Received: 25 June 2019 | Revised: 17 September 2019 | Accepted: 23 September 2019
DOI: 10.1111/conl.12679

Conservation Letters
A journal of the Society for Conservation Biology
Open Access
WILEY

LETTER

An experimental test of community-based strategies for mitigating human–wildlife conflict around protected areas

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Funding information
Save the Elephants; Rufford Foundation; Campizondo Foundation; Artipopart; National Science Foundation, Grant/Award Numbers: IOS-1656527, IOS-1656642

Abstract
Natural habitats are rapidly being converted to cultivated croplands, and crop-raiding by wildlife threatens both wildlife conservation and human livelihoods worldwide. We combined movement data from GPS-collared elephants with camera-trap data and local reporting systems in a before–after-control-impact design to evaluate community-based strategies for reducing crop raiding outside Mozambique's Gorongosa National Park. All types of experimental fences tested (beehive, chili, beehive and chili combined, and procedural controls) significantly reduced the number of times elephants left the Park to raid crops. However, placing beehive fences at a subset of key crossing locations reduced the odds that elephants would leave the Park by up to 95% relative to unfenced crossings, and was the most effective strategy. Beehive fences also created opportunities for income generation via honey production. Our results provide experimental evidence that working with local communities to modify both animal behavior and human attitudes can mitigate conflict at the human–wildlife interface.

KEYWORDS
African savanna elephant, beehive fences, chili fences, crop raiding, human-dominated landscapes, keystone species, *Loxodonta africana*, movement corridors

1 | INTRODUCTION

The availability of high-quality forage in cultivated croplands attracts wildlife (e.g., Middleton et al., 2017), and crop raiding causes billions of dollars in economic losses every year (Conover, 2002). Crop raiding by elephants (*Loxodonta africana*, *Elephas maximus*) poses an especially severe threat to human livelihoods in agroecosystems of Africa and Asia (Chiyo, Cochrane, Naughton, & Basuta, 2005; O'Connell-Rodwell, Rodwell, Rice, & Hart, 2000; Shaffer, Khadka, Van Den Hoek, & Naithani, 2019) and often occurs along the boundaries of protected areas, where close proximity of dense human and wildlife populations exacerbates human–wildlife conflict (Bruner, Gullison, Rice, & da Fonseca, 2001; Wittemyer, Elsen, Bean, Burton, & Brashares, 2008).

Because human–elephant conflict involves both elephants and humans, efforts to foster coexistence should ideally integrate the modification of both elephant behavior (Mumby & Plotnik, 2018) and human behavior/perceptions, the latter of which are shaped by myriad factors (Dickman, 2010; Treves & Bruskotter, 2014). Attitudes toward wildlife and protected areas are influenced not only by crop losses per se, but also by the degree to which individual beliefs and values are included in decision-making processes (Infield, 2001; Bennet et al., 2016). Thus, working closely with communities that are experiencing conflict to foster relationships and establish rapport, and then equipping them to participate directly in the mitigation process, may be an effective means of fostering human–wildlife coexistence through a combination of decreased crop losses and increased tolerance of elephants among community members (Madden, 2004; Shaffer et al., 2019).

The coupling of animal deterrents with tangible incentives to humans also holds powerful potential for fostering long-term coexistence between humans and elephants. Indeed, offsetting economic losses is considered essential to managing human–elephant conflict successfully (Hartter, Solomon, Ryan, Jacobson, & Goldman, 2014; Snyman, 2014). Although programs for compensating subsistence farmers for crop losses to elephants have met with difficulties in Africa (Shaffer et al., 2019), the production of marketable commodities such as honey (King, Lala, Nzumu, Mwambingu, & Douglas-Hamilton, 2017), chili products (Hedges & Gunaryadi, 2010), or other cash crops (Parker & Osborn, 2006) as a byproduct of deterrence can increase community buy-in and foster greater tolerance toward elephants (Shaffer et al., 2019).

We studied human–elephant conflict along the southern border of Gorongosa National Park, Mozambique, where the elephant population is recovering from decimation by a civil war that ended in 1992 (Pringle, 2017; Stalmans, Massad, Peel, Tarnita, & Pringle, 2019). The goal of our project was simultaneously to reduce the frequency of crop-raiding by elephants and to improve attitudes toward elephants by working with community members to develop and test multiple mitigation techniques with the potential to produce profitable byproducts. We evaluated the efficacy of three techniques for reducing elephant crop-raiding: (1) beehive fences (Karidozo & Osborn, 2005; King, Lawrence, Douglas-Hamilton, & Vollrath, 2009; King, Douglas–Hamilton, & Vollrath, 2011; King et al., 2017; Scheijen, Richards, Smit, Jones, & Nowak, 2018); (2) chili-pepper fences (Hedges & Gunaryadi, 2010; Wiafe & Sam, 2014); and (3) a combination of the two that we termed "spicy beehive" fences. We conducted a manipulative experiment in which we used two independent data streams (movement data from GPS-collared elephants, and daily reports from community members about the presence of elephants at each fence location) to compare: (1) use of crossing points by GPS-collared elephants between years with (year 2) and without (year 1) fences; and (2) use of crossing points with treatment, procedural-control, or no fences during year 2. We hypothesized that fences of any kind would reduce the number of times elephants exited the Park in year 2 (H1). We further hypothesized that "spicy beehive" fences would be most effective for reducing crop raiding by elephants, followed by beehive fences, chili fences, and procedural-control fences (H2).

