



# Pattern and distribution of human-elephant conflicts in three conflict-prone landscapes in Myanmar



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## ABSTRACT

Human-elephant conflicts (HEC) are detrimental for both humans and elephants. A better understanding of HEC enhances effective mitigation strategies and promotes the well-being of humans and wild elephants. This study assesses the pattern and distribution of HEC in three different HEC hotspots in Myanmar and identifies local factors that contribute to HEC. A face-to-face questionnaire survey was performed in three HEC landscapes in 30 villages. Our study showed that larger croplands were more vulnerable to crop attacks. Crop damage was found more frequent and was more severe in the more deforested landscapes. The landscapes with higher human density and where local people frequently encountered elephants, were at higher risk to elephant attack. Our results indicate that distance to the forest reserves influenced the incidents of HEC most. We suggest the implementation of land-use plans in the potential elephant migration areas to mitigate HEC and improve the local resilience to economic vulnerability due to HEC.

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## 1. Introduction

Human-elephant conflicts (HEC) are regarded one of the most crucial threats in the conservation of wild elephants (Choudhury et al., 2008; Dublin et al., 2006; Heffernan, 2005; Røskaft et al., 2014; Sukumar, 2003). Competition between humans and elephants for resources and space triggers HEC (Chatterjee, 2016), which are intensified when humans settle close to and encroach into elephant-occupied habitats (Sukumar, 1995, 2003).

Depredation of crops by wild elephants is common in elephant range countries in Asia and Africa (Sukumar, 2003) and is the most cited conflict between humans and elephants (Chatterjee, 2016; Parker et al., 2007; Røskaft et al., 2014; Sarker and Røskaft, 2010; Sitati et al., 2003). The croplands at the edge of forest reserves or protected areas will be prone to increased intensity of crop damage (Chatterjee, 2016; Chiyo et al., 2005; Pittiglio et al., 2014; Røskaft et al., 2014; Sarker & Røskaft, 2010, 2011; Sukumar, 2003). Croplands at a distance of up to 5 km from a protected area can experience severe crop losses (Gubbi, 2012; Hariohay et al., 2018). Elephants raid and destroy a variety of cultivated crops (Chiyo et al., 2005), vegetables, fruits and plants (Chatterjee, 2016; Sarker and Røskaft, 2014). The severity and frequency of elephant raids differ between localities,

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time and crop regimes. The peak period coincides with crop ripening and harvesting time for seasonal crops such as paddy or maize (Parker et al., 2007; Sarker and Røskaft, 2014; Thouless, 1994). Elephant damage to human property and lives is less frequent than crop depredation (Mukeya et al., 2019; Pant et al., 2016). Human property which exists close to the elephant habitats is vulnerable to elephant damage (Pant et al., 2016). Most human deaths occur in forests, followed by villages and croplands (Sarker et al., 2015; Sukumar, 2003).

Myanmar is enriched by 170,000 km<sup>2</sup> of suitable elephant habitats and is recognised as the largest remaining habitat for wild Asian elephants (Leimgruber et al., 2003). In addition, Myanmar was one of the largest remaining populations of wild Asian elephants (Blake and Hedges, 2004; Leimgruber et al., 2008; Santiapillai and Jackson, 1990; Songer et al., 2016). Wild elephants are widely distributed throughout the country, but they are primarily found in five regions (Choudhury et al., 2008; Leimgruber et al., 2011; Santiapillai and Jackson, 1990). However, five percent of elephant habitats (15,000 km<sup>2</sup>) were lost between 1992 and 2006 (Songer et al., 2016), and the population of wild elephants has undergone a decline from approximately 10,000 elephants in 1935 to less than 2000 individuals in the early 2000s (Leimgruber et al., 2011; Leimgruber and Wemmer, 2004).

Encroachment of forestland for subsistence farming and human habituation, illegal and unsustainable logging, massive establishment of forest plantations, development of infrastructures, and local dependency on forest resources are the main contributors to deforestation in Myanmar (Bhagwat et al., 2017; Leimgruber et al., 2005). Deforestation and habitat fragmentation exacerbate HEC, resulting in decreasing number of wild elephants (Leimgruber et al., 2011; Songer et al., 2016). An experts' workshop held in 2015 identified six regions as HEC hotspots in Myanmar (MECAP, 2018). Although office data at the Forest Department and Leimgruber et al. (2011) indicate that the incidents of HEC have intensified in the past two decades, there are few studies on the extent, distribution and pattern of HEC in Myanmar.

Parker et al. (2007) identified crop damage, property damage and elephant attacks on humans as direct HEC, which causes serious physical, social and economic impacts on local people. Assessing patterns and distributions of such HEC in relation to activities and identity of local inhabitants as well as their location with respect to elephants will provide a better understanding of its context, supporting more effective management of HEC in the future. Using a questionnaire survey among local inhabitants, we aimed to provide insight into which of these human factors significantly affect HEC in three landscapes in Myanmar. We hypothesized that people living close to the forest reserve boundary, who own larger amounts of land or are frequent forest resource users are more likely to encounter elephants and are therefore more impacted by HEC. In addition, we hypothesized that HEC incidents significantly differ between gender, age groups and residency.

