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Human–elephant coexistence challenges in Myanmar: An analysis of fatal elephant attacks on humans and elephant mortality

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ABSTRACT

Understanding the underlying causes behind human–elephant conflict (HEC)-driven mortality of humans and elephants will help improve both parties' wellbeing. The objective of this study was to examine the temporal and spatial mortality patterns of humans and elephants and the influence of local attitudes, conflict factors and habitat factors on elephant poaching. We used the Myanmar Forest Department data from 2001 to 2020 for humans and 2011 to 2020 for elephants together with explanatory data on human attitudes, habitat, and conflict factors. Approximately seven persons were killed annually in elephant attacks, with a bias towards men. The annual mortality of elephants during the study period was on average 16 individuals, and most elephants were killed by humans. There was a significant relationship between the number of killed humans and human-killed elephants around HEC villages. Villages with more property damage exhibited a higher rate of human mortality, which also correlated with negative feelings of local people towards elephants. Elephant poaching was higher in villages with less suitable habitat available for elephant use. Human encroachment is an important cause of HEC, leading to human loss and forming the main threat to the survival of wild elephants. We suggest local involvement to ensure good governance in conflict resolution and mitigation strategies and to strengthen law enforcement.

1. Introduction

Because the pace of biodiversity loss has accelerated in the Anthropocene, the establishment of protected areas needs to speed up the protection and conservation of threatened wildlife and to reduce anthropogenic disturbances. To achieve the global conservation of ecosystems and biodiversity, 15.7% of the global terrestrial and fresh water areas, as well as 7.9% of marine areas, are under the protected area system (UNEP-WCMC, 2022). However, most wildlife habitats in developing countries are still outside protected area networks, and this is where conflicts between humans and wildlife often occur (Barua, Bhagwat, & Jadhav, 2013; Woodroffe, Thirgood, & Rabinowitz, 2005). Wildlife in unprotected areas suffers more stress due to higher anthropogenic disturbances, resulting in a reduction in animal fitness (Hariohay, Jackson, Fyumagwa, & Røskaft, 2018; Hunninck et al., 2017). Human–wildlife conflict (HWC) negatively impacts the structure and function of ecosystems and causes human fatalities and injuries, crop and property damage, livestock depredation and extinction threats to wildlife (Thant, May, & Røskaft, 2021a; Woodroffe et al., 2005). HWC hinders coexistence and sustains antagonisms between humans and wild animals.

Coexistence between humans and wild elephants will be difficult to resolve when escalation of conflict results in mortality on both sides. Poaching and human–elephant conflicts (HEC) increase the mortality of humans and elephants (Lenin & Sukumar, 2011) and are serious threats to the survival of elephants in Asia and Africa (Chase et al., 2016; Leimgruber et al., 2011). Anthropogenic pressures, including poaching, are attributed to the loss of half the population of African elephants (*Loxodonta africana*) (Douglas-Hamilton, 1987; Maingi, Mukeka, Kyale, & Muasya, 2012) and more than 50% of Asian elephants (*Elephas maximus*) (Williams, Tiwari, Goswami, de Silva, Kumar, Baskaran, Yoganand, & Menon, 2020). The Asian elephant is listed as an endangered species under the International Union for Conservation of Nature (IUCN) Red List category and has been categorised under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) Appendix I since 1975 (Williams et al., 2020). The population of wild Asian elephants was estimated to be approximately 48,323–51,680 individuals in 13 countries (Menon & Tiwari, 2019; Williams et al.,

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2020). HEC, poaching and illegal trade of elephant parts are growing concerns threatening the conservation of wild Asian elephants (Menon & Tiwari, 2019).

The elephant population in Myanmar has been declining dramatically over the last decades due to habitat loss, forest fragmentation, HEC, poaching and live capture (Leimgruber et al., 2011; Sampson et al., 2018; Songer, Aung, Allendorf, Calabrese, & Leimgruber, 2016). The remaining population of wild elephants is therefore assumed to be less than 2000 individuals in Myanmar (Leimgruber et al., 2011). In the beginning of the 1990s, the number of human mortalities caused by elephant infestations was approximately two to four persons per year. However, fatalities increased to approximately twelve persons per year in the early 2000s in Myanmar (Leimgruber et al., 2011). When people encounter fatal attacks by wild elephants, local tolerance towards elephants may decrease to favour the killing of elephants. In contrast, elephants may become aggressive when harassed by poachers or when encroached into their natural habitat. Aggressive elephants can result in manslaughters (Sukumar, 1992; Sukumar, 2003). This vicious cycle is detrimental to both humans and elephants. Between 1968 and 1974, there were more than 200 elephant killings for ivory in Myanmar (Santiapillai & Jackson, 1990). Although elephant poaching previously targeted ivory and live capture in Myanmar, the trend has shifted to the trade of meat and skin (Sampson et al., 2018). The total elephant mortality throughout the country was 245 elephants, with 131 individuals killed by humans between 2010 and 2020 (Forest Department, unpublished data).

On the other hand, the lack of good governance in conflict management with the participation of local people affects the tolerance level of local people towards wild elephants. It is therefore vital to understand the underlying causes of mortality patterns of humans and elephants to support local tolerance and identify strategies for coexistence. However, information is currently lacking on the extent of human and wild elephant fatalities due to lethal confrontation in Myanmar. The aim here is to evaluate the temporal and spatial patterns of elephant fatal attacks on humans and the distribution of elephant mortality in three conflict-prone landscapes and to examine how much influence local attitudes, elephant-induced damages, and habitat conditions have on these patterns. We hypothesized that there is a significant relationship between elephant attacks on humans and elephant mortality and that areas with more human encroachment have higher levels of human and elephant fatalities.