2 | MATERIAL AND METHODS

2.1 | Study area

In the Rift Valley of Gorongosa, annual precipitation averages roughly 840 mm and occurs mostly between November and March (Tinley, 1977). The Park is surrounded by a 5,333-km^2 "buffer zone" where an estimated 200,000 people currently reside. A large proportion of these residents cultivate crops along the southern boundary of the Park, which is formed by the Pungue River (Figure 1). From the 1970s–1990s, >90% of Gorongosa's 2,500+ elephants were killed to feed soldiers and to finance the purchase of arms during the Mozambican Civil War (Convery & Morley, 2014; Stalmans, 2012). Elephants are now recovering under the auspices of the Gorongosa Project (Pringle, 2017), and the most recent aerial census counted roughly 600 individuals (Stalmans et al., 2019). After the war, however, much of the buffer zone has been converted to agricultural lands (Figure S1, Appendix S1), which strongly attract elephants (Branco et al., 2018).

2.2 | Animal capture and location data

We fit 12 adult male elephants (six in December 2015 and six in August 2016), all of which were captured <1 km from crops, with GPS collars (Model AWT IM-SAT, Africa Wildlife Tracking, Pretoria, South Africa) that were programmed to transmit a location every 30 minutes for 2 years through the iridium satellite system. (Male elephants are generally more prone to crop-raiding behavior: Hoare, 1999.) A detailed description of our capture and handling procedures is provided by Branco et al. (2018); all procedures were approved by the Animal Care and Use Committee at the University of Idaho (protocol #2015–39). In addition, our research was certified as exempt from continuing review by the Institutional Review Board at the University of Idaho.

2.3 | Community-based data

To evaluate the relative effectiveness of different fence types at preventing elephants from crossing the Pungue to raid crops (i.e., to test H2), we hired and trained a group of six community members to work as project monitors during year 2 of the study. Each monitor was responsible for monitoring 1–4 treatment or control fences (depending on distance to their home and size of the fences), which they visited

