M.Sc. thesis

Effect of forest mosaics, water availability and landscape fragmentation on the spatial distribution of Human-Elephant Conflict: An exploratory study in the Human-impacted landscapes of Western Ghats, India.

- **Harin Aiyanna Cheriyanda Raveendra**
(Reg.no WUR- 1131710, Reg.no UNIPD- 2009395)

Supervisors: Dr. Joost de Jong**,** Dr. Ignas Heitkonig ,
Prof. Maurizio Ramanzin
Master in Forest and Nature Conservation
Wildlife Ecology and Conservation Group
Thesis (REG80436)
Master of Forest sciences
Department Of Land, Environment, Agriculture and Forestry (UNIPD)

WAGENINGEN UNIVERSITY & RESEARCH

UNIVERSITAS STUDII PADUANI MCCXXII

Abstract

Despite the worldwide intensifying human-wildlife conflict, there is still an incomplete understanding of how the configuration of human-modified landscapes affects the occurrence of wildlife crop raiding. Whereas often being homogeneous (in particular: monoculture farming), human-modified landscapes may also be rather heterogeneous (e.g., the mosaic patchwork of natural vegetation and various crop types). The spatial factors associated with wildlife crop raiding in heterogeneous human-modified landscapes remain largely unexplored, especially for the notorious crop raider: the Asian Elephant (*Elephas maximus*). The objective is to elucidate ecological dimension variables that influence the presence of human Elephant conflict in a human-modified heterogeneous landscape by examining occurrences of crop depredation by Asiatic Elephants in the Western Ghats, Karnataka, India. The study was conducted in Western Ghats, India, which is a heterogeneous landscape of various anthropogenic land use types (plantations, diverse agricultural fields, water ponds, and villages), interspersed with natural forest patches. Socioeconomic data obtained through semi-structured interviews, observations, and group discussions with the forest authorities provided ecological dimension variables. The governmental financial compensation data for crop losses were analyzed to assess the spatial distribution of human-Elephant conflict (HEC). We used the land cover data from ESA Sentinel-2 imagery to generate a GIS map, which distinguishes forest type, vegetation type, water sources, and settlements along with the spatial arrangement of HEC-affected farmers. We quantified heterogeneity of land cover as the majority of land cover types occur in a buffer of 500 m radius around the farmers' field. Principal Component Analysis (PCA) was used to identify ecological predictors that best explained the occurrences of conflict in the study area. The relationship between the presence of HEC and landscape attributes was investigated using a logistic regression model with a binomial error structure which depicted that the presence of HEC increases with land cover heterogeneity and proximity to natural forests and decreases with the distance to settlements. Further, no correlations of HEC events were found with the proximity of the farmer's field to water sources. For the heterogeneous human-modified landscape of Western Ghats, nearby patches of natural forests are a prerequisite for Elephant presence and crop raiding, with plantations merely acting as temporary Elephant refuge. More generally, the implication is that homogenization of the landscape (e.g., attrition of natural forest patches) would locally reduce conflict and intensify crop raiding towards heterogeneous areas containing the very last forest fragments.

Acknowledgement

This thesis owes its existence to the help, support, and inspiration of several people. Firstly, I would like to express my sincere appreciation and gratitude to my supervisors from Wageningen University and Research, Dr Ignas Heitkönig, and Dr Joost de Jong. Also my humble acknowledgements to Prof. Maurizio Ramanzin for being my internal supervisor from the University of Padua. Your support and suggestions have been precious, and you all have been a constant source of encouragement and enthusiasm throughout this thesis project. I wish to extend my gratitude to Ananda Sidhartha and Ravi Yellapur for their constant advice and for helping me with getting my fieldwork off its feet.

Furthermore, I would like to thank my family: as always, you all have been the best support system I could ever wish for, standing right beside me. Many thanks to all the friends that supported me through this process, keeping me company during the long nights and days while writing this thesis. My gratitude also goes to all my friends from WUR and the University of Padua.

My sincere gratitude to Karnataka Forest Department for allowing me to conduct this research as well as for helping me obtain data for conducting this research. I would also like to thank the people living in Khalgatagi, Karnataka, India for making time to do interviews and focus groups with me and for the hospitality they have shown me during my fieldwork.

Contents

Abstract 1
Acknowledgement 2
Introduction 5
Elephants in the Western Ghats Ecosystem 7
Research objective 8
Materials and methods 8
1. Study Area 8
2. Habitat Covariates. 9
3. Determination of distance factors. 11
    I. Distance of farmers' field to Elephant Entry Points 11
    II. Distance of farmers' fields to Water Sources 11
    III. Distance of elephant entry points to Human Settlements 11
    IV. Extraction of Raster Values (RV) 11
4. Data Collection 12
5. Statistical Analysis 12
Results 14
1. Selection of variables through a principal component analysis (PCA) 14
2. Developing a multiple linear regression model (GzLM). 16
Discussion 23
1. Key findings 23
2. Landscape complementation a driver of Elephant movement? 24
3. Role of habitat heterogeneity in causing HEC 25
4. Tolerance of farmers towards Elephant damages 26
Conclusion 28
References 29
Appendix 32

Figure 1: The effects of heterogeneous landscape on the habitat selection of elephants. ____ *7*
Figure 2: Map showing the study area ____ *9*
Figure 3: Map indicating the study area 1; Khalghatagi Region of the Uttar Kannada Landscape, Western Ghats ____ *10*
Figure 4: LULC Map indicating the possible Elephant pathways in the human-dominated landscape. ____ *10*
Figure 5: PCA-Biplot with all the ecological and social variables ____ *14*
Figure 6: Cos2 PCA Biplot of ecological variables showing along with the scale of effective representation of each variable. ____ *15*
Figure 7: PCA Model 3 with the final filtered variables. ____ *16*
Figure 8: qq-plot detecting overall deviations from the expected distribution (left). Plot of the residuals against the predicted value (right). ____ *17*
Figure 9: Histogram of Dispersion test ____ *18*
Figure 10: Histogram of Zero-inflation ____ *19*
Figure 11: Final output of the Generalized Linear Model (GzLM). ____ *20*
Figure 12: Box plot of affected and unaffected farmers Vs distance to elephant entry points between all the villages in the study area. ____ *21*
Figure 13: Scatter plot of HEC presence (1)/absence (0) vs Distance from elephant entry points. ____ *22*
Figure 14: Scatter plot of HEC presence (1)/absence (0) vs Distance from Water Sources (WS). ____ *22*
Figure 15: Scatter plot of HEC presence (1)/absence (0) vs Distance from human settlements to elephant entry points. ____ *23*
Figure 16: Scatter plot of HEC presence (1)/absence (0) vs raster values obtained through focal statistics. ____ *23*
Figure 17: Elephant Pathways in the heterogeneous landscapes. ____ *25*
Figure 18: Elephant pathways connecting isolated fragments through the dense natural forests. ____ *26*
Figure 19: Number of farmers and their frequencies of applying for crop damage compensations mainly by elephants. ____ *27*
Figure 20: Plots from GzLM ____ *36*
Figure 21: 250 stimulated datasets from the fitted model. ____ *37*
Figure 22: NDVI map for the Khalghatagi region ____ *37*
Figure 23: Monthly conflicts of crop depredation from the year 1977 to 2020 of Thithimathi region. ____ *38*

Key Words: Heterogeneous human-dominated landscape, Elephants, Human-elephant conflicts, Forest Mosaic.

Introduction

The impact of humanity on the decline of nature is so significant that experts believe we are approaching the Anthropocene, a new geological age (Almond, 2020). The extinction of large mammals is the result of anthropogenic activities encompassing deforestation, conversion of forests into agricultural lands, human settlements, habitat fragmentation, and livestock grazing (Naha, 2020). Among all the other factors that can negatively impact mammalian species, habitat loss is the most worrying. It has also been known to be the single greatest threat to biodiversity worldwide and certainly holds for mammals. It also decreases population size, promotes the loss of species diversity, contract species' geographical distribution, and facilitate species loss (Lino, 2019). Anthropogenic landscapes typically have scattered natural vegetation, which over time become further disconnected from larger natural core areas due to fragmentation. This may change the behavior (Almond, 2020) of local wildlife species, driving them to explore human-dominated agricultural areas and causing conflicts. Any interaction between wildlife and humans leading to a negative impact on one another is defined as human-wildlife conflicts (HWC) (Madden, 2004).

As the human population grows and environmental issues such as climate change and habitat degradation increase, negative interactions between people and wildlife are predicted to increase in both frequency and intensity (Hodgson, 2020). The fragmentation of natural habitats and increasing anthropogenic activities have created an increased likelihood of contact between people and wildlife, often leading to HWC. These conflicts not only affect the wildlife and local communities, but also lead to antagonistic relationships between local communities, wildlife managers, and conservationists. This further aggravates the problem of wildlife and biodiversity conservation. Attacks on humans, depredation of crops and livestock, and damage to property all pose a significant threat to human livelihoods and safety. Periodic crop damages and losses caused due to wildlife attacks reduce societal tolerance of local people and prompt retaliatory killings, leading to local extinctions with an impact on the overall ecosystem (Skogen, 2019). Mega-herbivores such as Asian Elephants (*Elephas maximus* herein after Elephants) transverse a mosaic of heterogeneous landscapes. They also tend to employ any landscape that provides forage, water, and potential mates.

The largest terrestrial mammals also regarded as landscape engineers, elephants symbolize global conservation and co-occur with humans within multiple-use landscapes of Asia including India. They range across large areas for dietary, and reproductive requirements. They forage on a diverse variety of grasses, shrubs, tree leaves, roots, and fruits (Sukumar, 2003). The rising impact of anthropogenic activities on the natural ecosystems leads to close proximities between humans and elephants thus increasing the likelihood of conflicts (Sukumar, 1989); (Hoare RE, 1999); (Estes JA et al., 2011); (Liu P et al., 2017). Anthropogenic activities along with human-elephant conflicts (HEC) within shared landscapes affect both survival and conservation of the elephants. HEC is not uniform as ecological and anthropogenic factors which influence these incidents are dynamic (De Boer, et al., 2013) In addition to being a serious negative societal concern, HEC has substantial socioeconomic and political implications (Fernando P, 2008).

Elephants' habitat preferences and selection are driven by variables such as the composition of habitat mosaics, resource quality, and availability of water resources (Okello, et al., 2015). Understanding how land-use mosaics affect elephant distribution and their adaptation to the fragmented landscapes is crucial for conservation (Krishnan, et al., 2019). Studies that have attempted to assess the impact of landscape fragmentation on elephants have generally focused on the geometrical aspects of the fragmentation, such as roads (Blake, et al., 2008) (Barnes, et al., 1991), agricultural fields (Graham, et al., 2009) (Hoare, 1999), and human settlements (Harris, et al., 2008), to the distribution of elephants in isolation. Even though these approaches revealed how an elephant would react to each fragmentation geometrics, it is more crucial to comprehend how these infrastructures collectively affect elephant movements than to focus just on the effects of individual fragmentation geometrics. It is essential to note that elephant ranges are split up into a range of smaller and isolated habitats by fragmentation geometrics (roads, settlements, fields, and fences). In this regard, it is crucial to examine the impact of these fragmentation geometrics on the scattered natural resources to determine how they interact to affect elephant movements.

Ideally, the possibilities of elephants moving within the habitat fragments are for (1) Maximizing resource acquisition (Thaker, 2019)(2) Searching for individuals to mate or avoiding territorial conflicts between individuals, or (3) Minimizing predation/competition (in this context to avoid human contact). Expansion of human settlements and agricultural fields across Asia has resulted in widespread loss of elephant habitat, degraded forage, reduced landscape connectivity, and a significant decline in elephant populations relative to their historical size and overall range (Shaffer, 2019). The habitat selection of elephants varies due to the availability of resources, types of vegetation, human presence, landscape, and cropping patterns in natural and modified habitats. This variation is also seen seasonally based on precipitation, temperature, etc. (Granados, et al., 2012). As an adaptive response to living in seasonal environments and to the Spatio-temporal distribution of resources (Dingle, 2007) large herbivore migration is typically linked to the seasonal distribution of resources related to food availability and quality (Fryxell, 1991). Availability of water, swamps, streams, and rivers are crucial drivers of habitat utilization by elephants within a landscape. Adult elephants have enormous dietary requirements. Elephants spend 12-18 hours on average a day feeding. Adult elephants can eat up to 150 kg of food a day (Yamamoto-Ebina, 2016). As herbivores, elephants consume grasses, tree foliage, bark, twigs, and other vegetation daily they can also drink up to 190 litres of water a day. Consequently, the effects of habitat fragmentation and the presence of forest plantations have fashioned mosaics of forage availability within the forest creating pockets of suitable habitat spread across the elephant habitat. A herbivore's foraging pattern is greatly impacted by the spatial scale of food patch heterogeneity, besides elephants being generalist species they can adapt ecologically and behaviourally to changing environments (McArthur, et al., 2014). Resource availability, available area, vegetation type, and stresses associated with transformed landscapes influence how they employ a mosaic of natural and modified habitats (Krishnan, 2019).

The foraging trip of an elephant involves a dynamic resource utilization pattern. The phrase mosaic environment in tropical ecosystems refers to an environment that has patchy forest interspersed with forest plantations, endemic trees, and bare lands (Noble, et al., 1997). This dynamically causes natural food resources to spread out over the entire elephant habitat. In a heterogeneous landscape, amongst all other ambient resources, even crop fields also occur close to forest edges making those fields more prone to crop depredation by elephants. As one of the elements of a heterogeneous landscape, forest mosaics act as a source of food as well as a refuge (Bell, 1984) for elephants. These forest mosaics can therefore act as a gateway to nearby agricultural fields through specific elephant entry points. A study on patterns of crop-raiding by Asian elephants in Eastern India (Naha, 2020), shows the relations between crop depredation, cropping pattern, land use type, human behavior, and activity within multi-use landscapes of South Asia but little has been shown on the effect of mosaics of forests on elephant movements and HEC. Altogether heterogeneous human-modified landscapes create a scenario where HWC such as crop depredation is most prone to occur for farmers who have their crop fields located close to elephant entry points *(figure 1A)* and water sources *(figure 1B).* Moreover, spatial occurrences of area and density of human settlements in a land-use mosaic can further alter elephant movements (Hoare, 1999). But in a heterogeneous landscape, two scenarios occur, the human settlements closer to the crop fields and the settlements far from the crop fields. In this kind of scenario, the longer the distance from elephant entry points to the human settlements higher is the occurrences of HEC (crop depredation) as in *figure 1C*. Summing up heterogeneous human-dominated landscape will invariably increase the occurrences of HEC *(figure 1D)*.

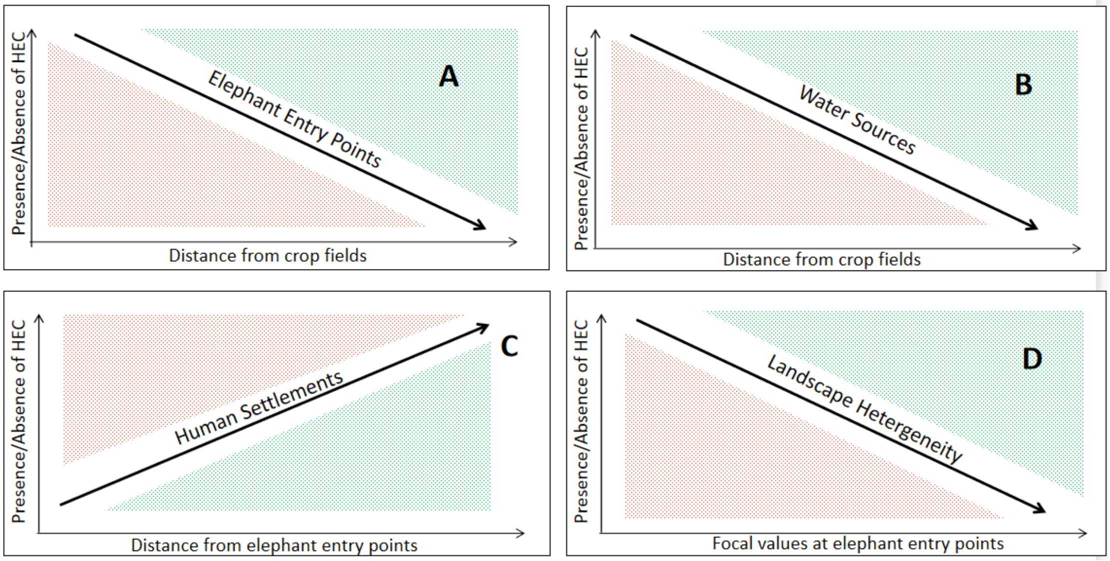


Figure 1: The effects of heterogeneous landscape on the habitat selection of elephants.

Elephants in the Western Ghats Ecosystem

As the largest terrestrial mammal, elephants symbolize global conservation and co-occur with humans within multiple-use landscapes of Asia including India. They range across large areas for dietary, and reproductive requirements, and forage on a diverse variety of grasses, shrubs, tree leaves, roots, and fruits (Sukumar, 2003) ; (Whyte, 2012). The distribution of natural resources, seasonal climatic conditions, agricultural practices, and socio-economic cultural beliefs are the factors that influence the intensity of HEC (Shaffer LJ, 2019).

HEC is particularly of concern in less developed nations where protected areas designated for wildlife protection have zones of overlap with human settlements (Ogra, 2008). India, the seventh largest country in the world geographically and yet second in terms of population, is no exception; there are human settlements within and in the vicinity of ~65% of the protected areas in the country, where occurrences of HECs are common (Kothari, 1989); (Ogra, 2008). The intensity of HEC depends on the variations in environmental factors such as distribution of natural resources, agricultural practices, seasonal climatic conditions, and socio-economic cultural beliefs and differs widely in Africa and Asia.

