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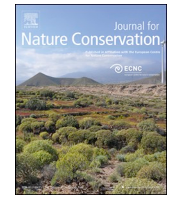

Does traditional and advanced guarding reduce crop losses due to wildlife? A comparative analysis from Africa and Asia

Eva M. Gross[a,b,*], Bibhuti P. Lahkar[b,c], Naresh Subedi[d], Vincent R. Nyirenda[e,f], Laly L. Lichtenfeld[g,h], Oliver Jakoby[i]

[a] Faculty of Biological Sciences, Goethe University Frankfurt, Max-von-Laue-Str. 9, 60438 Frankfurt, Germany
[b] Awely, Wildlife and People, 3 Place de la République, 45000 Orléans, France
[c] Aaranyak, 13, Tayab Ali Bi-lane, Bishnu Rabha Path, Guwahati, Assam 781028, India
[d] National Trust for Nature Conservation, P.O. Box 3712, Khumaltar Lalitpur, Nepal
[e] Department of Zoology and Aquatic Sciences, School of Natural Resources, Copperbelt University, Kitwe, Zambia
[f] Department of National Parks and Wildlife, P/B 1, Chilanga, Zambia
[g] African People & Wildlife Fund, P.O. Box 624, Bernhardsville, NJ 97924, USA
[h] Tanzania People & Wildlife Fund, P.O. Box 11306, Arusha, Tanzania
[i] RIFCON GmbH, Goldbeckstraße 13, 69493 Hirschberg, Germany

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ABSTRACT

Crop damage caused by herbivorous wildlife species on farms located within conservation landscapes, is a driver of human-wildlife conflict (HWC). Guarding of farms, whereby farmers spend the night out in the fields, in areas adjacent to protected areas is, therefore, very common in many African and Asian countries. Furthermore, guarding is often combined with other crop protection measures, but little is known about the efficacy of these measures.

We examined the effect that different traditional and advanced crop protection measures (active and passive guarding strategies, barriers and combinations of measures) had on the magnitude of damaged crops. For this, we examined the cost of crop damage caused by a total of 20 wildlife species in two African and two Asian study areas, where different protection types were applied. Data was compared with the cost of crop damage on unprotected fields. We continuously used a standardised HWC assessment scheme over six years (2009–2014), based on site observations and measurements in addition to interviews with victims.

The analysis of crop damage costs revealed substantial losses, especially from that caused by elephants (*Loxodonta africana* and *Elephas maximus*) and other large herbivores, such as zebra (*Equus quagga*) and common eland (*Taurotragus oryx*). Once wildlife had entered the farms, it was found that crop protection measures by farmers were only able to reduce damage costs when applied as a communal, strategic guarding system. Surprisingly, all other traditional crop protection strategies have proven ineffective in reducing crop damage costs. Electrical fences actually increased the risk of crop damage when combined with guarding and the chasing of wildlife strategies. Therefore, we recommend reviewing the practice of traditional guarding strategies and the effectiveness of fences. Furthermore, we emphasise the need for objective evaluation of HWC mitigation strategies in the long-term.

1. Introduction

The damage of crops by wildlife species has been described as one of the main drivers for conflicts between people and wildlife in African and Asian countries (Thirgood, Woodroffe, & Rabinowitz, 2005). When the species concerned are protected by law, this conflict becomes a matter between the local communities, governmental, as well as non-governmental, wildlife conservation agencies and other stakeholders (Madden & McQuinn, 2014). People affected by crop damage are mostly living adjacent to protected areas, or in multiple-use zones (Treves, Wallace, Naughton-Treves, & Morales, 2006) where natural wildlife habitat and agriculture are interspersed, or in areas that have been lately transformed from natural habitats to human dominated forms of land-use (Distefano, 2005).

* Corresponding author at: Linking Conservation and Development, Heinrich-von-Kleist-Str. 19, 69198 Schriesheim, Germany.
E-mail address: mail@eva-gross.com (E.M. Gross).

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Furthermore, biodiversity hotspots and extreme poverty are geographically coincident. Due to the lack of resources and poor governance structures dominated by rigid institutions, people living in rural areas, located close to protected areas, face poor income situations (Barrett, Travis, & Dasgupta, 2011). When subsistence farming is the only source of income, crop damage can directly affect survival. Wildlife species involved in crop damage range from small mammals such as macaques (*Macaca* spec.) or baboons (*Papio* spec.) (Taylor, Ryan, Brashares, & Johnson, 2016), to larger mammals such as bush pigs (*Potamochoerus larvatus*) or wild boars (*Sus scrofa*) (Barrios-Garcia & Ballari, 2012), and to the largest terrestrial herbivores, the Asian and African elephants (*Elephas maximus* and *Loxodonta africana*) (Hoare, 2000; Sukumar, 2006).

In order to decrease the amount of crop damage caused by wildlife species, farmers have developed several methods to protect their fields against hungry visitors. Traditional protection measures range from guarding and scaring intruding wildlife by drumming and shouting, to the use of natural barriers (Thapa, 2010) or olfactory repellents (Osborn, 2002). In several cases farming communities are supported by conservation agencies (Treves, Wallace, & White, 2009) in the application of improved, low-tech protection strategies such as chilli techniques (Karidozo & Osborn, 2015; Pozo, Coulson, McCulloch, Stronza, & Songhurst, 2017) or bee hive fences (King, Lala, Nzumu, Mwambingu, & Douglas-Hamilton, 2017) or by the installation of highly cost intensive measures such as electric fences (Sapkota, Aryal, Baral, Hayward, & Raubenheimer, 2014) or trenches (MacKenzie, 2012). Measures to protect fields against wildlife can involve considerable tangible and intangible costs for farmers, particularly when guarding out in the fields at night is involved (Barua, Bhagwat, & Jadhav, 2013). However, not much is known about the effectiveness of the guarding methods and their potential to decrease the costs of damage (Davies et al., 2011; Graham & Ochieng, 2008).

