Perceptions and realities of elephant crop raiding and mitigation methods

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Abstract

Crop raiding by African elephants (Loxodonta africana) jeopardizes human livelihoods and undermines conservation efforts. Addressing this issue is particularly important in subsistence farms adjacent to protected areas and requires assessing the perceived and actual scale of the problem and the benefits, limitations and adoption potential of mitigation techniques. To achieve these objectives, we assessed the effectiveness of chili and beehive fences relative to control plots, using a daily farm monitoring protocol implemented on 20 farms bordering the Ngorongoro Conservation Area (Tanzania). Prior to the field study, we interviewed 65 farmers about human–elephant interactions and contrasted interview findings with those of daily farm monitoring. Farmer perception of crop raiding frequency declined with increasing distance from the protected area and was, on average, eight times greater than daily farm monitoring data indicated. The majority of interviewees expressed a willingness to try chili or beehive fences, though chili fences were preferred. Generalized-linear-mixed models indicated that neither elephant farm intrusions nor damages were significantly reduced by either chili or beehive fences relative to the control sites. Losses per month and hectare did not differ significantly by fence type. However, farm plots with chili fences did not experience massive damages which occasionally occurred in beehive or control plots. This partial effectiveness of chili fences was further confirmed by contrasting crop losses from a subset of farms that were subject to a cross-over experimental design. Our multidimensional case study suggests that chili fences have greater adoption potential than beehive fences. Nevertheless, additional efforts are required to increase effectiveness and to realize adoption potential. By providing insights into the context and circumstances that presented challenges to the effectiveness, sustainability and scalability of beehive fences, this article is particularly important for conservation practitioners working on implementing methods to mitigate human–elephant conflicts and equally targets scholars who investigate general aspects of human–wildlife conflict and coexistence scenarios.
1 | INTRODUCTION

Crop raiding by African elephants (*Loxodonta africana*) presents challenges to human–elephant coexistence (Hoare, 1999; Thouless, 1994). From the human perspective, this human–elephant conflict (HEC) is associated with direct economic losses (O’Connell-Rodwell, Rodwell, Rice, & Hart, 2000), reduced food security (Mackenzie & Ahabyona, 2012), social (Naughton, Rose, & Treves, 1999; Sitati, Walpole, Leader-Williams, & Stephenson, 2012) and opportunity costs (Barua, Bhagwat, & Jadhav, 2013), and poses a risk to the physical and psychological wellbeing of farmers (Barua et al., 2013; Hoare, 2000). Consequently, such manifold impacts on humans can result in negative views toward elephants and conservation as a whole (Bencin, Kioko, & Kiffner, 2016; Browne-Nuñez, Jacobson, & Vaske, 2013; Kansky, Kidd, & Knight, 2014). In turn, negative attitudes can hinder efforts to protect elephants (Schlossberg, Chase, Gobush, Wasser, & Lindsay, 2020) and may lead to retaliatory killing of elephants (Hoare, 2000; Mariki, Svarstad, & Benjaminsen, 2015; Okello, Njumbi, Kiringe, & Isiiche, 2014; Wakoli & Sitati, 2012).

In savannah Africa, the elephant range overlaps substantially with human dominated landscapes (Graham, Douglas-Hamilton, Adams, & Lee, 2009; Hoare & du Toit, 1999). In these social-ecological systems, the spatio-temporal distribution of elephant crop raiding has been associated with multiple environmental, anthropogenic, ecological, and behavioral variables (Denninger Snyder, Mnene, Benjamin, Mkilindi, & Mbise, 2021; Dublin & Hoare, 2004; Graham, Notter, Adams, Lee, & Ochieng, 2010; Hoare, 1999; Jackson, Mosojane, Ferreira, & van Aarde, 2008; Sitati, Walpole, Smith, & Leader-Williams, 2003). Conflicts are often particularly severe along protected area boundaries; however, little data exist about the economic severity of the problem for subsistence farmers. Likely, this is associated with the frequent retrospective assessment of crop raiding incidents via official reports (Denninger Snyder et al., 2021; Pozo, Coulson, McCulloch, Stronza, & Songhurst, 2017), or via memory recall obtained during farmer interviews (Kioko, Kiringe, & Omondi, 2006). As both techniques are prone to reporting bias, trained enumerators are occasionally employed to systematically record crop raiding (Malima, Hoare, & Blanc, 2005; Sitati, Leader-Williams, Stephenson, & Walpole, 2007). Combined with a recall study, such assessments can be used to assess the objectivity of self-reporting (Gillingham & Lee, 2003). Moreover, possible disjunctions between perceived and real intensity of crop raiding could hint to deeper-rooted conservation conflicts (Gillingham & Lee, 2003), which may pose challenges beyond implementing technical solutions to reduce crop damages by elephants (Zimmermann, McQuinn, & Macdonald, 2020).

Irrespective of such possible discrepancies, effectively reducing actual crop damage caused by elephants is vital to improving human–elephant coexistence in shared landscapes (Dublin & Hoare, 2004; Shaffer, Khadka, Van Den Hoek, & Naithani, 2019). Historically, lethal control of elephants has been widely implemented in East Africa (Rodgers & Lobo, 1982). However, in recent decades a variety of non-lethal mitigation methods have been employed and studied systematically (Davies et al., 2011; Hoare, 2012). Among these measures, chili fences (Chang’a et al., 2016) and beehive fences (Karidozo & Osborn, 2005; King, Douglas-Hamilton, & Vollrath, 2011; King, Lala, Nzumu, Mwambingu, & Douglas-Hamilton, 2017) have been suggested. Chili fences (a perimeter fence around the farm made of sisaI strings and flags, soaked in a solution of used engine oil and ground chili (*Capsicum* spp.) work as olfactory deterrents (Hedges & Gunaryadi, 2010; Osborn, 2002). In contrast, beehive fences (a perimeter fence constructed with wire that connects equally-spaced beehives) capitalize on the elephants’ avoidance of bee (*Apis mellifera*) sounds and stings (King, Douglas-Hamilton, & Vollrath, 2007; King, Soltis, Douglas-Hamilton, Sage, & Vollrath, 2010; Vollrath & Douglas-Hamilton, 2002). Across East Africa, both beehive (King et al., 2011, 2017; Scheijen, Richards, Smit, Jones, & Nowak, 2019) and chili fences (Chang’a et al., 2016; Gunaryadi, Sugioy, & Hedges, 2017) have been tested using quasi-experimental approaches. Although both methods appear suitable for implementation in subsistence farm settings (Branco et al., 2019; Karidozo & Osborn, 2015; Osborn & Parker, 2002; Sitati & Walpole, 2006), there are few studies in which both methods are tested in a comparative set-up (Branco et al., 2019). In addition, as efficacy of damage mitigation methods may vary in space and time (e.g., due to elephant habitation/learning, differences in elephant

**KEYWORDS**
crop-raiding, human–elephant conflict, human–wildlife coexistence, human–wildlife interactions, mitigation techniques
populations, environmental conditions, and agricultural practices), site-specific experiments can provide insights into the local context and can inform which mitigation tools are likely to be effective and are able to be implemented at scale (Gunaryadi et al., 2017; König et al., 2020).