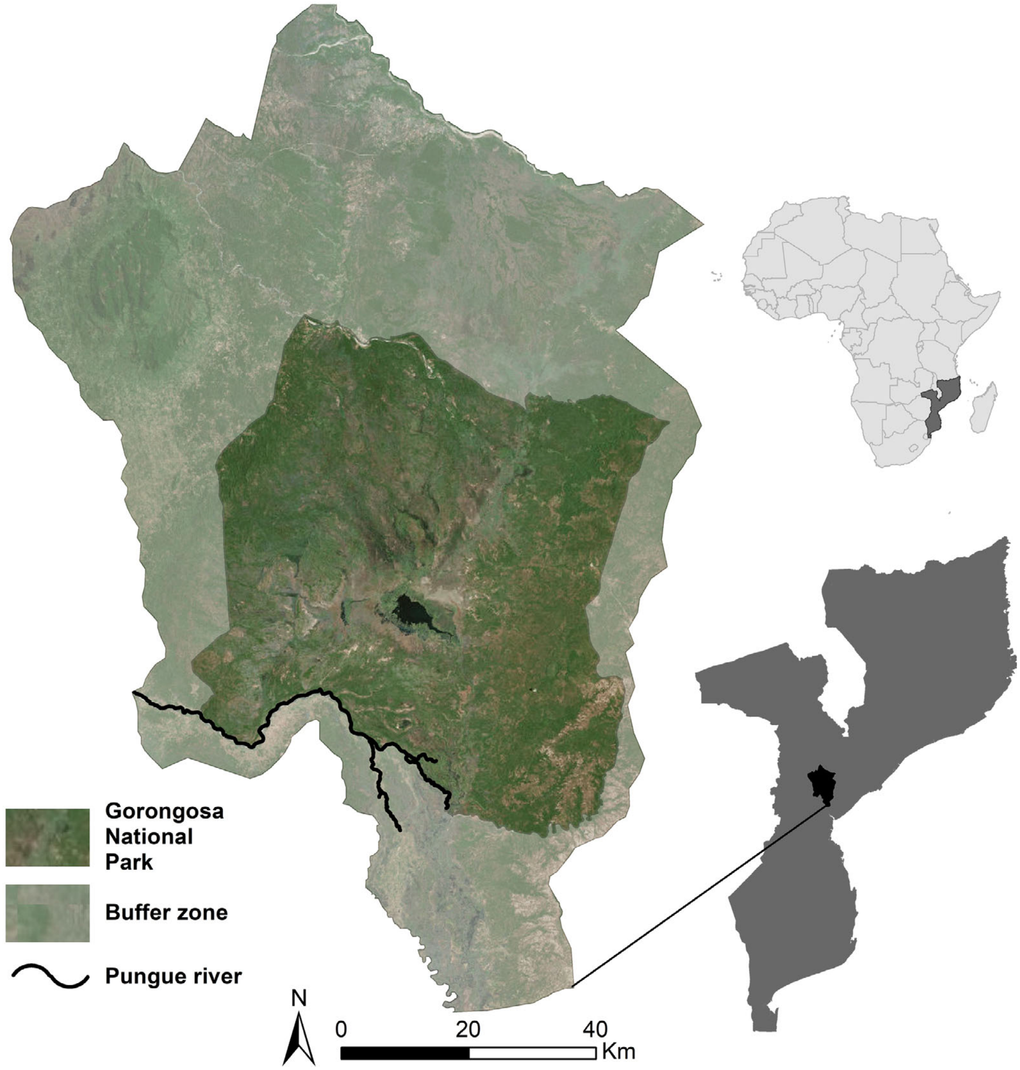

FIGURE 1 Map of our study area in Gorongosa National Park, Mozambique in southeastern Africa. The Pungue River forms much of the southern boundary of the Park, where we conducted our experiment. The Park is surrounded by a 5,333-km^2 buffer zone where ~200,000 people currently reside, many of whom are subsistence farmers

each morning to complete reports on whether elephants had approached the fence, whether they had crossed the fence, and the approximate number of elephants that had visited the location (based on elephant footprints and fresh dung, damage to fences, and photos from camera traps; Appendix S2). Monitors were responsible for daily maintenance of fences and camera traps during the mitigation experiment, and received full-time salaries from Gorongosa National Park (commensurate with those of full-time science technicians employed by the park), as well as uniforms and bicycles to facilitate access to their assigned areas in communities along the Pungue River.

2.4 | Randomized mitigation experiment

We used elephant GPS-collar data in combination with information gleaned from community members to visually identify locations where elephants routinely crossed the Pungue to raid crops. We then visited all of the known crossing locations that were used by elephants to access four of the most-affected communities in the buffer zone—Micheu, Madangua, Vinho, and Bebedo—which were dispersed along ~18.7 km of the Pungue River (n = 18 locations). We only had sufficient resources to construct 13 fences as part of our mitigation experiment, and thus we randomly selected 13 of these 18 crossings as treatment locations (Figure S3, Appendix S3). Two of these locations could not be accessed by vehicle and were therefore excluded from the study and replaced by random selection from the five crossings that were not selected as treatment locations (vehicular access was essential for ensuring the safety of the research team and for transporting fence construction materials to the crossing locations). The remaining three accessible crossing locations were left unmanipulated; there were no systematic

