LETTER

Effectiveness of intervention methods against crop-raiding elephants

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Abstract

The raiding of crops by elephants is one of the major components of human-elephant conflict, causing loss of livelihood and retaliation against elephants. To mitigate this conflict, various intervention methods are in use by farmers across Africa and Asia; yet there have been few rigorous assessments of their effectiveness. We provide an assessment of the efficacy of interventions in use by communities in Assam from a 3-year survey dataset using Generalized Linear Mixed Modeling. We found spotlights, chili fences, and electric fences to be highly effective at preventing crop damage by elephants when used in isolation, but when used in combination with noise their efficacy was compromised. Our study highlights the importance of evaluating intervention methods to determine their effectiveness. We propose the use of fences and spotlights be promoted in Assam, in conjunction with long-term habitat protection and restoration strategies.

Introduction

Northeast India is recognized as a high-priority area for Asian elephant conservation (Choudhury 1999). The state of Assam harbors one of the last remaining large, viable populations of Asian elephants (c. 5,000 individuals, Project Elephant synchronized census 2002). This population, however, is also acutely threatened (Sukumar & Santiapillai 1996; Choudhury 1999). The growing human population in Assam and increasing demand for land rights is resulting in continual habitat fragmentation through unsustainable extraction of forest products and agriculture, causing conflict between elephants and people (Kushwaha & Hazarika 2004; Fernando *et al*. 2005).

Human-elephant conflict is a complex and pervasive problem in Africa and Asia and is a major threat to the long-term persistence of elephant populations. One of the major components of human-elephant conflict is crop raiding. The damage elephants can inflict is devastating for the individual farmer (Parker *et al*. 2007; Osei-Owusu & Bakker 2008). Elephants are more dangerous than other herbivore species, causing more human deaths and injuries (Sitati 2003) and as a result they often elicit fear in rural communities (Parker *et al*. 2007). Consequently, damage by elephants creates anger among the communities who live with them, and can lead to farmers killing elephants or turning a blind eye to poaching in retaliation for the damage elephants have caused (Parker *et al*. 2007). Ultimately, human-elephant conflict undermines support for elephant conservation and casts an ominous shadow over the future of elephants outside protected areas.

Empowering the local community to take responsibility is considered the most sustainable solution to human-elephant conflict (Osborn & Parker 2003; Zimmermann *et al.* 2009), and a wide variety of relatively inexpensive, low-tech and humane intervention methods are in use by farmers across Africa and Asia. These include early-warning systems such as trip wires and watchtowers, barriers such as trenches and electric fences, and deterrents such as chili smoke and spotlights. Enabling local communities to take action and reduce the impact of human-elephant conflict on their livelihoods is thought to improve communities' perceptions of elephants and conservation (Naughton *et al.* 1999; Messmer 2000).

Evidence-based conservation is fundamental to the management of practical conservation problems (Pullin & Knight 2001; Sutherland *et al.* 2004) and therefore, assessment of intervention methods is important to determine the most effective methods for reducing human-elephant conflict. Given the variability and widespread use of intervention methods, there are surprisingly few studies that attempt to quantify their effectiveness at reducing conflict (Osborn & Parker 2003). The available literature varies in scientific approach, from gathering farmers' perceptions (e.g., Nyhus *et al.* 2000), to assessing uptake and continued use of individual interventions (e.g., Graham & Ochieng 2008), to the difference between traditional and experimental methods (e.g., Osborn & Parker 2002), and the effectiveness of specific interventions such as electric fencing (e.g., Kioko *et al.* 2008; Graham *et al.* 2009). The lack of intervention qualification arises in part because of the difficulty of field experimentation (Osborn & Parker 2003; Hedges & Gunaryadi 2010); for example, finding a suitable control plot and accounting for the associated random effects. Furthermore, specific intervention methods are rarely used in isolation, making inferences about specific methods difficult. Instead, our understanding of the efficacy of interventions tends to come from control-plot experiments or surveys with natural variation in combinations of interventions among elephant raids, among villages, among regions, and among years. Such "natural experiments" usually suffer from nonindependence and unbalanced designs, preventing the use of traditional analyses of variance to tease out main effects of single intervention strategies, or interactions between them. As yet, few studies on human-elephant conflict interventions have accounted for data structure such as spatial organization, seasonal patterns, and repeated measures, which cannot be accommodated by traditional statistical analyses, such as bivariate or multivariate analyses of variance. Shoehorning data into classical statistical frameworks often violate statistical assumptions and increases the chance of Type I or II errors (Bolker *et al.* 2008). However, in this article we show that these difficulties can be overcome by using generalized linear mixed-effects models (GLMM), which allow for repeated measures, missing data, and various nonnormal probability distributions for the response. Furthermore, the use of model simplification and model comparisons can help to deal with unbalanced representation of, and correlations among, intervention methods.