If the aim is a wider adoption of a mitigation method, such assessments not only evaluate the technical efficacy, but also assess the acceptance, sustainability and scalability of a given method (Denninger Snyder & Rentsch, 2020). Providing such multidimensional evidence to inform conservation management decisions has been underpinned by research that suggests conservation decisions are often made based on anecdotes, rather than evidence-based practices, and recommends the use of cross-disciplinary evidence in order to best predict the outcome of a particular intervention (Game et al., 2018; Salafsky et al., 2019).

To address these interrelated issues, we carried out an interdisciplinary study with the aims of assessing and comparing (a) real and perceived patterns of crop raiding by elephants, (b) the willingness of people to adopt beehive and chili fences, and (c) the effectiveness of chili and beehive fences to reduce crop raiding by elephants and. Finally, we discuss our findings with a focus on the wider adoption of the tested mitigation methods.

2 | MATERIALS AND METHODS

2.1 | Study area

We conducted this study in Tloma village, in the Karatu district of northern Tanzania. The village directly borders the forest section of the Ngorongoro Conservation Area (NCA); the forest is occupied by several wildlife species, including a resident elephant population (Homewood & Rodgers, 1991). Near the study site (c. 3 km; within the NCA) is a large salt lick, which attracts wildlife to the area due to the high concentrations of micronutrients (Mills & Milewski, 2006). Long distance elephant movement does not regularly occur through the agricultural matrix of the Karatu district, and is largely restricted to the Upper Kitete corridor where the NCA forest connects to the Selela forest in the Tarangire ecosystem (Caro, Jones, & Davenport, 2009).

The landscape of the area is undulating and at an elevation of approximately 1700 m asl. The area experiences a bimodal rainfall pattern with precipitation (~1,000 mm/year) typically occurring from late October to December (short rains) and from March to May (long rains). January and February are typically relatively dry and the main dry season is from June to mid-October (Prins & Loth, 1988).

Tloma village hosts several tourist lodges, but commercial coffee farms (protected with electric fences), settlements, and subsistence farming are the primary land-use types. In the Karatu district, the vast majority of people earn their livelihood through subsistence agriculture (Owenya, Mariki, Kienzle, Friedrich, & Kassam, 2011). Common crops in the study area are pigeon peas, beans, and maize. Almost all farmers in this area practice the same sequential cropping scheme in their plots. Pigeon peas are planted in January/February and primarily harvested in September/October. Maize is usually planted in February/March (in between the peas) and harvested in July and August. Beans are planted in November and harvested in January/February (pers. observation).

2.2 | Experimental plots and field sampling

To test two crop prevention techniques (chili fences and beehive fences), we selected 20 small-scale farms (average 0.7 ha, range: 0.1–2.3 ha) bordering the NCA forest. The boundary to the NCA is demarcated by a c. 4 m wide fire break. In addition, a thorny hedgerow (ca. 3 m tall and 2–3 m wide) separates the farmland from the fire break and thus serves as an additional physical barrier between the NCA forest and the farmland.

In close cooperation with the 20 farmers (farmers expressed their willingness to support the project and we agreed upon equal benefit sharing of bee products), we distributed two beehive fences and 10 chili fences to the plots; eight sites were left untreated as a control (Figure 1). Ideally, experiments to assess conservation evidence distribute an equal number of treatments and controls (Khorozyan, 2020), yet funding constraints limited us to two beehive treatments only. As we worked in collaboration with the farmers and some farmers were not willing to host a beehive fence, a random allocation of treatments was not possible. At one plot, the allocated beehive fence remained active for the entire duration of the experiment. However, we had to shift one beehive fence to a different site following complaints by neighbors. To counteract the non-random placement of treatments, and to distribute potential crop-protection benefits of the project in a just way, we swapped the treatment of 16 sites, interchanging chili fences with control sites. This partial cross-over was implemented approximately half way through the experiment so that these paired sites were subject to 11–13 months of chili fencing and 11–12 months without additional fencing.

Construction and maintenance of the fences was conducted by a trained person, in cooperation with the corresponding farmer of each plot. At the beginning of
the project, a field crew of PAMS foundation also provided a workshop to demonstrate and practice chili fence construction. In line with Chang’a et al. (2016), we constructed chili fences by soaking sisal strings and rags in a solution of used engine oil and ground chili peppers (*Capsicum frutescens*). Wooden poles were placed about 5–10 m apart around the perimeter of a field. We tied the soaked sisal rope between the poles and tied the soaked rags along the string (2–3 rags in between poles). The chili fences required periodic refreshing to maintain their offensive odor; we renewed the fences once or twice a month (depending on precipitation) and daily monitored and repaired potential damages (Chang’a et al., 2016). We constructed beehive fences by creating a fence around a field plot with nine foot posts connected by a strong wire. The posts were coated in insecticide to prevent termite infestation. We strung beehives along the wire with small holes in the sides of the hive and 10 m between hives. Beehives consisted of an 80 cm long Kenyan top-bar hive constructed out of industrial plywood, a rainproof roof made from corrugated iron sheet, and a flat-thatched roof to protect the hive from the sun. Hives were locally sourced and cost c. US $50 unit$^{-1}$. We aimed to facilitate bee occupation by twig (*Ocimum kilimandscharicum*) and beeswax baiting. If elephants tried to enter the farm, the wire would be stretched or broken, disturbing the hives and causing bees to become agitated and prone to attacking intruders (King et al., 2011). We maintained and cleaned beehives periodically to prevent degradation and repaired damages to the wire and hives within 24 hours from when the damage was observed.

A trained enumerator monitored fields daily from March 2016 through October 2016, December 2017 through April 2017, and December 2018 through October 2019. Daily assessments included recording the crop type, identifying which species invaded the farm (based on animal signs), quantifying the area (m$^2$) or crop quantity (number of cobs or plants) damaged by wildlife, and assessing the direction from which elephants invaded the farm, the time of day of the intrusion (day or night, based on age of elephant signs and conversation with local farmers), and the number of invading individuals (based on inspection of elephant tracks and estimating how many individuals caused the tracks). Inherent to the monitoring method, time of intrusion and herd sizes had to be based on indirect evidence and is thus subject to some level of uncertainty. In sum, our monitoring stretched over four calendar years and covers a total of 14,528 plot visits.

### 2.3 Interviews

In November 2015, and thus prior to the implementation of the experiment, we conducted 65 structured interviews...
with residents of TLoma village. We walked along transects and approached households at c. 200 m intervals. With the aid of translators conversant in Swahili and the local Iraqw language, we asked people for their consent to participate in an interview. We asked predetermined questions about the frequency at which elephant crop-raiding occurred in a year, the typical group size of crop raiding elephants, the methods currently in use to mitigate crop-raiding, and willingness to try chili fences or beehive fences in the future (the principles of both beehive and chili fences were briefly explained before asking about willingness to adopt either of the methods; Appendix S1).

2.4 | Data analysis

We conducted all analyses using R 3.6 (R Core Team, 2016) and used packages **ggplot2** (Wickham, 2016), **ggpubr** (Kassambara, 2020a) to create figures and **rstatix** (Kassambara, 2020b) to conduct non-parametric tests.