Due to the loss of forest cover and severe anthropogenic impacts on their habitats, Asian elephants now occupy only 5% of their historic range. Moreover, India is home to more than 27,000 Asian elephants, the largest Asian elephant population in Asia, but only about 16% of their range persists today in small, insular populations in the existing Protected Area network (Kalam, 2018). India has 60% of the global Asian elephant population mostly concentrated in the southern region with the highest population in Karnataka.

The antagonistic interactions between humans and elephants have been on a rise over the years. Crop raiding is regarded as one of the indicators of HEC and is known to be the most reported form of damage, yet a rise in human injuries and deaths has been reported in Asia (Sitati NW, 2003); (Lenin J, 2011); (Lamichhane BR, 2018); (Van de Water A, 2018). Due to HEC, an estimated number of 600 humans and 300 elephants (Islam, 2011), (Mathur, 2014) die annually in India with an additional 1 million hectares of land affected through crop raiding (Fernando P, 2008); (Pokharel SS, 2018). Small-scale farmers are most vulnerable to damages caused by elephant attacks and as a result, such low-income groups engage in retaliatory killings, help organized poachers or prevent wildlife tourism-based activities (Naha, 2020). Although attacks on humans are being studied recently, we still lack information on how heterogeneous landscape leads to crop-raiding in human-dominated landscapes which creates a knowledge gap for the mitigation of HEC within the affected regions. Although HEC is key conservation and social concern in India, very few studies have quantitatively assessed the distribution of reported incidences ((Gubbi, 2012); (Gubbi, 2014)). However, such assessments are important as the levels of HEC are not consistent across areas, information in this regard can assist in the development of region-specific mitigation/management strategies ((Lenin, 2011); (Gubbi, 2014)).

Research objective

The objective is to elucidate ecological dimension variables that influence the presence of human-elephant conflict in a human-modified heterogeneous landscape by examining occurrences of crop depredation by Asiatic elephants in the Western Ghats, India.

I. Specific research questions
   a. How do the mosaics of forage availability affect the occurrences of elephant entry points and crop-raiding behaviour of elephants?
   b. Up to what extent does the distance between crop fields and water sources increase the chances of HEC?
   c. To what extent does the distance from elephant entry points to human settlements influence the occurrences of HEC?

Materials and methods

1. Study Area

The Western Ghats is divided into four major landscapes: (1) Uttara Kannada, (2) Brahmagiri-Nilgiris, (3) Anamalai-Nelliyampathy-High Range, and (4) Periyar-Agasthyamalai, which span 30,000km2 and are home to at least 10,000 elephants in six different populations, with some showing signs of an increasing trend (Baskaran, et al., 2013). Located between the moist deciduous and the mountain rainforest of North-Western Ghats, the Uttara Kannada elephant habitat consists of a wide range of tropical deciduous tree plantations (e.g., *Tectona grandis, Acacia auriculiformis, Eucalyptus spp. Casuarina equisetifolia*, among others), tree savanna, shrub savanna, grassland (in our landscape, primarily montane grasslands) and uncultivated revenue department or private lands (Devcharan Jathanna, 2015). Spreading 5,081 square km of elephant-rich habitat constitutes the forest divisions of Haliyal, Dandeli, Sirsi, Yellapur, and Karwar (Karnataka) where the northern population of 50 Asian elephants is scattered in a low density (Baskaran, et al., 2013). The Dandeli Anshi Tiger Reserve (also kali tiger reserve) with precipitation ranging from 6,500 mm at the crest to about 1000mm on the plateau is an important elephant habitat in this region supporting the bulk of the population consistently. Dandeli's tiger reserve has an area of 1300 square kilometers and has two main protected areas. The Anshi National Park encompasses 339.866 square kilometers, and the Dandeli Wildlife Sanctuary, which covers roughly 475 square kilometers. The natural vegetation in the environment is dominated by evergreen forests (26 per cent or 6,055 km^2), followed by a nearly equal spread of tropical deciduous (2,700 km^2) and dry-thorn forests (11 per cent, 2,525km^2). With commercial plantations coffee (*Coffea arabica*) and tea (*Camellia sinensis*) account for 11% or 2500km^2 of the land use while Human settlement/cultivation, on the other hand, occupies two-thirds of the land cover (33 per cent or 7,800 km^2) indicating the level of fragmentation at the landscape level (Baskaran, et al., 2013).

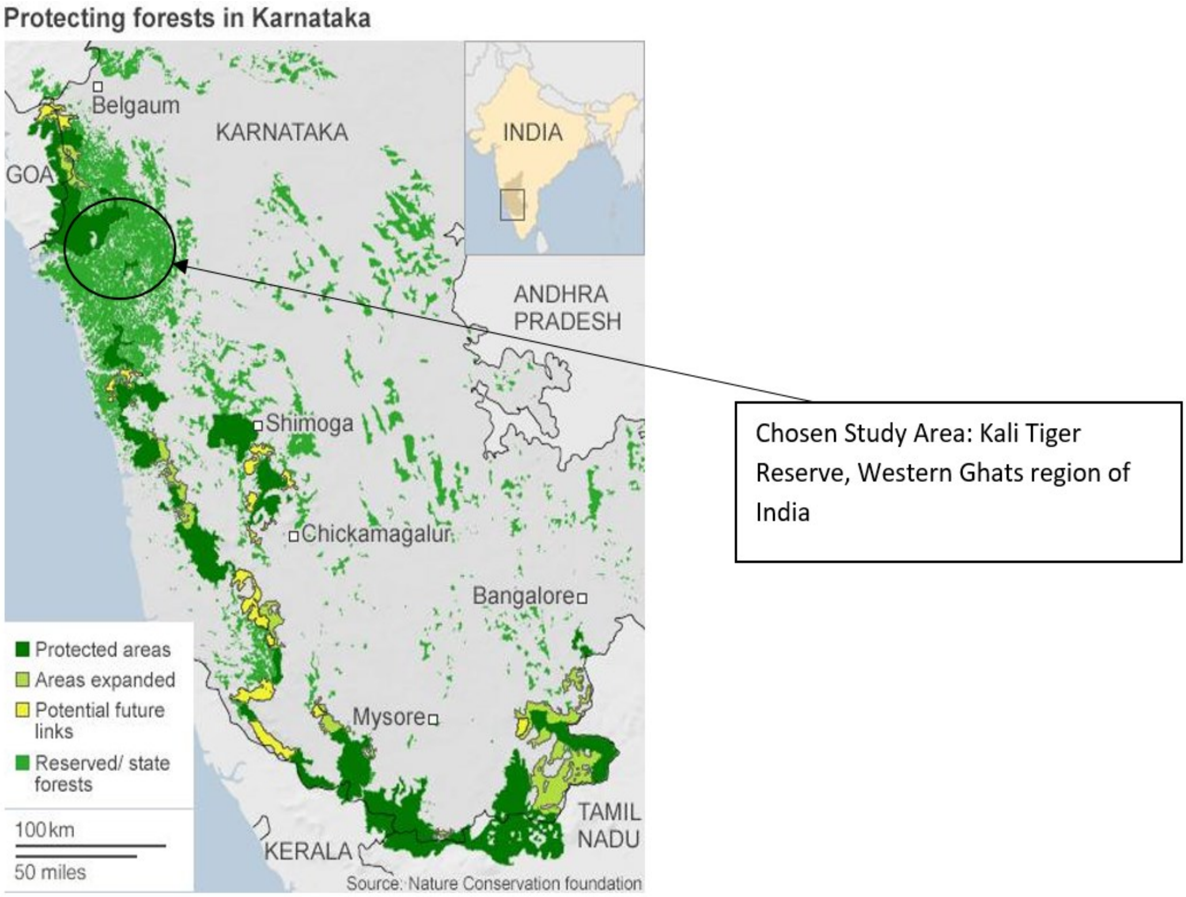


Figure 2: Map showing the study area

2. Habitat Covariates.

Stakeholder perceptions on the causal factors of HEC mentioned in (Bal, et al., 2011) elaborate that teak (*Tectona grandis*) plantations and scarce water sources in the dry deciduous forests are one of the reasons for elephants to venture into agricultural fields and commercial plantations. Besides providing temporary refuge for the elephants (Bell, 1984), plantations might not suffice their nutritional requirements as the natural forest vegetation does. Also artificially maintained water sources that are close to the agricultural fields attract elephants and bring them closer to human settlements, thus increasing HEC. This behaviour when correlated with the distance of crop fields and the spatial drivers, allows us to quantify the influence of forest vegetation mosaics and water sources on the movement of elephants. Studies have identified (Distefano, 2005) water sources on the fringes of forests that attract not only elephants but also other wild animals closer to human settlements. GIS maps showed the presence of natural forests, water sources, crop fields and human settlements with which we were able to construct a habitat suitability model to understand the occurrence of crop depredation caused by elephants while moving along the human-dominated landscapes. The water bodies have an important role in rice-based agriculture and human settlements. Therefore, this spatial driver of HEC was analyzed by correlating the distance between agricultural fields to water sources.

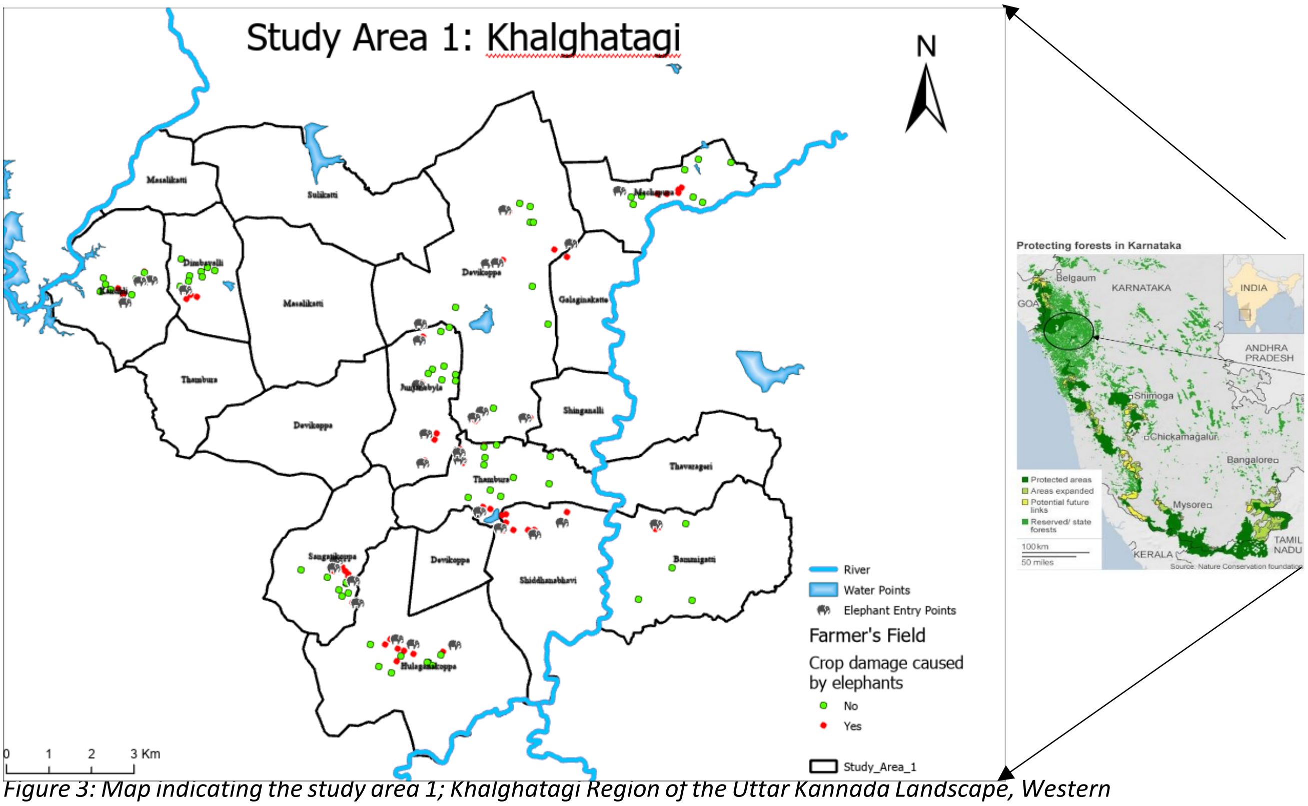


Figure 3: Map indicating the study area 1; Khalghatagi Region of the Uttar Kannada Landscape, Western Ghats

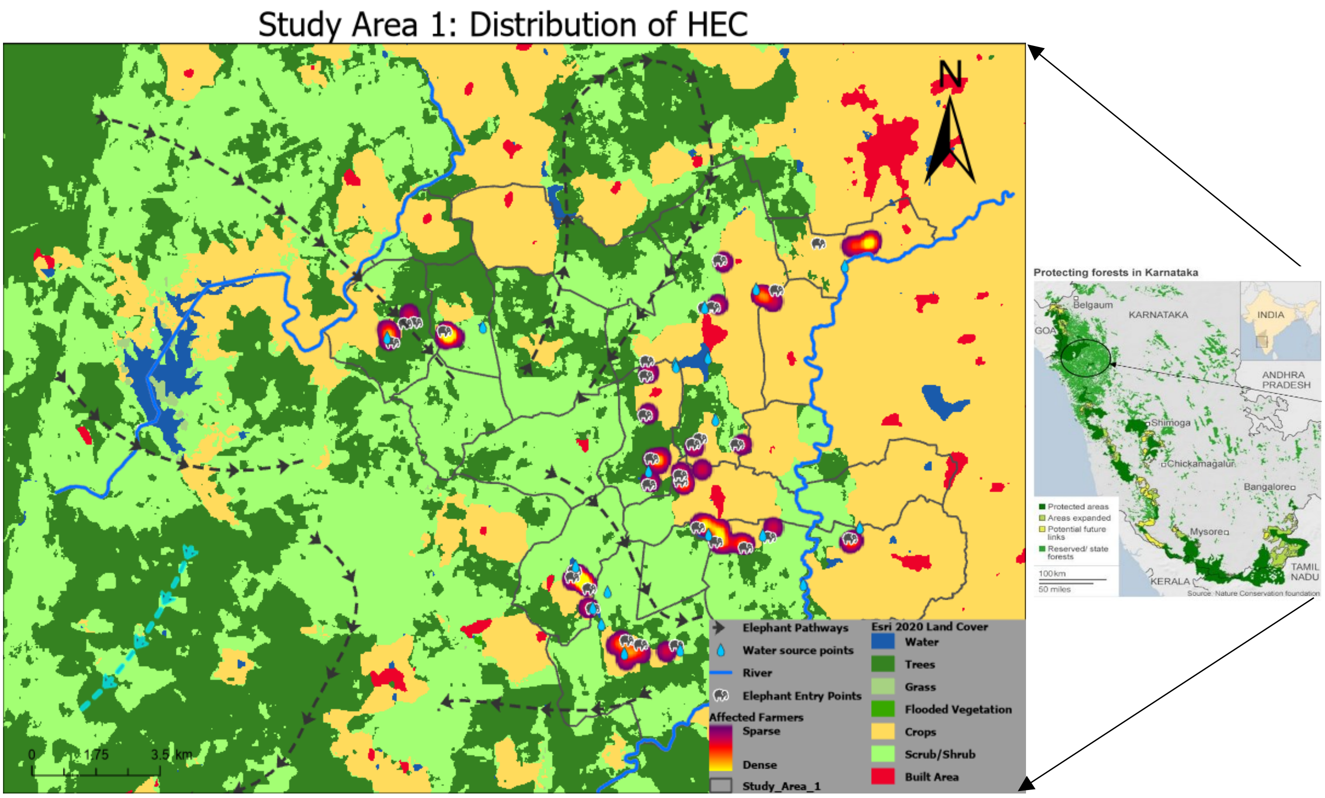


Figure 4: LULC Map indicating the possible Elephant pathways in the human-dominated landscape.

3. Determination of distance factors.

a. Distance of farmers' field to Elephant Entry Points

Crop depredation by elephants is a frequent interaction that happens in an intricate landscape where elephant habitat and agricultural crop fields coincide. Farmers mainly at the forest edge prefer to retaliate by implementing various deterrent measures such as elephant-proof trenches (made by the Government of Karnataka in coordination with the forest department), concrete walls or electric fencing, etc. Human-dominated landscapes thus invariably introduce anthropogenic stimuli. With behavioural responses to these stimuli, elephants do show behavioural plasticity by causing crop damage to fields that are near the forest edge (Bal, et al., 2011). Often due to landscape attributes, certain points at the farm boundary become a regular entry point to crop fields. Moreover, vegetation differences in the vicinity of the crop fields can provide a temporary shelter for refuge (Bell, 1984) and forage for the elephants. These coordinates of the elephant entry points were recorded during field observations with the coordination of the local forest authorities from the Khalgatagi range and the villagers themselves. Using excel the distance between the two GPS coordinates (elephant entry points and crop field) was calculated for further analysis.

b. Distance of farmers' fields to Water Sources

The presence of dams, rivers, lakes, and dykes forms an important water source for both agriculture and wildlife. In the study area, man-made water sources were present mainly at the borders of the forests, while some ponds were distributed between farm fields. The extreme temperatures nearly dry up natural water sources in the summer causing variability in water sources. In turn artificially maintained water sources that are close to the agricultural fields attract elephants and bring them closer to human settlements, thus increasing HEC as stated in (Thouless, 1994). Therefore coordinates of water sources were collected to measure the distances to the farmer's field. This distance was analyzed to find out the extent of water sources acting as a contributing factor to elephant movements eventually leading to crop raiding in a heterogeneous landscape.

c. Distance of elephant entry points to Human Settlements

The most important element of a human-modified landscape is the human settlements and the presence of different hamlets within a heterogeneous landscape. The configuration of the human-dominated landscape in the study area depicted a wide array of roads, crop fields, houses and villages. Therefore the GPS coordinates of the closest settlements with a minimum population of 1500 were chosen to calculate the distance factors from elephant entry points.

d. Extraction of Raster Values (RV)

Land cover data displaying a global map of land use/land cover (LULC) was derived from ESA Sentinel-2 imagery at 10m resolution. It was a composite of LULC predictions for 10 classes throughout the year to generate a representative snapshot of 2020 (Karra, et al., 2021). The grid cells surrounding a processing grid cell (in our case the respondent's crop field GPS location) were used in the statistical calculation for obtaining the majority of the nearest neighbourhood. There were several predefined neighbourhood types but the '*majority*', in which the circle of radius of 500 meters was chosen to calculate the focal statistics of neighbouring grid cells of each crop field. The 500-meter considered gave an elephant's eye view of the available resources within its reach from the crop field. Therefore higher the nearest neighbourhood values indicate higher heterogeneity of landscapes. This raster value varied from 4.1 to 6.3 depicting the majority of the following land covers (forests, trees, shrubs, grasses and crop fields – which also included human settlements).