Over six years, we have continuously examined the extent of crop damage by three different groups of wildlife species (i.e. elephants, other large herbivores and small herbivores) in two African and two Asian study areas prone to human-wildlife conflicts (HWCs). With this study we aim to understand the magnitude of crop damage for local farmers caused by different wildlife species and to evaluate the effect that different crop protection strategies have on income losses from crop damage.

2. Materials and methods

2.1. Study area

Two African and two Asian study areas were selected, in which the same standardised HWC assessment scheme was implemented by the French conservation NGO *Awely* (Gross et al., 2018). From January 2009 to December 2014 data were collected in three study areas (South Luangwa/Zambia, Bardia/Nepal and Manas/India) and from January 2010 to December 2011 in Tarangire/Tanzania. The economies of Zambia and India are classified as low middle income and those of Tanzania and Nepal as low income (World Bank Group, 2017).

South Luangwa/Zambia (SL): this study area encompasses five chiefdoms of the Lupande Game Management Area (GMA) (Fig. 1a) adjoining the South Luangwa National Park in the Eastern Province of Zambia. The rural per capita income has been calculated to be 24.82 USD per month (CSO, 2015). The population (predominantly the Kunda ethnic group) of the Lupande GMA is estimated at 51,457 people (CSO, 2012), utilising about 45.4% of the GMA for living, agriculture and infrastructure (Watson, Becker, Milanzi, & Nyirenda, 2014), representing a population density of 23.4 people/km^2 in the agricultural and rural areas. Small-scale subsistence farming of maize (*Zea mays*), sorghum (*Sorghum bicolor*) and finger-millet (*Eleusine coracana*) are the main agricultural activities in the study area (Gross et al. subm.). The Luangwa valley holds the largest elephant (*Loxodonta africana*) population in the country (DNPW, 2016) as well as large populations of other herbivores.

Tarangire/Tanzania (TA): east of Tarangire National Park in northern Tanzania. This study area encompasses the community of Loibor Siret in the Simanjiro District (Fig. 1b), with a total land holding of 550 km^2 (Lichtenfeld, Trout, & Kisimir, 2014) and a low human population of seven people/km^2 (Davis, 2011). The largest ethnic group are the Kisongo Maasai (Cooke, 2007) who traditionally perform transhumant pastoralism (Baird & Leslie, 2013), but today are increasingly involved in agricultural activities, especially the farming of maize, groundnuts (*Arachis hypogea*) and beans (*Phaseolus vulgaris*) (Cooke, 2007). The rural per capita income for this region (Manyara) is estimated to be 55.79 USD per month (UNDP, 2015). The area belongs to one of East Africa's most important wildlife habitats with large numbers of migratory ungulates.

Bardia/Nepal (BA): in the lowlands of Nepal. This study area is located in the western Buffer Zone (BZ) of the Bardia National Park, encompassing four Village Development Committees (VDC) on the Western bank of the Geruwa River and four VDCs on the Eastern side (Fig. 1c). With about 306 people/km^2 (Thapa & Chapman, 2010), the study area is densely populated with a majority of indigenous Tharu (Studsrod & Wegge, 1995). Subsistence farming and livestock keeping are the main economic activities (Thapa Karki, 2013; Gross et al. subm.), resulting in a rural per capita income of 56.0 USD per month in the Bardiya district (UNDP, 2014b). The national park holds a high density of herbivores, including the largest number of resident elephants (*Elephas maximus*) in Nepal and a small population of re-introduced greater one-horned rhinos (*Rhinoceros unicornis*) (Flagstad, Pradhan, Kvernstuen, & Wegge, 2012; Wegge, Odden, Pokharel, & Storaas, 2009).

Manas/India (MA): this study area includes the southern belt of private agricultural and community lands bordering the Manas National Park (MNP) of Assam, encompassing156 villages (Fig. 1d). With approximately 1280 people/km^2, the study area is heavily populated. The ethnical composition is diverse with 35.7% of indigenous Bodo people (Sarma et al., 2015) making their living from paddy (*Oryza sativa*) cultivation and the sale of crops from homestead gardens (Gross et al. subm.). In contrast to the rest of India, the economic situation of North-East India is more difficult with the rural per capita income of the Baksa district south of MNP estimated to be 25.23 USD per month (UNDP, 2014a). MNP is home to a wide range of fauna including the Asian elephant (Borah et al., 2013). The greater one-horned rhino has also been re-introduced since 2008 (Lahkar, Talukdar, & Sarma, 2011; Sarma, Talukdar, Sarma, & Barua, 2009).