2. Method

2.1. Study area and data collection

This study was conducted in three Myanmar regions: Ayeyawady Region, southern Rakhine State and Yangon Region (Fig. 1). These three regions include those of six HEC hotspots in Myanmar (MECAP, 2018). The study area in Ayeyawady is situated along the southwestern coast of Myanmar connected to the Rakhine Yoma mountain range. Ayeyawady has been a hotspot area of elephant poaching (Leimgruber et al., 2011; Sampson et al., 2018). In the southern Rakhine State, we conducted our study around the Rakhine Yoma Elephant Range. In the Yangon Region, the study focus was on the northern part of the elephant-inhabited forest (Fig. 1). Yangon has been notorious for having higher human mortality caused by elephant attacks (Thant et al., 2021a). The central part of the study area is a relatively flat terrain covering residential areas and agricultural lands. The study's main focus was on the elephant-inhabited areas consisting of mountainous areas with forests. These forests are home to wild Asian elephants. Between May and August 2019, we visited the Forest Department offices at the township, district, regional, and head office levels and the park office of Rakhine Yoma Elephant Range and Myanma Timber Enterprise (MTE) office in the study area to collect mortality records of elephants and humans.

Human mortality data were split into two different decades: 2001–2010 and 2011–2020. Region, gender, age, incident year, month (January – December), and place were recorded. Age was classified into four groups: children (<18 years), young adults (18–35 years), adults (36–60 years), and elders (>60 years). Incident months were

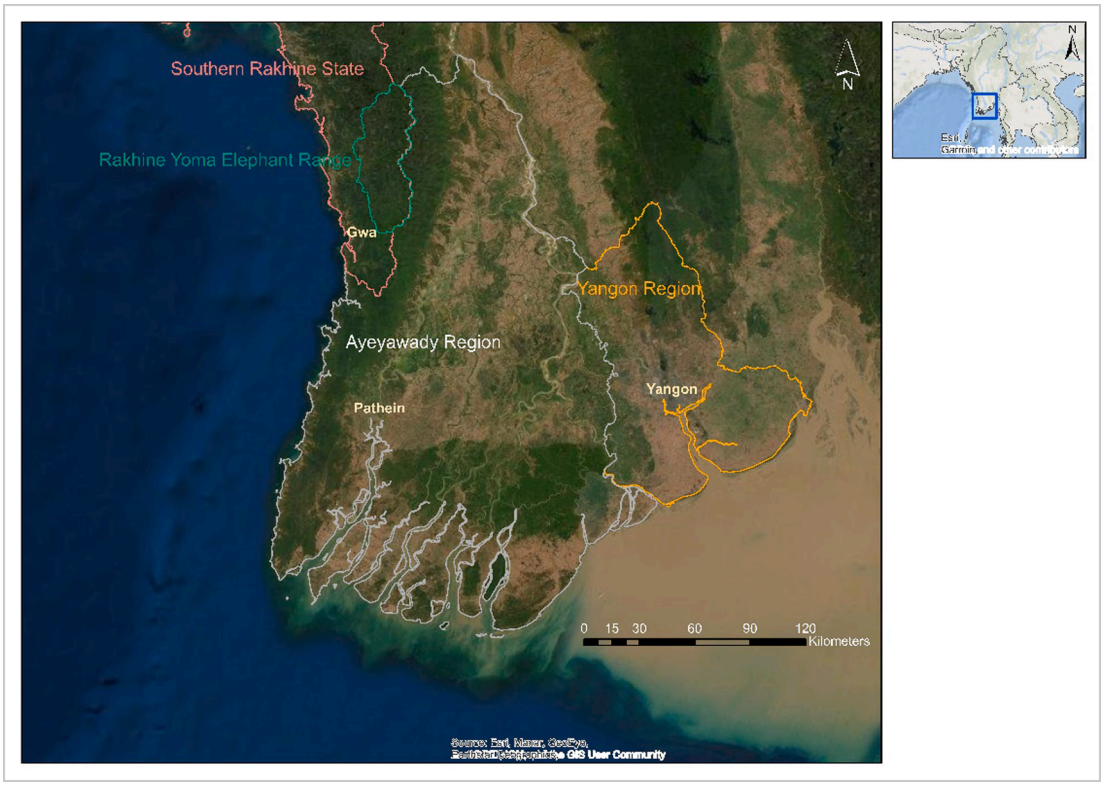

Fig. 1. Map of the study area showing three different regions in Myanmar.

categorized into dry and wet seasons, with November to May as the dry season and June to October as the wet season (Horton et al., 2017). The incident place was identified as inside or outside the forest reserves.

Elephant mortality was documented during the years 2011–2020 and recorded in relation to region, sex, age, incident year, month, location of incidents, and cause of death. Incident month and place of incidents were categorized according to the same method applied for human mortality. The cause of elephant death was documented as killed by humans or other causes. Killed elephants were recorded when elephants were found to be skinned or killed by man-made weapons such as poisonous darts or guns. Other causes were cases of mortality due to malnutrition, diseases, and other natural causes.

Nine environmental covariates (elevation, distance to water sources, distance to river or creek, distance to road, mean annual precipitation, land-use/land-cover, normalized vegetation index (NDVI), terrain ruggedness index, and human footprint index) were used, and the respective values for elephant kill sites and GPS relocations from free-ranging elephants from Thant et al. (2022) were extracted. Thant et al. (2021a, 2021b) performed village-based interviews recording the extent of crop/property damage and local attitudes. From their study, we extracted the proportion of interviewees who had crop damage or property damage, who reported elephant aggressive behaviour, who feared or hated elephants, who disagreed with the presence of elephants in the neighbourhood, and who agreed with the statement that "only a dead elephant is a good elephant". The average elephant habitat suitability was extracted within a 10-km buffer surrounding each of the 30 HEC villages from Thant et al. (2022). We also extracted the number of elephants killed within 10 km of each village using data from their exact kill site locations. The number of human mortalities within each village was derived from the focus group discussion (Thant et al., 2021a).