4. Data Collection

To elicit human dimension variables socioeconomic data collected through semi-structured interviews and group discussions with the forest authorities were obtained. The questionnaire provided details of the land holding, perceptions and attitudes towards crop depredation by elephants. The sampling method involved a stratified random selection of respondents by combining two different data sources where each stratum depicted different villages. The data from a) *Governmental financial compensation data* (Karanth, et al., 2018) which provided details of estimated area damage and money provided as compensation from each of the 10 villages and b) *Crop Survey data* provided details on land holding and crops are grown of all the farmers in each village. From the 10 villages, a total of 132 farmers were sampled for conducting the semi-structured interviews.

5. Statistical Analysis

Two models of principal component analysis (PCA) were used to determine patterns in the obtained data. The data set containing observations that are described by the ecological variables that are interdependently correlated is summarized and visualized using PCA. Through PCA it is possible to think of each variable as a different dimension (Richardson, 2009). The PCA was used to identify explanatory variables that best explained the concurrences of conflict in the study area. Out of the filtered variables that showed maximum deviations, we were able to perform the multiple binomial regression analysis using the glm() function to indicate the influence of a combination of selected variables on HEC.

- Logit Link Function.

$$log\left(\frac{\pi}{1-\pi}\right) = \beta_0 + \beta_1 x_1 + \epsilon_i, \qquad \epsilon \sim Binom(\lambda)$$

Table 1: Ecological variables and social variables that were obtained during the fieldwork in the Khalgatagi region of Uttara Kannada landscape, Western Ghats, India.

Variables	Variable Code	Variable type
Proportional Area Damaged	Area_Damage	<Numeric>
Distance from crop fields to elephant entry points	Dist_EEP	<Numeric>
Distance from crop fields to water sources	Dist_WS	<Numeric>
Distance from crop fields to human settlements	Dist_Settle	<Numeric>
Village-wise population	Population	<Numeric>
Total land holdings per farmer	Land_Holding (Sq.m)	<Numeric>
Focal value of FF extracted from LULC Raster	Raster_Value	<Numeric>
Presence of FF at the forest edge	Forest_edge	Yes/No
Types of Forests	Forest_type	Dense Forest/Mixed Forest/Plantations
Types of water sources	WS_Type	No WS/ Perennial or Natural Source/ Intermittent or Man-made Source/ Both

Interaction of Elephants with water sources before crop-depredation event.	Use_Before	Never/ Rarely/ Sometimes/ Frequently/ Always
Interaction of Elephants with water sources after crop-depredation event.	Use_After	Never/ Rarely/ Sometimes/ Frequently/ Always
Do farmers prefer having Elephant proof measures in their field?	EPM	Yes/ Maybe/ No
Involvement of farmers in Elephant drive operations conducted by local authorities.	Oper	Never/ Sometimes/ Always
Does the farmers have close encounters while interacting with Elephants in his field?	Enco	Yes/ No
Farmers' perception of the proximity of crop fields to the forest edge is a reason for HEC occurrence	Perc_Fedge	Yes/ Maybe/ No
Farmer's perception of the proximity of Crop Fields to the water source is a reason for HEC occurrence.	Perc_WS	Yes/ Maybe/ No
Farmers' perception of lack of forage abundance in the forest is a reason for HEC occurrence.	Perc_Forage	Yes/ Maybe/ No
Farmer's perception of changing cropping patterns is a reason for HEC occurrence.	Perc_CP	Yes/ Maybe/ No

From the GzLM models, Akaike's Information Criterion (AICc) was used to evaluate relationships between the presence and absence of HEC for farmers with 5 explanatory variables: Farmers' fields' (FF) distance from elephant entry points (EEP), water sources (WS) human settlements (HS), population (P) of each village and the focal value of crop fields from the LULC raster (RV). Model selection was performed based on the lowest AICc values from the different combinations of predictor variables *(table 2).* These models considered the presence and absence of crop depredation by elephants as the response variable (y) and the distance of crop fields (FF) from elephant entry points (EEP), water sources (WS), human settlement (HS), population (P) & the raster values (RV) as the predictor variables (x). Here we primarily focused on investigating if there was a relationship between the binary response variable(y) and the linear predictor(x). The assumption was that all data points were independent as they followed a stratified random sampling procedure. However, because of the small sample size, we also considered models containing different combinations of explanatory variables. The predicted distribution of data varied along the range of fitted values for several reasons where diagnosing was miss-specified by GzLMs from standard residual plots. The use of standardized (Pearson) residuals or deviance residuals partly addressed this issue, yet they still did not offer complete consistent diagnoses across all issues such as miss-specified model, over-dispersion, or zero-inflation. An alternative approach was to use simulated data from the fitted model to calculate an empirical cumulative density function from which residuals are generated as values corresponding to the observed data along the density function. The rationale is that if the model is correctly specified, then the observed data can be considered as a random draw from the fitted model. Thus residuals calculated from empirical cumulative density functions based on data simulated from the fitted model became uniform across the range of the linear predictors regardless of the type of model *(figure 20 see appendix).* This uniformity was explored by examining qq-plots and plots of residuals against the fitted values and each individual predictor *(figure 8)*

Results

1. Selection of variables through a principal component analysis (PCA)

Although when the first PCA model included both ecological and social variables, the bi-plot *(figure 5)* generated with all the vectors of each variable gave out interesting patterns. It also helped in detailing factors such as the use of water sources by elephants before and after crop depredation. PCA model 1 indicated clusters of vectors, in other words strongly correlating variables depicting the social variables and ecological variables in different directions. This biplot also suggests that the vectors with the longest length have better individual variations compared to the rest, of the principal component. The red vector clusters indicated the use of water sources by elephants during the event of crop-raiding (*use_before and use_after)* which strongly correlated with the perception of farmers on the role of water sources in the cause of crop depredation. While the types of water sources vector *(WS_Type)* formed in a different cluster indicating that both natural and man-made water sources became a landscape entity that was used by the elephants during the event of crop depredation.

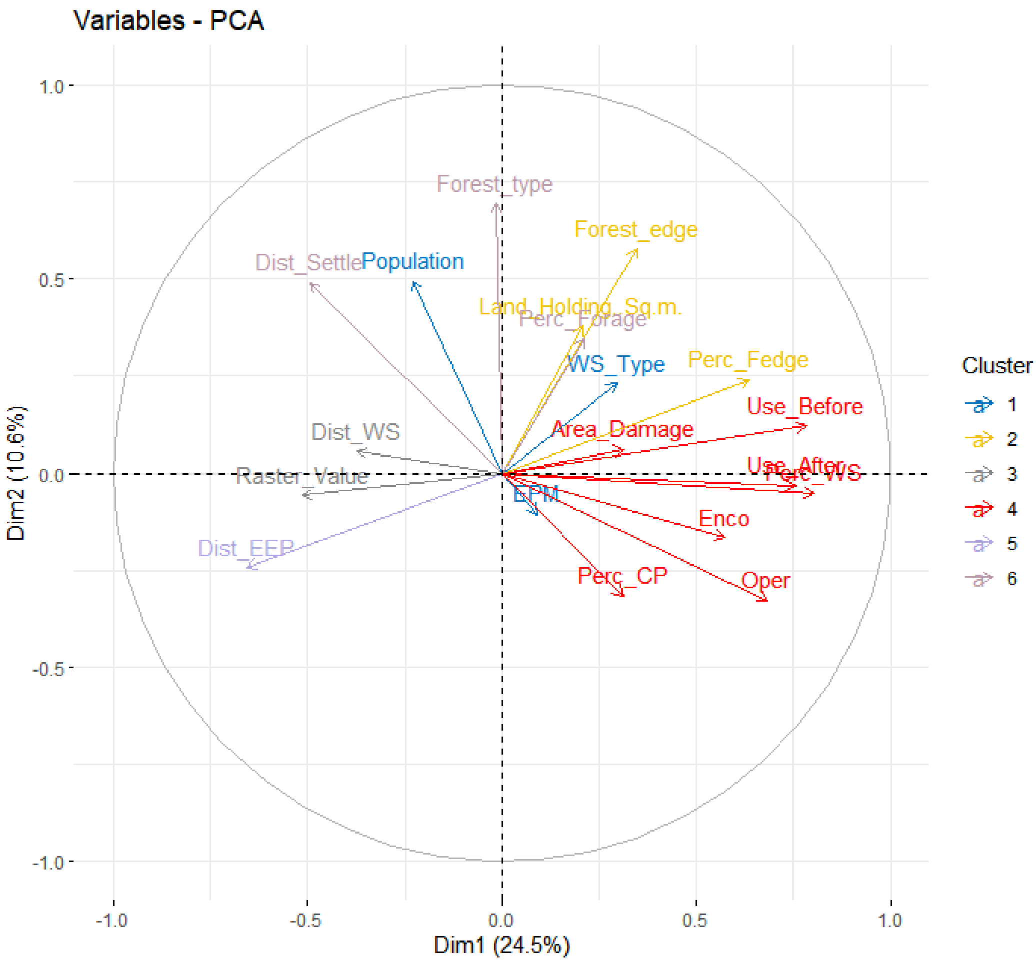


Figure 5: PCA-Biplot with all the ecological and social variables

Moreover, the distance of crop fields to water sources *(Dist_WS)* negatively correlated with the red cluster. Distance from elephant entry points *(Dist_EEP)* almost forms a right angle with the distance from human settlements *(Dist_Settle)* indicating that either they occur independently or possibly they show deviations w.r.t other variables. Further PCA model 2 *(figure 6)* was produced with only the ecological variables to observe the individual variation of each vector. It further showed variables such as *Raster_Values* ~ heterogeneity of landscape and *population* vector have strongly correlated. *Forest_type* indicates the types of forests at the forest edge have a very small vector. This can be neglected as the influence of landscape fragmentation on the variations in the forest vegetation. Also, forest types depict the availability of natural vegetation which is already well explained by raster values. The landholding variable depicts the extent of land under the procession of each farmer, even though it shows large individual variation but this can be neglected since we are analysing the presence of HEC rather than the intensity of HEC.

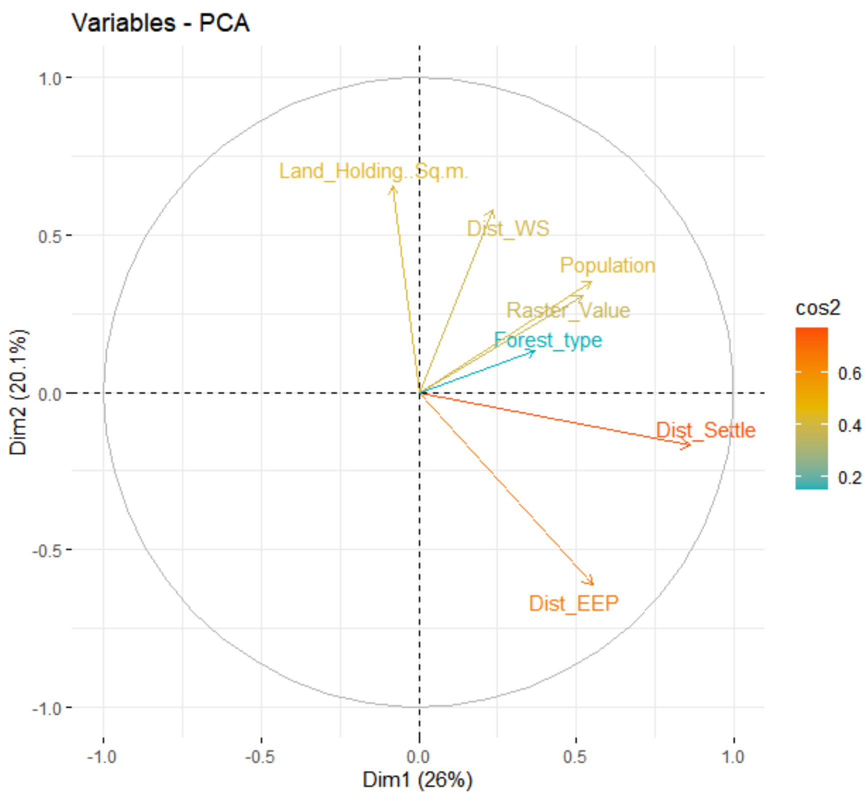


Figure 6: Cos2 PCA Biplot of ecological variables showing along with the scale of effective representation of each variable.

This gives us the final model 3 *(figure 7)* indicating the relationship between crop field distance from elephant entry points and water sources, distance to settlements from elephant entry points, population and the raster values. Population and distance to water sources have a positive correlation while the distance from elephant entry points and distance from water sources have almost no correlation (each vector in the right angle). By filtering out the best variables that define the occurrences of HEC these variables were further included in the generalized linear model (GzLM).

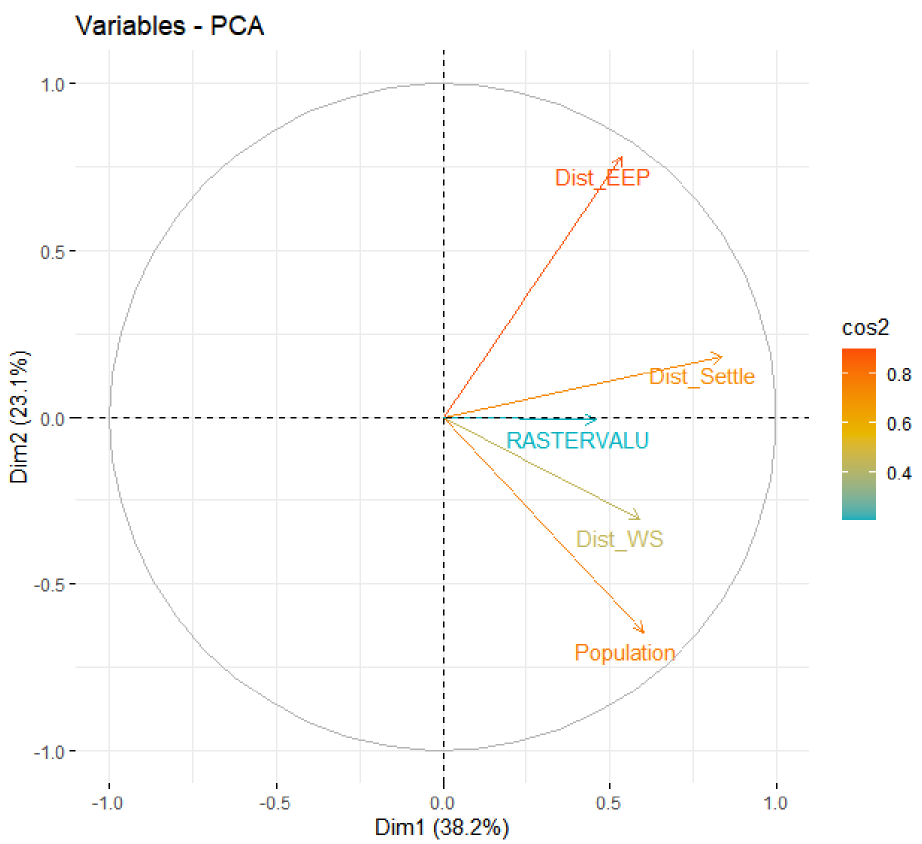


Figure 7: PCA Model 3 with the final filtered variables.

2. Developing a multiple linear regression model (GzLM).

The results of multiple binomial regression analysis showed the best models to explain the amount of conflict which included the distance of crop fields (FF) from elephant entry points (EEP), water sources (WS), human settlement (HS) and the raster values (RV) (AICc = 126.73) datasets *(see Tables 2 and 3).* The best model revealed that the distance from elephant entry points, human settlements along with raster values were the most important predictors of HEC (p-value < 0.05) (Table 3). Independent GzLMs for each explanatory variable showed significance (p-value < 0.05) for variables like distance from elephant entry points, water sources and raster values. The population variable however did show any significance (p-value = 0.561) in its independent GzLM model as well as in the best model. While the distance to human settlements showed significance in the best model (p-value = 0.006) but not in its independent GLM model (p-value = 0.242). To illustrate the use of simulated data from the fitted model to calculate an empirical cumulative density function from which residuals are generated as values corresponding to the observed data along the density function, we generated 250 simulated data sets from our fitted model. This generated a matrix with 250 columns *(see appendix figure 19)* and as many rows as there were in the original data. Considering this as 250 attempts to simulate the original data from the model the empirical cumulative density function was calculated for each row of these simulated data. With this function, new y-values were predicted and basically, the residuals are corresponding to each observed y-value. For binary responses, uniform random noise was added to both the simulated and observed data so that we could sensibly explore zero inflation. The resulting residuals are on a scale from 0 to 1 and therefore the residual plot is centred on the y-value of 0.5. As the residuals are generated from simulated data, the exact residuals will vary from run to run. Nevertheless, the pattern of residuals against fitted values should remain stable -

although of course when sample sizes are small, small stochastic changes can have a large impact *(appendix figure 18).*

Table 2: Summary of model selection with corrected Akaike's Information Criterion.
Delta AIC shows the difference between each model and the best model selected for our analysis. The relative likelihood (1-Deviance/Null Deviance) of each model represents the model fit i.e. the quasi R^2.

