Determinants of Human-Elephant Conflict in Mudumalai Tiger Reserve, Southern India

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Abstract

Human-elephant conflict (HEC) is a negative interaction between elephants and humans. HEC affects local community livelihood and the success of elephant conservation. The Asian elephant population and HEC were studied in the Niligiri Biosphere Reserve in the year 1992 (Balasubramanian et al. 1995) using this information as baseline data. We have studied HEC in the selected 14 villages located in the Moist Deciduous forest and Thorn forest areas of Mudumalai Tiger Reserve from Nov 2006 to Mar 2008, which were part of the earlier study. The data on crop species, elephant damages, protection method and land-use changes concerning HEC were collected fortnightly by direct enumeration and questionnaire survey. A total of 297 crop damage incidences were recorded. The crop-raiding pattern and the peaks in raiding are during monsoon periods were similar to the earlier study. A total of seven people were killed and six were injured by the attack of elephants in the ten years (1998 to 2008) and results in 1.3 incidences/year. The overall crop damage has declined from 2.1% in the early 1990s to 0.98%. The spatial location of HEC indicated that the mean damage percent was higher in the peripheral areas (1.51%) than in the center of the village (0.18%). There is a major shift from crops grown for food (finger millet) to commercial reasons. Multiple regression analysis revealed that the effective perimeter length (perimeter with cultivation) and total area of cultivation had a primary influence on the crop damage, followed by the area of degradation around the village and percent edible crops in the boundary. Further, logistic regression on crop-raiding incidences with the independent predictors indicated that among habitats in the MDF the crop-raiding incidences were 95% higher than that of TF. Palatable crop species plantain, paddy, finger millet and vegetable crops were 391% raided more frequently than the non-palatable species. Crops with protection methods were 22% less frequently damaged than the crops without any protection. Thus changes in the crop species, improved protection and land-use changes have reduced HEC in the adjacent areas of Mudumalai TR. The resettlement of villages from the core area of reserve in MDF would greatly reduce HEC in MTR.

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The data were presented in the manuscript and raw data is available with corresponding author ready to provide if needed.

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MA: Involved in data collection, developed theory, performed computation and prepared manuscript. SC and SK Assisted in the field sample collection and preparation of the manuscript. SS and AAD Supervised the work and revision of the manuscript. All authors discussed the results and contributed to the final manuscript.

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Introduction

The growing human population with its increasing demand for land for agriculture and development has reduced the once vast natural habitats into small habitat islands. These habitats continue to be exposed to further fragmentation and degradation, leading to an increase in the level of conflict between wild animals and humans. Elephant being a large mammal, they range over large areas to meet their requirements of food, water and shelter (Sukumar 1989; Baskaran et al. 1995). Further land-use changes in the adjacent forest area increase encounters with elephants and thus conflict. Globally elephant population is threatened by Human-elephant conflict (HEC), poaching, habitat fragmentation and degradation (Campos-Arceiz et al. 2009; Chartier et al. 2011; Webber et al. 2011). HEC has social, economic, and conservation consequences at both the local and regional scales (Campaore et al. 2020). According to Sitati et al. (2003), the presence of elephants within human settlements affects normal activities, for example, disrupts commuting to work and school.

India has the largest Asian elephant population (Williams et al. 2020) and also is the second-most populous country in the world. HEC occurs when people and elephants interact negatively (Naughton-Treves 1998; Perera 2009). When elephants and humans interact there is conflict from crop-raiding by elephants, injuries and deaths to humans caused by elephants, elephants killed by poaching or retaliatory killing due to crop damage. Studies on the conflict between elephants and humans in Asia (Sukumar and Gadgil, 1988; Santiapillai and Widodo 1993; Balasubramanian et al., 1995; de Silva 1998; Williams and Johnsingh, 2004; Gubbi 2012; Prins et al. 2021) and Africa (Thouless 1994; Barnes et al., 1995; Tchamba 1996; Hoare 2012) have identified crop-raiding as the main form of conflict. Elephants annually damage crops worth from a few thousand dollars to million dollars (Sukumar, 1989). Every year more than 600 humans and 450 elephants were killed during crop-raiding in Asia with greater than 80% from India and Srilanka (Williams et al. 2020).

Crop raiding has been studied in some detail, but the success or failures of various crop protection methods under field conditions has not been quantified, which were studied in Africa (Sitati and Walpole 2006; Massey et al. 2014). We have evaluated different methods of crop protection such as electric fencing, guarding, traditional crop protection method, hedges and their efficacy in mitigating HEC. Identification of suitable mitigation method is significant for achieving the conservation goal. As conflict shows geographically specific patterns, understanding underlying causes will help in establishing appropriate mitigation methods that are site specific.

The study area is located in the Nilgiri Biosphere Reserve in South India with an area of 5520 sqkm and supports largest elephant population (6000) in India (Williams et al. 2020). The developmental activities in the form of the construction of series of hydroelectric power stations numbering about three in Singara, Masinagudi and Moyar around the Masinagudi village in the eastern part of Mudumalai Tiger Reserve caused rapid growth in the human population to 143% between 1961 to 1991 (Silori and Mishra, 2001). Thus assessment of HEC would support the management of elephants in these areas and conflict mitigation. Further study area has baseline information on HEC earlier in the year 1992 (Balasubramanian et al. 1995). We compared the results of the present crop species, protection method and elephant damage to the earlier study. We hypothesis that area of cultivation, area of degradation, perimeter with cultivation, crop protection method and percent edible crops in the boundary as the underlying causes crop damage. These variables were chosen based on direct filed observations and earlier studies on HEC (Hoare 1999; Sitati et al. 2003) and we have analysed data on two spatial scales, area of damage in relation to predictors at the village level and susceptibility of individual crop fields to crop-raid. Land-use changes indicated there was an increase in the conversion of the agricultural area into holiday homes in the Thorn forest area and HEC related abandoning of cultivation.