2.2. Statistical analyses

We used R (R Core Team. (2021), 2021) for statistical analyses. Chi-square tests for independence and goodness-of-fit were used for categorical variables. However, Mann–Whitney U tests were used for the numerical data due to a nonnormal distribution. To assess the spatial patterns in elephant kill sites relative to elephant habitat use, we compared nine environmental covariates at kill sites versus habitat use using Mann–Whitney U tests. Prior to analyses, covariate collinearity was assessed with Spearman's correlation tests, using a threshold of 0.7 to identify highly correlated covariates (Table S1). Generalized linear models (GLMs) were fitted to explore the effects of the seven explanatory covariates on the number of elephant deaths and human mortality. Because overdispersion was encountered for GLM with a Poisson distribution, we applied a negative binomial distribution instead. The negative binomial distribution is a formal way to handle overdispersion in count data, and it has advantages of association with a formal likelihood to generate information criteria such as AIC (Zeileis, Kleiber, & Jackman, 2008). Model selection was performed in the MuMIn package using AICc, and the relative importance of the summed AICc weight of the explanatory variables was used to determine the model selection (Table 1).

Table 1
The relative importance of the summed weight of AICc for explanatory variables in GLM (negative binomial) models.

Explanatory variables	Human mortality	Elephants killed
Proportion of property damage	**0.69**	0.20
Negative feelings towards elephant presence	**0.48**	**0.32**
Disagreement on the presence of elephant in the neighbourhood	0.43	0.21
Proportion of crop damage	0.22	0.21
Agreement that "only a dead elephant is a good elephant"	0.21	**0.68**
Reported elephant aggressive behaviour	0.21	0.22
Habitat suitability (mean)	0.20	**0.55**

3. Results

3.1. Temporal pattern of human and elephant mortality

Between 2001 and 2020, 143 cases of elephant-caused human mortality were recorded. Out of these cases, 96 people were killed by elephants during the years 2001 and 2010, while 47 mortalities occurred between 2011 and 2020. The annual number of human mortalities was different between the two decades ($\chi^2 = 16.79$, df = 1, $p < 0.001$). Approximately 73.5% of all reported cases were men, while 26.5% were women ($\chi^2 = 30.12$, df = 1, $p < 0.001$; Table 2). The mean age of victims was 40.1 years (SD = 20.0), and adults were more likely to encounter fatality (Table 2). Human mortality was higher in the dry season (Fig. 2, Table 2). The mean annual number of human mortalities was 7.2 people (SD = 3.4). The highest number of mortalities in a year was 15 individuals in 2007 (Fig. 3-A).

From 2011 to 2020, 156 dead elephants were recorded in the study area. Of these, 106 elephants were killed by humans, while 50 died of other causes. The majority of all recorded dead elephants were males and males were more killed by humans (Table 3). The average (known) age of dead elephants was 23.8 years (SD = 14.2). The number of human-killed elephants was highest in 2015 (24 individuals: Fig. 3-B). The average annual number of dead elephants was 16 individuals, while 11 elephants were killed by humans.

3.2. Spatial pattern of human and elephant mortality

There was a difference in human mortality between the three regions over the two decades ($\chi^2 = 164.32$, df = 2, $p < 0.001$). The highest mortality was found in Yangon, followed by Ayeyawady and Rakhine. However, when comparing the two decades, the mortality rate declined by 35.2% in Yangon, while it increased by 31.0% in Ayeyawady in the second decade. There were differences in the location of incidents between the two decades ($\chi^2 = 4.35$, df = 1, $p = 0.037$). Human mortality mostly occurred outside forest reserves (64.6%) in the first decade, whereas 55.3% of mortality was found inside forest reserves in the second decade.

The highest elephant mortality was found in Ayeyawady, where 71.2% of all elephant deaths were found, followed by 23.1% in the Yangon Region and 5.8% in southern Rakhine State. Most elephant mortality (71.8%) occurred inside the forest reserves, while 28.2% occurred outside the reserves ($\chi^2 = 5.95$, df = 1, $p = 0.015$). Approximately 78.3% of human-killed elephants were found inside the forest reserves, while 21.7% occurred outside the forest reserves.

Six environmental predictors showed a difference between elephant ranging sites and elephant kill sites. Areas close to roads were associated

Table 2
Temporal pattern of human mortality by elephant attacks between two decades.

Variables		First decade (2001–2010) (n = 96) %	Second decade (2011–2020) (n = 47) %	Total (n = 143) %	*P* value
Gender	Men	68.8	75.0	73.5	NS
	Women	31.3	15.0	26.5	
Age group	Children	19.8	13.5	18.1	< 0.001
	Young adults	17.7	21.6	18.8	
	Adults	45.8	54.1	48.1	
	Elders	16.7	10.8	15.0	
Season	Dry	71.9	63.8	69.2	NS
	Wet	28.1	36.2	30.8	

NS = nonsignificant.

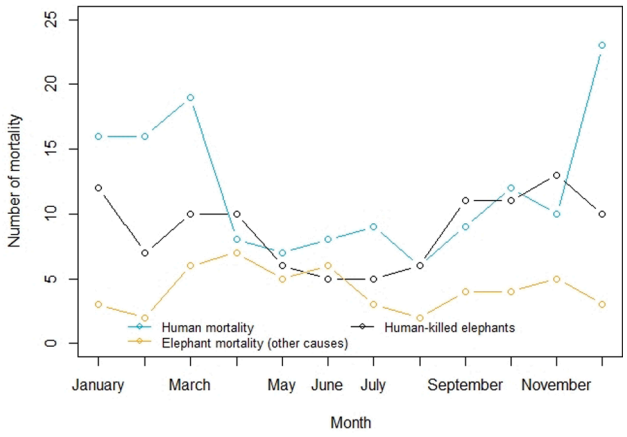

Fig. 2. Monthly mortality of humans and elephants in the study area.

with elephant kill sites (W = 66543, $p < 0.001$; Fig. 4-A). Elephants were more likely to be killed at lower elevations (W = 62148, $p < 0.001$; Fig. 4-B). Elephants were also killed closer to rivers or creeks (W = 59930, $p < 0.001$; Fig. 4-C), less in human disturbed areas (W = 54770, $p = 0.043$; Fig. 4-D), more in higher precipitated areas (W = 38634, $p < 0.001$; Fig. 4-E), and more in greener vegetation areas (W = 35579, $p < 0.001$; Fig. 4-F).