Because interviews were distributed across TLoma village, we first tested if reported elephant farm invasion frequency was related to distance from the protected area using a logistic regression model. As dependent variable, we created a two column matrix, where the first column includes the number of reported farm invasions in a year (i.e., successes) and the second column represents the number of days without farm invasions by elephants (failures). As explanatory variable, we used the Euclidian distance between interview location and border to the NCA. To assess patterns of perceived and daily enumerated patterns of crop raiding by elephants, we compared perceived (from the interview data; calculated as reported number of farm invasions per year / 365 days) and enumerated (from the farm monitoring; calculated as...
observed number of farm invasions / number of monitoring
days) invasions by elephants per plot and day, as well as
perceived and estimated elephant herd sizes. Given non-
normal distribution of the data, we tested for differences
between perceived and enumerated farm intrusion frequen-
cies and elephant herd sizes using a Mann–Whitney U test.

To assess the willingness of interviewees to adopt either
beehive or chili fences, we visually compared the proportion
of interviewees willing to adopt the mitigation method.

To assess and compare the effectiveness of chili and bee-
hive fences in reducing the daily likelihood of elephant intru-
sions and of causing crop damage, we fitted two separate
mixed effects logistic regression models (response variable for
Model 1: elephant intrusion observed on this day yes [1] or
no [0]; response variable for Model 2: crop damage caused
by elephants observed on this day yes [1] or no [0]) using the
lme4 package (Bates, Maechler, Bolker, & Walker, 2015). We
considered all farm intrusions as independent, although the
same elephant group may have entered multiple farm plots
in one night. However, as treatments were designed as
perimeter fences, possible non-independence of the response
variable is unlikely to have a major impact. Importantly, if
elephants invaded farms during one night, they mostly
targeted a single farm: 62% of invasions were recorded on
unique plot-day combinations. Of note, 21% of invasions
occurred on two plot-unique day combinations (average of
five plots in between invasions) and only few nights (17% of
nights which experienced at least one intrusion) were subject
to more than three elephant intrusions.

As explanatory variables, we considered the fence
treatment (three level factor: chili, beehive or no fence)
and “month” (11 level factor, no monitoring during
November) as fixed effects. Month was entered as fixed
effect because crop raiding by elephants is associated
with crop maturity (Denninger Snyder et al., 2021),
which in our system is primarily a function of the season.
To account for the repeated measure design (Zuur, Ieno,
Walker, Saveliev, & Smith, 2009), we included “plot id”
as random effect. To account for the possibility of ele-
phant habituation to fences (Hoare, 2012; Shaffer
et al., 2019), we included the year as random effect in our
models. In addition, we included the farm area (in ha) as
explanatory variable to control for potential area effects
on invasion and damage likelihood.

As a third measure to test the efficacy of treatments, we
estimated the monetary value of crop damage by collecting
data on damaged area (m²) and number of damaged plants
and cobs for maize and pigeon peas (we did not record any
damage in beans). To standardize the data, the damaged
area was first converted into number of plants. Based on
local farming practice, we estimated that six plants made
up one m² of maize and four plants covered one m² of
pigeon peas. Vegetables were excluded due to lack of spe-
cific market value information and damage occurrence only
made up 1% of all crop damages. Assuming that maize
plants yield on average two cobs (each weighing 0.22 kg),
one maize plant was estimated to produce 0.44 kg of maize.
In 2019, the market price for maize was 600 TZS kg⁻¹.
Therefore, one maize plant was valued at 264 TZS. For
pigeon peas, we assumed a harvest of 2 kg of peas per plant
and a 2019 market price of 800 TZS kg⁻¹, and thus a value
of 1,600 TZS plant⁻¹. Because farm sizes differed, we stan-
dardized the losses to 1 ha. For each plot, we divided the
total losses by the corresponding number of months in
which the specific treatment was associated with the spe-
cific plot to derive an estimate for monthly losses per ha for
each farm. To assess whether these economic losses differed
by treatment, we carried out a Kruskal–Wallis ANOVA.

Because eight of the experimental plots were subject
to a cross-over design, we tested for differences in plots
that served both as control sites without additional treat-
ment and with chili fences using a paired Wilcoxon test.

2.5 | Integrated assessment of mitigation
methods

To systematically and holistically evaluate the effective-
ness and the adoption potential of beehive and chili fences

![Figure 3](image-url) Proportion of interviewees (n = 65) in Tloma
village expressing their willingness to try beehive or chili fences
(this had been assessed in 2015, prior to field tests of the fences) to
prevent elephant crop raiding
we adopted a recent framework (Denninger Snyder & Rentsch, 2020) and employed an integrated assessment scheme. Based on quantitative evidence from the interviews and the farm monitoring as well as qualitative aspects, we rated attitudes, effectiveness, sustainability, and scalability of beehive and chili fences using a 3-point scale (3 points: very effective/conducive for adoption; 2 points: effective/conducive for adoption; 1 point: less effective/ conducive for adoption). We present the integrated assessment in the discussion.

### TABLE 1  Regression coefficient estimates and associated statistics of generalized linear mixed models (with binomial error structure and log link) explaining the likelihood of daily elephant intrusions (A) and elephant damage (B) in 20 subsistence farms in Tloma village (Karatu district, Tanzania)

|                | Estimate | 95% CI        | SE  | z-value | p-value | Odds ratio | 95% CI        |
|----------------|----------|---------------|-----|---------|---------|------------|---------------|
| **A Intrusion**|          |               |     |         |         |            |               |
| Intercept      | −3.848   | −5.314, −2.381| 0.748| −5.142  | <.001  | 1.863      | 0.977, 3.550  |
| Beehive fence  | 0.622    | −0.023, 1.267 | 0.329| 1.890   | .059   | 1.863      | 0.977, 3.550  |
| Chili fence    | −0.051   | −0.470, 0.368 | 0.214| −0.237  | .813   | 0.951      | 0.625, 1.446  |
| Plot size      | 0.183    | −0.449, 0.816 | 0.323| 0.568   | .570   | 1.201      | 0.638, 2.261  |
| February       | −0.398   | −1.143, 0.347 | 0.380| −1.047  | .295   | 0.672      | 0.319, 1.415  |
| March          | −0.410   | −1.053, 0.233 | 0.328| −1.250  | .211   | 0.664      | 0.349, 1.262  |
| April          | 0.574    | 0.025, 1.124  | 0.280| 2.048   | .041   | 1.776      | 1.025, 3.077  |
| May            | −0.142   | −0.819, 0.535 | 0.346| −0.411  | .681   | 0.867      | 0.441, 1.708  |
| June           | −0.056   | −0.726, 0.614 | 0.342| −0.164  | .869   | 0.945      | 0.484, 1.848  |
| July           | 0.008    | −0.649, 0.665 | 0.335| 0.023   | .981   | 1.008      | 0.523, 1.944  |
| August         | −0.363   | −1.078, 0.352 | 0.365| −0.996  | .319   | 0.695      | 0.340, 1.421  |
| September      | 0.853    | 0.270, 1.436  | 0.297| 2.569   | .004   | 2.347      | 1.310, 4.204  |
| October        | 1.497    | 0.947, 2.048  | 0.281| 5.331   | <.001  | 4.470      | 2.578, 7.752  |
| November       | No monitoring |           |     |         |         |            |               |
| December       | −2.137   | −4.224, −0.050| 1.065| −2.007  | .045   | 0.118      | 0.015, 0.951  |