Methods

Study area

The study was carried out between Nov-2006 and Mar-2008 at Mudumalai Tiger Reserve (MTR) located in the Nilgiri District of Tamil Nadu (11º 32´ and 11º 42´ N and 76º 20´ and 76º 45´ E). It extends over an area of 321 km^2 and forms a part of the Nilgiri Biosphere Reserve (NBR). The sanctuary is located in the Western Ghats, which is one of the 35 Biodiversity hotspots of the world (Mittermeier et al. 2011). Altitude in the study area varies from 485 to 1226m above MSL with a general elevation of about 900 to 1000m. The annual rainfall varies from 1001mm to 1648mm. This reserve receives rain from both Southwest (May to August) and Northeast (September to December) monsoons. Based on climate, there are three distinct seasons recognized; dry season (January to April), first wet season (southwest monsoon) and second wet season (Northeast monsoon). The study area has three major forest types namely tropical moist forest (MDF), dry deciduous forest (DDF) and tropical thorn forest (TF) (Champion and Seth 1968). MTR is threatened by habitat degradation from overgrazing, poaching and human disturbance (Ashokkumar et al. 2010). The estimated population of elephants in the reserve 2.6/km^2 (Daniel et al. 2008).

Agriculture in the study area is mainly rain-fed cultivation with the very little area under irrigation using groundwater. Crops are planted at the beginning of the southwest monsoon in June and harvested in the month of December. The major crops cultivated in the Moist deciduous forest are Paddy (*Oryza sativa*), Ginger (*Zinger officinale*), Plantain (*Musa paradisiaca*), Coffee (*Coffea arabica, C. robusta*) and Arecanut (*Areca catechu*). Whereas in the thorn forest area mostly cash crops/vegetable crops were grown Beans (*Dolichos lablab*), Garlic (*Alium cepa*), Finger millet (*Eleusine coracana*), Brinjal (*Solanum melongina*), Capsicum (Capsicum annum) and Potato (*S. tuberosum*).

Human-elephant conflict data were collected from a total of 14 villages located inside Mudumalai Tiger Reserve from Nov-2006 to Mar-2008. Of these four enclaves and two peripheral villages on the southwestern boundary (MDF) and eight villages (Fig 1 & 2) were selected in the eastern boundary (TF) of the reserve which acts as a corridor for elephants (Desai 1991; Baskaran et al. 1995). These villages were selected based on the earlier study conducted in the year 1992 by (Balasubramanian et al. 1995) for comparison of crop species, protection method and elephant damage.

The locations of crop-raiding incidences were obtained from Global Positioning System (Garmin e-trex). All the crop fields in a village with the owner of the land, land area, size of fields, type of crop protection method, crops, planting months and fruit trees (Tamarind *Tamarindus indicus*, Jackfruit *Atrocarpus integrifolia*, Mango *Mangifera indica* and Bamboo *Bambusa* sp.) available within villages and nearest water resources were collected with location information. All these field areas were identified in the google maps printed in A3 sheet with details. Later these details were digitized in the georeferenced maps in the Q-GIS software. Crop raiding details were gathered fortnightly to estimate the intensity of crop-raiding and age-sex class involved in raiding. The area of cultivation, stage of the crop and proportion of damage were also assessed quantitatively. The percentage of damage due to eating and trampling was noted separately. Elephants trample a significant amount of crops so the distinction must be made, especially where crops that are not fed on are trampled. Based on the tracks and inquiries with local farmers, it was determined whether the herd or male (male group) responsible for the damage.

All existing crop protection methods and the extent of their use were determined for the study area surveying all villages selected for the study. We accessed quantitatively the changes that have taken place since the last study. We also recorded the cropping patterns to determine if there have been any changes in cropping patterns brought about by changes in crop protection methods. Based on interviews with owners and actual field observation the success rate of different crop protection methods was evaluated.

Analysis was done in two spatial scales, in the first analysis total crop area damaged per village by elephant was regressed with total area of cultivation (ha), area of degradation around villages within two-kilometer radius around a village selected based on the ranging study in the study area (Balasubramanian et al. 1995), effective perimeter (perimeter of villages with cultivation), Percent edible crops in the boundary to total cultivation in the boundary, total perimeter, habitats (MDF and TF) and protection methods were included in the model. Linearity was examined by plotting the relationship between the response variable (area of damage) and each predictor variable using a Lowess plot in SPSS 16 (IBM SPSS Inc., Illinois, USA). To investigate multicollinearity between the environmental covariates, a correlation analysis was conducted before using multiple regression to assess the relationship between the response variable and predictor variable, thereby providing valid parameter estimates and p values.

In the second analysis, we have used logistic regression to find out the susceptibility fields to crop raid to the predictors (Barnes, 2009). Logistic regression was used to test if the likelihood of elephant crop damage with predictor variables such as habitats (MDF and TF), palatability of crop species (Plantain, Paddy, Finger Millet and vegetable crops as palatable and Ginger, Capsicum, etc non-palatable), protection method (with or without crop protection such as electric fencing, guarding and trip-wire alarm with guarding) and individual crop field size. Wald statistics were used to evaluate the univariate effects of a generalized linear model (GLM; with log-link function). The differences in the male and female raids were tested by a non-parametric Wilcoxon signed rank test.

Results

A total of 297 crop damage incidences were recorded for a period of 15 months from Nov-2006 to Mar-2008. The crop-raiding pattern and the peaks in raiding are during the monsoon period (June to September; Fig 2). A total of seven people were killed and six were injured by the attack of elephants in the ten years (1998 to 2008) and results in 1.3 incidences/year. The extent of crops damaged has declined in both the thorn forest (TF 0.51%) and the moist deciduous (MDF 0.98) relative to what it was 2.0% and 2.2% respectively in the early 1990s (Balasubramanian et al. 1995). The overall crop damage has declined from 2.1% in the early 1990s to 0.98% during the present study.

The spatial location of conflict incidences (Fig 1&2) indicated that there was higher damage to crop fields at the periphery than those on the inside. The bulk of the crop damage by elephants occurred in the first row of crop fields that immediately abutted the forest boundary. In the TF, out of a total of 125 crop-raiding incidents, 101 or nearly 81% of the crop fields damaged were on the periphery. Only in 19% of the cases did the raiding elephants extend their range beyond the first row of crop fields along the forest boundary. The mean damage percent was higher in the peripheral areas (1.51%) than in the center of the village (0.18%).