3.3. Factors affecting human mortality and elephant death

There was a strong positive correlation between the number of human deaths and the number of human-killed elephants in and around HEC villages (Fig. 5). A GLM that included the proportion of property damage and negative feelings towards elephant presence was the best model in the analysis of human mortality. The probability of human mortality was found to be higher in villages with a higher proportion of reported property damage (coefficient estimate = 2.37, SE = 0.95, z = 2.5, $p = 0.012$; Fig. 6-A). Likewise, villages where local people reported negative feelings towards elephant presence had higher human mortality (coefficient estimate = 2.14, SE = 1.05, z = 2.04, $p = 0.042$; Fig. 6-B).

For human-killed elephants, the most parsimonious model included agreement that "only a death elephant is a good elephant", mean habitat suitability, and negative feelings towards elephant presence. Interestingly, villages where local people agreed with the statement that "only a dead elephant is a good elephant" were less likely to have any killed elephants (coefficient estimate = −8.86, SE = 3.69, z = −2.40, $p = 0.016$; Fig. 7-A). Villages with higher habitat suitability for wild elephants tended to have fewer killed elephants, although they were only close to being statistically significant (coefficient estimate = −3.36, SE = 1.73, z = −1.94, $p = 0.052$; Fig. 7-B). The factor of having negative feelings towards elephant presence was not significant.

4. Discussion

This study presents the mortality patterns of humans and wild elephants in relation to habitat factors, local attitudes, and conflict factors.

Table 3
Temporal pattern of elephant mortality between 2011 and 2020 in the study area.

Variables		Human-killed elephants (n = 106) %	Other causes (n = 50) %	Total (n = 156) %	*P* value
Sex	Male	70.4	53.3	65.0	NS
	Female	29.6	46.7	35.0	
Season	Dry	64.2	62.0	63.5	NS
	Wet	35.8	38.0	36.5	

NS = nonsignificant.

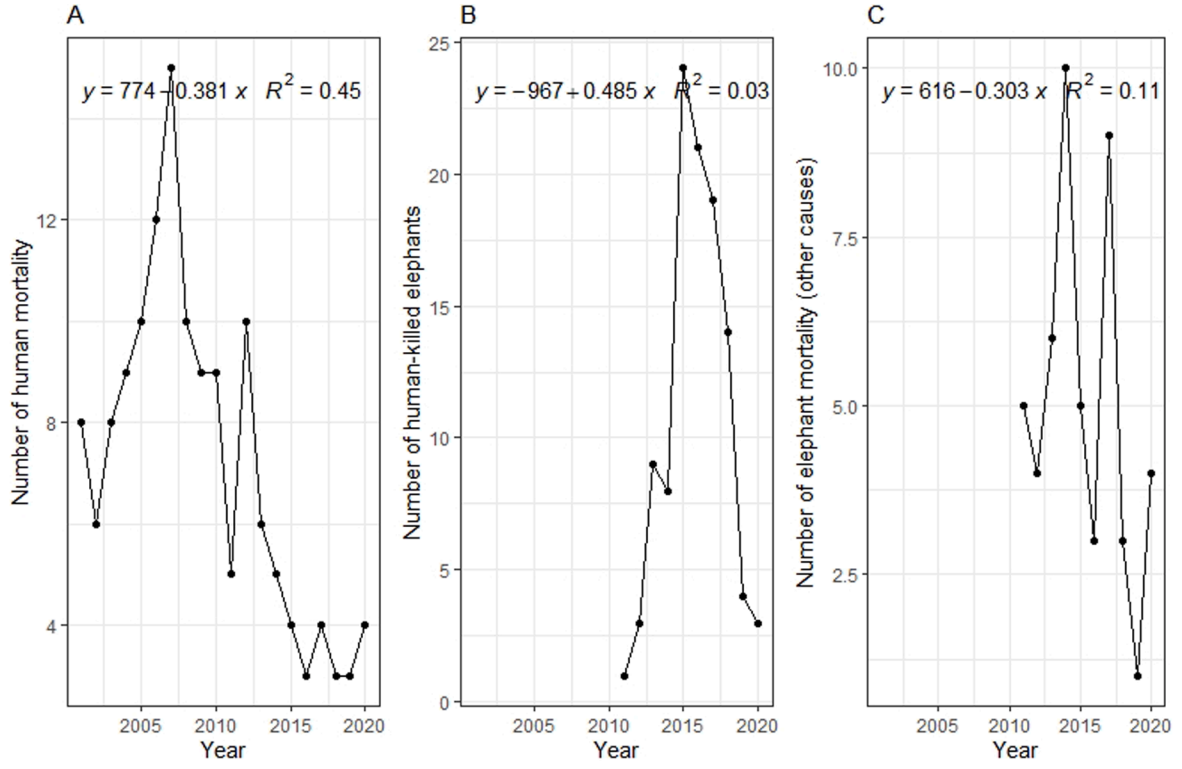

Fig. 3. Annual mortality pattern of A) humans from 2001 to 2020, B) human-killed elephants during 2011 and 2020, and C) elephant deaths by other causes during 2011 and 2020 in the study area.

