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Elephants in the village: Causes and consequences of property damage in Asia and Africa

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Abstract

In recent years, reports of elephants causing damage in rural villages by destroying houses and foraging on stored food have been increasing, but little is known about the determinants and magnitude of this damage. In this study, we have examined the extent of property damage by elephants (*Loxodonta africana* and *Elephas maximus*), in one African and two Asian study areas over a six-year period. A total of 1,172 damaged constructions were observed on site, involving detailed damage assessment by trained enumerators and standardized interviews with witnesses. Depending on the study area, between 67.1 and 86.4% of damage events were attributed to single, individual elephants or pairs of males. The majority of properties were damaged in search for food (62.5–76.7% respectively). Property damage caused higher mean losses than crop damage on farmland in all study areas. Results suggest that property damage by elephants has been largely underestimated and needs to form a focus in future human–elephant conflict research. We suggest a need to reduce the attractiveness of villages by storing food in locked and safe places, away from sleeping areas and to foster the development of elephant safe stores, appropriate to the particular cultural background of the target area.

KEYWORDS

attractive crops, conflict mitigation, elephant damage, elephant-safe stores, human–elephant conflict, land-use planning, property damage

1 | INTRODUCTION

With an expansion of settlements and built-up areas in many parts of the world, natural wildlife habitats are rapidly changing into human dominated landscapes. Adapting to these newly developing niches may require a change in behavior, such as reduced migratory behavior, changes in foraging behavior, and habituation (Luniak, 2004). Besides farmlands, wildlife species also use rural villages and even urbanized areas to forage (Gross et al., 2018; Magle, Hunt, Vernon, & Crooks, 2012). In particular, opportunistic species, with regards to food and habitat needs and wide behavioral plasticity, are capable of adapting to new habitat types (Adams, VanDruff, & Luniak, 2005). Species surviving in and adapting to human dominated landscapes develop strategies to cope with human disturbances (Ciuti et al., 2012), yet such areas may provide new sources of nutrition. Subsequently, wildlife in anthropogenic characterized areas have to trade-off between optimal forage and anthropogenic risks (Bowers & Breland, 1996; Chiyo et al., 2011). Most studies on wildlife species in urban, suburban, or exurban areas concentrate on North America, Europe, and Australia (Magle et al., 2012). However, also in African and Asian countries the emerging growth of built-up areas may also result in an increasing number of wildlife species being forced to adapt for co-existence to human-dominated areas (Hathaway et al., 2017; Landy, Rodary, & Calas, 2018).

In recent years, studies on human–elephant conflicts (HECs) in African and Asian countries have increased, although these focus mainly on crop damage in fields (Goswami, Medhi, Nichols, & Oli, 2015; Pittiglio, Skidmore, van Gils, McCall, & Prins, 2014) accidents with humans (Acharya, Paudel, Neupane, & Kohl, 2016; Das & Chattopadhyay, 2011) and the consequences they have to the conservation of the species (Shaffer, Khadka, Van Den Hoek, & Naithani, 2019). Elephants causing damage in rural villages by damaging houses, foraging on stored food products and post-harvest crops, have been less well studied. A small number of scientific publications and some other documentations raise awareness of such issues; in Zambia, elephants were reported to search for locally brewed beer in houses (Chomba, Senzota, Chabwela, Mwitwa, & Nyirenda, 2012), and in Odisha, India, they have damaged houses, consuming stored food and salt (Palei, Rath, Pradhan, & Mishra, 2015). Likewise, property damage was reported in Nepal and Sri Lanka (Pant, Dhakal, Pradhan, Leverington, & Hockings, 2015; Santiapillai et al., 2010). Neupane, Johnson, and Risch (2017) have shown that house damage by elephants in the lowlands of Nepal is influenced by land-use as well as home-use practices. Furthermore, elephants have been reported to forage on garbage in Zimbabwean open dump sites resulting in the death of eight elephants (Gogo, 2016), while in Sri Lanka, large herd sizes have been observed regularly at garbage and landfill sites (AFP, 2017). Beyond these publications, to our knowledge, there are currently no studies available on the use and resource selection of African and Asian elephants from properties in suburban areas and rural villages. Considering the high potential for conflict arising from elephants' presence in human habitations, the drivers and patterns for property damage by elephants need to be better understood. In order to draw conclusions for the management of wild elephant conservation, we have analyzed property damage (damages to houses, grain stores, and other constructions) caused by African elephants (*Loxodonta africana*) and Asian elephants (*Elephas maximus*) at the interface between people and wildlife over 6 years (2009–2014). Our analysis focused on (a) identifying parameters influencing property damage behavior of elephants, (b) understanding the seasonal patterns of property damage, and (c) examining the economic dimension of property damage.

2 | MATERIALS AND METHODS

The property damage data (damages of houses, grain stores and other constructions) were collected from January 2009 to December 2014 in three study areas (South Luangwa/Zambia, Bardia/Nepal and Manas/India).

2.1 | Study areas

South Luangwa/Zambia: In Zambia national parks are adjoined by Game Management Areas (GMAs), these are multiple use-zones for agriculture, tourism, hunting, and conservation (Lindsey et al., 2014). With approximately 13,898 individuals the Luangwa ecosystem holds the largest elephant (*L. africana*) population of the country (DNPW, 2016), utilizing both, national parks and GMAs. This study area encompasses five chiefdoms of the Lupande GMA adjoining South Luangwa National Park (Figure 1a). About 45.4% of the GMA is used for settlement, agriculture and infrastructure (Watson, Becker, Milanzi, & Nyirenda, 2014), by about 10,000 households (CSO, 2012), representing a population density of 23.4 people/km^2. Rural villages hold a very basic infrastructure (community boreholes for drinking water, small shops, and dirt roads) and houses are made of mud or bricks, covered with thatch or metal sheets. The market center (Mfuwe) is located directly on the national park border and is characterized by income generation through tourism and trade (Lewis et al., 2011; Mvula, 2001), a main tar road and large concrete or brick houses covered with metal sheets. The income, per capita, of the study area has been calculated to be USD 25 per month (CSO, 2015).