|                | Estimate | 95% CI        | SE  | z-value | p-value | Odds ratio | 95% CI        |
|----------------|----------|---------------|-----|---------|---------|------------|---------------|
| **B Damage**   |          |               |     |         |         |            |               |
| Intercept      | −6.009   | −7.463, −4.556| 0.742| −8.104  | .000   | 2.592      | 1.038, 6.470  |
| Beehive fence  | 0.952    | 0.038, 1.867  | 0.467| 2.040   | .041   | 2.592      | 1.038, 6.470  |
| Chili fence    | −0.460   | −1.162, 0.242 | 0.358| −1.284  | .199   | 0.631      | 0.313, 1.274  |
| Plot size      | 0.169    | −0.858, 1.196 | 0.524| 0.322   | .747   | 1.184      | 0.424, 3.306  |
| February       | 0.115    | −1.091, 1.321 | 0.615| 0.187   | .852   | 1.122      | 0.336, 3.746  |
| March          | 0.078    | −1.020, 1.175 | 0.560| 0.139   | .890   | 1.081      | 0.361, 3.237  |
| April          | 0.995    | 0.022, 1.968  | 0.497| 2.004   | .045   | 2.705      | 1.022, 7.159  |
| May            | 0.781    | −0.260, 1.823 | 0.531| 1.470   | .142   | 2.184      | 0.771, 6.189  |
| June           | 0.963    | −0.060, 1.987 | 0.522| 1.844   | .065   | 2.621      | 0.941, 7.296  |
| July           | 0.515    | −0.566, 1.595 | 0.551| 0.934   | .351   | 1.673      | 0.568, 4.930  |
| August         | −1.783   | −3.880, 0.313 | 1.070| −1.667  | .096   | 0.168      | 0.021, 1.368  |
| September      | 0.893    | −0.139, 1.925 | 0.527| 1.695   | .090   | 2.442      | 0.870, 6.856  |
| October        | 1.226    | 0.231, 2.220  | 0.507| 2.416   | .016   | 3.406      | 1.260, 9.205  |
| November       | No monitoring |           |     |         |         |            |               |
| December       | −0.509   | −2.215, 1.196 | 0.870| −0.586  | .558   | 0.601      | 0.109, 3.306  |

Note: Reference level for the fence type was “no treatment”. Plot size (ha) was entered as linear predictor. January is the reference level for the monthly effect size. The SDs of the random intercepts for “plot id” were: 0.662 (intrusion model) and 1.057 (damage model). SDs of the random intercepts for “year” were: 1.173 (intrusion model) and 0.612 (damage model). Significant associations are highlighted in bold.
3 | RESULTS

3.1 | Perceived and observed patterns of crop raiding

When asked how interviewees perceived elephants on a scale from positive-neutral-negative, all 65 interview participants responded “negative.” The frequency of reported elephant crop raiding declined significantly with increasing distance from the NCA (odds ratio of distance [km]: 0.556; 95% CI [0.535, 0.580]; \( p < .001 \); Figure 2a). However, as interviews were not always conducted at farm locations, we used the average of the reported elephant intrusion frequency for comparison with observed intrusion frequencies. Interviewees perceived elephant intrusions (intrusions plot\(^{-1}\) day\(^{-1}\), averaged over a calendar year: \( \bar{x} = 0.168; 95\% \) CI [0.114, 0.221]) as c. 7.6x more frequent than our farm monitoring data (\( \bar{x} = 0.022; 95\% \) CI [0.017, 0.027]) suggested (Figure 2b). This difference was statistically significant (\( W = 1,050, p < .001 \)).

Similarly, interviewees perceived herd sizes of crop raiding elephants (\( \bar{x} = 6; 95\% \) CI [6, 7]) to be significantly greater (\( W = 214.5; p < .001 \)) than estimated herd sizes during the farm monitoring (\( \bar{x} = 1; 95\% \) CI [1.2, 1.3]; Figure 2c).

In addition, our farm monitoring provided insights into crop raiding behavior of elephants. Farm intrusions by elephants apparently exclusively occurred during nighttime. Elephants primarily (71%; 227/318 occasions in which intrusion direction was assessed) entered from the NCA forest, occasionally entered from adjacent lateral farms (37%; 85/318) and rarely entered from the southern side that borders the village (2%; 6/318).

3.2 | Attitudes toward mitigation methods

Based on the interviews prior to the experiment, the majority of interviewees were willing to try chili fences (87.5%), and to a slightly lower degree (64%), beehive fences (Figure 3). Interviewees who did not want to adopt beehive fences frequently justified this by expressing fear of bees.

3.3 | Effectiveness of mitigation methods

The odds for elephants to intrude farms with beehive fences were approx. 1.9 times greater compared to farms without additional fences; however this association did not reach statistical significance (Table 1A). Compared to control farms, the odds for elephants to enter farms with chili fences was lower, but this relationship was also not statistically significant. Farm size did affect the likelihood of elephant intrusion. Elephant intrusions were most likely to occur during the months of April, September, and October and least likely in December (all months compared to January; Table 1A). The elephant damage model revealed a similar pattern (Table 1B). The odds for elephant damage occurring in a farm were highest in farms with beehive fences, and this association was statistically significant (odds ratio 95% CI [1.0, 6.5]). Farms with chili fences experienced lower odds of elephant damage compared to farms without additional fences, but this effect was not strong (indicated by \( p\)-value = .199 and confidence intervals of odds ratios overlapping with 1). Similar to the elephant intrusion model, crop damages predominantly occurred during the months of April and October. Regression coefficients for the months May–July also suggested greater damage likelihoods compared to the reference month (January), but the estimates were associated with relatively wide margins of error (Table 1B). Farm sizes were neither associated with intrusion nor damage likelihood.

In both models, unexplained variation from farm to farm was evident (SD of the random intercepts: 0.66 [intrusion model]; 1.06 [damage model]). The intercepts of the random effect “year” indicate that elephant damages were more likely in the last 2 years of the monitoring (Figure 4). Elephant intrusions were most likely in
2018. However, in 2019, they returned approximately to levels similar to 2016 and 2017.

The third indicator to test effectiveness of chili and beehive fences, monetary value of raided crops, yielded similar results as frequency based measures (Figure 5a). Fences with beehives suffered the greatest amount of monthly crop losses ($\bar{x} = 44,835$ TZS month$^{-1}$ ha$^{-1}$; 95% CI [0, 126,631]), followed by farms with no additional treatment ($\bar{x} = 26,235$ TZS month$^{-1}$ ha$^{-1}$; 95% CI [0, 52,506]) and farms with chili fences ($\bar{x} = 16,245$ TZS month$^{-1}$ ha$^{-1}$; 95% CI [455, 32,035]). Although differences in mean losses per treatment appear substantial, monetary losses did not differ significantly by fence type (Kruskal–Wallis $X^2 = 0.797$; df = 2, $p = .67$). Comparing economic losses of the eight plots that were subject to a cross-over design, highlights that economic losses were typically smaller when the plots where fenced with chili rags although one farm plot showed the opposite pattern (Figure 5b). However, the reduction in economic losses was not statistically significant (Paired Wilcoxon test $V = 7$; $p = .27$).