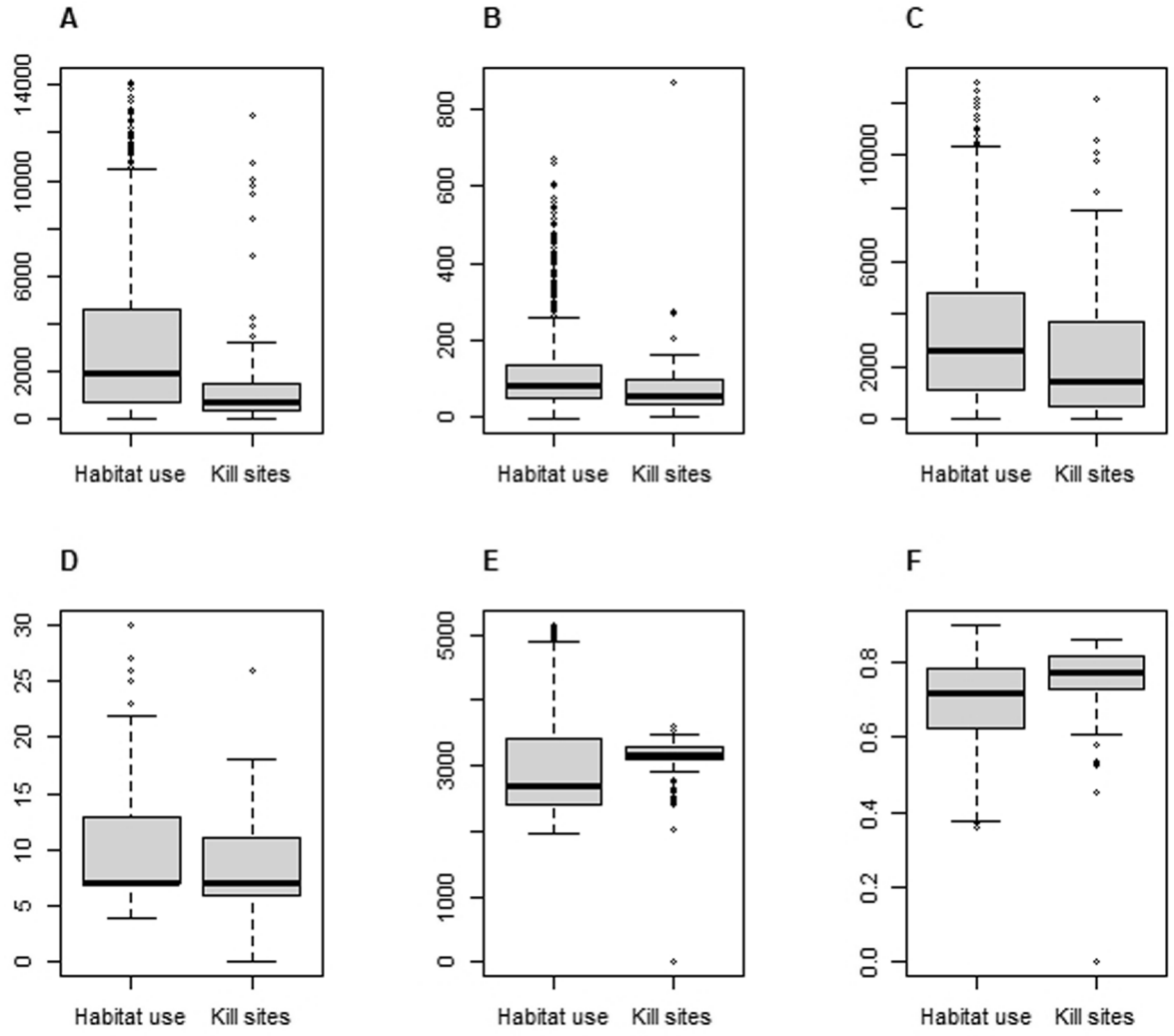

Fig. 4. Boxplots displaying differences in six environmental covariates between elephant ranging sites (habitat use) and elephant kill sites by A) distance to road, B) elevation, C) distance to river or creek, D) human footprint, E) mean annual precipitation, and F) normalized difference vegetation index.

Our results indicate that there was a significant relationship between elephant attacks on humans and human-killed elephants, indicating that there seems to have been retaliatory killing of elephants. The escalation of conflict between humans and wildlife may increase local involvement in the retaliatory killing and poaching of problem animals (Moreto, 2019; Muriuki, Ipara, & Kiringe, 2017; Packer, Ikanda, Kissui, & Kushnir, 2005).

The number of human mortalities caused by elephants is influenced by human encroachment or forest resource collection in elephant-occupied forests, the density of the human population (Thant et al., 2021a) and elephant behaviour (Sukumar, 1992; Sukumar, 2003). We found that fatal elephant attacks on humans were skewed towards men. Similar results have been found by Prakash, Wijeratne, and Fernando (2020) in Sri Lanka, Sarker, Hossen, and Røskaft (2015) in Bangladesh, and Wakoli and Sitati (2012) in Kenya. Men are responsible for guarding crops and searching for forest resources to earn money for subsistence (Radhakrishna & Sinha, 2010; Sukumar, 1992; Sukumar, 2003). Most victims were middle-aged, which may negatively impact a family's wellbeing through the loss of breadwinners. The loss of family members thereby exacerbates subsequent economic, social and psychological issues (examples in Jadhav and Barua (2012)). Such loss of breadwinners shifts the economic burden of households to women and children, accelerating indirect costs such as absence of school attendance and loss of child–parent relationships (Barua et al., 2013). Jadhav and Barua (2012) explained the mental and psychosocial impacts of fatal elephant attacks on a victim's family members. Most victims were marginalized people who live along the forest fringes. Resource competition is therefore likely the main reason for human mortality (Lenin & Sukumar, 2011). Thant et al. (2021a) found that areas where local people are strongly dependent on forest resources tend to have encounters with wild elephants that are more intense. Human mortality was higher between December and March. This period falls in the dry season, which is when humans collect forest resources. These months are also the time for crop harvesting, and people need to stay longer in the fields to harvest and guard or store the grain. Additionally, green forest foliage declines, and ripened crops attract elephants out of the forests. This increases confrontation between humans and elephants, resulting in human mortality. Our results indicate that human mortality occurred more inside forests in the second studied decade. This is consistent with the results found in Thant et al. (2021a). Sukumar (1992) explained that poor visibility inside forests might increase human mortality due to later detection of elephants and that closed vegetation may lead to limited space when an elephant charges.

