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Factors affecting susceptibility of farms to crop raiding by African elephants: using a predictive model to mitigate conflict

N. W. SITATI, M. J. WALPOLE and N. LEADER-WILLIAMS
Durrell Institute of Conservation and Ecology, University of Kent, Canterbury, Kent CT2 7NS, UK

Summary

1. Crop raiding by African elephants *Loxodonta africana* erodes local tolerance for elephants and thereby impedes conservation efforts, so solutions are urgently required. Within conflict zones, crop raiding is not distributed equally amongst farms, which may be a result of variation in local physical or geographical factors, or in farmers' efforts to defend their fields. Understanding the efficacy of local conflict mitigation methods is important, but few quantitative evaluations exist.

2. Using a comparative survey of raided and non-raided farms in Transmara District, Kenya, and multivariate logistic and linear regression analyses, we explored a range of factors affecting (i) the susceptibility of farms to elephant crop raiding and (ii) the amount of crop damage once elephants had entered a field.

3. The results revealed that farms that had been habitually raided in the past were more likely to be raided during the study period, as were those that were larger and bordered by hedges or fences. Greater guarding effort increased the likelihood that elephants were detected prior to entry and decreased the likelihood of successful crop raiding, as did the use of fire and noise.

4. However, there was an interaction between physical and human factors; larger farms used more advanced barrier methods at the expense of guarding effort. Farmers' efforts did not appear to diminish the damage inflicted once elephants had entered a field.

5. A subsequent experimental test confirmed these results; the application of enhanced early warning and guarding effort on previously raided farms reduced incidents of crop raiding by 89·6% over 2 years in comparison with a control group of farms.

6. *Synthesis and applications*. These results suggest that early detection of elephants approaching fields, increased guarding effort, and the use of active deterrents could form the basis of an effective mitigation strategy regardless of location and the physical attributes of a farm. Validating the results of predictive models through participatory mitigation trials serves to demonstrate effective solutions to farmers themselves. Researchers and practitioners should be encouraged to replicate such field trials over broader spatial and temporal scales and to find means to encourage farmers to take up appropriate solutions.

Key-words: African elephant, crop damage, deterrence, guarding effort, Kenya

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Introduction

Much of the current biodiversity crisis arises as a result of increasing competition with humanity for space and resources (Pimm *et al*. 1995; Balmford *et al*. 2001). As a result, and as protected areas become isolated islands of natural habitat in a sea of human settlement, human–wildlife conflict is affecting more and more species, particularly the large mammals (Naughton-Treves 1998). Where such species have negative impacts on people's livelihoods, local support for conservation is eroded (de Boer & Baquete 1998; Hill 1998) and large mammals are at higher risk of extinction (Woodroffe & Ginsberg 1998; Woodroffe, Thirgood & Rabinowitz 2005). Thus, mitigating

Present address and correspondence: M. J. Walpole, Fauna and Flora International, Great Eastern House, Tenison Road, Cambridge CB1 2TT, UK (fax +44 1223461481; e-mail matt.walpole@fauna-flora.org).

human–wildlife conflict is critical to the success of conservation efforts for many charismatic flagship species.

The African elephant *Loxodonta africana* Blumenbach is no exception, and human–elephant conflict has become increasingly significant as human populations expand and encroach on elephant habitat (Dublin, McShane & Newby 1997; Hoare & du Toit 1999; Hoare 1999a). The African Elephant Specialist Group (AfESG) of the World Conservation Union's Species Survival Commission (IUCN/SSC) has given a high priority to human–elephant conflict and recognizes it as one of the most pressing threats to the future of the African elephant (Hoare 2000).

One of the major forms of human–elephant conflict is agricultural crop raiding. Although not the most common crop pest, elephants may cause considerably more damage per conflict incident than other species (Naughton-Treves 1998). Moreover, elephants are more dangerous than other herbivore species, resulting in more human deaths and injuries (Sitati 2003). For these reasons elephants are generally less tolerated than other crop-raiding species (Naughton-Treves, Treves & Rose 2000). As approximately 80% of the African elephant's range lies outside protected areas (Blanc *et al*. 2003), it is vital to find ways to reduce crop losses, thereby improving food security and maintaining the tolerance of rural communities to elephants.