2.2. Data collection

The data collection on crop damage was conducted within a broad study on human-wildlife conflicts which also included property damage, livestock predation and human accidents with wildlife. Therefore, observations of the damage sites by locally trained independent enumerators (HWC officers), as well as structured interviews with victims, were conducted using the Awely HWC assessment scheme during six consecutive years from 2009 to 2014, as described in Gross et al. (2018). Wildlife species causing damage were identified via tracks, dung and bite marks. Costs of damage were estimated by measuring damaged proportions and calculating the potentially achievable revenues in local currency, taking into consideration the crop value based on annual market prices and quality. Furthermore, the degree of damage was ranked into six categories (just a bit; less than half; half; more than half; almost everything; everything), in relation to the total farmland utilised by the victim. Proximity to the next natural refuge, water point and village was recorded. Demographic data of crop owners/victims were gathered from interviews and were categorised. Information on the exact crop protection measures used against wildlife crop damage during a particular incident was collected through

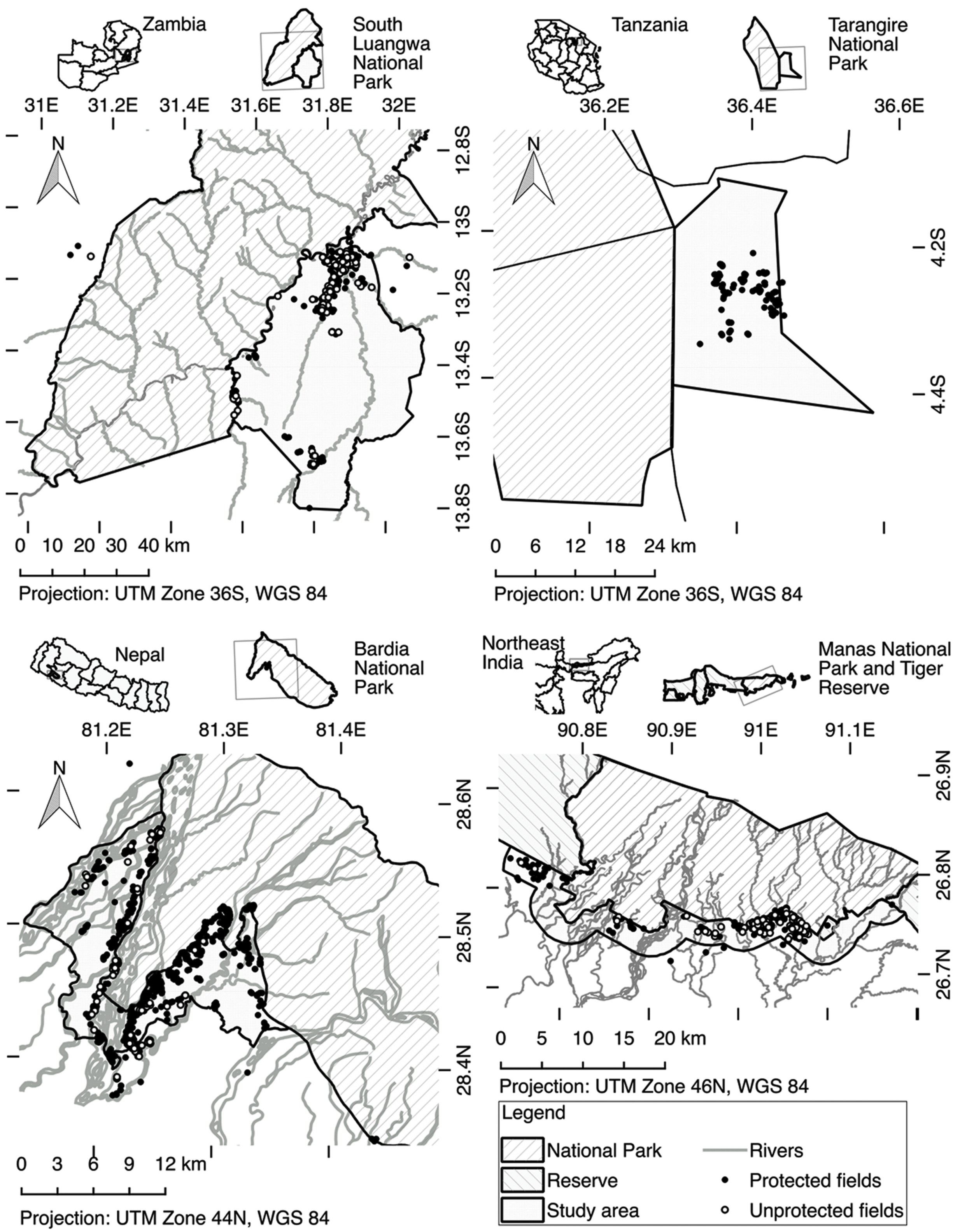

Fig. 1. Distribution of damaged crop fields in the study areas a) SL, b) TA, c) BA, and d) MA. Fields protected by guarding and/or with barriers are indicated as black dots, fields without any protection are indicated as white dots. Permanent water bodies (rivers) are indicated as grey lines. Few crop damage events located outside of the exact study area were included in the study. Author: Eva Klebelsberg.

interviews and field verification. Unprotected fields experiencing crop damage were used as controls. Protected and unprotected fields damaged by wildlife were mapped using the Quantum GIS Geographic Information System, Version 2.14.3 Essen (QGIS Development Team, 2016).

2.3. Data analysis

All costs of damage were converted from the local currency into USD, using the exchange rate on the 30th of June of each year (XE Currency Converter, 2017). The total of 20 species was pooled into

Table 1
Frequencies of small (< 40%) and large (> 40%) crop damage incidents per study area caused by different species groups from 2009 to 2014. Percentages of all incidents per study area are indicated in brackets.

