business or salaries were calculated based on information available online, shared by respondents, and trusted locals (Appendix 6.6).

Livelihood strategies and calculation of household economics: Initially based on the source(s) of income stated by the households, they were categorized into different livelihood strategies (Table 6.2, 6.5)**.** Once income from various sources was calculated, they were summed up to calculate the total household income. The calculated income was then scanned for anomalies, for e.g. If a household owned both farmland and livestock but reported income less than 9000 INR per year, it was not included in the analyses, since clearly either there were issues in calculations or the household had not revealed all sources of income. Moreover, since these were very rough estimates, I did not wish to treat them as absolute incomes, hence these incomes were categorized based on poverty line(s) and income tax slabs and then used for modelling (Government of India Planning Commission, 2014; Appendix 6.7).

Livestock husbandry practices: Based on the information shared on fodder collection and grazing practices; dependence on forest for fodder, for grazing, fodder collection strategy, livestock grazing strategies (accompanied/unaccompanied; time of grazing) were categorized and used in the model (Table 6.3, 6.4, 6.6, 6.7).

Variable selection using univariate models & information value

Since there were a lot of independent variables (IVs), for the purpose of feature selection the relationship of IVs with livestock loss was tested. Firstly, univariate logistic regressions were run, after performing Box-Tidwell procedure to test for logistic regression linearity assumption i.e., logit transformation of the dependent variable and continuous independent variables have a linear relationship (Shin & Ying, 1994; Wuensch, 2016). Secondly, univariate GAMs were run to understand how much r sq/deviance was explained by each of the predictors. Additionally, Information Value and Weight of evidence were employed for feature selection (Good & Osteyee, 1974). Results of univariate logistic regression, univariate GAM, and Information value were studied to select the major explanatory variables, removing the variables with very little explanatory power and poor ranks. The selected variables were then checked for multicollinearity. To check for multicollinearity among the selected variables, appropriate tests of association were run (for continuous vs continuous and continuous vs ordinal variables, Kendall's tau b; for categorical vs continuous variables, logistic regression; and for categorical vs categorical variables, Cramer's V). The correlated variables were not used together in a model.

Model building and selection

To model socio-economic determinants of conflict, since our data did not meet the assumption of binary logistic regression, GAM (using package mgcv (Wood, 2011)) and random forest were employed. GAM as discussed in chapter 4, are much more flexible than linear models because they allow for modelling of nonlinear relationships (Hastie & Tibshirani, 1990; Larsen, 2015). Random forests are one of the most popular ensemble machine learning algorithms, widely applied for solving classification problems (Breiman, 2001; Cutler et al., 2012). And have been used in the past to model HTC risk (Soh et al., 2014; Struebig et al., 2018).

Since the livestock loss datasets could be considered imbalanced but not highly, GAM was applied to the data without correcting for the imbalance (Stewart, 2020). However, when I advanced to applying random forest on the data, it was performing very poorly and since like all bagging ensemble machine learning methods, random forest is sensitive to class imbalance I used balanced random forest (using imbalanced.rfsrc function in randomForestSRC package) (that down-samples/undersample majority class) and grew the forest to great size (1000 trees) to avoid the side effects of using under-sampling of majority class i.e. loss of information (Chen et al. 2004; Brownlee, 2020; Ishwaran & Kogalur, 2017).

After removing outliers and missing data, modelling was done on 306 observations for PTR and 336 observations for STR. Since the data set was small and covariate number was large, therefore, I did not split the data into test and training sets. Moreover, randomly splitting data set into whatever proportions, create unique issues related to data distribution and therefore may produce unreliable accuracy measures (Borovicka et al., 2012). Therefore, k-fold (10) cross-validation was used for calculating AUC and true skill statistics for each of the GAM (Borovicka et al., 2012). In case of random forest, out-of-bag (OOB) error estimates, were used.

Stepwise backward selection was used to retain the best predictors in each of the models (Ruczinski 2005) and final model selection (within GAM and random forest models and between GAM and random forest models) was based on pseudo R^2

and discrimination ability (classification accuracy and AUC value of the receiver operating characteristic (ROC) curve).

6.3. Results

6.3.1. Status of Socio-economic variables

Sariska Tiger Reserve

Demography: of the 361 respondents, 66.8% were male and 33.2% were female. Average age of the respondents was 41.80±16.04 years. Average number of members in a household were 8.3±4.6.

Community/Caste/Social class: Total 17 communities were sampled in STR. Of the 361 respondents, 62% (n=225) belonged to Gujjar community, they, along with other communities belonging to OBC category, make up 73.1% of our sampled population. Of the rest, Meena community comprised 16% of the sampled population, they, along with Dhanka (n=3) belonged to ST category. Balai belonging to SC category comprised 5% of sampled HHs. 4% of the sampled HHs belonged to general category, comprising of Brahmans and Rajputs. Only one sampled HH belonged to minority (muslim) community, which was Mayo or Khan.

Education: Most of the respondents (66.5%) were uneducated, 9.4% respondents had studied up to primary, 8.6% had studied to middle school level, 6.1% up to high school, 4.4% up to intermediate, 4.7% to bachelor's and 1 had studied up to master's level. Illiteracy was higher among women, since 87% of females that were interviewed were uneducated as compared to 56% males.

Livelihood strategies and HH economics: Most of the HH were involved in livestock husbandry (n=330), agriculture (n=267) and often in combination with other activities like working as labourers (n=41) etc. (Table 6.2) Most commonly HHs were involved in both livestock rearing and agriculture (53.7%), followed by only livestock rearing (20.8%), livestock rearing and agriculture plus daily wage labour (6.1%), and only agriculture (3.6%). Very few people were also involved in driving safari gypsy, business, and crafts. Overall, only 9 of 361 sampled HH were directly employed by forest department. The average HH income was estimated to be approximately INR 156346.2 per annum.

Table 6. 2: Categorization of various combination of livelihood strategies reported by households sampled in STR to be used for modelling HTC

S. No.	Income source_1	Income source_2	Income source_3	Income source code	Frequency (N=336)
1	Agriculture			5.0	10
2	Livestock Husbandry	Agriculture	Labour	3.0	26
3	Livestock Husbandry			1.0	74
4	Livestock Husbandry	Agriculture		2.0	169
5	Major income source livestock husbandry & agriculture plus some other minor income source in different combinations			4.0	26
6	Major income source livestock husbandry plus some other minor income source in different combinations			6.0	13
7	Major income source agriculture plus some other minor income source in different combinations			7.0	12

Forest resource use: Of the 361 HH sampled, 89.5% (N=323) depend upon reserve forest for primarily fuelwood and fodder. 9.4% (N=34) of sampled HH reported no dependency on forest resources, 1.1% (N=4) did not wish to reveal the information. Fuelwood was the most common resource exploited (88.4% HH), commonly exploited species were *Anogeisus pendula* (vern. Dhok), *Acacia nilotica* (vern. Babool/kikar), and *Prosopis juliflora* (vern. Vilayati kikar). Wood and bamboo for construction and fencing purpose were collected by 66.5% of HH, *Acacia nilotica* was the most common species. As for fodder, 87% of HH collected grass, leaves, and pods. Common species were *Anogeisus pendula* (leaves collected as feed for buffaloes) and *Butea monosperma* (vern. Chila) (leaves), 4% HH also collected *Ziziphus mauritiana* (vern. Ber) fruits for themselves, and fruits and leaves as feed for goats. Some HH (11.4%) also reported collecting dates from date palm (*Phoenix sylvestris*).

In order to collect these forest-produce people were estimated to be going on an average 2.6±1.1km from their village, inside the forest (Figure 6.3). Similarly, to graze their livestock people went an average distance of 3.6±1.2km from their village. When grazing alone, livestock were estimated to venture about the same distance as people i.e., average 3.6±2.0km from the village.

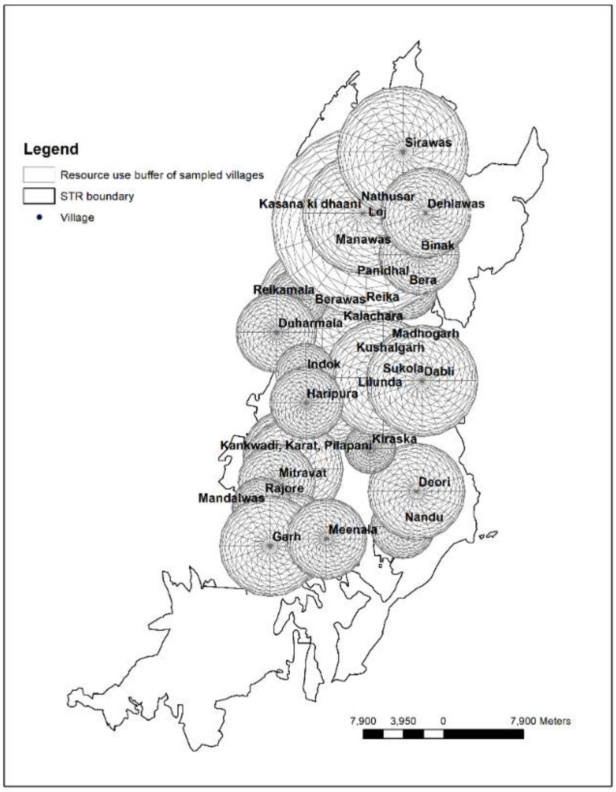

Figure 6. 3: Distance covered by people to collect forest resources from sampled villages in STR

Livestock husbandry: Of all the 361 sampled HH 97.5% (n=352) owned livestock. Their total livestock holding was 7322, which comprised mostly of domestic buffalo (46.9%) and goat (42%), followed by cattle (11.1%). Average livestock holding of sampled HH was 20.3±23.9. 93.6% of the sampled HH or 96% of the livestock owning HH (LOH) depend upon tiger reserve for fodder. Most of these HH (40.5% LOH) graze their cattle in forest during monsoon-winter and rest of the year collect fodder from forest and/or feed dry husk (*bhusa*, by-product of crops grown in their farms) and/or buy fodder from market. The cost of fodder collected and grazed from reserve forest for each HH was estimated to be on an average INR 2,75,757.5 (USD 3,657.09) per annum per HH for STR.

86.9% of sampled LOH, graze their livestock in tiger reserve. Most of these HHs leave their livestock in the forest unaccompanied to graze, livestock return back to the village on their own (32%), some always accompany their livestock (17.5%), some accompany only goats (16%) and others accompany their livestock occasionally (12.4%). Of these LOH (n=352) 322 HH, reported the time at which they graze their cattle, 50.6% of which said that they graze their livestock during day time in winter and summer while during monsoon, cows and buffaloes stay in jungle and graze both during day and night.

Table 6. 3: Livestock grazing strategies categorized for STR to be used for modelling HTC

S. No.	Grazing strategy description	Code	Frequency (N=336)
1	Do not own livestock/graze in forest	0	33
2	Always accompany themselves or a herder does	1	62
3	Leave in jungle, livestock return on their own or are brought back in the evening	3	110
4	Always accompany goat sometimes buffalo but not cattle	5	59
5	Sometimes accompany for e.g., when they graze far away or at night	7	55
6	Accompany during day but not usually at night	8	17

Table 6. 4: Livestock grazing time & season categorized for STR to be used for modelling HTC

S. No.	Graze time description	Code	Frequency (N=336)
1	Do not own livestock/graze in forest	0	33

2	Graze during day time in winter and summer, during monsoon (August to October) stay in jungle and graze both during day and night	1	154
3	Graze during day time in summer, during monsoon and winter graze both during day and night	2	16
4	Graze all season only during day, never at night	3	37
5	Graze only during monsoon and then too only during daytime	4	30
6	Graze only during monsoon, day and night	5	46
7	Graze during day and night throughout the year, but only non-milch cattle, milch cattle only graze during the day	7	20

Patterns and economics of HTC mediated loss: Of the 361 respondents, 107 (29.6%) said that they have suffered loss by reintroduced tigers, while 249 HH did not report any conflict with tiger, five respondents were not sure whether they have suffered any losses due to conflict with tiger. A total of 233 livestock were reported to be lost by HFC. All the HFC (n=107) were further questioned about the last livestock lost, to understand the spatio-temporal pattern of conflict. Of the livestock lost, the highest number was that of domestic buffalo (n=65), followed by domestic cow (n=41) and goat (n=1). Most of the depredation events occurred inside the forest (n=90), followed by forest boundary (n=7), between forest and village boundaries (n=5), and inside the village boundaries (n=3). Three people could not recall the place of incident. The season in which the highest number of depredations occurred was winter (n=45), closely followed by monsoon (n=39), and least in summer (n=12), eleven respondents did not know/remember the season in which the incident occurred. Most number of depredation events were reported to have taken place at night (n=34), followed by morning (n=22), afternoon (n=13), evening (n=9), and early morning (n=1), many respondents (n=28) could not recall or did not know the time of depredation. The total monetary loss suffered by the HFC since tigers were reintroduced (2009-2016) was estimated to be INR 5705747.5, which averages to INR 53324.7 per HFC or INR 7,617.8 (USD 102.20) per HFC per year. All (n=330) respondents stated that as per their knowledge tigers have never attacked any human being.

Panna Tiger Reserve

Demography: Of the 330 respondents, 68.8% were male and 31.2% were female. Average age of the respondents was 43.52±16.20. Average number of members in a household were 6.8±3.2.

Community/Caste/Social class: Total 31 communities were sampled in PTR. Of the 330 respondents, 52.42% (n=173) belonged to other backward class (OBC) category, of which Yadav (milkmen) comprised the largest proportion, others were Pal (Ahirs/herders), Ahirwal, Kushwaha (agriculturists), Raikwar (Kewat/boatman), Barhai/Vishwakarma (carpenters), Kurmi and Patel both of which are landholders (agriculturists by profession), Mistri (mechanic), Sahu (moneylenders), Soni (goldsmith), Mondal and Hari. Scheduled Tribe (ST) category constituted 32.12% (n=106) of the sampled HH, dominated by Gonds (n=103), which further comprised of Rajgond, the thakur or ruling class within the community and Jagat (Gond sorcerers). General caste category constituted 11.21% (n=37) of the sampled HH, dominated by Brahmans and Thakurs (Bundel and Lakhera Rajputs), other important castes being Rai (agriculturists), Sahai and Serare. Scheduled Caste (SC) category constituted 3.64% (n=12) of the sampled HH, which comprised of Basor, Rajak

(Dhobi/washerman), Kori (weavers), Anuragi, Bansal, Mehtar (sweepers), Kondar and Prajapati (Kumhar/potter).

Education: Most of the respondents (57.9%) were uneducated, 15.5% respondents had studied up to primary, 9.4% had studied to middle school level, 6.4% up to high school, 6.1% up to intermediate, 3% to bachelor's and 1.2% to master's level. Illiteracy was higher among women, since 75.73% females were uneducated as compared to 50.66% males.

Livelihood strategies and household economics: In PTR, most of the HH were involved in agriculture (77.81%), manual labour (54.41%), selling NTFPs (42.25%), and livestock husbandry (36.78%), often in combination with each other (Table 6.5). Most commonly respondents stated that they cultivate their lands and between cropping seasons (mostly during summer) they or someone in their family, work as daily wage labourer in nearby towns or big cities or under MNREGA in their village (13.7%). Only 26 of 330 (7.9%) sampled HH were directly employed by forest department, most of which (n=24) were working as daily wage labourer, some as forest watcher or tracker in tiger monitoring parties. The average HH income was estimated to be approximately INR 127151.4 per annum.

Table 6. 5: Categorization of various combination of livelihood strategies reported by households sampled in PTR to be used for modelling HTC

S. No.	Income source_1	Income source_2	Income source_3	Income source code	Frequency (N=306)
1.	Agriculture	Labour		17.0	39
2.	Agriculture	Labour	NTFP	33.0	34

3.	Livestock Husbandry	Agriculture		2.0	32
4.	Agriculture			16.0	27
5.	Livestock Husbandry	Agriculture	Labour	3.0	20
6.	Livestock Husbandry	Agriculture	NTFP	51.0	22
7.	Labour (oth)	NTFP		39.0	19
8.	Agriculture	NTFP		35.0	12
9.	Labour (oth)			23.0	14
10.	Livestock Husbandry	Labour	NTFP	48.0	10
11.	Majorly livestock husbandry dependent household also involved in several combinations of other livelihood strategies			60.0	29
12.	Other income sources			61.0	48

Forest resource use: Of the 330 HH sampled, 84.8% depend upon reserve forest for resources which include fuelwood, fodder, and NWFPs. Fuelwood was the most common resource exploited (81.2% HH). Wood for construction and fencing purposes was collected by 30.9% of HH. As for the NWFPs, 43.0% HH collected mahua (*Madhuca indica*), 42.1% HH collected amla (*Phyllanthus emblica*), 39.4 % collected achar/chironji (*Buchanania lanzan*), one HH also collected Bamboo and cane for making baskets, etc. Average annual HH income from NTFP was estimated to be INR 12,398 (USD 166.33).

A total of 268 HH reported venturing into the forest to collect forest produce and graze livestock. In order to collect these forest-produce, 22% people reported going about 2-4 km from their village, inside the forest; an equal number (19.4%) of people reported going about 1-2 km and 4-6 km inside the forest, followed by 11.9% travelling about 0-1km and 6.7% about 6-8km. Very few people (2.6%) reported venturing further than that.

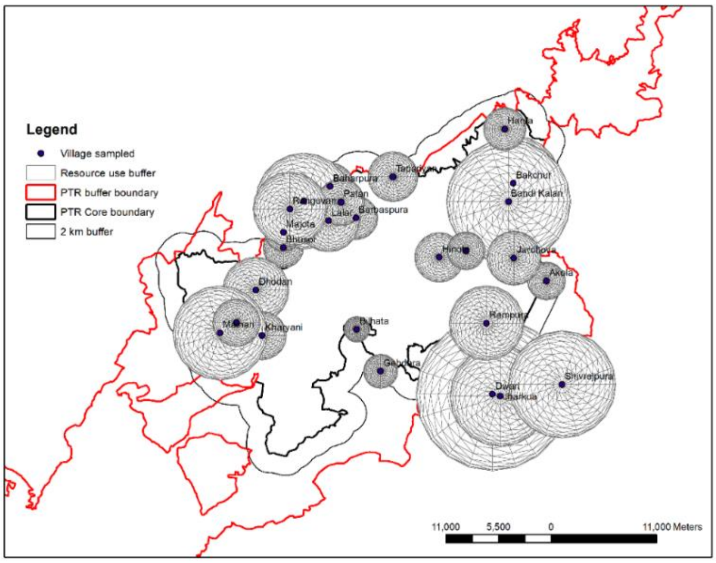

Figure 6. 4: Distance covered by people to collect forest resources from sampled villages in PTR

Therefore, on average people were going approx. 3.8±2.1km from their village, inside the forest to collect these forest-produce (Figure 6.4). Similarly, to graze their livestock people went an average distance of 3.4±1.7km from their village. When grazing alone, livestock were estimated to venture about the same distance as people i.e., average 3.7±1.7km from the village.

Livestock husbandry: Of all the sampled HHs, 66.1% (n=218) owned livestock. Their total livestock holding was 1431, which comprised mostly of domestic buffalo (43.3%) and cattle (36.9%) followed by goat (19.1%) and pig (0.7%). Average livestock holding of sampled HH was 4.34±6.8. Out of these 218 livestock owning HHs (LOH), 67% stated that they depend upon forest for fodder and graze their livestock in the reserve forest. Cost of fodder collected and grazed from reserve forest for each HH was estimated to be on an average INR 44,038 (USD 584.03) per year per HH for PTR.

Of these LOH (n=134), 59% stated that they graze their livestock in reserve forest in all seasons but during day time never at night, 20.1% HH graze their livestock during day time in winter and summer, while during monsoon, cows and buffaloes stay in the jungle and graze both during day and night, 9% HH graze their livestock only during winter and monsoon but at daytime never at night and 6.7% reported grazing only during monsoon and then too only during daytime. Most of these HHs leave their livestock in the forest unaccompanied to graze, livestock return back to the village on their own (33%), some hire herders to accompany their livestock (29.3%), some accompany their livestock themselves (27.1%) and few accompany only goat (3%).

Table 6. 6: Livestock grazing strategies categorized for PTR to be used for modelling HTC

S. No.	Grazing strategy description	Code	Frequency
1	Do not own livestock/graze in forest	0	178
2	Leave in jungle, livestock return on their own	3	38

3	Hire a shepherd	6	38
4	Always accompany	1	37
5	Sometimes accompany	7	15

Table 6. 7: Livestock grazing time & season categorized for PTR to be used for modelling HTC

S. No.	Graze time description	Code	Frequency
1	Do not own livestock/graze in forest	0	178
2	Graze all season, only during day never at night	3	79
3	Graze during day time in winter and summer, during monsoon (August to October) stay in jungle and graze both during day and night	1	49
4	Graze only during winter and monsoon, at daytime never at night	14	20

Patterns and economics of HTC mediated loss: All (n=330) respondents stated that as per their knowledge tigers have never attacked any human being. Of the 330 respondents, 90 (27.3%) said that they have suffered livestock loss by reintroduced tigers, while 235 HH did not report any livestock loss due to reintroduced tigers, five respondents were not sure whether or not, they have suffered any losses due to tiger. Total 141 livestock were reported to be lost by the HFC. Of the livestock lost, the highest number was that of domestic cow (n=69), followed by domestic buffalo (n=19) and goat (n=2). The highest number of cattle depredation incidents took place inside reserve forest (n=58), followed by forest edge/boundary (n=13), inside village or agricultural field (n=12), and between village and forest (n=6), one respondent did not know the place of incident. The season in which the highest number of depredation events occurred was monsoon (n=29), closely followed by summer (27) and winter (n=25), nine respondents did not know/remember the season in which the incident occurred. Most number of cattle lifting incidents were reported to have taken place in the morning (n=13), followed by afternoon (n=10), evening (n=6), night (n=5), and early morning (n=1), but since many respondents (n=55) could not recall or did not know the exact time of kill, any pattern as far as time of the day is concerned, cannot be discerned. The total monetary loss suffered by the HFC since tigers were reintroduced (2009-2016) was estimated to be INR 2887521, which averages to INR 32083.56 per HFC or INR 4583.4 (USD 61.49) per HFC per year.

6.3.2. Socio-economic drivers of HTC

STR: A total of around 33 models were constructed, of which the final model selected was a GAM with five variables, viz. community, education, grazing time, farm (own or not), and household income category (Table 6.8). The model explains 16.8% deviance. Among the five variables in the model, two have a statistically significant relationship with livestock loss (Table 6.9). First being community, given everything else is equal, Gujjars were more likely to face livestock loss than Meena and all other communities (Table 6.9). Second being, time of grazing, everything else being equal, people who graze their livestock inside the reserve forest in winter and summer during day time, and in monsoon, during both day and night, are more likely to face livestock loss as compared to those who do not graze their livestock inside reserve forest (Graz_time_cat0). But less likely to face livestock loss as compared to people who graze their livestock inside the reserve forest in summer during day time, but in monsoon as well as winter, both during day and night (Graz_time_cat2) (Table 6.9). Indicating that it is grazing at night that makes livestock vulnerable to depredation by tiger. The third being, household income, the households with the highest income (>5 lakh per annum), are more likely to face livestock loss as compared to the household with the lowest income (<27000 per annum) (Table 6.9).

Table 6. 8: GAM and Random Forest top models predicting livestock loss by tiger in STR, compared across different statistical measures

Model covariates	r-sq	cvAUC (GAM)	cvAccuracy (GAM)	cvError (GAM)	AUC (RF)	OOB error (RF)
commun_simple + EDU_RECLASS + Graz_time_cat + farm + hh_inc_cat	**0.144**	**0.700**	**0.684**	**0.369**	**0.689**	**0.364**
commun_simple + Graz_time_cat + D_FP_cat_recoded + farm + hh_inc_cat	0.14	0.703	0.651	0.349	0.691	0.352
commun_simple + EDU_RECLASS + Graz_time_cat + D_FP_cat_recoded + farm + hh_inc_cat	0.141	0.700	0.631	0.369	0.691	0.352
commun_simple + EDU_RECLASS + Tot_family + D_FP_cat_recoded + graze_cat + farm + hh_inc_cat	0.119	0.684	0.628	0.372	0.698	0.340
commun_simple + EDU_RECLASS + Tot_family + Graz_time_cat + farm + hh_inc_cat	0.144	0.699	0.625	0.375	0.698	0.343
commun_simple + EDU_RECLASS +	0.142	0.695	0.622	0.378	0.686	0.354

Graz_time_cat + D_FP_cat_recoded + loss_herb + Cost_fodder_forest_peryear_all_livestock + hh_inc_cat						
Tot_family + commun_simple + graze_cat + hh_inc_cat + EDU_RECLASS + loss_herb	0.126	0.698	0.616	0.384	0.686	0.354

Note: The model which is highlighted was selected

Table 6. 9: Parametric coefficients of selected GAM model predicting livestock loss by tiger in Sariska Tiger Reserve

Parameter	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-0.24638	0.3469	-0.71	0.477557
commun_Meena	**-2.58273**	**0.75905**	**-3.403**	**0.000668**
commun_other	**-0.68772**	**0.39404**	**-1.745**	**0.080934**
EDU_RECLASS.L	0.09195	0.505	0.182	0.855513
EDU_RECLASS.Q	0.04259	0.51022	0.083	0.933477
EDU_RECLASS.C	-0.65233	0.4879	-1.337	0.181215
EDU_RECLASS^4	0.25911	0.50736	0.511	0.609554
Graz_time_cat0	**-1.52205**	**0.80228**	**-1.897**	**0.057808**
Graz_time_cat2	**1.60712**	**0.66039**	**2.434**	**0.014949**
Graz_time_cat3	-0.37214	0.47821	-0.778	0.436457
Graz_time_cat4	-0.04691	0.51234	-0.092	0.927046
Graz_time_cat5	-0.39647	0.41838	-0.948	0.343316
Graz_time_cat7	0.01517	0.5168	0.029	0.976581
farm1	-0.4751	0.29661	-1.602	0.109199
hh_inc_cat.L	0.29374	0.52723	0.557	0.577426
hh_inc_cat.Q	0.17145	0.48344	0.355	0.722846

hh_inc_cat.C	-0.47512	0.41134	-1.155	0.248067
hh_inc_cat^4	-0.25369	0.33925	-0.748	0.454579
hh_inc_cat^5	**0.51817**	**0.29866**	**1.735**	**0.082739**

PTR: A total of around 50 models were constructed, of which the final model selected was a GAM with six variables, viz. age, grazing time, gender, community, household income category, attitude towards tiger (Table 6.10). The model explains 27.6% deviance. All the six variables in the model have statistically significant relationships with livestock loss (Table 6.11). Among time of grazing categories, everything else being equal, people who graze their livestock inside the reserve forest in winter and summer, during day time, and in monsoon, during both day and night, are more likely to face livestock loss as compared to those who do not graze their livestock inside reserve forest (liv_graz_time0) or graze all season but only during the day never at night (liv_graz_time3), or graze only during winter and monsoon but again at daytime never at night (liv_graz_time14). Again, indicating that it is grazing at night that makes livestock vulnerable to depredation by tiger (Table 6.11). Among communities, Yadavs were more likely to face loss as compared to other communities, especially other livestock holding OBC communities (Caste_commun_simp_code3) like Pal, Ahirwal, Patel, and Kushwaha (Table 6.11). If the reference category is changed to Gonds (Caste_commun_simp_code1), then it becomes clear that other livestock holding communities (Caste_commun_simp_code3) are more likely to face losses than Gonds (Caste_commun_simp_code1). Therefore, OBCs are more likely to face livestock loss than other castes (ST, SC, General), because they have more livestock holdings, and among OBCs, it is the Yadavs that are most likely to face livestock loss.

