



Beehive fences as a multidimensional conflict-mitigation tool for farmers coexisting with elephants

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Abstract: *Increasing habitat fragmentation and human population growth in Africa has resulted in an escalation in human–elephant conflict between small-scale farmers and free-ranging African elephants (*Loxodonta africana*). In 2012 Kenya Wildlife Service (KWS) implemented the national 10-year Conservation and Management Strategy for the Elephant in Kenya, which includes an action aimed at testing whether beehive fences can be used to mitigate human–elephant conflict. From 2012 to 2015, we field-tested the efficacy of beehive fences to protect 10 0.4-ha farms next to Tsavo East National Park from elephants. We hung a series of beehives every 10 m around the boundary of each farm plot. The hives were linked with strong wire. After an initial pilot test with 2 farms, the remaining 8 of 10 beehive fences also contained 2-dimensional dummy hives between real beehives to help reduce the cost of the fence. Each trial plot had a neighboring control plot of the same size within the same farm. Of the 131 beehives deployed 88% were occupied at least once during the 3.5-year trial. Two hundred and fifty-three elephants, predominantly 20–45 years old entered the community farming area, typically during the crop-ripening season. Eighty percent of the elephants that approached the trial farms were kept out of the areas protected by the beehive fences, and elephants that broke a fence were in smaller than average groups. Beehive fences not only kept large groups of elephants from invading the farmland plots but the farmers also benefited socially and financially from the sale of 228 kg of elephant-friendly honey. As news of the success of the trial spread, a further 12 farmers requested to join the project, bringing the number of beehive fence protected farms to 22 and beehives to 297. This demonstrates positive adoption of beehive fences as a community mitigation tool. Understanding the response of elephants to the beehive fences, the seasonality of crop raiding and fence breaking, and the willingness of the community to engage with the mitigation method will help contribute to future management strategies for this high human–elephant conflict hotspot and other similar areas in Kenya.*

Keywords: beehive fences, community, elephant deterrents, elephant management strategy, Elephants and Bees Project, human–elephant conflict, participatory trials, Tsavo National Park

Cercos de Panales como una Herramienta Multidimensional para la Mitigación de Conflictos entre Agricultores y Elefantes

Resumen: *El incremento de la fragmentación del hábitat y el crecimiento de la población humana en África han resultado en un aumento del conflicto entre los pequeños agricultores y los elefantes africanos (*Loxodonta africana*) libres. En el 2012, el Servicio de Vida Silvestre de Kenia (KWS, en inglés) implementó a nivel nacional la Estrategia de Manejo y Conservación para el Elefante en Kenia con duración de 10 años, la cual incluye una acción enfocada en probar si los cercos de panales pueden utilizarse para mitigar el conflicto humano – elefante. De 2012 a 2015, probamos en el campo la eficiencia de los cercos de panales para proteger de los*

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elefantes a diez granjas de 0.4 ha colindantes con el Parque Nacional Tsavo del Este. Colgamos una sere de panales cada 10 m alrededor de los límites de cada lote agrícola. Los panales se conectaron con un alambre fuerte. Después de una prueba piloto inicial en dos granjas, los ocho permanentes de los diez cercos con panales también incluyeron panales-señuelo bidimensionales entre los panales verdaderos para ayudar a reducir el costo del cerco. Cada lote de prueba tuvo un lote de control vecino del mismo tamaño dentro de la misma granja. De los 131 panales implementados, el 88% fue ocupado por lo menos una vez durante la prueba de 3.5 años. Doscientos cincuenta y tres elefantes, predominantemente entre los 20 - 45 años de edad, entraron a la comunidad agrícola, comúnmente durante la temporada de maduración de las cosechas. El 80 % de los elefantes que se acercaron a las granjas de prueba se mantuvieron fuera de las áreas protegidas por los cercos de panales, y los elefantes que rompieron los cercos estuvieron dentro de grupos más pequeños al promedio. Los cercos de panales no sólo hicieron que grupos grandes de elefantes no invadieran los lotes agrícolas, sino los agricultores también se beneficiaron socialmente con la venta de 228 kg de miel amigable con los elefantes. Conforme se informó sobre el éxito de la prueba piloto, doce agricultores más pidieron unirse al proyecto, lo que llevó al número de granjas protegidas por cercos de panales a 22 y al de los panales a 297. Esto demuestra la adopción positiva de los cercos de panales como una herramienta comunitaria de mitigación. Entender la respuesta de los elefantes a los cercos de panales, la temporalidad de las incursiones hacia las cosechas y de la ruptura de los cercos, y la disponibilidad de la comunidad por participar en el método de mitigación ayudará a contribuir con las siguientes estrategias de manejo para este gran punto caliente del conflicto humano - elefante y en otras áreas similares en Kenia.