4 | DISCUSSION

This interdisciplinary case study suggests that stakeholders may have an exaggerated perception of the frequency (and possibly also herd sizes) of elephant crop raids. Importantly, neither beehive nor chili fences significantly reduced the occurrence and economic magnitude of crop damages by elephants. Because these two methods are widely implemented to prevent elephant crop raiding in East Africa and beyond, reporting negative results is important. Below, we discuss the context and circumstances that possibly impaired the effectiveness and wider adoption of beehive and chili fences in this case study.

4.1 | The perception–reality gap associated with HECs

The difference between perceived and independently enumerated frequency or intensity of wildlife-caused damages is a widespread reported phenomenon observed in studies on human–wildlife interactions such as livestock depredation (Kissui, Kiffner, König, & Montgomery, 2019) and crop raiding by great apes (Campbell-Smith, Sembiring, & Linkie, 2012) or multiple species (Gillingham & Lee, 2003; Hill, 2004). In this study, the magnitude of difference was c. 7.6 fold. This may even be an underestimation, as we considered perceived invasion frequency from the entire village, including data from areas further away from the protected area where elephant intrusions are less frequent (Figure 2a). We acknowledge a slight temporal mismatch between the interview data (interview data: recall for 2014–2015; farm monitoring: 2016–2019). However, given the magnitude of the difference and the relatively small variation in the yearly effects (Table 1), we assume that such disjunctions are unlikely to be explained by year-to-year variation in elephant movement.

Interestingly, interviewees apparently also perceived that elephant groups were larger than observed based on tracks. Certainly, accurate herd size estimation is difficult if based solely on tracks, yet the emerging pattern (Figure 2c) suggests that this difference may indeed be disjointed (as differentiating tracks from single vs. large elephant herds can be done with some confidence).
In this case study, most crop raiding likely occurred by single elephants which aligns with other research that has found elephant bulls to be responsible for the majority of crop raiding events (Hoare, 2001; Jackson et al., 2008).

Multiple hypotheses have been suggested to explain this apparent disjunction between perception and reality, including extreme damage events (which occasionally occurred in our study as indicated by the wide margin of crop damages Figure 5a), opportunity costs associated with guarding farm plots, a feeling of powerlessness to deal with wildlife (Gillingham & Lee, 2003), or underlying deep-rooted conflicts such as broader disagreements with protected area management (Zimmermann et al., 2020). Additional studies could be insightful to substantiate these hypotheses and may help elucidating whether local attitudes toward elephants improve if elephant damage is effectively reduced (Davies et al., 2011).

### 4.2 Integrated assessment of mitigation methods

The work presented by Denninger Snyder and Rentsch (2020) provides a suitable framing for a multi-dimensional assessment of the two mitigation methods (Table 2).

The general attitudes toward the tested mitigation methods suggested openness among the interviews toward beehive and chili fences, whereas more interviewees were willing to implement chili fences. While the majority of interviewed subjects were open to try beehive fences (Figure 3), those who did not expressed their concerns that bees may sting them while working on farms. Indeed, we had to shift one of the beehive fences to another plot because neighbors did not tolerate the bees. In addition, we received complaints that bees caused problems when livestock grazed on the farms (livestock grazing is common once crops have been harvested), when farmers worked on their farms, or when children played in the vicinity of the fences. In terms of attitudes, we thus evaluated chili fences with 3 and beehive fences with 2 points (Table 2).

Surprisingly, none of the three indicators employed (likelihood of farm intrusion, crop damage by elephant, or the extent of monetary losses) provided strong evidence for the effectiveness of either beehive or chili fences in reducing crop damages caused by elephants. In part, nonsignificance of treatment effects may be the result of limited spatial replication and unequal sample sizes of treatments (especially considering few beehive treatments), possibly resulting in low test power (Khorozyan, 2020). Nevertheless, nonsignificant reduction of crop damage (and occasional greater elephant intrusion and damage likelihood in treatments relative to control sites) is surprising because previous studies reported strong evidence for the effectiveness of beehive (King et al., 2011, 2017; Scheijen et al., 2019), and

| TABLE 2 | Qualitative assessment of beehive and chili fences as a means to mitigate crop raiding by elephants in the Tloma case study, Tanzania |
|-----------|---------------------------------------------------------------|
| **Beehive fence** | **Chili fence** |
| **Attitudes** | | |
| Preferences | 2 (partly skeptical) | 3 (open to try) |
| Resistance to change | n/a | n/a |
| Risk aversion | n/a | n/a |
| **Effectiveness** | | |
| Damage prevention | 1 | 2 |
| **Sustainability (capacity)** | | |
| Labor | 2 (initial setup is intensive) | 2 (regular maintenance needed) |
| Material | 1 (costly material input needed) | 2 (little investment) |
| Local availability | 3 (beekeeping common in area) | 3 (all material locally available) |
| Local expertise | 1 (special knowledge needed) | 2 (little special knowledge needed) |
| Time to habituation | 2 (beekeeping requires training; bees may not immediately occupy hives) | 2 (one training sufficient) |
| **Scalability** | | |
| Can be done without external support | 2 (training in beekeeping, initial investment may be prohibitive) | 3 (no external support necessary after initial training) |
| Availability of materials | 2 (beehives available but costly) | 3 (materials available & inexpensive) |
| Saturation point | 1 (carrying capacity of bees in landscapes likely limited) | 2 (can easily be scaled up) |

Note: Criteria of the assessment (attitudes, effectiveness, sustainability, and scalability) have been adopted from a recent framework developed by Denninger Snyder and Rentsch (2020). Points (3 points: very effective/conducive for adoption; 2 points: intermediate effective/conducive for adoption; 1 point: less effective/conducive for adoption) were assigned by the authors based on interview data (attitudes), daily farm monitoring on experimental plots (effectiveness), and experiences during the case study (sustainability and scalability).
chili (Chang’a et al., 2016; Davies et al., 2011) fences. However, such a finding is consistent within a broader context of assessing evidence for the effectiveness of methods to prevent damage by wildlife, as reviews on this topic typically highlight mixed and often limited effectiveness of different prevention methods (Hoare, 2012, 2015; van Eeden et al., 2018).