Bardia/Nepal: This study area is located in the western Buffer Zone of Bardia National Park. It holds a high density of herbivores, including an estimated number of 57 elephants, the largest number of resident elephants (*E. maximus*) in Nepal (Flagstad, Pradhan, Kvernstuen, & Wegge, 2012; Wegge, Odden, Pokharel, & Storaas, 2009). Elephants inhabit the national park as well as BZ community forests. The study area encompasses four Village Development Committees (VDC) on the Western bank of the Geruwa River and four VDCs on the eastern side (Figure 1b) with a total of 8,700 households. With 306 people/km^2, the study area is densely populated (Thapa & Chapman, 2010). Subsistence farming and

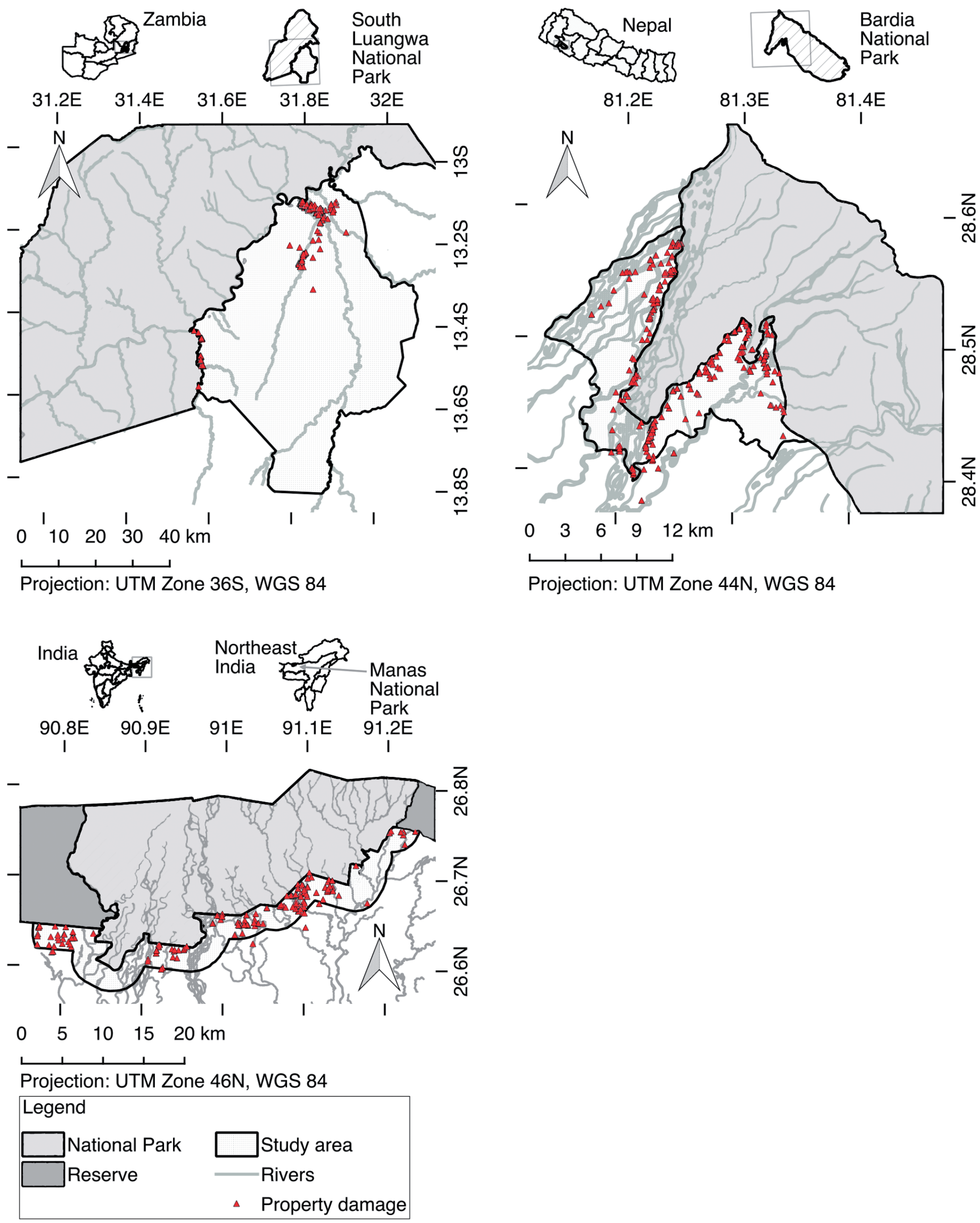

FIGURE 1 Distribution of property damage in the study areas (a) South Luangwa, (b) Bardia, and (c) Manas. Permanent water bodies (rivers) are indicated as grey lines. Also, a few adjoining cases of property damage located outside of the exact study area were included in the study

livestock keeping are the main economic activities (Thapa Karki, 2013), with people living in typically regional houses made of wattle and daub walls with thatch roofs (Bodach, Lang, & Hamhaber, 2014). However, the VDC of Thakurdwara in the south-eastern part of the study area is influenced by tourism and trade. In this area, more concrete or brick houses covered with metal sheets, as well as paved roads, are found. The income per capita in the Bardia district is calculated at USD 56 per month (UNDP, 2014b).