Palabras Clave: cercos de panales, conflicto humano - elefante, estrategia de manejo de elefantes, impedimentos para elefantes, Parque Nacional Tsavo, Proyecto Elefantes y Abejas, pruebas de participación comunitaria

Introduction

Small-scale subsistence farmers in Africa are confronted by unprecedented climatic changes (Rockström et al. 2009) and face many complex challenges for survival, including in some places an increase in resource competition with wildlife (Hill 2004). Because human-wildlife conflict can negatively affect species survival (Cardillo et al. 2005), damage traditional cultural tolerance for coexistence with wildlife (Kissui 2008; Dickman 2010), and often leads to strained relationships with wildlife managers (Woodroffe et al. 2005; Baruch-Mordo et al. 2009), human-wildlife conflict remains one of the greatest unresolved challenges for conservation. People in communities affected by wildlife can have extremely negative attitudes toward those species and may retaliate by killing wildlife, aiding poachers, or blocking tourist activities (Sifuna 2005; Mackenzie & Ahabyona 2012; Benjaminsen et al. 2013).

Conflict between farmers and free-ranging elephants (*Loxodonta africana*) is common in Kenya (Sitati & Walpole 2006; Graham & Ochieng 2008), and finding practical tools to help mitigate this conflict and to create avenues for productive coexistence remains a substantial challenge (Okello & Amour 2008; Hoare 2012). In Kenya both conservationists and local communities increasingly believe there is no one effective elephant deterrent appropriate for use in all circumstances. The consensus is that multiple mitigation methods are needed for use by wildlife managers and farmers for repeated and sometimes rotational use (Osborn & Parker 2002; Dublin & Hoare 2004; Hoare 2012).

Existing options for human-elephant conflict (HEC) mitigation include macro methods, ranging from the creation of wildlife corridors and national parks, and micro farm-level methods, often used by families tackling one-on-one conflict situations (Dublin & Hoare 2004). Tried and tested methods include construction of passive (immovable) barriers, such as flashing solar lights, fences strung with chili-oil soaked rags, ditches, watch towers, walls, buffer crops (e.g., chilies), and active (moveable) deterrents such as fire or firecrackers, chili powder bombs, guard dogs, and human patrols (Thouless & Sakwa 1995; Osborn & Parker 2002; Graham & Ochieng 2008; Hoare 2012).

Common criticisms of established micro-level HEC mitigation methods are high establishment cost, elephant habituation, farmer fatigue, lack of funds for maintenance, and poor uptake by the wider community even when pilot studies prove successful (Sitati & Walpole 2006; Graham & Ochieng 2008). Despite these challenges, mitigation can be successful when multiple methods are used together or in random rotation to reduce habituation (Sitati & Walpole 2006).

An emerging micromitigation method that combines passive and active deterrent characteristics is the deployment of beehive fences around the outer boundary of small-scale farms (King 2010; King et al. 2011). Elephants are wary of foraging near African honey bees (*Apis mellifera scutellata*) (Vollrath & Douglas-Hamilton 2002) and will run away from either the sound of (King et al. 2007) or a threat of being stung by a swarm of honey bees (King 2010). Elephants retreating from the threat of bees emit a unique alarm call to nearby family members (King

et al. 2010). A 2-year field trial with 34 farms in Kenya revealed that beehive fences reduced crop-raiding incidents and farmers unanimously thought the fences were successful due to the additional benefits derived from the bee colonies pollinating crops and producing honey they could sell (King 2010; King et al. 2011). Although the positive response from the farmers was encouraging, the effect of the open-ended fence design was not fully explored (Hoare 2012) and the effect of the severe 2009 drought limited both hive occupation and crop-raiding incidents (King et al. 2011).

In 2012, Kenya Wildlife Service (KWS) launched a collaborative 10-year Conservation and Management Strategy for the Elephant in Kenya. One of its 7 key aims was to “[e]nhance human-elephant conflict mitigation by involving stakeholders at all levels in the use of appropriate site-specific methods” (Litoroh et al. 2012). In cooperation with Save the Elephants, KWS, and a community of subsistence farmers in Sagalla co-existing with elephants next to Tsavo East National Park, we tested the efficacy of a beehive fence design to keep elephants away from invading small-scale farms.

Methods

Study Area

Sagalla is a rural farming community in Voi subcounty, southern Kenya. It has 4 villages nestled at the base of the steep slopes of Mount Sagalla and is approximately 3 km from the boundary of Tsavo East National Park, which is home to approximately 6214 elephants (Ngene et al. 2013). The land between Mt. Sagalla and Mt. Kasigau to the south is a corridor where elephants migrate out of Tsavo East into Taita-Taveta County and is composed of a complex mosaic of community ranches and wildlife-friendly sanctuaries connected on the western boundary by Tsavo West National Park. The 4 villages along the eastern slope of Mt. Sagalla (Kirumbi, Mwakoma, Mwambiti, and Kajire) are all subject to human-wildlife conflict. Mwakoma, the smallest of these communities, has 150 households and is situated closest to the park. Elephants primarily disturb front-line farms (i.e., those on the eastern side of the road that are first approached by elephants leaving Tsavo East National Park) at night as they disperse from the park in search of water and sustenance. The elephants often break into the farms to eat crops or occasionally stored grains, which they access by pushing down house walls or pulling off roofs. Rangers are frequently called out to these communities to drive elephants off and several human fatalities have occurred, which has strained relations between the community and KWS (Sakellariadis 2015).