Model	Explanatory variables	AICc	Delta AICc	Model Fit (quasi R^2)
model 1	EEP + WS + HS + P + RV	128.7	1.97	0.312
model 2	**EEP + WS + HS + RV**	**126.73**	**0**	**0.313**
model 3	EEP + WS + RV	133.43	6.7	0.261
model 4	WS + RV + HS	159.52	32.79	0.107
model 5	WS + HS + P	168.61	41.88	0.054
model 6	EEP + WS	136.27	9.54	0.233
model 7	EEP + RV	138.67	11.94	0.269
model 8	WS + RV	160.88	34.15	0.088
model 9	HS + P	185.13	58.4	0.013
model 10	EEP	143.56	16.83	0.231
model 11	WS	167.54	40.81	0.037
model 12	HS	184.13	57.4	0.007
model 13	P	185.16	58.43	0.001
model 14	RV	174.58	47.85	0.060
null	1	183.5	56.77	0

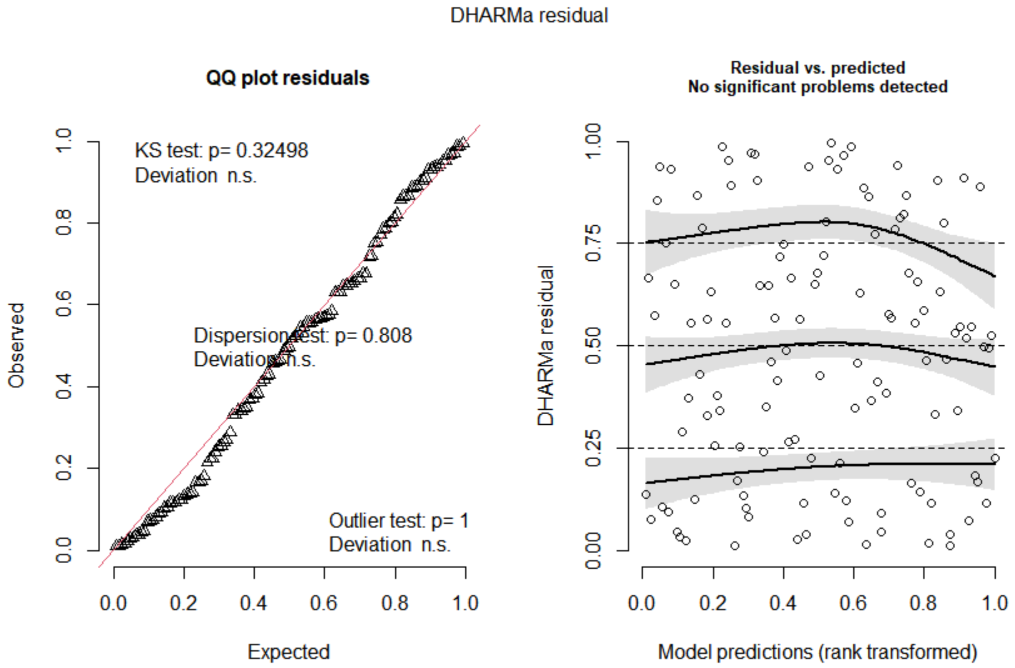


Figure 8: qq-plot detecting overall deviations from the expected distribution (left). Plot of the residuals against the predicted value (right).

Using the DHARMa package (Hartig, 2020) in RStudio provides several convenient routines to explore standardized residuals simulated from fitted models based on the concepts outlined above. Along with generating simulated residuals, simple qq-plots and residual plots are shown in *figure 8.* By default, the residual plots include quantile regression lines (0.25, 0.5 and 0.75), each of which should be straight and flat. But we do observe certain patterns in the qq-plot *(figure 8),* therefore these trends could be the reason for overdispersion or non-linearity.

We also conducted the goodness of the fit of the model via:

1. Pearson's ($\chi2$) residuals explore whether any significant patterns are remaining in the residuals. *($\chi2$ = 0.6898688)*
2. Deviance (G^2) - similar to the $\chi2$ test above, yet by using deviance. = 0.5156414

This package has a routine for running a one-sample Kolmogorov-Smirnov test to explore the overall uniformity of the residuals as a goodness-of-fit test on the scaled residuals *(D = 0.085844, p-value = 0.325)* (Alternative hypothesis: two-sided). This further concludes that Pearson residuals, Deviance or Kolmogorov-Smirnov tests indicate a lack of fit *(p values greater than 0.05).* The test for overdispersion showed significance by comparing the approximate deviance of the observed model with those of the simulated models.

- For all the four predictor variables, dispersion = 0.95164, p-value = 0.632, alternative hypothesis: two-sided) *(figure 9).*

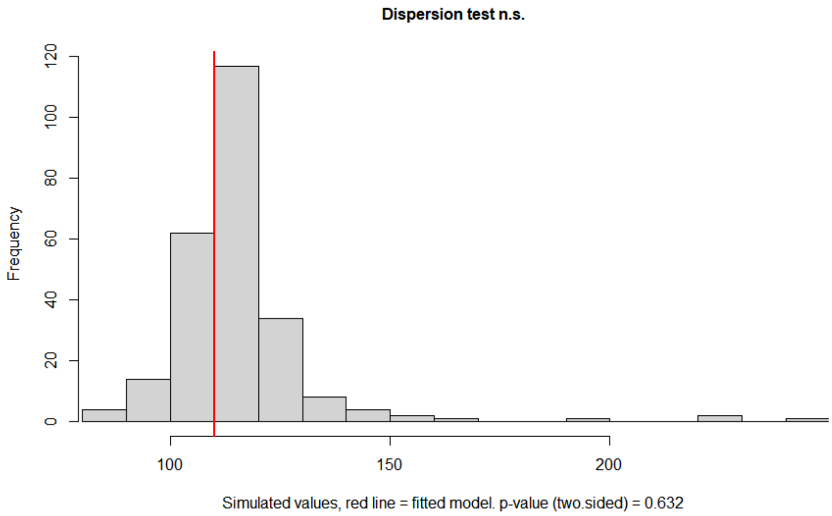


Figure 9: Histogram of Dispersion test

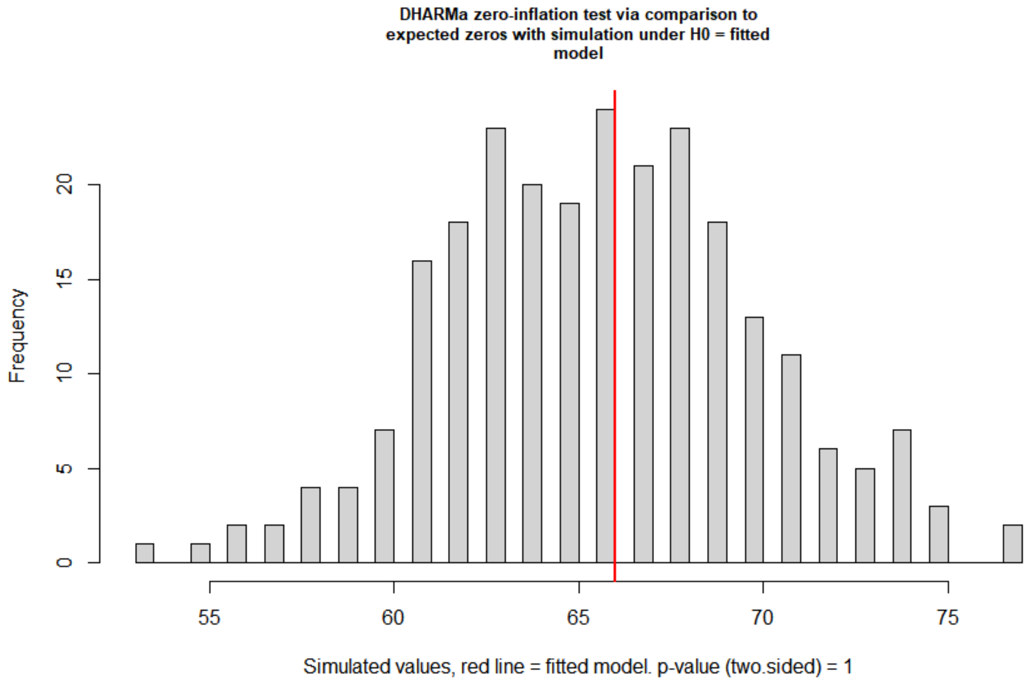


Figure 10: Histogram of Zero-inflation

The DHARMa zero-inflation test yielded a value = 1 *(figure 10)* indicating that data has more zeros than expected (aka zero-inflation). Per default, the function tests both sides *(ratioObsSim = 1.0024, p-value = 1*, alternative hypothesis: two-sided). This concludes that there is evidence of overdispersion and zero-inflation when the model only includes Distance to elephant entry points, also when all four predictor variables are included there is evidence of overdispersion nor zero-inflation *(ratioObsSim = 1.0001, p-value = 1*). Since there was evidence that the model was not an appropriate fit, then we reconsidered the model and ran the process again. In this case, there is no evidence that the test will be unreliable hence proceeded to explore the test statistics. The main statistic of interest is the Wald statistic (z) (Elston, 1998) for the slope parament

Table 3: Intercept table

Intercept	**143.181**
Elephant entry points	**0.996**
Water sources	**1.000**
Human settlements	**1.001**
Raster values	**0.412**

Intercept: when x is equal to zero, the odds of success are 143 times greater than the odds of failure. Slope: for every 1 unit increase in x, the ratio odds of success to odds of failure changes by a factor of 0.996, 1.000, 1.001 and 0.412 respectively. That is the odds ratio of success to failure nearly equal to 1 with every 1 unit increase in x. From an inference testing perspective, we would reject the null hypothesis of no relationship.

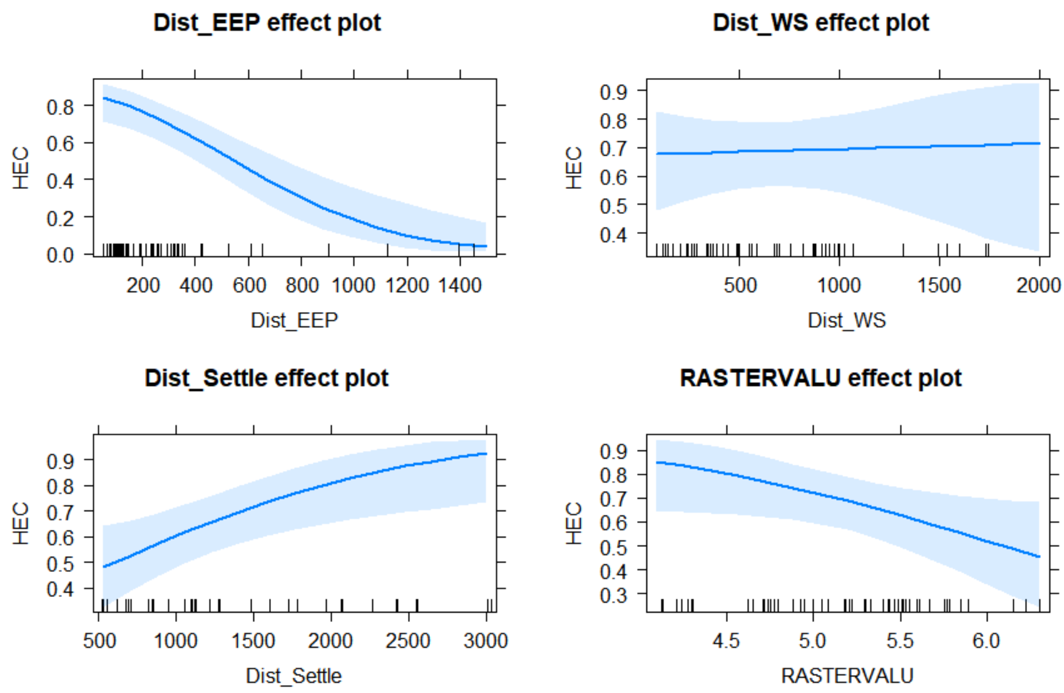


Figure 11: Final output of the Generalized Linear Model (GzLM).

Table 4: Summary of the best model

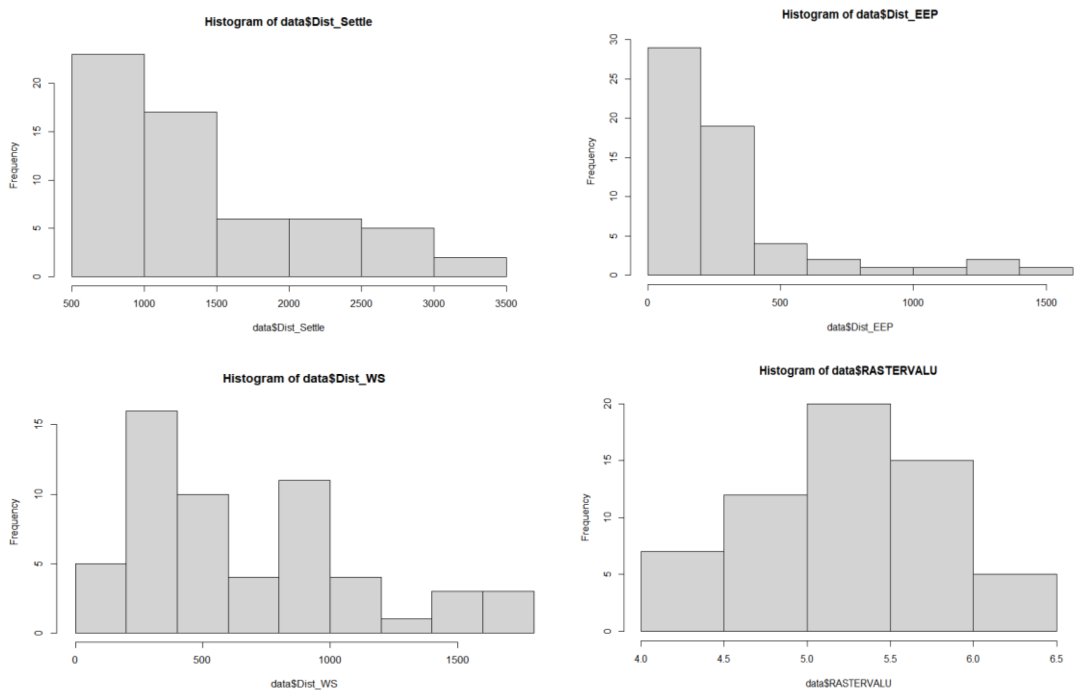
Best Model	Coefficient	Estimate	Standard Error	t-Value	Pr(>|t|)
Model 2	(Intercept)	4.96411503	2.304	2.154	0.031
	EEP	-0.00336651	0.0007	-4.52	0.000006
	WS	0.00009156	0.0005	0.159	0.873
	HS	0.00103936	0.0003	2.736	0.006
	RV	-0.88479398	0.4277	-2.068	0.038

Summary of best model coefficient estimates in Model 2 *(table 2)* which came out to have the lowest AICc value indicating the best fit for this model (Wagenmakers, et al., 2004). Coefficient shows model intercept and explanatory variables included in the analysis: Farmers' fields' (FF) distance from elephant entry points (EEP), water sources (WS) human settlements (HS), and the focal value of crop fields from the LULC raster (RV). Estimate and standard error show the magnitude of each specific coefficient effect and the variation attributed to it, respectively. The t-value and Pr(>It) columns show the value of the t-statistic and p-value for testing whether the corresponding coefficient is significantly different from 0.

Histograms of each explanatory variable

The variables that influence the HEC were then scored using the histograms for the pictorial representation. Each histogram indicates the frequency of the HEC recorded in response to the variable considered for the study. It is very clear from the histograms that the elephant entry points and water sources directly related to the HEC while the human settlements and the raster values influenced HEC, but not in a uniform pattern. The highest frequency was recorded when the distance from the elephant entry point and water sources was less than 1000 m. Villages with populations less than 1000 have a high frequency of HEC incidents.

While raster values which were a proxy for landscape heterogeneity indicated higher frequency at 5-5.5.



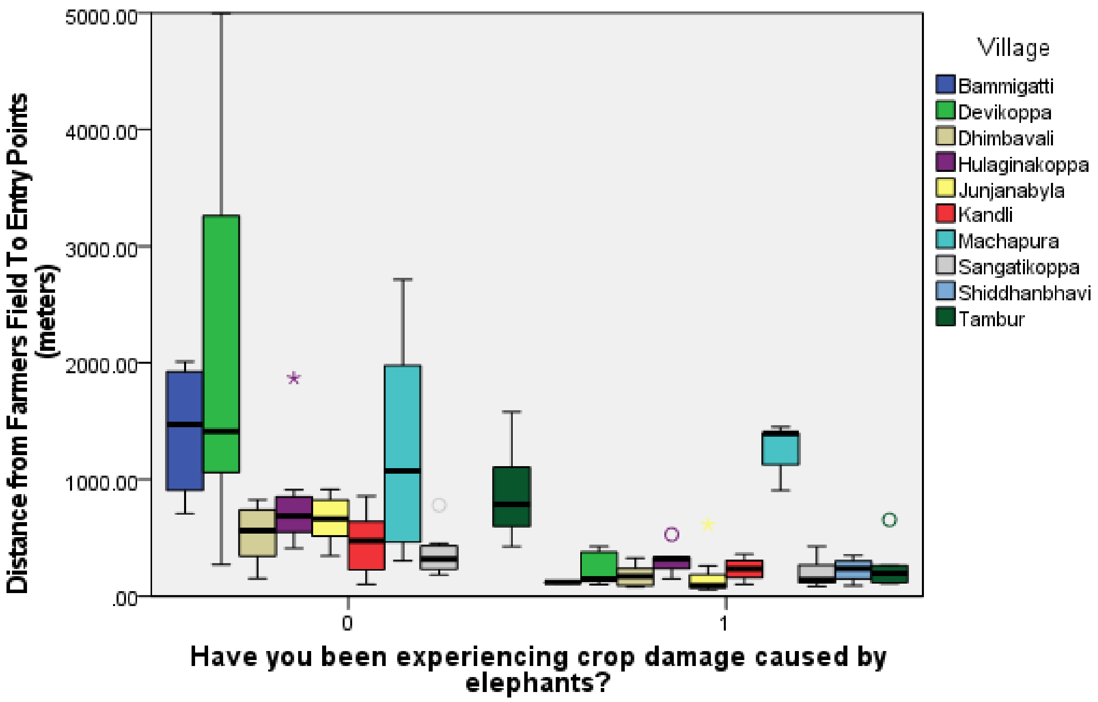


Figure 12: Box plot of affected and unaffected farmers Vs distance to elephant entry points between all the villages in the study area.