Herbivore category	SL		TA*		BA		MA	
	damages < 40%	damages > 40%	damages < 40%	damages > 40%	damages < 40%	damages > 40%	damages < 40%	damages > 40%
elephants[1]	661 (67.7)	208 (21.3)	4 (3.9)	2 (2.0)	899 (53.4)	227 (13.5)	329 (86.6)	41 (10.8)
other large herbivores[2]	33 (3.4)	6 (0.6)	38 (37.3)	18 (17.6)	172 (10.6)	71 (4.2)	6 (1.6)	0
small herbivores[3]	67 (6.9)	2 (0.2)	40 (39.2)	0	269 (16.0)	44 (2.6)	4 (1.1)	0
total	761 (77.9)	216 (22.1)	82 (80.4)	20 (19.6)	1340 (79.7)	342 (20.3)	339 (89.2)	41 (10.8)

[1] SL and TA *Loxodonta africana*, BA and MA *Elephas maximus*.

[2] SL: hippo (*Hippopotamus amphibius)* and African buffalo (*Syncerus caffer*), TA: African buffalo, Burchell's zebra (*Equus quagga burchellii*) and common eland (*Taurotragus oryx*), BA: greater one-horned rhino (*Rhinoceros unicornis*), and blue bull (*Boselaphus tragocamelus*), MA: greater one-horned rhino and wild water buffalo (*Bubalus arnee*).

[3] SL: bushpig (*Potamochoerus larvatus*), vervet monkey (*Chlorocebus pygerythrus*), baboon (*Papio cenocephalus*), and cape porcupine (*Hystrix africaeaustralis*), TA: bushpig and warthog (*Phacochoerus africanus*), impala (*Aepyceros melampus*), vervet monkey, and crested porcupine *(Hystrix cristata),* BA: wild boar (*Sus scrofa*), spotted deer (*Axis axis*), common langur (*Semnopithecus entellus*), and Indian porcupine (*Hystrix indica*), MA: wild boar.

* Damage numbers for TA refer to the years 2010 and 2011 only.

three weight categories (Table 1): elephants (> 2500 kg), other large herbivores (150–2500 kg; rhino, hippo, buffalo, zebra and large antelopes) and small herbivores (< 150 kg; small antelopes/deer, boars/hogs, primates and porcupine).

The protection measures taken by farmers were categorized into active guarding (people being present in the field with the aim of guarding the fields), passive guarding (people sleeping in nearby dwellings and rushing out to scare away wildlife when alarmed) and barriers (electric, wire, natural fences or trenches). Active guarding in SL, TA and BA was traditionally conducted by each farming family on their own fields and wildlife was chased away to the bush or other fields, after it had entered the guarded field. In MA active guarding was conducted in a strategic community-based approach, whereby the boundary between a large farming block and the national park was guarded and detected wildlife species were pushed back into the forest jointly by farmers.

Active or passive guarding combined with a barrier were defined as separate categories. Fields without any crop protection measures (no protection) were regarded as controls. Statistics were calculated with R version 3.2.5 (R Core Team, 2016).

The costs of damage were analysed using linear mixed effect models (with R-package *lme4*; Bates, Machler, Bolker, & Walker, 2015). To ensure normally distributed residuals, the response variable "cost of damage" had to be log-transformed for all following analysis. For each study area, a separate model was calculated and simplified according to backwards model selection using the likelihood ratio test (model selection results SOM 01). For the final model, least-squares means (with R-package *lsmeans*; Lenth, 2016) were used to conduct pairwise comparisons between species groups and protection strategies, respectively (using tukey-adjustment of p-values). The difference in the costs of damage between the three groups of species in each of the four study areas was analysed using the species group, season and their interaction terms as fixed, with the protection strategy, crop type and year as crossed random variables.

The influence of protection strategies and the three groups of wildlife species on the costs of damage in each of the four study areas were calculated using species group, protection strategy and their interaction terms as fixed, whilst the crop type and year were used as crossed random variables. For this analysis, we restricted the data set to damage events in the rainy (RS) and intermediate seasons (IS) and excluded the costs of damage events in the dry season. Farming and guarding practices of the RS and IS can be assumed as being similar; staple crops farming generally starts in the RS and is finalised in the IS (Gross et al., 2018). Dry season farming may differ in terms of guarding strategies, but for small and other large herbivores only low numbers of damage events were available.

As data were exclusively collected from fields experiencing crop damage, we were not able to include data from fields that were not visited by wildlife species and, therefore, created no cost of damage.

3. Results

For this study, data on 5366 damage incidents from four study areas (SL, TA, BA, MA) were collected and analysed.