Farm Selection

Mwakoma village is divided in half by a north-south access road. Two-thirds of the farms are to the west of the road under the steep slopes of the mountain. In May 2012, we used ArcGis (version 10.1) to map the boundaries of all 52 front-line Mwakoma farms on the eastern side of the road (see map in Supporting Information). We did not deploy beehive fences on 17 of these farms because they were not planted regularly and did not have permanent homes. Of the remaining 35 farms, 2 already had beehive fences from a successful 2009 pilot study (farms K and M) (see King [2010] for pilot-study details), 1 was already engaged in an HEC-reduction project (planting aloe vera, farm 4), and 11 farms were along the main road and were thus relatively protected due to human activity and their greater distance from the park. This left 21 permanent front-line farms as good candidates for beehive-fence deployment.

During a village meeting, 64 participants identified the 10 farms most affected by elephant raids and owned by active farmers whom they believed would benefit most from a beehive fence. We used a semistructured questionnaire to interview owners of these 10 farms to gather baseline data on their socioeconomic status and historical information on elephant incidents (Sakellariadis 2015). We selected 8 farms for beehive fences based on socioeconomic conditions and intensity of past crop-raiding events. To this group, we added 2 farms from the pilot study that still had operational beehive fences.

In a change from the pilot-study fences (King 2010) and to reduce costs, every other beehive was replaced with a 2-dimensional plywood dummy beehive; thus, fences had 12 real beehives and 12 dummy beehives interlinked around each 0.4-ha plot (Fig. 1) (King 2014). The real beehives and dummy beehives were alternatively hung 1.5 m off the ground between live fence posts cut from locally available species of *Commiphora*, a tree that regrows once planted. These live posts reduced the effort and cost of replacing termite-weakened posts and eventually will grow into trees, providing natural shade and food for the bees and an additional physical barrier to elephants. Each hive and dummy were interlinked with plain fencing wire (Fig. 1). Elephants attempting to pass between the hives would set multiple beehives swinging. The swinging caused the bees to fly out and chase away the elephants (King et al. 2007; King 2010).

We built 6 new beehive fences during the dry season (June–August) of 2012 and 2 more in February 2013. Two of the new beehive fences incorporated 12 Kenyan Top Bar Hives (KTBH) with 18 frames each that were constructed by community carpenters at a cost of \$35/beehive (all monetary units are in U.S. dollars unless otherwise noted). Langstroth hives were sourced from Honey Care Africa for \$60/hive and were adapted with wooden blocks nailed to the side of the hive to facilitate hanging