Among income sources or livelihood strategies, households majorly dependent on both agriculture and livestock husbandry are more likely to face livestock loss than households majorly dependent on agriculture, NTFP, and labour (income_cat_merged33), and, households majorly dependent on NTFP and labour (income_cat_merged39). Thus, households dependent on livestock husbandry as a major source of income, are more likely to face loss as compared to those that are majorly dependent on agriculture, manual labour, or selling NTFP. As for the perception that a livestock loss was due to tiger, among gender, males are more likely to perceive livestock loss due to tiger (SexM) as compared to females and, respondents that have expressed positive opinions towards tiger are less likely to perceive livestock loss due to tiger as compared to respondents that have not clearly stated their opinion about tiger, by saying that they 'don't know' (Att_Tigr_recodedDK) (Table 6.11).

Table 6. 10: GAM and Random Forest top models predicting livestock loss by tiger in PTR, compared across different statistical measures

Model covariates	r-sq	cvAUC (GAM)	cvAccuracy (GAM)	cverror (GAM)	AUC (RF)	OOB error (RF)
Age + Liv_graz_time_cat_recoded + Sex + Caste_commun_simp_code + income_cat_merged + Att_Tigr_recoded	**0.252**	**0.757**	**0.703**	**0.290**	**0.754**	**0.296**
Cost_fodderfromforest_peryear_allliv + FM + Tot_inc_for_new + Sex + resource_use +	0.224	0.742	0.720	0.280	0.757	0.307

income_cat_merged + Att_Tigr_recoded						
FM + LIV_GRAZ_new_cat_simp + Sex + Caste_commun_simp_code + D_FP_cat_new + income_cat_merged	0.22 3	0.736	0.693	0.307	75.3 90	0.30 5
Liv_graz_time_cat_recoded + Sex + Caste_commun_simp_code + income_cat_merged + Att_Tigr_recoded	0.22 7	0.756	0.687	0.310	0.74 7	0.29 6
Sex + graze_forest + Caste_commun_simp_code + Att_Tigr_recoded + NTFP_depend	0.18 7	0.752	0.700	0.299	0.74 6	0.33 4

Note: The model which is highlighted was selected

Table 6. 11: Parametric coefficients of selected GAM model predicting livestock loss by tiger in Panna Tiger Reserve

Parameter	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	0.916	0.877	1.045	0.296
liv_graz_time0	**-2.388**	**0.571**	**-4.179**	**0.000**
liv_graz_time3	**-1.240**	**0.550**	**-2.254**	**0.024**
liv_graz_time14	**-1.411**	**0.731**	**-1.930**	**0.054**
SexM	**1.433**	**0.411**	**3.484**	**0.000**
Caste_commun_simp_code1	-0.524	0.533	-0.983	0.326
Caste_commun_simp_code3	**-1.256**	**0.507**	**-2.475**	**0.013**
Caste_commun_simp_code4	**-1.103**	**0.625**	**-1.764**	**0.078**
Caste_commun_simp_code5	**-1.769**	**0.975**	**-1.815**	**0.069**
income_cat_merged3	-0.336	0.694	-0.484	0.628
income_cat_merged16	-0.567	0.688	-0.824	0.410
income_cat_merged17	**-1.104**	**0.647**	**-1.706**	**0.088**

income_cat_merged23	-38.720	17940000.000	0.000	1.000
income_cat_merged33	**-1.448**	**0.720**	**-2.012**	**0.044**
income_cat_merged35	0.649	0.819	0.793	0.428
income_cat_merged39	**-2.579**	**1.250**	**-2.063**	**0.039**
income_cat_merged48	-0.354	0.886	-0.400	0.689
income_cat_merged51	-0.068	0.720	-0.094	0.925
income_cat_merged60	-0.575	0.674	-0.853	0.393
income_cat_merged61	**-1.101**	**0.602**	**-1.829**	**0.067**
Att_Tigr_recodedb	0.365	0.384	0.952	0.341
Att_Tigr_recodedc	0.147	0.525	0.279	0.780
Att_Tigr_recodedDK	**1.841**	**0.847**	**2.174**	**0.030**

6.4. Discussion

HTI was very high in case of both Sariska and Panna Tiger Reserves, with people venturing deep into tiger-occupied habitat for extracting different kinds of resources from fuelwood to NTFPs, and so did their livestock, often unaccompanied.

As for the specific circumstances which were associated with the HTI resulting into HTC, the spatio-temporal pattern of livestock loss reported by people revealed that most of the depredation events were taking place inside the reserve forest in case of both Sariska and Panna. Because, tigers rarely venture outside to depredate livestock, most tiger attacks on livestock occur inside the forest (Malviya & Ramesh, 2015). The season in which the greatest number of depredation events occurred was winter closely followed by monsoon in case of STR. In case of PTR, there was no seasonality in livestock loss, with almost equal number of incidents reported in winter, summer and monsoon. Although most people were not aware of the exact time of incident, those who were, reported most of the depredation events to have occurred at night, in case of STR, while in case of PTR, most of the depredation events reportedly occurred during day time. Tiger has been reported to depredate livestock at night and during winter, around other tiger reserves as well (Borah et al., 2018; Malviya & Ramesh, 2015).

As for the livestock species most vulnerable to depredation by tiger, in STR, domestic buffalo was the most common livestock lost to tiger, while in case of PTR it was domestic cow. And since buffaloes are usually much more expensive than cows, local communities in Sariska are facing higher monetary loss, as compared to Panna.

Socio-economic drivers of HTC

The generalized additive modelling revealed that certain socio-economic factors explaining livestock loss due to tiger were common across the two populations viz. time of grazing in predator occupied habitat and community/caste. Additionally, in case of Sariska the household income is also associated with their odds of losing livestock. While in case of PTR, the livelihood strategy of the households, was associated with their odds of losing livestock. In PTR, it was also found that males were more likely to perceive loss due to tiger and those who had positive attitude as compared to those who were unsure about their opinion towards tiger, were less likely to perceive loss due to tiger.

In both Sariska and Panna, majority of the households leave their cattle unattended to graze at night inside the forest, during monsoon and some months into winter. Time of grazing and inadequate protection to livestock during herding has been found to influence the risk of livestock predation by tiger and other large carnivores (Behmanesh et al., 2019; Kolowski & Holekamp, 2006; Ogada et al. 2003; Tumenta et al., 2013; Wang & Macdonald, 2006). Which could be related to the activity patterns of the carnivores. Tigers have been varyingly defined as crepuscular and nocturnal in some areas (Karanth & Sunquist, 2000; Steinmetz et al., 2013; Yang et al., 2018) to diurnal (Allen et al., 2021; O'Brien et al., 2003; Kawanishi & Sunquist, 2004) in others. They are known to shift their activity pattern to avoid humans during the day (Athreya et al., 2014; Li et al., 2019). Which has also been observed in Sariska, where activity of tigers has been found to be mostly restricted from dusk to dawn, with a minor peak at dusk from 6:00-8:00 pm and a major peak post-midnight to 3:00 am (Mondal et al., 2012). Which makes it clear why livestock are more vulnerable to predation by tigers when grazing unaccompanied at night. Kolipaka et al. (2017) also found that easy availability of livestock due to poor husbandry practices is leading to livestock predation by tigers in the buffer area of PTR.

In case of Panna, even though the majority of households own livestock, it was found that households that were dependent on livestock as the major livelihood strategy, were more likely to lose their livestock to tiger. And it is because of their dependence on livestock husbandry that some communities are more vulnerable to losses due to carnivores (Hemson et al., 2009; Malviya & Ramesh, 2015; Okello et al., 2014; Tumenta et al., 2013). Which has also been observed in case of both these reserves, where livestock husbandry-dependent communities like Gujjars and Yadavs are more vulnerable to face loss due to tigers. Gujjars are a pastoral community and form the majority of population in the villages inside the CTH of Sariska. They have large livestock holdings which are almost completely dependent upon forest for fodder, therefore their likelihood of losing livestock to tiger is more than other communities like Meenas that are agro-pastoral. In case of Panna, although Yadavs are not pastoral but agro-pastoral, however, as compared to other communities in and around PTR, they have large livestock holding and are again highly dependent on reserve forest for providing fodder.

Studies have linked higher resource dependence of people and abundance of livestock with higher livestock predation risk by tiger (Ramesh et al., 2020). In case of Sariska and Panna, both are true, not only are people highly dependent on reserve forests, but these reserves also have very high densities of livestock, especially, Sariska. Therefore, what is of importance is to understand why there is such high dependence of local communities on these reserves, especially for grazing livestock. Both the reserves have dry-semi arid climates, facing severe and frequent droughts (Gupta et al. 2014; Rodgers & Panwar, 1988). This makes agriculture an unreliable source of livelihood, in such case, it has been found that rural households rely on livestock to shield them from economic hardships, by providing ready cash in form of selling goats or a subsidiary source of income in form of selling cow/buffalo and their milk (Kumar et al., 2010; Mahapatra, 2012; Toulmin, 1986). To sustain these economics, in both our study areas, majority of the households depend upon the reserve forest for providing free fodder, because, in absence of support from forest resources, large livestock holding would incur huge costs. If we look at the economics of HTI in these reserves, the profit due to dependence on forest far outweighs the losses faced by these communities in form of livestock depredation. And the economics of coexistence are balanced by grazing rights provided to forest-dwelling communities (Banerjee et al., 2013). Thus, dependence on reserve forests for grazing is both problem and solution for HTC. However, what needs to change is the herding practices. Better herding practices like herding during the day and accompanying the livestock when grazing, can reduce livestock loss to carnivores (Behmanesh et al., 2019; Ogada et al., 2003).

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Chapter 7. Negative effects of human-tiger interaction on tiger populations

7.1. Background

Retaliatory killing is driving large carnivore populations to extinction in many countries (Hazzah et al., 2009; Inskip & Zimmermann, 2009). However, killing is not the only negative impact that HTI may have on tigers, it also results in reduced welfare of the animals by impacting their habitat (fragmentation and degradation), prey (directly through hunting and indirectly through degradation of habitat and competition from livestock) and even their population growth.

The success of reintroduction programs is generally measured in terms of settling behaviour, fecundity, and survivorship of the introduced animals and that of F1 (first generation) offspring (Weeks et al., 2011). Since the beginning of the reintroduction program in PTR, the reintroduced tigers bred successfully and experienced rapid population growth (to >40 individuals in nine years) whereas no successful breeding was recorded in STR for the first four years after reintroduction and subsequent breeding contributed to only marginal population growth (to 15 individuals in ten years). This poor reproductive potential in the reintroduced tiger population of Sariska could be a direct impact of HTI because as established in the earlier chapters, the reserve has high anthropogenic disturbance and high overlap of human and tiger use of the area. Studies have shown that high amount of anthropogenic disturbance results in physiological stress in animals (Creel et al., 2013; Creel et al., 2002; Ellenberg et al., 2006; Janin et al., 2011, Knapp et al., 2013; Van Meter et al., 2009). Certain species that are semelparous or individuals that have very few breeding opportunities are able to reproduce even under stressful conditions (Wingfield et al., 1995; Wingfield & Sapolsky, 2003). In contrast, an iteroparous species (such as tiger) which has a comparatively longer life span and would get multiple opportunities to reproduce, will make decisions related to parental investment cautiously and might choose its own survival over that of offspring, resulting in termination of pregnancy or litter abandonment (Frid & Dill, 2002).

Large mammals are known to adapt well to environmental stochasticities (Whitman et al., 2007). However, only some carnivores like wolves have evolved to develop such behavioural plasticity and reproduction capabilities that make it possible for them to survive in close proximity to human beings. Species such as bears and tigers that are not proliferous breeders and have specialized requirements related to habitat quantity and quality are susceptible to threats posed by anthropogenic pressures (Weaver et al., 1996). Encounters with human, and anthropogenic disturbance leads to behavioural responses like abandoning feeding habitats, nest and offspring in wildlife (Klein, 1993) and physiological responses in form of poor immunity, low reproductive potential, and stunted growth. Therefore, anthropogenic disturbance may lead to both behavioural and physiological disruptions in tigers. I have thus examined both the direct (mortality) and indirect effects (reduced reproductive potential) that HTI has on the population growth of tigers in these reserves.

Another effect that HTC can have on tiger populations is by reducing support for tigers and their conservation, even leading to retaliatory killing (Tilson & Nyhus, 1998). However, killing a large carnivore is not always retaliatory in nature but driven by multiple psychosocial factors (Bruskotter & Wilson 2014; Inskip et al., 2014; Treves & Bruskotter, 2014). Sometimes it is not socio-economic status or the intensity of loss but the negative attitude stemming from general believes towards the carnivores that makes them vulnerable to killing by people (Carter et al., 2014; Inskip et al., 2014). Attitude is, thus, the most important predictor of acceptance of large carnivores like tigers, by local communities, with positive attitude translating to poor societal acceptance of tiger killing and vice versa (Inskip et al., 2014). Thus, I have also examined the attitude of people towards tigers, and the related factors, to understand not only how HTI affects the attitude of people but to throw light on the factors that may ensure the persistence of these tiger populations alongside the local communities, despite the negative HTI.

7.2. Methodology

7.1.1. Tiger mortality

Data on tiger mortality due to anthropogenic causes was obtained from forest department records, scanning through media, management reports, and research publications.

7.1.2. Physiological stress and stressors

Methodology on measuring FGM has been discussed in chapter 5 (biological determinants) the process of obtaining habitat and anthropogenic disturbance variables have been discussed in chapter 4 (ecological determinants). FGM concentrations obtained for both the reintroduced tiger populations were subjected to descriptive statistics. After checking for normality, FGM values were log-transformed and used as the dependent variable in linear mixed effect model (LMM) with tiger id as random effect and tiger reserve id and sex as fixed effects, to explore the effects of tiger reserve, sex, and individual tiger on FGM concentrations.

Differences between NDVI, NDWI, ungulate density, livestock density, DEM, slope, TRI, of the two reserves, were tested using independent samples t-test and their standard deviations using f (variance ratio) test. Means of canopy cover, prey, human, livestock, and vehicle encounter rates, and, cutting and lopping intensity rates, were also compared between the reserves, using the Mann Whitney U test (data were not normally distributed). All statistical tests and modelling were done in the statistical package for the social sciences (SPSS) versions15 and 23 (SPSS, 2006; IBM Corp., 2015). Statistical significance levels were set at $p < 0.05$ (Appendix 7.1).

On an average, daily movement of the tiger was 6.90 km/day for STR (no significant difference between sexes) (Bhattacharjee et al., 2015). Considering the daily movement as the radius, buffers were drawn around each scat location. Habitat and disturbance variables were extracted for each buffer from the rasters (created using interpolation tool, as discussed in chapter 4) using the zonal statistics as table 2 tool in ArcMap 10.5 (ESRI, 2016). Bivariate correlation was run and highly correlated variables were not used together in models.

LMM was constructed to explore the variables linked to log-transformed FGM levels in STR in SPSS (Duchateau et al., 1998; Henderson et al., 1959; IBM corp., 2015) with tiger id as a random effect to account for repeated measures of FGM for individual animals. LMM was also performed for PTR, but none of the variables showed significant effect on FGM levels, possibly due to inherently low stress in the population and low variance among the individuals. Therefore, analyses and interpretation were primarily focused on the STR population, which was experiencing poor reproductive growth. The transformed FGM values (dependent variable) had a normal distribution, and the residuals of all variables showed homoscedasticity and linear relationships. The maximum likelihood or full model (FML) was used for model reduction and restricted maximum likelihood (REML) for the final model to get more accurate estimates of random effect. The significance of explanatory variables (fixed effect) was tested using the Wald test. Canopy cover and its SD, prey, human and livestock encounter rates, vehicle encounter rate SD, cutting and lopping intensity rates, lopping SD, NDVI, NDWI, DEM, slope as well as, their SD (s), and, TRI, were entered in the model as fixed effects. Before using them in the model, multicollinearity among these variables was checked, only variables with variance inflation factor less than 10, were used together in a model. Stepwise backward model selection was based on partial p-values and model selection was based on AIC values.

7.1.3. Local communities' attitude towards tiger

To assess the attitude of people towards reintroduced tigers, data was collected from questionnaires as discussed in chapter 6. The semi-structured questionnaire was aimed at understanding demography, livelihood strategies and HH economics, resource dependencies, livestock loss due to tiger, compensation received, crop damage by herbivores, and peoples' attitude towards reintroduced tigers.

Respondents were asked about their opinion of reintroduced tigers. In case they could not comprehend the question, they were prompted whether they liked tigers or disliked them. Their answers were then dubbed as positive, negative, mixed, and neutral. ‘Negative’ opinion meant people stated that they ‘dislike tiger’ and/or made negative statements such as ‘tigers are a threat to their life and livelihood’. While ‘positive’ opinion meant people stated that they ‘like tigers’ and/or expressed positive views, such as ‘tigers are beautiful’ or ‘tigers should be present in the jungle’. Others who made such statements as ‘tiger are beautiful, but they also inflict harm’ were treated as ‘mixed’. People who expressed no opinion about the tiger, citing that they ‘did not know anything about tiger’ or ‘have never seen a tiger and never had to do anything with one’, were dubbed as ‘neutral’. And when people simply said ‘don’t know’, it was dubbed as ‘don’t know’. The interviews were conducted by the first author, thus maintaining consistency and avoiding observer bias. All the data were entered, coded, and summarized in MS-Excel. Percentages of attitude for each of the category was calculated. For all the explanatory variables descriptive statistics were calculated. Using box plot, outliers were identified and removed. Normality and linearity for all continuous variables was checked using the Shapiro-Wilk test and scatterplot.

To understand the factors that were shaping the attitude of people towards reintroduced tigers, at the inception, decision tree analysis was employed (Kohavi & Quinlan, 2002), to see how the variables were interacting and get an initial idea as to which variables might be important. Following this, multinomial logistic regression was employed to identify the factors associated with attitudes (Böhning, 1992). This was done for both PTR and STR. Since the attitudes might be different for the general populace, and for those who have faced direct losses due to the species, separate analyses were run for all the sampled HH and all the HFC, within both reserves. The explanatory variables tested were location of village (inside or outside core of the reserve) of the respondent, respondent's age, sex, education level, community to which they belonged, economic status (household income), livestock holding, livestock loss suffered due to tiger, last livestock species lost, and its age, compensation received, compensation satisfaction levels, value of fodder obtained from reserve forest, profit made from NTFP collection, and loss due to wild herbivores. Analysis was done in statistical package for the social sciences (SPSS) versions 23 (IBM Corp. 2015).

For decision tree analyses, CRT (Classification and Regression Tree) was selected as the growing method, and model validation was done using 10-fold cross-validation method (Borovicka et al., 2012). Stopping criteria were predefined, maximum tree depth was set at five and minimum number of cases for parent and child node in case of STR, were set as 50 and 25, respectively (IBM, 2018). For PTR, due to smaller sample size when analyzing all the cases, parent and child nodes were set as 30 and 15, respectively. And since conflict-only data set was even smaller, parent and child nodes were set as 18 and 9, respectively.

Multinomial logistic regression was then used to identify the factors that were shaping the attitudes of people towards reintroduced tigers, since, attitudes were recorded as multiple categorical variables, that is, positive, negative, mixed, and neutral (Park, 2013; Peng et al., 2002; Stoltzfus, 2011). Before employing multinomial logistic regression, its assumptions were checked, i.e., linearity of independent variables and log odds, and multicollinearity. The linearity assumption was checked with Box–Tidwell test. To check for multicollinearity, appropriate tests of association were run (for continuous vs continuous and continuous vs ordinal variables, Kendall's tau b; for categorical vs continuous variables, logistic regression; and for categorical vs categorical variables, Cramer's V). Based on the results of tests of association, highly correlated variables were not used together in a model (Appendix 7.2). For regression, positive category was assigned as the reference category. Stepwise backward model selection was based on partial p-values (Ruczinski, 2005) and final model selection was based on pseudo R^2 and discrimination ability (classification accuracy and AUC value of the ROC curve).

7.3. Results and discussion

7.3.1. Direct effect: Tiger mortality due to negative HTI

The first reintroduced tiger in STR, fell prey to HTC shortly after reintroduction, when it was poisoned by villagers, reportedly in response to livestock depredation (Sankar et al., 2013). Recently another male tiger ST11 was snared and one female tiger ST5 has gone missing and is suspected to be dead (Bhardwaj, 2018; Chandrabhal Singh v. Union of India & Ors, 2019; Mukherjee 2018). In Panna at least two tiger deaths were suspected to be due to poaching (Ghanekar, 2020; Noronha, 2020; Trivedi, 2017). However, several other tiger deaths dubbed as 'infighting' have also come under the scanner (Srivastava, 2020).

Even before the reintroduction, the Sariska debacle was also directly linked with HWC, wherein Bawarias (a nomadic hunting tribe) that were hired by villagers for protecting crops against raiding by wildlife, in turn, indulged in poaching of tiger and were given protection by the villagers (Dutt, 2004; Narain et al., 2005; Shekhawat, 2014). Cases have been reported wherein tigers were killed to retaliate cattle loss by local communities like Meenas and Gujjars and then these tiger parts were traded to these nomadic tribes which were supplied to smugglers like Sansar Chand (Sansar Chand v. State of Rajasthan, 2010; Shankar, 2007). Sariska has a history of hunting both by royals and commoners, it was legal here till 1955 i.e. before it was declared a sanctuary. Prior to independence it was a hunting reserve of Alwar princely state, and also home to several nomadic hunting tribes like Bawarias, that occasionally did subsistence hunting. Panna also has a history of hunting. When the reserve was part of Panna Kingdom, royalty used to indulge in hunting tigers and other animals. Nomadic hunting tribes like Pardhis and Bawarias were identified as the primary reason for the local extinction of tigers in Panna (Srivastava, 2010). Even now, despite stringent protection, occasional poaching of wild animals, especially herbivores, by forest-dwelling tribes and some influential people, is still reported in both Sariska and Panna (Bhardwaj, 2018; Murthy, 2018).

7.3.2. Indirect effect:

Effects on habitat and prey: Several studies have suggested that high anthropogenic pressure has resulted in degradation and fragmentation of tiger habitats in both Sariska and Panna (Chawdhry, 1996; Dular, 2015; Jain et al., 2016; Jain & Sajjad, 2016; Kumar & Shahabuddin, 2005; Parveen & Illyas, 2021; Tiwari & Sharma, 2018; Yadav & Gupta, 2006, 2007). Our results also suggested high anthropogenic pressure, especially, in Sariska (as discussed in chapters 2, 4, and 6). FRAGSTATS results indicate that habitat fragmentation was high in both Panna and Sariska (as discussed in chapter 4). Thus, tiger habitats are being degraded and fragmented in these reserves due to anthropogenic activities. Moreover, this high overlap of habitat uses by tiger and human, resulting in degradation and fragmentation of habitat, leave very few inviolate spaces for tiger, thus, reducing the chances of successful breeding which affects the population growth of these animals (Chundawat et al., 1999; Harihar et al., 2020). High disturbance and competition from livestock have also been observed to negatively affect the prey population of tigers in these reserves (Mathai, 1999). High anthropogenic disturbance in both Sariska and Panna has resulted in alteration of vegetation structure and proliferation of weeds like *Cassia tora* and *Lantana camera* which threaten the regeneration of native species (Gupta & Yadav, 2007; Kumar & Shahabuddin, 2005; Parveen & Illyas, 2021; Yadav & Gupta, 2006, 2007), directly affecting the forage availability to tiger prey species. Moreover, domestic livestock compete with wild herbivores for forage which results in alteration in habitat use and foraging behaviour of wild herbivores (Bhattacharya et al., 2012; Syed & Khan, 2017). In certain areas, tiger prey populations have been suppressed by livestock mediated resource limitations (Madhusudan, 2004). Therefore, competition from livestock can have serious ramifications for the survival of the prey species, which could directly affect the survival of tigers. Detailed studies in this regard should be carried out in both the reserves.

Effect on behaviour and physiology: According to Sapolsky et al. (2000), "Reproduction is a highly costly anabolic state, particularly in a female, and should logically be deferred during a stressor". Many studies have suggested that anthropogenic disturbance leads to low breeding success in wild animals (Beale & Monaghan, 2004; Ellenberg et al., 2006; Giese, 1996). Studies suggest that animals perceive humans as predators and as a result are stressed by their presence (Beale &

Monaghan, 2004; Frid & Dill, 2002). The energy tradeoff strategy the animal applies to predation risk is also applied in case of non-lethal human activities (Frid & Dill, 2002; Stankowich, 2008).

