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Alleviating Human-Elephant Conflict Through Deterrent Fences and Environmental Monitoring in Southern Kenya

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ALLEVIATING HUMAN-ELEPHANT CONFLICT THROUGH DETERRENT FENCES AND ENVIRONMENTAL MONITORING IN SOUTHERN KENYA

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Master of Science

By
Sophia Carmen Corde

April 2022

ALLEVIATING HUMAN-ELEPHANT CONFLICT THROUGH DETERRENT FENCES AND ENVIRONMENTAL MONITORING IN SOUTHERN KENYA

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I dedicate this thesis to my parents, Daniel Corde and Zoraya Corde, who have always believed in me and pushed me to “be the best” that I can be.

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TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 1

CHAPTER 2

LIST OF FIGURES

CHAPTER 1

CHAPTER 2

APPENDIX I

APPENDIX II

ABSTRACT

ALLEVIATING HUMAN-ELEPHANT CONFLICT THROUGH DETERRENT FENCES AND ENVIRONMENTAL MONITORING IN SOUTHERN KENYA

Human-wildlife conflict is present across the world. In areas where human settlements overlap with elephant habitats, human-elephant conflict can result from crop raiding events, compromising farmers' food and economic security, and putting humans and elephants in danger through farmer retaliation. Elephants raid crops primarily at night, when detection by humans is lowest, and during the dry season, as crops are developing towards harvest and natural forage quality drops. People living in these areas facing HEC have developed mitigation strategies to lessen the impacts and move towards coexistence. As a team member on the *Elephants and Sustainable Agriculture in Kenya* project, I conducted my research in the Kasigau Wildlife Corridor of southeastern Kenya. Over the past five years (2017-2022), our international team tested the effectiveness of eight deterrent fence designs, including four modern single deterrents (one line of deterrent strung between fence posts), three modern double deterrents (two strands of single deterrents), and one traditional deterrent (acacia branches). Each fence consisted of one or more negative stimuli to deter elephants, and any deterrent was hypothesized to perform better than the grand control of just fence posts alone. Compared to single deterrents, double deterrent fences were hypothesized to deter elephants better because they stimulate more sensory modalities. We also examined timing within the crop season and moon phase as potential predictors of crop raiding events. Elephant presence around experimental fields was hypothesized to be higher during the end of the crop season and inversely related with lunar light levels. To test these four hypotheses, eight blocks of land were leased from farmers along the boundary between Sasenyi Village and Rukinga Wildlife Sanctuary. Four of the eight blocks were divided into eight fields each around which four experimental deterrent fences and their matching four controls were erected. The other four blocks were each divided in half with one half encompassed by a beehive fence and the other by fake hives. Moon phase and timing within the crop season were determined using a lunar calendar, camera trap evidence, and crop data. During each of the two growing seasons per year, all elephants within 12 m of the deterrent fences were categorized as approaching; an instance of entering a field was termed a breach and not entering a deterrence. Analyses consisted of generalized linear mixed models, Linear Regression, and mixed effect logistic regression models. In support of my first hypothesis, the modern experimental deterrents performed better than the grand control, which had a successful deterrent rate of 27%. The traditional acacia fence (19%), and the cloth fence (66.6%) were the only deterrents tested that did not perform significantly better than the grand control. In contrast to the second hypothesis, the double deterrent fences (68%) did not perform significantly better than single deterrent (62.3%) fence designs. The third hypothesis on elephant presence being positively correlated with progression of the crop season was supported and aligned with past findings in other study sites. However, the fourth hypothesis that presence was inversely correlated with lunar light levels was not upheld, though was impacted by the direction of lunar light level, as more elephants were present during the waning moon phases, as light levels were decreasing. Using these results, we can advise farmers on which deterrents to use, and at what times to be more vigilant due to changes in the probability of crop raiding events. The results of this study are being shared with the farmers living in the KWC and may be useful to others living in high HEC areas by providing additional crop raiding mitigation strategies. Our methods of analysis can be expanded past HEC and applied to areas facing other forms of HWC to promote coexistence.

CHAPTER 1: A COMPARISON OF DETERRENT FENCE TYPES AS A MEANS OF HUMAN-ELEPHANT CONFLICT MITIGATION IN THE DRY AND ARID CLIMATE OF SOUTHERN KENYA