## 2. Methods

### 2.1. Study area

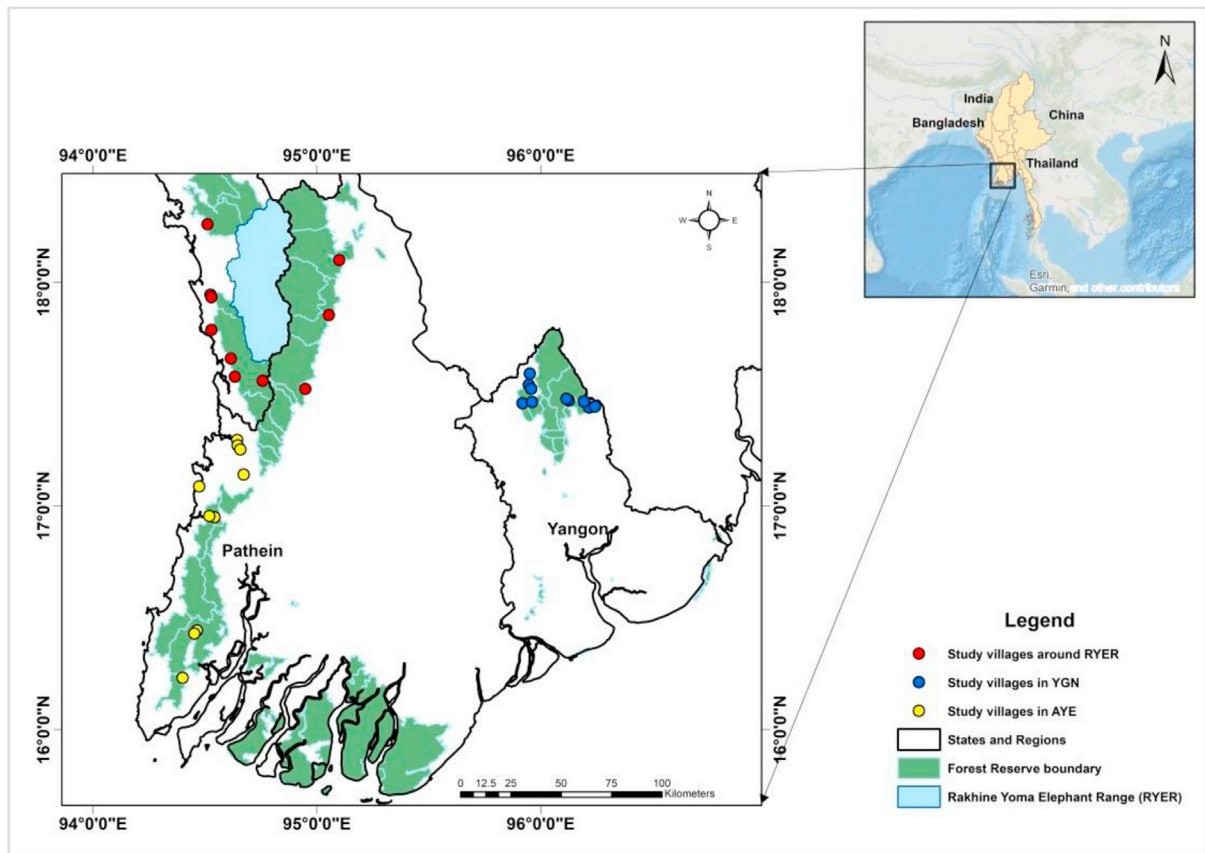
Our study took place in three different HEC landscapes (Fig. 1, Table 1). The first HEC landscape was Rakhine Yoma Elephant Range (RYER), situated in the southern Rakhine State. RYER was established in 2002 as an elephant sanctuary covering 1755 km<sup>2</sup>. The elephant sanctuary is covered and surrounded by forests, which are natural habitats for wild elephants. The dominant forest type inside RYER includes evergreen forest and bamboo (*Melocanna baccifera*). The abundance of bamboo in RYER enriches the food supply available to elephants as bamboo is a favourite elephant food source (Santiapillai and Jackson, 1990). The data from the park warden office indicated that crop damage by wild elephants has occurred sporadically since 2004. Most incidents of crop damage occurred in the western and southwestern parts of the elephant sanctuary, and one human death was reported in 2018.

Taikkyi and Hlegu townships in Yangon Region (YGN) are situated in the southern part of the Bago Yoma Mountain Range; one of the wild elephant habitats in Myanmar (Fig. 1, Table 1). The original deciduous forest and elephant habitat has gradually been fragmented and degraded due to reservoir construction; overexploitation of timber, firewood and non-timber forest products (NTFPs); and forestland conversion into private plantations. YGN is notorious for HEC with many cases of human and elephant mortality.

Pathein, Ngaputaw and Tharpaung townships in Ayeyawady Region (AYE) are also regarded as one of the main HEC hotspots in Myanmar (Fig. 1, Table 1). The area lies along the western coast of Myanmar and elephant habitats connect to the RYER. The excessive harvesting of firewood and charcoal exacerbate the fragmentation and degradation of wild elephant habitats. Poaching is believed to be the most threatening factor that affects the wild elephant population in AYE (Sampson et al., 2018).

### 2.2. Data collection

A questionnaire survey was performed in 30 villages in the three above described HEC landscapes encompassing 299 respondents. Between May and June 2019, local forest department offices and the RYER park office were visited to collect office records with regard to HEC. Simultaneously, the local forest staff, park staff and some local people who were assumed to have good experience and reliable knowledge about HEC were interviewed as key informants to gain a clear insight of the study areas. A preliminary test survey was performed in Hlegu township before the actual survey, to test whether questions were clearly understandable to respondents and where necessary adjusted and clarified. The survey was then implemented in 10 different villages in the three HEC landscapes (30 villages) between July and August 2019. To validate the incidents of



**Fig. 1.** A map of the study area showing study villages as red dots around Rakhine Yoma Elephant Range (RYER), blue dots in Yangon Region (YGN), yellow dots in Ayeyawady Region (AYE) in Myanmar.