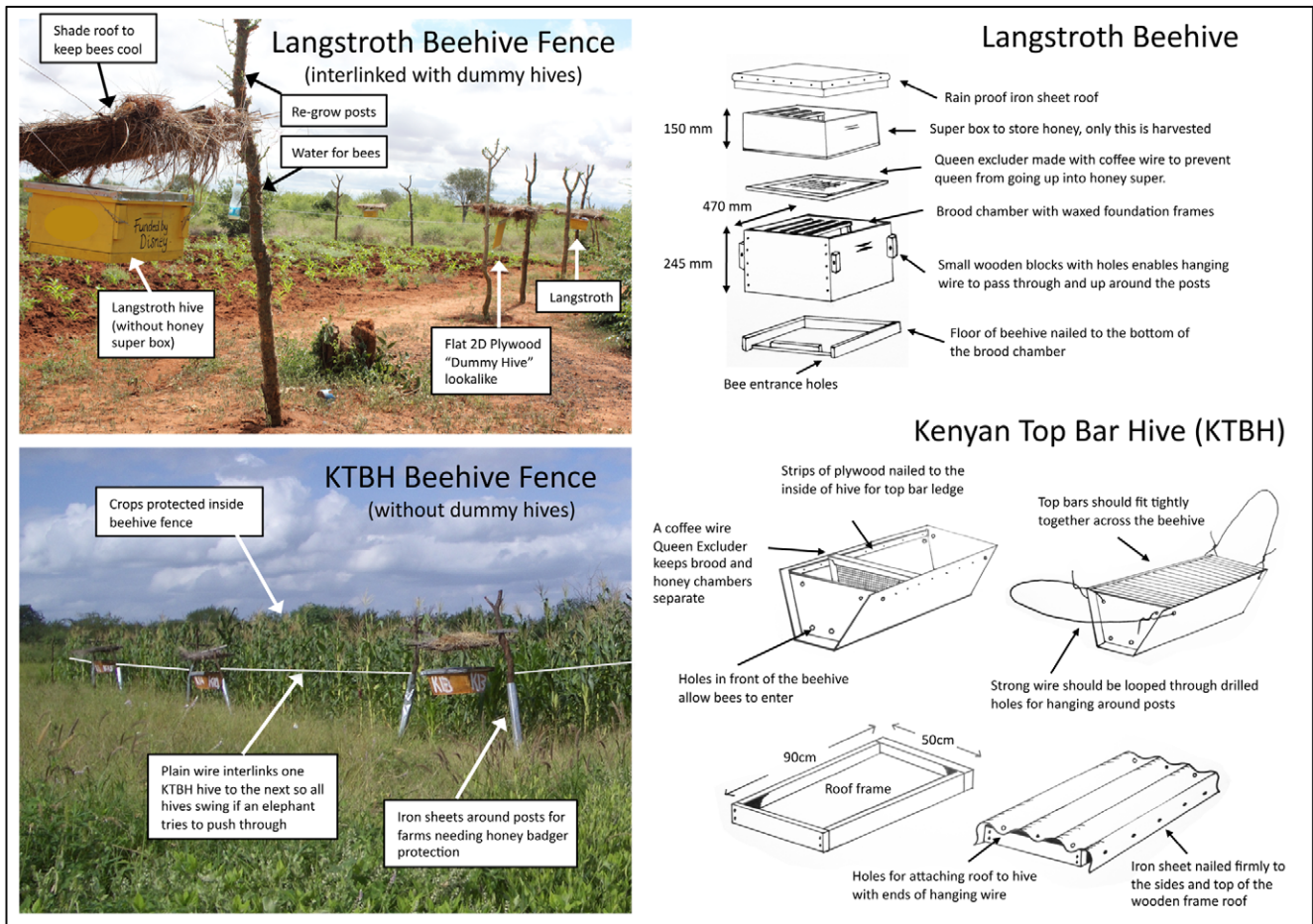


Figure 1. Construction of Langstroth beehives and Kenyan Top Bar Hives (KTBH) used in elephant-deterrent beehive fences and setup and components of the fences. The waxed combs of the Langstroth hives help attract bees and provide ample storage for honey in the super box above, separated from the brood chamber by a horizontal queen excluder. The KTBH hives have a vertical queen excluder separating the front and back chambers for brood and honey respectively. Real hives and dummy hives (2-dimensional plywood) hang alternately along plain fencing wire attached to regrowing *Commiphora sp.* posts. Iron sheets tied onto the posts help deter honey badger attacks.

(Fig. 1). The Langstroth hives consisted of a large lower brood box of 10 large frames and a secondary upper super box of 10 small frames for honey collection. From each of the small frames a bar with approximately 1 kg of honey could be harvested once the colony was settled. Both KTBH and Langstroth hives had a mesh queen excluder to separate brood from honey (Fig. 1). Materials for a 240-m beehive fence constructed with 12 Langstroth beehives and 12 dummy hives cost on average \$850. A 12 KTBH and 12 dummy beehive fence cost \$550. The 10 trial beehive fences around 10, 0.4-ha plots incorporated 68 Langstroth hives (6 fences) and 63 KTBH hives (4 fences). Each of the 10 farm plots protected by a beehive fence was paired with a control plot of the same size within the same farm.

We trained each participating farmer in beekeeping and to record both hive occupation events and elephant

movements around the beehive fences. We trained one community member to help the farmers with honey harvesting and major fence maintenance and to track elephant movements and crop raiding with a GPS. Dung and urine markings were observed to help identify whether elephants were male or female, and the length and width of each clear hind footprint were measured to help establish age (Lee & Moss 1997). We could not accurately measure night-guarding efforts by the farmers or compare our data with any quantitative crop-raiding data prior to the trial because of a lack of detailed elephant-incident records.

Significant Events during the Trial

Eighteen months into the trial we constructed a community office and honey processing room that enhanced our