Individuals exhibit both proactive and reactive responses to cope with stress, mediated by neuroendocrine and behavioural characteristics (Koolhas et al., 1999). Traditionally, several behavioural responses have been monitored to study the impact of anthropogenic disturbance on wild animals, for example, abandoning of nest by birds and den abandonment by bears and wolves (Anderson, 1988, Linnell et al., 2000; Sazatornil et al., 2016), altered space use and activity pattern (Constantine et al., 2004; Dwyer, 2010; Kuck et al., 1985; Sastre et al., 2009), flight response on approach by foot or vehicle (Frid & Dill, 2002; Klein, 1993; Stankowich, 2008), reduced or elevated vocalization and social behaviour (Torre et al., 2000; Topp-jørgensen et al., 2008), disrupted or altered feeding behaviour (Beckmann & Berger, 2003; Klein, 1993; Williams et al., 2006), vigilance behaviour (Pangle & Holekamp, 2010), altered movement patterns and habitat selection to avoid human disturbance (Beauchesne, 2012; Stewart, 2011). A few have applied both behavioural cues and stress hormones, such as flight initiation distance and level of corticosterones to describe female eider reponses under stress (Seltmann et al., 2012) and allogrooming and faecal glucocorticoid levels in Barbary macaque (Maréchal et al., 2011).

Behaviour can be an unreliable measure of impact of human disturbance; it only provides evidence for immediate effects (Beale, 2007). The animal may not always exhibit a fight or flight response but that does not mean that it does not perceive human presence as a threat (Beale, 2007). The animal makes the decision based on its options and experiences (Bejder et al., 2009). If it perceives the threat often, then it is not possible for the animal to flee every time, hence, by experience, it stays, even though wary of the disturbance (Beale, 2007). Also, it can only abandon foraging in the area and exhibit flight response, if it has the option to forage somewhere else (Bejder et al., 2009). In case the animal does not have another suitable alternate habitat, it may continue to use the same area even when it does perceive human presence as a threat. Therefore, the long-term impact on the health of the animal resulting from psychological stress caused by staying under prolonged stressful conditions or nutritional stress caused by lost feeding opportunities in case it exhibits flight response, cannot be enumerated by behavioural studies (Beale, 2007). In contrast, glucocorticoids (GCs) are direct measures of stress in animal populations, irrespective of whether the animals exhibit outward responses or not. Stress hormone analysis can thus better establish the effect of anthropogenic disturbance in the tiger populations under study.

Although GCs or as they are called ‘stress hormones’ are secreted in the body to help prepare an individual against external factors, channelling the body’s energy to effectively cope with immediate stressful stimuli (Wingfield & Kitaysky, 2002). However, in case the stressful state continues for a prolonged period of time, excess GCs are released, leading to chronic stress (McEwen, 2007). Excess GCs often negatively affect reproduction. The various negative consequences of stress on the reproductive capacity of animals include delay in timing of reproduction, low release of reproductive hormones, lower fertility, higher inter-birth intervals, and abortions, and impairment of erectile function in males (Sapolsky et al., 2000; Sapolsky, 2004; Schoech et al., 2009; Whirledge & Cidlowski, 2013).

In case of the reintroduced population under study, the mean FGM concentration of tigers in STR (mean ± SD = 50.14 ± 42.84 ng/g; n=103) was significantly higher than in PTR (20.29 ± 16.34 ng/g; n=144) (Table 7.1). The results of various anthropogenic disturbance indices as assessed in this study revealed that overall anthropogenic disturbance was significantly higher in Sariska as compared to Panna (Appendix 7.1). Sariska had higher lopping, weed, and livestock presence than PTR. In STR, the intensity of lopping was higher than cutting, reflecting that people are using the reserve forest for their subsistence, exploiting it for fuelwood and fodder. Human encounter rate was also higher in STR, but the difference was not statistically significant.

Table 7. 1: Results of linear mixed-effect model to explain FGM concentrations' association with tiger reserve and sex of the sampled individuals (Dependent variable log FGM)

Parameter	Estimate	Std. Error	df	t	p value	95% Confidence Interval	
						Lower Bound	Upper Bound
Intercept	1.22	0.10	10.24	12.67	<0.001	1.00	1.43
Tiger Reserve ID	0.28	0.09	10.03	3.25	0.01	0.09	0.47
[SEX=F]	-0.05	0.11	9.81	-0.50	0.63	-0.29	0.18
[SEX=M]	-0.02	0.11	10.77	-0.18	0.86	-0.26	0.22
[TR_ID] * [SEX]	0.16	0.11	9.54	1.55	0.15	-0.07	0.40

High FGM concentrations in STR tiger population were positively linked to the presence of humans; high canopy cover, low water availability, and to homogeneous elevation, and low TRI values, within their habitat (Table 7.2). Therefore, at a fine scale, it seems that the simple act of a villager going inside the forest areas frequented by tigers, is leading to increased physiological stress in tigers of STR. Stress is reduced where tigers are occupying areas with homogenous distribution of water and the opportunity provided by topographic features to avoid detection. In PTR, stressful encounters for tigers are few and far apart, with the opportunity to navigate through escarpments, resulting in low average FGM concentrations of the population and high reproductive output.

Table 7. 2: Results of linear mixed-effect model to explain FGM concentrations in tiger population of Sariska Tiger Reserve (dependent variable log FGM)

Parameter	Estimate	Std. Error	df	t	p value	95% Confidence Interval	
						Lower Bound	Upper Bound
Intercept	18.42	6.23	88.58	2.96	<0.001	6.04	30.81
Human encounter rate	1.48	0.62	68.11	2.40	0.02	0.25	2.72
Canopy cover	4.96	1.71	42.39	2.89	0.01	1.50	8.42
NDWI SD	1.45	0.67	94.62	2.17	0.03	0.12	2.78
DEM SD	-4.21	1.71	84.87	-2.47	0.02	-7.60	-0.82
TRI	-2.02	1.37	94.93	-1.47	0.15	-4.74	0.71

Therefore, in case of Sariska, since human and their livestock and the prey species of tiger, occupy the same habitat, the tigers inevitably encounter human beings and cannot avoid stressful situations. Studies have also shown that animals that are frequently disturbed spend less time feeding and thus have low energy intake (Williams et al., 2006). Therefore, even though there is enough prey, nutritional stress in tigers can occur as a result of disturbance at kill sites because of which the animal might abandon the kill. It has been observed in Amur tigers that tigers spend more time at the kill site and consumes more at undisturbed sites (Kerley et al., 2002). In contrast at disturbed sites only small portions of the kill is eaten and kill abandoning is common (Kerley et al., 2002). Similar instances have occurred in Sariska where the two new reintroduced tigresses ST-9 and ST-10 during the exploration period when roaming in human-dominated habitats were frequently abandoning their kill and not spending much time at a kill site. In Panna, when T3 was moving out of PTR for long distance, made several kills and consumed very little near human habitations. Therefore, the encounter of tigers with people are not only psychologically stressful but can also lead to nutritional stress in tigers residing close to human settlements.

Thus, it can be inferred that tigers experience physiological stress in case of frequent encounters with human beings, which is exacerbated in a habitat that does not provide sustainable space to negotiate or avoid these disturbance elements, which, eventually, seems to affect their reproductive output. In comparison, if there is low human presence within their habitat, coupled with complex terrain and optimum water availability, tigers experience low stress and thereby attain healthy population growth.

7.3.3. Attitude of local communities towards reintroduced tiger

HTC may also lead to more negative attitudes towards tiger, thus, directly affecting their chances of co-existing with local communities. Hence HTC mediated attitude becomes an important indicator of tiger persistence in such landscapes. As recently observed in Satkosia Tiger Reserve in India, failure to ensure support of local communities in areas where tigers are being translocated, jeopardizes the entire reintroduction program (Vasudeva et al., 2021). Because local communities are the primary bearers of the cost of conservation in form of not only livestock loss due to conflict but also livelihood loss due to suspension of their traditional forest rights (Green et al., 2018). Therefore, not only to ensure that no tigers are lost due to retaliatory killing but also to garner local support for conservation, it is crucial to understand the attitude of local communities towards these large carnivores and the factors that shape these attitudes.

Tolerance towards conflict-causing wildlife is one of the most important factors that determine not only the success of their conservation programme (Naughton-Treves et al., 2003) but also their continued survival in some landscapes (Goldman et al., 2013). Tolerance is often defined as acceptance of loss caused by a wild species (Kansky et al., 2014). Economic cost of the damage is an important factor that determines the tolerance of people towards the loss-causing wildlife (Rocha & Fortes, 2015). However, experiencing first-hand loss by wildlife is not the only reason for negative attitudes towards them; people who have never experienced loss also express negative attitudes towards wildlife (Marchini & MacDonald, 2018). Tolerance (or the lack of it) towards a wildlife, is therefore not guided by loss alone (Kansky et al., 2014; Zimmermann et al., 2005) but a number of complex socio-economic and psycho-cultural factors, which calls for a deeper understanding of the issue.

Studies have related attitude and the resulting tolerance of people towards large carnivores to a myriad of reasons. The reasons vary from socio-economic factors like age, gender, education level, occupation, community, household wealth, dependence on livestock for livelihood, number of livestock owned, livestock loss due to depredation/magnitude of loss, change in traditional practices, severity of effect that loss has on livelihood (Consorte-McCrea et al., 2017; Gebresenbet et al., 2018; Kansky et al., 2014, 2016; Marchini & Macdonald, 2012; Margulies & Karanth, 2018; Naughton-Treves et al. 2003; Zimmermann et al., 2005) to psychosocial factors like traditional or religious beliefs, inherent/cultural value, social trust and norms, fear, risk perception, past experiences, and hazard acceptance/acceptance capacity (Banerjee et al., 2013; Bruskotter & Wilson, 2014; Browne-Nuñez et al., 2015; Carter et al., 2014; Doubleday, 2020; Gebresenbet et al., 2018; Marchini & Macdonald, 2012; Struebig et al., 2018; Zimmermann et al., 2005). Protection status of carnivores, protected area management strategies, relationship or trust towards forest management/authorities or government agencies, and compensation to mitigate loss or other monetary incentives (insurance, conservation payment, subsidies, etc.), also influences people's opinions about carnivores (Banerjee et al., 2013; Browne-Nuñez et al., 2015; Karlsson & Sjöström, 2011; Margulies & Karanth, 2018; Mishra et al., 2003; Naughton-Treves et al., 2003; Struebig et al., 2018). People are more accepting of problems caused by wild animals that they appreciate (Kaltenborn et al., 2006). Thus, positive or negative opinions of people eventually dictate how tolerant they would be towards loss-causing wildlife, making it important to understand the attitude of people towards these large carnivores.

In case of the study population, Among the 361 respondents that were interviewed in STR, 173 (47.92%) had positive attitudes towards tiger, 126 (34.90%) had negative attitudes, while four respondents were ambivalent; 46 (12.74%) had neutral responses while 6 (1.66%) said they ‘don’t know’. Irrespective of whether HH were facing loss or not, respondents were more positive towards tiger ($\chi2=1.326$; $p=0.249$) (Table 7.3). The attitudes of women respondents were more likely to be either neutral or negative as compared to men (Table 7.4). Total 17 communities were sampled, of which nine communities had more respondents with positive attitudes, as compared to negative, and seven communities had more respondents with negative attitudes, as compared to positive. Notably, the dominant community Gujjars, had more respondents with positive attitudes towards tiger, as compared to negative. Among the respondents, only 40 were able to articulate the reasons for why they liked or disliked tigers. Respondents who expressed positive opinions of tiger (n=13) mostly (38.46%) believed that ‘tigers are king/pride of jungle’. The reason stated by people who had negative attitudes (n=27) were, most frequently (44.44%), fear for their life and livestock, and negative sentiments towards forest department (29.63%).

Among the 330 respondents that were interviewed in PTR, 81 (24.55%) had positive attitudes towards tiger, 172 (52.12%) had negative attitudes, and 7 (2.12%) had mixed; 57 (17.27%) had neutral responses while 13 (3.93%) said they ‘don’t know’. Irrespective of whether HH were facing loss or not, respondents were more negative towards tiger ($\chi2=0.202$; $p=0.653$) (Table 7.3). Women gave more neutral responses as compared to men, while men gave more positive responses as compared to women (Table 7.4). Total 31 communities were sampled, of which eight communities had more respondents with positive attitudes as compared to negative and 12 communities had more respondents with negative attitudes, as compared to positive; rest were either neutral, mixed, or positive-negative in equal proportion. Notably, the two dominant communities Gonds and Yadavs had more respondents with negative attitudes towards tiger, as compared to positive. Of all the sampled respondents, only 105 were able to articulate specific reasons for why they liked or disliked tigers. The reason stated by people who had negative attitudes (n=80) were, most frequently (35%), fear for their life and livestock, closely followed by loss (28.75 %) caused by tiger. Interestingly, some respondents (15%) had negative sentiments towards forest department which was spilling over to tigers. At the same time, some respondents (n=6) expressed positive opinions of tiger because they were employed by the forest department.

Table 7. 3: Attitude of households that have faced livestock loss due to tiger, towards tiger, in PTR and STR

Loss suffered	Attitude			
	PTR		STR	
	Positive (%)	Negative (%)	Positive (%)	Negative (%)
Yes	23	54	44	39
No	25	51	50	33

Table 7. 4: Gender-wise attitude of local communities towards tigers in PTR and STR

Attitude	Gender			
	PTR		STR	
	Male (%) (N=227)	Female (%) (N=103)	Male (%) (N=241)	Female (%) (N=120)
Like/positive	28.19	16.50	60.17	23.33
Dislike/negative	52.86	50.49	26.97	50.83
Can't tell/don't have any opinion/neutral	13.22	26.21	8.30	21.67
Don't know	2.64	6.80	1.24	2.50

Our results show that the attitude of respondents varied significantly between the two study sites, viz. STR and PTR, with significant difference between the number of respondents having negative attitude towards tiger, as compared to positive, in STR and PTR ($\chi 2=36.846$; $p<0.001$).

Thus, in case of reintroduced tigers of India, overall, more respondents were found to have negative attitudes as compared to positive, but only marginally so. As for the two sites, in STR, more respondents expressed positive opinions towards tiger, as compared to negative. An earlier study done in Sariska also found that people were tolerant towards wildlife including tiger, because of the benefits that they get from forest and their social and religious beliefs (Sekhar, 1998). In PTR, the trend was inverse, with more respondents expressing negative opinions towards tiger, as compared to positive. It is to be noted that an earlier study done in PTR by Kolipaka et al. (2015) found that people are tolerant of tigers in the area. It could be because as

Kolipaka et al. (2015) also observed, the tiger presence was limited in the buffer area (in 2014), and livestock kill by tigers were occurring in few pockets, affecting only a few pastoralists. However, the tiger movement has since increased, thus increasing the chances of people encountering tiger, which potentially increased the number of people that feel threatened by tigers.

In both PTR and STR, irrespective of whether the HH were facing loss or not, respondents had the same attitude towards tigers, indicating that in case of reintroduced tigers in India, direct loss is not the best explanatory variable when it comes to tolerance (Inskip et al., 2016; Kansky et al., 2016). Therefore, merely reducing livestock loss may not automatically bring about change in the attitude of the people. Social, cultural, and environmental factors are likely to play a bigger role in determining the attitude of people as compared to economic loss (Struebig et al., 2018). Thus, unravelling these factors will be crucial in managing conservation attitudes. 'Fear for life and livestock' and 'conflict with reserve management' were the most oft-stated reason by the respondents expressing negative opinions towards tiger. The statistical modelling (decision tree and multinomial regression) revealed the factors associated with attitude towards reintroduced tiger in both the reserves. Results are discussed in further detail in following paragraphs.

Factors associated with attitude of people towards reintroduced tigers

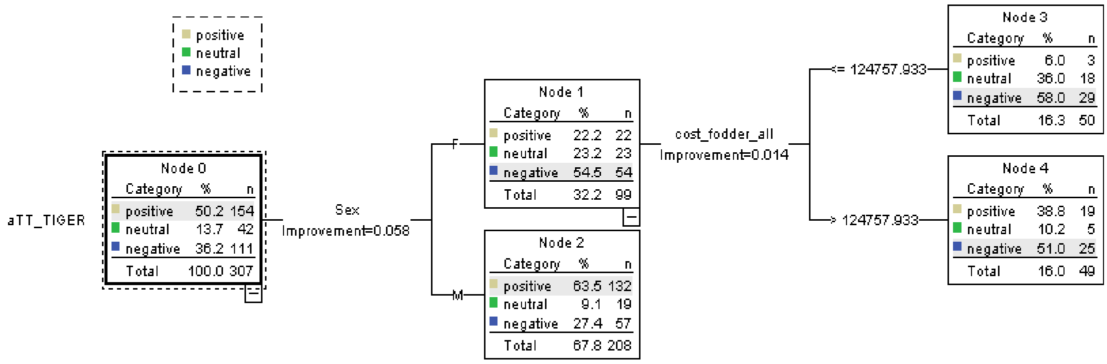

Figure 7. 1: Decision tree of attitude of local communities towards tigers in STR

Sariska Tiger Reserve: Decision tree analyses revealed that sex (gender) was the most important classifier, followed by cost (value) of fodder obtained from forest. Close examination of the splits reveal that female respondents were more negative (54.5%) than positive (22.2%) or neutral (23.2%) while male respondents were more positive (63.5%) than negative (27.4%) or neutral (9.1%). The next split reveals that females that are drawing more benefits from the reserve in form of higher cost of fodder obtained from forest, were more positive as compared to females that obtained less fodder from forest, even though females were more negative in general (Figure 7.1). Overall classification accuracy of the model was 60.6% (Risk=0.39).

While constructing multinomial logistic regression models the results of decision tree were considered and gender and value of fodder obtained from TR were kept as key explanatory variables. Results of logistic regression revealed that in STR, attitude towards tiger among local communities was influenced by apart from gender and education of the respondent and value of the fodder collected from forest (Appendix 7.4). Neutral opinion is influenced by education of the respondent, with odds of a more educated person expressing neutral opinion rather than positive being 0.86 times than less educated person (p=0.011). The odds of women expressing neutral opinion rather than positive are 5.07 times higher than those of men (p<0.001) (Appendix 7.3). The odds of respondents that collect more fodder from the reserve forest expressing neutral opinion rather than positive are 0.99 times than respondents that collect more fodder (p=0.010). For the logistic regression model of negative opinion versus positive, the odds for women to have negative opinion rather than positive are 4.93 times higher than men (p<0.001) (Appendix 7.3). The classification accuracy of the model was 60%. AUC of the ROC curve for the model was 0.69 (positive actual state as positive opinion).

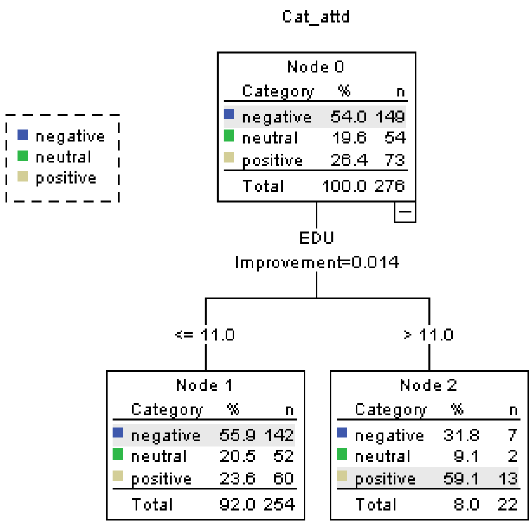

Figure 7. 2: Decision tree of attitude of local communities towards tigers in PTR

Panna Tiger Reserve: Decision tree analyses for PTR revealed that education was the most important classifier but due to the small dataset the tree did not split any further. Close examination of the classification reveals that people who have received education higher than high school were more positive (59.1%) while people who were less educated were more negative (55.9%) (Figure 7.2). Overall classification accuracy of the model was 56.2% (Risk=0.457).

While constructing multinomial logistic regression models the results of decision tree were considered and education was kept as a key explanatory variable. Logistic regression modelling revealed that in PTR, neutral opinion is influenced by the gender of the respondent, with odds of females expressing neutral opinions rather than positive is 3.19 times higher than those of males (p=0.005) (Appendix 7.4). For the logistic regression model of negative opinion versus positive, the odds for more educated persons to have negative opinion rather than positive are 0.92 times than that of a less educated person (p=0.029), meaning education is inversely related to negative opinion (Appendix 7.3). Classification accuracy of the model was 53.71%. AUC of the ROC curve for the model was 0.62 (positive actual state as negative opinion), which means the model has class separation capacity.

Factors associated with the attitude of households facing direct livestock loss due to tiger

Apart from the above discussed factors associated with general attitudes, there were certain factors that were explaining the attitude of HFC.

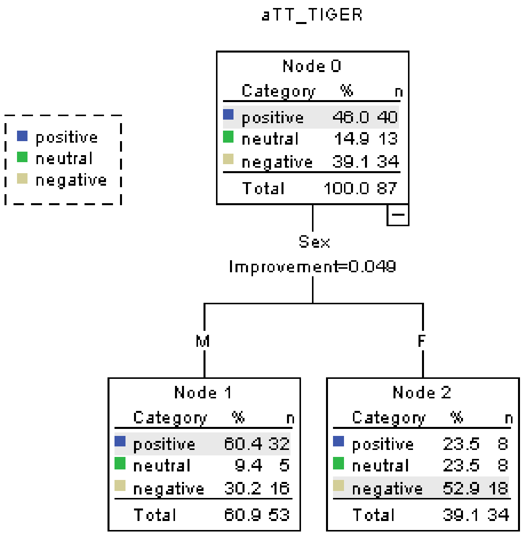

Figure 7. 3: Decision tree of the attitude of households facing conflict towards tigers in STR

Sariska Tiger Reserve: In the case of STR, for the respondents that have experienced direct loss due to tigers, decision tree analyses again revealed that sex (gender) was the most important classifier. Female respondents were more negative (52.9%) than positive (23.5%) or neutral (23.5%) while male respondents were more positive (60.4%) than negative (30.2%) or neutral (9.4%) (Figure 7.3). Overall classification accuracy of the model was 57.5% (Risk=0.471).

While constructing multinomial logistic regression models the results of decision tree were considered and gender was kept as a key explanatory variable. The results of logistic regression revealed that the factors explaining attitude towards tiger in HFC are value of fodder collected from reserve forest (respondents who obtained more benefit from forest were more likely to be positive), total livestock owned (respondents who owned more livestock were more likely to be negative), and community beliefs (Appendix 7.5). The classification accuracy of the model was 62.07%. The AUC of the ROC curve for the model was 0.61 (positive actual state as positive opinion).

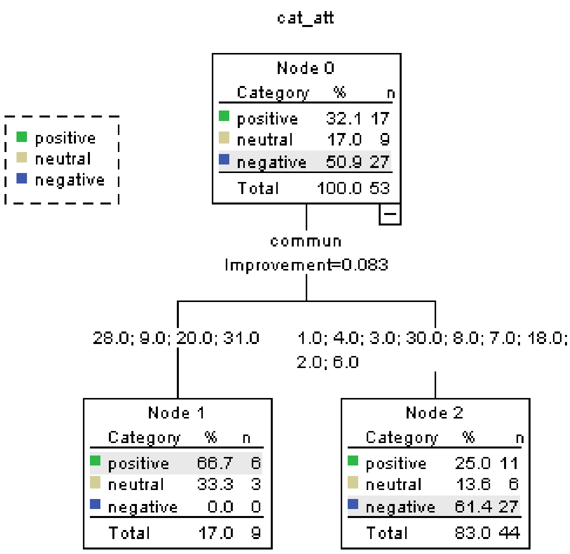

Figure 7. 4: Decision tree of attitude of households facing conflict towards tigers in PTR

Panna Tiger Reserve: In the case of PTR, for the respondents that have experienced direct loss due to tigers, decision tree analyses revealed that community was the most important classifier. Close examination of the classification reveals that respondents who were Brahman, Serare and Mehtar were more positive (66.7%) than negative (0%)

while all the other communities like Gonds, Yadavs, etc., were more negative (61.4%) than positive (25%) (Figure 7.4). Overall classification accuracy of the model was 62.3% (Risk=0.5).

Even though decision tree suggested that community was an important explanatory variable, it was not possible to use community as an explanatory variable in multinomial logistic regression model due to high SE associated (as a result of a large number of communities and small dataset).

The results of logistic regression revealed that the factors explaining attitude towards tiger in HFC are age of the respondent (older respondents were more negative), age of last livestock lost (respondents who had lost mature cattle were more likely to be negative as compared to those who had lost immature cattle), and compensation received (respondents who received compensation were more likely to be positive) (Appendix 7.6). The classification accuracy of the model was 72.46%. AUC of the ROC curve for the model was 0.54 (positive actual state as negative opinion).

In the following paragraphs the major factors as identified by our regression modelling (gender and education), as well as, major reasons stated by the respondents for negative/positive attitude, which were found to be common across the two reserves (fear and relationship with reserve management), are discussed in further detail, followed by site-specific factors. I have also attempted to explicate how these factors are likely intertwined.

Major factors

Gender: In both STR and PTR very few women expressed positive opinions towards tigers as compared to men, which resonates with earlier studies that not only does gender influences attitudes towards wildlife, women are more negative towards large carnivores as compared to men (Kaltenborn et al., 2006; Karanth et al., 2019; Marchini & Macdonald, 2018; Mir et al., 2015). A recent study done in Sariska also found that women had negative perceptions of tigers (Doubleday & Adams, 2020). It could be because men and women perceive risk differently (Gore & Kahler, 2012). It could be a construct of their different social roles, trust in authorities, and even how empowered they feel (Gore & Kahler, 2012; Ogra, 2008). Women bear disproportionate burden of conflict costs but are often not included in decision-making processes, much less in conservation-related discussions, and hence might more readily express negative opinions (Doubleday & Adams, 2020; Ogra, 2008).

Education: Women in rural India also have lesser opportunities to get formal education as compared to men, and thus are not exposed to the modern ideas of conservation. In both STR and PTR, more women were uneducated as compared to men. It is known that education plays a crucial role in shaping attitudes towards wildlife, educated people being more positive (Carter et al. 2014; Cavalcanti et al., 2010; Gebresenbet et al., 2018; Karanth et al., 2019). Education has been found to have bearing on individual's acceptance of carnivores and conservation programmes, more educated people being more proconservation (Hazzah, 2007; Jyrwa et al., 2020; Karlsson & Sjöström, 2011; Pinheiro et al., 2016). In PTR and STR also, it was found that more educated a person, more likely they were to express positive opinion of tigers.