In this article, we examine the effectiveness of various intervention methods used regularly by communities in Assam by analyzing the probability of crop loss when elephants are locally present, and the area of crop loss when raiding occurs as determinants of their success. This study builds on previous interventions analysis by accounting for structuring within the data and identifies the most effective intervention methods to prevent elephant crop raiding in Assam.

Methods

Assam (total area = 78,438 km^2) is a state in northeast India located south of the eastern Himalayas; it contains a transitional habitat zone and is a high-priority conservation area (Myers *et al.* 2000; Olson & Dinserstein 2002). Assam has a tropical monsoon climate with a mean annual rainfall of 2,818 mm and two distinct monsoon seasons (June to September and October to December). Data were collected from two study sites each with an area of approximately 1,250 km^2 from two districts of Assam, Goalpara and Sonitpur. The natural vegetation in this region is moist deciduous forests, but both districts have been highly transformed and contain a mosaic of land use and vegetation, including rice cultivation, villages, commercial tea plantations, degraded secondary forest, and protected areas.

To establish a reliable and independent conflict-reporting system, a team of 33 community members were trained as monitors to enumerate crop-raiding incidents. This eliminates the problem of farmers exaggerating the conflict (cf. Siex & Struhsaker 1999). Monitors were stationed to ensure complete coverage of the two study areas and visited all crop-raiding incidents within their assigned area to verify, quantify, and record the location using a GPS unit. All such incidents were recorded for 3 years, from 1 March 2006 to 28 February 2009. Incidents were defined by events on a specific community on a specific date; therefore incidents at the same community on different dates were recorded as separate incidents, as were incidents at different communities on the same date. Incident details were recorded on a standardized reporting form including: elephant group size, composition, herd identification (if known), time of incident, any damage caused to crops, property, humans, or elephants, and any intervention methods used.

Elephant crop-raiding intervention methods

During this study, we recorded the following methods in use by communities: (1) Chili smoke: made by burning a cardboard wrap of dried chilies, tobacco, and straw, which creates a pungent smoke. This is then positioned at the edge of the village or used to chase away the elephants; (2) spotlights: powerful, rechargeable searchlights used for chasing elephants away by directing the light at the elephants' eyes; (3) electric fencing: solar-powered, 2.5-m high two-strand electric fences with protected posts; (4) chili fencing: engine grease mixed with ground chili paste, spread on to a jute or coconut rope and strung between posts to form a simple, one-strand fence; (5) elephant drives: in some areas, trained domesticated elephants (*kunkies*) are used to round up wild elephants and drive them away from villages. Elephant drives such as this do not involve local communities and are usually employed by a government agency; (6) fire: a widely used, traditional method; involves lighting fires in pits on the ground at the edge of the village, or carrying fire torches; (7) noise: a widely used traditional method; includes purposeful shouting, crackers or drums, and is different from general village hubbub. For detailed information on the interventions used in Assam please refer to Assam Haathi Project 2008; Zimmermann *et al*. 2009.

In this analysis, we grouped chili fences and electric fences together due to their similar properties: both function as a barrier and could easily be broken by elephants. Previously live wires were used in some areas of our study site to protect areas of crops and we have since observed elephants avoiding any fence-like wires, even if these are not electrified. Throughout this study, no chili or electric fence was broken by elephants suggesting that chili and electric fences are functioning as deterrent fences in our study sites in Assam.

Analyses

To determine the effectiveness of the above-mentioned intervention methods employed by communities in Assam, we used GLMM because these can accommodate situations where observations are spatially or temporally nonindependent (e.g., villages within districts, and repeated observations through time) (Goldstein 1995). GLMM also allow the use of data transformations without loss of statistical power and are appropriate tools for analyzing nonnormal data involving random effects (Bolker *et al*. 2008). GLMM of surveys also have advantages over control-plot experiments for intervention analysis, especially in human-elephant conflict areas where villagers' welfare and livelihoods must take priority over scientific experimentation. GLMMs have been applied to a range of different situations, but are not yet common in the analysis of human-wildlife conflict data. Other conservation studies that have applied GLMMs include the effect of conservation management on bees (Batáry *et al*. 2010), spatial and temporal associations of bird populations (Amar *et al*. 2010), and the effectiveness of tracking devices on fitness (McMahon *et al*. 2008). There are also numerous papers detailing the suitability of GLMMs for ecological data (see Whittingham *et al*. 2006).