ABSTRACT

Negative interactions between humans and wildlife are inevitable with the expansion of the human population and further exploitation of wild habitats. One interaction prevalent in both Africa and Asia is human elephant conflict (HEC) in the form of crop raiding. Projects conducted in the Kasigau Wildlife Corridor (KWC) in southeastern Kenya have discovered new and promising ways of mitigating this conflict through deterrent fences. Data collected over eight trials in the KWC (2017 – 2022) were used to evaluate four modern deterrent methods, namely the Kasaine metal strip, chili pepper, cloth, beehive, and one traditional deterrent, the acacia fence; and combinations of these including the double metal strip, chili pepper + metal strip, and cloth + metal strip fences. The experimental deterrent fence designs were hypothesized to deter elephants better than the grand control of just fence posts because they provide a negative stimulus upon contact. The effectiveness of each experimental fence was also compared to a matched control that lacked the key sensory stimulus of the experimental. The double deterrent fences were hypothesized to deter elephants better than their single deterrent counterparts because they produce negative stimuli via multiple sensory modalities and/or at higher intensities. Each deterrent fence type was constructed around four different fields in four separate locations along the boundary of the wild land and the village of Sasenyi. generalized linear mixed models were used to test these hypotheses. All deterrents performed significantly better than the grand control at deterring approaching elephants except the traditional acacia fence, and the cloth fence. However, no one fence was significantly more effective than its matched control.

The active beehive and double metal strip fences were most effective at deterring elephants from breaching fence lines, with a deterrence rate of 87.7% and 70.5% respectively. Double deterrents (68%) were not significantly more effective than their single counterparts (62.3%) but because the direction of effectiveness was higher, more testing is warranted to increase sample size. These results allow us to advise and teach farmers about the use of modern deterrents, and which ones work best in a naturally dry and arid environment. The findings from this study can be expanded to provide others living in high HEC areas with improved strategies for coexisting with elephants and other wildlife.

INTRODUCTION

Human Wildlife Conflict (HWC) can occur in any region where human and wildlife habitats overlap, and a negative outcome results from their interaction (Decker & Chase, 1997). From white-tailed deer (*Odocoileus virginianus*) attacks on humans due to heavy overlap of human and deer populations in the United States (Hubbard & Nielsen, 2009) to leopards (*Panthera pardus*) stealing livestock in Bhutan (Wang & Macdonald, 2006), HWC is a common occurrence in the lives of people globally (Seoraj-Pillai & Pillay 2016). HWC comes in many forms including crop raiding, livestock depredation, and property damage (Barua et al. 2013, Treves et al. 2006) and can escalate and lead to the death of humans and wildlife (Riddle et al. 2010, Webber et al. 2007). HWC challenges the conservation and biodiversity of the area surrounding these conflicts because of human retaliation (Mwangi et al. 2016).

In areas where people rely on their harvest for economic and nutritional security, HWC has an especially large impact on human livelihoods (Gemeda & Meles 2018, Nyamwamu 2016). Crop raiding is a prominent example. Wildlife that consumes harvest or livestock are direct competitors of human workers, and in retaliation, community members will kill individuals of that species often without knowing which individuals were the culprits (Hamer et al. 2012, Long et al. 2020, McManus et al. 2015, Moreto 2019).

Human elephant conflict (HEC) is a form of HWC that impacts humans and wildlife in both Africa and Asia. A spreading human population escalates HEC, further threatening already endangered elephant populations. All three species of elephant are currently on the IUCN Red List of Threatened Species. African savannah elephants (*Loxodonta africana*), and Asian elephants (*Elephas maximus*) are listed as endangered, while African forest elephants (*Loxodonta cyclotis*) are listed as critically endangered (Gobush et al. 2021a, Gobush et al. 2021b, Williams et al. 2020). As with other types of HWC, HEC takes place in many ways, including destruction of property, raiding of farmland crops, and disturbance of everyday life activities (Bond, 2015, Mukeka et al. 2019). HEC can escalate, resulting in injury or death of the people or elephants involved, and retaliatory killings of elephants due to the immense destruction they cause (Acharaya et al. 2016, Jacobson & Plotnik, 2020, Nayak & Swain, 2020, Sitati et al., 2003). Many steps have been taken to mitigate HEC. In some areas of both Asia and Africa, high power electric fences are used to keep elephants out of crop fields (Gunaratne & Premarathne 2005, Thouless & Sakwa 1995). However, even when electricity is available, it may be unreliable or too expensive to work effectively over time. Other areas use human patrols (Barua et al. 2013), chemical repellents (Chang'a et al. 2016), fires, or loud noises such as trip alarms, banging drums, and shooting firearms into the air (Enukwa 2017, O'Connell-Rodwell et al. 2000) to deter elephants from entering crop fields.

Because of their relatively low costs compared to other means, fences have been an integral method of deterring potential crop raiders. In Africa, fences have been constructed using locally growing acacia (*Vachellia spp.*) trees (Chang'a et al. 2015), chili peppers (Chang'a et al. 2016), Kasaine metal strips (Von Hagen et al. 2021), and beehives (King et al. 2009, King et al. 2011) among others. An effective mitigation method must deter elephants from entering crop fields while also being cost effective and easy to maintain. While these fence types have shown potential in deterring elephants, no one fence is 100% effective in keeping out crop raiders. Thus, combining fence types may be a viable strategy.