Research into human–elephant conflict has revealed landscape-level predictors of susceptibility (Osborn & Parker 2003a; Sitati *et al*. 2003) yet within areas of high susceptibility crop raiding is not distributed evenly amongst farms. Despite this, there have been few if any assessments of the predictability of human–elephant conflict at the farm level. Developing predictive models at the local as well as the landscape level is important for conflict mitigation (Malo, Suarez & Diez 2004). Studies of crop raiding by birds have been used to identify which characteristics of a farm make it more susceptible to damage (Somers & Morris 2002). For example, smaller rice fields with hedges were less likely to be visited by flamingos, and so growing hedges was recommended to mitigate rice raiding (Tourenq *et al*. 2001). Equally, livestock predation by large carnivores can be predicted on the basis of physical characteristics of livestock enclosures and pastures, and the presence of human guarding (Stahl *et al*. 2002; Ogada *et al*. 2003).

In the case of crop-raiding elephants, a huge variety of relatively inexpensive, low-tech, non-fatal mitigation methods are in use by local farmers across Africa. These range from passive barrier methods such as ditches, fences, walls and hedges around fields, to active deterrent methods including shouting, banging tins and drums, throwing stones, lighting fires and burning chillies (Hoare 2001a; Osborn & Parker 2003b). The extent to which any of these influence elephant crop-raiding behaviour remains relatively untested. Such tests are vital, however, if the most effective combination of methods is to be identified Moreover, whilst predictive models of conflict and its mitigation have been developed for other species as described above, independent tests of their predictions and recommendations are rare.

This study provided an *in situ* assessment of factors that might influence susceptibility to elephant crop raiding by comparing raided and non-raided farms in a relatively high conflict area in Kenya, and then explicitly testing the findings in an experimental trial. We aimed to answer two questions. First, which physical characteristics of a farm and / or the mitigation methods deployed upon it influence the success or otherwise of elephant crop raiding? Secondly, would an experimental manipulation of these characteristics on susceptible farms reduce their susceptibility to crop raiding?

Methods

STUDY AREA

The study took place between 1999 and 2003 in Transmara District, Kenya. Transmara District lies in the south-west of Kenya on the border with Tanzania (0°50′–1°50′S, 34°35′–35°14′E) and encompasses the western portion of the world famous Masai Mara National Reserve (MMNR) (see Appendix S1). Transmara District covers an area of some 2900 km^2, of which approximately 2200 km^2 is unprotected, populated land separated from the protected, unpopulated MMNR by a steep escarpment. For a full description of the areas see Sitati *et al*. (2003).

There is a resident population of approximately 200–300 elephants living in human-occupied areas of Transmara District that is distinct from a larger population of 1000+ individuals living mostly within MMNR that only passes up the escarpment out of MMNR seasonally (Sitati 2003). The elephant range outside MMNR has been gradually reduced to its present central area of approximately 1000 km^2. As cultivation has increased, so too has crop raiding, which has become a perennial problem over the past 15–20 years. Although complaints are made to Kenya Wildlife Service, the national wildlife authority, regarding the problem (*c*. 45% of all reported human–wildlife conflict incidents in Transmara District between 1986 and 2000 involved elephants), little action is taken. A short-lived compensation scheme for losses to wildlife collapsed amid the usual problems of corruption, maladministration and problems of verification (Bell 1984; Hoare 1995, 2001a,b) and many farms have since been abandoned as unworkable (Sitati 2003). The remaining farmers have implemented a range of cheap, non-fatal mitigation methods to protect their farms. This offered an ideal opportunity to compare and contrast different mitigation methods *in situ* at the level of individual farms.

COMPARATIVE SURVEY OF RAIDED AND NON-RAIDED FARMS

To establish a reliable and independent conflict-reporting system, a team of 10 community members was selected

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and trained to enumerate crop-raiding incidents (Sitati *et al*. 2003). After community consultation, enumerators were selected from 10 different villages to offer widespread coverage within the elephant range where conflict was known to occur. Farmers from the surrounding area were encouraged to report elephant crop-raiding incidents to their local enumerator, who then visited farms to collect evidence to verify details of each incident. This circumvented the problem of over-exaggeration of reported conflict by farmers themselves (Siex & Struhsaker 1999).