HEC, we conducted focus group discussions by inviting villagers who had experienced HEC after the survey was performed in every study village. The distance between villages and the forest reserve boundary was categorized as <1 km, 1–4 km, and 4–10 km. The distance was determined on a map of forest reserve boundaries from the Forest Department using ArcGIS (10.7) (Fig. 1). Before the survey, we informed the village headmen, briefly explained our research objectives and methods, and enquired when the questionnaire survey would be best conducted in the village. In the study village, we randomly selected households where respondents were 18 years or older regardless of their HEC experiences. First, we explained our research and indicated that their answers would be recorded as anonymous. We then invited them to participate in our survey. When local people agreed, we proceeded with a face-to-face interview. Most questions were closed-ended, but a few open-ended questions were also included. Generally, questions about crop damage, property damage and elephant attacks were intended at household level. Residency was categorized as native people which were regarded as those who were born in the study villages, and non-native being those who migrated from other places and resided in the study villages.

### 2.3. Statistical analyses

Statistical analyses were performed with IBM SPSS Statistics for Windows, Version 26.0 and R Studio version (1.3.959) (R Core Team, 2020). Chi-square tests were initially performed to identify any association between response and predictor variables. Eight predictors were first checked with Cramer's V test to assess the strength of association between pairs of variables (Kotrlik et al., 2011) (Table S1, supplementary material). Three predictors (size of farmland, type of farmland and occupation) were strongly associated with each other. Therefore, type of farmland and occupation were eliminated in further analyses. Generalized linear mixed effects models (GLMM) were fitted with the `glmer` function in the `lme4` package (Bates et al., 2015), using a binomial probability distribution. Six predictors were included in the GLMM models based on the location with respect to elephants (distance to the forest reserve boundary), respondent's activities (frequent use of forest resources and size of farmland) and respondent's identity (gender, age group and residency) to find which predictors significantly affected elephant encounters and HEC incidents (binary response variables: yes (1) or no (0)). The six predictors were included as fixed effects, while controlling for HEC landscape as random effect, to assess their relative contribution in explaining HEC incidents. Village did not include as random because the sample size is not big. Models with all possible

**Table 1**  
Comparison of HEC, forest cover, human density and elephant population for three HEC landscapes.

Variables	RYER	YGN	AYE
HEC incidents <sup>(1)</sup> (%)	24.5	36.0	39.5
Percentage of forest cover (%) (FAO, 2015)	56 <sup>(2)</sup>	5 <sup>(3)</sup>	13 <sup>(4)</sup>
Human density (persons per km <sup>2</sup> ) (Department of Population, 2015a; 2015b; 2015c)	77.0	164.7	117.5
Elephant Population (Leimgruber and Wemmer, 2004; Leimgruber et al., 2011)	100 - 150 individuals	200–240 <sup>(5)</sup> individuals	100 individuals

Denote that <sup>(1)</sup> is pooled by crop damage, property damage and elephant attacks as total HEC incidents. <sup>(2)</sup> is the estimation for Rakhine State; <sup>(3)</sup> is the estimation for Yangon Region; and <sup>(4)</sup> is the estimation for Ayeyawady Region. <sup>(5)</sup> denotes the estimation of wild elephant population for Bago Yoma Mountain Range (including YGN).

predictor combinations were constructed (26 models). Model selection was based on AICc using the AICcmodavg package (Mazerolle, 2020). Summed AICc weights were calculated for each of the six predictors to compare their relative importance across models (Burnham and Anderson, 2002). The generalized variance inflation factor (GVIF) was calculated to detect multicollinearity if the best model included more than one predictor. However, multicollinearity was not detected as  $GVIF^{(1/2 \times df)}$  values for the predictors in the best model was less than two (Fox and Monette, 1992). The significant level for statistical analyses was set at  $P \leq 0.05$ .

### 3. Results

#### 3.1. Characteristics of respondents

Of the 299 respondents, 69.9% ( $n = 209$ ) were males, and 30.1% ( $n = 90$ ) were females. The mean age of the respondents was  $48 \pm 13$  years, and the age of respondents was grouped into three categories: 18–35 (16.7%), 36–59 (61.9%) and 60 years and over (21.4%). Approximately half (50.5%) had finished primary education and 26.1% were educated at the secondary level or above. Moreover, 23.4% had no formal education. Approximately fifty percent (50.2%) were farmers, 19.1% were farmers with other side occupations, and 30.8% were non-farmers. In total, 32.8% owned less than 2 ha of land, 24.7% owned 2–4 ha and 11.7% owned more than 4 ha of farmland. However, 30.8% of the respondents owned no land. In total, 62.9% ( $n = 188$ ) respondents lived within 1 km from the nearest forest reserve boundary, 13.4% ( $n = 40$ ) lived between 1 and 4 km, while 23.4% ( $n = 71$ ) lived between 4 and 10 km. In addition, 68.2% were not born in the area, while 31.8% were born in the area. The main agricultural crop was paddy.