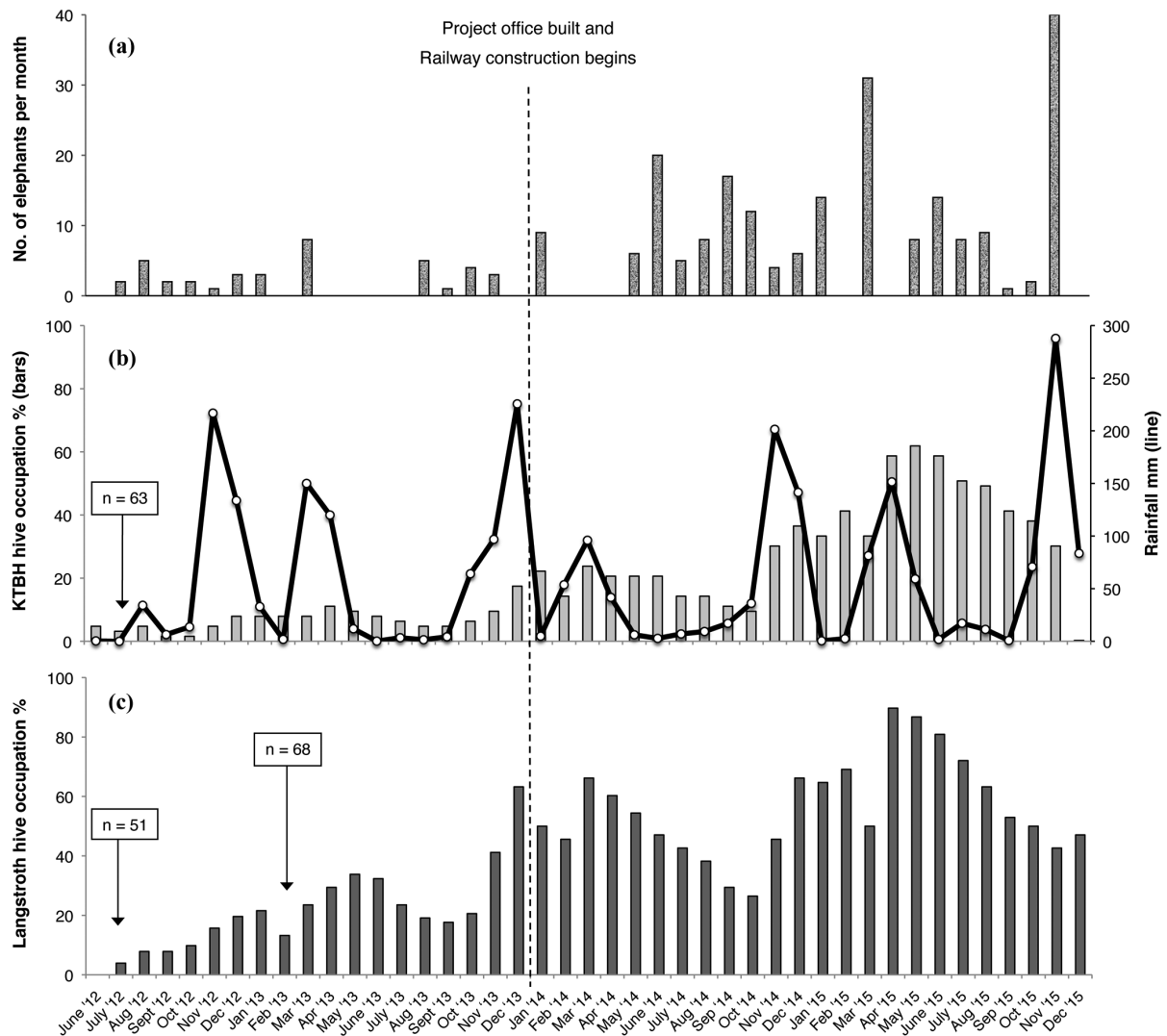


Figure 2. The (a) number of elephants in the community over the project period (after December 2013 monitoring effort and railway construction activity increased); (b) bee occupation of Kenyan Top Bar Hives (KTBH) (bars) and their occupation relative to rainfall (line); and (c) bee occupation of Langstroth hives.

data-collection capacity and enabled us to process honey and beeswax on site. In December 2013, construction began on the new high-speed standard gauge railway between Mombasa and Nairobi. Railway construction along a 7-m-high ridge along the boundary of Tsavo East, generated substantial mechanical disturbance along the park boundary. Concurrently, the number of elephant crop-raiding incidents increased 500% from 39 elephant visits from June 2012 to December 2013 to 199 elephant visits during the second half of our study period, (June 2014 to December 2015) (Fig. 2).

As the trial developed, demand for beehive fences increased from Mwakoma's unfenced farmers. Consequently, with 30 beehives donated from the Tsavo KWS office, a further 3 Mwakoma beehive fences were added in mid-2014 (Farms HN, KR and S) (Supporting Information). Demand from neighboring Mwambiti community

resulted in us establishing 9 additional beehive fences in 2015. Hence, at the end of the 43-month trial in December 2015, the project had expanded to 22 farms and had a total of 297 beehives. We present data from only the first 10 farms with beehive fences, but we considered the likely reasons for this progressive demand for beehives by the wider community.

Results

During the 43-month trial all 10 of the beehive fences became naturally occupied with wild African honey bees. Out of the 131 beehives, 116 were occupied at least once; 98% of the Langstroth hives and 78% of the KTBH hives were occupied at least once during the trial. Occupation rates increased as rainfall increased

with the onset of the biannual rainy seasons (November-December and March-April each year), which triggered both crop and natural vegetation growth that provided ample water and foraging sources to attract wild bee swarms to the beehive fences (Fig. 2).

A total of 253 elephant visits were recorded within <30 m of the 10 farms protected by beehive fences. Each elephant visit was recorded as a unique data point. Of the 238 elephants that directly approached the farms with beehive fences 80% ($n = 190$) were deterred from entering the area protected by the fence and significantly fewer (20%, $n = 48$) broke through the beehive fences (mean deterrent events per farm = 19 [SE 7.9], mean breakthroughs per farm = 4.8 [SE 1.3]; 1-tailed paired t test, $p = 0.046$). Of the remaining subsample of 15 elephants, 11 elephants walked through a gap in the fence without touching any part of it (usually an opening in the fence near the house), and 4 elephants walked along a portion of the beehive fence to enter a gap without breaking any part of the fence (Fig. 3).