From March 1999 to August 2000, all farms that reported incidences of crop raiding by elephants were visited by their local enumerator along with the principal investigator to ensure consistency and reliability of reporting. Details of each incident were recorded on a standard report form (Hoare 1999b). At each farm, verification of the damage was made, and the areas of both the field and the damaged area were estimated in square metres. Details of the mitigation methods employed by the farmers were also collected, and verified where possible. This included the number of field guards and the use of various active deterrents, such as lighting fires on the boundary of the property, shouting, using torches and banging tins and drums. Various other characteristics of each farm were recorded, including the date of establishment, the presence of barriers, such as dry brush hedges, wooden pole fences and barbed wire fences, and the number and location of houses (within or adjacent to fields, or located > 50 m from fields), as this affected whether guards remained outside throughout the night. The ethnicity and family size of each farmer were also recorded, along with whether the farm had been raided in previous seasons.

A comparative survey of non-raided farms was conducted between January and August 2000. In areas where crop raiding had taken place, farms that had been successfully defended on independent occasions were visited and details of their mitigation methods were collected. Although not strictly an experimental approach with random allocation of mitigation treatments, this approach represented a 'natural experiment' that enabled us to compare mitigation methods on raided and non-raided farms in a comparable manner to studies involving other species (Tourenq *et al*. 2001; Ogada *et al*. 2003).

STATISTICAL ANALYSES OF CORRELATES OF SUSCEPTIBILITY TO CROP RAIDING

Only data collected between January and August 2000, when non-raided farms were also surveyed, were included in the analyses. For the purposes of statistical analysis, we chose the elephant raid (successful or otherwise) on a particular farm as the independent unit of analysis. In general, each farm employed independent mitigation methods. However, because farms are spatially clustered (Sitati *et al*. 2003) it is likely that, once elephants attempted to raid one farm, nearby farmers were alerted and modified their behaviour accordingly. Equally, elephants may have altered their behaviour in response to the mitigation efforts of the first farm encountered, which may have affected their response to subsequent farms encountered. For this reason, farms in the same location during the same elephant raid cannot be considered independent. To control for this, only the first farm that was raided in any location on any one night was included in the analyses. Equally, if the same farm was raided more than once in the same season, these events could not be considered entirely independent and only the first raid was included in the analyses. Because of the relatively short duration of the comparative study, these situations were relatively rare.

Farms were coded as raided (1) or non-raided (0), as were many of the mitigation methods (0 = not used, 1 = used). Continuous variables, for example area of crop damage, were $\log_{10}$ transformed to approximate better to a normal distribution. A measure of guarding effort ($\log_{10}$ guards ha^{-1}) was calculated by dividing the number of guards by the area of the farm. The data were screened for collinearity and outliers prior to analysis.

The relationship between underlying factors and whether farms were raided was examined individually using chi-squared tests for binary variables and *t*-tests for continuous variables, and in combination using multiple stepwise logistic regression (Freeman 1987). Logistic regression identifies significant variables affecting the log odds-ratio in binary variables such as presence/absence. It is the most common technique for such analyses and compares well against other methods (Manel *et al*. 1999; Tourenq *et al*. 2001). Entry and exit of variables were specified by the Wald statistic with probabilities of 0·05 and 0·1, respectively. The goodness-of-fit of the model to the observed data was assessed by calculating the area under the curve (AUC) of receiver operating characteristics (ROC) plots (Pearce & Ferrier 2000; Osborne, Alonso & Bryant 2001). AUC values range from 0·5 to 1·0. Values above 0·7 indicate an accurate fit to the data while those above 0·9 indicate a highly accurate model (Swets 1988).

A second set of analyses explored whether any features of a farm or its defences affected the magnitude of damage once raiding took place. The effects of each variable on crop damage during crop raiding were analysed independently using *t*-tests and Pearson's correlation coefficient (r_p), and in combination using multiple stepwise linear regression (Tabachnick & Fidell 1989). Two measures of crop damage were used. First, the area of damaged crops and, secondly, the proportion of the area of each farm that was destroyed. These measures reflected actual and relative loss, respectively. These variables were $\log_{10}$ and square-root transformed, respectively, prior to analysis to approximate better to a normal distribution.