Manas/India (MA): Manas National Park (MNP), located in the State of Assam, south of the Bhutanese border, is an important core habitat for the Asian elephant population at the northern bank of the Bramaputra river, with an estimate of 3,250 individuals (Choudhury, 1999). The study area includes the southern belt of private agricultural and community lands bordering the MNP of Assam, encompassing 156 villages (Figure 1c) with a total of 38,500 households. With approximately 1,280 people/km^2 the study area is heavily populated. The main rural activities are rice (*Oryza sativa*) cultivation and the sale of crops from homestead gardens. People live in typically regional houses made from processed mud, wood and bamboo covered with thatched roofs or galvanized tin sheets (Singh, Mahapatra, & Atreya, 2009). The center part of the study area, close to the national park entrance, is influenced by tourism and trade as well as tea plantations. In that area brick houses covered with metal sheets as well as paved roads are found. Each village cluster has a market place, with permanent and temporal shops and stalls, mainly constructed from wood and bricks. The rural income per capita of the Baksa district south of MNP is estimated at USD 25 per month (UNDP, 2014a).

2.2 | Data collection

Data on property damage (Gross, 2020) were collected within a broad study on HWCs, which also included crop damage, livestock predation, and human accidents with wildlife (Gross et al., 2018; Gross et al., 2019). An observation of the damage site by trained local independent enumerators (HWC officers) as well as structured interviews with victims by the HWC officers were conducted using a detailed HWC assessment scheme during six consecutive years from 2009 to 2014, as described by Gross et al. (2018). To improve coverage of damage assessments, voluntary HWC informants were identified in each village or village cluster of the respective study area to inform the HWC officers about the occurrence of damage; HWC assessment was carried out within 24 hr. Furthermore, regular site visits (at least twice a month) to all villages were conducted by HWC officers. The species causing damage was identified through tracks, dung and damage pattern. Group sizes were identified through tracks (single or multiple) and group composition through the measurement of foot sizes (circumference in cm), to establish the number of adults, sub-adults and calves (Lee & Moss, 1995; Sukumar, Joshi, & Krishnamurthy, 1988). Tracks of one or two single adults without any other tracks were categorized as 1–2 males. Tracks of groups with adult and calve tracks were defined as female group. Tracks of more than two adults without any indication of calves or juvenile elephants among them were defined as male groups. Tracks of groups with 3–8 individuals, for which the composition of adults and juveniles was not clear and calves surely were not present, were defined as group 3–8 (sex unclear). Direct observations by eyewitnesses were also taken into consideration and were validated with on-site observations. Each damaged property was classified (domicile house, kitchen house, food/grain store, livestock shelter, other, unknown) and inspected regarding the cause of damage. The damage cause was classified into damage in search for food (typical searching patterns involved, for example, breaking a hole into a wall, window or roof with tusks or trunk, or searching for food with trunk) or trampling by accident or in panic, without searching for food (typical trampling patterns involved general destruction without specific target). Further observations were carried out regarding the food content of the damaged properties. All stored edible goods, whether damaged or not, were listed. Proximity to the next natural refuge, water point, traditional wildlife corridor and village was also recorded. The costs of the damage were estimated by measuring damaged proportions of construction and calculating the reconstruction costs. Furthermore, the damaged interior/food content was observed and the value of damaged goods, based on local market prices in local currency, was estimated. Information on the protection measures used against property damage by wildlife species was gathered by interviews and field verification. The demographic data of crop owners/victims were gathered through interviews and were categorized. Information on the exact property protection measures used against damage, during a particular incident, was collected through interviews and field verification. The influence of a protection measure was analyzed by comparing them to damaged properties where the owner did not employ any protection measures. Spatial autocorrelation, resulting from clustered damages were reduced by the collecting data per damage event (damage by an individual or group of one wildlife species during one time period in a defined area), not only per damaged property, as described in Gross et al. (2018). Georeference of properties damaged by elephants was taken and mapped using the Quantum GIS Geographic Information System, Version 2.14.3 Essen (QGIS Development Team, 2016; Figure 1).

2.3 | Data analysis

All costs of damage were converted from local currency into USD, using the rate on June 30th of each year (XE Currency Converter, 2017). Exchange rates of the six study years fluctuated maximum 12.6% in Zambia, 26.2% in Nepal and 22.7% in India. Seasons were determined by date (Table S1). Elephants causing damage were pooled into five groups (male single/pair: 1–2 males; male group: >2 males; unknown group: 3–8 individuals with sex unclear; family group: female led group >2; and unknown). The construction strength of properties was pooled into three groups: weak, medium, and strong construction (Table S2). Food content was pooled into nine categories: alcohol, staple crops, fruits, legumes/nuts, salt, straw/hay, sweets/sugar, vegetables, and other (Table S3). The protection measures taken by farmers were categorized into active guarding (people being present at the property with the aim to guard it, mostly using sounds and fire/light to deter wildlife), passive guarding (people sleeping in the property or nearby houses and rushing out to scare away elephants mostly by sounds when alarmed) or no protection (no person took notice of damage, no chasing of elephants).

Statistics were calculated with R version 3.2.5 (R Core Team, 2016). For all analyses, the R-packages *lme4* (Bates, Machler, Bolker, & Walker, 2015) and *lsmeans* (Lenth, 2016) were used.

The number of property damage events during the whole study period depending on seasonality, study area, elephant group composition and combination with crop damage was analyzed with a generalized linear model (GLM; R-function *glm*) using a quasipoisson family (because the response variable were count data and the data showed overdispersion) and the season length as an offset (Model 1). The number of property damage events was aggregated per season, study area, type of elephant group and combination with crop damage.

The influence of building construction type, food content and study area on the cause of damage (either "searching for food" or "trampling") was determined by a generalized linear mixed effect model (GLMM; R-function *glmer*) using a logit link function for a binomial response (Model 2). The year was modeled as a random factor because the variance between different years was not of primary interest for the posed question.

The cost of damage depending on the protection strategy and the study area was analyzed using linear mixed effect models (LME; R-function *lmer*; Model 3). The response variable cost of damage had to be log-transformed for the analysis to ensure normally distributed residuals. The year of damage was modeled as random effect. In each model, all two-fold interactions between the explanatory variables were included.