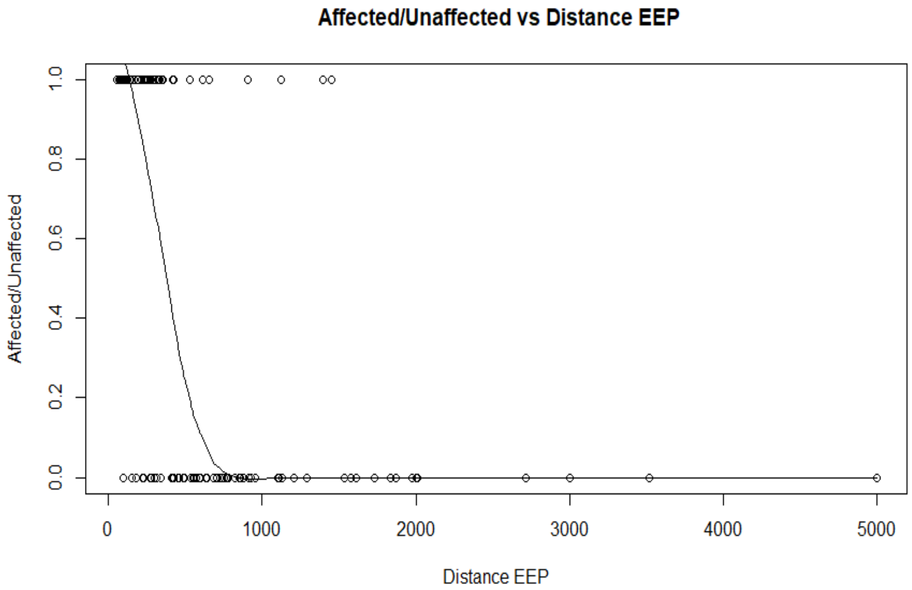


Figure 13: Scatter plot of HEC presence (1)/absence (0) vs Distance from elephant entry points.

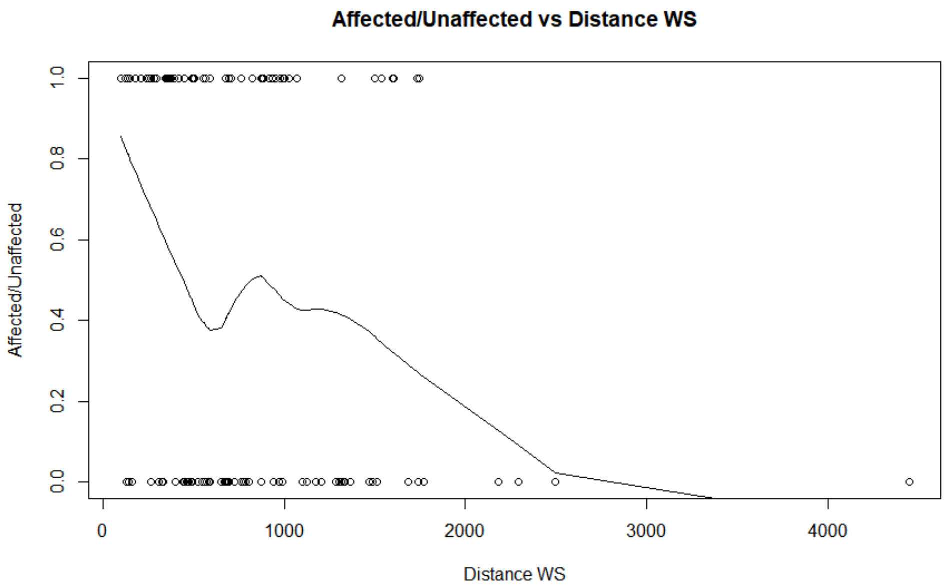


Figure 14: Scatter plot of HEC presence (1)/absence (0) vs Distance from Water Sources (WS).

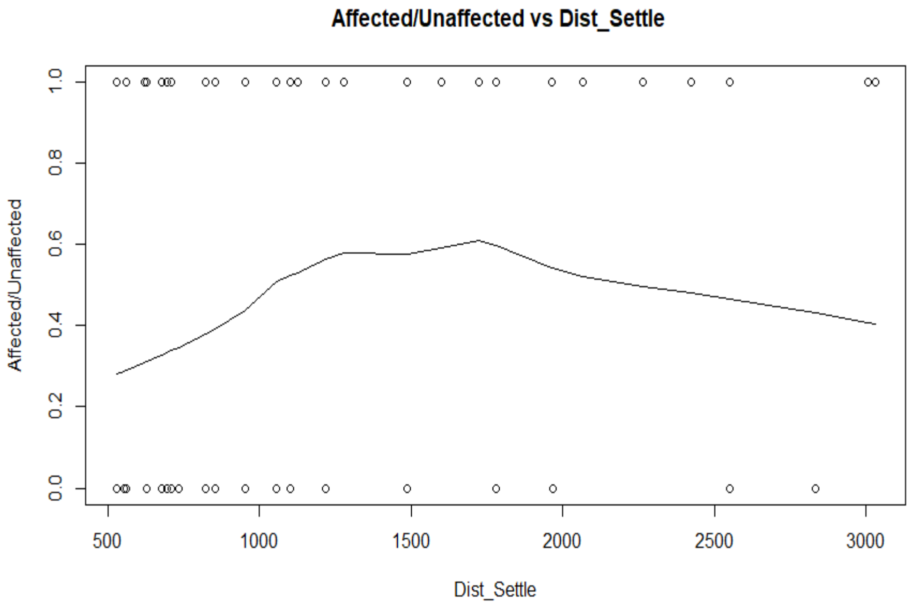


Figure 15: Scatter plot of HEC presence (1)/absence (0) vs Distance from human settlements to elephant entry points.

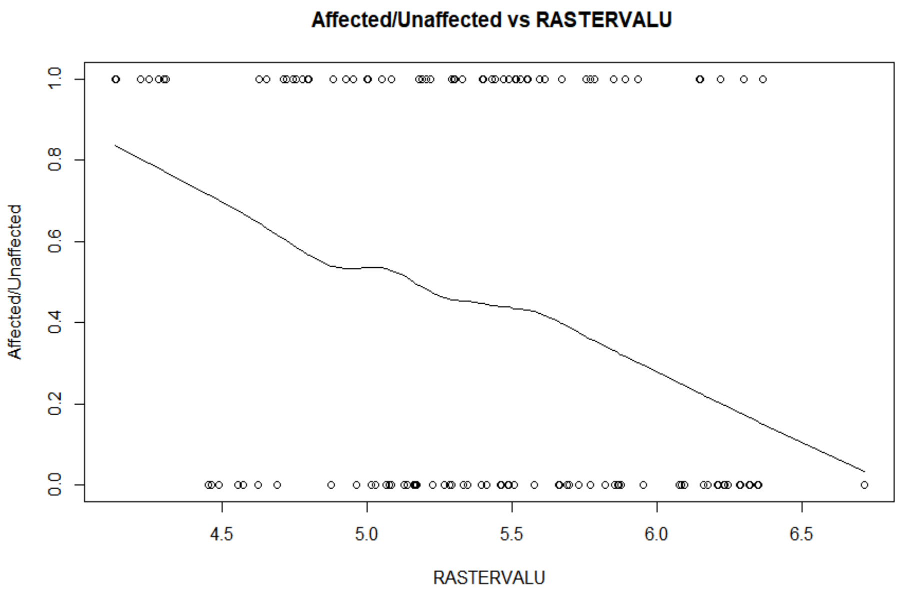


Figure 16: Scatter plot of HEC presence (1)/absence (0) vs raster values obtained through focal statistics.

Discussion

1. Key findings

This research work was focused on the determination of the factors that influence the occurrence of HEC in heterogeneous human-dominated landscapes. The presence of elephant entry points closer to the crop fields (~800 m) was found to have a major contributor to the presence of HEC (p-value = 0.000006). The distance between human settlements and the elephant entry points with the presence of ecological factors *(p value=0.00622)* had a positive influence on the HEC. The

GzLM analysis of the heterogeneous landscape in the study area had a significant role in the HEC *(p-value =0.03862)*. Though most of the selected factors showed a positive influence on the occurrence of the HEC, the presence of the water sources did not have any significance (*p value= 0.8429*).

2. Landscape complementation a driver of Elephant movement?

The farmers that are affected by crop-raiding are situated near the forests. This finding is supported by other studies that have also found that conflict with elephants increases in intensity with proximity to forests ((Kiiru, 1995); (Nath, 1998); (Treves, et al., 1999); (Nyhus, et al., 2000); (Das, 2007)). (Sukumar, 1989) found that herds tended not to venture further than 1 km from a forest boundary.

The graph *(figure13)* on the distance to elephant entry points showed a varied range of influence by the distance of elephant entry points to crop fields on the presence and absence of HEC. There is also a portion of the graph that says they were people that were not affected by the distance of elephant entry points *(Figure 13).* Here it is important to note that the data collected was only in the year 2022 and the chosen study areas were highly affected by HEC. Thus unaffected areas could be the possible results of elephant-proof measures taken by the people or the government to avoid HECs such as elephant barriers or trenches etc. Moreover, the availability of such facilities from the government is completely pressure-driven, in other words, if people strongly demand more compensation, these elephant-proof measures are implemented within the vast boundaries of each village. Another possibility could also be the cropping pattern which shows seasonal variation and also because of the high-risk high-gain forage strategy (Srinivasaiah, et al., 2019), elephants might prefer depredating certain favourable crops like sugarcane and paddy.

Although the water source might have some influence *(figure 14)* on HEC there was no significance observed. This finding implies that heterogeneity of forest is invariably a major cause of conflicts between humans and elephants, while the severity of the effects varies depending on what the habitat provides for their survival. Thus indicating the high-risk high-gain forage strategy followed by elephants often while depredation on crop fields in a human-dominated landscape (Srinivasaiah, et al., 2019). Most studies demonstrate high elephant densities in landscapes close to water sources (Distefano, 2005) (Okello, et al. 2015). This could also be explained by the abundance of water sources, especially in the Western Ghats. Providing adequate tropical climatic conditions with precipitations ranging from 6,500 mm at the crest to about 1000mm, water sources are present within the forests as well. The presence of dams and reservoirs such as the '*Thattihalla dam* located close to *Kandli* village' may majorly suffice their needs to obtain water in this human-dominated landscape. The presence of a water source directly influences the cropping pattern of the region and thus indirectly plays a role in the HEC. There is no substantial proof directly relating the presence of water sources and crop raiding behaviour of the elephants. Water influences human-population density and crop density, as expected for water-based agricultural systems, but it is the distribution of forest mosaic that influenced elephant movement and thus human–Elephant conflict patterns in this study.

In this project, the analysis of the distance of settlements concerning the effects on the HEC *(figure 15)* revealed ecological effects if the farms closer to the forests sustained high levels of HEC. This can be explained by the nature of the spatial arrangement of the farms that sustained crop damage in the study areas. Farmers have widely encroached on the used-to-be elephant habitats and converted them into farming lands and settlements over time. This has eventually created pockets of agricultural land surrounded by forest mosaics. Nonetheless, elephants raided not only farms close to the mosaics but also those further away indicating a wide use of habitat even in the human-dominated areas.

3. Role of habitat heterogeneity in causing HEC

Habitat heterogeneity played a crucial role in the steep increase of HEC in recent times. The villages in the study areas were also closely located to the elephant corridors as an intricate matrix of human settlements, crop fields, plantations and forests. The focal values obtained from the LULC raster (RS) which was used as a proxy for landscape heterogeneity gave a clear significance in the GzLM indicating that the higher the heterogeneity *(figure 16),* the higher will be the chances of occurrences of HEC. Elephants try to avoid contact with humans as they rest in the plantations acting as a temporary refuge (Bell, 1984) during the day and raid crops during the night (Wilson, et al., 2015). This particular matrix of a landscape provides them with the perfect nutritious forage conditions (crop depredation during the night) and the nearby forest mosaic provides shelter during the day.

Forest mosaics may also have a physiological role, such as the provision of shade to assist thermal regulation (Kinahan, et al., 2007). Elephants head out in search of food mainly after sun-down and HEC occurs mostly between dusk and dawn. This diurnal resting pattern has been observed in other elephant populations experiencing conflict with humans (Venkataraman, et al., 2005). *Figure 17 and figure 1*8 are cropped images of the HEC map *(figure 4)* obtained with the LULC raster. It shows the forest pathways that the elephants follow in the human-dominated landscapes of the Western Ghats region. This was developed based on the group discussions conducted during fieldwork with the forest authorities. It was observed that the habitat usage of elephants in this region vastly depended on the forest mosaics. It was quite evident that the distance between forest mosaics and crop fields played a crucial role in the occurrences of elephant entry points. The shorter the distance of crop fields from these elephant entry points higher were the chances of HEC occurrence. *Figure 18* also depicts how these forest mosaics help in connecting fragments of forests.

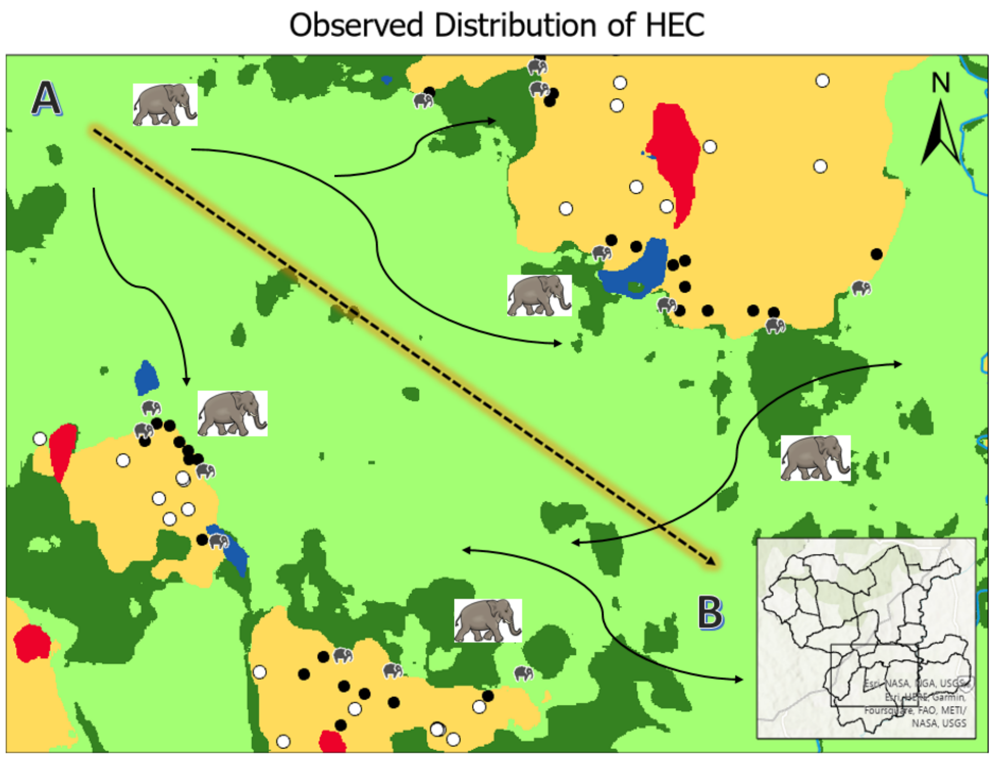


Figure 17: Elephant Pathways in the heterogeneous landscapes.

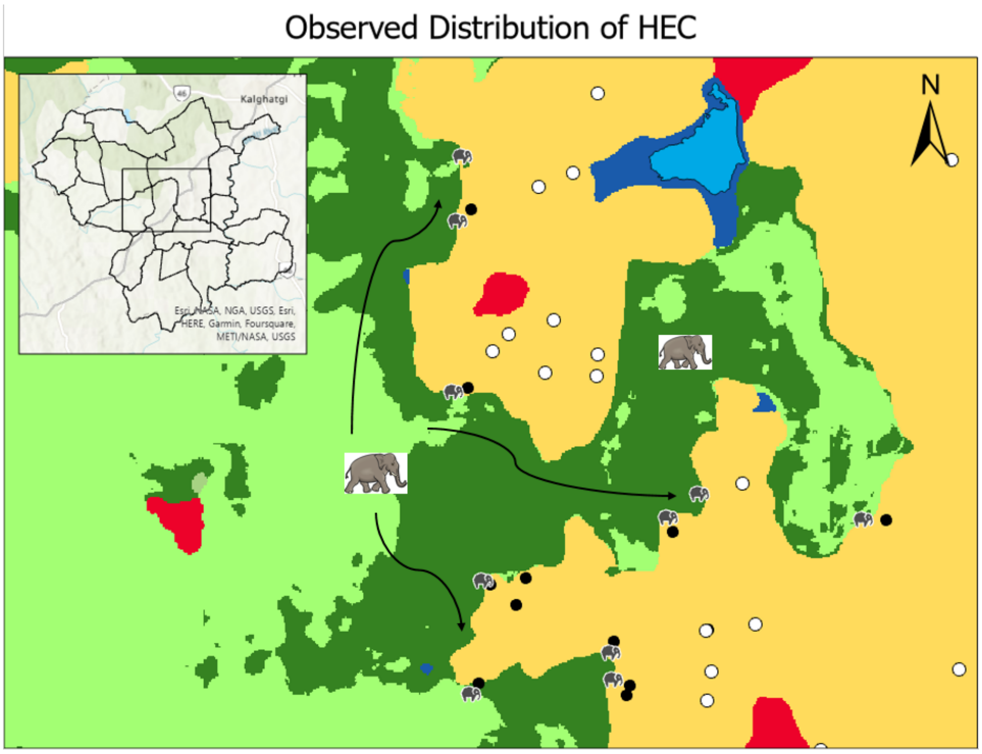


Figure 18: Elephant pathways connecting isolated fragments through the dense natural forests.