The "probability of crop damage" and "area of crops damaged" by elephants were used as determinants of the effectiveness of the intervention method: the lower the probability or area of damage to crops, the more effective the method. We analyzed the effectiveness of the interventions in two stages: (1) Preventing damage: the first stage of the analysis highlighted the interventions that are best at preventing crop damage, using a binary response variable of whether damage was caused or not, with binomial error distribution and the corresponding logit-link function; (2) Minimizing damage: the second stage assessed the amount of damage when damage occurs using a Gaussian error structure and a log-link function, to reveal the interventions that minimized damage once the elephants were already in the crop fields. For both stages, the models were compared on the basis of evidential support, using (1) Akaike information criterion (AIC) and (2) Bayesian information criterion (BIC): methods that tend to reinforce parsimony (the simplest combination of factors providing the strongest explanatory power) via their bias correction terms (see Bradshaw & Brook 2010).

All analyses were performed using R v.2.9.0 (R Development Core Team 2005), with GLMM models applied using the library "lme4" (Bates & Maechler 2009). All possible combinations of main effects, followed by a subset of two-way interactions were explored (see below) and then compared using estimated probabilities of model truth; AIC and BIC model weights, compared among all possible combinations of explanatory variables. AIC is an evidence factor that is corrected for model complexity. Weighting AICs can be used to assess the relative "truth" by approximating Kullback-Leiber information loss to see how changing the model affects the fit (Bradshaw & Brook 2010). A small value represents a better fit of the model to the data. BIC is a dimension-consistent form of model comparison that provides a measure of weight of evidence relative to other models (see Burnham & Anderson 2002; Whittingham *et al*. 2006; Bradshaw & Brook 2010). AIC and BIC are considered especially useful when comparing model fits for a subset of a priori hypotheses, or when comparing nonnested models (i.e., those with different explanatory variables). In our study, we had no clear a priori predictions of intervention efficacy, or of interactions among various interventions. We therefore adopted the principles of the "multiple working hypotheses" (Elliott & Brook 2007) to specifically accommodate the simultaneous comparison of hypotheses and avoid the arbitrary selection of a threshold probability of making Type I errors to conclude "significance" of effect (Whittingham *et al*. 2006; Bradshaw & Brook 2010).

In the absence of a priori hypotheses regarding the value of the various intervention techniques, our set of candidate models was very large. Our exploration of main effects, comparable to a multiple regression approach, tested all combinations of the presence or absence of noise, fire, fences (chili and electric), spotlight, chili smoke, or *kunkie*: this yielded $2^6 = 64$ models for comparison. We used AIC and BIC model weights (Burnham & Anderson 2002) to estimate the dimension of "true" combination of main effects before moving on to assessment of two-way interactions among interventions.

Tests of interactions between intervention methods, that is, how effective multiple intervention methods were in instances when they were applied simultaneously, were limited to two-way interactions, due to small sample sizes of three-way intervention combinations. Even so, the model set that included all possible combinations of two-way interactions was $2^{15} = 32{,}768$. We reduced the complexity of this model selection procedure by considering only interactions among the intervention techniques identified as important as main effects during the analysis of either response variable (probability of damage or extent of damage). This yielded 64 interaction models, defined by combinations of two-way interactions among noise, fire, fences, and spotlights. We used AIC weights to guide us to the two-way interaction models, and a combination of AIC and BIC to identify the parsimonious model.

Random effects for all models were defined by space (villages within districts) and by time (regression against Julian date, nested within years). The spatial and temporal components were coded as additive random effects

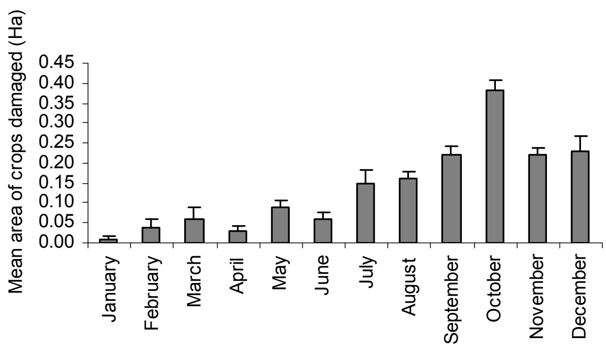

Figure 1 Seasonal pattern of crop damage for both districts, 2006–2009. Bars are standard error.

Results

During the 3-year duration of the study, 1,761 conflict incidents were recorded across the two study sites. The estimated herd sizes of the crop-raiding elephants ranged in size from 1 to 130 individuals (median = 11). Conflict occurred all year with a peak from August to December (Figure 1). The total area of crops damaged by elephants over the study period amounted to 359 hectares, with an estimated local market value of INR 3,599,809 (US$77,151). Rice was the principal crop damaged, accounting for 91.2% of the total area damaged. Homestead gardens (small plots of land adjacent to homes used for growing fruits and vegetables) were the second most targeted, accounting for 4.7% of the total. In 53.7% of incidents no loss of crops occurred, and in all of these cases some form of intervention was employed.