Changes in Crop species grown and damaged

Cropping patterns have changed significantly in the villages in the TF when compared to the past in 1992 (Balasubraminan et al. 1995). There is a major shift from crops grown for food (Finger-millet) to crops grown for commercial reasons. The area under Finger-millet has come down drastically from 48% to a little over 13% while sunflower (10% in 1987) which was the main commercial crop in the past has disappeared. The main commercial crops today are vegetables like Beans (39.6), Garlic (8.9%), Potato (5.3), Capsicum (2.7%) and other vegetables (2.9%) because these find an easy market in the nearby towns which are only one or two hours away. Other crops like Coconut and Banana which were earlier grown on a small scale for use by the landowners are now grown on a larger scale commercially. Similar changes have also taken place in the MDF where Paddy and Ginger were the main crops in 1992 (Balasubraminan et al. 1995). Although they remain major crops other commercial crops are being grown increasingly. Pepper, Areca nut, Plantain and coffee are the major new crops in this area. Hence there were changes in the crop species grown in MDF and TF areas of MTR.

The change in cropping patterns over time is reflected in the crops eaten by elephants as shown by the current study (Table-1). In the TF Finger millet (35%) and Maize (25%) accounted for the bulk of the crops eaten by elephants in the past (Balsubramanian et al. 1995). Today they form only a small proportion (7% and 1.3% respectively) of the crops eaten by elephants. Similarly, in the MDF paddy (32%) was the main crop eaten by elephants during crop raiding. Today it accounts for only 14% of the crops eaten by elephants. Crop species such as plantain (45%), coconut (4.5%), beans (13%) and areca nut (10%) constituted the major crops eaten by elephants.

Factors influencing crop-raiding

To predict the area of damage, the variables such as area of cultivation (ha), area of degradation (ha), effective perimeter length (km), the percent edible crops in the boundary, total perimeter length of the village, distance to water source and distance to the guarding shed were loaded in the multiple regression. Among these variables effective perimeter area, area of cultivation and the total perimeter was a significant predictor of the area of damage. The model was highly significant and explained 84.5% of overall crop damage ($F=8.696$; $df=3$; $p=0.004$; Table-2). From the standardized partial regression co-efficient, it was inferred that effective perimeter length and area of cultivation had a primary influence on the crop damage, followed by the area of degradation around the village and percent edible crops in the boundary.

Further logistic regression on crop-raiding incidences with independent predictors indicated that among habitats in the MDF crop-raiding incidences were $(\exp(0.68)-1)*100$ 95% higher than that of TF (Table-3). Palatable crop species such as Plantain, Paddy, Finger millet and vegetable crops were 391% raided more frequently than the non-palatable species. Protection methods such as electric fencing, electric fencing with a wooden post, guarding and trip-wire alarm with guarding were 22% less frequently damaged than the crop without any protection method. Mean-field size of crop field had a negative effect on the crop raid. This was due to the greater frequency of occurrence of a smaller area of cultivation in the study villages (0.44±0.91 ha).

Influence of Fruiting trees in crop raid

The presence of fruiting trees in agricultural areas attracts elephants and consequently, this results in crop damage, 8% (n=301) of total damage incidences were due to fruiting trees. When crops were damaged people cited fruiting trees or sprouting bamboo in agricultural areas as the reason for elephants intruding into crop areas and we have recorded signs of damages. Damages due to Jackfruit fruiting were (21% (n=62) in boundary villages of MDF, similarly Tamarind and Mango fruit (each 17.6%) in Chokkanalli and Bokkapuram villages in TF attracted elephants.

Male-female differences in crop-raiding

Overall males raided more often 51.2% than females 43.9% and it was statistically insignificant (Wilcoxon test z=-0.629; df=13; p>0.05). In 5% of cases we were unable to classify into different age-sex classes. Male elephants raided more frequently in the TF whereas herds in MDF (Fig 6). There were habitual crop raiders these include female herds and males. One known bull elephant in the Bokkapuram village area broke the electric fence several times for no apparent reason as there were no crops inside.

Crop protection method

A variety of crop protection methods are used in the study area but they can be broadly classified into three categories, namely electric fencing, ordinary fencing with guarding and guarding using tripwire alarms. Most of the crop fields were protected with electric fences (46%) and ordinary fences and guarding (25.3%; Fig 7). The trip-wire is used primarily in the villages in the MDF. In this method, an explosive firecracker was set with a wire along the border of the crop field (Fig 3d) which may or may not frighten the elephant but it helps to alert the villagers of an elephant's (or wild pig's) approach and they then wake up to drive the intruding animal. They also have specially constructed guard huts that have an elephant-proof trench around them so that the people guarding are safe (Fig 3c).

A total of 45 electric fences were assessed in the study area. Of these 4 (8.9%) were community-based and the rest 41 (91.1%) were privately erected fences. The community-based fences had been funded by the government (Tamil Nadu Forest Department). The total length of community fences was 8.3 km while the total length of private fences was 19.525 km. The community fences were by and large much longer than the private fences. On average, the length of a community fence was 2075 m as it had to cover the entire landholding of a community/village. Compared to this the average length of the private fence was just 476 m long as it was covering just one individual property. Private fences had been working an average for 9.1 years which is almost double that of community or government erected fences whose average age was five years.

In terms of functioning, only two (50%) of the government erected fences are operational, even of these two one cannot be said to be working effectively. The success of privately erected fences is significantly greater with 14 (92.7%) functioning. Of these 41 functioning fences 43.9% were considered as good and 48.8% as satisfactory and only 3 (7.3%) were not functional. Of the functioning fences, 35% had been broken by elephants during the study period. However, quick repairs ensured that these fences remained operational through the study period.

Land use changes

A large number of tourist resorts have been started in the thorn forest area to the east of MTR. This has diverted land that was earlier agricultural or fallow in the 1980s. There were about 5 or 6 resorts up to the mid-1980's, today there are nearly ten times as many. The area lost to resorts is only in the thorn forest area with the highest being in the Bokkapuram area where nearly 250 ha (28%) of the area has been converted to resorts. It is followed by Valathottam 49 ha (19.5%) and Mavanalla 33.8 ha (7.6%). The least has been in Chemmanatham (0.36%), Moyar (0%) and Annakatti (0%) mainly because the latter two villages have no legally convertible land that can be acquired for resorts.