3.1. Characteristics of crop damage

In all four study areas the majority of the crop owners with damaged crops were men (SL: 77.7%, TA: 72.9%, BA: 90.6%, MA: 96.1%), mostly aged 36 to 50 years. The main source of their income was agriculture (SL: 81.1%, TA: 98.1%, BA: 97.5%, MA: 90.5%), whilst only small proportions of the crop raiding victims made their main living from other sources of income including livestock-keeping, wage earning, trade or craft. On average, six to seven family members were dependent on the damaged crops (SL: 6.2 ± 3.9, TA: 6.8 ± 5.0, BA: 7.9 ± 5.1, MA: 6.3 ± 4.0). In the two African study areas, farmers had been farming on their land for an average of 6.8 ± 7.2 years (SL) and 5.0 ± 4.0 years (TA), respectively. In the two Asian study areas, however, farmers had been cultivating their fields for much longer, in BA for 29.3 ± 21.2 years and in MA for 31.4 ± 3.5 years. The majority of victims explained that they had experienced crop damage more than once a year (SL: 82.7%, TA: 55.7%, BA: 72.2%, MA: 75.8%) with an average of three to four damage events per year (SL: 3.53 ± 2.39, TA: 4.36 ± 1.15, BA: 3.49 ± 5.66, MA: 3.67 ± 4.64).

3.2. Severity of crop damage

In relation to the total field sizes the affected farmers had under cultivation, the majority of crop damage through wildlife affected up to 40% (Table 1). In SL, the proportions of large crop damage (> 40% of total field size) were highest with 22.1%, followed by BA (20.2%) and TA (18.9%), whilst MA showed the lowest proportion of such extensive damage (10.8%). Most of the large crop damage incidents (> 40% of total field size) were due to elephants in SL, BA and MA and due to other large herbivores (mainly zebra) in TA. Small herbivores, such as primates, small antelopes/deer and hogs/boars, caused more damage

Table 2
Total number of farmers with fields damaged by wildlife in four different study areas from 2009 to 2014, in addition to mean and standard deviation of losses per farmer per damage incident in USD.

Parameters	SL	TA*	BA	MA
Number of farmers with damaged fields	2760	107	1689	810
Total costs of damage 2009 to 2014 [USD]	90,338.98	9,055.03	46,413.60	8,358.17
Mean ± sd of cost of damage per incident per farmer [USD]	32.73 ± 49.89	84.63 ± 119,72	27.48 ± 29.06	10.32 ± 39.25
Median cost of damage per incident per farmer [USD]	19.32	47.51	19.22	4.21

* 2010/2011.

below 40% in all four study areas. The majority of crop damage below 40%, nevertheless, was caused by elephants (SL, BA and MA) and zebra (in TA).

3.3. Costs of crop damage

The costs of damage caused by wildlife to farmers through feeding on their fields or trampling crops varied considerably (Table 2), with minimum costs ranging from SL: 0.39, TA: 3.72, BA: 0.4 and MA: 0.06 USD to maximum costs up to SL: 952.38, TA: 930.53, BA: 557.66 and MA: 1008.97 USD. However, the distribution of costs is skewed towards lower values.

The mean costs of crop damage varied between the different species categories (Fig. 2). In SL, elephants caused significantly higher damages than other large (mainly hippo) and small herbivores (mainly bush pig and porcupine). In TA, large herbivores (mainly zebra and common eland) caused significantly higher damage costs than small herbivores (mainly bushpig, warthog and impala). Mean costs of damage due to elephants, however, did not differ statistically, neither from large nor small herbivores. In BA, no significant difference for the costs of crop damage caused by the three species groups throughout the year was observed. However, seasonal differences do exist; in the rainy season, significantly lower costs of damage resulted from elephants compared to small herbivores, whereas in the intermediate season, significantly larger costs were observed for other large (mainly rhino) compared to small herbivores (mainly wild boar and spotted deer). In MA, no variable showed any statistical difference regarding the crop damage costs caused by the three species groups (as the “species group” as well as the “season” were not included in the final model).

3.4. Influence of crop protection measures on costs of damage

On the majority of damaged fields crop protection measures were used (SL: 69.5%, TA: 100%, BA: 93.8%, MA: 52.7%). In SL, BA and MA protected as well as unprotected fields were found to be distributed all over the study area, in TA, however, only protected fields were present (Fig. 1). Protection measures were grouped into seven categories (see Appendix A, Table A1). Active and passive guarding were the most frequently used strategies in all four study areas. In TA and BA barriers were also used frequently, either as a single measure (BA) or in combination with active (TA, BA) or passive guarding (BA). Barriers used in BA were generally two-strand electric fences (4–5 kV) located along the boundary of the forest, while in TA barriers consisted of thorny bushes around the fields. In MA, active guarding has been carried out as a community based guarding system, strategically protecting a large farming block, whereas in SL, TA and BA, active guarding was carried out by single or small groups of farmers guarding single plots of land. The costs of crop damage on fields with different protection categories varied between the study areas as well as between species categories (Fig. 3).

In SL no significant difference in the costs of crop damage by elephants or small herbivores were observed between any of the crop