All models were simplified, according to backwards model selection, using the likelihood ratio test (see S6 for final models). For the final models, least-squares means (R-function *lsmeans*) were used to conduct pairwise comparisons between relevant explanatory variables for each study area, using Tukey-adjustment of p-values.

3 | RESULTS

Within a six–year period (2009–2014) a total of 782 property damage events with 1,178 damaged properties were assessed, out of which 778 property damage events (99.5%) were caused by elephants. For this reason, this study takes into consideration only the data on property damage caused by elephants. In South Luangwa, African elephants were involved in 246 property damage events causing damage to properties of 327 households (3.3% of all households in the study area). Asian elephants were involved in 326 property damage events (575 households, representing 6.6% of all households in the study area) in Bardia and in 206 property damage events (270 households, 0.7% of all households in each study area) in Manas, encompassing a total of 1,172 effected households.

3.1 | Location of damaged properties

The majority of properties damaged by elephants were located directly within villages (South Luangwa 97.7%, Bardia 95.4% and Manas 89.4%). Most of the damaged properties were further located within 200 m to farmland (South Luangwa 75.1%, Bardia 94.2% and Manas 93.8%) and within 200 m to water sources (South Luangwa 71.3%, Bardia 73.2% and Manas 86.9%), whereby rivers, waterholes, wells or irrigation systems were considered. Furthermore, in South Luangwa and Bardia natural elephant refuges were found within 200 m in the majority of property damage sites (South Luangwa 64.9%, Bardia 81.2% and Manas 44.4%). Traditional wildlife corridors were only located within 200 m of the property damage sites in the majority of the Bardia cases (South Luangwa 42.3%, Bardia 67.0% and Manas 19.4%).

3.2 | Characteristics of property damage

In South Luangwa, elephants damaged up to 11 properties within one property damage event (mean 1.19 ± SD 0.78), in Bardia up to 8 (mean 1.76 ± SD 1.25), and in Manas up to 5 (mean 1.15 ± SD 0.55). The majority of those properties were domicile houses (South Luangwa: 53.4%, Bardia: 83.5%, Manas: 53.2%), followed by grain stores in South Luangwa (34.2%) and kitchen houses in Bardia and Manas (8.9 and 19.1%; Figure 2). In most of the studied cases, property damage was a one-off incidence, but in 15% of the cases in Bardia and Manas and 39% in South Luangwa property damage occurred to the same household repeatedly within a years' time (South Luangwa: mean 0.75 ± SD 1.45, Bardia: mean 0.16 ± SD 0.39, Manas: mean 0.25 ± SD 0.55).

Damaged properties mainly contained edible goods (South Luangwa 79.9%, Bardia 95.2%, and Manas 93.7%) compared to damaged properties that did not contain any edible goods (South Luangwa 20.1%, Bardia 4.8%, and

FIGURE 2 Property damage caused by elephants in search for food (a) to a grocery store in Manas at Gadulee Market/Bansbari in May 2009 and (b) to a farmhouse in Bardia at Suryapatuwa in May 2009, where the entire wall has been removed by the elephant

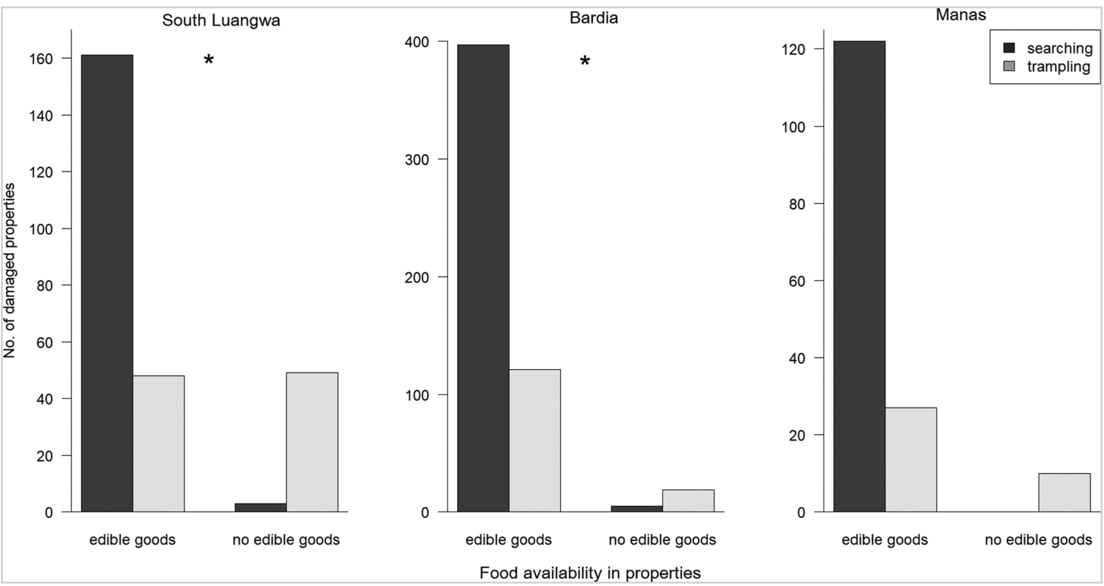

FIGURE 3 Number of properties damaged by elephants in South Luangwa, Bardia, and Manas in search for food and by trampling only, in constructions containing edible goods or no edible goods, from 2009 to 2014. Significant difference (see S6, Model 2 [ii]) was observed in the relation of searching to trampling between properties containing edible goods and those containing no edible goods in South Luangwa and Bardia (i.e., more damage incidences were caused due to searching in places where edible goods were stored, in contrast to places where no edible goods were stored), but not in Manas