We found that human mortality was the highest in Yangon. One explanation is the higher human density and dependency on forest resources in Yangon (Thant et al., 2021a). In addition, people who live near elephant migration routes are more vulnerable to elephant attacks. In Sri Lanka, people occupy 69% of the elephant range (Fernando, De

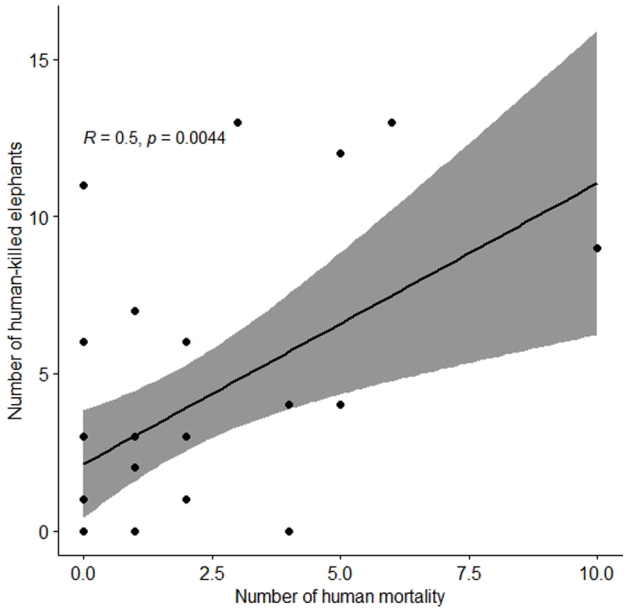

Fig. 5. A Spearman correlation between the number of human deaths and human-killed elephants in 30 HEC villages.

Silva, Jayasinghe, Janaka, & Pastorini, 2021), resulting in the mortality of 121 people and 405 elephants in 2019 alone (Prakash et al., 2020). The need for forestland and resources will be higher in the densely populated areas adjacent to forests. Human disturbance and encroachment may lead to more deforestation, loss of elephant habitat and more intense confrontations between humans and elephants. If the proportion of elephant habitat covered by forest declines to below 30–40%, the probability of HEC becomes higher (Chartier, Zimmermann, & Ladle, 2011). Lenin and Sukumar (2011) elaborated that deforestation exacerbates the mortality of humans and elephants due to increased HEC. This explanation is supported by our study, where Ayeyawady was the most deforested region (Leimgruber et al., 2005; Leimgruber et al., 2011) as well as the hotspot for elephant poaching (Sampson et al., 2018). Elephants are most vulnerable to being killed in deforested areas (LaDue, Farinelli, Eranda, Jayasinghe, & Vandercone, 2021b; Ling, Ariffin, & Abd Manaf, 2016; Sampson et al., 2018) and are more vulnerable in areas with higher crop damage (Compaore et al., 2020). Thant et al. (2021a) stated that the declining number of problem elephants resulted in decreased human mortalities in Yangon. Some local people who encounter HEC might assist poachers by giving them information about the location of wild elephants (Htun & Myat, 2017; Sampson et al., 2018).

We also found that human mortality increases in areas with more property damage. Elephant aggressiveness and property damage were positively correlated (Thant et al., 2022). Sukumar (1992) stated that African elephants were not aggressive towards people in a peaceful or nonharassed habitat, whereas they were aggressive in an area where poaching was present. Thant et al. (2021a) reported that elephant attacks on human property were highest in Yangon. Sukumar (1992) mentioned that elephants hide during the daytime and enter villages at night in search of stored food, resulting in fatal elephant attacks on humans. This also creates negative feelings, including fear, among the local people. As it is practically impossible to avoid contact, it is pivotal to understand and address the underlying causes of elephant-induced human mortality to ensure local tolerance towards elephants. To mitigate the encounter rate between humans and elephants, Mumby and Plotnik (2018) suggested providing elephant food plants and water away from human settlements.

Our results are similar to Mar (2002), who found that the natural mortality of elephants was higher in the hottest months. This mortality occurs due to insufficient forage and water and due to heat stress. A study of climatic effects on semicaptive elephants in Myanmar showed that elephant mortality is more likely to occur when temperatures exceed 24 ℃ (Mumby, Courtiol, Mar, & Lummaa, 2013). Mar (2002) and Mumby et al. (2013) also stated that male elephants suffered a higher rate of natural mortality than did females in Myanmar. Male elephants

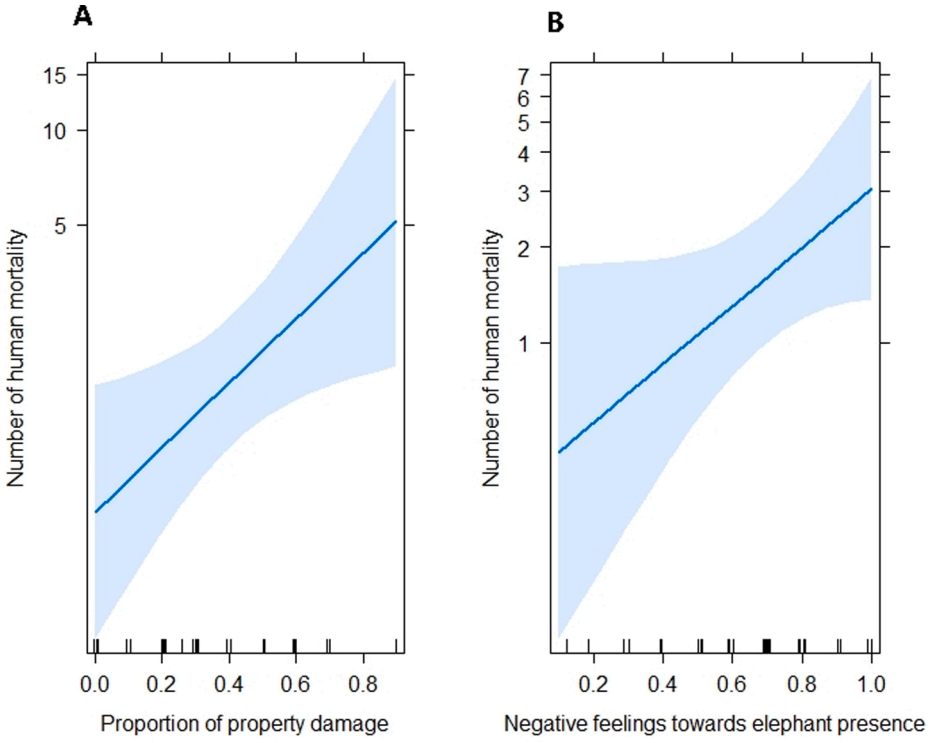

Fig. 6. Effect plots displaying the effect of A) the proportion of property damage and B) negative feelings towards elephant presence on human mortality.