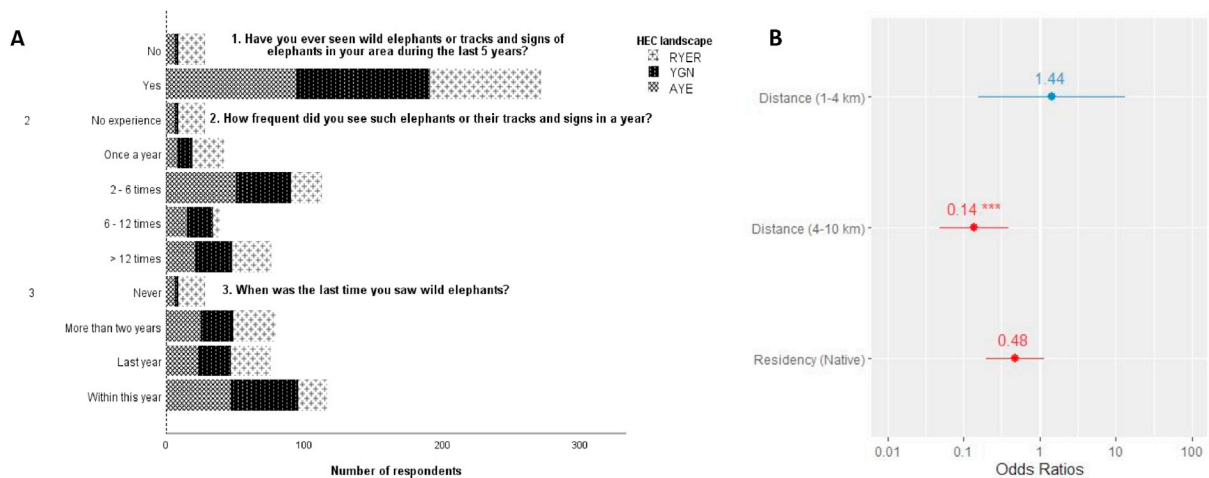
#### 3.2. Collection of forest resources and experiences with wild elephants

When asked the question “How often do you enter into the nearest forest to collect forest resources?”, 33.8% of the respondents noted that they extracted the resources daily from the forests; others did so less frequently (weekly: 13.0%; monthly: 24.4%; occasionally: 14.4%). In contrast, 14.4% never went into the forest to gather forest products. Firewood and bamboo were the most commonly collected resources (37.0% and 33.0%, respectively). In total, 92% of the respondents in YGN, 91.8% in RYER and 73.3% in AYE expressed that they utilised forest products. More people in YGN (40%) were daily resource users than in AYE (34.7%) and RYER (26.5%). The frequency of collecting forest resources was significantly different among the three HEC landscapes ( $\chi^2 = 32.1$ ,  $df = 8$ ,  $p < 0.001$ ). Landless people depended more on forest resources than did farmland owners ( $\chi^2 = 60.2$ ,  $df = 12$ ,  $p < 0.001$ ), and immigrant people were higher resource users than were native people ( $\chi^2 = 21.5$ ,  $df = 4$ ,  $p < 0.001$ ).

Approximately 91% of the respondents in the three HEC landscapes answered “yes” to the question “Have you ever seen wild elephants or tracks and signs of elephants in your area during the last 5 years?” The encounter rate differed significantly among the three HEC landscapes and was highest in YGN followed by AYE and RYER ( $\chi^2 = 17.8$ ,  $df = 2$ ,  $p < 0.001$ ; Fig. 2-A). In the GLMM analysis, distance to the forest reserve boundary and residency were the best explanatory predictors (summed AICc weight of 1.00 and 0.47 respectively, Table 2). For the most parsimonious model (Table S2, supplementary material), people who lived close to the forest reserve boundary (<1 km) (coefficient estimate = 3.51, SE = 0.64,  $z = 5.46$ ,  $p < 0.001$ ) were more likely to experience frequent encounters with wild elephants. However, there was no significant difference between native and non-native respondents (Fig. 2-B).

#### 3.3. Crop damage

In total, 49.8% of the respondents in the three HEC landscapes reported that they experienced crop damage. Of these respondents, 30.4% of people lost less than 50% of their crop, while 19.4% suffered serious loss of their crops. Also, 26.7% admitted elephant raids occurring within the last two years and 23.1% reported the crop damage for more than three years ago. Crop attacks peaked in November in the study area (Fig. 3-A). The respondents in AYE reported more crop damage than those in YGN and around RYER. AYE was also the landscape that experienced the most severe crop damage and the most recent incidents of crop raiding (Fig. 3-B). Paddy (25.1%) was the most raided crop by wild elephants in the three HEC



**Fig. 2.** Extent of wild elephants encounters or tracks and signs of elephants as reported by respondents within HEC landscapes in Myanmar. **A)** Distribution of last experience of the respondents encountering or tracks and signs with wild elephants by different landscapes. **B)** The effect size of encounter probability using a GLMM with distance to the forest reserve boundary and residency as fixed effects and with HEC landscape as a random effect. Reference level for distance is < 1 km from the forest reserves and for residency is non-native. Significant level ( $p$  value) at 0.001 = "\*\*\*\*". The value for blue colour represents positive and red colour represents negative values.

landscapes, while the second most raided crop was banana (14.4%) as well as other crops (maize, cashew nuts, sugarcane, peanut, tapioca, turmeric, tree tomato, pineapple, lemongrass, and guava; 10.4%).