Additionally, we also observed that most farmers having farms or settlements adjacent to the mosaics conducted routine night guarding at specific points that they believed to be the elephant entry points. In villages like *Tambur, Sangatikoppa* and *Hulaginakoppa* farmers were always vigilant and guarded their farms, in fact, these farmers mainly helped me determine GPS coordinates of elephant entry points of those villages. Although *Machapur* village had one peculiar pattern where four farmers constantly had crop loss in the last four years even though their farm fields were located ~1000 meters away from elephant entry points. This explains that human presence during crop raiding seasons and different cropping patterns can impact greatly their movement. Such situations give a perfect forage abundance condition to the elephants and crop-raiding can spread to other farms away from the forest edge as well.

4. Tolerance of farmers toward Elephant damages

Instances of people not applying for compensation of crop damages and their willingness to participate in elephant driving operations with the forest department gives the level of tolerance of people towards crop damages by elephants in 10 different villages. This further entails analysing their perspectives on the cause of HEC and attitudes w.r.t their involvement in deterring elephants with the help of local forest authorities. Understanding the degree to which people tolerate elephants when they coexist with people is essential for creating mitigating measures (Frank, 2016).

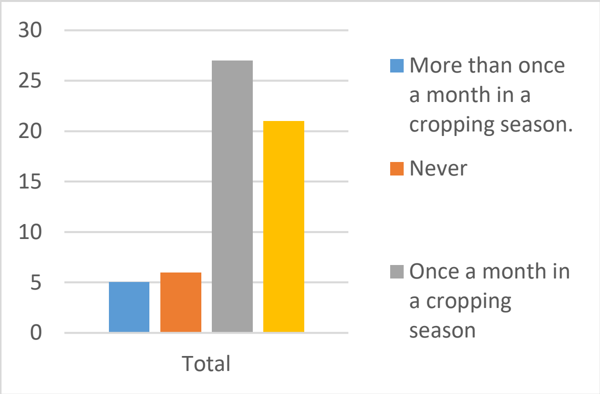


Figure 19: Number of farmers and their frequencies of applying for crop damage compensations mainly by elephants.

Conclusion

In landscapes that have been transformed due to intense anthropogenic activities such as the expansion of agriculture, isolated populations of species occur, continuing to live in the remnants of suitable habitats. Populations of wide-ranging species such as elephants, however, may continue to move through such landscape mosaics, and their movement patterns are often influenced by the spatial distribution of the remaining forest areas. This study thus indicates the relationship between such intricate landscape geometrics, elephant movement patterns, and the occurrence of HEC. Increased landscape heterogeneity and scattered natural vegetation generally become a high priority for megaherbivores for their movement in terms of forage availability and nutritional quality. Effective management of forests by ensuring homogeneity of forage abundance can greatly restrict elephant movements within corridors. At a community scale, an understanding of the spatial and temporal patterns of HEC is necessary for effective elephant conservation but must be combined with an understanding of cultural and socio-economic influences. Forest plantations which are maintained by the local forest authorities should have an even composition of both timber and natural vegetation. Also, the inclusion of cropping pattern data can vividly explain the frequency of HEC occurrences as certain crops like sugarcane and paddy are given high compensation. Supporting this particular behaviour of crop raiding, secondary crop compensation data from another part of the Western Ghats elaborated monthly pattern shifts of elephant pathways directing to fields that were ready to be harvested (see appendix). Whereas spatial patterns of elephant movement and HEC are influenced by the location of forest mosaics. But seasonal patterns are more strongly influenced by the agricultural calendar. Therefore the inclusion of habitat matrix quality indicators is particularly crucial in managing fragmented landscapes in the tropics where agriculture frontiers are still expanding. Furthermore, the dissemination of knowledge on elephant movements and behaviour will help farmers to safeguard their fields through community guarding and thus encourage co-existence.

References

[Journal].
Almond R. E., Grooten, M., & Peterson, T. Living Planet Report 2020-Bending the curve of biodiversity loss. [Report]. - 2020.
Bal Payal [et al.] Erratum to: Elephants Also Like Coffee: Trends and Drivers of Human–Elephant Conflicts in Coffee Agroforestry Landscapes of Kodagu, Western Ghats, India [Book]. - [s.l.] : Environmental Management 48(2):263-75, 2011.
Baskaran N., [et al.] A landscape-level assessment of Asian elephant habitat, its population and elephant–human conflict in the Anamalai hill ranges of southern Western Ghats, India. [Journal]. - [s.l.] : Mammalian Biology, 2013. - Vol. 7.
Bell R.H.V. The man–animal interface: an assessment of crop damage and wildlife control. [Journal] // Conservation and Wildlife Management in Africa (eds R.H.V. Bell & E. Mcshane-Caluzi). - [s.l.] : US Peace Corps, Malawi., 1984. - p. 387 416.
Benjaminsen TA Goldman MJ, Minwary MY, Maganga FP. Wildlife management in tanzania: state control, rent seeking and community resistance [Journal] // Development and change. - 2013. - pp. 1087-1109.
Blake S [et al.] Roadless wilderness area determines forest elephant movements in the Congo Basin [Journal] // PLoS ONE. - 2008. - pp. 3(10), e3546.
D. Nath C., R. Sukumar and L. & Caudhurī D. Elephant-human conflict in Kodagu, southern India: distribution patterns, people's perceptions and mitigation methods. [Journal]. - [s.l.] : Asian Elephant Conservation Centre., 1998.
Das A., Ahmed, M. F., Lahkar, B. P., & Sharma, P. A preliminary report of reptilian mortality on road due to vehicular movement near Kaziranga National Park, Assam, India. [Journal]. - [s.l.] : Zoos' Print Journal,, 2007. - 7 : Vol. 22. - pp. 2742-2744.
De Boer W. F. [et al.] Understanding spatial differences in African elephant densities and occurrence, a continent-wide analysis. [Journal] // Biological Conservation 159. - [s.l.] : Biological Conservation,, 2013. - Vol. 159. - pp. 468-476.
De Boer WF et al. Understanding spatial differences in African elephant densities and occurrence, a continent-wide analysis. [Journal] // Biological Conservation 159. - 2013. - pp. 468-476.
Devcharan Jathanna K. Ullas Karanth,N. Samba Kumar,Krithi K. Karanth,Varun R. Goswami Patterns and Determinants of Habitat Occupancy by the Asian Elephant in the Western Ghats of Karnataka, India [Journal] // PLOS ONE / ed. Sadie Jane Ryan University of Florida,UNITED STATES. - 2015.
Dingle H. & Drake, V. A. What is migration? Biosci. [Journal]. - 2007. - Vol. 57(2). - pp. 113–121 .
E Distefano. Human-Wildlife Conflict worldwide: collection of case studies, analysis of management strategies and good practices. Food and Agricultural Organization of the United Nations (FAO), Sustainable Agriculture and Rural Development Initiative (SARDI), Rome, It [Book]. - [s.l.] : FAO Corporate Document repository, 2005.
Elston D. A. Estimation of denominator degrees of freedom of F-distributions for assessing Wald statistics for fixed-effect factors in unbalanced mixed models. [Journal]. - 1998. - Biometrics. - pp. 1085-1096.
Estes JA et al. Trophic downgrading of [Journal] // Science 333. - 2011. - pp. 301-306.
Fernando P Kumar AM, Williams CA, Wikramanayake E, Aziz T, Singh SM Review of human–elephant conflict mitigation measures practiced in South Asia [Journal]. - 2008.
Frank B. Human–wildlife conflicts and the need to include tolerance and coexistence: An introductory comment. [Journal]. - [s.l.] : Society & Natural Resources,, 2016. - Vols. 29(6),. - pp. 738-743..
Fryxell J. M. Forage quality and aggregation by large herbivores. [Journal] // Amer. Nat.. - 1991. - Vol. 138(2). - pp. 478–498.
Global land use/land cover with Sentinel-2 and deep learning. [Journal]. - [s.l.] : IGARSS, 2021.
Graham M. D [et al.] The movement of African elephants in a human dominated land use mosaic. [Journal] // Animal Conservation. - 2009. - pp. 12(5), 445-455.
Granados A, R. B Weladji and M. R Loomis Movement and occurrence of two elephant herds in a human-dominated landscape, the Be´noue´ Wildlife Conservation Area, Cameroon. [Book]. - [s.l.] : Tropical Conservation Science, 5, 150–162., 2012.
Gubbi S. Patterns and correlates of human–elephant conflict around a south Indian reserve [Journal] // Biological Conservation, 148(1). - 2012. - pp. 88-95.

Gubbi S., Swaminath, M. H., Poornesha, H. C., Bhat, R., & Raghunath, R. An elephantine challenge: human–elephant conflict distribution in the largest Asian elephant population, southern India. [Journal] // Biodiversity and conservation, 23(3). - 2014. - pp. 633-647.
Harris G M [et al.] Rules of habitat use by elephants Loxondonta africana in southern africa: Insights of regional management. [Journal] // Oryx. - 2008. - pp. 42(1), 66-75.
Hartig F. DHARMa: residual diagnostics for hierarchical (multi-level/mixed) regression models. R package version 0.3, 3. [Journal]. - 2020.
Hoare R. E Determinants of human-elephant conflict in a land use mosaic [Journal] // Journal of applied ecology. - 1999. - pp. 36(5), 689-700.
Hoare R. E. Determinants of human–elephant conflict in a land-use mosaic. [Journal] // Journal of applied ecology. - 1999. - 5 : Vol. 36. - pp. 689-700.
Hoare RE Du Toit JT Coexistence between people and elephants in African [Journal] // Conservation Biology 13. - 1999. - pp. 633–639.
Hodgson I. D., Redpath, S. M., Sandstrom, C., & Biggs, D. The state of knowledge and practice on human-wildlife conflicts [Book]. - 2020.
IJ Whyte The elephant management dilemma. [Journal] // Environmental ethics: what really matters, what really works.. - 2012. - pp. 71–84.
Islam M. A., Mohsanin, S., Chowdhury, G. W., Chowdhury, S. U., Aziz, M. A., Uddin, M., ... & Azam, I. Current status of Asian elephants in Bangladesh [Journal] // Gajah, 35. - 2011. - pp. 21-24.
K Karra [et al.] Global land use/land cover with Sentinel-2 and deep learning. [Conference] // IEEE international geoscience and remote sensing symposium IGARSS. - [s.l.] : IGARSS, 2021. - pp. 4704-4707.
K Karra [et al.] Global land use/land cover with Sentinel-2 and deep learning. [Conference] // IEEE international geoscience and remote sensing symposium IGARSS. - [s.l.] : IGARSS, 2021. - pp. 4704-4707.
Kalam T., Kumar Baishya, H., & Smith, D. Lethal fence electrocution: a major threat to Asian Elephants in Assam, India [Journal] // ropical Conservation Science, 11. - 2018. - p. p.1940082918817283.
Karanth K. K, Gupta S and Vanamamalai A. Compensation payments, procedures and policies towards human-wildlife conflict management: insights from India. [Journal]. - [s.l.] : Biol. Conserv., 2018. - Vol. 227. - pp. 383–389.
Kiiru W. The current status of human-elephant conflict in Kenya. Pachyderm, [Journal]. - 1995. - Vol. 19. - pp. 15-19.
Kinahan A. A., Pimm S. L. and & Van Aarde R. J. Ambient temperature as a determinant of landscape use in the savanna elephant, Loxodonta africana. [Journal] // Journal of Thermal Biology. - 2007. - 1 : Vol. 32. - pp. 47-58..
Kothari A., Pande, P., Singh, S., & Variava, D. Management of national parks and sanctuaries in India: a status report [Report]. - 1989.
Krishnan V., Kumar, M.A., Raghunathan, G. and Vijayakrishnan, S., Distribution and habitat use by Asian Elephants (Elephas maximus) in a coffee-dominated landscape of southern India. [Journal] // Tropical Conservation Science, 12. - 2019. - p. 1940082918822599.
Lamichhane BR Persoon GA, Leirs H, Poudel S, Subedi N, Pokheral CP, Bhattarai S, Thapaliya BP, De Iongh HH. Spatio-temporal patterns of attacks on human and economic losses from wildlife in Chitwan National Park, Nepal [Journal] // PLOS ONE 13(4). - 2018. - p. e0195373.
Leimgruber P. [et al.] 2003). Fragmentation of Asia's remaining wildlands: Implications for Asian elephant conservation. [Book]. - [s.l.] : Animal Conservation, 6, 347–359., 2002.
Lenin J Sukumar R. Action Plan for the mitigation of human-elephant conflict in India [Report]. - 2011.
Lenin J., & Sukumar, R. Action Plan for the mitigation of human-elephant conflict in India [Journal] // Asian Nature Conservation Foundation, Report.. - 2011.
Lino A., Fonseca, C., Rojas, D., Fischer, E., & Pereira, M. J. R. A meta-analysis of the effects of habitat loss and fragmentation on genetic diversity in mammals [Journal] // Mammalian Biology 94, no. 1. - 2019. - pp. 69-76.
Liu P et al. Conflict between conservation and development: cash forest encroachment in Asian elephant distributions. [Journal] // Scientific reports 7:6404. - 2017.
Mackenzie CA Ahabyona P Elephants in the garden: financial and social costs of crop raiding. [Journal] // Ecological Economics 75. - 2012. - pp. 72-82.

Madden F. Creating coexistence between humans and wildlife: global perspectives on local efforts to address human–wildlife conflict. [Journal] // Human dimensions of wildlife. - 2004. - pp. 247-257..
Mathur P., Nielsen, R. H., Prasad, N. R., & Prasad, R. Wildlife conservation and rail track monitoring using wireless sensor networks. [Journal]. - 2014. - pp. 1-4.
McArthur Clare, Banks Peter B and Forbey Rudy Boonstra and Jennifer Sorensen THE DILEMMA OF FORAGING HERBIVORES: DEALING WITH FOOD AND FEAR [Journal] // Biology faculty publications and presentations. - [s.l.] : Springer, 2014.
Naha D., Dash, S. K., Chettri, A., Roy, A., & Sathyakumar, S. Elephants in the neighborhood: patterns of crop-raiding by Asian elephants within a fragmented landscape of Eastern India [Journal] // PeerJ. - 2020. - pp. 8, e9399.
Naha D., Dash, S.K., Chettri, A., Roy, A. and Sathyakumar, S. Elephants in the neighborhood: patterns of crop-raiding by Asian elephants within a fragmented landscape of Eastern India [Journal] // PeerJ, 8. - 2008. - pp. 93-99.
Naha D., Sathyakumar, S., Dash, S., Chettri, A., & Rawat, G. S. Assessment and prediction of spatial patterns of human-elephant conflicts in changing land cover scenarios of a human-dominated landscape in North Bengal. [Journal] // PloS one, 14(2). - 2019. - p. e0210580.
Nath C. D., Sukumar, R., & Caudhurī, D. L. Elephant-human conflict in Kodagu, southern India: distribution patterns, people's perceptions and mitigation methods. [Journal]. - [s.l.] : Asian Elephant Conservation Centre., 1998.
Nicolè S. [et al.] Biodiversity studies in Phaseolus species by DNA barcoding [Book].
Noble I. R. and Dirzo R. Forests as human-dominated ecosystems [Journal]. - [s.l.] : Science 277, 1997. - Vol. 5325. - pp. 522-525.
Nyhus P. J. and Tilson R. Crop-raiding elephants and conservation implications at Way Kambas National Park, Sumatra, Indonesia. [Journal]. - [s.l.] : Oryx, 2000. - 4 : Vol. 34. - pp. 262-274.
Ogra M., & Badola, R. Compensating human–wildlife conflict in protected area communities: ground-level perspectives from Uttarakhand, India [Journal] // Human Ecology, 36(5). - 2008. - pp. 717-729.
Okello M. M. [et al.] Habitat use and preference by African elephant outside of the protected areas, and management implications in the Amboseli landscape. [Journal] // International Journal of Biodiversity and Conservation. - 2015. - Vol. 3. - pp. 211–236.
Pokharel SS Singh B, Sukumar R [Journal] // Animal Conservation 22. - 2018. - pp. 177-188.
R. Sukumar Ecology of the asian elephant in southern india. i. movement and habitat utilization patterns [Journal] // Journal of Tropical Ecology 5. - 1989. - pp. 1–18.
Richardson M. Aleš Hladnik [Report] / Dr., Ass. Prof., Chair of Information and Graphic Arts Technology, ; Faculty of Natural Sciences and Engineering, University of Ljubljana.. - Slovenia ales : [s.n.], 2009. - pp. hladnik@ ntf. uni-lj. si, 6, 16..
Riddle HS Schulte BA, Desai AA, Van der Meer L. Elephants—a conservation overview [Journal] // Journal of Threatened Taxa 2. - 2010. - pp. 653-661.
S Wilson [et al.] Understanding spatial and temporal patterns of human–elephant conflict in Assam, India. [Journal]. - [s.l.] : Oryx, 2015. - 49. - pp. 140-149.
Shaffer L.J., Khadka, K.K., Van Den Hoek, J. and Naithani, K.J., Human-elephant conflict: A review of current management strategies and future directions. [Journal] // Frontiers in Ecology and Evolution, 6, . - 2019. - p. p.235..
Shaffer LJ Khadka KK, Van Den Hoek J, Naithani KJ. Human–elephant conflict: a review of current management strategies and future directions. [Journal] // Frontiers in Ecology and Evolution 6. - 2019. - pp. 1–12.
Sitati NW Walpole MJ, Smith RJ, Leader-Williams N. Predicting spatial aspects of human–elephant conflict [Journal] // Journal of Applied Ecology 40. - 2003. - pp. 667–677.
Skogen K. E. T. I. L., Ghosal, S. U. N. E. T. R. O., Skuland, S. I. L. J. E., Krishnan, S. I. D. D. H. A. R. T. H. A., Frank, B., Glikman, J. A., & Marchini, S. Predators in human landscapes [Book]. - 2019.
Srinivasaiah Nishanth [et al.] All-Male Groups in Asian Elephants: A Novel, Adaptive Social Strategy in Increasingly Anthropogenic Landscapes of Southern India [Journal]. - 2019.
Sukumar R The Asian Elephant: Ecology and Management. [Journal]. - 1989. - Cambridge University Press, New York. - p. 255pp.
Sukumar R The living elephants: evolutionary ecology, behavior, and conservation [Journal] // Biological Conservation, Volume 55, Issue 1. - 2003. - pp. 93-102.
Sukumar R. A brief review of the status, distribution and biology of wild Asian elephants Elephas maximus. [Journal] // International Zoo Yearbook, 40(1). - 2006. - pp. 1-8.