AN EXPERIMENTAL TEST OF MITIGATION MEASURES

To test the model of susceptibility to crop raiding, and to distinguish between the effects of the physical features of a farm and human effort, a subsequent experimental test was conducted from September 2001 until October 2003. Two farming areas with a history of significant crop raiding were chosen, in close proximity to each other, and nearby to the village of Lolgorien. In one area, human efforts were manipulated to reduce the likelihood of susceptibility, whilst in the other no interventions were made. Monitoring of crop raiding by enumerators continued throughout this period, enabling a time series comparison, before and after the implementation of mitigation methods, between treatment and control farms. Comparison of crop raiding incidences was made between two equivalent 17-month periods before and after trial implementation began (April 1999–August 2000 and April 2002–August 2003). These were the longest continuous, comparable periods available in the data, and each included three crop-raiding 'seasons'.

Results

CHARACTERISTICS OF ELEPHANT CROP RAIDING

A total of 224 farms was raided by elephants during the initial study period (1999–2000) and a further 157 non-raided farms were visited for comparison. All 224 recorded crop-raiding incidents occurred during the hours of darkness from 19:00 to 05:00 h. Crop-raiding elephant groups ranged in size from 1 to 40 individuals (median 6), with 80% in groups of ≤ 10 animals that were principally female-led family groups (Sitati *et al*. 2003).

Elephants destroyed a variety of crops, although principally maize *Zea mays* L. In total, 267 ha were recorded as damaged during the study period. The mean amount of damage was 1·17 ± 0·096 ha incident^{-1}. The median proportion of damage per farm was 37·5%. A quarter of raided farms suffered less than 10·0% damage while a quarter suffered more than 66·7% damage.

CORRELATES OF ELEPHANT CROP RAIDING

The samples of raided and non-raided farms were similar in many respects. Both had a similar spatial distribution within the elephant range and a similar date of establishment (the median being 1995). All farms planted predominantly maize, which was the principal crop raided by elephants. The size and composition of farmers' families did not differ significantly between samples, but Maasai farmers were more likely to suffer crop raiding that non-Maasai farmers (χ^2 = 11·1, P < 0·001). Equally, farms that had been raided during the previous five seasons were more likely to be raided than those that had not (χ^2 = 14·9, P < 0·001).

Table 1. A logistic regression of the factors affecting the presence (coded 0) and absence (coded 1) of crop raiding in 341 farms. A negative coefficient (B) indicates reduced likelihood of raiding, whilst a positive coefficient indicates increased likelihood. Entry and exit of variables was specified by the Wald statistic with probabilities of 0·05 and 0·1, respectively (*P < 0·05, **P < 0·01, ***P < 0·001)

Factors	B	SE	Wald
Burning fires	−3·64	0·65	31·68***
Externally stationed guards	−1·79	0·36	24·98***
Log guarding effort	−1·47	0·41	12·95***
Banging tins and drums	−1·47	0·71	4·26*
Dry vegetation barrier	1·56	0·51	9·16**
Previously raided farm	1·75	0·52	11·54***
Barbed wire barrier	2·43	0·63	14·69***
Pole barrier	3·17	0·65	23·44***
Constant	3·38	1·05	10·34**

Greater guarding effort increased the chance of detecting elephants before they entered farms (t_{201} = −4·169, P < 0·001). Moreover, guarding effort was significantly higher on non-raided farms (t_{342} = 3·84, P < 0·001). Farms were less likely to be raided where fires were lit and where guards were stationed outside (χ^2 = 18·2, P < 0·001 and χ^2 = 22·5, P < 0·001, respectively). Conversely, farms with pole and wire barriers were more likely to be raided (χ^2 = 19·1, P < 0·001 and χ^2 = 7·1, P < 0·01, respectively).

The results of the multiple logistic regression suggested that greater guarding effort, combined with active deterrents such as lighting fires and banging tin drums, decreased the likelihood that farms would be raided (Table 1). Equally, farms where fields were located > 50 m from houses, so that guards were stationed outside, were less likely to be raided. Conversely, the use of dry brush, pole and wire barriers increased the likelihood that farms would be raided. Farms that had been raided in previous years were also more likely to be raided. Shouting and using torches did not appear to influence the model. The area under the curve of the ROC plot was 0·889 ± 0·018, indicating a very accurate model.

INTERACTIONS BETWEEN GUARDING, FENCING AND FARM SIZE

Guarding effort was strongly and negatively correlated with farm size, suggesting that larger farms tended to be less well guarded (r_p = −0·819, P < 0·001). As a result, raided farms tended to be not only less well guarded but also generally larger than non-raided farms (t_{381} = −7·93, P < 0·001; Fig. 1a,b). Furthermore, as farm size increased the composition of barriers changed from dry vegetation, through wooden pole fences, to barbed wire fences ($F_{2,325}$ = 16·5, P < 0·001). With each change in barrier composition, guarding effort declined ($F_{2,294}$ = 11·5, P < 0·001; Fig. 1c,d).