Manas 6.3%). The majority of properties were damaged in search for food (South Luangwa 62.5%, Bardia 73.9%, and Manas 76.7%), for example, by opening the house selectively and searching the inside with the trunk. Damaging of properties, however, occurred to some extent without the searching for food (South Luangwa 37.5%, Bardia 26.1%, and Manas 23.3%), where accidental damage of houses, while feeding on fruits of a tree close to the house took place, or by running over a building when being chased away by people. Properties which were damaged by elephants in search for food contained food more often than properties which were damaged by trampling (Figure 3; significant differences were observed in South Luangwa ($p < .0001$) and Bardia ($p < .0001$), but not in Manas ($p = .793$); for details see also S6, Model 2 [ii]). In contrast, properties containing no edible goods were more often damaged through trampling than through searching for food. In properties containing edible goods (South Luangwa $n = 211$; Bardia $n = 519$; Manas $n = 149$) staple crops (i.e., rice, maize, wheat and sorghum), as well as salt, were found significantly ($p < .05$) more often in properties damaged by elephants through searching for food than in properties damaged through trampling only (Table 1). Although a weak correlation was observed between the storage of salt and staple crops (Pearson correlation coefficient = .32), no conclusion derived on whether only salt or the combination of salt and staple crops influenced the elephants search for food.

In South Luangwa the majority of damaged properties had a medium construction type, followed weak and strong constructions (weak: 37.0%, medium: 42.3%, strong: 19.6%, NA: 1.1%, $n = 265$); whereas in the Asian study areas the majority of damaged properties was of weak construction (Bardia: weak: 76.0%, medium: 21.7%, strong: 1.8%, NA: 0.5%, $n = 549$ and Manas: weak: 62.5%, medium: 33.8%, strong: 3.1%, NA: 0.6%, $n = 160$). Only in South Luangwa proportionally more properties with a medium construction type were damaged by trampling only, than through searching for food (compared to both weak ($p = .002$) and strong ($p = .026$) construction type).

Seasons varied in time and length between the study areas (Table S1), and the seasonal pattern of property damage also varied between the African and Asian study areas (Figure S4; for details see also S6, Model 1 (ii). In South Luangwa, property damage occurred in both the intermediate season and dry season significantly more often than in the rainy season (intermediate season vs. rainy season: $p < .0001$ and dry season vs. rainy season: $p = .0013$, respectively). In Bardia, no difference in property damage frequencies was found between rainy season and intermediate season, and rainy season and dry season, but between intermediate season and rainy season ($p = .0036$). In Manas, no difference was found between any seasons.

Individuals and pairs of male elephants caused significantly more property damage than all other elephant group compositions throughout all seasons (South Luangwa 67.1%, Bardia 86.4%, and Manas 84.6%; $p < .0001$), followed by groups of 3–8 elephants (sex unclear) in South Luangwa (20.7%) and Manas (4.6%) and male groups in Bardia (4.0%) (for details see also S6, Model 1 [iii]). Only a small number of female groups damaging properties were identified (South Luangwa 5.0%, Bardia 1.0%, and Manas 3.8%; Table 2). Furthermore, property damage throughout all seasons occurred significantly more frequently as independent, single damage events rather than events occurring in combination with crop damage ($p < .0001$; for details see also S6, Model 1 [iv]).

3.3 | Severity and costs of property damage

More than 30% of all damaged property constructions consisted of 50% destruction or more (Table 3). Furthermore, the costs of elephant damage caused to effected households per damage varied considerably, with minimum costs ranging from USD 1 in South Luangwa and Manas to USD 3 in Bardia to maximum costs up to USD 456 in South Luangwa, USD 672 in Bardia, and USD 835 in Manas (details in Table 3).

3.4 | Protection of properties

In South Luangwa, the majority of damaged properties were not protected at all (45.5%), followed by properties

TABLE 1 Number of properties damaged by elephants searching for food or trampling per study area, containing specific food items (multiple food contents in one property were possible). Properties containing no edible good were omitted from this analysis. Percentage of different food contents present in properties damaged by elephants searching for food are indicated in brackets vs. percentage of different food contents present in properties damaged by elephants trampling only

	South Luangwa		Bardia		Manas		Total	
	Searching 162	Trampling 49	Searching 398	Trampling 121	Searching 122	Trampling 27	Searching 682	Trampling 197
Staple crops[a]	154 (95.1)	39 (79.6)	391 (98.2)	113 (93.4)	103 (84.4)	21 (77.8)	648 (95.5)	173 (87.8)
Vegetables	25 (15.4)	7 (14.3)	30 (7.5)	7 (5.8)	13 (10.7)	4 (14.8)	68 (10.0)	18 (9.1)
Fruits	6 (3.7)	2 (4.1)	0	0	6 (4.9)	1 (3.7)	12 (1.8)	3 (1.5)
Legumes/nuts	6 (3.7)	0	17 (4.3)	0	1 (0.8)	0	24 (3.5)	0
Salt[a]	33 (20.4)	16 (32.7)	317 (79.6)	79 (65.3)	84 (68.9)	12 (44.4)	434 (63.6)	107 (54.3)
Alcohol	3 (1.9)	0	36 (9.0)	26 (21.5)	13 (10.7)	3 (11.1)	52 (7.6)	29 (14.7)
Sugar/sweets	18 (11.1)	6 (12.2)	2 (0.5)	6 (5.0)	34 (27.9)	9 (33.3)	54 (7.9)	21 (10.7)
Straw/hay	0	0	3 (0.8)	6 (5.0)	2 (1.6)	3 (11.1)	5 (0.7)	9 (4.9)
Others[a]	3 (1.9)	3 (6.1)	262 (65.8)	36 (29.8)	3 (2.5)	1 (3.7)	268 (39.3)	40 (20.3)

[a]Indicates significant difference in the proportions of edible goods/no edible goods between searching and trampling ($p < .05$), referring to the overall set of data.