The most parsimonious model explaining the probability of crop damage (Table S3, supplementary material) included size of farmland and residency (summed AICc weight of 0.99 and 0.34 respectively, Table 2). The size of farmland had the largest contribution in explaining crop damage (Fig. 3-C), where people who owned larger (>4.05 ha) croplands (coefficient estimate = 3.99, SE = 0.63,  $z = 6.31$ ,  $p < 0.001$ ; Fig. 3-C) were more likely to suffer elephant crop raiding. However, there was no statistically significant difference between native or non-native people in the GLMM test (coefficient estimate = -0.48, SE = 0.32,  $z = -1.53$ ,  $p = 0.125$ ; Fig. 3-C).

### 3.4. Property damage

Among the three HEC landscapes, 34.8% of the respondents encountered elephant attacks on their property. Eleven percent encountered little damage of their property, whereas 23.7% suffered extensive damage of their property. Likewise, 16% experienced the damage for two years while 18.7% reported property damage for more than three years. The property damage was more severe in YGN compared with the other two landscapes. However, incidents of damage were higher in RYER within the last two years (Fig. 4). Damage to human infrastructure was highest in the area between 1 and 4 km, whereas the highest level of damage to plantations was found within 1 km of the forest reserve boundary ( $\chi^2 = 15.4$ ,  $df = 4$ ,  $p = 0.004$ ).

There was no clear pattern in human factors explaining property damage across models (Table 2). Although the distance to the forest reserve boundary was the best explanatory predictor explaining the probability of property damage (summed AICc weight of 0.42), it was not statistically significant (1–4 km: coefficient estimate = 0.16, SE = 0.40,  $z = 0.40$ ,  $p = 0.689$ , and 4–10 km: coefficient estimate = -0.79, SE = 0.50,  $z = -1.60$ ,  $p = 0.110$ ) (Table S4 and Figure S1, supplementary material).

### 3.5. Wild elephant attacks on humans

Elephant attacks on humans were reported by 21.7% of the respondents in the HEC landscapes. Of these respondents, 14.4% encountered the attack in the forests, whereas 3% experienced attacks in the croplands. Likewise, 2.7% were attacked in the villages while 1.7% experienced elephant attacks on the road. People in YGN and in AYE had experienced higher rates of elephant attacks than those around RYER. The rate of injury by elephants was highest in AYE, while the death rate was highest in YGN (Fig. 5-A). Those people who had a higher frequency of encounters with wild elephants (or their tracks and signs) experienced more often elephant attacks ( $\chi^2 = 19.3$ ,  $df = 4$ ,  $p = 0.001$ ). Non-native respondents encountered more elephant attacks ( $\chi^2 = 6.8$ ,  $df = 1$ ,  $p = 0.009$ ). Additionally, they experienced a higher rate of injury (17 people) compared with native respondents (4 people) ( $\chi^2 = 10.0$ ,  $df = 3$ ,  $p = 0.018$ ).

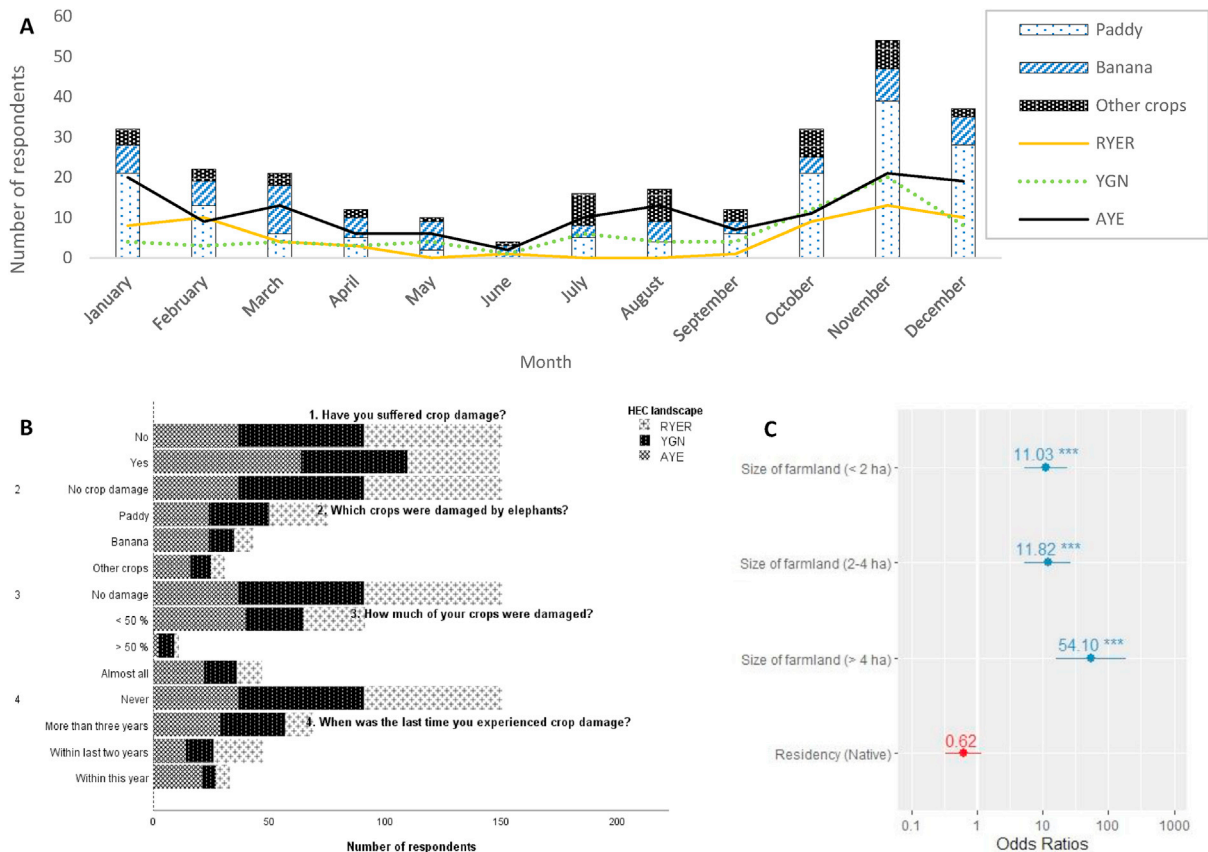
The GLMMs revealed that distance to the forest reserve boundary was the best predictor explaining the probability of elephant attacks (summed AICc weight of 0.63, Table 2) (Table S5, supplementary material). The respondents who lived more than 4 km from the forest reserves were less likely to attack by elephants (1–4 km: coefficient estimate = 0.14, SE = 0.39,  $z = 0.36$ ,  $p = 0.718$ , and 4–10 km: coefficient estimate = -1.02, SE = 0.45,  $z = -2.27$ ,  $p = 0.023$ ; Fig. 5-B).