Elephant death due to conflict

The increase in pressure in the eastern part of the MTR coupled with development in the corridor area has resulted in starting to take retaliatory action against elephants. A few tuskers and one adult female were noticed in our study area with gunshot injuries. Often elephants are not killed outright by these gunshots, but the injuries result in secondary infections and general weakening of the animal or death in some cases. Another important cause of elephant mortality has been the use of high voltage electrified fences which are installed illegally around crop fields. There is one case of electrocution was reported from Bokkapuram village where an adult female was electrocuted (fig 3b).

Discussion

The crop-raiding pattern and the peaks in raiding are similar to what was reported in the earlier study by Balasubramanian et al. (1995) and other areas (Williams and Johnsingh 2004; Gubbi 2012). There were conflict incidences in the moist deciduous forest (MDF) areas during the North-East monsoon which was not reported earlier as there were no crops. More intense cultivation which operates year-round and also new crops (especially tree crops) might result in raiding incidences throughout the year (Rohini et al. 2016). The extent of crops damaged has declined in both the thorn forest (TF) and the moist deciduous area (MDF) relative to what is was in the early 1990s. The overall crop damage has declined from 2.1% in the early 1990s to 0.98% during the present study.

The change in cropping patterns over time is reflected in the crops eaten by elephants as shown by the current study. In the TF the crop species such as finger-millet (35%) and maize (25%) accounted for the bulk of the crops eaten by elephants in the past (Balsubramanian et al. 1995). They constitute less percent in the present study (7% and 1.3% respectively) of the crops eaten by elephants. Similarly, in the MDF paddy (32%) was the main crop eaten by elephants during crop raiding. Today it accounts for only 14% of the crops eaten by elephants. Hence there were changes in the crop species from edible crops to commercial crops.

Only in 19% of the cases did the raiding elephants extend their range beyond the first row of crop fields along the forest boundary. This is because elephants are stopped or driven off when they enter the first row of crop fields and rarely get access to the inner fields (Hoare 2012). Where such peripheral fields are left fallow the inner fields then get exposed to crop-raiding. This is easily seen by villagers and results in different responses to HEC at the community level. Those whose fields lie beyond the first row of crop fields that abut the forest tend to show little or no interest or commitment to cooperative or community-based crop protection efforts. The onus of crop protection is largely limited to farmers on the periphery.

Further studies in Bardia National park, Nepal also have shown that the farmers in the boundary had small landholding and had a relatively higher cost of damage (Prins et al. 2021). This results in a situation where community/cooperative-based protection measures do not work effectively because of varying interests and cooperation among farmers thus undermining or eliminating more effective or efficient crop protection methods that need a cooperative approach from the villagers. Electric fences, trenches, cooperative protection, *etc*. tend to fail because of this problem.

Continued damages in forest boundary areas result in some of the peripheral crop fields being left fallow as farmers cannot sustain repeated crop damage by elephants. The socio-economic status of farmers also has a role to play in this as rich farmers are better placed to implement more effective crop protection methods and are better able to manage crop damage. Additionally, some farmers with very small holdings may find it more remunerative to work as laborers than to cultivate small and unproductive patches of land. The disparity in the economic status of farmers on the periphery adds another dimension to the crop protection scenario (Prins et al. 2021). Poor or marginal farmers are likely to abandon their fields thus creating gaps in the peripheral protection. Abandoned crop fields place a greater burden on adjoining farmers requiring them to protect their fields from elephants using the abandoned fields in addition to their forest boundary. Such gaps also make it difficult to apply community-based protection measures like barriers that require additional support (guarding/maintenance) as there is no one to take responsibility for the abandoned areas. Many barriers (especially electric fences) tend to fail because of this.

Factors influencing crop damage

The greater the perimeter length the more frequent the raids and also the greater the damage were concordant with results of other studies (Sukumar 1990; Hoare 1999; Naha et al 2020). This can be expected as a greater perimeter would imply several things like greater habitat loss, fragmentation and degradation of habitat, potential to extend into more home ranges, *etc*. all of which would affect elephants. It would also mean a greater perimeter to guard and hence greater chances of failure. A long perimeter can imply a larger area enclosed or it could imply a more convoluted boundary enclosing a smaller area. While both are problems for elephants the latter is a major problem for HEC mitigation strategies that involve stopping elephants from entering crop fields.

Studies on HEC along the forest boundaries of Karnataka reported forest area frontage and degradation were the main factors of the determinant of HEC in the tropical forest (Gubbi, 2012). From the multiple regression, it is inferred that effective perimeter length and area of cultivation had a primary influence on the crop damage followed by the area of degradation and percent edible crops. Baskaran and Desai (1996) had shown that elephants avoid areas within two kilometers of human settlements and we took this distance as the area of disturbance around that was degraded. The implication for management is that the perimeter length of the settlement needs to be the smallest (least convoluted) as it helps reduce HEC and reduces the cost of protection. The use of non-edible crops which is often suggested as an HEC mitigation measure is feasible if and only if alternate crops that generate greater revenue are available.

There is also a need to address the cultural as well as the socio-economic aspects to bring about such changes.

In the raiding pattern of the two sexes, there was no significant difference between males and females. Male elephants raided more frequently in the TF whereas herds in MDF. Which was similar to the earlier study in the study area (Balasubramanian et al. 1995). Both extant and frequency of herd damages were higher in the MDF area, where a greater extent of the forest was lost due to human settlements. Studies in Northeast India have shown that increase in conflict due to habitat degradation (Chartier et al 2011; Naha et al 2020) Further elephant herds move in the southern border of the Mududmalai and Gudalur forest division were tend to raid crops. This concordance with an earlier study that greater frequency and extent of damages were reported in the MDF than TF in MTR. Further studies on the range use pattern of individual clans will help to understand the pattern of damages and appropriate mitigation methods.

Spatial segregation of people through resettlement has been progressed in the tiger reserves (Gubbi 2012). The people in the settlements of MDF (Settlement 1,2 & 3) of MTR were willing to get relocated from the tiger reserves (Ramesh et al. 2019). They were in the process of resettlement under project tiger, in the first phase 58 tribal families and 177 non-tribe families were resettled in the year 2016-17. A total of 55 tribal and 200 non-tribal were relocated in the year 2017-18. In the third phase, 168 families have been resettled. Thus, the relocation of these human settlements would be the permanent solution to the conflict within the tiger reserve. Hence the people were voluntarily relocated they get the resettlement package as per National Tiger Conservation Authority (NTCA) guidelines. The effect of resettlement, in the recovery of these lands and HEC in the boundary villages, needs to be studied.