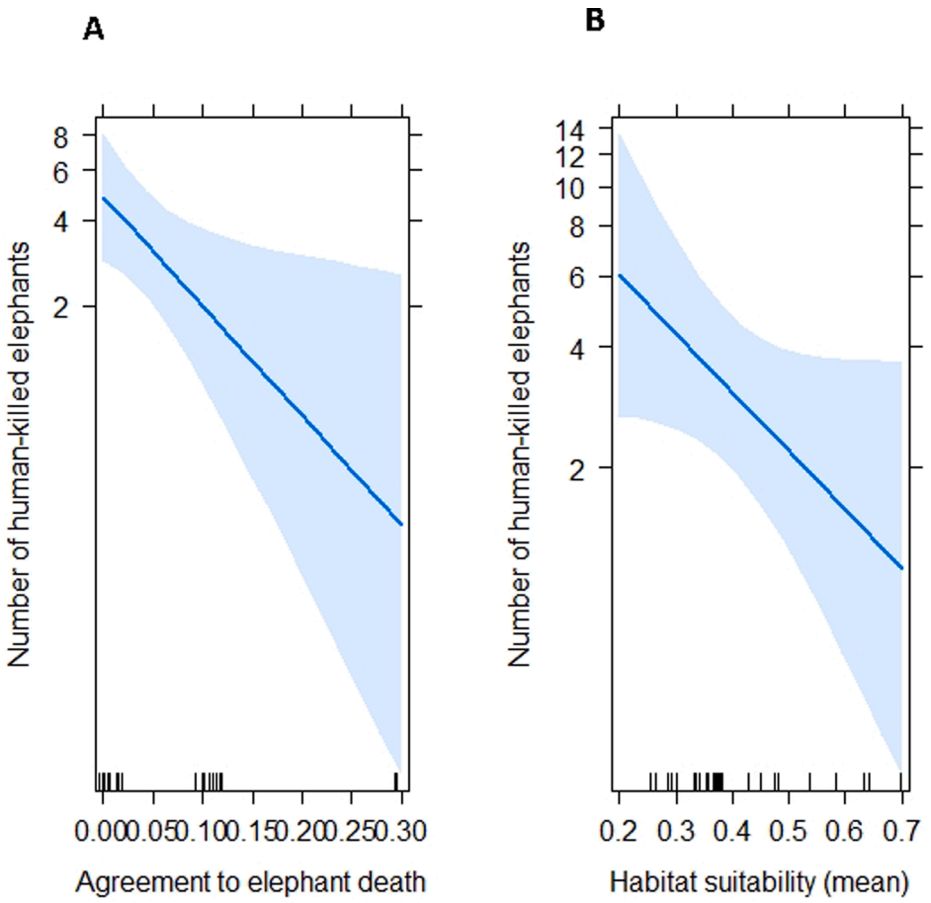

Fig. 7. Effect plots displaying the effect of A) agreement that "only a dead elephant is a good elephant", and B) mean habitat suitability on the elephants killed by humans.

were also killed more than females (LaDue, Eranda, Jayasinghe, & Vandercone, 2021b; Sukumar, 1992). Generally, more elephants were killed in the dry season. Htun (2019) reported that elephant poachers in Myanmar generally enter forests in the dry season. Studies in West Africa by Compaore et al. (2020) found that elephant poaching is higher after the harvesting period as well as in the dry season. Contrary to African elephants, female Asian elephants do not have tusks, and only some males have tusks. While poaching for Asian elephants was previously biased towards bulls for ivory (Sukumar, Ramakrishnan, & Santosh, 1998), elephant males have recently been targeted for their thicker skin and larger gross weight (Htun, 2019). Targeting males may affect the sex ratio and genetic fitness of elephant populations in the long term (Santiapillai, 1997).

Our findings reveal that elephant killings were more likely to occur in areas close to roads, rivers, or creeks and at lower altitudes. Such areas are easily accessible, and human activities are generally higher in those areas. Elephant Family (2019) stated that elephants run to water sources or streams when they are shot by poisonous arrows, as the poison causes horrible thirst in elephants. This explains why most elephant deaths were found near creeks in the study area. Maingi et al. (2012) found a positive correlation between the density of poaching and the density of anthropogenic disturbances. They demonstrated that poaching has become higher in areas close to roads and in the dry season. Roads inside wildlife habitats increase the access of poachers to forests (Lynam, 2003). The results also indicate that elephants were more likely to be killed in areas that are less human-disturbed, that have more green vegetation, or that receive higher amounts of rainfall. Elephants were more likely to be killed inside forests, as this reduced detection by law enforcement groups and reduced disturbance during the process of elephant butchering. Thant et al. (2022) demonstrated that elephants are more aggressive in less suitable habitats. Additionally, we found that human-caused elephant mortality increased in less suitable habitat. Although yet untested, elephants may well be more stressed due to poaching and human disturbance pressures.

Our results show a positive correlation between human mortality and human-killed elephants, indicating the probability of retaliatory killing of elephants in the study area. Despite this, this kind of sensitive information is less likely to be admitted by local people. McEvoy et al. (2019) conducted a hunter survey throughout Myanmar. However, no one admitted to elephant poaching.