**Table 2**  
The relative importance of predictors (sum AICc weight) in relation to each response variable.

Predictors	Seen elephants	Crop damage	Property damage	Human injury or death
DTF	<b>1.00</b>	0.17	<b>0.42</b>	<b>0.63</b>
Residency	0.47	0.34	0.21	0.42
Gender	0.40	0.10	0.34	0.22
Age group	0.29	0.08	0.14	0.14
FRU	0.07	0.02	0.09	0.04
SFL	0.03	<b>0.99</b>	0.39	0.03

DTF = Distance to the forest reserve boundary, SFL = Size of farmland, FRU = Frequent use of forest resources. The highest values of sum AICc weight were shown in bold.

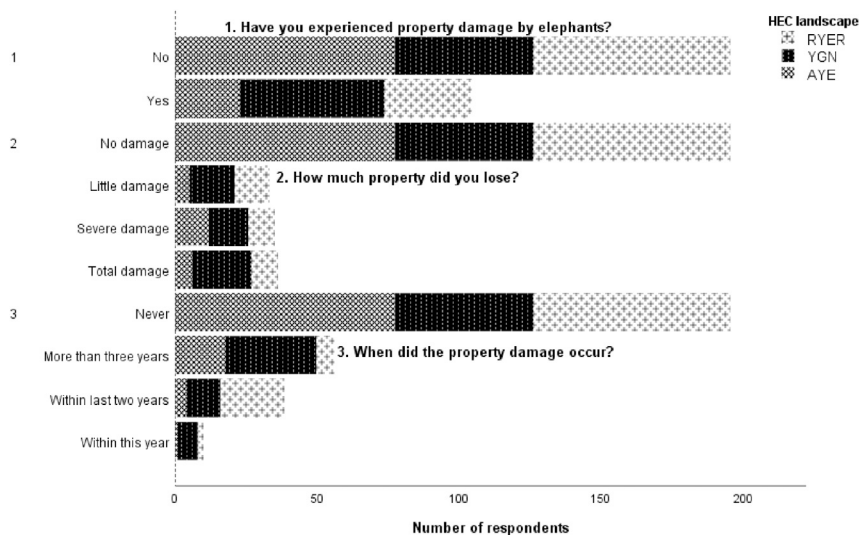


**Fig. 3.** Extent of crop damage by elephants as reported by respondents within HEC landscapes in Myanmar. **A)** Temporal pattern of elephant crop-raiding to different crops in three HEC landscapes. **B)** Distribution of crop damage in different landscapes. **C)** The effect size of crop damage probability using a GLMM with size of farmland and residency as fixed effects and with HEC region as a random effect. Reference level for farmland is landless and residency is non-native. Significant level (p value) at 0.001 = "\*\*\*\*". The value for blue colour represents positive and red colour represents negative values. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