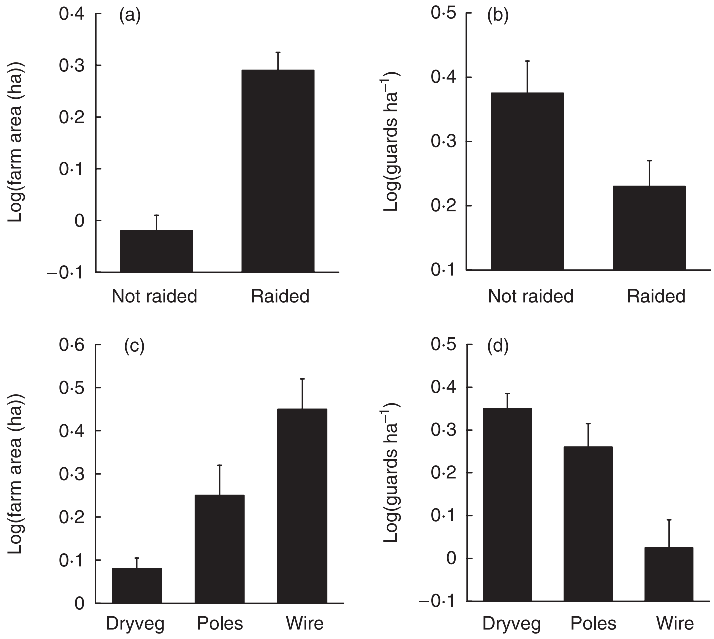

Fig. 1. The relationship between farm size, guarding effort and fencing (n = 381). Raided farms are (a) larger, and (b) less intensively guarded. Larger farms (c) use more 'improved' types of barrier [wooden pole (Poles) or barbed wire fences (Wire) as opposed to dry brush vegetation (Dryveg)] and, (d) as barriers improve, guarding effort declines.

Table 2. Multiple regression of the factors affecting the area of crop damage on raided farms (*P < 0·05, **P < 0·01, ***P < 0·001). A positive coefficient (B) indicates a positive association with the amount of damage

Factors	*B*	SE	*t*
Log farm size (ha)	0·594	0·078	7·61***
Banging tins and drums	0·851	0·114	7·50***
Burning fires	0·319	0·069	4·60***
Log elephant group size	0·492	0·110	4·47***
Shouting	0·578	0·169	3·42**
Pole barrier	0·176	0·069	2·54*
Shining torches	−0·345	0·124	−2·78*
Constant	1·90	0·183	10·38***

Table 3. Multiple regression of the factors affecting the proportion of crop damage on raided farms (*P < 0·05, **P < 0·01, ***P < 0·001, NS, not significant). A positive coefficient (B) indicates a positive association with the proportion of damage

Factors	*B*	SE	*t*
Banging tins and drums	4·29	0·625	6·97***
Log elephant group size	2·50	0·596	4·19***
Burning fires	1·65	0·375	4·40**
Shouting	3·01	0·916	3·28**
Pole barrier	0·87	0·376	2·32**
Shining torches	–1·97	0·673	–2·93**
Log farm size (ha)	–2·311	0·423	–5·47***
Constant	1·02	0·730	1·398 NS

DAMAGE LIMITATION DURING ELEPHANT RAIDS

The area of crops destroyed by elephants on each farm was positively correlated with elephant group size and farm size, and negatively correlated with guarding effort (r_p = 0·461, 0·611 and –0·462, respectively, P < 0·001). The proportion of damage was weakly and positively correlated with both elephant group size and guarding effort (r_p = 0·152 and 0·151, respectively, P < 0·05) but not with farm size (r_p = –0·111, P > 0·1).

A stepwise multiple regression suggested that, counter-intuitively, many active mitigation methods were positively correlated with the amount of crop damage ($F_{7,203}$ = 43·9, P < 0·001, r^2 = 0·620; Table 2). A similar but weaker model held for the proportion of damage to farms ($F_{5,205}$ = 15·3, P < 0·001, r^2 = 0·365; Table 3).