Sukumar Raman The living elephants: evolutionary ecology, behaviour, and conservation [Book]. - [s.l.] : Oxford University Press, 2003.
Thaker Maria, Pratik R. Gupte, Herbert H T Prins, Rob Slotow, and Abi T. Vanak. Fine-Scale Tracking of Ambient Temperature and Movement Reveals Shuttling Behavior of Elephants to Water. [Report]. - [s.l.] : Frontiers in Ecology and Evolution., 2019.
Thouless C.R. & Sakwa, J. Shocking elephants: Fences and crop-raiders in Laikipia District, Kenya. [Journal] // Biological Conservation . - 1994. - Vol. 72. - pp. 99-107.
Treves A. and Naughton-Treves L. Risk and opportunity for humans coexisting with large carnivores. [Journal]. - [s.l.] : Journal of human evolution,, 1999. - 3 : Vol. 36. - pp. 275-282.
Van de Water A Matteson K. Human–elephant conflict in western Thailand: socio-economic drivers and potential mitigation strategies. [Journal] // PLOS ONE 13. - 2018. - p. e0194736.
Venkataraman A. B. [et al.] Using satellite telemetry to mitigate elephant–human conflict: an experiment in northern West Bengal, India. [Journal] // Current Science. - 2005. - pp. 1827-1831..
W Barnes R F [et al.] Man determines the destribution of elephants in the rain forests of northeastern Gabon [Journal] // African journal of ecology. - 1991. - pp. 29(1), 54-63.
Wagenmakers E. J and Farrell S. AIC model selection using Akaike weights. [Journal]. - [s.l.] : Psychonomic bulletin & review., 2004. - Vol. 11(1). - pp. 192-196.
Yamamoto-Ebina S., Saaban, S., Campos-Arceiz, A., & Takatsuki, S. Food habits of Asian elephants Elephas maximus in a rainforest of northern Peninsular Malaysia. [Journal] // Mammal study, 41(3). - 2016. - pp. 155-161.

Appendix

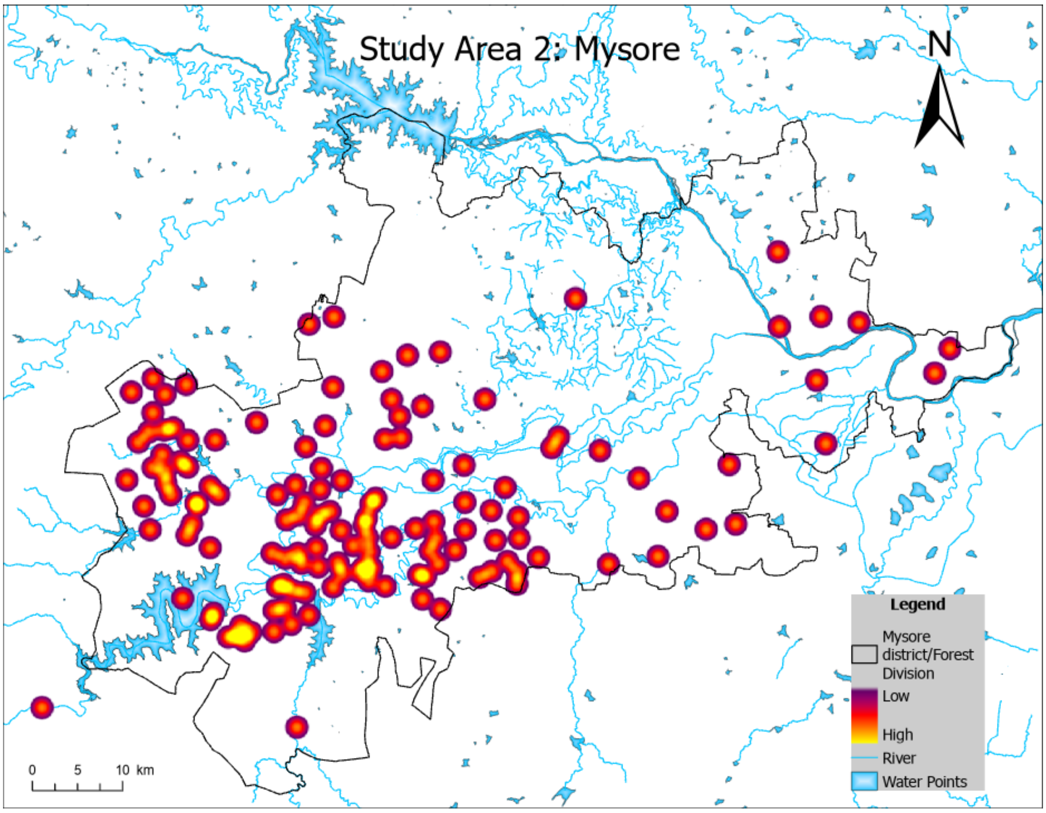


Figure 1: Map indicating the study area 2: Mysore Division of the Brahmagiri-Nilgiris Landscape, Western Ghats

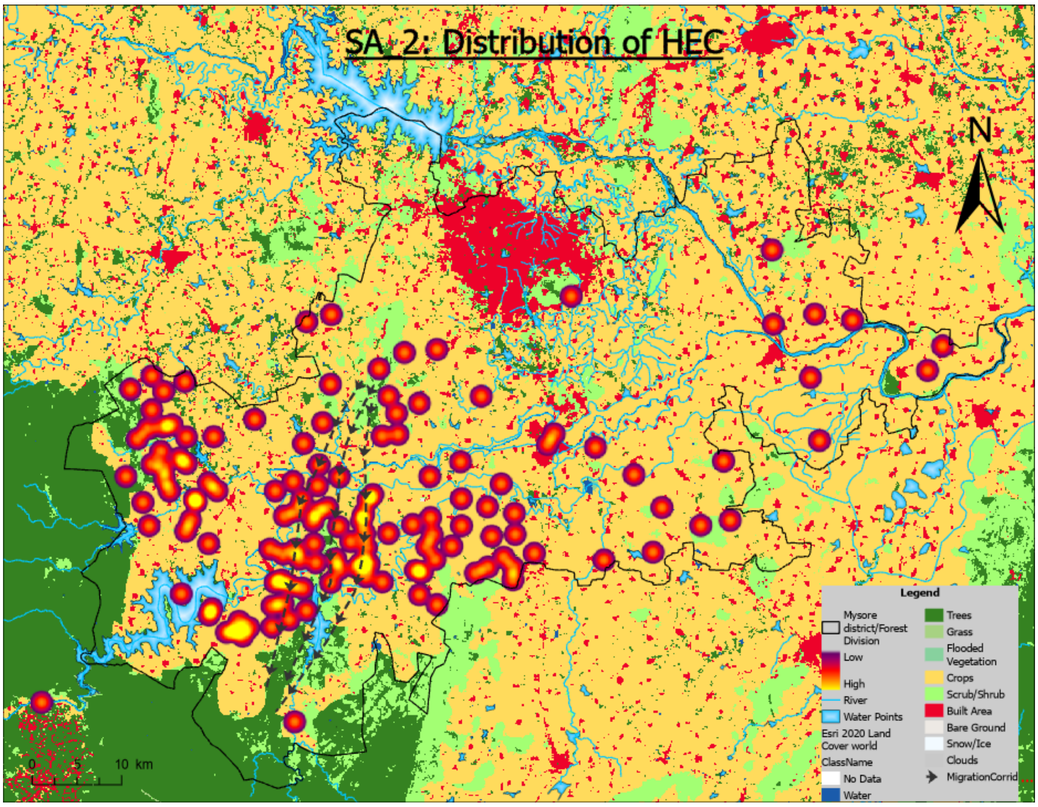


Figure 2: LULC Map indicating the possible ***Elephant*** *pathways in the human-dominated landscape.*

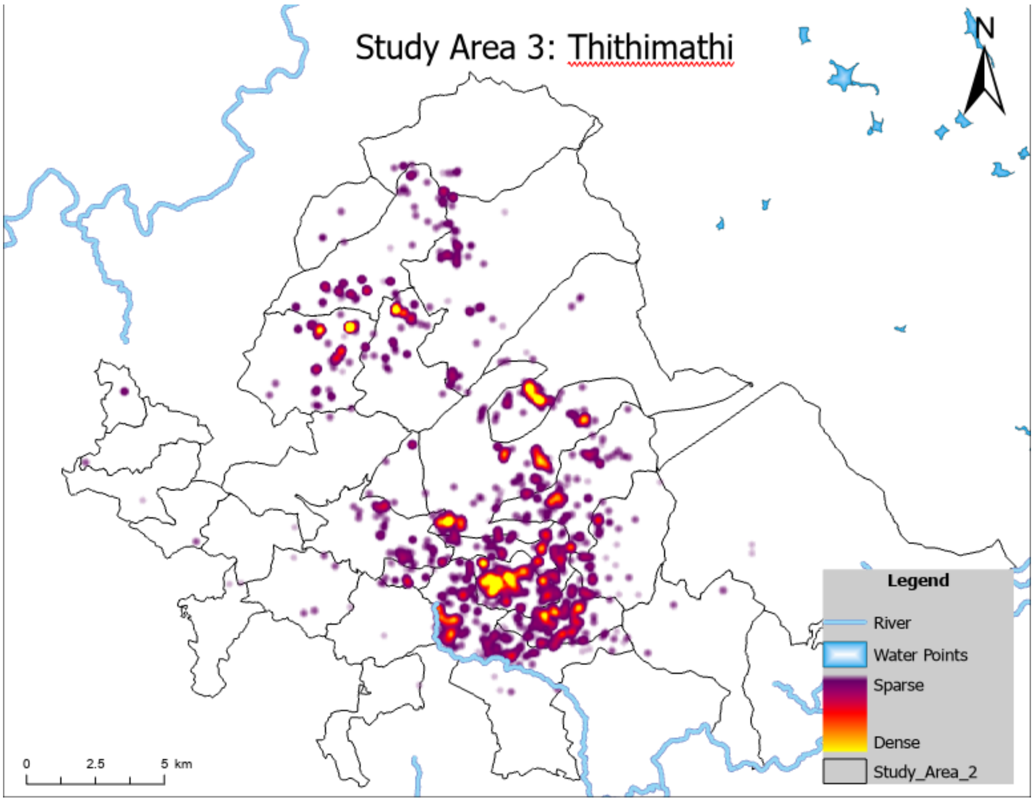


Figure 3: Map indicating the study area 3: Thithimathi Range of the Brahmagiri-Nilgiris Landscape, Western Ghats

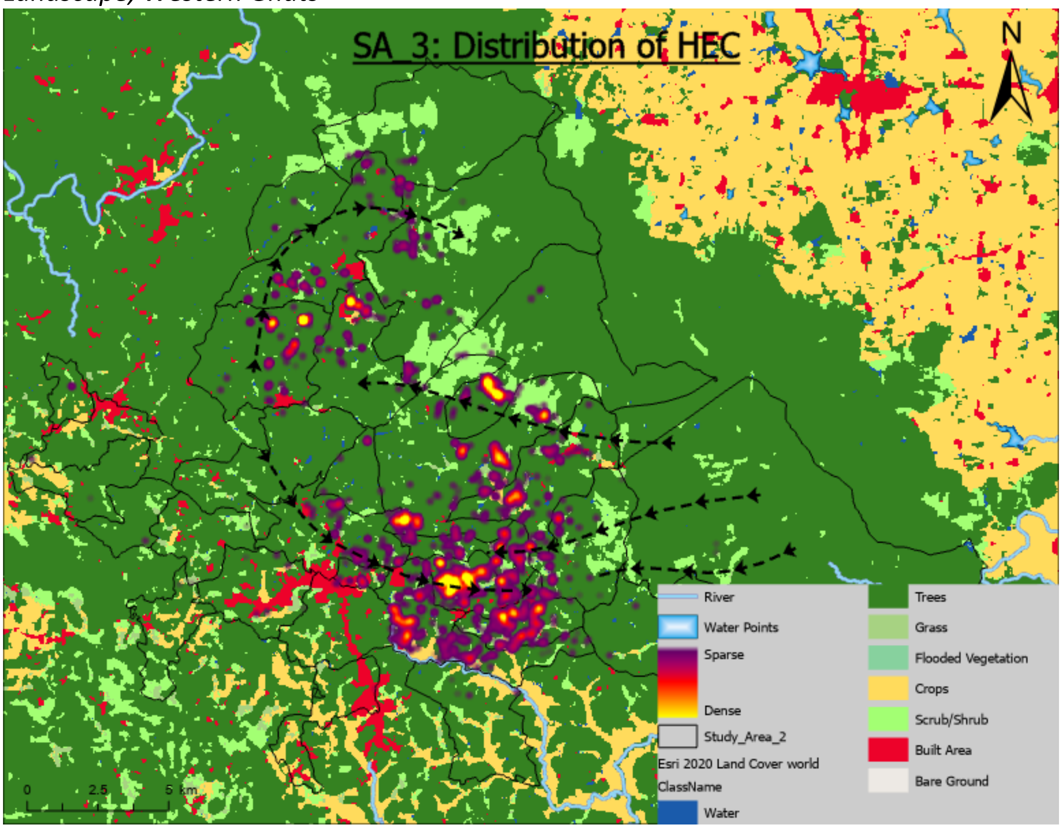
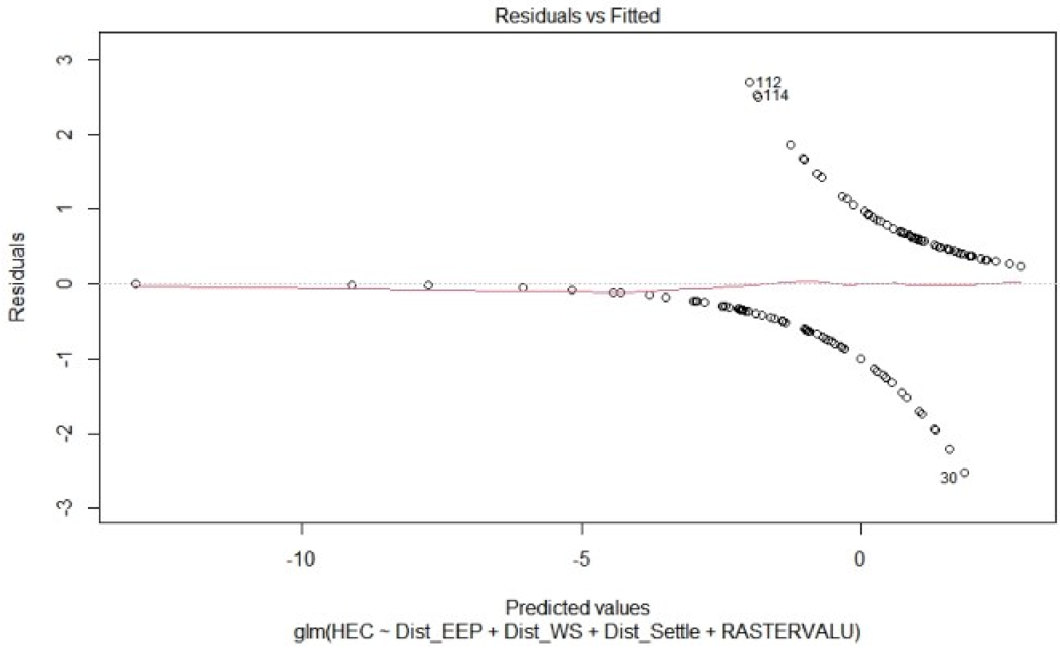
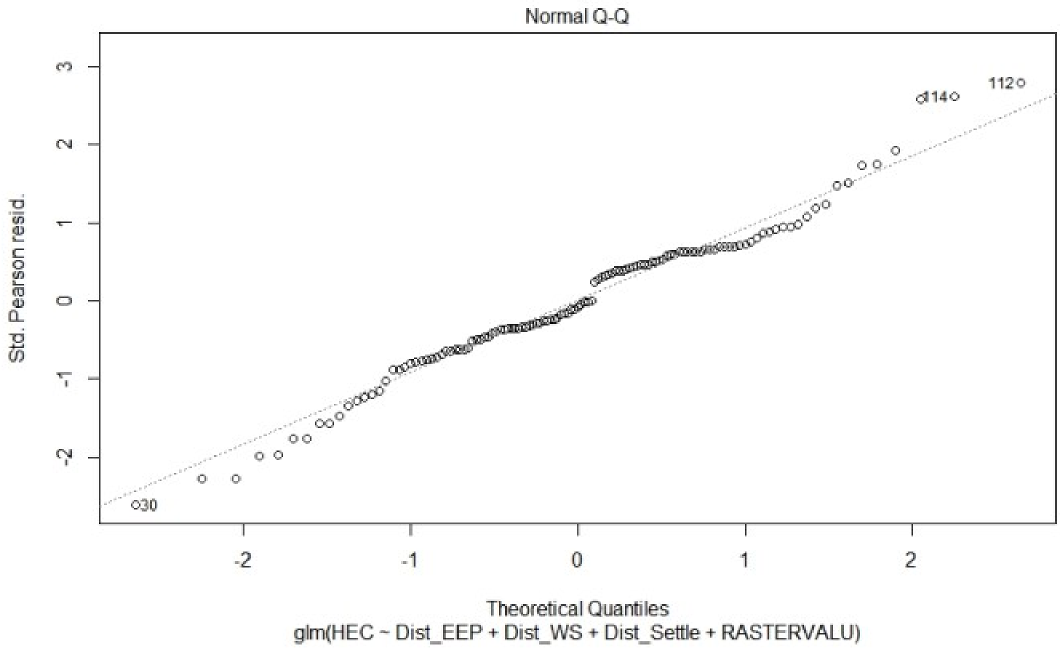
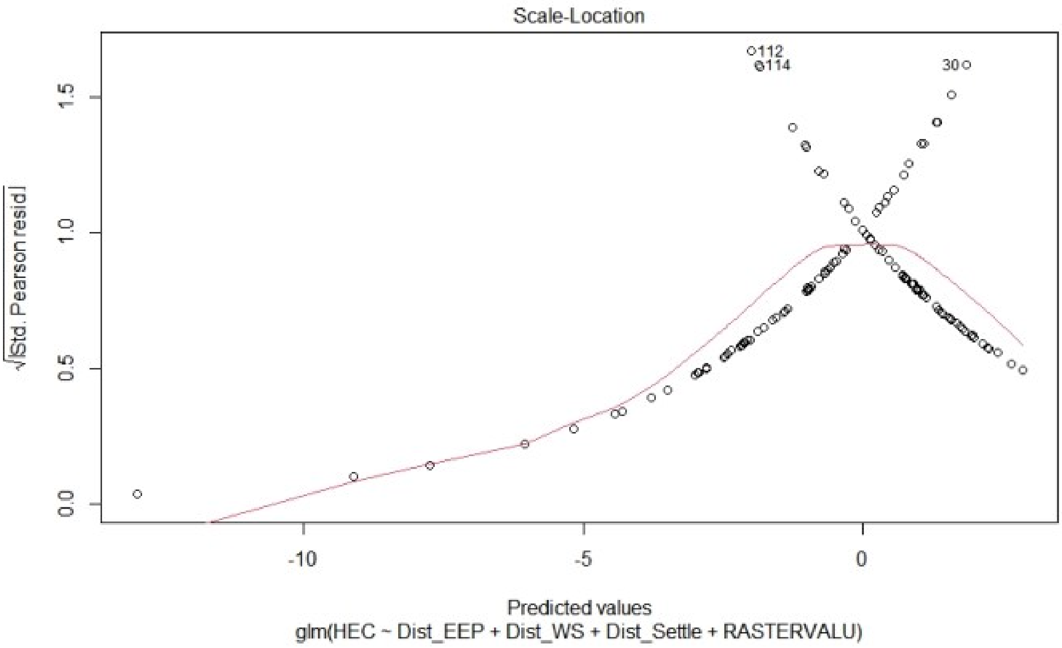