Fear: The major reason for disliking tigers as given by respondents in our study, in both PTR and STR, was 'fear' for their life and livestock. Many studies have found that women are more negative or less tolerant than men towards 'fear'-inducing species like large carnivores or mega herbivores (Gadd, 2005). More so in forest dwelling communities, as in the case of STR and PTR, where women are the ones going to forest for forest produce collection or water and hence, are more vulnerable (Gadd, 2005; Ogra, 2008; Rubino & Doubleday, 2021). Thus, negative attitudes towards predators, especially in the case of women, often stem from fear of the species (Kaltenborn et al., 2006; Marchini & Macdonald, 2012). And a recent study done in Sariska, have shown that this fear towards tiger is augmented by their vulnerable position in the patriarchal Indian household (Doubleday & Adam, 2020; Doubleday, 2020).

Relationship with reserve management: Negative interactions of local communities with forest management that may have aggressive conservation strategies can also result in decline of tolerance for wildlife (Bond & Mkutu, 2018; Margulies & Karanth, 2018). In PTR, people expressed negative sentiments towards forest department, and because they termed tigers as 'their (forest department's) tigers', by extension of association, people did not like tigers, as well. It is because they felt, in the olden days, they would be compensated for the loss caused due to wildlife, by collecting profitable NTFPs, but now citing the protected status of these forests, they have been incapacitated to do so by the department. Although forest department supported eco-development committees have been active in these forests, providing people with gas connections and employment, most people are disengaged from these committees, not aware of their functioning and distrusting of the department. The distrust at both the place has been fuelled by inadequate relocation attempts (Shahabuddin et al., 2007). Traditional forest dwellers find it difficult to relocate outside of forest reserves and resent conservation programmes or forest department/government that ask them to relocate, and the resultant negative sentiment spills over to the very species that the programme seeks to conserve (Hazzah, 2007).

Site specific factors

Sariska Tiger Reserve:

Forest dependence and community beliefs: Sometimes communities have been found to be highly tolerant of a large carnivore, even in face of high loss, because of their inherent values and the financial capability to bear the losses (Zimmermann et al., 2005). Unlike PTR, people in STR do not sell NWFP, but by depending on forest for fodder, they make considerable savings. This dependence of people on fodder plays a critical role in shaping their opinions. It has been observed that forest dwellers that enjoy grazing rights inside PA are more likely to coexist with large carnivores (Banerjee et al., 2013). Similarly, in STR, local communities make huge profit from selling milk products, the economics of which are sustained by free fodder and fuelwood from reserve forest, therefore, people who were drawing more benefit from forest, were also more positive towards tiger. Moreover, in STR tigers are an important part of their lores and faith and people in general are very religious. Earlier studies have also found that tolerance for wildlife in Sariska is driven by the benefits they draw from reserve forest, as well as, their religious beliefs (Sekhar, 1998). In cultures across the world, tolerance towards carnivores is linked to their cultural and religious beliefs because of which they see some carnivores as beneficial (Baynes-Rock, 2013) or revere them (Banerjee et al., 2013) even on the face of HWC (Can & Macdonald, 2018). In several cases tolerance stemming from culture and beliefs has led to long term coexistence of wild animals like Ethiopian hyenas and Gir lions, with human beings (Banerjee et al., 2013; Baynes-Rock, 2003). As religion helps rural uneducated people rationalize risk (Inskip et al., 2016), thereby increasing the coping capacity of people towards loss causing wildlife (Gogoi, 2018).

Tourism: Some people in Sariska were also positive towards tigers, because they are involved in tourism activities as either vehicle owners, drivers or guides. Eco-tourism is advocated to counter the losses faced by communities due to wildlife, because it incentivizes them for living in close proximity to wildlife, hence reducing negative attitudes (Hemson et al., 2009). However, in STR, even though some were getting benefited by tiger safaris, benefits were largely limited to only two villages out of the 28 residing within the critical tiger habitat. As also highlighted by other studies, communities often perceive tourism to be profitable for 'government' and not them, because profits from tourism are shared by very few in the community (Hemson et al., 2009).

Panna Tiger Reserve

Age: Older people are more negative towards large carnivores, as compared to, younger people (Blekesaune & Rønningen, 2010; Cavalcanti et al., 2010; Kretser et al., 2009; Marchini & Macdonald, 2012; Zimmermann et al., 2005), with younger people being more pro conservation (Arjunan et al., 2006; Consorte-McCrea et al., 2017; Hazzah, 2007; Karlsson & Sjöström, 2011; Meena et al., 2020). The present study also found that, in PTR, for the households that were facing loss, older people were more likely to have negative opinions about tiger, as compared to, positive or neutral, than younger people.

Community: Beliefs of an individual about the right and wrong is shaped by the society they live in. It has been found that societal factors influence tolerance perception and eventually poaching of large carnivores more than individual sentiment of retaliation or threat to life (Treves & Bruskotter, 2014). So, the community to which a person belongs to, shapes their opinion towards loss causing wildlife (Kretser et al., 2009). Certain communities in Panna owing to their high resource dependency on the reserve forest, have also suffered higher losses due to tiger, hence, may harbour more negative sentiments towards tigers.

Age of last livestock lost: People who lost mature and more costly cattle, were more intolerant towards tiger as compared to people who lost immature and less costly cattle. It is because, high economic loss caused by wildlife makes people intolerant towards them (Rocha & Fortes, 2015).

Compensation received: In PTR, households that have faced loss and compensated for it were more positive towards tiger than households that have faced loss and not compensated. It has been observed that when local communities are benefitted by the presence of large carnivores either in the form of tourism benefits or compensation for loss, coupled with benefits from forest in form of free fodder (Banerjee et al., 2013; Hazzah, 2007; Naughton-Treves et al., 2003), people are more tolerant and in favour of conservation.

Eventually gaining an insight into these factors that determine the attitude of people towards these endangered species, better equip us to design participatory tools to mitigate conflicts and accomplish lasting conservation goals.

7.4. Summary

Global tiger populations continue to face challenges from various kinds of negative HTI, viz. poaching, habitat loss, prey depletion and anthropogenic disturbances (Dinerstein et al., 2007). Such interactions are stressful and sometimes fatal to both humans and tigers. In case of both Panna and Sariska not only was negative HTI responsible for the extinction of their natural tiger population but even the reintroduced and recovered tiger population in both the reserves continue to face the challenges of poaching and retaliatory killing. With attitudes towards tigers, especially in case of Panna being more negative than positive, how managers handle HTI may truly determine the success of these conservation programs. HTI is also indirectly contributing to poor population growth of tigers in case of Sariska, as indicated by the results of this study, which reveals that if there are frequent encounters of tiger with human i.e., high HTI, it may lead to chronic stress in tigers which may adversely affect their reproductive potential resulting into slow population growth.

Thus, to manage the negative effects of HTI on tiger population in these reserves not only the direct human-tiger interface should be reduced by managing resource use of the local communities but the attitudes of these local communities towards the tigers should also be improved. Since, gender and education were found to be important determinants of people’s attitude towards reintroduced tigers, encouraging education, especially that of rural women, should be aimed at, in order to secure support of local communities for tiger conservation.

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Chapter 8. Determinants of human-tiger conflict: Summary and application

8.1. Background

Species that frequently get into conflict with people are more prone to extinction (Woodroffe, 2001). Thus, conflict resolution has become a priority for conservation of endangered species like tiger. However, human-wildlife conflict poses the most complex challenge to achieving 'coexistence' (Gross et al., 2021). There are numerous apparent and hidden factors involved, therefore, when identifying drivers or determinants of conflict it becomes necessary to include all the possible variables. In absence of a holistic understanding of the conflict, any conclusions drawn would be biased and resultant management strategies, ineffectual.

8.2. Status of HTI in Sariska and Panna Tiger Reserves

8.2.1. STR: In Sariska, there are 26 villages inside the CTH. All these villages are highly dependent on the reserve forest. During this study it was found that 89.5% of sampled households were dependent upon reserve forest for fuelwood and fodder. Owing to the livelihood strategy of the dominant Gujjar community which is dependent on livestock husbandry, 97.5% of sampled households owned livestock and the average livestock holding is also very high (20.3±23.9). 86.9% of households that own livestock, graze them in the reserve forest. People venture on an average 2.6±1.1km to collect fuelwood and 3.6±1.2km to graze livestock, and livestock venture on an average 3.6±2.0km inside the reserve forest from their village, to graze unaccompanied. Thus, the entire CTH including the notified national park area is heavily exploited, with people and their livestock moving everywhere. At the same time all tigers in STR have home ranges (that are often overlapping in case of females) within the CTH, concentrating around the national park area (Bhardwaj, 2021). On an average home range centers of these tigers lie at a distance of 12.5 km from village settlements. This high HTI within the CTH was captured in camera traps, where out of the 36 tiger occupied grids 32 also registered presence of either human, livestock or vehicle, and 27 grids had all of them.

8.2.2. PTR: In Panna, there are three villages inside the CTH. However, 49 villages within buffer and seven villages within Gangau WLS also exploit the CTH. During this study it was found that 84.8% of sampled households were dependent upon reserve forest for fuelwood, fodder and NTFPs. And although most of the communities here, are agro-pastoral, some of the communities dependent on livestock husbandry have large livestock holdings. The number of households owning livestock (66.1%) and the average livestock holding (4.34±6.8), however, were much less than Sariska. And only 67% of households that own livestock, graze them in the reserve forest. However, since people are highly dependent on the reserve forest for fuelwood and NTFP but most do not stay within the CTH, they travel longer distance from their villages (on an average 3.8±2.1km) to collect these resources, as compared to Sariska. They also travelled almost similar distance (average 3.4±1.7km) to graze livestock, and livestock also venture on an average 3.7±1.7km from their village, to graze when unaccompanied. Thus, the in case of PTR, fringe areas closer to the villages and reserve boundary are heavily exploited, but unlike Sariska there are still areas where movement of people and their livestock is restricted. However, several of these disturbed habitats are utilized by tigers, especially males that have larger home ranges, often encompassing areas outside CTH. And on an average the home range centres of radio collared tigers lie at a distance of 17.04 km from village settlements. This HTI within the CTH was captured in camera traps, where all the tiger occupied grids also registered presence of either human, livestock or vehicle, but most of these humans and vehicles were of reserve management, the HTI is thus better indicated by livestock, which were found to be present in 14 out of 21 tiger occupied grids.

Thus, HTI is high in both the reserves, however, owing to presence of villages inside CTH and their larger livestock holdings, overall anthropogenic disturbance and grazing pressure seems to be higher in STR. Thus, even though HTI is similar in the two reserves, there is higher overlap in livestock and tiger use of same habitat in Sariska, as compared to, Panna.

8.3. Negative HTI: HTC in Sariska and Panna Tiger Reserves

8.3.1. Impact on humans

During this study all respondents stated that as per their knowledge tigers have never attacked any human being. The forest department records have also not registered any human life loss due to tiger. Thus, in these reserves, loss of life due to tiger is restricted to livestock.

STR: In Sariska, 29.6% of the households interviewed, reported livestock loss by reintroduced tigers. Which was a total of 233 livestock (from 2009-2016), costing INR 5705747.5, which averages to INR 7,617.8 (USD 102.20) per household per year. The livestock compensation records reveal that a total of 217 livestock have been lost to tiger, between mid-2011 to December 2014. Which indicates that livestock loss to tiger are underreported, even if we take into account that people may be exaggerating their losses during the interview.

PTR: In Panna, 27.3% of the households interviewed, reported livestock loss by reintroduced tigers. Which was a total of 141 livestock (from 2009-2016), costing INR 2887521, which averages to INR 4583.4 per household per year (USD 61.49). The livestock compensation records reveal that a total of 224 livestock have been lost to tiger, between mid-2011 to December 2014. Which indicates that livestock loss to tiger are underreported, although not as grossly as Sariska.

Therefore, almost similar number of households are facing livestock loss due to tiger but due to the higher number of livestock that are lost to tiger per household and the higher cost of these lost livestock, the loss when looked at in monetary terms, is much more severe in Sariska.

However, economic loss is not the only negative effect of HTC on people. There are also the loss of opportunity, psychological stress and other hidden costs like increased vulnerability of women (Barua et al. 2013; Doubleday 2018).

8.3.2. Impact on tigers

HTI can have several negative impacts on tiger, from direct loss in form of conflict related killings to indirect loss in form of habitat loss, reduced welfare and impacting the population growth rate by causing physiological stress.

Direct loss: HWC has been found to play a role in extinction of the original tiger population in Sariska. Moreover, the first reintroduced tiger in Sariska was also lost to retaliatory killing. Since then, one tiger has also died of anthropogenic causes and another is also believed to be dead because of the same. In Panna, since reintroduction, at least two tigers have died due to anthropogenic causes.

Indirect loss: High level of interaction with human, can lead to behavioural and physiological changes in tigers. It was hypothesized that the slow population growth of tigers in Sariska is due to anthropogenic disturbance mediated physiological stress. The results of stress hormone analysis showed that the mean FGM concentration of tigers in STR (mean $\pm$ SD = 50.14 $\pm$ 42.84 ng/g; n=103) was significantly higher than in PTR (20.29 $\pm$ 16.34 ng/g; n=144). And the results of statistical modelling to reveal the factors associated with high physiological stress in Sariska tiger population, revealed that FGM concentrations were positively linked to the presence of humans; high canopy cover, low water availability and homogeneous elevation and low TRI values. Therefore, it seems that HTI is the reason behind slow population growth of tigers in Sariska because at a fine scale it is the simple act of a villager going inside the high cover forest areas frequented by tigers, which is leading to increased physiological stress in tigers of STR. Stress is reduced where tigers are occupying areas with homogenous distribution of water and the opportunity provided by topographic features to avoid detection.

8.4. Proximate drivers of HTC, vulnerable tiger and communities

8.4.1. Sariska Tiger Reserve

In STR, the ecological variables reveal that livestock are at high risk of getting depredated by tiger in areas with high prey, less slope and near road. It was clear that livestock are venturing into tiger habitat (with high wild prey) and becoming easy prey when grazing in flatter terrains and near road. And from the predation risk map it seems that most of the tigers are occupying high risk habitat. However, only some tigers, especially younger individuals, are making frequent livestock kills and from the study of tiger home range characteristics, it was found that less cover (both canopy and shrub) and high anthropogenic activities were correlated with frequency of livestock kill. Therefore, even though, almost all the tiger are occupying high risk habitat, it is those tigers within whose home ranges there is less cover and high disturbance in form of high human presence, that are more likely to depredate livestock. Similarly, it may seem that all livestock that are grazing within the high-risk area would be equally vulnerable to tiger attack, however, the study of socio-economic drivers reveal that livestock that are left to graze at night unaccompanied in forest, especially, during winter are susceptible to getting predated upon by tigers. And among the communities that are more likely to face livestock loss are Gujjars due to their pastoral livelihood strategy.

When these proximate drivers are put together the reason for HTC in Sariska become lucid. Gujjars owing to their traditional livelihood and husbandry practices, leave cattle to graze in the forest at night, especially during winter. These forests are occupied by tigers because of high availability of prey at coarse scale, tigers whose activity patterns also peak at night, because they are trying to avoid humans that venture within their home range during the day time. And, some of these tigers have home ranges that have less ambush cover, and even though, they may occupy areas with flatter terrains (like valleys) where it is easier to make a kill, wild prey due to their anti-predator behaviour in absence of cover may spot the tiger and move to steeper slopes, in which case if the optimal foraging theory (large prey, high in abundance, easy to catch) is applied (Emlen, 1966; MacArthur & Pianka, 1966; Werner & Hall, 1974), the tiger kills what is easily available i.e. livestock, because they have lost most of their anti-predator behaviour during the domestication process.

8.4.2. Panna Tiger Reserve

In PTR, the ecological variables reveal that livestock are at high risk of getting depredated by tiger in areas with less prey, and medium shrub cover. Therefore, livestock when grazing in tiger occupied habitat that have conducive ambush cover, but less prey, get depredated. And from the predation risk map it seems that many tigers are occupying high risk habitat. However, biological drivers reveal that only certain tigers are making frequent livestock kills, especially males with large home ranges. Tigers that are occupying optimal habitat with higher availability of preferred prey are less frequently depredating livestock. As for livestock vulnerability, the socio-economic drivers, reveal that livestock that are left to graze in the forest at night are more likely to getting depredated. And most of these livestock would belong to Yadav community, because of their traditional livestock husbandry-based livelihood.

Putting these proximate drivers together makes the reason for HTC in Panna clearer. Yadavs owing to their traditional livelihood and husbandry practices, sometimes leave cattle to graze in the forest at night, especially during monsoon and winter. Some parts of these forests have low availability of prey but high availability of cover, thus the habitat is conducive for making a kill but there is less availability of prey. These areas would usually not be occupied by females that have much smaller home ranges which must fulfil all their resource requirement (presence of prey and cover), but males that have much larger home ranges, may occupy and utilize such habitats, especially during monsoon-winter when they are in search of mates. And upon encountering livestock would depredate them, especially, at night when they are unaccompanied and thus more vulnerable.

8.5. Management of HTC

8.5.1. Existing management strategies and their status

Compensation

Compensating people for their losses can significantly decrease carnivore killing by them (Hazzah et al., 2014). Even though some studies have found that there is no significant difference between tolerance level of people who have received compensation and those who have not (Gusset et al., 2009; Hazzah et al., 2009; Naughton-Treves et al., 2003). They still view compensation as an important HWC management strategy (Hazzah et al., 2009; Naughton-Treves et al., 2003).

Forest department at both the reserves pay a compensation of INR 10000 on loss of milch cattle both cow and buffalo, for bulls 5000 is paid, for calves 2000 and for goats 1000-2000. In STR, forest department paid a total of INR 31,14000 from 2011-2016, which means on an average 5,19000 rupees per annum, is spent by the forest department in compensating tiger related livestock losses alone. In PTR, forest department paid a total of INR 31,68848 from 2009-2015, which means on an average 4,52692 rupees per annum is spent by the forest department in compensating tiger related livestock losses.

Status of compensation scheme in Sariska: During the interviews with respondents that have faced livestock loss due to tiger, all (n=107), except three said that they have knowledge of the livestock compensation scheme by forest department. However, only 71% (n=76) applied for compensation, of these only 53.9% (n=41) received compensation. On an average compensation amounted to only 27.1% (±16.5) of the actual/market cost of the lost livestock. For this reason, only two people who received compensation were satisfied, 13 (31.7%) were somewhat satisfied and 23 (56.1%) were not satisfied. When asked whether they faced any problem in getting compensation or had any complaints, 26.8% (n=11) of the respondent who have received compensation (n=41) replied that they did not face any problem. However, 34% (n=14) did face problem, rest (n=16) did not reply to the question.

Status of compensation scheme in Panna: During the interviews with respondents that have faced livestock loss due to tiger, all respondents from HFC (n=90), except two said that they have knowledge of the livestock compensation scheme by forest department. However, only 57.8% (n=52), applied for compensation, of these only 57.7% (n=31) received compensation. On an average compensation amounted to only 24.8% (±20.1) of the actual/market cost of the lost livestock. For this reason, only four people who received compensation were satisfied, 12 were somewhat satisfied and 11 were not satisfied. When asked whether they faced any problem in getting compensation, 48.4% (n=15) of the respondent who have received compensation (n=31) replied that they did not face any problem, however 29% (n=9) did face problem, rest (n=7) did not reply to the question. The major problem faced by 54% of these respondents was that the compensation process was complicated.

Thus, on an average only 50% of reported losses are compensated by the forest department, that too amounting to only on an average 26% of the actual market price of the lost livestock. And for getting even this meagre compensation people have to bear a lot of transaction cost and find the overall process complicated, as also found by other studies (Barua et al. 2013; Karanth et al. 2013; Ogra & Badola, 2008). A study done in Sariska found that forest department staff instead of assisting people in the application process, dissuades them from claiming compensation (Torri, 2011)

Village relocation

Presence of villages inside the core area was cited as one of the key reasons for tiger extinction from Sariska in 2005 (Meena, 2015; Narain et al., 2005). Since then, efforts to relocate villages outside the national park area has been doubled, however, having learned lessons on forced relocation of villages from the past, the current relocation programs in both the reserves are voluntary (Gurjar & Bladwa, 2013; Kamalanathan, 2018; Shrimali, 2015).

STR: Interviews were conducted in eleven villages to understand village relocation associated views in STR. All the sampled villages were either inside the national park area or very close to the boundary and hence are being, or quite likely to be, relocated in immediate future.

Of the 57 respondents who answered question on village relocation, 11 had already accepted the relocation package. Of the rest (n=46), 80.4% (n=37) said that they are willing to relocate if their demands are met. Opinion of all respondents (n=46) was therefore further sought on the relocation packages offered by the forest department/NTCA (INR 10 lakh or 2 ha. (20000 m^2) land plus some cash for building house) (Shekhawat, 2014; NTCA, 2008). 67.4% were unsatisfied and 18.6% were satisfied with the cash only package. 53.5% were unsatisfied and 14% were satisfied with the land package. The people who are willing to relocate if their demands are met (n=37) were questioned about their reason/demands. All the people who were satisfied with either of the relocation package (n=13) wanted compensation for all the adult males in the family (compensation is being offered to only male members of the family who were adult in 2008). There were also others (n=6) who were dissatisfied with both the packages but would go if all the adult males in the family were offered compensation. Other respondents who were dissatisfied with both the relocation packages (n=17) wanted either more money, more land or mostly both (n=15).

PTR: Interviews were conducted in seven villages to understand village relocation associated views in PTR. All the sampled villages were either inside the core area or very close to the national park boundary and hence quite likely to be relocated in immediate future.

Of the 41 respondents who answered questions on village relocation, 43.9% said that they are not willing to relocate, however, 29.3% said that they are willing, rest of them said that they are willing to relocate if their demands are met. The people who said that they are not willing to relocate were asked the reason for it, all but two said that the money offered is too less. Opinion of all respondents (n=41) was thus further sought on the relocation package offered by the forest department/NTCA, 53.7% were unsatisfied, 14.6% were somewhat satisfied, and 7.3% were somewhat unsatisfied. 17% were unsatisfied with the cash only package but somewhat satisfied with the land package. Only one person, expressed satisfaction and two did not wish to share their opinion, saying they would only do so when they are actually offered these packages. Respondents were then questioned about the compensation for which they would relocate, of the 22 who clearly stated their expectations, most expected more money which ranged from >10 lakh up to 50 lakh rupees.

Respondents were also asked about what they thought were the advantages or disadvantages associated with relocating outside the reserve, only 23 respondents replied to this, the rest saying that they don't know. Of these 23 respondents, most, expected better job (30.8%) and education (26.9%) opportunities. As for the disadvantage associated with moving outside the forest, all but one, stated inaccessibility to forest resources.

Thus, it was found that most people in Sariska are willing to relocate but not for the current package/unless all male members are compensated, in case of PTR also, most people are unwilling to relocate, because of the inadequate package. In both places, more than half of the sampled households were unsatisfied with the current relocation package being offered by the forest department. Other studies on village relocation from Sariska has found that people were not fully informed about the relocation mechanism and packages (Shahabuddin et al., 2007). Most are unwilling to relocate in lieu of cash package, but even those who were willing were not fully informed about the package and how much monetary benefits they would really get (Kodiveri, 2015; Shahabuddin et al., 2007).

Displacement of people from national park has been used as a HWC management tool, however, displacing or relocating forest dwelling communities from their traditional homes, result in disruption of their social and economic well-being (Massé, 2016; Shahabuddin & Shah, 2003). And is a prime example of the most marginal communities bearing the cost of conservation (Torri, 2011). Studies done on relocation of villages from Sariska have observed that the relocated people have a reduced quality of life and face new types of conflicts, including those related to caste and resource use (Azeez et al., 2014; Kodiveri, 2015, Meena, 2015; Shahabuddin et al., 2007). And it has created livelihood issues for pastoral communities like Gujjars that in the scarcity of grazing pastures in the villages they have been rehabilitated to, are forced to abandon livestock husbandry and move to agriculture, something about which they have little knowledge and practice, resulting in considerably reduced household incomes (Kodiveri, 2015; Meena, 2015; Shahabuddin et al., 2007). Similar narratives of loss of forest rights and inadequate water at relocation sites have also been presented by families relocated from PTR (Kamalanathan, 2018; Kakvi, 2019). These and past experiences with inadequate relocation attempts in both the reserves, have diminished the trust of locals towards the whole relocation program (Gurjar & Bladwa, 2013; Kakvi, 2019; Kamalanathan, 2018; Kodiveri, 2015; Shahabuddin et al. 2007).

Community engagement

In Panna, some measures to involve people in tiger conservation have been initiated under the aegis of 'Jan samarthan se bagh sanrakshan' (tiger conservation through people's support). A trust named 'Friends of Panna' have also been established. Nature camps are organized to engage school children from surrounding semi-urban areas, however, similar camps are not reportedly organized for children residing in the villages within the reserve.

In Sariska attempts were made to engage communities both before the local extinction of tigers in the form of 'Sariska Sansad' and after, in form of constituting 'Sariska Tiger Conservation Foundation' (STCF). STCF have organized a few nature camps for children from schools around the reserve. However, these attempts have been few and far apart. No ongoing community engagement strategy exists in a reserve that has a sizable number of villages residing within the CTH, with the forest management calling for increasing the registration of offences under stringent Wildlife Protection Act (Bhardwaj 2018), instead of helping community find alternate livelihood strategies to reduce their dependence and promoting pro-park sentiments.

8.5.2. Conflict resolution strategies suggested by communities

STR: During the interviews with local communities in Sariska, when enquired about the measures that are taken by them or should be taken by forest department to protect their livestock from tiger attacks, only six respondents said that they accompany the livestock when grazing in the forest, stay vigilant or make noise on perceiving threat, all the rest felt they did not do anything specific to keep their livestock safe. As for the measure that should be taken by the department, again apart from three respondents, all said that they don't know.