The presence of fruiting trees in agricultural areas attracts elephants and consequently, this results in crop damage. Studies carried out in African elephants have also proven that fruit trees attract elephants to crop fields (Neupane et al. 2017; Ngama et al. 2019). Fruiting trees can be kept outside the enclosed area (electric fence/ordinary fence) then they should be left out. In areas where they cannot be kept out it would be better to eliminate them from vulnerable areas. Further removal of fruits before they ripen could reduce HEC.

There were several reports (confirmed by us) of habitual crop raiders; these included female herds and males (Lahm 1996; Osborn 1998). These elephants repeatedly raided crops and overcame barriers and guarding efforts. One known bull in the Bokkapuram village area regularly broke the electric fence on one particular property 11 times during the study period. As this was a farmhouse/holiday home with no crops there was no real incentive for the bull to break the fence. The fence was also not a barrier to the movement of elephants. So why this particular bull repeatedly broke this fence is difficult to explain. Habitual fence-breaking male elephants have been reported in Africa as well (Thouless and Sakwa 1995). There is a need to address such animals specifically trying out new approaches to stop them effectively.

There is a reduction in the HEC relative to what it was in an earlier study in the same area by Balasubramanian et al 1995. The reasons could be due to improved protection in the terms of increased use of electric fences and increased efforts at crop protection as more cash or commercial crops are being grown. There has also been the conversion of land to non-agricultural use like tourist resorts and holiday homes thus reducing the area of agriculture. Further the existence of corridor in the eastern part of MTR support movement of elephants (Baskaran et al. 1995). Emergence of resorts and protection of revenue lands by electric fencing could potentially hinder the movements of elephants. The honorable supreme court of India has given direction in the year 2020 to shut 39 illegal resorts that were operational and remove electric fences that block the movement of elephants in the corridor areas of MTR. It is essential to maintain this corridor in the eastern part of MTR that helps in movement of elephants between western and eastern Ghats.

Certain villages had community fences active enabled us to comparison and problems in maintaining the fences and hence we evaluated individual farms. While HEC mitigation has improved, this most probably by private investment in crop protection. Government-based efforts, mainly electric fences have largely failed because of poor planning and implementation and also because communities have not taken responsibility for maintaining fences. The failure of such fences results in a blame game and further disgruntles people although they are equally to blame. There is a clear need to improve capacity (of government agencies and communities) for HEC mitigation, to bring about better coordination between government agencies and communities and also within communities. We also need to develop the ability to apply HEC mitigation measures on a sustained basis and lastly seek long-term solutions that resolve HEC on a more lasting basis. The last would take into account land use, agricultural practices, provide/develop mechanisms to improve livelihoods, develop crop protection mechanisms that cover elephants and other animals also (especially wild pigs), develop the ability to deal with habitual raiders, and sustainably manage elephant populations.

In addition, the land is also being left fallow due to HEC where farmers do not have resources to stop HEC or bear with the losses due to HEC. HEC may be the main reason for such land being left fallow but better earnings from labor and also the cheap rice available to those below the poverty line also make agriculture a poor livelihood option for those with very small landholdings and with little or no resources to develop their fields for commercial crops. In addition to this, there is also another agricultural land that is going fallow as people from urban areas buy land here to set up holiday homes.

While shorter fences are more expensive they are also likely to be more effective as there is little chance of a power drop off at the extreme edges and they are also easier to maintain given the small perimeter. Private fencing started much earlier than government efforts to use electric fences to stop crop raiding. However, failure of government erected fences is also a major cause for the lower average age seen, as many fences are no longer operational and have not been taken into consideration.

The traditional crop protection method, tripwire alarm system has two main advantages, first, it allows the people guarding to sleep till the crop-raiding animal approaches the crop fields. This takes away the major stress factor when guarding crops – lack of sleep. The second advantage is the elephant-proof trench which allows them to safely attempt to drive away from the intruding elephant. The stress related to the fear of getting killed is eliminated and this increases their ability to continue attempts to drive away from the elephants even when elephants appear to be bold or aggressive. Hence, among the different crop protection methods, the traditional trip-wire alarm system works more efficiently in reducing HEC.

Loss of human life and injuries due to elephants adds to the resentment people feel towards elephants and the Forest Department at times. With more than one person being killed or injured by elephants annually the threat of death is very real. This is especially true for farmers who guard their crops at night. The fact that there are several other incidents where people are attacked and escape or feel threatened by elephants means that the actual number of incidents is likely to be greater than one incident/year. These other incidents never get reported but they add to people's fear and consequently to the adverse response to HEC.   However, such killings and attacks cannot be stopped as long as elephants intrude into human use areas and people intrude into elephant habitat, they can only be reduced by increasing the knowledge and capacity of local people in dealing/interacting with elephants when they encounter them or move in areas where they are likely to encounter them.

Management suggestions

The resettlement of villages from the MDF of Mudumalai Tiger Reserve would reduce HEC.

The existing forest connectivity through corridors in the TF area of Mudumalai is essential to for the movement of elephants. These areas were included in the buffer area of tiger reserve.

There is a need to review HEC mitigation inputs by government agencies and NGOs so that problems can be identified and better methods implemented. Capacity and motivation need to be developed within the department so that the Forest Department can develop better partnerships with local communities and implement HEC mitigation strategies in an effective and sustained manner.

There is a need to address other human-wildlife conflicts, especially problems created by wild pigs as they are the cause for some of the accidental killings of elephants due to electrocution.

There is a need to bring about an integrated approach in the various government departments that deal with various aspects of the development of local communities in the area. At present some departments work at cross-purposes and that does little to improve the livelihoods of the locals. These developmental efforts also need to stay in tune with the conservation goals of the protected areas and the landscape through coordination with the Forest Department.