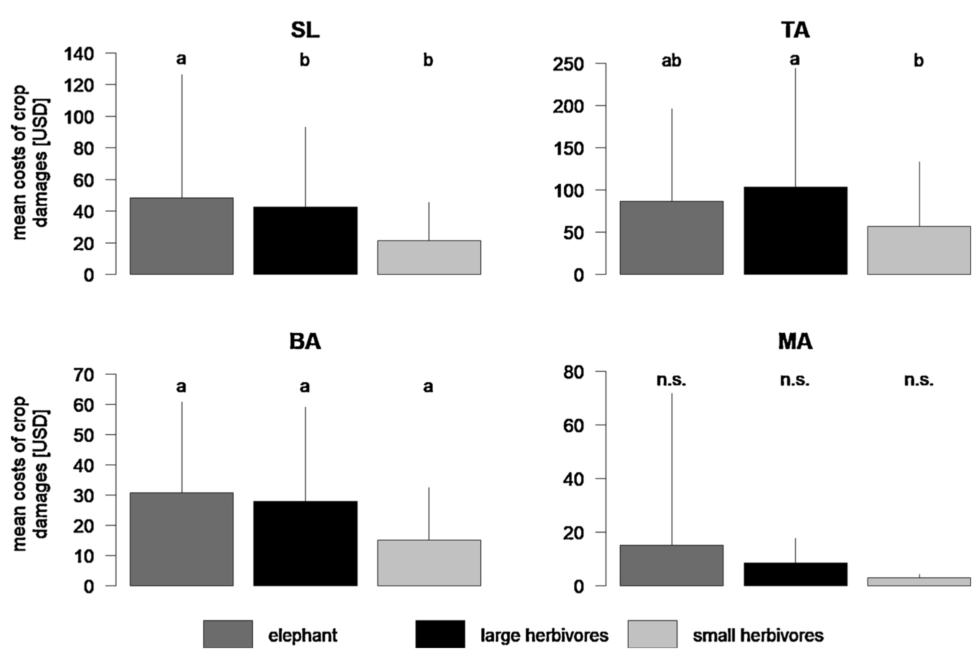

Fig. 2. Mean costs of crop damage by species groups per study site [USD] from 2009 to 2014 (TA 2010/2011). Different lower case letters indicate significant differences ($p < 0.05$) between species groups. Whiskers indicate the standard deviation over the six study years.

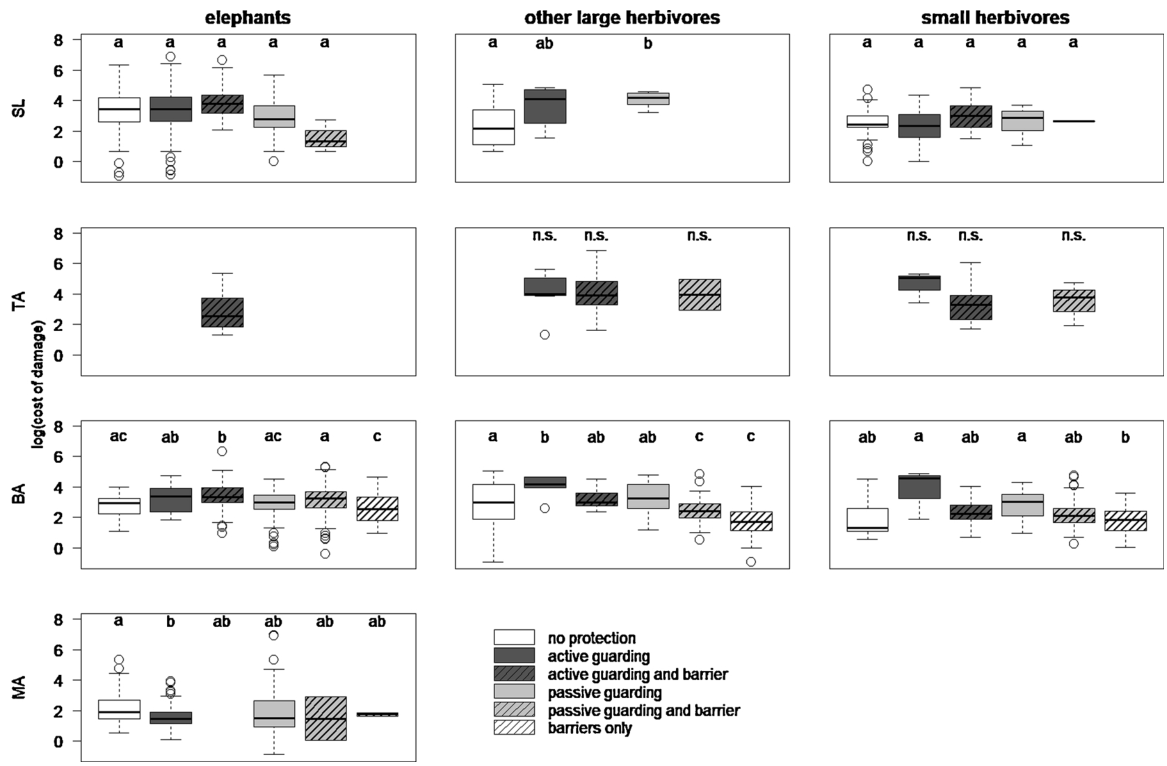

Fig. 3. Mean costs of crop damage [USD] caused by three different wildlife species groups in four different study areas on fields with different protection strategies from 2009 to 2014 (TA 2010/2011). Different lower case letters indicate significant differences ($p < 0.05$) between protection strategies. Error bars indicate standard deviation over the six study years, circles indicate outliers.

protection categories, including non-protected fields (Fig. 2). Only large herbivores caused significantly higher costs of crop damage on fields which were passively guarded compared to non-protected fields ($p = 0.0043$). In TA (Fig. 3b), no significant cost reduction between the protection measures was observed for any of the species groups (during model selection, neither the variable *mitigation* nor its interaction was found to be significantly affecting the *cost of damage*).