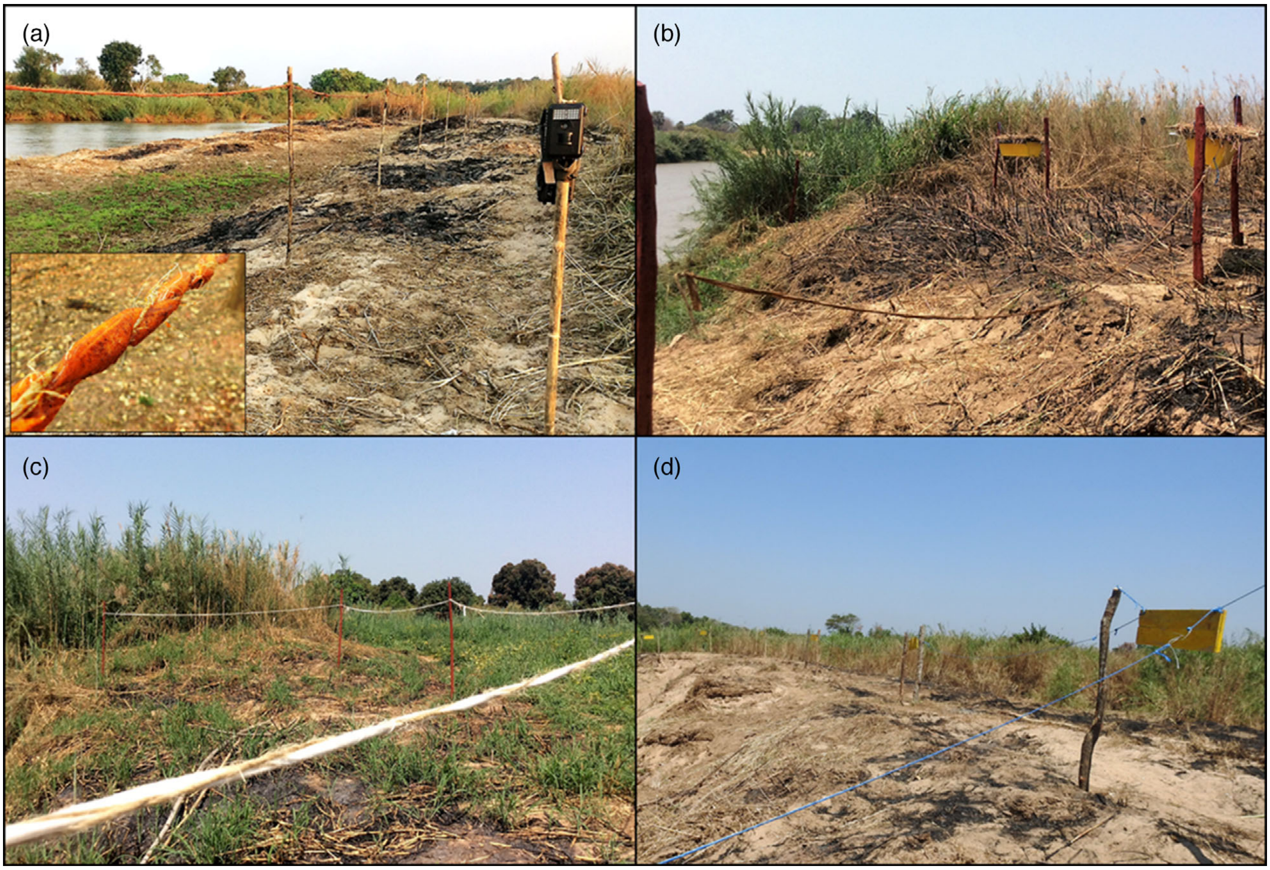

FIGURE 2 Examples of elephant-deterrent strategies evaluated as part of our mitigation experiment in the buffer zone of Gorongosa National Park (the park is to the left of each fence, farmlands to the right). (a) Chili fence. (b) Spicy beehive fence (beehive fences had the same design, but hives were connected by baling twine). (c) Fake chili fence (control). (d) Fake beehive fence (control)

differences in river width, width of the crossing path, or proximity to roads or agriculture between crossings where fences were placed and crossings that remained unfenced. For example, river width averaged 155 ± 30.3 m (*SE*) at locations where fences were constructed and 154 ± 7.0 m at unfenced locations. We assigned the four fence types to the 13 treatment locations in a completely randomized manner.

We constructed beehive fences (free-swinging hives connected with light bailing twine) at three crossings, chili fences (cotton fabric soaked in chili-impregnated vegetable oil and interwoven with sisal ropes) at three crossings, and spicy beehive fences (a combination of beehive and chili fences) at three crossings. In addition, we constructed beehive procedural-control fences (wooden planks of similar shape, size, and color as active hives; Figure 2) at two crossings and chili procedural-control fences (ropes without chili) at two crossings. Detailed descriptions of fence design and construction are in Appendix S2.

We left fences in place for 3 months (September 17 to December 20 2017) and evaluated results of the experiment using two independent data streams: (1) movements of GPS-collared elephants; and (2) daily reports from project monitors, which included assessments of elephant sign (e.g., tracks and dung), fence damage, and photos from camera traps. GPS-collar data were collected throughout 2016–2017, and allowed us to compare use of crossing locations before versus after fences were erected (H1), and to evaluate the effectiveness of different fence types at preventing elephants from crossing the river (H2). Project monitors collected data only during the mitigation experiment, and thus monitor data were used to test H2 only.

2.5 | Statistical analysis

We used generalized linear models (GLMs) to test our hypotheses that (H1) fences of any type would reduce the number of times elephants crossed the river to raid crops, and that (H2) spicy beehive fences would be most effective for reducing river crossings, followed by beehive fences, chili fences, and procedural-control fences. For analyses of GPS-collar data, the number of times collared elephants exited the Park at each of the 16 crossing locations was used as the response variable in a Poisson GLM. For analyses of monitor data, the proportion of fence approaches by elephants that ended in a river crossing (as opposed to a return to the park) was used as the response variable in a binomial GLM. Detailed descriptions of our statistical analyses are in Appendix S4.

3 | RESULTS

In our focal stretch of ~18.7 km of river adjacent to the four heavily affected settlements, there were 67 crossings by GPS-collared elephants between September 17 and December 20, 2016, but only 32 crossings during that same period in 2017 after fences were erected (Table S5a, Appendix S5). The mean number of crossings by GPS-collared elephants at locations that remained unmanipulated (unfenced) during the mitigation experiment doubled from 3.3 (95% CI = 1.25–5.35) in 2016 to 6.7 (95% CI = 3.79–9.61) in 2017, suggesting that elephants increased their use of unfenced crossings when fences were erected at alternative crossing locations (note that the majority of these posttreatment crossings occurred at a single unfenced location, NF2; Table S5a, Appendix S5). In contrast, the mean number of crossings at locations with fences declined from 4.4 (95% CI = 3.27–5.53) in 2016 (before fences) to 1.0 (95% CI = 0.46–1.54) in 2017 (after fences) (Figure 3). The Treatment × Year interaction was highly significant ($p < .001$), consistent with our prediction that there would be significantly fewer crossings at fenced than at unfenced locations in 2017, after fences were constructed. Park-wide (i.e., along the entire length of the Pungue River that borders the Park), the total number of crossings by GPS-collared elephants was 766 in 2016 (before fences) and 744 in 2017 (after fences).