AN EXPERIMENTAL TEST OF MITIGATION METHODS

The comparative analysis suggested that larger, fenced, poorly guarded Maasai farms that had been habitually raided by elephants in the past were more susceptible to crop raiding. The two groups of farms chosen for the experimental test displayed these characteristics and had predicted probabilities of raiding of 75–96%. Both had suffered similar numbers of raids during 1999–2000 (14 vs. 16 for treatment vs. control, respectively). On the treatment farms, guarding effort was on average increased approximately 10-fold, by deploying a communal team of nine guards stationed overnight in two watchtowers and using powerful torches to scan the area for approaching elephants. After deployment, crop raiding on the group of treatment farms decreased by 93%, compared with 31% on the group of control farms (the latter being equivalent to that witnessed across the wider district during the same period). This represents a relative reduction in crop raiding of 89·6%.

Discussion

SUSCEPTIBILITY TO ELEPHANT CROP RAIDING

Farmers in Africa face real challenges in preventing elephants from entering their farms and limiting crop damage during successful raids. Elephant crop raiding is often localized but can be catastrophic where it does occur (Naughton-Treves 1998; Sam, Haziel & Barnes 2002), with many farms suffering habitual raiding. This is in part because of location and physical factors; patterns of landscape variability and the seasonal movement of elephants determine the location of human–elephant conflict zones (Osborn & Parker 2003a; Sitati *et al*. 2003), and farm-scale variation in physical attributes may also play a part in determining the likelihood of elephant incursions. This may be why, in our study, previously raided farms were more likely to be raided again. However, elephants respond to risk as well as opportunity (Sukumar & Gadgil 1988), and the evidence from this study suggests that increasing human effort can reduce crop raiding even where physical factors and geography render farms more susceptible. Of particular importance are (i) early detection of elephants prior to their entry into a farm, (ii) increased guarding effort and (iii) use of active deterrents such as fire.

Investment in human resources appeared to be a significant factor in preventing crop raiding. However, the high degree of collinearity between guarding effort and farm size in our data permit an alternative explanation, namely that elephants were raiding larger farms because of greater availability of crops, as opposed to lower guarding effort. Indeed, broader-scale spatial analyses suggest that crop raiding is more likely where the proportion of cultivated land is greater (Sitati *et al*. 2003). However, three pieces of evidence support our conclusion that guarding effort is an important element of mitigation. First, a higher density of guards per farm increased the likelihood that elephants were detected, enabling deterrents to be applied. Secondly, the importance of guards actively patrolling was highlighted in the comparative analysis. In farms where houses were close to fields, there was a greater temptation for those guarding fields to retreat inside during the night, thereby reducing vigilance and patrol effort. In other areas farmers spend the night in makeshift huts within fields to increase their chances of detecting elephants and responding rapidly, but this was not generally the case in Transmara until the second phase of this study when watchtowers were erected within or adjacent to fields. Finally, evidence from field trials conducted in the second phase of the study revealed that applying increased vigilance and guarding effort to habitually raided farms did result in elephants being repelled.

Active methods to scare away elephants, such as burning fires and banging tins and drums, increased farmers' ability to prevent raiding. Noise and light will deter elephants from entering a field but only if they are loud and bright. Less forceful methods, such as shouting or using battery-powered torches, appeared less successful. Our methodology did not capture information on the intensity of shouting, but if this were greater, and the elephants in question more naive to farmers' efforts to defend their crops, then more success might be likely. However, farmers in this study site and elsewhere complain that elephants become used to such hollow threats and no longer fear them, so that stronger deterrents are needed.

Passive barrier methods were largely ineffective, as elephants were easily able to break through them. Larger farms appeared to invest more heavily in 'improved' barrier methods comprising wooden post and barbed wire fences at the expense of guarding effort, which actually declined as farm size increased (Fig. 1). This was doubly bad for large farms, as weak guarding effort and barriers both increased the risk of crop raiding (Table 1). There are two possible explanations for this additive effect of barriers. Elephants may have associated the presence of such barriers with worthwhile rewards within, and therefore targeted farms with such barriers. More likely, however, is that farmers with such barriers, besides having fewer guards overall, were more complacent about actively guarding fields and so did not detect elephants soon enough to prevent them entering fields.