Group sizes of elephants entering the community varied from single bulls to groups of 10; the median group size was 3. Elephants were most commonly (73%) in small group of 1-3. The remaining 27% came in large groups of 4-10. Compared with the typical size of elephant groups visiting the community, elephants managing to break into farms through a beehive fence did so in proportionally smaller group sizes. Thirteen groups of 1-3 (88%) broke the fence (median group size of 2), and 3 large groups of 4 elephants (12%) broke through a beehive fence across the 10 farms (Fig. 4). Camera trap footage and 238 footprint measurements collected from 59 elephants showed it was likely the majority of the elephants were bulls, but females were also observed raiding crops. Sixty-eight percent of the crop-raiding elephants entering the farming community were estimated to be 20-45 years old.

Out of the 89 total events of elephant groups approaching the farms, there were 65 events where elephants went within 10 m of the fences. Of these 65 events, 39 elephant groups ($n = 114$ elephants) turned away at the beehive fence line and 26 groups ($n = 50$ elephants) broke the beehive fences. Two elephants were deterred by the action of breaking the fence, and 48 elephants broke the fence and gained access to the farm. Fences with low hive occupancy at the contact points (0-25% of hives occupied) showed both high breakthrough events ($n = 11$ groups) and high deterrent events ($n = 15$ groups), which suggests that even without bees occupying the hives some elephant groups were deterred by the fence structure itself. Where occupation of hives was high (60-100% of the hives occupied), only 7 elephant groups broke through over the 43 months, and 14 groups were kept out by the fence (Supporting Information).

Rainfall influenced when elephants entered the community: 70% of elephants entered the community and broke the fences in the driest period (≤ 30 mm rainfall

in the 28 days prior to their visit) (Fig. 5). During times of heavy rainfall (>91 mm over the previous month), 6 elephants entered the community and none broke a beehive fence, which indicates a reduced need for crop species as a nutritional resource during and immediately after high rainfall.

During the last 2 years of the project (January 2014 to December 2015), the 6 farmers with Langstroth beehive fences had a mean monthly occupancy rate in their 68 hives of 68% and produced a total of 255 bars of honey (mean 42.6 [SD 21.7]), which yielded 206 kg of raw honey, significantly more honey than the 4 farmers using KTBH hives. These farmers experienced a lower mean hive occupancy rate of 32% and all had poor honey harvests, producing 23.5 bars of honey (mean 5.9 [SD 5.75]; t test, $p < 0.01$) among them that yielded 22 kg of raw honey. The 6 Langstroth farmers made a total income of \$627, whereas the 4 KTBH farmers made \$57 (Supporting Information). For subsistence farmer W, who was living off his pension of \$22 per month, his honey income for 2015 represented a 21.5% increase in his cash-based income for the year.

The 228 kg of honey produced by all 10 farmers was bottled and produced 480 jars of honey in 450-g glass jars, which cost \$0.48 each. Labels cost \$0.30 each. Each jar was sold locally within Kenya for 600 Kenyan shillings (\$7) each. Total income was \$3388. Once the payments to farmers (\$684) and costs of honey jars (\$230), labels (\$170), honey extractor (\$600), beesuits (\$390 for 6), buckets (\$40 for 10), and miscellaneous tools (\$140) had been taken into account (total expenses \$2254), the profit from honey sales was approximately \$1134.

Discussion

Our 43-month trial provided ample time to thoroughly test the beehive fence system as a mitigation tool against crop-raiding elephants and to observe the acceptance and adoption of the method by the wider community. We could not compare our crop-raiding data with crop-raiding incidents prior to the establishment of the fences, but the community thought the fences effectively reduced crop-raiding. Thus, additional community members requested to join the project, and we supported establishment of 22 beehive fences by the end of the trial.

Although 20% of the elephants that directly approached the beehive fences broke the fences and accessed the farms, the farmers accepted that the method was helping them because the number of elephants that broke through was typically small (median group was 2), they could scare single or smaller elephant groups away on their own, and they were being compensated for damage caused by infrequent fence breaks by honey sales. There were 7 incidents of elephants succeeding in breaking the fence where the proportion of occupied