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Tables

Table-1: Comparison between crop eaten by elephants in the early 1990's and as estimated by the present study in Mudumalai Tiger Reserve

S. No.	Crops	Percent crops eaten by elephants (%)	
		1992 (Balsubramanian *et al.*, 1995)	Present study
1	Finger millet	35.06	7.4
2	Cotton	2.46	-
3	Horse gram	4.64	-
4	Maize	25.17	1.3
5	Paddy	32.67	14.0
6	Plantain	-	45.7
7	Beans	-	13.0
8	Areca nut	-	10.0
9	Coconut	-	4.5

Table-2: Multiple regression to investigate the factors influencing area damage by elephant in Mudumalai Tiger Reserve

Independent variable	Predictor variables	Unstandardized Coefficients		Standardized Coefficients	t	p	Model R^2 and p
		β	SE	β			
Area damaged (ha)	(Constant)	-0.558	0.513		-1.089	0.308	R^2=0.845 (F=8.696; df=3; p=0.004)
	Area of cultivation (ha)	0.007	0.004	0.407	1.873	0.098	
	Area of degradation (ha)	0.001	0.001	0.269	1.148	0.284	
	Effective perimeter length (km)	0.146	0.061	0.481	2.376	0.045	
	Percent edible crops in the boundary	0.002	0.006	0.059	0.383	0.712	
	Total perimeter (km)	-0.103	0.046	-0.418	-2.235	0.056	

Table-3: Logistic regression model where the dependent variable is crop raids (raids/no raids) and the independent variables are the area of cultivation (log), habitats (MDF & TF), Palatability (Edible & Non edible), Protection method (with crop protection such as electric fencing, tripwire with guarding or guarding and without protection). Test for the overall fit of the model c^2=191.53; df=4; p<0.001

Parameters	Estimated coefficient (B)	S.E.	Wald	df	p	Exp(B)	95% C.I. for EXP(B)	
							Lower	Upper
Habitat*	0.668	0.152	19.24	1.0	0.000	1.95	1.45	2.63
Palatability*	1.592	0.159	99.71	1.0	0.000	4.92	3.60	6.72
Protection method	-0.244	0.137	3.18	1.0	0.075	0.78	0.60	1.02
Area cultivation (log)	-0.381	0.052	53.36	1.0	0.000	0.68	0.62	0.76
Constant	-2.948	0.229	166.28	1.0	0.000	0.05		

*-Habitat and palatability entered in the model as categorical variable with reference to TF and non-edible respectively

Figures

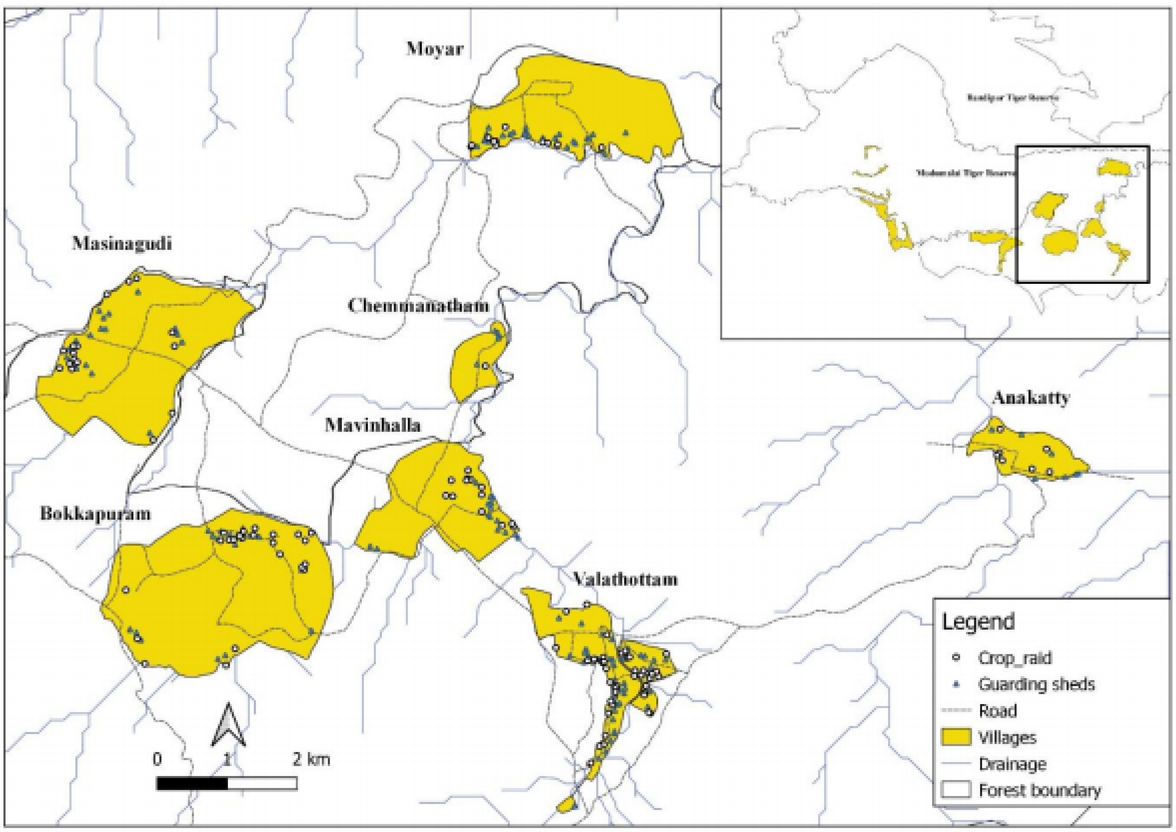

Figure 1

Map showing location of village boundary, guarding sheds and crop raid locations in the eastern part of Mudumalai Tiger Reserve (Thorn forest)