In this case study, chili fences appear as partially effective in reducing crop damage (Figure 5), but the effect sizes were statistically not significant. While chili fences did not prevent the occurrence of crop damages, the economic crop losses in this treatment were in a narrower range (US $ 0.2–13.9 month$^{-1}$ ha$^{-1}$) as compared to the control (US $ 0–22.8$ month$^{-1}$ ha$^{-1}$) or the beehive fences (US $ 0–55.1$ month$^{-1}$ ha$^{-1}$). This suggests that chili fences can at least prevent large economic losses in farms. Although elephants occasionally broke the chili fences, elephants possibly spend little time (and thus cause relatively little damage) in chili-fenced farms due to the olfactory deterrence function of chili (Osborn, 2002). The limited effectiveness of beehive fences can partially be explained by the fact that elephants in our study, and indeed other study areas (Jackson et al., 2008; King et al., 2011), primarily raid crops at night, when bees reduce their activity (Kaiser, 1988; Kronenberg & Heller, 1982). Thus, beehive fences may be limited in their ability to reduce nocturnal crop raiding by elephants (Hoare, 2012). While deterring elephants with bees may clearly work (King et al., 2010; Ngama, Korte, Bindelle, Vermeulen, & Poulsen, 2016; Vollrath & Douglas-Hamilton, 2002), the nature of the deterrent may cause unforeseen issues. For example, on one occasion elephants approached a beehive fence upon returning to the forest. The elephants triggered the wire, followed by a subsequent attack by bees. As the fence blocked their way to the forest, the elephants fled from the bees by running back to the village land, causing additional trampling damage to adjacent properties in the process. In summary, we thus assigned 2 points for chili and 1 point for beehive fences for the effectiveness criteria (Table 2).

Likely, the limited effectiveness of both methods in this case study is associated with aspects of sustainability of their implementation. For example, because the deterrent effect of chili is likely closely related to time since application, a more frequent re-application of the chili-oil solution (and including the time since re-application as covariate in assessment models) may provide greater effectiveness, yet requires more manual labor and greater financial investment. Similarly, we hypothesize that the overall poor performance of beehive fences in these trials was related to low bee occupancy. From 2018 to 2019, bee occupancy was relatively low in the two fences (28.6% [6/21]; 34.8% [8/23]) and this may explain their limited effectiveness (Scheijen et al., 2019). Indeed, low bee occupancy and substantial time lags between beehive fence construction and bee occupancy have been observed in other studies as well (King et al., 2011).

Obviously, the investment and maintenance costs are an important consideration even if costs for these trials were mostly covered by external funds. Renewing chili fences costs approx. US $14 per hectare and application (Chang’a et al., 2016) and thus c. US $10 for an average sized farm (0.7 ha) in our area. With c. US $50 per hive and a required spacing of 10 m, a perimeter fence for one hectare would cost c. US $2000 for hives only (and thus excluding additional costs for wire and poles). Even for a 0.7 ha farm (~US $1400), these costs are likely prohibitive for subsistence farmers in our study area. Theoretically, beehive fences can produce bee products (honey and wax) and thus may generate money to recuperate the initial investment and generate income (King et al., 2017). Unfortunately, in our case study third parties repeatedly stole honey and wax, and hence effectively reduced the potential of income generation. In addition, beehives were repeatedly stolen by third parties and placed inside the NCA for honey production. Although the stolen beehives were recovered with the help of village and NCA management, such human inference can limit both the effectiveness and economic viability of this method. Moreover, these examples highlight the clandestine human-human conflicts that can hinder the effective solution of human-wildlife conflicts. In sum, and based on the experience of this case study (which may not be representative for other settings) chili fences thus scored more points that beehive fences in terms of sustainability (Table 2).

Similarly, chili fences scored higher in the scalability criteria than beehive fences (Table 2). Actively trying to increase the occupancy of beehives in fences (Ngama et al., 2016), or implementing large-scale beehive fences may not only be constrained by funding and technical expertise but also by the carrying capacity of bees in the landscape. In our case study, this appears limited by the availability of flowering plants and widespread distribution of beehives (operated by subsistence beekeepers and small business) across the landscape. Despite initial demonstrations to train farmers in setting up chili fences (Gunaryadi et al., 2017), no additional farmers set up chili fences; we assume that the associated costs of setting up chili fences may have prevented widespread adoption. If the observed slight damage reductions (Figure 5) are deemed sufficient enough to upscale the use of chili fences (Chang’a et al., 2016), cost–benefit considerations will be an important aspect. In terms of fairness and benefit distribution, it may be a worthwhile consideration...
that stakeholders who benefit financially from the presence of elephants (e.g., lodges, administration of the protected area) could bear these costs (Sommerville, Jones, Rahajaharison, & Milner-Gulland, 2010). Possibly, such concentrated and joint efforts could also alleviate parts of the apparent deep-rooted conflict that may underlie the negative perceptions of elephants in this area. If such a funding and implementation scheme could be established, fencing off the border line between the village and the NCA (instead of perimeter fences around single farms) could be a cost-effective solution.

In summary, our multi-dimensional assessment suggests that chili fences appear more effective and score more points in terms of attitudes, sustainability and scalability and thus appear to have greater adoption potential (Table 2). Nevertheless, our analyses highlight substantial potential for improving the effectiveness, sustainability and scalability of both methods and the need to include socio-economic factors when evaluating methods to mitigate human-wildlife conflicts (Denninger Snyder & Rentsch, 2020).

4.3 | Ways toward human–elephant coexistence

Results of this case study mirror previous conclusions that mitigating crop raiding by elephants is challenging (Hoare, 2012, 2015) and that no single prevention method is a panacea to solve this issue. One potential for more effective crop reduction could be to focus interventions on months when crops are mature (Denninger Snyder et al., 2021), and thus elephant damage is most likely (in this study area from April to July and September to October; Table 1). In addition, this study indicated that chili fences are only partially effective, and that over time elephants may become habituated to crop protection methods (Figure 4). Therefore, use of additional deterrent methods during high risk periods may be a worthwhile consideration. If such additional methods are to be implemented, particular emphasis should be directed toward assessing not only technical effectiveness, but also attitudes, sustainability and scalability to maximize the potential for local adoption (Denninger Snyder & Rentsch, 2020).

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CONFLICT OF INTEREST

Hayley Adams and Krissie Clark were partly funding this research project, yet were not involved in study design or data analysis.

AUTHOR CONTRIBUTIONS

Christian Kiffner: conceptualization, methodology, validation, formal analysis, investigation, resources, data curation, writing—original draft, writing—review & editing, visualization, project administration, funding acquisition. Isabel Schaal, Leah Cass, Kiri Peirce, Olivia Sussman, Ashley Gruese, Ellie Wachtel: formal analysis, investigation, data curation, writing—review & editing, visualization. Hayley Adams, Krissie Clark: conceptualization, methodology, resources, writing—review & editing, funding acquisition. Hannes J. König: conceptualization, methodology, writing—review & editing. John Kioko: conceptualization, methodology, validation, investigation, resources, writing—review & editing, project administration, funding acquisition.

DATA AVAILABILITY STATEMENT

All data are available on reasonable request from the corresponding author (ckiffne@gwdg.de).

ETHICS STATEMENT

This research was carried out with permission from TAWIRI and COSTECH (permits: 2015-169-ER-2013-191 to 2019-92-NA-2013-191) and consent of the T’loma village administration. The interview protocol was reviewed and was exempt from further Institutional Review Board examination under Type B, Category 2 of the US federal code 45 section 46 on human subject protections in research. All interviewees were above 18 years of age and expressed their consent, and the data were managed to ensure anonymity.

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REFERENCES

Barua, M., Bhagwat, S. A., & Jadhav, S. (2013). The hidden dimensions of human-wildlife conflict: Health impacts, opportunity and transaction costs. Biological Conservation, 157, 309–316.