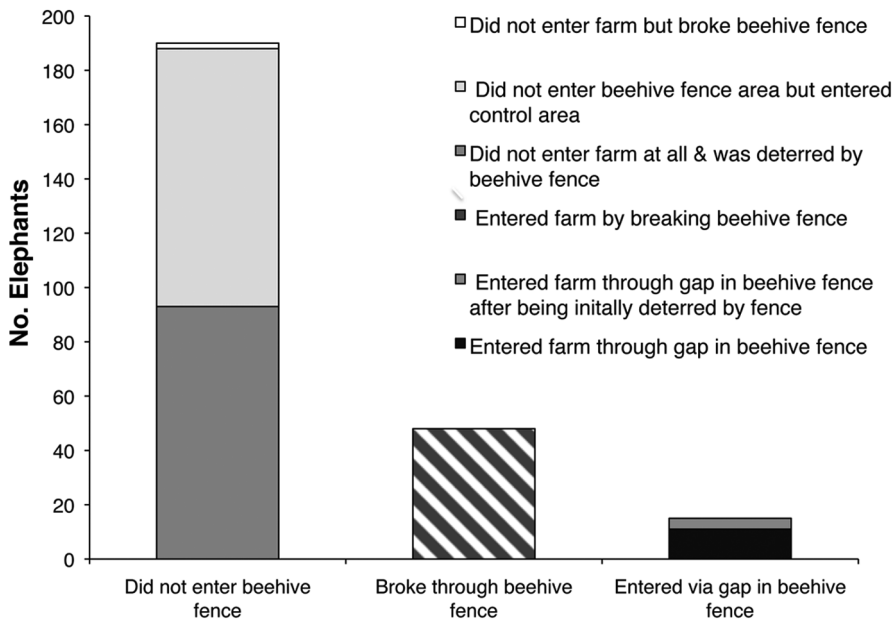


Figure 3. Effectiveness of the 10 beehive fences against 253 elephants over 43 months of the trial in Mukoma Village.

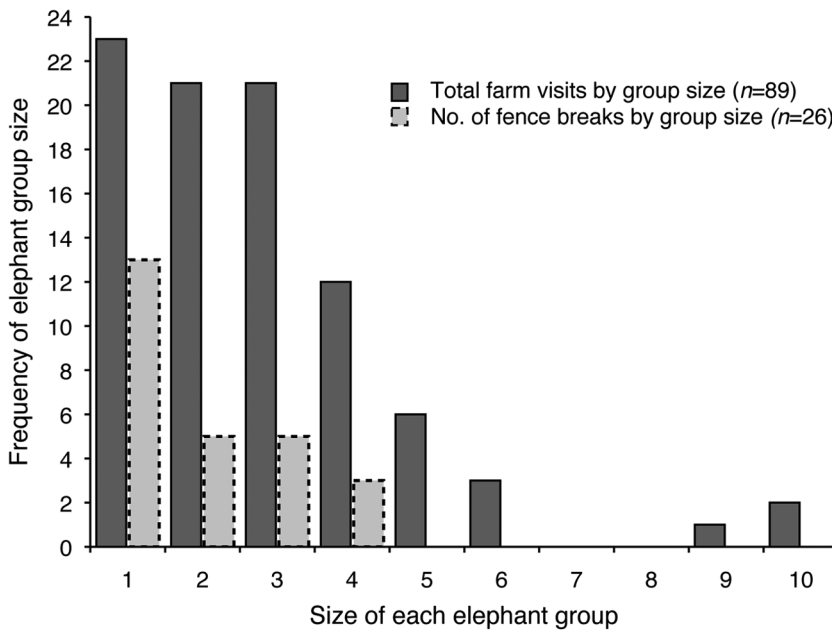


Figure 4. Results of elephant visits to farms with beehive fences.

beehives on either side of the break point was high. It is possible that either these few elephants had no experience with bees prior to the event or they rushed through the fence and moved quickly away from the hive into the farm, where the bees were less likely to fly after them in the dark.

The income generated by the honey provided an incentive to maintain the beehive fences even when it was not crop-raiding season. Often farmer-managed elephant fences fall into disrepair after a breakthrough or after harvest because materials are expensive and elephant events are not that frequent (King 2010). However, for the beehive fence farmers, maintenance or breakages were typically swiftly dealt with so as to avoid honey

losses from ants and honey badgers and to maximize this alternative income-generating project all year round (Raja 2015). The honey provided farmers with a financial incentive (Supporting Information) and a cultural and social benefit because honey is prized in Sagalla, is often given as a gift during family events, and is highly valued by medicine men as a method for protection against illness and bad spirits (Raja 2015). These cultural and medicinal markets for honey in Sagalla provide an alternative destination for the beehive-fence products. By providing farmers with a mitigation tool that they felt fully engaged in all year round, the farmers were able to maximize their own returns depending on how much effort they put into maintenance and beekeeping activities.