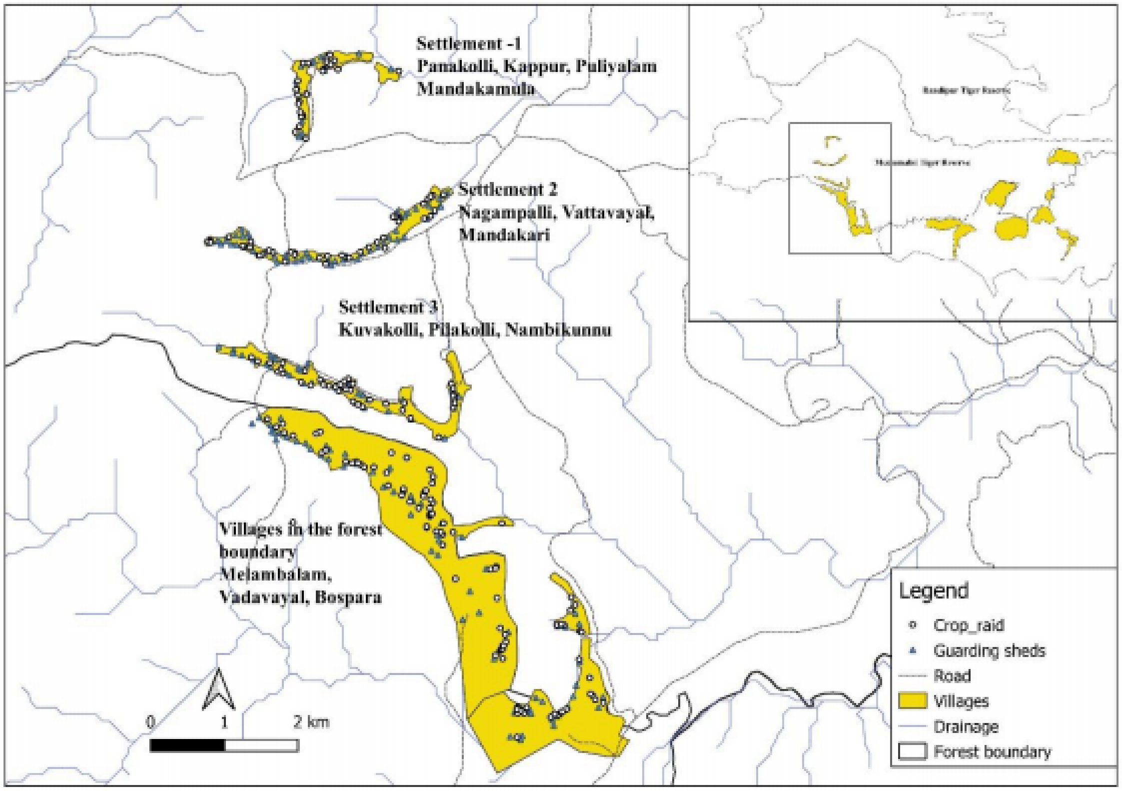

Figure 2

Map showing location of village boundary, guarding sheds and crop raid locations in the central part of Mudumalai Tiger Reserve (Moist deciduous forest)

Figure 3

Human-elephant conflict incidents and protection method used in the villages of Mudumalai Tiger Reserve

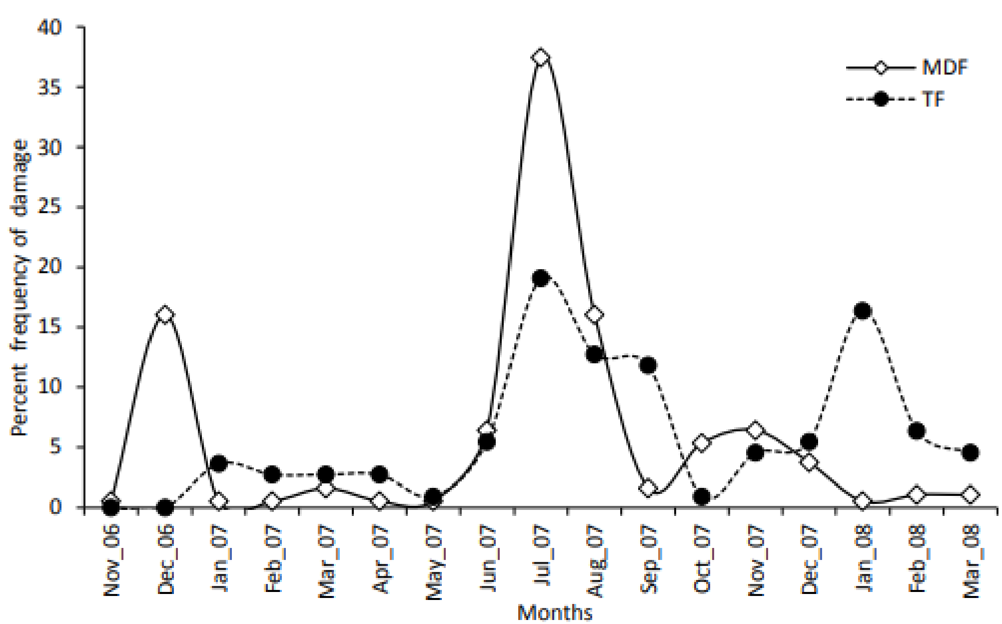

Figure 4

Percent frequency of Human-elephant conflict in the Moist deciduous and Thorn forest of Mudumalai Tiger Reserve