TABLE 2 Number of property damage events caused by the different compositions of elephant groups in the three study areas (South Luangwa, Bardia, and Manas) from 2009 to 2014 in the rainy season (RS), the intermediate season (IS) and the dry season (DS). The percentage (per study area for total, and per study area and season for the seasons) is indicated in brackets

Elephant group categories	South Luangwa				Bardia				Manas			
	RS	IS	DS	Total	RS	IS	DS	Total	RS	IS	DS	Total
1–2 males	29 (13.3)	51 (23.4)	69 (31.7)	149 (68.3)	0	112 (37.1)	149 (49.3)	261 (86.4)	0	39 (31.0)	71 (56.3)	110 (87.3)
Male group	1 (0.5)	0	0	1 (0.5)	0	0	12 (4.0)	12 (4.0)	0	0	0	0
Group 3–8 (sex unclear)	6 (2.8)	18 (8.3)	22 (10.1)	46 (21.1)	0	0	8 (2.6)	8 (2.6)	0	2 (1.6)	4 (3.2)	6 (4.8)
Female group	2 (0.9)	3 (1.4)	2 (0.9)	7 (3.2)	0	0	3 (1.0)	3 (1.0)	0	4 (3.2)	1 (0.8)	5 (4.0)
Composition unknown	2 (0.9)	4 (1.8)	9 (4.1)	15 (6.9)	0	3 (1.0)	15 (5.0)	18 (6.0)	0	3 (2.4)	2 (1.6)	5 (4.0)

TABLE 3 Total number of property damage by elephants in the three different study areas from 2009 to 2014, as well as the mean and standard deviation of losses per effected households per damage incident in USD

Parameters	South Luangwa	Bardia	Manas
Number of households effected by property damage	327	575	270
Proportion of construction damage under 50% and above 50%[a]	61.8%|36.7%	63.1%|36.1%	62.7%|33.5%
Total costs of property damage 2009 to 2014 [USD]	21,273	55,965	12,666
Mean ± SD of total annual costs of property damage [USD]	3,546 ± 2051	9,289 ± 7,195	2,111 ± 654
Mean ± SD of cost of damage per effected household [USD]	65 ± 73	97 ± 93	47 ± 81
Median cost of property damage per incident per farmer [USD]	41	73	22

[a]Difference to 100% was indicated as "proportion unknown."

protected by passive guarding (20.9%) and active guarding (11%). In Bardia and Manas, passive guarding was the most commonly used protection practice on the properties involved in damage events (59.7 and 70.0%, respectively), followed by active guarding in Bardia (23.1%) and no protection in Manas (28.1%). Active guarding did not reduce the costs of property damage compared to unprotected properties experiencing damage. In contrast, in South Luangwa, damaged properties, which were actively guarded, showed higher costs of property damage when compared with those which were not or passively guarded (Figure S5). In Manas properties, which were passively guarded, showed significantly lower costs of damage compared to damaged properties without protection ($p < .05$; S6, Model 3 [ii]). In Bardia, no differences in the costs of damage relating to any guarding strategy could be determined.

4 | DISCUSSION

In contrast to numerous studies on crop damage, property damage and damage to stored crops (post-harvest damage) have only been investigated in a few studies (Chomba et al., 2012; Neupane et al., 2017; Palei et al., 2015; Pant et al., 2015; Santiapillai et al., 2010; Treves, Wallace, & White, 2009). Damage caused by elephants on fields has been described as the main driver for HECs (Hoare, 2000; Sukumar, 2006; Thirgood, Woodroffe, & Rabinowitz, 2005), but our study suggests that damage to property and stored crops is equally substantial. We have examined crop damage by elephants in all three study areas with the same methodology and during the same time, as used in this study (Gross et al., 2018). Comparing the number of these events in our study areas (South Luangwa: 1036 crop vs. 246 property damage events, Bardia 455 crop vs. 326 property damage events, Manas 474 crop vs. 206 property damage events) indicates a relatively high frequency of property damage compared to crop damage.

4.1 | Why do elephants damage properties?

In a previous study, we found that crop damage by elephants in fields, both in African and Asian countries, coincided with the time of the ripening of crops (Gross et al., 2018), in the rainy and following intermediate seasons. Elephants significantly preferred mature and harvested crops compared to crops that were still ripening (Gross et al., 2018). As in South Luangwa property damage occurred toward the dry season, when staple crops have already been harvested and stored in the villages, elephants seemingly followed the crops from the fields into the villages. In Bardia and Manas, however, elephants searched for food in properties all year round. Even in the rainy season, when food sources are extensively available in the natural habitat as well as in farms, Asian elephants (in Bardia and Manas) were damaging houses and villages in search for food. Reasons for this may originate in the higher and easier availability of stored food in the Asian study areas, the stronger habituation of individual elephants or in the degradation level of the natural habitat (Chartier, Zimmermann, & Ladle, 2011). To gain more insight into this complex matter, investigating the drivers for property damage by elephants should be part of future studies. Whatever the reasons may be, our findings suggest that elephants in all three study areas were selectively searching for food in properties, independently of crop damage in fields. Therefore, taking precautionary measures to avoid post-harvest damage in the village is highly recommended. Details for such measures are discussed in the section “Management Implications” below.

The results of our study show that elephants seldom incurred more than 50% damage to the targeted construction. Damage to properties was generally selective, which leads us to assume that the damaging behavior continued only until the individuals gained access to the desired food. A well-documented example from Bardia described how a single elephant bull searched for food in six houses in a village one after the other, opening them specifically where food was stored (e.g., attic with stored rice, kitchen with different food stuffs), while being followed by a crowd of people trying to scare it away (personal observation by EMG). This exemplifies a change in behavior of an individual, wild elephant regarding its habituation to human disturbance as well as the directed behavior of searching for food in houses. Behavior change of elephants in reaction to the presence of people has been observed, for example, in changing resting times from night to day (Wittemyer, Keating, Vollrath, & Douglas-Hamilton, 2017).