Other hunter surveys in Myanmar showed no evidence of elephant poaching (Evans et al., 2020; Rao, Htun, Zaw, & Myint, 2010; Rao, Myint, Zaw, & Htun, 2005; Rao, Zaw, Htun, & Myint, 2011). Many studies highlighted that an increased demand for elephant skin from China was the main cause of elephant killing in Myanmar (Elephant Family, 2019; Htun & Myat, 2017; Nijman & Shepherd, 2014). Trade of elephant skin to China is believed to have begun before 1990 (Santiapillai & Jackson, 1990; Shepherd, 2002). However, illegal skin trade increased after 2000 (Elephant Family, 2019). Elephant skin is used for traditional Chinese medicine and is believed to relieve stomach ailments and cure skin fungi or infection (Sampson et al., 2018; Shepherd, 2002). In addition, ornamental beads are made from elephant skin (Menon & Tiwari, 2019). Elephant Family (2019) reported that the illegal trade of elephant skin products spreads through online social media in China. Myanmar is the main source of elephant skin (Elephant Family, 2019; Nijman & Shepherd, 2014). For example, two significant confiscations of elephant skin in southern China are believed to be the equivalent to approximately 280 elephants originating from Myanmar (Nijman & Shepherd, 2014). These factors demonstrate that Myanmar elephants are at a high risk of local extinction. Myanmar used to domesticate wild

elephants for logging, especially for the state-owned MTE and the private sector. Leimgruber, Senior, and Uga (2008) estimated that wild elephants in Myanmar will go extinct around 2040 due to the country's annual offtake of approximately 100 wild elephants for domestication. The capture of wild elephants for domestication has been banned by the government since 1994 (Schmidt & Mar, 1996), reducing the number of domestication captures (Lahdenperä, Mar, Courtiol, & Lummaa, 2018). However, elephant poaching for skin is a new emerging threat for Myanmar elephants.

There are many complex driving forces behind elephant poaching. Elephant Family (2019) stated that more than one-fifth of the rural population in Myanmar lives under the poverty threshold and that the amount of money that can be obtained from skin traders is inescapably enticing for rural villagers. Htun (2019) demonstrated that financial lures have turned local hunters living close to the Rakhine Yoma Elephant Range and in Ayeyawady into elephant poachers. Poverty and lack of job opportunities drive those hunters to become involved in elephant poaching (Htun, 2019). These poachers have good butchering skills to skin the whole elephant body within three hours. The skin is then smoked to dry in the forests and smuggled to China through wildlife trafficking channels. This type of wildlife crime is committed by well-organized groups (Nijman & Shepherd, 2014; Sampson et al., 2018). Ivory trade is complicated in Myanmar. Some local dealers for ivory products are found in some cities, and they openly sell their products (MECAP, 2018; Shepherd, 2002; Shepherd & Nijman, 2008). Reports stated that raw ivory came from domestic poaching and from India and was mainly smuggled to Thailand (Shepherd, 2002; Shepherd & Nijman, 2008). A significant loophole in earlier legislation of Myanmar was that tips and tusks from naturally dead elephants owned by the government or private owners were allowed to be sold (Shepherd & Nijman, 2008). Weak law enforcement is a challenge to combat illegal wildlife trade in Myanmar. Elephants are listed as completely protected wildlife under the Conservation of Biodiversity and Protected Area Law enacted in 2018, which emphasizes that those who commit poaching, selling, and trafficking of completely protected wildlife and their products will receive 3–10 years of prison time and a fine. Our results provide support for a hope that elephant poaching has declined in recent years. This is a similar conclusion as that of Elephant Family (2019), who concluded that increased law enforcement in Myanmar resulted in a decline in elephant killing. In 2019, there was no evidence of elephant killing in Yangon. This was the result of close collaboration within the anti-poaching programme between local forest departments and WWF-Myanmar (U Thaung Naing, personal communication). Maintaining international collaboration and spreading it to other parts of Myanmar will support the long-term survival of wild elephants in Myanmar.

4.1. Recommendation

We recommend that human disturbances in conflict hotspots be minimized and strictly regulated. Strong and efficient law enforcement is quite important to fight against elephant poaching and illegal wildlife trade. Patrolling in poaching hotspot areas might be one option to combat elephant poaching and to reduce human mortality. However, regular patrolling requires sufficient resources such as funding and staff. Strengthening the collaboration between responsible government institutions and international conservation organizations will therefore be one of the key successful factors in tackling HEC. Strong governance positively correlates with successful wildlife conservation (Calabrese et al., 2017; Smith, Muir, Walpole, Balmford, & Leader-Williams, 2003) and influences the sustainable conservation of wild elephants (Burn, Underwood, & Blanc, 2011; Calabrese et al., 2017). It will also be important to introduce effective mitigation methods for HEC and encourage local involvement while ensuring good governance in conflict resolutions. Communication networks should be established to ensure the participation of local people to report instances of elephant poaching and illegal wildlife trade to law enforcement agencies. Wildlife forensic science in general and elephant forensics in particular are urgently needed. The declining trend of elephant poaching should be maintained by strengthening law enforcement and improving collaboration with neighbouring countries. Systematic reporting and establishing an archive system of HEC incidents are of utmost importance, especially pertaining to the mortality of humans and elephants.

4.2. Limitations of the study

We did not include the incident time of human mortality (e.g., morning or midnight), elephant characteristics (e.g., bull or cow) and human characteristics (e.g., social status) because these factors were recorded inconsistently. Some elephant kills were reported to the authorities when local people found elephant skeletons in the forest. This indicates that elephant mortality that occurred during the study period might have been unreported, possibly leading the current study to underestimate the total level of mortality. However, this might not influence the conclusion of our analyses. In addition, those cases of elephant mortality with skeletons did not report the age and gender due to the potential difficulty of visual identification.

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

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jnc.2022.126260.

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