Camera-trap imagery indicated that elephants were, in general, cautious in their interactions with fences (see Appendix S6 for more detailed information on elephant behavioral responses). All fence types, including procedural controls, significantly (all $p < .05$) reduced the number of times elephants crossed the river during the experiment in 2017 (Figure 4). Mean (±95% CI) predicted number of crossings per fenced crossing location (relative to unfenced crossing locations) was lowest at locations with beehive fences ($\bar{x} = 2.99 \pm 2.01$ fewer crossings), followed by spicy beehive fences ($\bar{x} = 1.90 \pm 1.21$ fewer crossings), procedural-control fences ($\bar{x} = 1.67 \pm 0.98$ fewer crossings), and chili fences ($\bar{x} = 1.61 \pm 1.07$ fewer crossings; Figure 4; Table S5a, Appendix S5), although none of the differences among fence types were statistically significant after controlling for multiple comparisons. Odds ratios (i.e., exponentiated regression coefficients) indicated that experimental fences reduced the odds of an elephant crossing the river by anywhere from 80% (chili fences) to 95% (beehive fences).

The data collected by project monitors during the experiment told a story that was qualitatively similar to the data from GPS-collared elephants. The mean (±95% CI) predicted proportion of approaches by elephants that resulted in a river crossing was lowest (relative to procedural-control fences) at beehive fences ($\bar{x} = 25\% \pm 35\%$ fewer crossings), followed by spicy beehive fences ($\bar{x} = 7\% \pm 35\%$ fewer crossings) and chili fences ($\bar{x} = 25\% \pm 35\%$ more crossings; Figure 4; Table S5b, Appendix S5). Again, however, none of the differences among fence types were statistically significant after controlling for multiple comparisons.

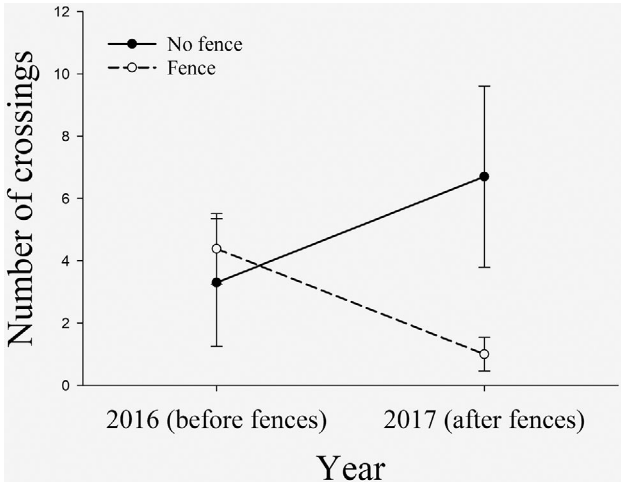

FIGURE 3 Mean number of river crossings (± 95% CI) by GPS-collared elephants ($n = 12$) at crossing locations that were or were not blocked by fences during our mitigation experiment from September 17 to December 20, in 2016 (prior to fence construction, when all crossings remained unobstructed) and in 2017 (after fences had been constructed at some crossings). The Treatment × Year interaction was significant ($p < .001$) in a Poisson GLM; p-values for the main effects of Treatment (Fence vs. No fence) and Year were $p = .42$ and $p = .07$, respectively

4 | DISCUSSION

All fence types in our study reduced crop-raiding excursions by elephants, providing support for our hypothesis (H1) that use of crossing points by elephants would decline in year 2 after fences were constructed. This result suggests that several different mitigation techniques can effectively reduce crop-raiding; combining multiple techniques may also help to minimize the potential for habituation (Hoare, 2015; Shaffer et al., 2019). Prior research has demonstrated that elephants quickly habituate to harmless mitigation methods (O'Connell-Rodwell et al., 2000), and we suspect that the effect of procedural-control fences in particular would quickly attenuate. On the contrary, honey bees are naturally avoided by elephants (King et al., 2011), and thus the likelihood of habituation is largely dependent upon hive occupation (King et al., 2017). Beehive fences were especially effective in our study, and hive occupancy reached 94% in the first 7 weeks following fence construction, likely aided by the proximity