The most commonly employed intervention methods were noise and fire, used during 1,614 (91.6%) and 1,439 (81.7%) of human-elephant conflict incidents, respectively. The next most commonly employed method was spotlights used during 444 (20.1%) incidents, followed by fences on 63 (3.7%) and *kunkies* on 40 (2.3%) occasions (Figure 2). During 3.5% of incidents, no intervention methods were employed.

Effectiveness of the interventions

Preventing damage

AIC and BIC model weights agreed on the combination of intervention techniques, modeled as main effects, that best explained variation in the probability of damage being caused by elephant raids: logit (P(raid is successful)) is influenced by noise, fire, spotlight, and fences (Table 1). The weighting of this model compared to all other main effects models was 19.77%. Rival models with weightings

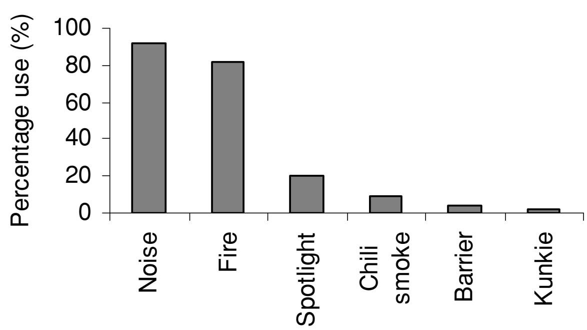

Figure 2 Percentage use of various intervention methods used during crop-raiding incidents.

Table 1 Summary of the model weights (estimated probabilities of model truth) relating probability of damage to combinations of intervention techniques[a]. Presented here are the top ten models ranked according to AIC model weights, with corresponding BIC model weights. Model weights are also presented for null models, for comparison. See main text for discussion of use of AIC and BIC.

	Model	AIC model weighting (%)	BIC model weighting (%)
Stage 1: main effects	Noise + Spotlight + Fire + Fence	19.77	0.98
	Noise + Fire + Fence	11.62	8.91
	Noise + Spotlight + Fire + Fence + *Kunkie*	10.26	0.03
	Noise + Spotlight + Fire	10.15	7.78
	Noise + Spotlight + Fire + Fence + Chili	7.27	0.02
	Noise + Fire	6.27	74.25
	Noise + Fire + Fence + *Kunkie*	6.13	0.30
	Noise+ Spotlight + Fire + *Kunkie*	4.93	0.24
	Noise+ Fire + Fence + Chili	4.70	0.23
	Noise+ Spotlight + Fire + Chili	3.83	0.19
	Null model	<0.01	1.04
Stage 2: two-way interactions. Model is Noise + Light + Fire + Fence +. . .	Spotlight:Noise + Spotlight:Fence + Fire:Noise + Fence:Noise	26.49	6.38
	Spotlight:Noise + Fire:Noise + Fence:Noise	14.12	52.53
	Spotlight:Noise + Spotlight:Fence + Fire:Noise+Fence:Noise + Fence:Barrier	10.99	0.17
	Spotlight:Noise + Spotlight:Fence + Fire:Noise + Fence:Fire	10.20	2.46
	Spotlight:Noise + Spotlight:Fence + Fire:Noise + Fence:Noise + Spotlight:Fire	9.30	0.15
	Spotlight:Noise + Fire:Fence + Fire:Noise + Fence:Noise	5.79	1.39
	Spotlight:Noise + Spotlight:Fire + Fire:Noise + Fence:Noise	5.34	1.29
	Spotlight:Noise + Spotlight:Fence + Fire:Fence + Fence:Noise + Fire:Noise	4.50	0.07
	Spotlight:Noise + Light:Fence + Fire:Noise + Fence:Fire + Spotlight:Fire	4.23	<0.01
	Spotlight:Noise + Fire:Fence + Fire:Noise	2.41	8.96
	Null model	<0.01	0.01

[a]Weightings are given for both Akaike information criteria and Bayesian information criteria. Models are ranked according to their AIC model weightings, based on two stages of analysis. The first stage considered 64 models describing all combinations of presence or absence of noise, spotlight, fire, fence, chili smoke, and *kunkie*. The second stage used the top-ranking AIC-weighted model from the first stage as a baseline model, and then considered all 64 possible combinations of presence or absence of two-way interactions among the main effects of noise, spotlight, fire, fences.

of 11.63% and 10.16% lacked the contribution of light and fences, respectively. Another rival model, with a weighting of 10.26%, promoted the use of *kunkie* to reduce the probability of a raid, but the BIC weighting for this model was only 0.03% (Table 1). Exploration of interaction models revealed a highest AIC model weighting of 26.49%, for the model that included two-way interactions between noise and spotlight, noise and fire, noise and fences, and spotlight and fences. Rival AIC weightings were 14.12% for a model that excluded the interaction between spotlight and fences, 10.99% for a model that included the interaction between fire and fences, and 10.20% for a model that replaced the interaction between noise and fences with the interaction between fire and fences. However, BIC weightings penalized the extra parameters required to estimate the interactions between spotlight and fences and between fire and fences.