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). lme4: Linear mixed-effects models using Eigen and S4. Retrieved from http://cran.r-project.org/package=lme4

Bencin, H., Kioko, J., & Kiffner, C. (2016). Local people’s perceptions of wildlife species in two distinct landscapes of northern Tanzania. Journal for Nature Conservation, 34, 82–92.
Brannon, P. S., Merkle, J. A., Pringle, R. M., King, L., Tindall, T., Stalmans, M., & Long, R. A. (2019). An experimental test of community-based strategies for mitigating human–wildlife conflict around protected areas. *Conservation Letters*, 13, e12679.

Browne-Nuñez, C., Jacobson, S. K., & Vaske, J. J. (2013). Beliefs, attitudes, and intentions for allowing elephants in group ranches around Amboseli national park, Kenya. *Wildlife Society Bulletin*, 37, 639–648.

Campbell-Smith, G., Sembiring, R., & Linkie, M. (2012). Evaluating the effectiveness of human-orangutan conflict mitigation strategies in Sumatra. *Journal of Applied Ecology*, 49, 367–375.

Caro, T., Jones, T., & Davenport, T. R. B. (2009). Realities of documenting wildlife corridors in tropical countries. *Biological Conservation*, 142, 2807–2811.

Chang’a, A., de Souza, N., Muya, J., Keyuu, J., Mwakatobe, A., Malugi, L., Ndossi, H. P., Konuche, J., ... Olson, D. (2016). Scaling-up the use of chili fences for reducing human-elephant conflict across landscapes in Tanzania. *Tropical Conservation Science*, 9, 921–930.

Davies, T. E., Wilson, S., Hazarika, N., Chakrabarty, J., Das, D., Hodgson, D. J., & Zimmermann, A. (2011). Effectiveness of intervention methods against crop-raiding elephants. *Conservation Letters*, 4, 346–354.

Denninger Snyder, K., Mneney, P., Benjamin, B., Mkilindi, P., & Mbise, N. (2021). Seasonal and spatial vulnerability to agricultural damage by elephants in the western Serengeti, Tanzania. *Oryx*, 55(1), 139–149.

Denninger Snyder, K., & Rentsch, D. (2020). Rethinking assessment of success of mitigation strategies for elephant-induced crop damage. *Conservation Biology*, 34, 829–842.

Dublin, H. T., & Hoare, R. E. (2004). Searching for solutions: The evolution of an integrated approach to understanding and mitigating human–elephant conflict in Africa. *Human Dimensions of Wildlife*, 9, 271–278.

Game, E. T., Tallis, H., Olander, L., Alexander, S. M., Busch, J., Cartwright, N., ... Sutherland, W. J. (2018). Cross-discipline evidence principles for sustainability policy. *Nature Sustainability*, 1, 452–454.

Gillingham, S., & Lee, P. C. (2003). People and protected areas: A study of local perceptions of wildlife crop-damage conflict in an area bordering the Selous Game Reserve, Tanzania. *Oryx*, 37, 316–325.

Graham, M. D., Douglas-Hamilton, I., Adams, W. M., & Lee, P. C. (2009). The movement of African elephants in a human-dominated land-use mosaic. *Animal Conservation*, 12, 445–455.

Graham, M. D., Notter, B., Adams, W. M., Lee, P. C., & Ochieng, T. N. (2010). Patterns of crop-raiding by elephants, *Loxodonta africana*, in Laikipia, Kenya, and the management of human–elephant conflict. *Systematics and Biodiversity*, 8, 435–445.

Gunaryadi, D., Sugiyo, & Hedges, S. (2017). Community-based human-elephant conflict mitigation: The value of an evidence-based approach in promoting the uptake of effective methods. *PLoS One*, 12, e0173742.

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

Hill, C. M. (2004). Farmers’ perspectives of conflict at the wildlife-agriculture boundary: Some lessons learned from African subsistence farmers. *Human Dimensions of Wildlife*, 9, 279–286.

Hoare, R. (2000). African elephants and humans in conflict: The outlook for co-existence. *Oryx*, 34, 34–38.

Hoare, R. (2001). Management implications of new research on problem elephants. *Pachyderm*, 30, 44–48.

Hoare, R. (2012). Lessons from 15 years of human-elephant conflict mitigation: Management considerations involving biological, physical and governance issues in Africa. *Pachyderm*, 51, 60–74.

Hoare, R. (2015). Lessons from 20 years of human–elephant conflict mitigation in Africa. *Human Dimensions of Wildlife*, 20, 289–295.

Hoare, R. E. (1999). Determinants of human-elephant conflict in a land-use mosaic. *Journal of Applied Ecology*, 36, 689–700.

Hoare, R. E., & du Toit, J. T. (1999). Coexistence between people and elephants in African Savannas. *Conservation Biology*, 13, 633–639.

Homewood KM, Rodgers WA. 1991. Maasailand ecology: Pastoralist development and wildlife conservation in Ngorongoro, Tanzania.

Jackson, T. P., Mosojane, S., Ferreira, S. M., & van Aarde, R. J. (2008). Solutions for elephant *Loxodonta africana* crop raiding in northern Botswana: Moving away from symptomatic approaches. *Oryx*, 42, 83–91.

Kaiser, W. (1988). Busy bees need rest, too. *Journal of Comparative Physiology A*, 163, 565–584.

Kansky, R., Kidd, M., & Knight, A. T. (2014). Meta-analysis of attitudes toward damage-causing mammalian wildlife. *Conservation Biology*, 28, 924–938.

Kardozo, M., & Osborn, F. V. (2005). Can bees deter elephants from raiding crops? An experiment in the communal lands of Zimbabwe. *Pachyderm*, 39, 26–32.

Kardozo, M., & Osborn, F. V. (2015). Community based conflict mitigation trials: Results of field tests of chilli as an elephant deterrent. *Journal of Biodiversity & Endangered Species*, 9, 278.

Kassambura, A. (2020a). ggpubr: “ggplot2” Based Publication Ready Plots. Retrieved from https://rpkgs.datanovia.com/ggpubr/

Kassambura, A. (2020b). rstatix: Pipe-Friendly Framework for Basic Statistical Tests. Retrieved from https://rpkgs.datanovia.com/rstatix/

Khorozyan, I. (2020). A comparison of common metrics used to quantify the effectiveness of conservation interventions. *PeerJ*, 8, e9873.

King, L. E., Douglas-Hamilton, I., & Vollrath, F. (2007). African elephants run from the sound of disturbed bees. *Current Biology*, 17, 832–833.

King, L. E., Douglas-Hamilton, I., & Vollrath, F. (2011). Beehive fences as effective deterrents for crop-raiding elephants: Field trials in northern Kenya. *African Journal of Ecology*, 49, 431–439.

King, L. E., Lala, F., Nzumu, H., Mwambingu, E., & Douglas-Hamilton, I. (2017). Beehive fences as a multidimensional conflict-mitigation tool for farmers coexisting with elephants. *Conservation Biology*, 31, 743–752.

King, L. E., Solitis, J., Douglas-Hamilton, I., Savage, A., & Vollrath, F. (2010). Bee threat elicits alarm call in African elephants. *PLoS One*, 5, e10346.