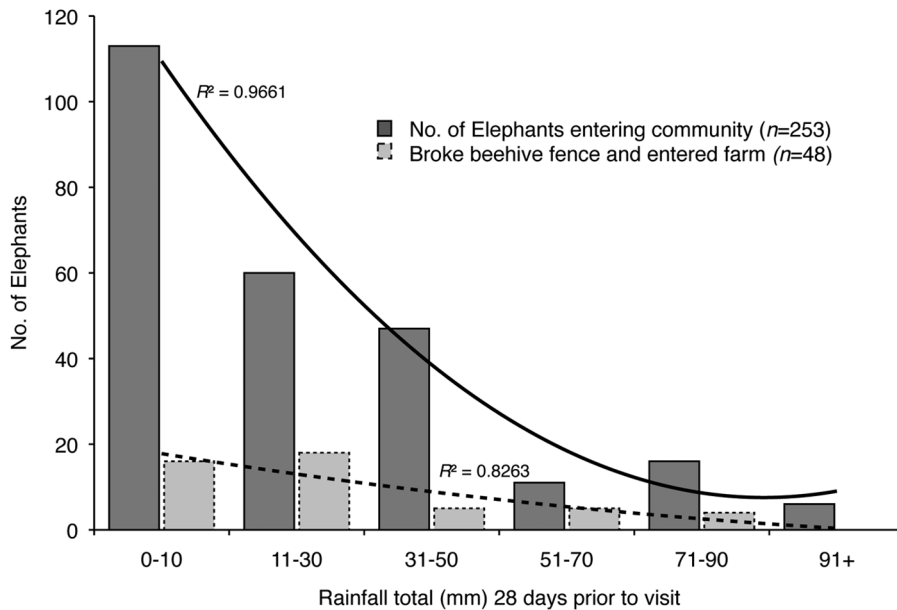


Figure 5. Frequency of elephants visiting farms and breaking through beehive fences relative to biannual rainfall periods.

The profit from the honey sales was enough to pay 70% of the annual salary of the beehive fence officer, which suggested that with careful equipment maintenance the beehive-fence project with 131 beehives was potentially a year away from becoming self-sustaining. Self-sustainability depends on the existence of a consistent local buyer, which is likely because there are a number of supermarkets and tourist lodges near Voi Town and Tsavo East National Park. However, had the Langstroth farmers been required to fund 100% of the cost of the materials for their fences themselves it would have taken the 5 best honey producers an average of 6.8 years at the 2015 rate of honey production to pay back the expense of their 68 Langstroth hives. This time frame is considerable but could be reduced by additional sales of value-added products, such as candles and lip balms, and by higher profits from higher crop yields. It is likely that start-up material costs for Langstroth beehive fences (\$850/240 m) will need to be funded initially by one-off donations or microloans. Although a considerable upfront cost, this is significantly lower than the expense of installing a 6-strand electric fence to keep elephants out, which costs at least \$9000/1000 m (Kioko et al. 2008) and requires continual maintenance and expensive upkeep.

The onset of the biannual rainy seasons triggered increases in hive occupations, which were followed naturally by the growth of crops. There was typically a period when the seedlings were growing during the rainy season when only a few elephants approached the farms. It was only once the rains slowed or stopped completely and the bee colonies and crops had had a chance to mature that the elephants started to enter the community more frequently looking for ripe crops and water. Elephant visitation going into the dry seasons coincided with the maximum hive occupation of bees that were benefiting

from the plethora of natural flora, creating a synchronicity between occupied hives and the highest number of elephants attempting to raid crops.

Beehive fences constructed with Langstroth beehives were consistently more successful at attracting bees, keeping bees after harvest events, and retaining bees between dry seasons. This was likely because the thicker wood helped keep the hives cool and the brood box prevented the queen from being disturbed during honey harvesting. The fences with KTBH hives had a mean occupancy rate of only 32% during the last 2 years of the trial. The farmers struggled to keep their bees during the dry seasons; honey harvests were low; and the 4 KTBH farmers made little money from their beehive fences. Lack of financial benefit to the beehive fences may result in a reduction of incentive for the KTBH farmers over time; thus, farmers should invest more initially by purchasing Langstroth hives. Higher rates of hive occupancy appeared to have a positive impact on elephant deterrent success relative to low occupancy (Supporting Information), so skills or equipment that can sustain high occupancy are worth investing in. Without bees to trigger the conditioned retreat response (King et al. 2007; King 2010), the likelihood of elephants becoming habituated to the physical beehive fence is likely to increase the longer hives in a fence remain empty.

The acceptance and consequent adoption of beehive fences in the wider community (12 additional farms joined after the trial) may be the best sign the beehive fences were perceived as effective by the farmers. Although there were some maintenance problems (new grass shades, replacement posts needed, or occasional honey badger attacks), the beehive fences typically generated more money for the farmer than the minimal maintenance costs because materials such as grass thatching

and *Commiphora* posts could largely be gathered sustainably and for free from the surrounding bush. As with most elephant-deterrent methods, at \$850/0.4 ha initial start-up costs are prohibitive for subsistence farmers, but as news of the success of the trial spread, hives were donated to the farmers from individuals within and outside Kenya. The KWS contributed 30 donated beehives halfway through the trial. Distributing a portion of park entrance fees to communities bordering national parks to build beehive fences could be a tangible way for wildlife departments to share revenues and thus reduce conflict and enhance community relations with park management.

Our data suggest beehive fences are a viable tool for small-scale farmers and wildlife managers to use when communities are struggling with high levels of HEC. The beehives are relatively affordable to build and maintain, and the multidimensional, practical, social, and cultural benefits of honey production and pollination services from the bees make it a method willingly being adopted by rural African farmers.

Acknowledgments

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Supporting Information

The experimental setup (Appendix S1), the relationship between number of elephant events and proportion of beehives (Appendix S2), and the amount of honey harvested (Appendix S3) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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