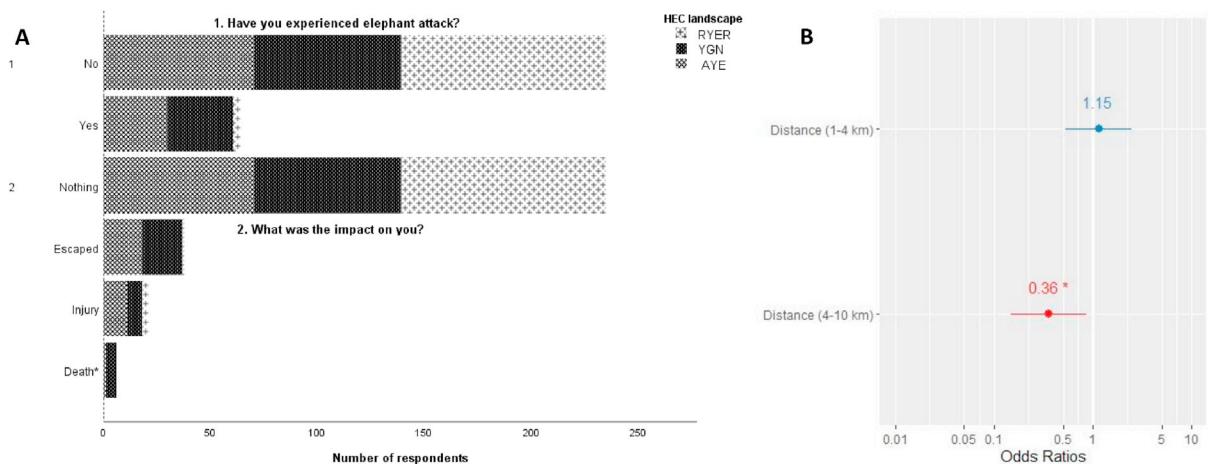
#### 4. Discussion

Many studies have revealed that crop damage is the major source of conflict between people and wild elephants (Chatterjee, 2016; Parker et al., 2007; Sarker and Røskaft, 2010). Our study shows that crop damage was the most significant form of HEC in the study area followed by property damage and human injury and death. HEC incidents varied in all HEC landscapes and decreased farther from the forest reserves. The distance to the forest reserve boundary and size of farmland are the main predictors to HEC. A limitation of this study is that we did not monitor HEC events or directly survey damages caused by elephants, and thus cannot rule out biases arising due to unreported or undetected HEC events (Goswami et al., 2015).

We found that landscapes with higher number of landless people led to a higher dependence on forest resources and increased encroachment into the elephant habituated forests. In turn, this led to more frequent encounters with wild



**Fig. 4.** Distribution of property damage pattern as reported by respondents within HEC landscapes in Myanmar.



**Fig. 5.** Extent of elephant attacks as reported by respondents within HEC landscape in Myanmar. **A)** Distribution of elephant attacks on humans in different landscapes. **B)** Effect size of attack probability using a GLMM with distance to the forest reserves as fixed effects and with HEC region as a random effect. Reference level for distance is <1 km from the forest reserves. Significant level ( $p$  value) at 0.05 = “\*”. The value for blue colour represents positive and red colour represents negative value. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

elephants. In addition, those people were generally non-native individuals. Firewood and bamboo were extracted most from the forests in the study area. Bamboo is usually collected for buildings and versatile products, and is also one of the most important food items in Asian elephant diet (Campos-Arceiz et al., 2008; Chen et al., 2006; Himmelsbach et al., 2006; Joshi and Singh, 2008). Local residents have to spend many hours or even days inside the forest to obtain good quality bamboos. Some respondents in YGN admitted they experienced wild elephant attacks while staying inside temporary camps in the forest for bamboo collection. Rondeau and Bulte (2003) concluded that rural dependence on natural resources has intensified human-wildlife conflicts. Firewood was also highly utilised in the study area. Population census data from 2014 indicated that firewood and charcoal were the main energy sources for cooking in the three landscapes (Department of Population, 2015a; 2015b; 2015c). The high consumption of firewood causes degradation and fragmentation of forests (Chakravarty et al., 2012; Puyravaud et al., 2010; Specht et al., 2015) and leads to habitat loss for wild elephants. Kushwaha and Hazarika (2004), and Leimgruber et al. (2011) found that HEC increased in areas with greater deforestation. Extraction of forest resources furthermore reduces the quality of elephant habitats through habitat degradation (Chatterjee, 2016) and increased confrontation with wild elephants.

Our findings indicate that approximately half of respondents experienced elephant crop raiding in the three HEC landscapes. The farmers who owned larger croplands were at higher risk of experiencing raids by elephants. Sukumar (1992)

stated that larger croplands adjacent to the forests were most vulnerable to crop raiding. Our study demonstrates that 88.6% of farmers who owned larger lands reported crop damage, while 60.2% of those who had smaller land experienced such damage. On the contrary, Chatterjee (2016) illustrated that smaller farmlands are more vulnerable to elephant attacks than larger farms. Some respondents in Laharmange and Kwantheemyaung villages in YGN reported that some large-scale farms owned by private companies or institutions were fenced with electric wire, so elephant raids were shifted to unprotected smaller crop fields. A similar study by Sampson et al. (2019) in YGN concluded that paddy farmers with small lands are less tolerant to HEC than sugarcane farmers with larger lands. The size of farmland was generally smaller inside or at the edge of the forest reserves and larger farther from the forest reserves.

We found that paddy was most frequently raided between October and January. Those months generally fall into the crop ripening and harvesting season in the study area. Sukumar (2003) stated that paddy is a preferred target crop raided by wild elephants in most Asian range countries, and a seasonal pattern of crop raiding was observed in the field of annual crops. Sukumar (1992) showed that the foraging strategy of elephants alters from browsing to grazing in relation to changes of protein and sodium content in grass. The mineral and nutrient contents in the inflorescence and grain of paddy peak in November (Sukumar, 1992). This explains why elephant raiding on paddy peaked in November in the study area. On the contrary, banana was raided throughout the year. Elephants prefer to consume the inner soften pith of banana rather than its fruits (Sukumar, 2003). In addition, wild elephants opportunistically raided maize, cashew nuts, pineapple, sugar cane and coconut trees. However, elephants trampled chilli, peanut, turmeric, tapioca, pea, tree tomato, and lemongrass when they traversed the crop fields. Of reported crop damages, the majority of crop depredations were caused by elephant consumption, whereas few damages were due to elephant trampling or passing through the crop field. This suggests that cultivated crops were preferred by elephants for consumption likely because they contain a higher nutritional value than wild plants (Sukumar, 1990, 2003).