Barriers are popular with communities because they may be of use against smaller crop pests such as zebra *Equus burchelli* Gray, and with donors because they represent a tangible and potentially long-term capital expense. Barriers alone are most effective if they are electrified and totally enclose an area of cultivation (O'Connell-Rodwell *et al*. 2000). They do, however, require significant resources for recurrent maintenance. For most farmers, therefore, investment in guarding is likely to be a better option.

Once elephants were within a field, there was little that could be done to reduce the damage caused. Both the proportional and actual amount of damage per incident were relatively high in Transmara compared with other sites with equivalent data elsewhere in Africa, such as Kibale, Uganda and the Red Volta area of Ghana (Naughton-Treves 1998; Sam, Haziel & Barnes 2002). This may be because elephants in Transmara do not forage from a protected area but exist in an unprotected farm–forest mosaic, and so may be more used to human presence and less easily displaced from fields. Counter-intuitively, the application of most active mitigation methods correlated with greater proportional and actual crop damage (Tables 2 and 3). This may be because such methods caused elephants to panic and thus damage more of the area of a field in their attempts to escape. Alternatively, it may be because such methods were deployed on some farms once elephants were already causing damage (Naughton-Treves 1998). This would confound any assessment of the effectiveness of guarding. Equally, it could be that the efforts farmers took to chase elephants out of their fields were not sufficiently strong to have an effect. Results from Zimbabwe, where guarding effort during crop raiding was experimentally manipulated, found that increased levels of sustained and varied harassment did reduce the amount of time elephants spent within fields, although substantial crop damage still took place (Osborn 2002). Clearly, early warning and the active deployment of deterrents before elephants gain entry to fields is critical to reducing conflict.

MITIGATING CROP RAIDING

This study used a comparative analysis to develop a model of susceptibility to crop raiding that was subsequently tested in field manipulation trials that resulted in reduced crop raiding by elephants. Although the research was small-scale and short-term, the results are unequivocal and demonstrate the value of evidence-based approaches to conservation problems (Sutherland *et al*. 2004). Few such studies currently exist. Equally, although the parameters of the model may be specific to the Transmara scenario, the broad findings are likely to be applicable elsewhere. The methodology is easily transferable to other sites to verify this.

Moreover, the participatory nature of the study enhanced its demonstration effect on local farmers. This is important because, despite the relatively intuitive findings, there is a lack of confidence in local mitigation methods and many farms remain insufficiently guarded against elephants. The results of this study reveal that enhanced early warning and other methods can work in the short term. However, many farmers fear that the success of such methods may be eroded over time by habituation (Bell 1984; Tchamba 1996). The fact that previously raided farms were more likely to be raided again may reflect a growing familiarity with commonly used mitigation methods. Therefore, a shifting combination of methods may succeed for longer as it will give elephants less chance to habituate. In that light, the development of novel, cost-effective methods, such as chilli essence (from *Capsicum* spp.), that farmers can use in combination with traditional methods is important (Osborn 2002). Moreover, extended trials in a range of high conflict zones will be required to validate fully such methods and demonstrate more broadly their utility to farmers. Extended trials are currently taking place within Transmara District, and are soon to be exported to other human–elephant conflict zones in Africa and Asia. The exchange of information between farmers in different areas using different mitigation methods will maximize both the spread of useful methods and the variety of methods employed in each area.

Besides a lack of confidence among local farmers, efforts to reduce crop losses to elephants incurs a significant array of additional costs. The direct and opportunity costs of investing in guarding and mitigation materials place such farmers at a commercial disadvantage compared with those living without the threat of elephants, and is particularly problematic for subsistence communities. Moreover, pitting human against elephant in this way is an inherently risky strategy as elephants can become aggressive when provoked (Bell 1984). For such large and unpredictable animals, the perceived risk of injury may greatly outweigh the actual risk (Naughton-Treves, Treves & Rose 2000). This psychological cost is equally if not more significant, and only serves to decrease local tolerance towards elephants. Besides the testing and demonstration of effective solutions, there may be a need to provide assistance to, or develop incentives for, poor farmers to invest in conflict mitigation. Such inputs are already improving local attitudes towards elephants in Transmara District (Kanton 2004) and so may represent a worthwhile investment.

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Supplementary material

The following supplementary material is available for this article online.

Appendix S1. Study area in Transmara District, adjacent to the Masai Mara National Reserve (MMNR), Kenya.

This material is available as part of the online article (full text) from http://www.blackwell-synergy.com