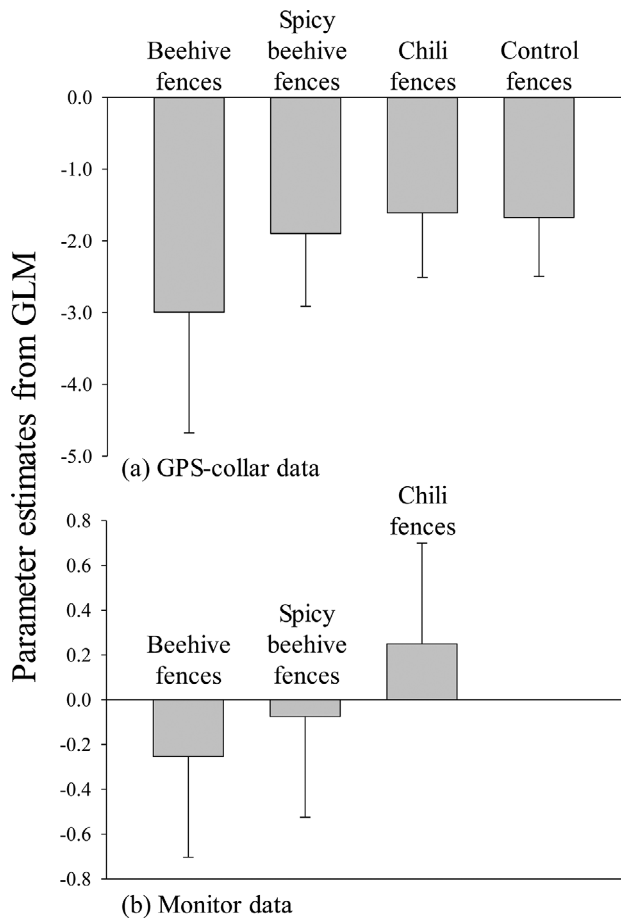

FIGURE 4 Parameter estimates (with 95% CI) from binomial GLMs of (A) the number of river crossings by GPS-collared elephants during our mitigation experiment (September 17 to December 20, 2017), and (B) the proportion of fence approaches by elephants that resulted in a river crossing during that same period (as determined by track, dung, and camera-trap data collected by project monitors). Parameter estimates in (A) indicate the predicted number of river crossings per crossing location at treatment sites with each fence type, relative to unfenced locations (all $p < .05$), whereas parameter estimates in (B) indicate the predicted proportion of fence approaches that resulted in a river crossing at locations with each treatment fence type, relative to control fences that lacked the putative deterrence mechanisms (i.e., chilies and/or bees; all $p > .15$)

of a stable water source (i.e., the Pungue River) (King et al., 2017). These results are similar to those of previous studies that evaluated the use of beehive fences (e.g., King et al., 2009; King et al., 2011; King et al., 2017; Scheijen et al., 2018) or chili fences (e.g., Chang'a et al., 2016; Gunaryadi, Sugiyo, & Hedges, 2017) around individual farms. Our work builds on those studies by demonstrating the efficacy of using discontinuous fencing to block key corridors used by elephants to access crops rather than fencing individual farms or erecting continuous fences along entire protected-area boundaries (at great expense). Our results suggest that if communities can tolerate some (much-reduced) level of crop raiding, then discontinuous beehive fencing at crossing sites may represent a compromise solution that simultaneously reduces both the incidence of crop raiding and the costs of mitigation.

Another important benefit of beehive fences is their potential to generate revenue from honey production. Gorongosa currently supports an apiculture program in the buffer zone, and we constructed our beehive fences using the same hives as those used by Park apiculturists. Park honey producers can harvest 10–14 kg of honey per hive annually, which they can sell for 60–70 Meticais ($1–1.5 USD) per kg. Thus, a single beehive fence consisting of 15 hives could produce 150–210 kg of honey per year, generating $150–315 USD. This is 2–4 times the current minimum annual wage in Mozambique. By way of comparison, construction of a beehive fence with 15 hives in our study cost ~$773 USD in materials. The hives themselves comprised the majority of the cost ($33.50 USD apiece for Kenyan top bar hives), with other equipment and supplies (bee attractant, hardwood poles, yellow paint, bailing twine, nails, wire, bee brush, and gloves) totaling ~$270 USD. A detailed list of costs associated with construction of all fence types is provided in Appendix S7 (Table S7). At Gorongosa, the initial cost of constructing fences for our study was borne by the park and various donors, and community members were responsible for subsequent maintenance, as well as the harvest and sale of honey. Such collaborative cost-sharing arrangements hold potential for fostering coexistence between humans and elephants by simultaneously reducing the frequency of crop raiding, by demonstrating the commitment of protected areas to both human and elephant well-being, and by providing economic incentives to community members through both reduced crop losses and the sale of honey.

Spicy beehive fences did not repel elephants as consistently as beehive fences alone. Although these results are contrary to our hypothesis (H2), camera-trap imagery suggests that they may have stemmed from differences in weight of the materials used to link hives together in beehive fences versus spicy beehive fences. The interwoven cotton strips and sisal ropes used to sustain the chili mixture (see Appendix S2) were considerably heavier than the simple twine ropes used to construct the beehive fences (Figure 2). As a result, these ropes sagged more, making it easier for elephants to step over them. With the chili fences, it was possible to tie the ropes very tightly to the bamboo poles. In contrast, with the spicy beehive fences it was necessary to leave the chili ropes looser to keep from pulling the hives sideways. Future work to improve the design of this strategy by keeping ropes at a height that prevents elephants from stepping over them would likely improve its effectiveness.