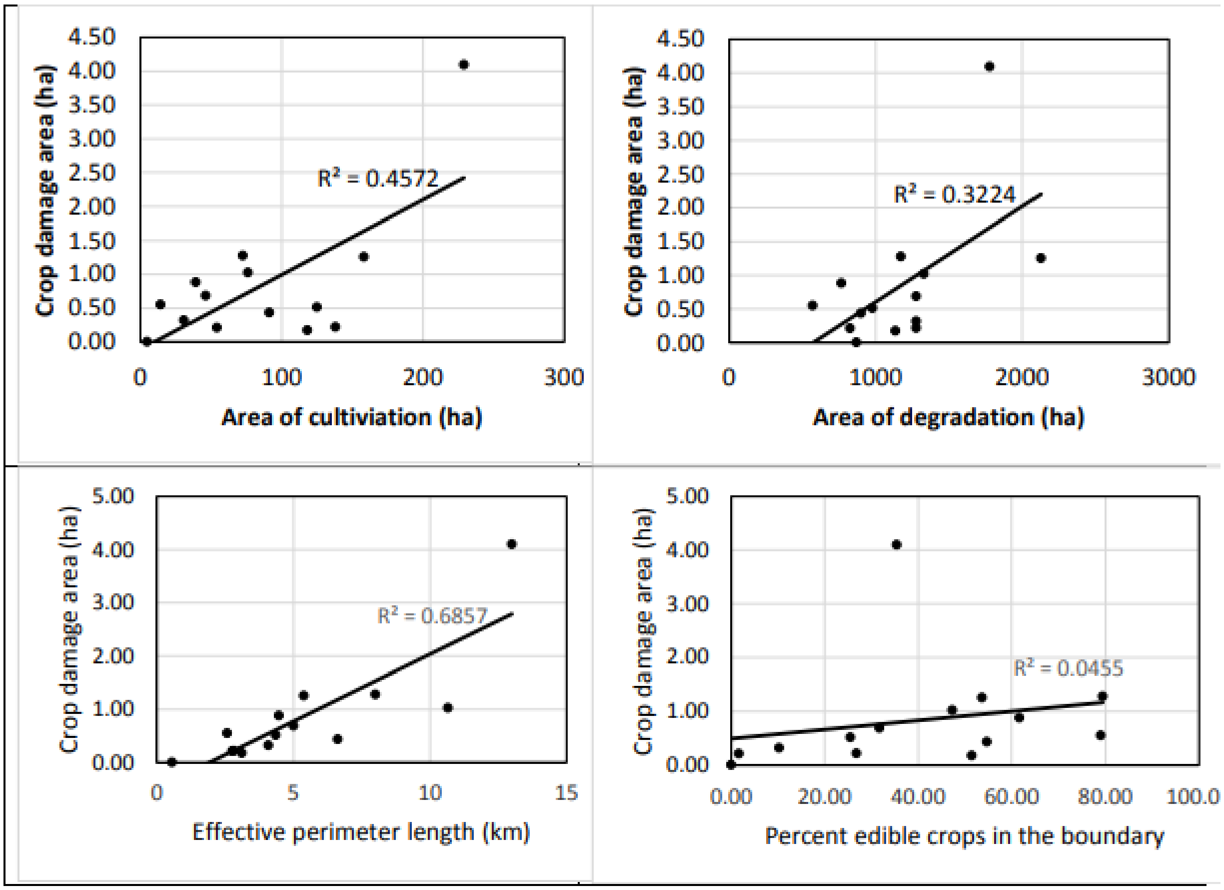

Figure 5

Relationship between the crop damage area (ha) with predictors (Area of cultivation (ha), area of degradation (ha), effective perimeter length (km) and percent edible crops in the boundary) in the Mudumalai Tiger Reserve

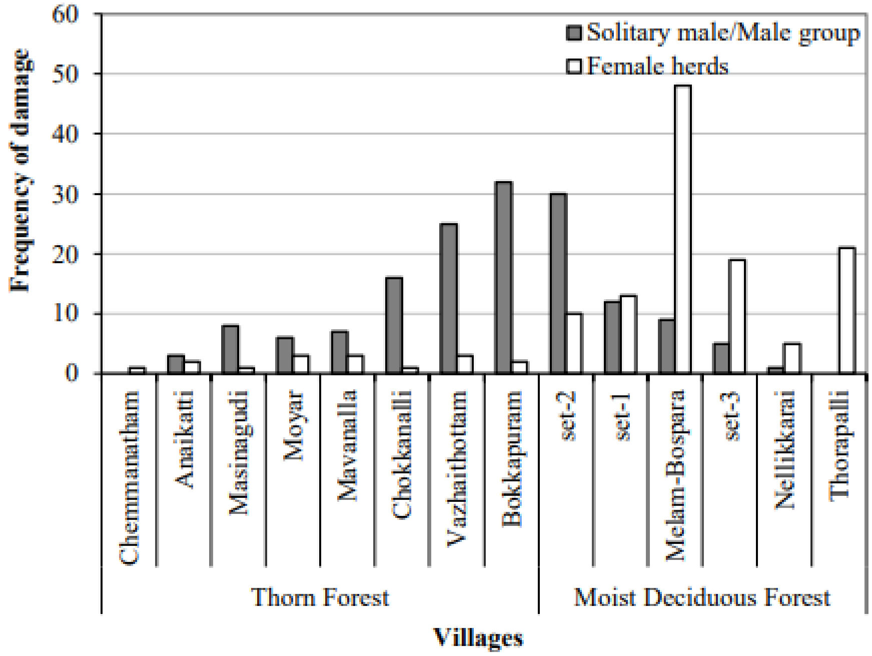

Figure 6

Male and female differences in the number of crop raiding incidences in Mudumalai Tiger Reserve

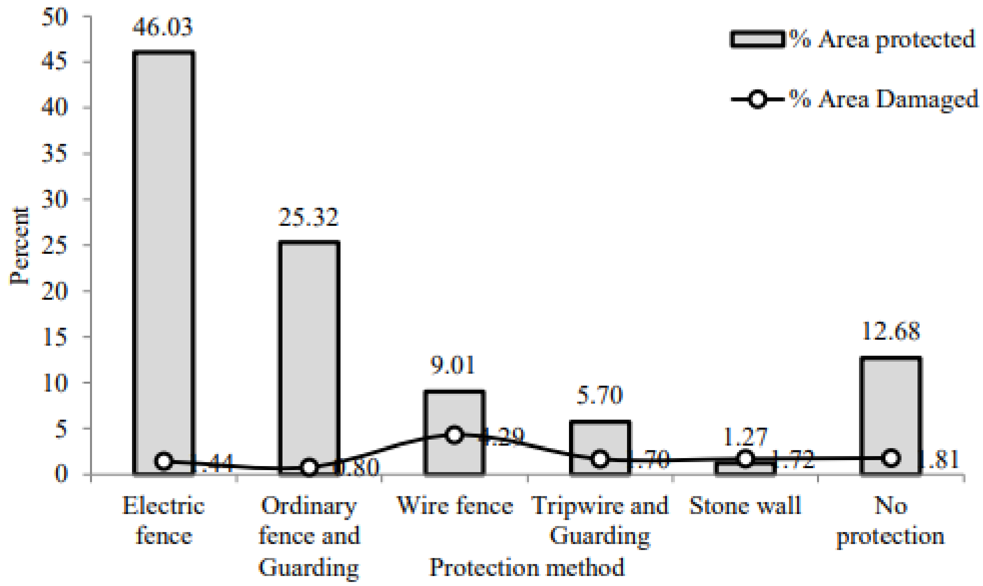

Figure 7

Crop protection method used in the study villages and the percent area damaged in the Mudumalai Tiger Reserve