To simplify presentation, we provide a figure that describes a consensus model that includes interactions between noise and spotlight, noise and fire, and noise and fences (Figure 3). The message of this model is that intervention techniques can be effective in isolation, but that their reduction of the probability of crop damage is compromised when interventions are used in combination. Spotlights, fire, and fences were each effective at reducing the probability of damage when used in isolation. However, when either were used in combination with noise their efficacy was compromised (Figure 3; described by interactions between noise and fire, noise and spotlight, noise and fences, Table 1). Noise also works as an

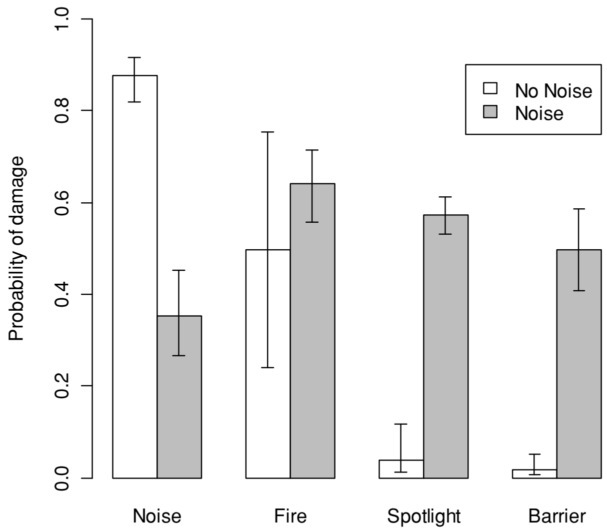

Figure 3 Average probability of damage occurring for various interventions in conjunction with and without noise. Note. The far left hand column indicates no intervention used. Chili smoke and kunkie are not included as they were not found to be effective.

intervention technique, but only when used on its own (Figure 3). All rival models confirmed this conclusion: a combination of fire and fence increased the probability of damage, as did a combination of spotlight and fence.

The relative contribution of the random effects terms to model deviance is shown in Table 2. Variation among years dominates the variation in the probability of successful raids by elephants and there also exists important variation among villages.

Minimizing damage

No interventions were found to reduce the extent of damage caused (Table 3), and no significant interactions were found between any of the intervention methods. The model with greatest AIC weighting (81.56%) and BIC weighting (98.72%) was the null model (Table 3). Unexplained variation dominates the variation in the extent of damage caused and there is also important variation among villages (Table 4).

Table 2 Relative contribution of spatial and temporal random effects to variation in the probability of crop damage during elephant raids.

Term	Relative contribution (%)
Village within district	18.53
District	0.52
Julian date per year	<0.001
Year	80.94

Discussion

Fences (chili and electric) were the most effective at reducing the probability of damage to crops, followed by spotlights and fire. But when either of these methods was used in combination with noise their efficacy was reduced, with the most pronounced negative effect seen with fences and spotlights. Spotlights and fences are static or directional methods, compared to noise which generally involves the whole village shouting and creating a commotion, which is less directional and could be disorientating to elephants. The compromised efficacy of interventions when used with noise could be because noise caused the elephants to panic, perhaps split up or react more erratically and in doing so damage a greater area of the field in their attempts to escape. Elephants reacting to a directional and relatively static deterrent such as ground fire, fences, or a spotlight might react more calmly, moving away from the deterrent in a more controlled manner as a whole herd. Noise and other active intervention methods were also correlated with greater crop damage in Kenya (Sitati *et al*. 2005). Villagers report that traditional methods, such as fire and noise, are losing their effectiveness, which could be a reflection of the decreased efficacy of noise when used in conjunction with other methods. These methods were employed during the majority of incidents, increasing the likelihood of eventual habituation. Chili smoke was not effective at preventing damage to crops, perhaps due to the requirement that the wind blew in the right direction toward the elephants. *Kunkies* were also ineffective at preventing damage to crops. This could be because the elephants and mahouts used in these drives are not sufficiently trained or experienced in this method and caused wild elephant herds to panic and run in different directions, increasing the trampling damage to crops by wild elephants as well as the *kunkies*. Spotlights were found to be an effective deterrent, correlating with Sitati *et al*. (2005) who also found spotlights to be an effective deterrent, especially when the lights were bright. Important variation was found to exist between villages, which perhaps reflects landscape-level factors, which have been shown to influence crop raiding, such as proximity to forest (Linkie *et al*. 2007) and area of cultivation (Sitati *et al*. 2003). We are currently completing further work with GIS to clarify these effects in Assam.