Our experimental design required leaving some key crossing points unfenced, and elephants increased their use of those crossings following fence construction (Figure 3). Osipova et al. (2018) reported similar results following construction of electrified fences in the Amboseli ecosystem in Kenya. Despite increased use of unfenced crossings by elephants during our experiment, however, the total number of crossings that occurred in our study area was reduced by more than half following construction of fences. This suggests that fences used in our study—and beehive fences in particular—shifted a considerable amount of elephant activity to other stretches of the river even though some crossing locations remained unobstructed. This shift in elephant activity away from communities that participated in our study likely contributed to the generally positive perceptions of our project among community members (Appendix S8). It is not possible to know from our data how fencing all crossing points might have influenced elephant crop-raiding behavior in our study area. However, based on results of our study, the Conservation Department at Gorongosa recently began large-scale deployment of beehive fences at crossings all along the Pungue River. This management experiment will provide opportunities to test the consequences of full-scale implementation of beehive fences.

Protected areas form the cornerstone of efforts to conserve biodiversity worldwide (Bruner et al., 2001; Hilborn et al., 2006). Crop raiding by wildlife undermines the effectiveness of protected areas—which is already tenuous owing to funding shortfalls (Lindsey et al., 2018)—by bringing wildlife into direct conflict with human populations. The future sustainability of many protected areas will depend in part on developing strategies for mitigating human–wildlife conflict that: (1) are affordable to implement; (2) can be maintained by local communities; (3) incentivize communities by providing avenues of economic gain (e.g., reduced crop losses coupled with revenue from honey production); and (4) help to alter perceptions of wildlife among community members (Shaffer et al., 2019). Our study experimentally demonstrates the potential effectiveness of one such strategy, and our approach can be further refined, adapted, and scaled up to reduce crop raiding by megaherbivores and other wildlife around protected areas.

ACKNOWLEDGMENTS

This work and its participants were supported by the U.S. National Science Foundation (IOS-1656642 to R.A.L.; IOS-1656527 to R.M.P.). We also thank the University of Idaho, Gorongosa Project, Rufford Foundation, Campizondo Foundation, Artipopart, Save the Elephants, Sr. Jean-Marc Grün and Victoria Branco for the financial support. We are grateful to our field assistants Castiano Lencastro, Michel Souza and Elyce Gosselin. We also thank Janet Rachlow, Joyce Poole and Petter Granli for their comments and support. The data that support the findings of our study are publicly available in the Dryad Digital Repository (doi 10.5061/dryad.m63xsj3xd).

REFERENCES

Bennett, N. J., Roth, R., Klain, S. C., Chan, K., Christie, P., Clark, D. A., … Wyborn, C. (2016). Conservation social science: Understanding and integrating human dimensions to improve conservation. *Biological Conservation*, *205*, 93–108.

Branco, P. S., Merkle, J. A., Pringle, R. M., Pansu, J., Potter, A. B., Reynolds, A., … Long, R. A. (2018). Spatiotemporal determinants of elephant foraging behavior in a coupled human-natural system: Is brown the new green? *Journal of Animal Ecology*, *88*, 780–792.

Bruner, A. G., Gullison, R. E., Rice, R. E., & da Fonseca, G. A. B. (2001). Effectiveness of parks in protecting tropical biodiversity. *Science*, *291*, 125–128.

Chang'a, A., de Souza, N., Muya, J., Keyyu, J., Mwakatobe, A., Malugu, L., … Olson, D. (2016). Scaling-up the use of chili fences for reducing human-elephant conflict across landscapes in Tanzania. *Tropical Conservation Science*, *9*(2), 921–930.

Chiyo, P. I., Cochrane, E. P., Naughton, L., & Basuta, G. I. (2005). Temporal patterns of crop raiding by elephants: A response to changes in forage quality or crop availability? *African Journal of Ecology*, *43*(1), 48–55.

Conover, M. R. (2002). *Resolving human-wildlife conflicts: The science of wildlife damage management*. Florida, USA: Lewis Publishers.

Convery, I., & Morley, R. (2014). Restoring Gorongosa: Some personal reflections. In I. Convery, G. Corsane, & P. Davis (Eds.), *Displaced heritage: Responses to disaster, trauma, and loss* (pp. 129–142). Woodbridge, UK: Boydell Press.

Dickman, A. J. (2010). Complexities of conflict: The importance of considering social factors for effectively resolving human–wildlife conflict. *Animal Conservation*, *13*, 458–466.

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. https://doi.org/10.1371/journal.pone.0173742.

Hartter, J., Solomon, J., Ryan, S. J., Jacobson, S. K., & Goldman, A. (2014). Contrasting perceptions of ecosystem services of an African forest park. *Environmental Conservation*, *41*, 330–340.

Hedges, S., & Gunaryadi, D. (2010). Reducing human–elephant conflict: Do chillies help deter elephants from entering crop fields? *Oryx*, *44*(1), 139–146.