Generally, human density is negatively correlated with elephant populations from a certain threshold onwards (Hoare & Du Toit, 1999) and the proximity to towns has been negatively correlated with crop damage by elephants (Sitati, Walpole, Smith, & Leader-Williams, 2003). In contrast to this, our study observes property damage mainly within villages/towns. Property damage outside of villages/towns was very low, however, the proximity of fields and farmland as well as natural habitats within a radius of 200 m was observed for the majority of property damage cases. This study included data on damaged properties, only, and is therefore limited in determining what exactly influences elephants to move into villages. The movement and behavior of species are influenced by multiple factors (Chiyo & Cochrane, 2005; Songhurst, McCulloch, & Coulson, 2015) and the determination of factors influencing the spatial distribution of property damage needs to take into consideration the entirety of properties (damaged and not damaged) of an area, should be scope of further research.

Taking into consideration the optimal foraging strategy of elephants (Sukumar, 1990), one explanation could be that elephants are moving to villages in a directed search for food. Moving into villages and built-up areas is a high-risk behavior for elephants. Minimizing the likelihood of interacting with people, the primary predator of elephants (Wegge et al., 2009), has been observed in several studies leading to the landscape of fear concept (Riginos, 2015; Wittemyer et al., 2017). Ahlering, Millspaugh, Woods, Western, and Eggert (2011) have shown elevated levels of stress hormones in male elephants when feeding on crops. Nevertheless, stored crops or processed human food are more nutritious than wild forage and, therefore, taking the risk to forage on these, pays off as it enhances the nutritional state and growth (Chiyo et al., 2011) and, thus, may positively influence reproductive success (Hollister-Smith et al., 2007). Similar to their foraging preference for staple crops in fields (Gross et al., 2018), we also found elephants searched mainly for staple crops in the villages. Whether elephants are additionally searching specifically for other food items, cannot be confirmed by our data, in particular salt, which was also found frequently in buildings damaged by elephants searching for food and was, in most cases, stored together with staple crops. Due to the very low number of houses damaged in search for food combined with stored alcohol, it is very unlikely that elephants in our study areas were specifically searching for alcohol, as reported by Chomba et al. (2012) and determined Neupane et al. (2017). However, more research is needed to better understand the movement ecology of elephants in human dominated landscape and the drivers for property damaging behavior.

Although the field conditions (e.g., sudden encounters in the dark, stressful situations for the villagers) did not allow for the reliable identification of individuals damaging property in all cases, we were able to identify the majority of elephants in all three study areas as single males or pairs of males. Also, when exploring new, potentially dangerous areas, female groups are more cautious than males (Druce, Pretorius, & Slotow, 2008). This finding is supported by this study, as family groups were seldom involved in property damage. The large proportion of property damaging groups with 3–8 individuals (sex unclear) in South Luangwa was probably more likely due to bachelor groups rather than family groups. Family groups are relatively easy to distinguish, due to the small foot size of calves within these groups, so that groups of elephants without calf footprints were very likely bachelor groups. However, some uncertainty remains, as, for example, substrate variations may influence elephant track measures. In the Luangwa valley, elephants formed bachelor groups of up to five individuals (Lewis, 1987), whilst in India, elephants were reported to form larger bachelor groups when feeding on field crops (Sukumar & Gadgil, 1988). The formation of larger groups, while taking a higher risk, may provide an explanation for the large proportion of bachelor groups involved in property damage. Elephants are social animals, passing on knowledge on resource availability and location within their kinship (Fishlock, Caldwell, & Lee, 2016; Greco, Brown, Andrews, Swaisgood, & Caine, 2013). In Amboseli, Kenya, the learning of crop damage behavior (targeted behavior of damaging crops on farms and fields) has been described for associations of male elephants (Chiyo, Moss, & Alberts, 2012), where younger males learned crop damaging behavior from older males. Regular property damage is a relatively new phenomenon in the three study areas and started not long before this study was conducted. Due to the sudden and frequent occurrence of property damage, we therefore presume that learning behavior has occurred. However, as problem elephant control (PEC), has been conducted (at least in South Luangwa) it has to be taken into consideration that hunting of bulls has direct effects (reduction of bull number) and indirect effects (disturbance resulting in movement of elephants) (Selier, Page, Vanak, & Slotow, 2014). Furthermore, the change of social structures through poaching, retaliation killing and so called PEC, may further intensify the destructive behavior of elephants (Slotow & van Dyk, 2001) and therefore increase damage and conflict. As behavioral effects have been observed, when young, inexperienced bulls or groups without an experienced leader continued their learned damaging behavior (Chiyo et al., 2012), or displayed untypical aggressive behavior toward other species (Bradshaw & Schore, 2007), PEC measures need to be carefully planned and potential risks and consequences need to be calculated.

4.2 | Social dimension of property damage

In all three study areas, people have experienced crop damage by wildlife species for a very long time (Nath et al., 2009; Nyirenda, Chansa, Myburgh, & Reilly, 2011; Thapa, 2010). In contrast to the higher number of pre-harvest crop damage in fields (Gross et al., 2018), the mean financial loss per property damage was found to be much higher compared to crop damage (South Luangwa: by 200%, Bardia: by 350%, and Manas: by 450%). Losing around two monthly incomes per property damage is a financial and social disaster for any household, in particular for families with high economic vulnerability and a low resilience. In all three study areas compensation schemes for property damages do not exist or are very difficult to access for farmers (Karanth, Gupta, & Vanamamalai, 2018; Pant et al., 2015). In Bardia and Manas, the total loss through property damage throughout the six study years was even higher than the total loss through crop damage (Bardia by 120% and Manas by 150%). We reason, therefore, that property damage has largely been underestimated regarding its severity and economic impact and needs to be taken into stronger consideration for HEC mitigation strategies. Compensation schemes should be considered to reduce the costs of living with wildlife and to increase tolerance toward wildlife (Dickman, Macdonald, & Macdonald, 2011; Karanth et al., 2018) and should be integrated into a comprehensive approach that includes damage prevention measures (Nyhus, Osofsky, Ferraro, Madden, & Fischer, 2005).