Previous studies on the effectiveness of interventions have produced varied results, which perhaps also reflects the varying scientific and statistical approach employed. The lack of intervention quantification is in part because of the difficulty of experimentation in a field situation (Osborn & Parker 2003) and it is a consistent problem in conservation that the majority of conservation actions

Table 3 Summary of model weights (estimated probabilities of model truth) relating extent of damage to combinations of intervention techniques. Weightings are given for both Akaike information criteria and Bayesian information criteria[a]. Presented here are the top ten models ranked according to AIC model weights, with corresponding BIC model weights. See main text for discussion on use of AIC and BIC.

	Model	AIC model weighting (%)	BIC model weighting (%)
Stage 1: main effects	Null model	81.98	98.72
	Kunkie	7.02	0.54
	Noise	3.03	0.23
	Fire	2.69	0.21
	Chili	1.50	0.12
	Fence	1.25	0.10
	Spotlight	0.97	0.07
	Fire + *Kunkie*	0.29	<0.01
	Noise + Fire	0.27	<0.01
	Noise + *Kunkie*	0.23	<0.01
Stage 2: two-way interactions.	Null model	81.56	98.72
	Kunkie	6.99	0.54
	Noise	3.02	0.23
	Fire	2.68	0.21
	Chili	1.49	0.12
	Fence	1.24	0.10
	Spotlight	0.96	0.07
	Noise + Fire + Noise:Fire	0.47	<0.01
	Fire + *Kunkie*	0.29	<0.01
	Fire + Noise	0.27	<0.01

[a] Models here are ranked according to their AIC model weightings, based on two stages of analysis. The first stage considered 64 models describing all combinations of presence or absence of noise, spotlight, fire, fence, chili smoke, and *kunkie*. The second stage then considered all 64 possible combinations of presence or absence of two-way interactions among the main effects of noise, spotlight, fire, fence (selected due to their importance in the "probability of damage" models.

Table 4 Relative contribution of spatial and temporal random effects to variation in the extent of crop damage during elephant raids.

Term	Relative contribution (%)
Village within district	11.05
District	0
Julian date per year	<0.001
Year	5.25
Residual	83.70

are based on experience, not evidence (Pullin & Knight 2001). Our analysis has shown that the effectiveness of interventions can be analyzed from a field dataset using GLMMs; considered one of the best tools for analyzing nonnormal data involving random effects (Bolker *et al*. 2008). Controlled trials for assessing interventions usually offer support to certain communities while leaving others undefended, therefore the use of GLMMs with survey data offers an approach that is more acceptable to villagers, providing there is sufficient natural variation in intervention techniques among villages and temporally. A weakness of this study (and indeed all previous intervention studies) is that our method did not record at what point during the incident the intervention was employed and did not capture information on the intensity of interventions such as fire and noise, which have the ability to vary considerably but are inherently difficult to measure and record.

Crop raiding by elephants erodes local people's tolerance of elephants (Sitati *et al.* 2005; Parker *et al*. 2007). Even in India where the elephant is revered through the Hindu God Ganesha (Hart 2005), the losses people sustain drives them to retaliatory actions, such as poisoning and electrocution of elephants in order to protect their livelihoods (Gureja *et al*. 2002; Zimmermann *et al*. 2009). As a result, it is thought that reducing the impact of crop raiding on people's livelihoods will improve attitudes toward elephants and conservation; however more work is required to verify this assumption and determine the effectiveness of intervention methods on changing attitudes toward elephants and conservation.

Crop damage affects subsistence farmers directly through loss of their primary food and income resources, and indirectly through a variety of social costs (Osborn & Parker 2003). It is therefore vital to find ways to mitigate this conflict to improve food security and rural communities' attitudes toward elephants. Equally however, it is essential to ensure introduced intervention methods are promoted based on evidence of their effectiveness. From our analysis, we propose mitigation efforts in Assam should focus on using chili fences, electric fences, and spotlights, with a reduction in the promotion of *kunkies* and chili smoke. To increase the effectiveness of spotlights and fences, the use of noise as an intervention method should be reduced. One solution could be for communities to instigate "village defense teams" trained in the best practices of intervention deployment and effective action during an elephant raid. Chili fences are a cheaper fence option than electric fencing, and can easily be installed and maintained by communities without any outside donor input. While our grouped analysis found electric and chili fences both effective at preventing damage, further analysis is needed to determine any differences in the effectiveness between the two fence types. An efficient conservation fence must balance the cost of breaches against the cost of a more secure design (Bode & Wintle 2010). The most effective interventions may not be the most cost effective and a balance between cost, effectiveness, and sustainability is required. Yet to avoid eventual habituation and ensure long-term effectiveness, new intervention methods will need to be developed and tested (Osborn & Parker 2002).