Hilborn, R., Arcese, P., Borner, M., Hando, J., Hopcraft, G., Loibooki, M., … Sinclair, A. R. E. (2006). Effective enforcement in a conservation area. *Science*, *314*, 1266.

Hoare, R. E. (1999) Data collection and analysis protocol for human-elephant conflict situations in Africa. UICN African Elephant Specialist Group' Human-elephant conflict working group.

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

Infield, M. (2001). Cultural values: A forgotten strategy for building community support for protected areas in Africa. *Conservation Biology*, *15*, 800–802.

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

King, L. E., Lawrence, A., Douglas-Hamilton, I., & Vollrath, F. (2009). Beehive fence deters crop-raiding elephants. *African Journal of Ecology*, *47*, 131–137.

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*(4), 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*(4), 743–752.

Lindsey, P. A., Miller, J. R. B., Petracca, L. S., Coad, L., Dickman, A. J., Fitzgerald, K. H., … Hunter, L. T. B. (2018). More than $1 billion needed annually to secure Africa's protected areas with lions. *Proceedings of the National Academy of Sciences of the USA*, *115*, E10788–E10796. https://doi.org/10.1073/pnas.1805048115.

Madden, F. (2004). Creating coexistence between humans and wildlife: Global perspectives on local efforts to address human–wildlife conflict. *Human Dimensions of Wildlife*, *9*, 247–257.

Middleton, A. D., Kauffman, M. J., Mcwhirter, D. E., Cook, J. G., Cook, R. C., Nelson, A. A., … Klaver, R. W. (2017). Animal migration amid shifting patterns of phenology and predation: Lessons from a Yellowstone elk herd. *Ecology*, *94*(6), 1245–1256.

Mumby, H. S., & Plotnik, J. M. (2018). Taking the elephants' perspective: Remembering elephant behavior, cognition and ecology in human-elephant conflict mitigation. *Frontiers in Ecology and Evolution*, *6*, 122. https://doi.org/10.3389/fevo.2018.00122.

O'Connell-Rodwell, C. E., Rodwell, T., Rice, M., & Hart, L. A. (2000). Living with the modern conservation paradigm: Can agricultural communities co-exist with elephants? A five-year case study in East Caprivi, Namibia. *Biological Conservation*, *93*, 381–391.

Osipova, L., Okello, M. M., Njumbi, S. J., Ngene, S., Western, D., Hayward, M. W., & Balkenhol, N. (2018). Fencing solves human-wildlife conflict locally but shifts problems elsewhere: A case study using functional connectivity modelling of the African elephant. *Journal of Applied Ecology*, *55*(6), 2673–2684.

Parker, G. E., & Osborn, F. V. (2006). Investigating the potential for chilli Capsicum spp. to reduce human-wildlife conflict in Zimbabwe. *Oryx*, *40*(3), 1–4.

Pringle, R. M. (2017). Upgrading protected areas to conserve wild biodiversity. *Nature*, *546*, 91–99.

Scheijen, C. P. J., Richards, S. A., Smit, J., Jones, T., & Nowak, K. (2018). Efficacy of beehive fences as barriers to African elephants: A case study in Tanzania. *Oryx*, *53*(1), 92–99.

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. https://doi.org/10.3389/fevo.2018.00235.

Snyman, S. (2014). Assessment of the main factors impacting community members' attitudes towards tourism and protected areas in six southern African countries. *Koedoe*, *56*, 1–12.

Stalmans, M. (2012). *Monitoring the recovery of wildlife in the Parque Nacional da Gorongosa through aerial surveys: A preliminary analysis*. Mozambique, East Africa: Gorongosa National Park.

Stalmans, M. E., Massad, T. J., Peel, M. J. S., Tarnita, C. E., & Pringle, R. M. (2019). War-induced collapse and asymmetric recovery of large-mammal populations in Gorongosa National Park, Mozambique. *PLoS ONE*, *14*, e0212864.

Tinley, K. L. (1977). *Framework of the Gorongosa ecosystem*. Thesis. Mozambique, East Africa: Gorongosa National Park.

Treves, A., & Bruskotter, J. (2014). Tolerance for predatory wildlife. *Science*, *344*, 476–477.

Wiafe, E. D., & Sam, M. K. (2014). Evaluation of a low-tech method, pepper-grease, for combatting elephant crop-raiding activities in Kakum Conservation Area, Ghana. *Pachyderm*, *55*, 38–42.

Wittemyer, G., Elsen, P., Bean, W. T., Burton, A. C. O., & Brashares, J. S. (2008). Accelerated human population growth at protected area edges. *Science*, *321*, 123–126.

SUPPORTING INFORMATION

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

How to cite this article: Branco PS, Merkle JA, Pringle RM, et al. An experimental test of community-based strategies for mitigating human–wildlife conflict around protected areas. *Conservation Letters*. 2019;e12679. https://doi.org/10.1111/conl.12679