Another important aspect of property damage is the potential of fear that these incidences provoke. The largest proportion of property damage occurred to domicile houses. As most property damage took place at night, victims were confronted with an elephant damaging their home whilst sleeping. Many victims expressed their fear in interviews, especially when children were present and started to scream and cry. The low number of human injury accidents, despite the high number of property damage in our study areas, should not mask the potential perceived threat in such situations. Furthermore, elephants in all study areas did not restrict themselves to rural village environments, but also targeted more built-up areas, such as a market place in Manas (Figure 2a), a school canteen in South Luangwa (constructed of bricks and metal tin sheet) or a solid built clinic in Bardia. The habituation of elephants to human disturbance is a risk factor, which is likely to increase, especially when guarding techniques are carried out in an uncoordinated and ineffective manner (Gross et al., 2019). The low effectiveness of property guarding strategies in our study areas further supports the theory of habituation and therefore failing of measures. Higher costs of damage in South Luangwa during active guarding of properties indicate a counterproductive activity, at least in some cases. One explanation for this may be that elephants were disoriented or stressed through less directional deterrent methods (Davies et al., 2011), causing even more damage by running over constructions and causing damage on their way back to their natural refuge, thus explaining the higher proportion of property damage without searching for food in South Luangwa (34.8%) compared to Bardia and Manas. Against this background, guarding strategies need to be reconsidered and more strategically designed and well managed (Gross et al., 2019).

5 | MANAGEMENT IMPLICATIONS

Although this study investigates the property damaging behavior of African and Asian elephants in three study areas, many details on this particular behavior have yet to be clarified. This study, however, demonstrates that elephants are able to enter villages and built-up areas, to search for food in properties and show a high level of habituation to human disturbance.

Furthermore, additional research is needed to fully understand property damage behavior by elephants, particularly the spatial structure of this behavior, the role of odors to determine food in properties and learning behavior. Elephants causing massive and repeated property damage are likely to be injured or even killed as retaliation or so called PEC. These measures, however, do not resolve the problem in long-term, as it is most probable that other individuals will then occupy this “niche” (Chiyo et al., 2012). Conservation management, therefore, needs to focus more strongly on the prevention of elephants feeding successfully in villages, to avert positive enforcement of such behavior and therewith the occurrence of larger damage.

As mainly single or pairs of bulls as well as bachelor groups are involved in property damage behavior, they should be the focus of intensive monitoring. Tracking bulls with real-time telemetry and setting up virtual geofences to alert rapid response (Wall, Wittemyer, Klinkenberg, & Douglas-Hamilton, 2014) may be used as a high-tech measure to prevent damage within human settlements. Early warning systems, using advanced sound systems, indicating elephants approaching a certain village and sending out a warning to the inhabitants, resulting in cohesive and strategic defense, is regarded as promising (Anni & Sangaiah, 2015; Zeppelzauer & Stoeger, 2015). Also, camera systems integrating artificial intelligence technology (Dinerstein & Fernando, 2020) can be used to ensure the detection of elephants before entering settlements. Such approaches can strategically enforce the spatial landscape of fear for elephants around villages, and therefore reduce frequency of access.

Additionally, strategies to reduce the attractiveness of villages to elephants should be taken, for example, by storing food in locked and safe places. Our study shows that elephants are deliberately searching for food in properties. Decreasing their feeding success in villages should decrease their intention to search for food in houses. Similar strategies were very successful used to reduce conflicts with American black bears (*Ursus americanus*). Here, proactive approaches for garbage management and developing comprehensive bear education programs (Spencer, Beausoleil, & Martorello, 2007) were used. Particularly, the emission of odors from food attractive to elephants must be decreased from bedrooms, to avoid elephants searching for food in areas where people are sleeping. Such initial attempts have been made by the construction of elephant safe grain stores (Fulconis, Drouet-Hoguet, & Gross, 2014) outside of living houses, in South Luangwa. However, there are more techniques, which can be explored further, such as the use of triple-layer hermetic bags for grain storage or the use of airtight plastic containers.

Within the scope of this study, we were not able to analyze the social response and perception of people toward elephants in our study areas and how these were influenced by the direct experience of property damage. As direct negative experience, such as the loss of property and direct confrontation with elephants, could shape the perception of and tolerance toward the species (Kansky, Kidd, & Knight, 2016), further research should be considered to evaluate social drivers of HWC in the study areas. Hereby, the exacerbation of conflict over wildlife by power imbalances should be further considered (Frank & Glikman, 2019).

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS

Eva M. Gross designed the study and trained enumerators for data collection. Bibhuti P. Lahkar, Naresh Subedi and Vincent R. Nyirenda supervised data collection. Eva M. Gross and Oliver Jakoby analyzed the data. Eva Klebelsberg produced the maps. Eva M. Gross wrote the final paper and Oliver Jakoby, Bibhuti P. Lahkar, Naresh Subedi, Vincent R. Nyirenda and Eva Klebelsberg contributed to the final paper.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the Open Science Framework osf.io/4v9fa.

ETHICS STATEMENT

Data collection and forms were approved by the implementing partner organizations CSL/Zambia, NTNC/Nepal and Aaranyak/India and their respective official partners DNPW/Zambia, DNPWC/Nepal and Bodoland Territorial Council/India.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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