PTR: During the interviews with local communities in Panna, when enquired about the measures that are taken by them or should be taken by forest department to protect their livestock from tiger attacks, only 12 respondents said that they accompany the livestock when grazing in the forest, stay vigilant or make noise on perceiving threat, all the rest felt they did not do anything specific to keep their livestock safe. As for the measure that should be taken by the department, again most (n=202) said that they don't know, from the rest (n=128), 32% said that a boundary wall made of stone or fence made of mesh wire should be constructed to keep the wild animals inside forest, of these four said that the height of the existing boundary wall should be increased. Some (17%) suggested that people should be relocated outside the reserve.

8.5.3. Suggested management strategy based on proximate drivers of HTC

Holistic management: Conflict Determinant Model

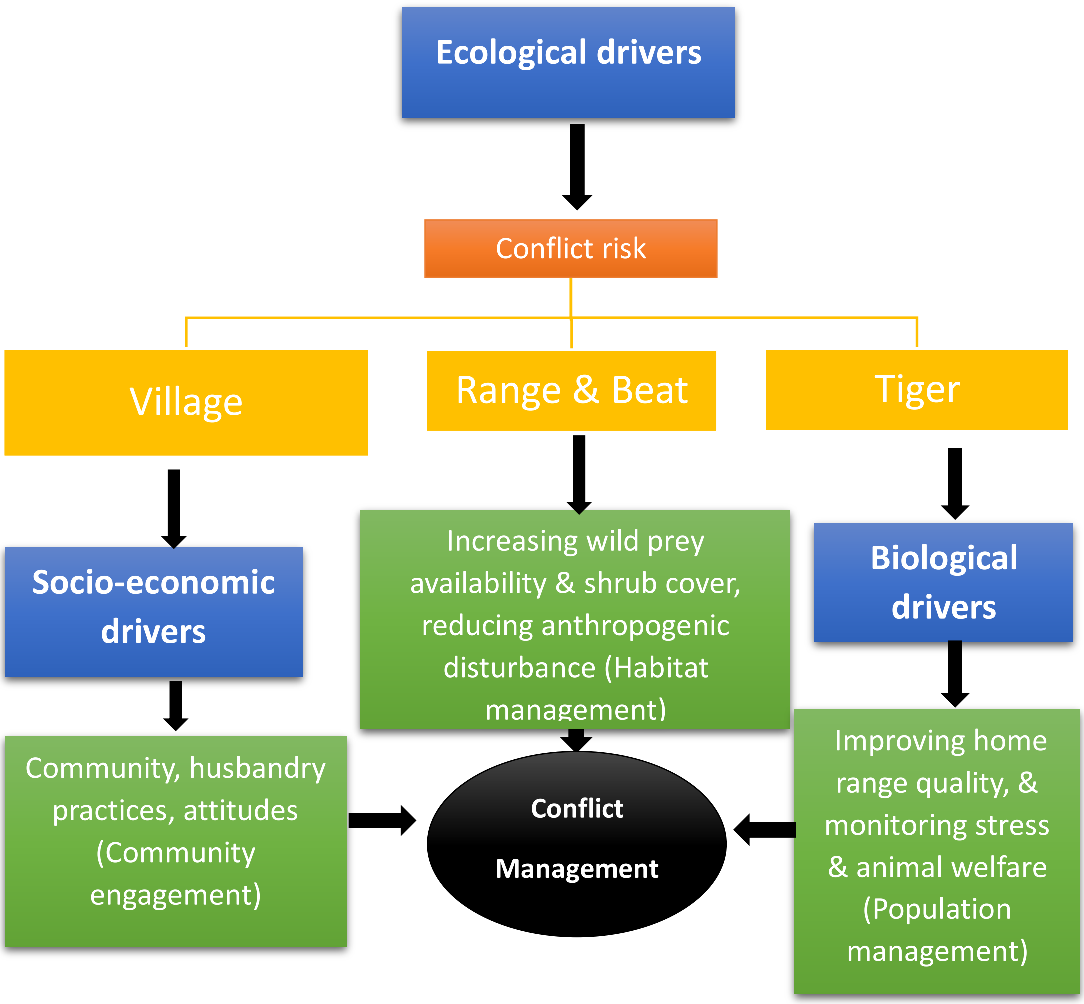


Figure 8. 1: Diagram depicting application of CDM for HTC management in Sariska and Panna Tiger Reserves

Managers need to see the whole problem and all its facets, before they can manage it. Applying CDM to the problem of HTC in Sariska and Panna Tiger Reserve, helped in gaining comprehensive understanding of the factors that were operating together resulting in livestock loss due to tigers (Figure 3.1). The same approach can be applied by managers to mitigate the issue (Figure 8.1). It can help answer the three questions, understanding which are critical for a manager to effectively resolve the problem at hand: When and where to focus? On whom to focus? And, how to focus?

Where to focus: Administrative units at risk

The first component of CDM the ecological driver helped in predicting where the risk of livestock predation was high in both the reserves (Figure 4.26, 4.29). Overlaying forest administration boundaries (range and beats) can help visualize where HTC management can focus.

Sariska Tiger Reserve

Range: In case of STR, overalying the range boundary it was learned that, Sariska and Talvriksh Ranges were high risk, Akbarpur Range was at medium risk and Tehla Range was at low risk of HTC (Figure 8.2).

Beats: Among the beats Nathusar, Binak, Panidhal, Madhogarh, Reika, Nangalhedi, Indok, Bhartari, Sarunda, Kiraska, Karnakawas, Kalighati, Pandupol and Kankwari are at very high risk (Figure 8.3).

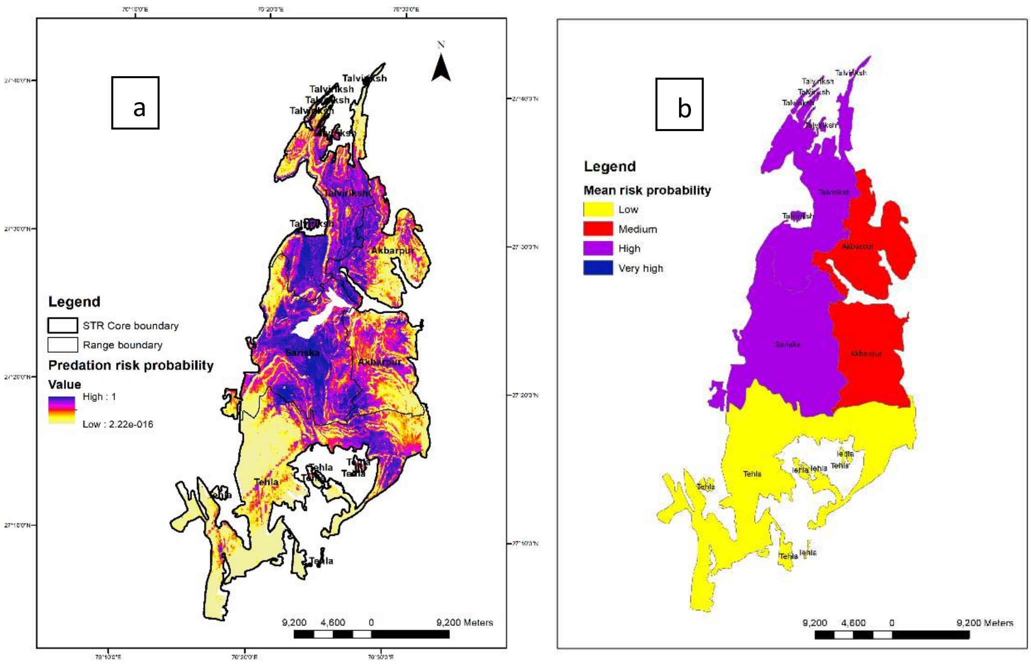


Figure 8. 2: Map depicting livestock predation risk within each forest range in STR core a) forest range boundaries laid over risk map, b) forest ranges classified according to their mean risk probability

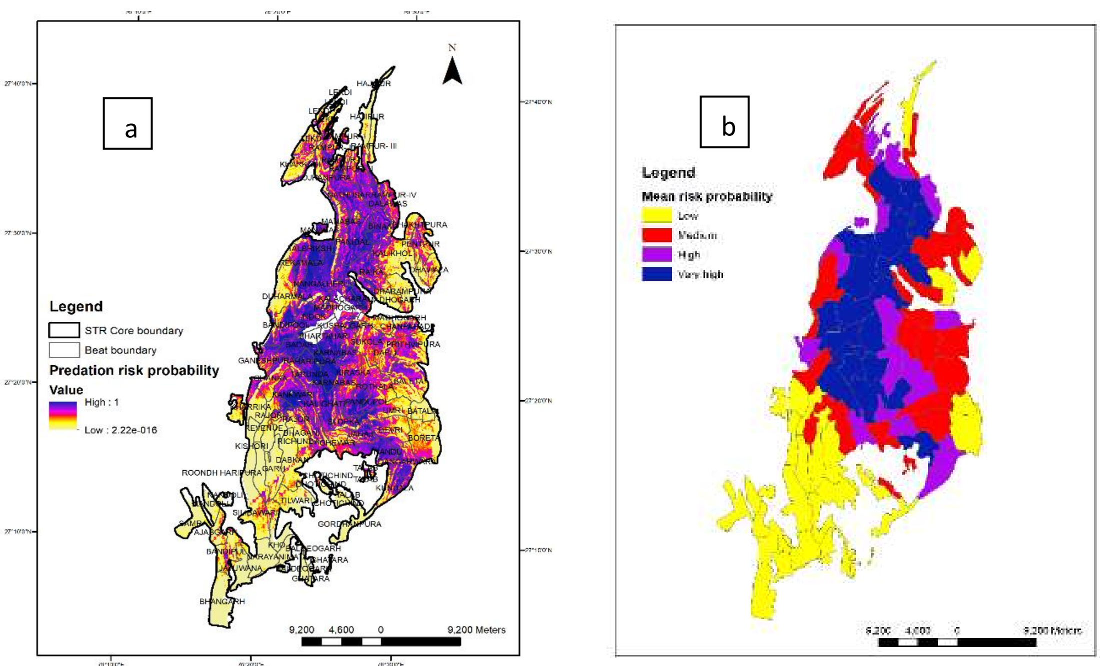
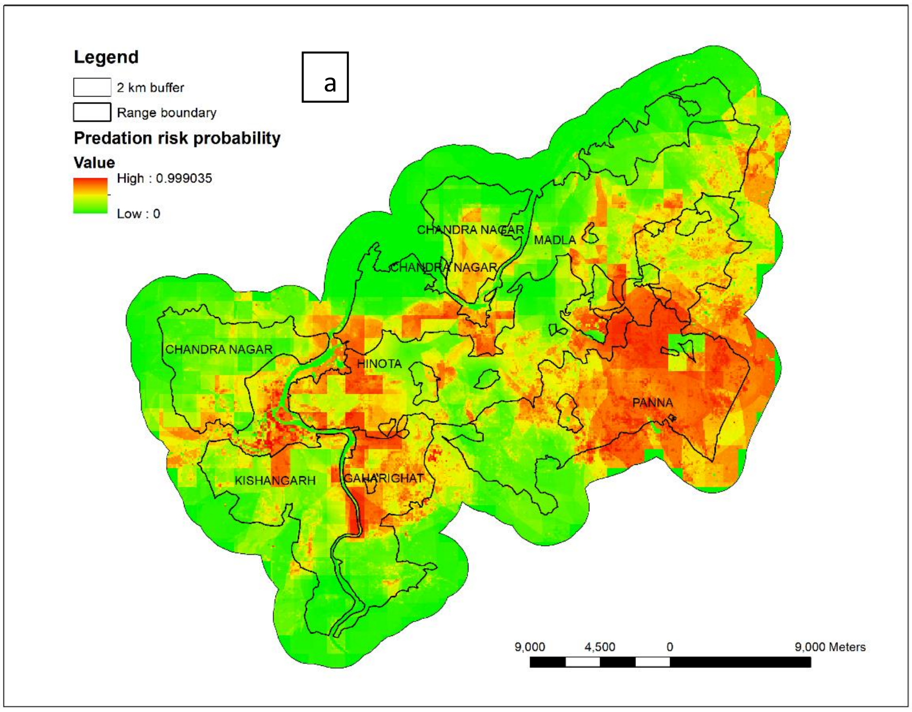


Figure 8. 3: Map depicting livestock predation risk within each forest beat in STR core a) forest beat boundaries laid over risk map, b) forest beats classified according to their mean risk probability

Panna Tiger Reserve



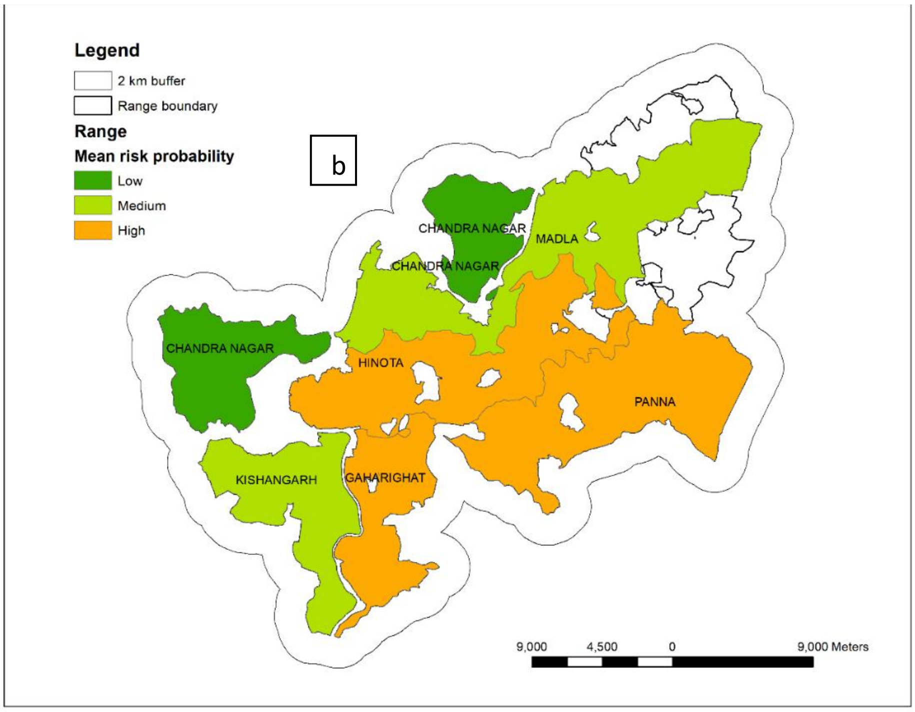
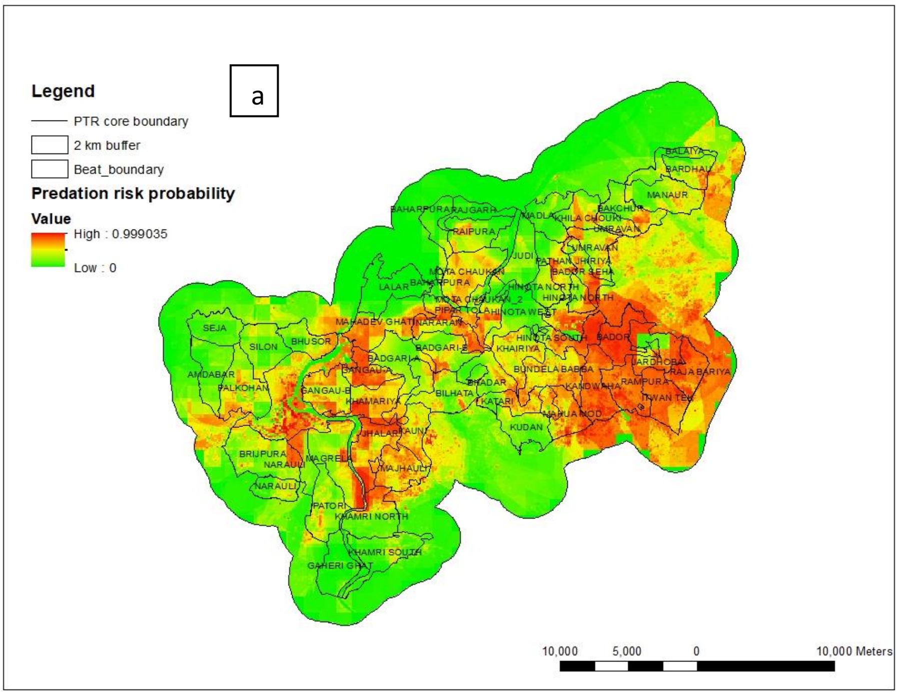


Figure 8. 4: Map depicting livestock predation risk within each forest range in PTR a) forest range boundaries laid over risk map, b) forest ranges classified according to their mean risk probability



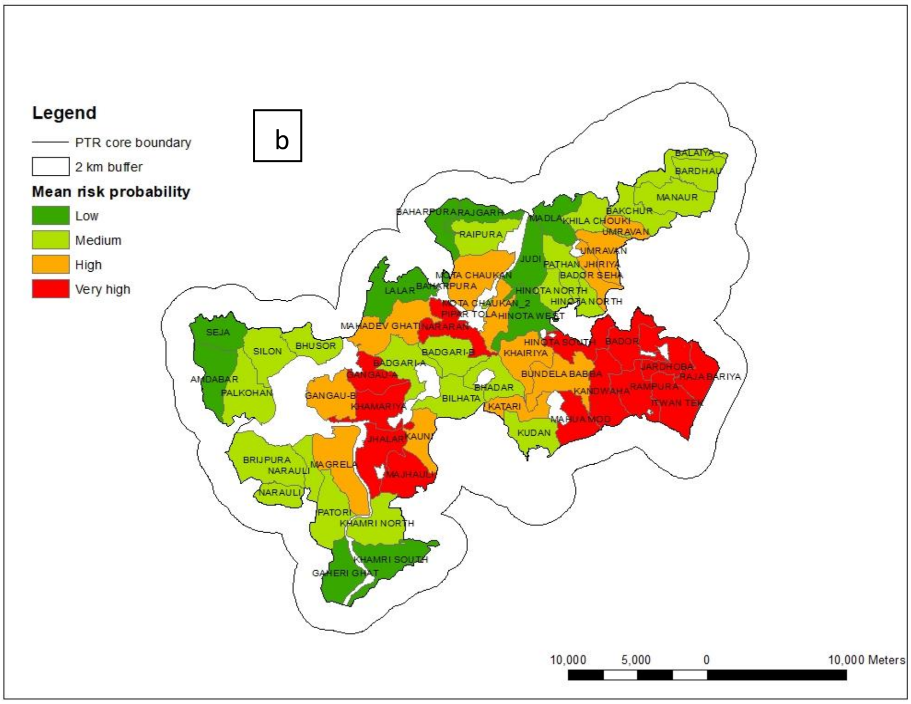


Figure 8. 5: Map depicting livestock predation risk within each forest range in PTR a) forest beat boundaries laid over risk map, b) forest beats classified according to their mean risk probability

Range: In case of PTR, overlaying the range boundary it was learned that, Panna, Hinota and Gahrighat Ranges were high risk, Kishangarh and Madla were at medium risk and Chandranagar was at low risk of HTC (Figure 8.4 a, b).

Beats: Among the beats, Rampura, Jardhoba, Khandwaha, Raja bariya, Itwan tek, Mahuamod, and Bador, in Panna Range, Nararan in Madla Range, Hinota South in Hinota Range, and, Khamariya, Jhalar and Majhauli, in Gahrighat Range are at very high risk of HTC (Figure 8.5 a, b).

When to focus: vulnerable seasons and time of the day

The socio-economic drivers and study of spatio-temporal pattern has revealed that livestock in both Sariska and Panna are more vulnerable to depredation during winter and monsoon seasons, and at night.

On whom to focus: vulnerable tiger and communities

Plotting tiger home range and village location on the risk map can tell us which tigers and which villages were most vulnerable to HTC (Figure 4.27, 4.30).

In case of Sariska, the villages that are at very high risk are Loge, Nathusar, Manawas, Talvriksh, Rekhamala, Berawas, Panidhal, Madhogarh, Kalachara, Indok, Lilunda, Haripura, Kundalkha, Kraska, Kankwari, Kanyawas, Ghewar, Jahaj, Nadoo, Bera and Bakhtpura (Figure 8.6 a, b). Villages that are at high risk are Binak, Raika, Banchhri, Meenala and Rampur, while Dhelawas, Garh, Dabkan, Mangalwas, Akbarpur and Kherka are at medium risk (Figure 8.6 a, b).

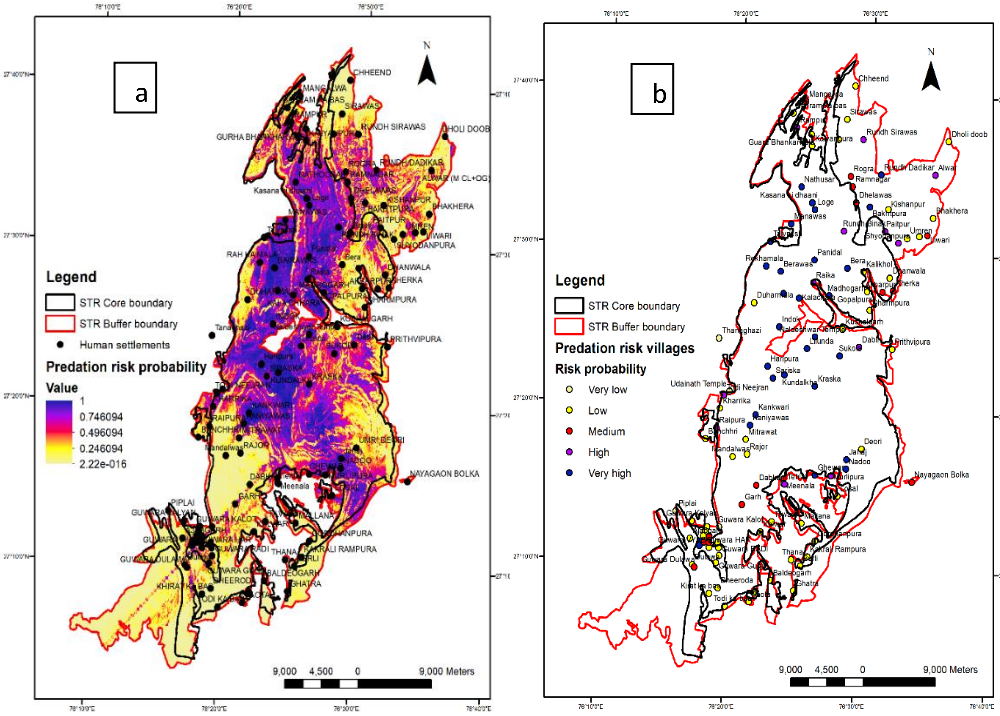
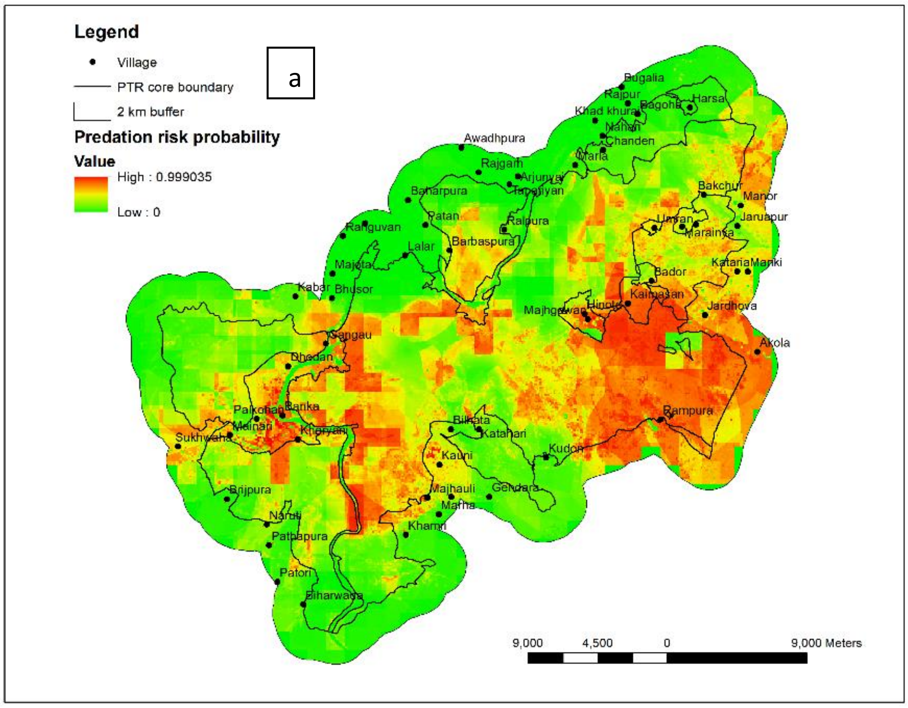


Figure 8. 6: Map depicting villages located within STR with the livestock predation risk a) village locations laid over risk map, b) Villages classified according to their risk probability

In case of Panna, the villages that are at very high risk are Hinota, Majhgawan, Kaimasan, Jardhova, Akola, Rampura and Kharyani (Figure 8.7 a, b). Villages that are at high risk are Kauni, Majhauli, Marha, Dhodhan, Mainari, Sukhwaha, Bador, Umravan, Manki, and Kataria, while Palkohan, Barbaspura, Marainya and Manor are at medium risk (Figure 8.7 a, b).

And within these villages, the focus should be on those communities that are dependent on livestock husbandry, like Gujjars in case of Sariska and Yadavs in case of Panna.