*Figure 4: LULC Map indicating the possible **Elephant** pathways in the human-dominated landscape.*


Residuals vs Fitted
Residuals
Predicted values
glm(HEC ~ Dist_EEP + Dist_WS + Dist_Settle + RASTERVALU)
112
114
30


Normal Q-Q
Std. Pearson resid.
Theoretical Quantiles
glm(HEC ~ Dist_EEP + Dist_WS + Dist_Settle + RASTERVALU)
114
112
30



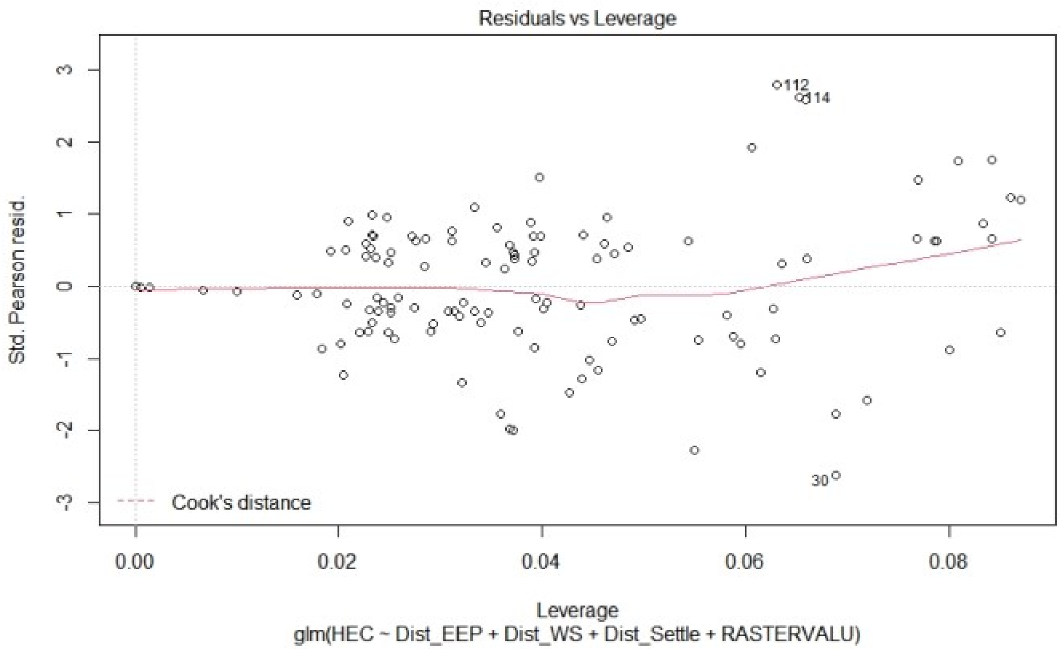


Figure 20: Plots from GzLM

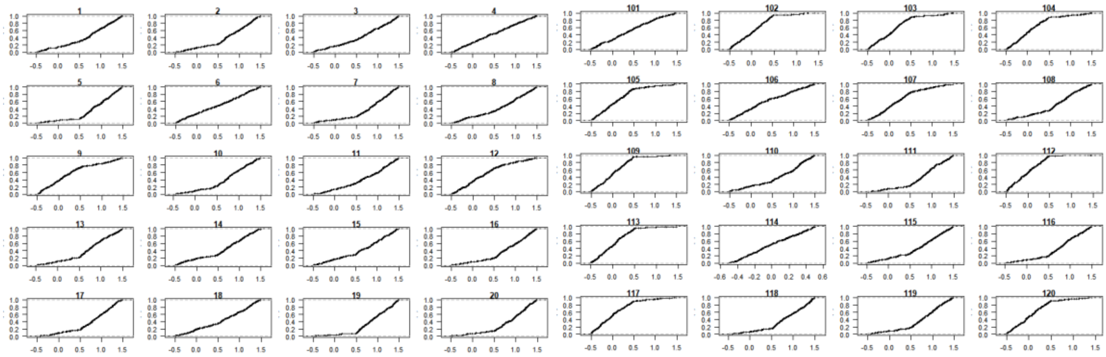


Figure 21: 250 stimulated datasets from the fitted model.

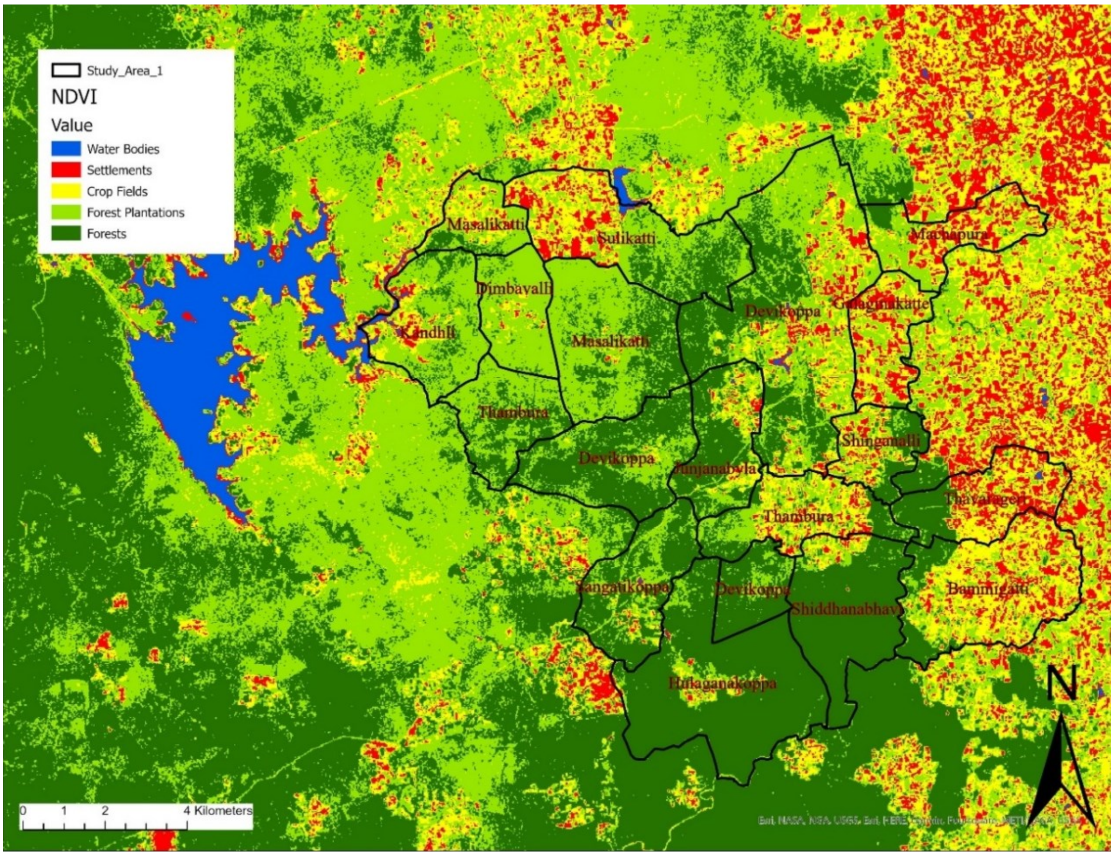


Figure 22: NDVI map for the Khalghatagi region

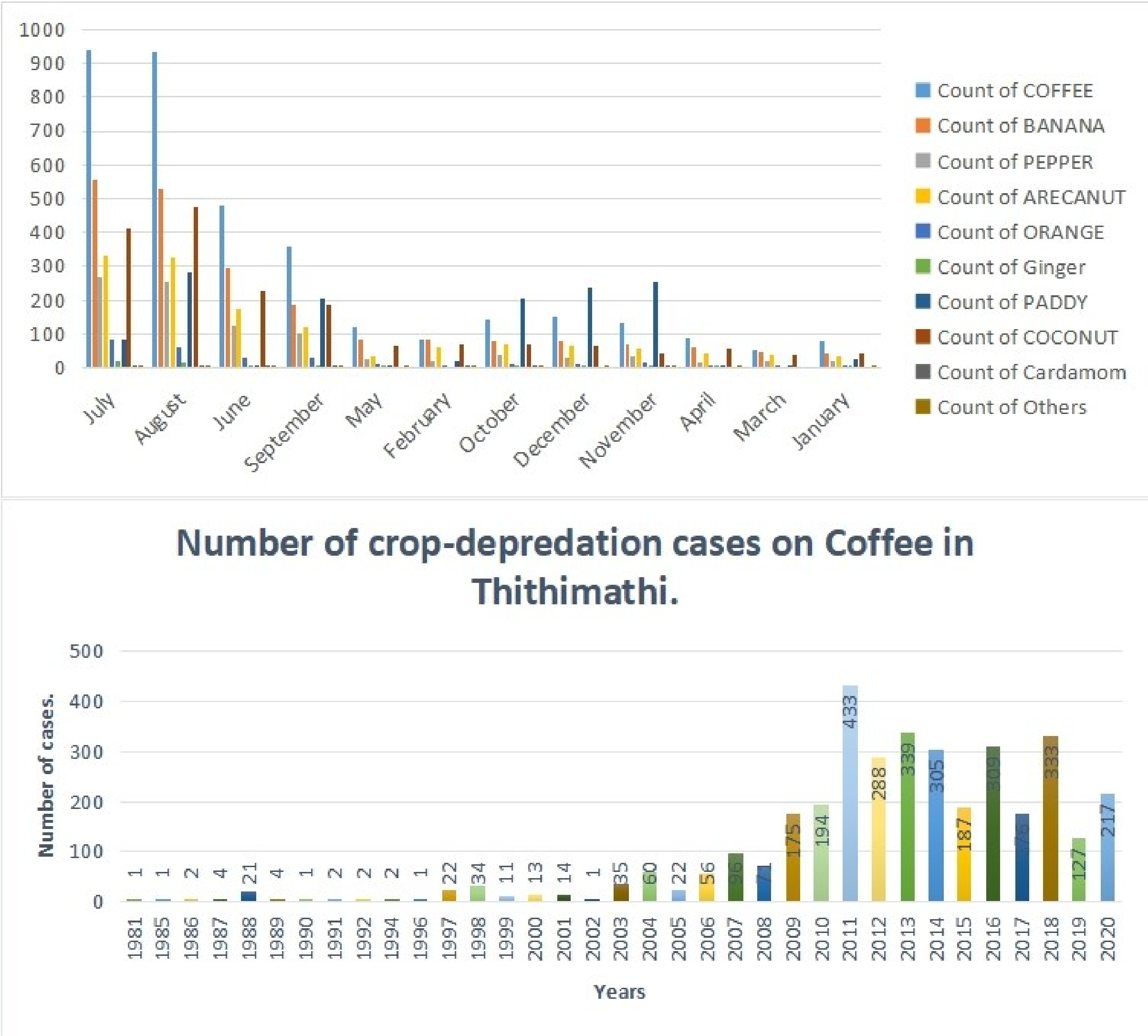


Figure 23: Monthly conflicts of crop depredation from the year 1977 to 2020 of Thithimathi region.

Questionnaire for the semi-structured interview.

Questionnaire for a Semi-structured interview of Farmers.

Name: Harin Aiyanna Cheriyanda Raveendra
Reg Nr: 1131710
Study: Masters in Forest and Nature Conservation
Master Thesis Topic: Spatial distribution and causal factors of Human-elephant Conflict: An exploratory study in the Human-impacted landscapes of Western Ghats, India.

*Required

Description
Greetings! I am Harin Aiyanna C R and I will be conducting semi-structured interviews with farmers and forest watchers to elicit local perceptions of the causes of Crop-depredation by elephants. The objective is to capture the diversity of views about the movement of elephants and to quantify the frequency of crop-raiding due to the presence of water sources, cropping pattern and forage availability around their village.

1. Date of Interview

   ____
   Example: 7 January 2019

2. Name of the Farmer *

   ____

3. Village? *

   ____

4. Survey no

   ____

5. Ownership of the land? *

Mark only one oval.

- Encroached land
- Encroached and documented land
- Revenue Land
- Joint Ownership
- Prefer not to say

6. Agriculture land use Within the Conflict Zone? *

Mark only one oval.

- Irrigated
- Rainfed
- Mixed Cropping
- Others

7. GPS coordinates of the Farm Field. *

____

8. Have you been experiencing crop damage caused by elephants? *

Mark only one oval.

- Yes
- No

9. If Yes, Since how many years?

Mark only one oval.

- ◯ 1-5 years?
- ◯ 5-10 years?
- ◯ 10-15 years?
- ◯ More than 15 years?
- ◯ Unknown

10. What kind of Crops do you grow and since how many year?

Mark only one oval per row.

	1-5 years	5-10 years	10-15 years	More than 15 years	Never	Shifted/Changed
Sugarcane	◯	◯	◯	◯	◯	◯
Paddy	◯	◯	◯	◯	◯	◯
Corn	◯	◯	◯	◯	◯	◯
Cotton	◯	◯	◯	◯	◯	◯
Arecanut	◯	◯	◯	◯	◯	◯
Banana	◯	◯	◯	◯	◯	◯
Vegetables	◯	◯	◯	◯	◯	◯
Coconut	◯	◯	◯	◯	◯	◯

11. Number of Elephant Entry Points to your Field?

____

12. GPS Coordinates of Elephant Entry Points.

____

13. Dominant habitat type? *

Mark only one oval.

- Dense Forest
- Mixed Forest
- Plantations
- Others

14. Is your field located at the Forest edge?

Mark only one oval.

- Yes
- No

15. If No how much is the distance from the Forest Edge to your field? Answer in meters.

16. Presence of elephant entry points close to water sources?

Mark only one oval.

- Yes
- No

17. Number of Water Sources used by elephants present in the Village Boundary.

24. Farmers perception on the reasons of Human-Elephant Conflict occurrence?

Mark only one oval per row.

	Yes	Maybe	No
Proximity of Crop Fields to the Forest Edge	◯	◯	◯
Proximity of Crop Fields to Water Source	◯	◯	◯
Lack of Forage availability in the forests surrounding the village	◯	◯	◯
Changing cropping pattern	◯	◯	◯

25. Is the elephant proofing measures around your field good?

Mark only one oval.

- ◯ Yes
- ◯ Maybe
- ◯ No

26. Would you join the forest department in elephant drive operations in your village?

Mark only one oval.

- ◯ Never
- ◯ Sometimes
- ◯ Always

27. Have you had close encounters with elephants in your field?

Mark only one oval.

- ( ) Yes
- ( ) No

28. Estimated crop loss by the forest department? (Rupees)

____

29. Area of Land Holding? (in acres)

____

30. Estimated area damaged? (Acres)

____

31. Compensation received?

____