Enabling communities to defend their crops only addresses the symptoms of conflict and not the underlying cause, which is the increasing settlement and cultivation within elephant ranges (Barnes 2002). Unfortunately, successful mitigation might encourage greater cultivation in elephant ranges (Sitati, 2003; Sitati & Walpole 2006) and to counteract this and develop a long-term solution, community-based intervention methods must be accompanied by conservation incentives and appropriate landscape-scale habitat management.

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References

Amar, A., Redpath S., Sim I., Buchanan G. (2010) Spatial and temporal associations between recovering populations of common raven *Corvus corax* and British upland wader populations. *J App Ecol* **47**, 253–262.

Assam Haathi Project (2008) *Living with elephants in Assam: a handbook*. Guwahati, Assam, India: EcoSystems-India and Chester, UK: North of England Zoological Society.

Barnes, R.F.W. (2002) Treating crop-raiding elephants with asprin. *Pachyderm* July-December 2002, 96–99.

Batáry, P., Báldy A., Sárospataki M. *et al*. (2010) Effect of conservation management on bees and insect-pollinated grassland plant communities in three European countries. *Agric Ecosyst Environ* **136**, 35–39.

Bates, D., Maechler M. (2009) lme4: linear mixed-effects models using S4 classes. R package version 0.999375–31. http://CRAN.R-project.org/package=lme4.

Bode, M., Wintle B. (2010) How to build an efficient conservation fence. *Conserv Biol* **24**, 182–188.

Bolker, B.M., Brooks M.E., Clark C.J. *et al*. (2008) Generalized linear mixed models: a practical guide for ecology and evolution. *Trends Ecol Evol* **24**, 127–135.

Bradshaw, C.J.A., Brook B.W. (2010) The conservation biologist's toolbox – principles for the design and analysis of conservation studies. Pages 313–339 in N.S. Sodhi, P.R. Ehrlich, editors. *Conservation biology for all*. Oxford University Press, Oxford.

Burnham, K.P., Anderson D.R. (2002) *Model selection and multimodel inference: a practical information-theoretic approach*, 2nd edition. Springer-Verlag, New York.

Choudhury, A.U. (1999) Status and conservation of the Asian elephant *Elephas maximus* in north-eastern India. *Mammal Rev* **29**, 141–173.

Elliott, L.P., Brook B.W. (2007) Revisiting Chamberlin: multiple working hypotheses for the 21st Century. *Bioscience* **57**, 608–614.

Fernando, P., Wikramanayake E.D., Weerakoon D., Jayasinghe L.K.A., Gunawardene M., Janaka H.K. (2005) Perceptions and patterns of human-elephant conflict in old and new settlements in Sri Lanka: insights for mitigation management. *Biodivers Conserv* **14**, 2465–2481.

Goldstein, H. (1995) *Multilevel statistical models*. Edward Arnold, London.

Graham, M.D., Gichohi N., Kamau F. *et al*. (2009) *The use of electrified fences to reduce human-elephant conflict: a case study of the Ol Pejeta Conservancy, Laikipia District, Kenya. Working Paper 1*, Laikipia Elephant Project, Nanyuku, Kenya.

Graham, M.D., Ocheing T. (2008) Uptake and performance of farm-based measures for reducing crop raiding by elephants *Loxodonta africana* among smallholder farms in Laikipia District, Kenya. *Oryx* **42**, 76–82.

Gureja, N., Menon V., Sarkar P., Kyarong S.S. (2002) *Ganesha to Bin Laden: human-elephant conflict in Sonitpur district of Assam*. Wildlife Trust of India, New Delhi.

Hart, L.A. (2005) The elephant-mahout relationship in India and Nepal: a tourist attraction. Pages 163–190 in J. Knight, editor. *Animals in person: cultural perspectives on human-animal intimacies*. Berg Publishers, Oxford.

Hedges, S., Gunaryadi D. (2010) Reducing human-elephant conflict: do chillies help to deter elephants from entering crop fields? *Oryx* **44**, 139–146.

Kioko, J., Muruthi P., Omondi P., Chiyo P.I. (2008) The performance of electric fences as elephant barriers in Amboseli, Kenya. *S Afr J Wildl Res* **38**, 52–58.