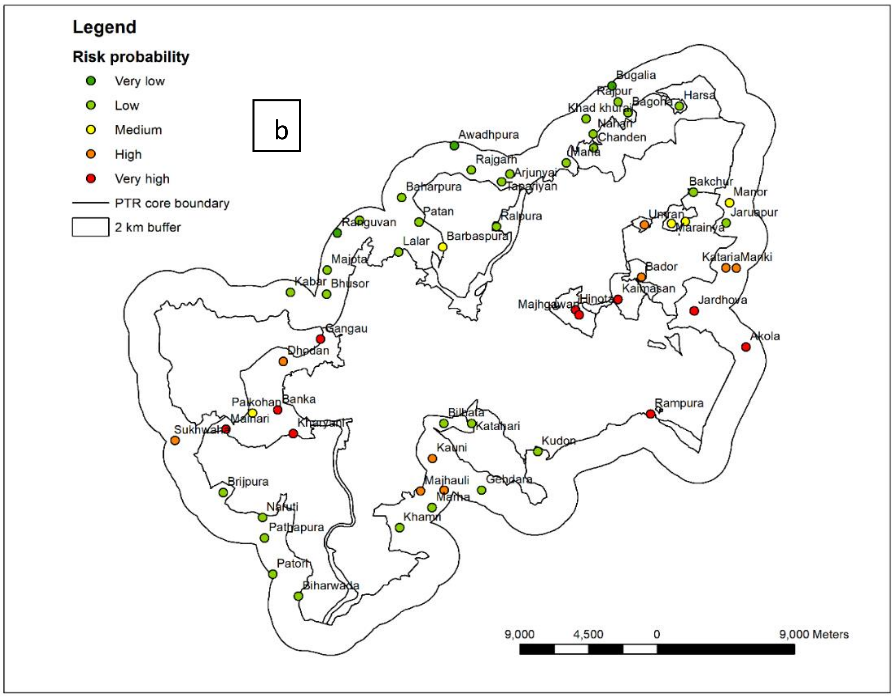


Figure 8. 7: Map depicting villages located within PTR with the livestock predation risk a) village locations laid over risk map, b) Villages classified according to their risk probability

How to focus: Comprehensive HTC mitigation measures

Ecological measures: In Sariska, since it is found that livestock are traversing in core tiger habitat, which is leading to their depredation, livestock movement needs to be restricted, especially in flatter terrain (like valleys) where they may be more vulnerable. In Panna since it was found that in certain areas, livestock depredation is associated with low availability of prey (although habitat is conducive for hunting), studies should be planned to understand the causal factors and augmentation of prey may be planned, in such areas.

Biological measure: Since certain tigers (like those that are dispersing or male tigers) due to their large home range and certain habitat characteristic are more vulnerable to depredating livestock, they should be provided adequate protection to eliminate the chances of retaliatory killing. Furthermore, attempts should be made to improve their habitat e.g. In case of Sariska, high anthropogenic disturbance and low cover within a tiger's home range are correlated with higher frequency of livestock depredation by tiger. Therefore, attempts should be made to remove or reduce anthropogenic disturbance from the home ranges of vulnerable tigers. Reducing anthropogenic disturbance is also recommended to reduce physiological stress in tigers which might be negatively affecting the population growth of tigers in Sariska. Behaviour and health of tigers should also be regularly monitored for signs of stress or compromised welfare.

Sociological measures: Managers should focus on vulnerable villages and within them vulnerable communities to implement community engagement programs. First and foremost, attempts should be made to encourage local communities to adapt better husbandry practices, and avoid leaving their livestock in forest at night. Second since during the present study it was found that many people have negative attitude towards tigers, especially in Panna, to improve their attitudes, factors that have been identified to be associated with attitudes, viz. gender, education, fear and relationship with park, and in case of Sariska forest dependence, while in case of Panna, age, community and compensation, should be focused upon. Following strategies may be adapted to engage communities and improve their attitudes towards tigers to ensure support for conservation:

Cost and benefit: Reducing tangible cost through compensation and increasing tangible benefits through ecotourism might improve tolerance towards tiger (Kansky et al., 2016). Since it was found that receiving compensation, especially, in case of PTR, is related to positive attitude. People should be compensated for their losses immediately, and the compensation process needs to be simplified. In case of Sariska, benefits from tourism have been found to be correlated with support for the reserve (Sekhar, 2003). Benefits incurred by tiger tourism should be spread out by encouraging local stakeholders over outsiders, in both the reserves.

At the same time letting forest-dwelling communities keep grazing or NTFP collection rights, may be crucial in fashioning attitude towards reserve management and wildlife. In STR people make substantial profit from their dairy business, the economics of which are sustained by free fodder and fuelwood from reserve forest, such that a few losses incurred by tigers may not make them negative. However, if they are not allowed to graze in the forest and that in turn affects their capability to keep large livestock holding, resulting in less profit, then the same number of livestock lost to tiger may invoke negative emotions.

Education and gender: Since level of education and knowledge about species influence attitudes towards wildlife (Karanth et al., 2019; Pinheiro et al., 2016;), when people are educated about the benefits of the species, they become more tolerant (Bruskotter & Wilson, 2014). Poor knowledge about the species itself can lead to people attributing their loss on carnivores (Marchini & MacDonald, 2018). Thus, educating people about carnivores may actually decrease their sense of loss. Moreover, when people have correct knowledge about a carnivore, they also fear them less (Marchini & Macdonald, 2012). Therefore, educating people about wildlife can make them more positive towards carnivores, especially women, by allaying their fears and encouraging conservation values.

Receiving formal education and especially higher education inclines individuals towards conserving environment (GEM report 2015). In both our study areas where formal education levels are low, and there are no regular programs for spreading awareness about conservation among the local communities; a multi-pronged approach is required, which firstly, focusses on ensuring formal education for both children, as well as, adults, especially women. Secondly, conducting conservation education and awareness programs, to reach the masses not covered by formal education. And lastly, sharing indigenous knowledge to promote traditional conservation values (GEM report team 2016). Conservation education programmes that take advantage of traditional beliefs and highlight benefits of carnivores in a manner that is relatable to the target communities may make people more accepting of large carnivores and proconservation (Carter et al., 2012; Gebresenbet et al., 2018). Like in case of STR, where tigers are an important part of their lore, they even have a temple dedicated to a tiger loving saint inside the reserve. These cultural ethics should be encouraged and traditions fostering human-wildlife coexistence promoted (Talukdar & Gupta, 2017). Studies have suggested involving religious leaders in places where attitudes towards carnivores are guided by religious sentiment (Hazzah, 2007). Therefore, roping in local religious leaders for promoting tiger conservation, may make attitudes more positive in both the reserves, especially in the case of elderly, who might respond to religious values more than conservation ethics.

Additionally, local communities in both the reserves, should also be educated about the ecological role of these apex predators, the direct and indirect manner in which people are benefited by their presence (Thinley et al., 2018). It is important to state such potential benefits of tiger presence then continuously highlight them in a manner that it becomes engrained in people's subconscious. Species behaviour related information may also help ward off feelings stemming from apprehensions associated with 'new' or 'foreign' tiger (as some people have been reported to address reintroduced tigers in STR [Doubleday, 2018]). In this regard, visitation of national park by local communities where they can see charismatic species and become more familiar with them, may make them more tolerant (de Pinho et al., 2014).

Women have responded very positively to environmental education in the past, which has resulted in them supporting conservation of endangered species (WWF TAL Project n.d.). They have further turned into educators themselves, teaching their children and larger community conservation value of a species and even employing this knowledge for income generation (Hausheer & Waters, 2016). Arjunan et al. (2006) found that in Kalakad-Mudanthurai Tiger Reserve in India, women were more positive towards tiger and its conservation than men. The positive opinion was a result of an ecodevelopment project that was benefiting women more than men. Similar efforts can be made in STR and PTR, by strengthening EDCs, so that women not only become aware of conservation issues but also become active participants in natural resource management decision-making at the household and village levels.

Managing people-park relationship: In Sariska earlier studies have found that relationship between people and forest department is antagonistic, due to widespread distrust and corruption (Torri, 2011). During this study also it was found that negative attitudes towards tigers were associated with poor relationship with reserve management. Thus, attempts should be made to improve people-park relationship by strengthening ecodevelopment committees, starting dialogues with community leaders to understand pertinent issues and concerns of people, making compensation process easy and fair, and relocation packages lucrative. Such attempts, as have been made by Sariska management, to install solar fencing for protecting farmlands from crop raiding wild herbivores, and in turn asking communities to reduce their demand for fuelwood, are laudable, and should be continued. Similarly in case of Panna attempts at engaging community especially children are crucial for tiger conservation and should be made more frequent and inclusive.

Managing other HWC

Addressing other types of conflict especially crop raiding can help build support for biodiversity conservation (Meena et al., 2020), which is essential for building long term support for tigers.

Threat due to other carnivores: In Sariska, most of the respondent during the interviews said that apart from tigers they felt threatened by leopard. In case of Panna, it was bear (55%), followed by leopard (17%), jackal (8%), mugger (3%), many named both sloth bear and leopard (12%). Since sloth bear and jackal are known to attack humans, resolving conflict with these species is imperative for gaining community support for wildlife conservation in these reserves. Further research should be carried out in both the reserves to understand other types of HCC employing CDM and design targeted mitigation strategies.

Crop loss due to herbivores:

STR: During the village survey, it was found that 67.6% (n=244) of the sampled household were facing crop loss due to herbivores, and most frequently ranked wild pig as the number one or the only problem species (n=129). Nilgai was most frequently ranked second among the problem species (n=123) and sambar as third (n=30). Overall, nilgai was identified as problem species by majority of the HHs (n=235). Wild pigs were reported to raid maize crop during monsoon, and nilgai, maize, millet, and barley. Of the respondents who shared crop protection measures (n=36), most used some kind of fence (n=14) or check wall (n=13). People were further asked about their readiness for solar fencing, that STR management is planning to put around agricultural fields in villages suffering from crop loss due to herbivores. 83.8% of 229 HHs answered in affirmative, of these 91.1% were willing to take responsibility for the maintenance of the fencing, 45.3% were also ready to pay for the fencing (mostly partial cost), and 41.1% were even ready to stop going to the forest (for livestock grazing and fodder collection) in exchange for solar fence.

PTR: In PTR, 70% (n=231) of the sampled HH were facing crop loss due to herbivores and most frequently ranked wild pig as the number one problem species (n=163) or the only problem animal (n=22). Nilgai was most frequently ranked second among the problem species (n=127) and chital as third (n=47). Other crop raiding species less frequently stated as problem were monkey, jackal, porcupine, hare, bear, civet and chinkara, in that order. As for the measure that should be taken by the department, again most (n=202) said that they don't know, from the rest (n=128), 32% said that a boundary wall made of stone or fence made of mesh wire should be constructed to keep the wild animals inside forest, of these four said that the height of the existing boundary wall should be increased.

Thus, solar fencing of the agricultural field of villages most severely affected by crop raiding herbivores, by forest department in collaboration with EDCs (as has been attempted in Sariska), could be the best method to not only reduce losses due to herbivores but also to reduce anthropogenic pressure on reserve forest and build local support for park and wildlife conservation.

8.6. Conclusion

HTI was high in both Sariska and Panna Tiger Reserves, however, grazing pressure was higher in Sariska, due to higher livestock dependence of communities. Severity of HTC seems to be higher in STR as compared to PTR both in terms of higher monetary loss to people, as well as, higher physiological stress, lowering the reproductive potential of tigers. To understand HTC in a holistic manner, I built a conceptual framework i.e., the conflict determinant model (CDM), and identified three key components to any human-carnivore conflict. In order to expose the first component, ecological variables were modelled at multiple scale against livestock kill, which revealed that, in Sariska, tigers occupy areas with high wild prey, and flatter terrain where prey might be more vulnerable. In such areas if livestock is also in high numbers, tigers may depredate them because wild prey change their habitat use in response to predators whilst livestock, due to the loss of most of their anti-predator behaviour, may become easy kill. And in case of Panna, if prey availability is low at fine scale within tiger occupied habitat, domestic livestock availability is high, and ambush cover is available, the odds of tiger depredating domestic livestock becomes high. Livestock kill by tiger is, thus, a culmination of predator choice and foraging tactics, and, prey vulnerability and defence mechanism.

Examination of the second component i.e., the biological associates of HTC indicate that certain tigers are more prone to conflict, male tigers owing to their large home range sizes, and younger individuals because they are trying to establish territories or occupying sub-optimal habitats, may depredate more livestock. And quality of home range is associated to livestock depredation, with tigers occupying high cover and wild prey habitat, depredating less livestock, while, those occupying habitats with less cover and high anthropogenic disturbance, depredating more livestock. And finally, the third component the, socio-economic drivers, illuminated the reason why livestock are venturing into the tiger habitat in the first place, and which specific circumstance makes them most vulnerable to getting depredated. Livestock venture into the reserve forest to graze, because of high dependence of local communities on these forests for fodder. This dependence is more severe in Sariska, because the major community residing within the reserve i.e., Gujjars are pastoral and have very large livestock holdings. And the factor that contributes the most to the increased vulnerability of these livestock to depredation by tiger, is the practice of leaving livestock inside the forest to graze unaccompanied at night.

Applying these results for mitigating HTC in STR and PTR, it is suggested that based on predation risk map, high risk areas (range, beats and villages) should be focussed upon, to improve tiger habitat by improving cover, prey and reducing anthropogenic pressure, especially home range of tigers that are more frequently depredating livestock, and, approaching livestock husbandry dependent communities like Gujjars in case of STR and Yadavs in case of PTR, to improve their husbandry practices. And although it was found that the attitude of people towards reintroduced tigers, is not associated with whether they have faced direct losses due to tiger or not, managing negative attitudes is important for ensuring persistence of tigers in this landscape and continued success of the reintroduction program. For which education especially that of rural women and improving people-park relationships (by improving compensation and relocation packages, and providing protection from crop raiding by wild herbivores), is suggested.

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Appendices

Appendix 6. 1: List of villages sampled in Sariska Tiger Reserve along with household sampling intensity

S. N.	Village	Total number of households	% Sampled	Village location
1	Kushalgarh	27	22.22	In
2	Kalachara	23	21.74	In
3	Kundalkha	64	23.44	In
4	Bera	58	20.69	In
5	Kankwadi, Karat, Pilapani	27	22.22	In
6	Reika	24	25.00	In
7	Panidhal	5	60.00	In
8	Nangalhedi	93	20.43	In
9	Kanyavas	27	18.52	In
10	Mitravat	52	23.08	In
11	Dabkan	50	14.00	In
12	Berawas	139	15.11	In
13	Rajore & Mandalwas	102	20.59	In
14	Garh	47	21.28	In
16	Deori	34	20.59	In
17	Lilunda	20	30.00	In
18	Madhogarh	127	17.32	In
19	Reikamala	30	26.67	In
20	Kiraska	66	19.70	In
21	Sukola	27	29.63	In
22	Duharmala	82	23.17	In
24	Loj	28	25.00	In
25	Nathusar	34	29.41	In
26	Kasana ki dhaani	16	25.00	In

27	Dabli	25	28.00	In
28	Indok	211	14.69	In
32	Haripura	20	45.00	In
15	Nandu	51	19.61	Out
23	Manawas	92	16.30	Out
29	Meenala	22	27.27	Out
30	Sirawas	42	23.81	Out
31	Binak, Dehlawas	180	11.11	Out

Appendix 6. 2: List of villages sampled in Panna Tiger Reserve along with household sampling intensity

S. N.	Village	Total number of households	% Sampled	Village location/HTC status
1	Mainari	48	16.67	Inside
2	Dhodan	144	15.28	Inside
3	Kharyani	161	14.91	Inside
4	Palkohan	336	10.12	Inside
5	Bakchur	9	33.33	On the edge of national park
6	Rampura	33	21.21	On the edge of national park
7	Shivrajpura	37	18.92	High conflict
8	Gehdara	82	14.63	High conflict
9	Akola	22	13.64	High conflict
10	Hinota	301	9.97	High conflict
11	Jardhova	141	9.93	High conflict
12	Lalar	136	9.56	High conflict
13	Kaimasan	13	15.38	Low conflict
14	Tapariyan	70	14.29	Low conflict
15	Bilhata	65	10.77	Low conflict
16	Baharpura	130	10.00	Low conflict
17	Patan	143	9.79	Low conflict
18	Bhusor	119	9.24	Low conflict
19	Bandi Kalan	245	7.35	Low conflict
20	Jharkua	321	5.61	Low conflict
21	Dwari	612	5.07	Low conflict
22	Dupariya	106	10.38	No conflict

23	Harsa	64	9.38	No conflict
24	Ranguvan	193	5.18	No conflict
25	Barbaspur a	14	28.57	Within tiger home range

Appendix 6. 3: Questionnaire for assessing socio-economic profile and conflict at household level

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

Assessment of Socioeconomic Profile of People and Conflict Situation

Reserve: **Date:** **ID:**

गाँव का नाम:	ग्राम पंचायत:
1. नाम:	

2. लिंग:

3. उम्र:

4. जन - जाती:

5. परिवार में सदस्यों की संख्या:			
Adult:	M:	F:	Children:

6. शिक्षा :

7. जंगल से क्या लाते हैं?	
a) कुछ भी नहीं	
b) चारा	
c) जलाऊ लकड़ी	
d) और कुछ	1.

	2. 3.
e) मांस	
कितना बेचते हैं : 1. Mahua 2. Amla 3. Achar	
Income from NTFP	

8. जंगल में कितने अंदर तक जाते हैं लकड़ी, चारा, महुआ, अमला वगेरह के लिए?

जगह का नाम: Distance:

Buffer: Sanctuary:

National Park:

i) 0-1km from village (inside forest)
ii) >1-2 km from village (inside forest)
iii) >2-4 km from village (inside forest)
iv) >4-6 km from village (inside forest)
v) >6-8km from village (inside forest)
vi) >8km from village (inside forest)

9. कितने और कौनसे मवेशी हैं?

Type	Milch	Non – milch	Average milk yield/day (in litre)	Milk sold/day	Selling price / kg
गाय					
बैल					
बछड़ा					
भैंस					
बछड़ा					

बकरी					
बच्चा					
भेड़					
बच्चा					
गधे					
बच्चा					
सूअर					
बच्चा					
मुर्गी					

10a. मवेशी/ पशु के चारे की व्यवस्था कैसे होती है?		
i)	चारा ला कर डालते है सारा साल	
ii)	जंगल में चरने छोड़ देते हैं	
iii)	गर्मियों में चारा डालते हैं बाकी साल जंगल में चरने छोड़ देते हैं	
iv)	सर्दियों में चारा डालते हैं बाकी साल जंगल में चरने छोड़ देते हैं	
v)	बरसात में चारा डालते हैं बाकी साल जंगल में चरने छोड़ देते हैं	
vi)	बरसात में कहीं और ले जाते हैं बाकी साल जंगल में चरने छोड़ देते हैं	
vii)	बरसात में जंगल में चरने छोड़ देते हैं बाकी साल चारा डालते हैं	
viii)	भूसा डालते है / खेत से	
ix)	और कुछ :	

10b) मवेशी को जंगल में कैसे चराते हैं ?		
i)	हमेशा चराने साथ जाते हैं	
ii)	सिर्फ रात में साथ जाते हैं बाकी समय आप चरने जंगल छोड़ देते हैं	
iii)	चरने जंगल छोड़ देते हैं , आप वापस आ जाते हैं	
iv)	भैंस के साथ जाते हैं बाकी आप चरने जंगल छोड़ देते हैं	
v)	बकरी के साथ जाते हैं बाकी आप चरने जंगल छोड़ देते हैं	
vi)	बरेदी के साथ	

11a) मवेशी को चराने जंगल में कितने अंदर तक जाते हैं ?

जगह का नाम: Distance:

Buffer: Sanctuary: National Park:

i) 0-1km from village (inside forest)
ii) >1-2 km from village (inside forest)
iii) >2-4 km from village (inside forest)
iv) >4-6 km from village (inside forest)
v) >6-8km from village (inside forest)
vi) >8km from village (inside forest)

11b) मवेशी आप जंगल में कितने अंदर तक जाते हैं?

जगह का नाम: Distance:

Buffer: Sanctuary: National Park:

i) 0-1km from village (inside forest)
ii) >1-2 km from village (inside forest)
iii) >2-4 km from village (inside forest)
iv) >4-6 km from village (inside forest)
v) >6-8km from village (inside forest)
vi) >8km from village (inside forest)

12(a) पशु को चराने जंगल में किस वक़्त ले जाते हैं?	
i) सर्दी (Nov-Feb)	I) दिन II) रात
i) गर्मी (March-June)	I) दिन II) रात
ii) बरसात (July-October)	I) दिन II) रात
(b) कितने मवेशियों को कितने लोग चराने जाते हैं?	
Remarks:	

13. रात में पशुओं को कहाँ रखते हैं?	Always	Summer	Winter	Monsoon
a) घर के नीचे/ सामने/ या अंदर बांधते हैं				
b) गौशाला में i) खुले में बाड़ लगाके ☐ ii) बंद a) कच्चा (घांस-फूंस, बांस का) ☐ b) पक्का (ईंट पत्थर, सीमेंट का) ☐				
c) गाव में खुला छोड़ देते हैं				
d) खेत में छोड़ देते हैं				
e) खेत में बाँध देते देते हैं और साथ रहते हैं				
f) जंगल में खुला छोड़ देते हैं				
g) जंगल में साथ जाते हैं				
Remarks:				

14a) Tiger के बारे में क्या सोचते हैं/ क्या विचार हैं?

a. पसंद है　　　　b. नापसंद है

c. कुछ नहीं

14b) क्यों?

15. a) Tigers को छोड़ने से पहले आपकी राय ली गयी थी, जंगलात, पंचायत या सरकार द्वारा?

i) हाँ　　　　ii) नहीं

iii) शायद / याद नहीं

b) तब आपकी क्या राय थी?

i) For　　　　ii) against

16. क्या टाइगर ने कभी आपके किसी पशु को मारा या हानि पहुंचाई है?

a) हाँ b) नहीं c) शायद / याद नहीं

17. किस साल में?	Number	Tiger ID
2008		
2009		
2010		
2011		
2012		
2013		
2014		
2015		
2016		
2017		
Total		

18. आखरी बार किस पशु को हानि पहुंचाई थी :	
a) Species	i) गाय
	ii) भैंस
	iii) बकरी
	iv) भेड़
	v) ऊठ
	vi) गधे
	vii) सूअर
	viii) मुर्गी
b) Age	i) Mature
	ii) Immature

c) Sex	i) नर
	ii) मादा
d)Cost	

e) कहाँ पर उठाया था?	
जगह का नाम:	
i) गाओं या खेत के अंदर	
ii) गाओं और जंगल के बीच	
iii) जंगल के किनारे	
iv) जंगल के अंदर Distance: Buffer: Sanctuary: National Park: I) 0-1km from village (inside forest) II) >1-2 km from village (inside forest) III) >2-4 km from village (inside forest) IV) >4-6 km from village (inside forest) V) >6-8km from village (inside forest) VI) >8km from village (inside forest)	
v) याद नहीं	

f) किस मौसम में?	
i) सर्दी (Nov-Feb)	
ii) गर्मी (March-June)	
iii) बरसात (July-October)	
iv) याद नहीं	

g) किस समय?	
i) तड़के सुबह (>4 a.m. –8 a.m.)	
ii) सुबह (>8 a.m. - 12 p.m.)	
iii) दोपहर (12 p.m. – 4 p.m.)	
iv) शाम (>4 p.m. – 8 p.m.)	
v) रात (>8 p.m. – 4 a.m.)	
vi) याद नहीं	

19. a) क्या आपको सरकार की तरफ से मिलने वाले मुआवज़े के बारे में कोई जानकारी है? i) हाँ ii) नहीं
b) क्या आपने कभी मुआवज़े के लिए अर्ज़ी दी है? i) हाँ ii) नहीं
c) क्या आपको मुआवज़ा मिला? i) Yes ii) No iii) Pending d) कितनी राशि मिली? e) किसके लिए?
f) क्या कोई मुश्किल या परेशानी हुई मुआवज़ा मिलने में? क्या ?

g) क्या आप मुआवज़े से संतुष्ट हैं?

iii) Yes ii) No iii) Somewhat satisfied

20. क्या कभी किसी इंसान पर हमला किया है?

a) Yes

b) No

c) Don’t know

21. और किस जानवर से खतरा महसूस करते हैं?

22. अपने मवेशियों को टाइगर से बचाने के लिए क्या करते हैं?

Nothing:

23. आपके हिसाब से पशुओं और आदमियों की सुरक्षा के लिए क्या इंतज़ाम करने चाहिए?

Don't Know:

24. a) विस्थापन के लिए जंगलात वाले जो पैकेज दे रहे हैं उसके बारे में आपका क्या विचार है?

i) Satisfied

ii) Unsatisfied

iii)Somewhat satisfied

iv) Somewhat unsatisfied

Details:

Can't tell:

b) क्या आप विस्थापन के लिए तैयार हैं?

i) Yes
ii) No
iii) Don't Know

c) क्यों नहीं?

Can't tell:

d) क्या जंगल के बाहर रहने से कोई फायदा या नुक्सान होगा?

Advantages:

Disadvantages:

Don't Know:

25. घर में काम करने वाले कितने सदस्य हैं?

26. आय का मुख्या साधन क्या है?

a. पशु-पालन

b. खेती

c. मजदूरी (FD)

d. मजदूरी (oth)

e. सर्विस (FD)

f. सर्विस (oth)

g. बिज़नेस/ कारोबार

27. माहवार आय (हज़ार में)	सालाना आय
1. 0 2. >0-2 3. >2-8 4. >8-16 5. >16-30 6. >30-50 7. >50	1. 0 2. >0-24000 3. >24000-96000 4. >96000-2 lk 5. >2-3.5 lk 6. >3.5-6 lk 7. >6 lk
Can’t tell:	

28. पिछले साल कितने और कौन से मवेशी बेचे :		
Type	No. sold (approx.)	Rate at which sold (average)
गाय		
बैल		
बछड़ा		
भैंस		
बछड़ा		
बकरी		
बच्चा		
भेड़		
बच्चा		
ऊठ		
बच्चा		
गधे		
बच्चा		
सूअर		
बच्चा		
मुर्गी		

29. क्या आप के पास खेती की ज़मीन है? कितनी?

30. पिछले साल के फसल के बारे में जानकारी:			
फसल	पैदावार (कुंटल / बोरी)	कितना बेचा (कुंटल / बोरी)	दाम (per quintal)

31. जंगली जानवर जो फसल का नुक्सान करते हैं (सबसे ज़्यादा से सबसे काम)

1.

2.

3.

4.

5.