During field visits, vast areas of paddy fields were found to have been abandoned over the years near Laharmange and Seikgyi villages in YGN and AYE due to fear of elephant raids by local farmers (U Hla Thein and U Tin Aung, personal communication) (see Fig. 6). Depredation of crops reduces income to farmers, thus negatively affecting a family's well-being. Some respondents claimed that it was ineffective to shift to fast-growing unpalatable crops, such as chilli or peanuts because elephants still trampled the crops. However, during field visits, changes in crop regimes were sporadic and did not show a systematic pattern at the landscape scale. It is suggested to initially implement land-use plans designed to stimulate growing of palatable crops farther from the elephant habitats. Later, changes in crop regimes that are unattractive and unpalatable to elephants should be attempted in accordance with local growing conditions. For example, Gross et al. (2017) suggest that attempts to grow plants for medicine and aroma, such as lemongrass, mint species, and citronella, would increase income for local farmers and reduce damage from elephant attacks in HEC hotspot areas.



**Fig. 6.** Examples of elephant damage on rice paddies and bananas around the RYER (Photo: A, B and C). Photo credit: RYER Park office. Photo D represents large areas of a rice paddy field that stopped growing due to fear of elephant raiding around La-Ha-Ma-Nge village in Yangon Region. Photo credit: Zaw Min Thant.



The crop damage was more likely to be severe in elephant habitats with a higher rate of deforestation (Kushwaha and Hazarika, 2004) and degradation of elephant habitat (Sukumar, 1992, 2003). Our study supports this statement as most respondents in AYE suffered more severe crop damage than those in YGN and RYER. The forests in Ayeyawady Region (AYE) underwent a higher deforestation rate in Myanmar than in Yangon Region and Rakhine State (Leimgruber et al., 2005; Wang and Myint, 2016; Yang et al., 2019). The most severe cases of HEC were experienced in the highest deforestation areas (Leimgruber et al., 2011).

Although half of respondents in YGN indicated that they suffered property damage, the majority of damage occurred over three years ago. The incidents of such damage within the past two years were higher in RYER compared to the other two HEC landscapes. It is possible that the decreasing number of problem elephants in YGN might explain the reduction in property damage. Likewise, increasing cases of elephant poaching around RYER in 2015 and 2016 would encourage elephant movement toward human-dominated landscapes and increase subsequent damage. These damages seriously affect the Rakhine community around RYER. To avoid further escalation, mitigation measures should be put in place before the current situation worsens as this community plays a significant role in the sustainable conservation of wild elephants in and around the elephant sanctuary.

Human infrastructures such as houses, huts or household goods are attacked more often than plantations including community or private forest plantations, and betel plantation. Most huts, located inside croplands or near forests, were not constructed well. They easily collapsed when elephants attacked to find stored grain. Houses were also under attack when wild elephants entered the villages in search of stored food. Most property damages were observed after crops were harvested and stored. In this context, elephants typically tried to find the stored paddy and consume it (Pant et al., 2016; Perera, 2009), but kitchen wares and clothes were sometimes destroyed.

Human injury or death by wild elephants generally occurred when local residents entered forests, cultivated or settled in elephant habitats or protected their crops from elephant attack (Chatterjee, 2016). Our study reveals that approximately thirty percent of respondents in both YGN and AYE encountered unpleasant situations with elephants, but most of them escaped from the attacks. We found that most victims were non-native who experienced attacks with higher rates of injury. Most immigrant people are landless and therefore more dependent on forest resources. They probably lack awareness or knowledge of escape techniques from lethal elephant attacks. In addition, the vegetation in the forest is relatively dense with poor visibility down to 5–10 m, enhancing the risk of elephant attack (Sukumar, 1992). Most villagers in the focus group discussions admitted that the riskiest place to be attacked by wild elephants is within the forests. Some people tried to escape a charging elephant by climbing into trees or running away.

The rate of injury caused by elephants was slightly higher in AYE compared to YGN and approximately three-fold in AYE relative to RYER. However, some injuries did not directly result from elephant attacks as victims sustained injuries from other causes while running from a charging elephant. High human density in close proximity to elephant habitats is one of main reasons causing HEC (Leimgruber et al., 2003; Sukumar, 2003), potentially explaining why elephant attacks on humans are more intense in YGN and AYE compared with RYER. Most human deaths occurred from trampling by wild elephants; villagers in Taughtanmyaung reported that a wild elephant trampled a non-native man and threw him around. Although local residents did not receive any compensation for HEC, some families of victims experienced significant problems when the main bread-earners were killed by wild elephants. A few people therefore expressed that responsible organisations should provide compensation for cases of human death. MECAP (2018) suggested that Myanmar should introduce a compensation program for human injury or death by wild elephants to promote elephant conservation. Some respondents in YGN cited that elephant attacks on humans have decreased because the number of problem elephants has also decreased. This is also consistent with records from the Forest Department indicating that only a few incidents of human death by elephants were reported in the study area in recent years compared with five years ago. Sampson et al. (2018) stated that some villagers in YGN might help poachers reduce the number of wild elephants and conflicts. HEC incidents resulting in social and economic hardships potentially causes the detrimental effect on wild elephants.

The compensation scheme itself is associated with some controversial issues (Bulte and Rondeau, 2005; Parker et al., 2007; Rondeau and Bulte, 2003; Santiapillai and Jackson, 1990), e.g., corruption or fraudulent claims of damage. To improve local tolerance to HEC and mitigate economic loss of local farmers, it is recommended that insurance schemes (MECAP, 2018; Parker et al., 2007) or incentive mechanisms should be introduced and practiced instead of compensation.

### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary data

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