Kioko, J., Kiringe, J., & Omondi, P. (2006). Human-elephant conflict outlook in the Tsavo-Amboseli ecosystem, Kenya. *Pachyderm*, 41, 53–60.
Kissui, B. M., Kiffner, C., König, H. J., & Montgomery, R. A. (2019). Patterns of livestock depredation and cost-effectiveness of fortified livestock enclosures in northern Tanzania. *Ecology and Evolution, 9*, 11420–11433.

König, H. J., Kiffner, C., Kramer-schadt, S., Fürst, C., Keuling, O., & Ford, A. T. (2020). Human–wildlife coexistence in a changing world: 00–1–9.

Kronenberg, F., & Heller, H. C. (1982). Colonial thermoregulation in honey bees (*Apis mellifera*). *Journal of Comparative Physiology, 148*, 65–76.

Mackenzie, C. A., & Abahyona, P. (2012). Elephants in the garden: Financial and social costs of crop raiding. *Ecological Economics, 75*, 72–82.

Malima, C., Hoare, R., & Blanc, J. J. (2005). Systematic recording of human-elephant conflict: A case study in South-Eastern Tanzania. *Pachyderm, 38*, 29–38.

Mariki, S. B., Svarstad, H., & Benjaminsen, T. A. (2015). Geophagy and nutrient supplementation in honey bees (*Apis mellifera*). *Journal of Comparative Physiology, 148*, 65–76.

Mills, A. J., & Milewski, A. V. (2006). Geophagy and nutrient supplementation in the Ngorongoro Conservation Area, Tanzania, with a particular reference to Selenium, cobalt and molybdenum. *Journal of Zoology, 271*, 110–118.

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. Gland. Retrieved from https://www.iucn.org/sites/dev/files/import/downloads/heucgcarev.pdf

Ngama, S., Korte, L., Bindelle, J., Vermeulen, C., & Poulsen, J. R. (2016). How bees deter elephants: Beehive trials with forest elephants (*Loxodonta africana cyclotis*) in Gabon. *PLOS One, 11*, 1–12.

O’Connell-Rodwell, C. E., Rodwell, T., Rice, M., & Hart, L. A. (2000). Geophagy and nutrient supplementation in the Ngorongoro Conservation Area, Tanzania, with a particular reference to Selenium, cobalt and molybdenum. *Journal of Zoology, 271*, 110–118.

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. Gland. Retrieved from https://www.iucn.org/sites/dev/files/import/downloads/heucgcarev.pdf

Osborn, F. V. (2002). Capsicum oleoresin as an elephant repellent: Field trials in the communal lands of Zimbabwe. *Journal of Wildlife Management, 66*, 674–677.

Osborn, F. V., & Parker, G. E. (2002). Community-based methods to reduce loss to crop raiding elephants. *Pachyderm, 33*, 32–38.

Owenya, M. Z., Mariki, W. L., Kienzle, J., Friedrich, T., & Kassam, A. (2011). Conservation agriculture (CA) in Tanzania: The case of the Mwaanga BCA farmer field school (FFS), Rhotia village, Karatu district, Arusha. *International Journal of Agricultural Sustainability, 9*, 145–152.

Pozo, R. A., Coulson, T., McCulloch, G., Stronza, A. L., & Songhurst, A. C. (2017). Determining baselines for human-elephant conflict: A matter of time. *PLOS One, 12*, e0178840.

Prins, H. H. T., & Loth, P. E. (1988). Rainfall patterns as background to plant phenology in northern Tanzania. *Journal of Biogeography, 15*, 451–463.

R Core Team. 2016. *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna. Retrieved from http://www.r-project.org/ Rodgers, W. A., & Lobo, J. D. (1982). Elephant control and legal ivory exploitation: 1920 to 1976. *Tanzania Notes and Records, 84*(85), 25–54.

Salafsky, N., Bosovich, J., Burivalova, Z., Dubois, N. S., Gomez, A., Johnson, A., ... Wordley, C. F. R. (2019). Defining and using evidence in conservation practice. *Conservation Science and Practice, 1*, e27.

Scheijen, C. P. J., Richards, S. A., Smit, J., Jones, T., & Nowak, K. (2019). Efficacy of beehive fences as barriers to African elephants: A case study in Tanzania. *Oryx, 53*, 92–99.

Schlossberg, S., Chase, M. J., Gobush, K. S., Wasser, S. K., & Lindsay, K. (2020). State-space models reveal a continuing elephant poaching problem in most of Africa. *Scientific Reports, 10*, 1–9 Springer US.

Shaffer, L. J., Khadka, K. K., Van Den Hoek, J., & Naithani, K. J. (2019). Human-elephant conflict: A review of current management strategies and future directions. *Frontiers in Ecology and Evolution, 6*, 235.

Sitati, N., Leader-Williams, N., Stephenson, P. J., & Walpole, M. (2007). Mitigating human-elephant conflict in a human dominated landscape: Challenges and lessons from Transmara District, Kenya. In M. Walpole & M. Linkie (Eds.), *Mitigating human-elephant conflict: Case studies from Africa and Asia* (pp. 37–46). Cambridge: Fauna & Flora International (FFI).

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., Smith, R. J., & Leader-Williams, N. (2003). Predicting spatial aspects of human and elephant conflict. *Journal of Applied Ecology, 4*, 667–677.

Sitati, N. W., Walpole, M. W., Leader-Williams, N., & Stephenson, P. J. (2012). Human–elephant conflict: Do elephants contribute to low mean grades in schools within elephant ranges? *International Journal of Biodiversity and Conservation, 4*, 614–620.

Sommerville, M., Jones, J. P. G., Rahajaharison, M., & Milner-Gulland, E. J. (2010). The role of fairness and benefit distribution in community-based payment for environmental services interventions: A case study from Menabe, Madagascar. *Ecological Economics, 69*, 1262–1271.

Thouless, C. R. (1994). Conflict between humans and elephants on private land in northern Kenya. *Oryx, 28*, 119–127.

van Eeden, L. M., Crowther, M. S., Dickman, C. R., Macdonald, D. W., Ripple, W. J., Ritchie, E. G., & Newsome, T. M. (2018). Managing conflict between large carnivores and livestock. *Conservation Biology, 32*, 26–34.

Vollrath, F., & Douglas-Hamilton, I. (2002). African bees to control African elephants. *Naturwissenschaften, 89*, 508–511.

Wakoli, E. N., & Sitati, N. (2012). Analysis of temporal and distribution patterns of elephant attacks on humans and elephant mortality in Transmara District, Kenya. *Greener Journal of Environmental Management and Public Safety, 1*, 27–37.

Wickham, H. (2016). ggplot2: Elegant Graphics for Data Analysis. Zimmermann, A., McQuinn, B., & Macdonald, D. W. (2020). Levels of conflict over wildlife: Understanding and addressing the right problem. *Conservation Science and Practice, 2*, e259.
Zuur, A. F., Ieno, E. N., Walker, N. J., Saveliev, A. A., & Smith, G. M. (2009). *Mixed effects models and extensions in ecology*. New York: Springer.

**SUPPORTING INFORMATION**

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

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