32. a) क्या आप पावर फेंसिंग लगवाने को तैयार हैं?

i) हाँ ii) ना

b) इसकी कीमत तक़रीबन दस हज़ार रूपए है, आप अपनी तरफ से इतने पैसे लगाने को तैयार हैं? यदि नहीं तो कितना व्यय कर सकते हैं?

i) हाँ ii) ना

Amount:

c) क्या आप इसका रखरखाव करने के लिए तैयार हैं?

i) हाँ ii) ना

d) क्या इसकी एवज में आप जंगल जाना बंद कर देंगे?

i) हाँ ii) ना

Appendix 6. 4: List of websites referred to for accessing information on livestock farming

Information sought	Website(s) referred
Feeding cost of buffalo per day	http://agrihealthfoods.com/start-buffalo-dairy-farm-cost-india/
	http://www.godhan.in/news/minimum-feeding-cost-murrah-buffalo/
Feeding cost of dairy cow per day	http://dairyknowledge.in/content/feeding-cost-day
	https://agritech.tnau.ac.in/expert_system/cattlebuffalo/Breeding%20management%20of%20cattle%20and%20buffaloes-2.html#introduction
	https://dir.indiamart.com/impcat/animal-feed.html
	http://www.ikisan.com/da_feedforcattle.htm
Goat farming	https://www.goatfarming.in/goat-farming-cost-profit
	https://www.roysfarm.com/goat-farming-in-india
Lactation length and dry period	https://agritech.tnau.ac.in/expert_system/cattlebuffalo/Breeding%20management%20of%20cattle%20and%20buffaloes-2.html#introduction
Medical expenses	http://agrihealthfoods.com/start-buffalo-dairy-farm-cost-india/
Insurance	http://dahd.nic.in/
	http://agrihealthfoods.com/start-buffalo-dairy-farm-cost-india/
Mortality (buffalo)	http://www.cirb.res.in/index.php?option=com_content&view=article&id=209%3Areduction-in-mortality-in-murrah-buffaloes&catid=107%3Alatest&Itemid=11&lang=en
Mortality (buffalo calf)	http://www.cirb.res.in/index.php?option=com_content&view=article&id=209%3Areduction-in-mortality-in-murrah-buffaloes&catid=107%3Alatest&Itemid=11&lang=en
Mortality (cow calf)	https://www.cabi.org/ISC/FullTextPDF/2010/20103049235.pdf

Appendix 6. 5: List of websites referred to for accessing information on yield, costs of cultivation and market price of various agricultural and horticultural crops

Crop	Website(s) referred
Sesamum (Til)	http://mpkrishi.mp.gov.in/
Mustard (Sarson/Rai)	http://mpkrishi.mp.gov.in/hindisite/krishi_capsules_sarso_New.aspx
Red gram (Tur/Arhar)	https://www.indiaagronet.com/indiaagronet/crop%20info/tur.htm
	http://agritech.tnau.ac.in/agriculture/
Chickpea/gram (Chana)	http://www.agrifarming.in/chickpea-farming/
Lentil (Masoor)	http://www.agriwatch.com
Black gram (Urad)	http://www.agriwatch.com/guar/guar-seed/
	https://www.indiaagronet.com
	http://mpkrishi.mp.gov.in/
Green gram (Moong)	https://agritech.tnau.ac.in/agriculture/agri_costofcultivation_indexpage12.html
Groundnut	https://agritech.tnau.ac.in/agriculture/agri_costofcultivation_indexpage12.html
Pearl Millet (Bajra)	http://www.agrifarming.in/bajra-cultivation/
	http://mpkrishi.mp.gov.in/
Maize (Makka)	http://mpkrishi.mp.gov.in/
Barley (Jau)	http://www.agrifarming.in/barley-cultivation/
Paddy (Dhaan)	http://agritech.tnau.ac.in/agriculture/agri_costofcultivation_rice.html
	http://mpkrishi.mp.gov.in/
Sorghum (Jwar)	http://agritech.tnau.ac.in/agriculture/
Cluster bean (Guar/Gawar)	https://www.agrifarming.in/cluster-bean-farming/
	http://www.agriwatch.com/guar/guar-seed/
	http://mpkrishi.mp.gov.in/hindisite/krishi_capsules_guar_New.aspx

	http://aciguarclutivationinindia.blogspot.com/p/harvesting-pods-of-guar-become-ready.html
Onion	https://www.agrifarming.in/onion-farming/
	http://mpkrishi.mp.gov.in/
Lady finger (Bhindi)	http://mpkrishi.mp.gov.in/
	https://www.agrifarming.in/ladies-finger-farming/
	https://www.agriinfo.in
	http://agritech.tnau.ac.in/horticulture/
Taro root (Arvi)	https://www.agrifarming.in/taro-root-farming/
Potato	https://www.commodityonline.com/mandiprices/potato/rajasthan/168/33
Tomato	http://mpkrishi.mp.gov.in/
Mandi prices	http://www.agri.live/India_Market_Prices_view.php?agriculture=India_Market_Prices
District wise yields	http://www.mp.gov.in/en/mp-krishi/arg-st/districtwisearea
MSP for crops	http://pib.nic.in/newsite/PrintRelease.aspx?relid=122585
	http://pib.nic.in/newsite/PrintRelease.aspx?relid=130275
	http://www.mp.gov.in/en/mp-krishi/arg-st/districtwisearea

Appendix 6. 6: List of websites referred to for accessing information on salaries and wages

Income source	**Websites referred**
Salary	http://www.naukrihub.com/salary-in-india
	https://www.payscale.com/?_ga=2.232150039.965667122.1625417279-1028469006.1625417279
	https://www.glassdoor.co.in/Monthly-Pay
	https://targetstudy.com/professions/bus-conductor.html
	https://in.indeed.com/career/registered-nurse/salaries/Madhya-Pradesh
	https://www.fresherslive.com/govt-jobs
Minimum Wage	https://pib.gov.in/
	https://paycheck.in/salary/minimumwages

Appendix 6. 7: Household income categories

Income categories	Reasoning for categorization	Household income code
>0-27000	Because for a family of five earning members INR 27000 per annum was the poverty line (PL) suggested by the Tendulkar committee report, 2009	2
27000-60000	Because for a family of five earning members INR 58320 per annum was the PL suggested by the Rangarajan committee report, 2014	3
60000-1LK	Just above PL, 3.2USD/day is also the PL suggested by World Bank for lower income countries (like India)	4
1-2.5	Not poor but below tax slab, can be dubbed as lower middle class	5
2.5-5	first tax slab (old tax regime) can be dubbed as middle class	6
5-10	Second tax slab (old tax regime) can be dubbed as upper middle class	7
>10	Third or highest tax slab (old tax regime) can be dubbed as rich	8

*Last two categories were merged before using the variable in the model because there were very few households with income falling within the last category

Appendix 7. 1: Comparison of habitat characteristics and anthropogenic disturbance among Sariska and Panna Tiger Reserves

Habitat characteristics	Panna Tiger Reserve		Sariska Tiger Reserve		T-test	F-test	p - value
	Mean	Sample size (n)	Mean	Sample size (n)			
Core area (km^2)	576.14		881				
Buffer area (km^2)	1002.42		334				
Villages (completely or partially inside the core)	5		28				
Average distance of villages from tiger home range centers (Km)	17.04		12.5				
NDVI (summer)	0.15	1520471	0.18	2493120	971.84		$p< 0.001$
NDVI standard deviation	0.03	1520471	0.03	2493120		1.00	$p< 0.001$
NDWI (summer)	-0.18	1520471	-0.21	2493120	-854.12		$p< 0.001$
NDWI standard deviation	0.04	1520471	0.03	2493120		1.78	$p< 0.001$
Wild ungulate density (N/km^2)	27.78	605	35.99	518	35.50		$p< 0.001$
Ungulate density standard deviation	2.61	605	4.94	518		0.28	$p< 0.001$
DEM	350.69	1494710	481.22	2521090	1375.69		$p< 0.001$

DEM standard deviation	83.84	1494710	96.38	2521090		0.76	p< 0.001
Slope (%)	9.58	1494710	21.4	2521090	716.94		p< 0.001
Slope standard deviation	9.93	1494710	18.65	2521090		0.28	p< 0.001
Terrain Ruggedness Index	63.68	1494710	22.43	2521090	-1654.10		p< 0.001

Appendix 7. 2: Table summarizing all the highly correlated variables, among the variables used for modelling attitude of local communities towards tigers in STR and PTR

PTR: all sampled households	
Continuous vs continuous: Kendall's tau b[a]	
Value of fodder obtained from forest all cattle	Value of fodder obtained from forest all livestock
Total livestock lost	Total monetary loss
Categorical vs continuous: binomial logistic regression[c]	
Gender	Total livestock lost
Loss	Total livestock owned
Loss	Value of fodder obtained from forest all cattle
Categorical vs continuous: multinomial logistic regression[c]	
Caste/community	Total livestock owned
Caste/community	Total Income FP
PTR: Households facing livestock loss	
Continuous vs continuous: Kendall's tau b[a]	
Value of fodder obtained from forest all cattle	Value of fodder obtained from forest all livestock
Total monetary loss	Cost of last livestock lost
Categorical vs categorical: Cramer's V[b]	
Species of last livestock lost	Loss due to herbivores
Categorical vs continuous: multinomial logistic regression[c]	
Compensation satisfied	Age
Compensation satisfied	Total livestock owned
Caste	Tot Income FP
STR: all sampled households	

Continuous vs continuous: Kendall's tau b[a]	
Value of fodder obtained from forest all cattle	Value of fodder obtained from forest all livestock
Total livestock lost	Total monetary loss
Categorical vs continuous: binomial logistic regression[c]	
Gender	Total livestock owned
Loss	Total livestock owned
Categorical vs continuous: multinomial logistic regression[c]	
Caste/community	Total livestock owned
Caste/community	Value of fodder obtained from forest all cattle
Caste/community	Value of fodder obtained from forest all livestock
Caste/community	Total livestock lost
Caste/community	Total monetary loss
STR: Households facing livestock loss	
Continuous vs continuous: Kendall's tau b[a]	
Value of fodder obtained from forest all cattle	Value of fodder obtained from forest all livestock
Categorical vs categorical: Cramer's V[b]	
Caste/community	Species of last livestock lost
Categorical vs continuous: binomial logistic regression[c]	
Gender	Total livestock owned
Gender	Total monetary loss
Age of last livestock lost	Total monetary loss
Age of last livestock lost	Cost of last livestock lost
Categorical vs continuous: multinomial logistic regression[c]	
Caste/community	Total livestock owned
Caste/community	Total livestock lost

Species of last livestock lost	Total monetary loss
Species of last livestock lost	Cost of last livestock lost
Compensation received	Total monetary loss
Compensation received	Cost of last livestock lost
Compensation received	Compensation satisfied
Compensation satisfied	Total monetary loss

a. For continuous vs continuous: correlation with $r>0.7$ considered high correlation
b. For categorical vs categorical: correlation with Cramer's $V>0.5$ considered high correlation
c. For categorical vs continuous: all variables with Wald's test of logistic regression significant at $\alpha=0.05$ and very high log odd values, were considered highly associated

Appendix 7. 3: Multinomial logistic regression model explaining the attitude of people towards tiger in Sariska Tiger Reserve: parameter estimates

Attitude	Parameters	B	Std. Error	Wald	df	p-value	Exp (B)
Neutral	Intercept	−0.938	0.342	7.531	1	0.006	
	Education	−0.003	0.001	6.573	1	0.010	0.997
	Value of fodder obtained from forest	−0.153	0.061	6.401	1	0.011	0.858
	(Gender=F)	1.624	0.404	16.174	1	0.000	5.072
	(Gender =M)	0^b	.	.	0	.	.
Negative	Intercept	−0.430	0.249	2.997	1	0.083	
	Education	−0.001	0.001	2.310	1	0.129	0.999
	Value of fodder obtained from forest	−0.052	0.032	2.685	1	0.101	0.949
	(Gender=F)	1.595	0.309	26.713	1	0.000	4.930
	(Gender =M)	0^b	.	.	0	.	.

a. The reference category is: positive.
b. This parameter is set to zero because it is redundant.

Appendix 7. 4: Multinomial logistic regression model explaining the attitude of people towards tiger in Panna Tiger Reserve: parameter estimates

Attitude	Parameters	B	Std. Error	Wal d	df	p-value	Exp (B)
Neutral	Intercept	−0.10 1	0.704	0.02 1	1	0.886	
	Education	−0.05 6	0.046	1.46 7	1	0.226	0.94 6
	Total livestock	0.013	0.047	0.07 1	1	0.790	1.01 3
	Total HH income	−0.10 0	0.157	0.40 4	1	0.525	0.90 5
	Total income FP	0.000	0.000	0.00 4	1	0.949	1.00 0
	(Gender=M)	1.161	0.411	7.96 8	1	0.005	3.19 4
	(Gender=F)	0^b	.	.	0	.	.
	(Village location=inside)	0.759	0.496	2.34 0	1	0.126	2.13 5
	(Village location = outside)	0^b	.	.	0	.	.
	(Loss due to herbivores= 0)	−0.70 0	0.436	2.58 1	1	0.108	0.49 6
	(Loss due to herbivores= 1)	0^b	.	.	0	.	.
Negative	Intercept	1.411	0.556	6.42 9	1	0.011	
	Education	−0.07 9	0.036	4.73 9	1	0.029	0.92 4
	Total livestock	0.065	0.036	3.27 2	1	0.070	1.06 7
	Total HH income	−0.21 8	0.126	3.00 8	1	0.083	0.80 4
	Total income FP	0.000	0.000	0.55 6	1	0.456	1.00 0
	(Gender=M)	0.438	0.353	1.53 9	1	0.215	1.55 0
	(Gender=F)	0^b	.	.	0	.	.

	(Village location=inside)	0.720	0.402	3.196	1	0.074	2.053
	(Village location = outside)	0[b]	.	.	0	.	.
	(Loss due to herbivores =0)	−0.412	0.332	1.544	1	0.214	0.662
	(Loss due to herbivores =1)	0[b]	.	.	0	.	.

a. The reference category is: positive.
b. This parameter is set to zero because it is redundant.

Appendix 7. 5: Multinomial logistic regression model explaining the attitude of people facing loss towards tiger in Sariska Tiger Reserve: parameter estimates

Attitude	Parameters	B	Std. Error	Wald	df	p-value	Exp (B)
Neutral	Intercept	−1.324	0.884	2.243	1	0.134	
	Value of fodder obtained from forest	0.000	0.000	2.786	1	0.095	1.000
	(Gender=F)	1.793	0.711	6.354	1	0.012	6.010
	(Gender =M)	0^b	.	.	0	.	.
	(Species of last livestock lost =Buffalo)	0.298	0.792	0.141	1	0.707	1.347
	(Species of last livestock lost =Cow)	0^b	.	.	0	.	.
Negative	Intercept	0.024	0.550	0.002	1	0.965	
	Value of fodder obtained from forest	0.000	0.000	0.210	1	0.647	1.000
	(Gender=F)	1.442	0.535	7.274	1	0.007	4.228
	(Gender =M)	0^b	.	.	0	.	.
	(Species of last livestock lost =Buffalo)	−0.898	0.519	2.991	1	0.084	0.407
	(Species of last livestock lost =Cow)	0^b	.	.	0	.	.

a. The reference category is: positive.
b. This parameter is set to zero because it is redundant.

Appendix 7. 6: Multinomial logistic regression model explaining the attitude of people facing loss, towards tiger in Panna Tiger Reserve: parameter estimates

Attitude	Parameter	B	Std. Error	Wald	df	p-value	Exp (B)
Neutral	Intercept	11.154	3.353	11.065	1	0.001	
	Value of fodder obtained from forest	0.000	0.000	0.021	1	0.885	0.999
	Total livestock lost	−19.320	0.000	.	1	.	4.067E-9
	Age	0.088	0.040	4.802	1	0.028	1.092
	Total livestock owned	0.223	0.143	2.443	1	0.118	1.250
	(Age of last livestock lost =mature)	2.789	1.961	2.022	1	0.155	16.259
	(Age of last livestock lost =immature)	0^b	.	.	0	.	.
	(Compensation received=Yes)	−3.088	1.388	4.953	1	0.026	0.046
	(Compensation received=No)	0^b	.	.	0	.	.
	(Species of last livestock lost=Cow)	2.226	1.392	2.557	1	0.110	9.259
	(Species of last livestock	2.615	2.079	1.582	1	0.208	13.673

	lost=Buffalo)						
	(Species of last livestock lost=Bullock)	0^{b}	.	.	0	.	.
Negative	Intercept	−5.439	2.532	4.615	1	0.032	
	Value of fodder obtained from forest	0.000	0.000	3.394	1	0.065	0.985
	Total livestock lost	−0.841	0.543	2.400	1	0.121	0.431
	Age	0.072	0.034	4.475	1	0.034	1.074
	Total livestock owned	0.231	0.127	3.302	1	0.069	1.259
	(Age of last livestock lost =mature)	4.517	1.851	5.955	1	0.015	91.518
	(Age of last livestock lost =immature)	0^{b}	.	.	0	.	.
	(Compensation received=Yes)	−1.541	0.758	4.133	1	0.042	0.214
	(Compensation received=No)	0^{b}	.	.	0	.	.
	(Species of last livestock lost=Cow)	0.331	0.746	0.196	1	0.658	1.392
	(Species of last livestock lost=Buffalo)	2.782	1.468	3.591	1	0.058	16.157

	(Species of last livestock lost=Bullock)	0^b	.	.	0	.	.

a. The reference category is: positive.
b. This parameter is set to zero because it is redundant.

List of publication and conferences

Malviya, M., Kumar, V., Mandal, D., Sarkar, M. S., Nigam, P., Gopal, R., Sankar, K., Umapathy, G., & Ramesh, K. (2018). Correlates of physiological stress and habitat factors in reintroduction-based recovery of tiger (*Panthera tigris*) populations. *Hystrix, the Italian Journal of Mammalogy*, *29*(2), 195-201. https://doi.org/10.4404/hystrix-00063-2018

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10th International Conference
on Behaviour, Physiology and Genetics of Wildlife

September 28th to October 1st, 2015
Berlin, Germany

Certificate of Attendance

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SPATIO-TEMPORAL PATTERNS OF CONFLICT BETWEEN REINTRODUCED TIGER AND LOCAL COMMUNITIES IN SARISKA AND PANNA TIGER RESERVES, INDIA

at Dept of Zoology, JB Campus, Bangalore University, Karnataka, Dec 04-05, 2018.

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Research Article

Correlates of physiological stress and habitat factors in reintroduction-based recovery of tiger (*Panthera tigris*) populations

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These tiger reintroductions were implemented as per the protocol issued by National Tiger Conservation Authority (NTCA), which is the supreme authority in India, as far as tiger management is concerned. In this protocol, NTCA has incorporated IUCN reintroduction specialist groups' guidelines. In term of field execution, the chief Wildlife Warden is empowered to carry out such management interventions, but because India is signatory to IUCN, the guidelines laid down by IUCN are generally followed and in this specific context has been incorporated through NTCA protocols.

Abstract

The ever-increasing human presence in tiger occupied landscapes mandates a better understanding of its effects on the species. The loss of tigers to conflict and poaching have been well established, while the indirect effects of human induced stress have not been widely discussed. Anthropogenic factors have driven tiger populations to extinction in Sariska and Panna Tiger Reserves in India. The reintroduction of tigers in these two reserves resulted in contrasting reproductive outcomes and population growth. In this paper, we demonstrate relationships between habitat factors and stress affecting reproduction of reintroduced animals in two contrasting wild tiger populations. The tiger population in Panna grew rapidly and reached carrying capacity within five years, while the Sariska population struggled with strikingly slow growth rate. Although past studies have linked anthropogenic disturbance to stress and low reproductive outcome in wild animals, we argue that it is the complexity and quality of the habitat that influence how animals perceive and cope with this disturbance, resulting in chronic stress and thereby poor reproduction. We quantified fecal glucocorticoid metabolite (FGM), prey density, terrain complexity, cover, water availability and anthropogenic disturbances at both study sites. As predicted, tigers in the population with low reproduction rate (Sariska) had higher FGM concentrations than in the population with high reproduction rate (Panna). We conclude that secure habitat conditions supported by terrain complexity, optimal prey, water availability and low anthropogenic disturbance determine levels of chronic stress, breeding success and population growth of tigers. Therefore, large carnivore reintroductions should consider physiological stress and suitable habitats at fine scale, for realistic population growth projections and adaptive management strategies.

Introduction

Global tiger (*Panthera tigris*) populations continue to face challenges from poaching, habitat loss, prey depletion and anthropogenic disturbances (Dinerstein et al., 2007). Additionally, tigers occupying fringe areas of reserves or unprotected forest patches in human dominated landscapes are exposed to anthropogenic pressures. This may lead to negative interactions that are stressful and sometimes fatal to both humans and tigers. Two tiger reserves in India, Sariska Tiger Reserve (STR) and Panna Tiger Reserve (PTR) experienced local extinction of tigers in 2008 and 2009, respectively, largely due to poaching, requiring reintroduction to mitigate the loss. Accordingly, eight adult tigers (three males and five females) were translocated from the nearby Ranthambore Tiger Reserve (RTR) to STR between 2008 and 2013 (Sankar et al., 2010). Similarly, seven tigers (two males and five females) were translocated from Bandhavgarh, Kanha and Pench Tiger Reserves to PTR between 2009 and 2015 (Sarkar et al., 2016).

Reintroduction of large mammals has emerged as one of the key management and conservation tools across the globe (Ripple and Beschta, 2003; Hayward, 2007, 2009). However, the reintroduction of a large carnivore such as tiger, in a populous country like India, with growing demands for land and increasingly degrading natural habitats, is a complex and challenging task (Johnsingh and Madhusudan, 2009). The success of reintroduction programs is generally measured in terms of settling behavior, fecundity and survivorship of the introduced animals and that of F1 (first generation) offspring (Weeks et al., 2011). The reintroduced population in PTR bred successfully and experienced rapid population growth (to >40 individuals in nine years) whereas no successful breeding was recorded in STR for the first four years after reintroduction and subsequent breeding contributed to only marginal population growth (to 15 individuals in ten years). Although the number of founder animals and broad contours of conservation problems and responses were similar in these two reserves, significant variation in breeding success and population growth patterns mandated detailed investigation because conservation investments have been significant in both sites. Furthermore, since these were the first successful reintro-

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ductions of Indian tigers, it was important to learn from the challenges that these populations were facing, to be able to guide such endeavors in the future. We approached this investigation from the fundamental physiological response of tigers to a new environment, focusing on glucocorticoid (GC) responses to human disturbance and habitat correlates.

An individual's body typically releases GCs (cortisol and corticosterone), the hormones produced by activation of hypothalamic-pituitary-adrenal (HPA) axis, in response to challenges posed by its environment, which may be termed as stressors (Sapolsky et al., 2000; Reeder, 2005). The GCs are secreted in the body to help prepare an individual against external factors, channeling the body's energy to effectively cope with immediate stressful stimuli (Wingfield and Kitaysky, 2002). By doing so GCs help the body deal with the harmful effects of stress called "allostatic load" (McEwen, 2007). In case the stressful state continues for a prolonged period of time, excess GCs are released, leading to chronic stress (McEwen, 2007). Excess GCs often negatively affect reproduction. The various negative consequences of stress on reproductive capacity of animals include delay in timing of reproduction, low release of reproductive hormones, lower fertility, higher inter-birth intervals, abortions and impairment of erectile function in males (Sapolsky et al., 2000; Sapolsky, 2004; Schoech, 2009; Whirledge et al., 2013). Certain species that are semelparous or individuals that have very few breeding opportunities are able to reproduce even under stressful conditions, but the mechanism by which they cope with stress and successfully reproduce are genetically determined, as well as environment dependent (Weeks et al., 1995; Wingfield and Sapolsky, 2003). In contrast, an iteroparous species (such as tiger) which has a comparatively longer life span and would get multiple opportunities to reproduce, will make decisions related to parental investment cautiously and might choose its own survival over that of offspring, resulting in termination of pregnancy or litter abandonment (Frid and Dill, 2002).

Studies suggest that animals perceive humans as predators and as a result are stressed by their presence (Frid and Dill, 2002; Beale and Monaghan, 2004; Smith, 2017). The energy tradeoff strategy the animal applies to predation risk is also applied in case of non-lethal human activities (Frid and Dill, 2002; Stankowich, 2008). Previous studies have established that anthropogenic disturbances increase stress hormone levels in several species (Creel et al., 2002; Ellenberg et al., 2006; Van Meter et al., 2009; Janin et al., 2011; Creel et al., 2013; Knapp et al., 2013).

Regarding our study sites, there are 2216 families in the 28 villages inside STR, with a total population of 11964 humans and 32704 livestock (Rajasthan Forest Department Record 2008). Two state highways (Alwar-Thanagazhi-Jaipur and the Sariska-Kalighati-Tehla) which are over 44 km in length, traverse through the designated national park. According to STR management records, from mid-2011 to mid-2014, a total of 77794 vehicles entered through one of the gates of Sariska national park area. Within this period, more than 131000 visitors entered the designated national park area. Of these, 89827 were eco-tourists and 41178 were pilgrims. The high vehicle and visitor count can be attributed to STR being a famous tourist destination, both because of its diverse fauna as well as historical structures and temples. Tigers in STR have been reported to have high fecal glucocorticoid metabolites (FGM) concentrations, linked to the disturbance in their habitat (Bhattacharjee et al., 2015). PTR, on the other hand, has only few villages on its fringes and experiences low tourism pressure, but the FGM concentrations of its tigers has not been previously measured.

Given this background, we hypothesized that breeding success of a reintroduced tiger population could be a function of GC response and habitat constraints. To test this hypothesis, we examined the physiological response to anthropogenic disturbances in these two reintroduced tiger populations, with the aim of contributing to the scientific management of large carnivores and their reintroduction, globally.