In BA, elephants caused significantly higher costs of damage on fields protected by active guarding + barrier compared to non-protected fields ($p = 0.0009$) (Fig. 3). For all other crop protection strategies, no significant difference in costs from crop damage by elephants was observed compared to unprotected fields. Furthermore, on fields protected by active guarding, active guarding + barrier, as well as passive guarding + barrier, significantly higher crop damage costs by elephants were observed than with barriers alone ($p = 0.004$; $p < 0.001$ and $p = 0.004$, respectively). Additionally, active guarding + barrier produced higher costs of damage than passive guarding + barrier ($p = 0.003$), whilst active guarding + barrier caused higher costs than passive guarding alone ($p = 0.001$). For the group of large herbivores in BA costs of crop damage on fields protected by passive guarding + barriers as well as barriers alone were significantly lower than on non-protected fields ($p = 0.045$ and $p < 0.001$) and all other protection categories ($p < 0.05$). However, costs of crop damage on fields protected by active guarding were significantly higher than on non-protected fields ($p = 0.015$). Costs of crop damage by small herbivores were significantly lower in BA on fields with barriers compared to active ($p = 0.010$) or passive guarding ($p = 0.006$).

In MA (Fig. 3d) actively guarded fields were the only fields on which the costs of crop damage by elephants were significantly lower than on non-protected fields ($p = 0.007$). Between all other protection categories, no significant differences in costs through crop damage were observed compared to non-protected fields, or between different crop protection categories.

4. Discussion

4.1. Socio-economic dimension of crop damage

Since the beginning of farming, the protection of crops against pests has been a major issue for farmers all over the world (Dehne & Schönbeck, 2012; Zadoks, 2013). It is estimated that today, farmers in South Asia and Southern Africa lose on average 40% (in Eastern Africa this is 50%) to weeds, pathogens and pests before the harvest (Oerke, 2006). Although the majority of crop losses due to wildlife in this study were found to be below 40%, it has to be taken into account that the crop losses due to weeds, insects, rodents, viruses and other pathogens, were not included and will additionally affect the crops not consumed by wildlife. With a very low per capita income (UNDP, 2014a, 2014b, 2015, 2016) and the high dependency on agriculture, farmers of the four study areas do not have the means to attenuate crop losses. In the two African study areas, the mean loss caused by a single crop damaged by wildlife exceeds the monthly rural per capita income of a farmer. In the Asian study areas, the mean loss per damage is about half of the monthly rural per capita income. Losing a monthly or half monthly income is a heavy drawback for any farmer, especially for those living in poverty. Although India and Zambia today are classified as low-middle income countries (World Bank Group, 2017), both are characterised by a strong inequality of income generation by the states (Directorate of Economics & Statistics, 2014) or regions (UNDP, 2016). Assam's economic situation differs greatly from southern India's, especially in the rural parts of the study area where per capita income is low (UNDP, 2014a). The economy of the Eastern Province in Zambia is even ranked as low income (UNDP, 2016). The vulnerability of farmers in MA and SL are, therefore, comparable to BA or TA. Although large crop losses with a damage of over 40% appear proportionally less frequently in all study areas (10% to 20%), they should not be underestimated. Such incidents may have life threatening consequences with catastrophic effects (Thirgood et al., 2005).

4.2. Effectiveness of crop protection

An increase in local guarding practices is meant to reduce the number and severity of crop damage by wildlife species (Hoare, 2001; Linkie, Dinata, Nofrianto, & Leader-Williams, 2007). In Kenya, the guarding effort combined with active deterrents, such as lighting fires and banging tin drums, decreased the likelihood of farms being damaged (Sitati, Walpole, & Leader-Williams, 2005). In Nepal, guarding on watchtowers and the use of scaring devices, flaming sticks and noise was regarded as effective by farmers against elephants, whilst barriers (net wires, trenches) were regarded as useful against deer and wild boars (Thapa, 2010) and, in Namibia, elephants were deterred by electric fences (O'Connell-Rodwell, Rodwell, Rice, & Hart, 2000). Although protecting crops against wildlife was an important activity for the majority of farmers of the damaged farms in our study areas, the traditional methods of guarding actively or passively did not reduce the costs of crop damage. Also, in Kenya a study on the effectiveness of farm based crop protection measures against elephants showed no difference between the treatment and control (Graham & Ochieng, 2008). In contrast, in SL, the costs of crop damage during passive guarding exceeded the costs of crop damage on non-protected fields caused by large herbivores (mainly hippo). One reason may be that hippos, when being chased by people, rage through the fields causing even more damage through trampling than what they would have caused if left alone. A similar effect was observed in BA for elephants, as well as for large and small herbivores. Only for large herbivores in BA was a significant cost reduction of crop damage observed in the presence of a barrier and passive guarding plus barrier. The main difference of the study site BA, when compared to the other sites, was the presence of an electrical fence along the forest boundary in large parts of the study area. This fence was installed mainly to limit the movements of wildlife, especially of the large wildlife species between the national park and the buffer zone (WTLCP, 2011). It has to be emphasised that we were not able to collect data on how often the wildlife attempted to challenge the fence and had been repelled successfully. However, the massive number of crop damage caused despite the presence of a fence (1267 crop damage incidents), puts the success of this measure into question. Once a wildlife species is able to break through a fence, its repellent effect is overcome (Watve, Bayani, & Ghosh, 2016), this is especially the case for elephants which manage to overcome electric fences by damaging them in multiple ways (Kioko, Muruthi, Omondi, & Chiyo, 2008; Thouless & Sakwa, 1995). Furthermore, low maintenance as well as the lack of resources for repair may reduce the voltage to zero, turning an electrical fence into a simple wire fence. The main cause for low maintenance of electrical fences is seen in missing out on participatory community involvement and integration of the farming community in the process of fence construction. This leads to low acceptance and support of such large donor or government funded investments, which tend to fail in the long-term.