Kushwaha, S.P.S., Hazarika R. (2004) Assessment of habitat loss in Kameng and Sonitpur elephant reserves. *Curr Sci* **87**, 1447–1453.

Linkie, M., Dinata Y., Nofrianto A., Leader-Williams N. (2007) Patterns and perceptions of wildlife crop raiding in and around Kirinci Seblat National Park, Sumatra. Anim Conserv **10**, 127–135.

McMahon, C.R., Field I.C., Bradshaw C.J.A., White G.C., Hindell M.A. (2008) Tracking and data-logging devices attached to elephant seals do not affect individual mass gain or survival. *J Exp Mar Biol Ecol* **360**, 71–77.

Messmer T.A. (2000) The emergence of human-wildlife conflict management: turning challenges into opportunities. *Int Biodet & Biodeg* **45**, 97–102.

Myers N., Mittermeier R.A., Mittermeier C.G., da Fonseca G.A.B., Kent J. (2000) Biodiversity hotspots for conservation priorities. *Nature* **403**, 853–858.

Naughton, L., Rose R., Treves A. (1999) The social dimensions of human-elephant conflict in Africa: a literature review and case studies from Uganda and Cameroon. *A report to the African elephant specialist, human-elephant conflict task force*. IUCN, Glands, Switzerland.

Nyhus, P., Sumianto, Tilson R.(2000) Crop-raiding elephants and conservation implications at Way Kambas National Park, Sumatra, Indonesia. *Oryx* **34**, 262–275.

Olson, D.M., Dinerstein E. (2002) The global 200: priority ecoregions for global conservation. *Ann Mo Bot Gard* **89**, 199–224.

Osborn, F.V., Parker G.E. (2002) Community-based methods to reduce crop loss to elephants: experiments in the communal lands of Zimbabwe. *Pachyderm* **33**, 32–38.

Osborn, F.V., Parker G.E. (2003) Towards an integrated approach for reducing the conflict between elephants and people: a review of current research. *Oryx* **37**, 1–5.

Osei-Owusu, Y., Bakker L. (2008) *Human-wildlife-conflict: elephant technical manual*. Food and Agricultural Organization of the United Nations, Rome.

Parker, G.E., Osborn F.V., Hoare R.E., Niskanen L.S., editors. (2007) *Human-elephant conflict mitigation: a training course for community-based approaches in Africa. Participant's manual*. Elephant Pepper Development Trust, Livingstone, Zambia and IUCN/SSC AfESG, Nairobi, Kenya.

Project Elephant Synchronised Census (2002) [WWW document]. URL. Available from: http://www.asiannature.org/resources/statistics.htm. Accessed 17 December 2009.

Pullin, A.S., Knight T.M. (2001) Effectiveness in conservation practice: pointers from medicine and public health. *Conserv Biol* **15**, 50–54.

R Development Core Team (2005) *R: a language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3–900051-07–0, URL http://www.R-project.org.

Siex, K.S., Struhsaker T.T. (1999) Colobus monkeys and coconuts: a study of perceived human-wildlife conflicts. *J Appl Ecol* **36**, 1009–1020.

Sitati, N.W. (2003) *Human-elephant conflict in the Masai Mara dispersal areas of Transmara district*. PhD Thesis. University of Kent, Canterbury, UK.

Sitati, N.W., Walpole M.J. (2006). Assessing farm-based measures for mitigating human-elephant conflict in Transmara district, Kenya. *Oryx* **40**, 279–286.

Sitati, N.W., Walpole M.J., Leader-Williams N. (2005) Factors affecting susceptibility of farms to crop raiding by African elephants: using predictive model to mitigate conflict. *J Appl Ecol* **42**, 1175–1182.

Sitati, N.W., Walpole M.J., Smith R.J., Leader-Williams N. (2003) Predicting spatial aspects of human-elephant conflict. *J Appl Ecol* **40**, 667–677.

Sukumar, R., Santiapillai C. (1996) *Elephas maximus*: status and distribution. Pages 327–331 in J. Shoshani, P. Tassy, editors. *The Proboscidea; evolution and palaeoecology of elephants and their relatives.* Oxford University Press, Oxford.

Sutherland, W.J., Pullin A.S., Dolman P.M., Knight T.M. (2004) The need for evidence-based conservation. *Trends Ecol Evol* **19**, 305–308.

Whittingham, M.J., Stephens P.A., Bradbry R.B., Freckleton R.P. (2006) Why do we use stepwise modeling in ecology and behavior? *J Anim Ecol* **75**, 1182–1189.

Zimmermann, A., Davies T.E., Hazarika N. *et al*. (2009) Community-based conflict management in Assam. *Gajah* **30**, 34–40.