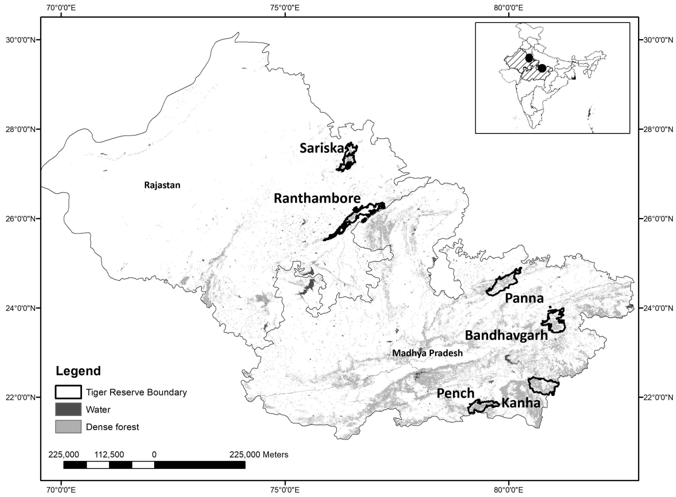

Figure 1 – Map showing location of Panna and Sariska tiger reserves along with their source population viz. Ranthambore, Kanha, Pench and Bandhavgarh tiger reserves.

Materials and methods

STR (27°5′ N to 27°33′ N and 76°17′ E to 76°34′ E) is situated in Alwar district of Rajasthan in India (Fig. 1, Tab. S1). This semi-arid tract lies in the Aravalli Hills, with altitude ranging between 540 and 777m a.s.l. and receives an annual rainfall of around 600 mm (Rodgers and Panwar, 1998). The major forest types here are tropical dry deciduous forest and tropical thorn forest (Champion and Seth, 1968). PTR (24°27′ N to 24°46′ N and 79°45′ E to 80°9′ E) is situated in Panna and Chhatarpur districts of Madhya Pradesh in India (Fig. 1, Tab. S1). The core zone comprises Panna National Park and Gangau Wildlife Sanctuary. Its altitude ranges between 330 and 540 m a.s.l. and it receives an annual rainfall of up to 1100 mm (Karanth et al., 2004). The major forest type here is dry deciduous forest (Meher-Homji, 1990).

Sample collection, hormone extraction and measurement

We collected fresh tiger scat samples from STR and PTR while monitoring reintroduced tigers based on VHF and GPS telemetry. Search efforts were focused on the home range of tigers and specifically around kill sites. Since all the tigers were radio-collared (minimum time between collaring and sample collection was approximately 1.5 months), they were monitored 24 hours a day, seven days a week. As such, it was possible to match fecal samples to individual tigers based on monitoring data, including inspection of kill sites. Freshness of samples was visually estimated, and only samples that were considered fresh were collected. We collected a total of 103 tiger scat samples from STR, and 144 from PTR between January 2013 and May 2014 for analyses of FGM concentrations and cataloged with its location (latitude and longitude), ID of the individual, date of collection and freshness. A total of 119 scat samples from PTR and all 103 from STR, were identified to individual tiger by correlating theirs and that of their kill's GPS location with that of scat, by tiger monitoring teams. Thereby, a total of nine individual tigers in PTR (of which five were founders and four were F1) and seven in STR (all founders), were sampled. The scat samples were oven dried at 80 °C for 48 hours. We extracted fecal steroid metabolites according to previously published protocols (Brown et al., 1994; Umapathy et al., 2013). We weighed 0.2-0.3 g of the dried, mixed and pulverized fecal sample and boiled it in 5 ml of 90% aqueous ethanol for 20 min. After centrifugation at 500 gf for 10 min, we recovered the supernatant and re-suspended the pellet in 5 ml of 90% aqueous ethanol, vortexed for one minute and re-centrifuged to recover the supernatant. We then combined both the ethanol supernatants, dried (in an oven at 40 °C), re-suspended in 1 ml of absolute methanol, vortexed for one minute and sonicated for 30 seconds (Branson Ultrasonics 250, CT, USA) to free particles adhering to the wall of the test tube. Samples were then stored at −20 °C until hormone assay. We examined extraction efficiency of protocols by adding known amount of radio labeled hormones in randomly selected samples before extraction. Extraction efficiencies were calculated as percentage of the amount of labeled hormones observed relative to the amount expected; these ranged between 85.2 and 93.4% (n=22).

We measured FGM concentration by cortisol enzyme immunoassay (EIA) (C. Munro, University of California, Davis), which has been successfully validated in various mammals, including tigers (Young et al., 2004; Narayan et al., 2013; Bhattacharjee et al., 2015). The cortisol polyclonal antibody (R4866) was diluted to 1:9000, HRP-conjugated cortisol 1:250000 and cortisol standards (1000-1.95 pg/well). The cross-reactivity of cortisol antibody with cortisol was 100%, prednisolone 9.90%, prednisone 6.30%, cortisone 5%, and <1% with corticosterone, desoxycorticosterone, 21 desoxycortisone, testosterone, androstenedione, androsterone, and 11-desoxycortisol (Young et al., 2004). Assay sensitivity was calculated at 90% binding and found to be 1.95 pg/well. To calculate inter and intra assay coefficients we pooled the fecal extracts and divided these into high (spiked with standards) and low (not spiked) quality controls, and used these on each EIA plate (n=10). The intra and inter coefficient of variation (CV) were 5.30% (n=10) and 9.60% (n=10) respectively. The cortisol EIA demonstrated parallel displacement curves between pooled serial dilutions of fecal samples and standards. We performed the EIA procedure as described previously (Young et al., 2004; Kumar et al., 2014; Umapathy et al., 2015).

Prey availability estimation

We used distance-sampling method for tiger prey species population estimation (Buckland et al., 2001). We surveyed a total of 41 and 48 line transects each up to 2 km in length in PTR and STR respectively, during the winter 2012-13 and 2013-14. All the line transects in both the reserves were walked in replicates of three. We combined data for the entire study period and calculated prey encounter rate for each transect. Further data analysis was done using conventional distance sampling engine in the software Distance 6.2 (Thomas et al., 2010). We selected suitable truncation distances to achieve better model fit of the data. Models were selected on the basis of quantile-quantile plot, chi-square goodness of fit test and lowest value of Akaike information criteria (AIC) (Buckland et al., 2001; Thomas et al., 2010).

Assessment of habitat conditions

We quantified vegetation indices viz. canopy cover and shrub abundance in 15 m circular plots laid at every 400 m on the line transects (Jhala et al., 2009). A total of 235 and 234 circular plots were laid in STR and PTR, respectively. Within each plot, we made visual estimation for canopy cover and scored shrub cover according to its abundance.

For further understanding the vegetation cover, we calculated normalized difference vegetation index (NDVI) (Rouse et al., 1974) for both the reserves based on LANDSAT 8 (OLI/TIRS) scenes; downloaded for STR (scene id LC81470412013140LGN01, downloaded on 24 December 2014) and PTR (scene id LC81440432013119LGN01, downloaded on 20 April 2015) from USGS website for the month of May and April 2013, respectively. We used raster calculator in ArcGIS 10.1 (ESRI, 2012) for calculating NDVI by the formula: $\mathrm{NDVI} = \frac{(\text{near infrared} - \text{red})}{(\text{near infrared} + \text{red})}$.

We downloaded Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) data from the USGS global visualization viewer website, for both the sites. We used slope tool in spatial analyst in ArcGIS 10.1 to calculate slope from DEM layers (ESRI, 2012). Additionally, we calculated topographic ruggedness index or terrain ruggedness index (TRI) that measures elevation difference between a cell and mean of its eight neighboring cells (Riley, 1999) for both reserves. We used raster calculator in ArcGIS 10.1 (ESRI, 2012) to calculate TRI by the formula $\mathrm{TRI} = \sqrt{\left|(\max(3\times3)^2 - \min(3\times3)^2)\right|}$ (Cooley, 2016).

The scenes we used for calculating NDVI, were also used to calculate normalized difference water index (NDWI) (McFeeters, 1996) with raster calculator in ArcGIS 10.1 (ESRI, 2012) by the formula $\mathrm{NDWI} = \frac{(\text{green} - \text{near infrared})}{(\text{green} + \text{near infrared})}$.

Status of anthropogenic disturbances

We quantified anthropogenic disturbance indices in the circular plots (as discussed under section "Assessment of habitat conditions"), at both the sites. In each plot, we counted all the lopped (only branches were cut) and cut (cut to stump) trees and ranked weed abundance. We divided tiger occupied area in both STR and PTR into 2×2 km grids and deployed camera trap (Cuddeback Attack) pairs, within these grids. In PTR, we deployed camera traps in 109 locations accounting for 7459 trap nights, in STR, camera traps were deployed in 104 locations accounting for 1827 trap nights. We then manually counted the number of livestock, humans, and vehicles captured in each camera trap and calculated encounter rates (total no. of captures/total trap nights). We considered livestock as an anthropogenic disturbance factor since it was often accompanied by humans and overgrazing by domestic stock can lead to habitat degradation.

Statistical analyses

We subjected FGM concentrations obtained for both the reintroduced tiger populations to descriptive statistics. After checking for normality, we log transformed FGM values and used these as dependent variable in linear mixed effect model (LMM) with tiger id as random effect and tiger reserve id and sex as fixed effects, to explore the effects of tiger reserve, sex and individual tiger on FGM concentrations.

We masked rasters viz. NDVI, NDWI, DEM, Slope, and TRI, with STR and PTR boundary polygons using ArcMap's extract by mask tool (ESRI, 2009). We then obtained means and standard deviations (SD) of all the listed variables from these rasters for both the reserves. Difference between NDVI, NDWI, ungulate density, livestock density, DEM, slope and TRI, of the two reserves, were tested using independent samples t-test and their standard deviations using f (variance ratio) test. We also compared means of canopy cover, prey, human, livestock, and vehicle encounter rates, and, cutting and lopping intensity rates between the reserves, using Mann Whitney U test (data were not normally distributed). All statistical tests and modeling were done in statistical package for the social sciences (SPSS) versions 15 and 23 (SPSS 2006; IBM, 2015). Statistical significance levels were set at $p<0.05$.

We interpolated canopy cover, prey, human, livestock, and vehicle encounter rates, cutting and lopping intensity rates, as well as their SD to create rasters, using the Geostatistical wizard in ArcMap 10.1 (De Smith et al., 2007; Cressie, 2015; ESRI, 2012). After trimming the outliers, testing for assumptions and transforming the data where necessary, we used Inverse distance weighting (IDW), Ordinary kriging (OK) and Empirical Bayesian Kriging (EBK) interpolation tools to create rasters. Only in case of vehicle encounter rate for STR we used IDW tool, since its probability distribution was highly non-Gaussian, even after transformation. The rasters were selected after comparing variograms and root mean square errors, for all listed variables, for both the reserves (Tab. 1).

Table 1 – Comparison of root mean square errors (RMSE) of rasters created using different interpolation tools for all habitat variables of Panna and Sariska tiger reserves.

	Panna Tiger Reserve				Sariska Tiger Reserve			
Variable (stressor)	**IDW**[1]	**OK**[2]	**EBK**[3]	**MS**[4]	**IDW**[1]	**OK**[2]	**EBK**[3]	**MS**[4]
Human encounter rate	1.1	1.07	1.06	EBK	1.43	1.38	1.39	OK
Vehicle encounter rate	5.12	5.19	4.92	EBK	0.95			IDW
Livestock encounter rate	2.61	3.1	3.13	OK	4.27	4.1	4.2	OK
Prey encounter rate	2.21	2.3	2.01	EBK	0.9	0.88	0.93	OK
Cutting frequency	2.16	2.01	1.99	EBK	1.6	1.5	1.5	EBK
Lopping frequency	0.97	0.9	0.89	EBK	6.85	6.4	6.5	OK
Canopy cover	0.16	0.15	0.15	EBK	0.16	0.15	0.16	OK

[1] IDW: Inverse distance weighting
[2] OK: Ordinary Kriging
[3] EBK: Empirical Bayesian Kriging
[4] MS: Method selected

On an average, daily movement of the tiger was 6.90 km/day for STR (no significant difference between sexes) (Bhattacharjee et al., 2015). Considering the daily movement as the radius, we drew buffers around each scat location. We extracted habitat and disturbance variables for each buffer from the rasters (created using interpolation tool, as discussed previously) using the zonal statistics as table 2 tool in ArcMap 10.5 (ESRI, 2016). Bivariate Pearson correlation was run and highly correlated variables (>0.7) were not used together in models.

We constructed LMM (Henderson et al., 1959; Duchateau et al., 1998) to explore the variables linked to log transformed FGM levels in STR in SPSS (IBM, 2015) with tiger id as random effect to account for repeated measures of FGM for individual animals. We also performed LMM for PTR, but found none of the variables to show significant effect on FGM levels, possibly due to inherently low stress in the population and low variance among the individuals. Therefore, we focused our analyses and interpretation primarily on the more disturbed STR population, which required management inputs to address the stress issues and improve reproductive outcome. This decision allowed us to streamline the content of the paper while avoiding the redundancy from PTR analyses. The transformed FGM values (dependent variable) had a normal distribution, and the residuals of all variables showed homoscedasticity and linear relationships. We used maximum likelihood or full model (FML) for model reduction and restricted maximum likelihood (REML) for the final model to get more accurate estimates of random effect. The significance of explanatory variables (fixed effect) was tested using Wald test. We explored canopy cover and its SD, prey, human and livestock encounter rates, vehicle encounter rate SD, cutting and lopping intensity rates, lopping SD, NDVI, NDWI, DEM, slope as well as, their SD (s), and, TRI, as fixed effects. We checked the variables for multicollinearity, only variables with variance inflation factor less than 10, were used together in a model. Stepwise backward model selection was based on partial p-values and model selection was based on AIC values.

Results

FGM concentrations of reintroduced tiger populations

The mean FGM concentration in the STR tiger population (mean±SD=50.14 ± 42.84 ng/g; n=103) was significantly higher than in the PTR population (20.29 ± 16.34 ng/g; n=144) (Tab. 2, 3). Tiger ID did not have a significant random effect on the covariance structure of our model (Wald's χ^2= 0.45, p=0.65).

There were no significant differences in FGM concentrations between the sexes, in either of the reserves (sex effect and sex by reserve interaction; all p>0.05; Tab. 3). In STR, FGM concentration for female tigers was 53.25 ± 42.62 ng/g (n=74) while for males it was 42.19 ± 43.12 ng/g (n=29). In PTR, it was 19.65 ± 16.11 ng/g (n=71) and 20.00 ± 14.09 ng/g (n=57) for females and males, respectively.

Prey and habitat conditions

Prey density estimates (including livestock) were 52.80 ± 7.10 n/km^2 in PTR and 199.50 ± 12.30 n/km^2 in STR. STR had higher wild ungulate prey density (Tab. S1, Fig. 2) and livestock density (85.20 ± 11.90 n/km^2) than PTR (39.80 ± 10.90 n/km^2). Average canopy cover and shrub abundance were higher for PTR (0.33 and 1.81, respectively) than STR (0.29 and 1.72, respectively). The difference was significant for shrub abundance (p=0.01) but not for canopy cover (p=0.53). NDVI during summer was higher for STR than PTR (Tab. S1). Mean elevation, slope and associated SD were higher in STR than PTR (Tab. S1). However, the TRI value was higher for PTR than STR. (Tab. S1). During summer in STR mean NDWI was lower than PTR (Tab. S1).

Regarding human disturbance, both lopping and weed presences were higher in STR (67% and 91% plots, respectively), as compared to PTR (22% and 71% plots, respectively), although woodcutting evidence (both old and new) was slightly higher in PTR (40% plots) than STR (31% plots). Mean lopping in STR (6.37 ± 8.19) was higher than in PTR (0.60 ± 1.50; p<0.001). There was no difference between sites in mean woodcutting (STR 1.06 ± 2.11; PTR 1.39 ± 3.28).

Mean livestock encounter rate for STR (μ=4.09 ± 5.94) was higher than for PTR (μ=3.19 ± 9.60; p<0.001). In contrast, vehicle presence was significantly higher in PTR (μ=4.57 ± 7.72) than STR (μ=0.50 ± 1.20; p<0.001). There was no difference in human encounter rate (STR μ=1.40 ± 1.97; PTR μ=1.02 ± 1.20; p=0.37).

Stress and stressor relationship

The selected LMM model retained tiger id as the random effect and included human encounter rate, canopy cover, NDWI SD (positive effects on FGM), TRI and DEM SD (negative effects on FGM) as fixed effects (Wald's χ^2=6.66; p< 0.001; Tab. 4). The random effect of tiger id was statistically not significant (Wald's χ^2= 0.69, p=0.49) implying that the repeated measures of same individuals in STR does not affect the model's covariance structure.

Table 2 – Fecal glucocorticoid metabolites (FGM) concentration of tigers sampled in Sariska tiger reserve (STR) and Panna tiger reserve (PTR).

Sl. no.	Tiger Reserve	Tiger ID	Generation	Sex	No. of samples	FGM (ng/g)	SD
1	STR	ST2	Founder	Female	12	39.5	19.37
2	STR	ST3	Founder	Female	25	55.01	54.75
3	STR	ST4	Founder	Male	8	42.87	29.82
4	STR	ST5	Founder	Female	14	52.95	37.5
5	STR	ST6	Founder	Male	21	41.94	47.87
6	STR	ST9	Founder	Female	15	63.42	45.24
7	STR	ST10	Founder	Female	8	49.86	28.25
1	PTR	T1	Founder	Female	16	26.13	13.98
2	PTR	T2	Founder	Female	28	25.81	21.89
3	PTR	T3	Founder	Male	16	18.73	17.63
4	PTR	T4	Founder	Female	5	27.14	23.05
5	PTR	T5	Founder	Female	7	13.26	13.57
6	PTR	P111	F1	Male	14	15.73	12.14
7	PTR	P112	F1	Male	4	19.72	12.97
8	PTR	P212	F1	Male	14	21.94	12.86
9	PTR	P213	F1	Female	15	14.49	9.6

Table 3 – Results of linear mixed-effect model to explain FGM concentrations' association with tiger reserve and sex of the sampled individuals (Dependent variable log FGM).

Parameter	Estimate	SE	df	t	p	95% CI	
Intercept	1.22	0.1	10.24	12.67	0.001	1.00	1.43
TRID	0.28	0.09	10.03	3.25	0.01	0.09	0.47
SEX=F	−0.05	0.11	9.81	−0.5	0.63	−0.29	0.18
SEX=M	−0.02	0.11	10.77	−0.18	0.86	−0.26	0.22
TRID * SEX	0.16	0.11	9.54	1.55	0.15	−0.07	0.40

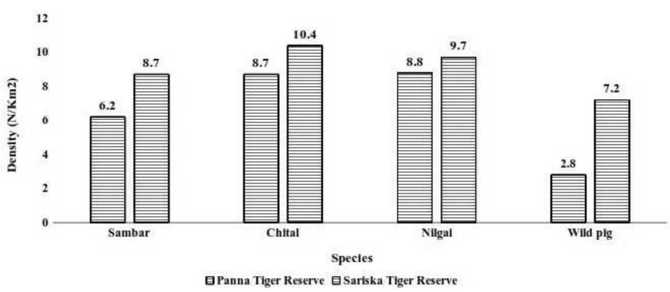

Figure 2 – Comparison of major tiger prey species densities between Panna and Sariska tiger reserves.

Discussion

Monitoring stress in reintroduced animals is important to ascertain animal wellbeing and reintroduction success (Teixeira, 2007; Gelling, 2012). The results of this study agree with our earlier findings (Bhattacharjee et al., 2015) that reintroduced tigers in STR have high indices of chronic stress. The mean FGM concentration of the Sariska tiger population was more than twice to that of Panna tiger population. We did not have pre-translocation FGM values for the studied tigers, so we cannot rule out completely a possible founder effect from the source site. However, we are convinced that this is unlikely. If the founders suffered chronic stress in their original habitat (RTR), the reproductive outcome would have been impaired in the source as well. RTR is one of the high-density tiger areas in India with a high reproductive rate (Jhala et al., 2015; Sadhu et al., 2017). Therefore, we presume that the individuals released were not affected by chronic stress. In terms of acute stress due to translocation, any stress hormone remains in body for a maximum period of 72 hours and stress levels are known to peak between 22 to 26 hours post stressful activity in big cats (Young et al., 2004). The scat samples used in this study were collected after a few months of translocation, excluding an effect of post translocation stress on our FGM measures.

High physiological stress in Sariska tigers necessitated the identification of habitat constraints that could act as stressors. For large carnivores such as tigers, preferred habitat parameters have been identified mainly as high prey density, forest contiguity, cover, thick understory, high altitude, steep slopes, proximity to water and low human impact, among others (Miquelle et al., 1999; Karanth and Sunquist, 2000; Sunarto et al., 2012; Takahata et al., 2014). Prey, the first essential requisite for tiger presence, was available in high densities to tigers in Sariska, and ungulate densities were higher in Sariska than in Panna. Given the low population of tigers and the overall high wild prey density in Sariska, the problem of demand-supply does not appear to exist and nutritional stress can be ruled out as the reason behind the poor breeding. Water, the second essential requisite, was a constraint in Sariska, with low water presence during summer months. Vegetation cover was high in Sariska and comparable to Panna. However, areas with high canopy cover in Sariska are frequented by both people and tiger; humans use it for fuelwood and fodder collection, tigers to get adequate cover from tropical heat and for hunting. Consequently, the role of terrain/topographic features which also provide cover, becomes significantly important. Topographic features not only provide cover to both prey and predator to avoid detection by each other (Canon et al., 1997; Lingle, 2002; Gorini, 2012), but also, impart protection and cover to animals from human and human-induced disturbances (Peyton, 1980; Sawyer, 2007). Low values of TRI in Sariska as compared to Panna, indicate inadequate terrain complexity. In Panna, the steep and rugged gorges act as escape cover and provide a secure environment for breeding tigers, which is absent in case of Sariska. Even so, the high FGM values in Sariska cannot be explained by insufficient water availability and terrain complexity alone. Low water availability can, however, elevate the basal cortisol levels and low terrain complexity reduce the chances of animals successfully avoiding encounters with humans, so that additional stress in the form of anthropogenic disturbance can lead to 'allostatic overload' in the animals (McEwen, 2007).

The results of various anthropogenic disturbance indices as assessed by us revealed that overall anthropogenic disturbance was significantly higher in Sariska as compared to Panna. Sariska had higher lopping, weed and livestock presence than PTR. In STR, the intensity of lopping was higher than cutting, reflecting that people are using the reserve forest for their subsistence, exploiting it for fuelwood and fodder. Human encounter rate was also higher in STR, but the difference was not statistically significant. Deeper examination of the data revealed that people frequently captured in PTR were forest department staff, carrying out various management related activities in and around the roads, in contrast, in STR, the people captured were mostly villagers moving inside the reserve to collect fuelwood and fodder or grazing livestock, infiltrating the forest irrespective of presence of roads and trails. Thus, even though similar number of people may be moving inside these reserves, the manner in which they are moving and the purpose of their movement are different. In Sariska, movement of people contributes to forest degradation, while in Panna it contributes to forest management. Further, in STR villages are located within small distance of tiger home ranges unlike in PTR where villages are located outside or in the fringe area of tiger habitats (Tab. S1).

Table 4 – Results of linear mixed-effect model to explain FGM concentrations in tiger population of Sariska tiger reserve (Dependent variable log FGM).

Parameter	Estimate	SE	df	t	*p*	95% CI	
Intercept	18.42	6.23	88.58	2.96	0.001	6.04	30.81
Human encounter rate	1.48	0.62	68.11	2.40	0.02	0.25	2.72
Canopy cover	4.96	1.71	42.39	2.89	0.01	1.50	8.42
NDWI SD	1.45	0.67	94.62	2.17	0.03	0.12	2.78
DEM SD	−4.21	1.71	84.87	−2.47	0.02	−7.60	−0.82
TRI	−2.02	1.37	94.93	−1.47	0.15	−4.74	0.71

Only some carnivores such as wolves have behavioral plasticity and reproduction capability that makes it possible for them to survive in close proximity to human beings. Species such as bears and tigers that have specialized requirements related to habitat quantity and quality are susceptible to threats posed by anthropogenic pressures (Weaver et al., 1996). High FGM concentrations in STR tiger population were positively linked to the presence of humans; high canopy cover, low water availability and to homogeneous elevation and low TRI values, within their habitat. Therefore, at a fine scale, it seems that the simple act of a villager going inside the forest areas frequented by tigers, is leading to increased physiological stress in tigers of STR. Stress is reduced where tigers are occupying areas with homogenous distribution of water and the opportunity provided by topographic features to avoid detection. In PTR, stressful encounters for tigers are few and far apart, with the opportunity to navigate through escarpments, resulting in low average FGM concentrations of the population and high reproductive output.

Thus, we can infer that tigers experience physiological stress in case of frequent encounters with human beings, which is exacerbated in a habitat that does not provide sustainable space to negotiate or avoid these disturbance elements, which, eventually, seems to affect their reproductive output. In comparison, if there is low human presence within their habitat, coupled with complex terrain and optimum water availability, tigers experience low stress and thereby attain healthy population growth.

Implications for tiger conservation

Tiger conservation efforts are increasingly focused on creating large undisturbed habitats, which involve voluntary relocation of people and legislative safeguards. However, the conservation objective can only be accomplished by spatial prioritization and rationalization of the resources, and accordingly management inputs have to be modified. It is also important to address anthropogenic issues before tiger translocation is implemented. In India, the key policy document for conservation of tiger that was drafted after extinction of tiger in Sariska (Narain et al., 2005) recommended reintroduction as one of the conservation agendas. With knowledge and experience gained through these tiger reintroductions in Sariska and Panna, this reintroduction agenda can now be improved through specific policy inputs in terms of land management and field operation strategies.

To the best of our knowledge, this is the first time that habitat-stress-reproduction relationships, incorporating multiple habitat elements across two contrasting populations were studied for wild tigers in general, and reintroduced tiger populations in specific. The results of this study affirm that costly conservation efforts for tigers, such as reintroduction programs, need to consider the levels of anthropogenic disturbance and availability of secure environments as major drivers of success/failure of breeding and population growth. This is especially true for habitats that lost their original population to anthropogenic factors. For such reintroduced populations, it is prudent to remove/reduce the disturbance elements while continuing to closely monitor the habitat and physiological responses of the tigers. Finally, our results suggest that successful reintroduction and population growth is a function of habitable space availability, including terrain complexity and low anthropogenic interactions. Therefore, conservation success of future reintroductions should be modeled and visualized keeping in view these parameters.

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Supplemental information

Additional Supplemental Information may be found in the online version of this article:

Table S1 Comparison of Sariska tiger reserve against Panna tiger reserve, across different habitat parameters.