If wildlife has managed to enter a crop field through the fence and is then chased by farmers, the way back to the natural refuge is cut off and more damage may be caused through trampling during the search for an exit through the fence (Durant et al., 2015). In addition, human noise, as a less directional deterrent method, could be disorienting to elephants or even cause panic (Davies et al., 2011). Such a scenario could, at least, partly explain the reason for significantly increased costs of crop damage by elephants and large herbivores (mainly rhino) in areas guarded actively in the presence of fences.

The only positive effect by a guarding system was determined in MA, where the significant reduction in the costs of crop damage by elephants was observed compared to damage on unprotected fields. In contrast to the other study areas farmers in MA had set up a community-based guarding system, applying a strategic way of guarding along the national park boundary, protecting a large farming area with paddy fields belonging to over one hundred community members. Periodically, every 50 m, a watchtower was constructed on an earth mound surrounded by a deep trench (Fulconis, Drouet-Hoguet, & Gross, 2014). Farmers formed guarding teams, taking turns in guarding. The moment one team spotted wildlife approaching the farming block, the neighbouring guarding farmers were alarmed with shouts and noise. Guards then moved from the watchtowers towards the animal, using fire torches and producing noise to chase it back into its natural habitat. Strategic guarding by a community of farmers, aimed at detecting wildlife before it enters the fields, seems to be the key in crop protection against elephants (Sitati & Walpole, 2006; Sitati et al., 2005). Through such strategies, labour can be reduced for the individual as the communal system allows protecting a larger agricultural area on which crop damage by elephants may decline (Graham, Notter, Adams, Lee, & Ochieng, 2010; Nyirenda, Myburgh, & Reilly, 2012).

Another strategy to decrease crop damage by elephants which should be investigated in future studies, is on the choice of crops which are less attractive to elephants than staple crops. Given the marketability, the specific plantation of crops containing so called antifeedants (Gross, McRobb, & Gross, 2016) bears the potential for a safe income generation in areas prone to crop damage by elephants (Gross, Drouet-Hoguet, Subedi, & Gross, 2017).

This study focussed on evaluating crop damage only. In cases where no wildlife damage occurred on the fields, e.g. due to successful crop protection measures, these cases were not registered in the survey. For this reason, conclusions can only be drawn for situations during which wildlife managed to enter fields, but not on the preventive effect of the guarding techniques. Due to the large number of crop damage which occurred despite protection measures being taken, such an analysis, nevertheless, bears important information for conservation and farmers' practices. We strongly propose thorough long-term evaluation on the total effectiveness of crop protection measures against various wildlife species, especially of those measures implemented by third parties such as governmental and non-governmental conservation agencies.

5. Conclusions

Despite the application of labour and cost-intensive guarding systems by farmers, the loss of crops to herbivorous wildlife species is considerable in all four study areas. Contradictory to our expectations, higher efforts in protection through the human presence on fields and by actively scaring wildlife species, overall, did not lead to the reduction of crop damage costs when applied without a strategy. Based on our results, only the strategic communal guarding of larger farming blocks bears the potential to significantly reduce crop damage. Therefore, we emphasise the need to re-think the non-strategic, small scale guarding practices and emphasise the need for preventive and collaborative community-led approaches. Strategic guarding implies detecting wildlife before it enters the fields and chasing it back into its refuge habitat. The aggregation of cultivated areas protected by a well-developed strategic communal guarding system, combined with areas leaving natural refuges for wildlife to use undisturbed, could lead to a less conflict-laden land-use concept for people and wildlife. We further emphasise the need for more in-depth studies on the total effectiveness of HWC mitigation strategies, particularly electric fences, as well as on the potentially negative consequences when combining different measures.

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Appendix A

Table A1

Number and proportions of damaged fields with different crop protection types per study areas from 2009 to 2014.

Crop protection type	SL	TA*	BA	MA
no protection	291 (30.5%)	0	104 (6.3%)	114 (47.3%)
active guarding[1]	257 (27.0%)	11 (10.4%)	45 (2.7%)	108 (44.8%)
active guarding and barrier[2]	53 (5.6%)	90 84.9%)	270 (16.1%)	0
passive guarding[3]	329 (34.5%)	0	255 (15.2%)	14 (5.8%)
passive guarding and barrier[4]	5 (0.5%)	5 (4.7%)	835 (49.9%)	2 (0.8%)
barriers only[5]	0	0	162 (9.7%)	2 (0.8%)
other[6]	18 (1.9%)	0	2 (0.1%)	1 (0.4%)
TOTAL	953	106	1673	241

[1] Farmers/guards spending the night out in their fields with the intention to chase away approaching wildlife. In MA only active guarding represents a strategic community based guarding approach.

[2] Active guarding plus the presence of an electrical or non-electrical fence.

[3] Farmers sleeping in dwellings, rushing out when being alarmed.

[4] Passive guarding plus the presence of an electrical or non-electrical fence.

[5] Electrical or non-electrical fence.

[6] Mainly scare crows, excluded from analysis due to low case numbers.

* Data refers to the years 2010 and 2011.

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