Figure 1. A map of the study site (purple dot) within the Kasigau Wildlife Corridor in Kenya. Map obtained through Online Street Map.

Farms located along the boundaries of national parks or other protected areas for wildlife are raided more often than internal farms (Chiyo et al. 2005; Kagwa 2011; Naughton-Treves & Treves 2005; Sitati et al. 2003). People living in our study site of Sasenyi village in the Kasigau Wildlife Corridor (KWC) in southern Kenya, located between Tsavo East and West National Parks, experience high levels of HEC, especially in the form of crop raiding as elephants move in and through the KWC (Figure 1) (Kagwa 2011; Von Hagen 2018). Limited access to resources, including high-cost electric fences, has frustrated local efforts to mitigate crop raiding in the KWC and other rural areas (Thouless & Sakwa, 1995).

Experimental testing of HEC mitigation methods is necessary to identify effective solutions and advocate for their use to protect both humans and elephants. Since its inception, the *Elephants and Sustainable Agriculture in Kenya* project has focused on testing the efficacy of deterrent fences over the past 5 years. A combination of eleven modern (deterrents consisting of negative stimuli created from man-made articles) and traditional (deterrents consisting of negative stimuli created from articles naturally present in the habitat) deterrent fences have been tested to date and are separated as follows: four modern single deterrents (Kasaine metal strip fence, beehive fence, chili pepper fence, and cloth fence), five modern double and combination (double Kasaine metal strip fence, chili pepper + metal strip fence, double Kasaine metal strip + cloth, beehive + Kasaine metal strip, and the cloth + metal strip fence), one traditional deterrent (acacia fence), and one overall control (grand control) of bare fenceposts. Fence types were chosen to assess practicality, affordability of use in our study site, and ability to stimulate an avoidance response through a variety of sensory modalities. The acacia and grand control fences were used to assess these fence types in comparison to traditional means, and to an overall control of no fence, just fence posts.

Due to elephants mainly crop raiding at night (Branco et al. 2018, Osborn & Parker 2003), most of the deterrent fences tested rely on negative auditory, chemosensory, and tactile stimuli followed secondarily by visual cues to create aversion and reinforce learning. These negative stimuli include loud noises and discomfort from contact with hanging metal strips (Von Hagen et al. 2021), the buzzing of bees followed by stings from bees around the eyes, ears, and inside trunks (King 2007), and discomfort to mucus membranes and the trigeminal nerve through odors and contact with chili oil (Le Bel et al. 2010). The metal strip fences also provide a visual stimulus by reflecting moonlight (Von Hagen et al. 2021). The beehive fences are painted bright yellow, enhancing visibility at night, and potentially promoting association of the yellow boxes with bee presence.

Combination fences of multiple deterrent types were included in the study starting in 2017 to test the hypothesis that they will be more effective than single fence types. The reasoning was their ability to provide a negative stimulus to multiple sensory systems or a stronger stimulus to one, and thereby serve as a stronger deterrent. Since then, four other combination fences have been introduced, including the double metal strip Kasaine fence (Figure 2). Each combination fence was designed to provide a negative stimulus to the approaching elephants through at least three of the four main sensory fronts, namely auditory, chemosensory, tactile, and visual.

Figure 2. A double Kasaine metal strip fence, constructed and erected in the farming community of Sasenyi, Kenya. Photo taken by Sophia Corde.

The primary purpose of this study was to analyze the efficacy of deterrent fences in the Kasigau Wildlife Corridor, and to determine if modern fence types have higher deterrent ability than the grand control because of their ability to provide a negative stimulus upon contact. I compared the effectiveness of each fence type to their matched control that lacked their main sensory stimulus and compared deterrents with an olfactory stimulus to those without. I also hypothesized that fields encompassed by fences constructed of two lines compared to one would have lower crop raiding incidents because they produce a negative stimulus through multiple sensory modalities and/or higher intensities.

METHODS

Study Site

The present study took place within the Kasigau Wildlife Corridor (KWC) located between Tsavo East and Tsavo West National Parks in Taita Taveta county of southern Kenya, Africa (Figure 1). The KWC is home to community and privately-owned ranches, including approximately 100,000 people and 15,000 elephants in the Greater Tsavo Ecosystem. The subset of this in the Kasigau Corridor region closest to our study site of the Rukinga Wildlife Sanctuary (RWS) is about 2,000 with 300-500 residents around the RWS and the Sasenyi farming community (Litoroh et al. 2012), where our study took place (Figure 3). The Sasenyi village was chosen as the study site because of its boundary with the wildlife refuge and high levels of human elephant conflict, particularly in the form of crop raiding (Kagwa, 2011, Mukeka et al. 2020).

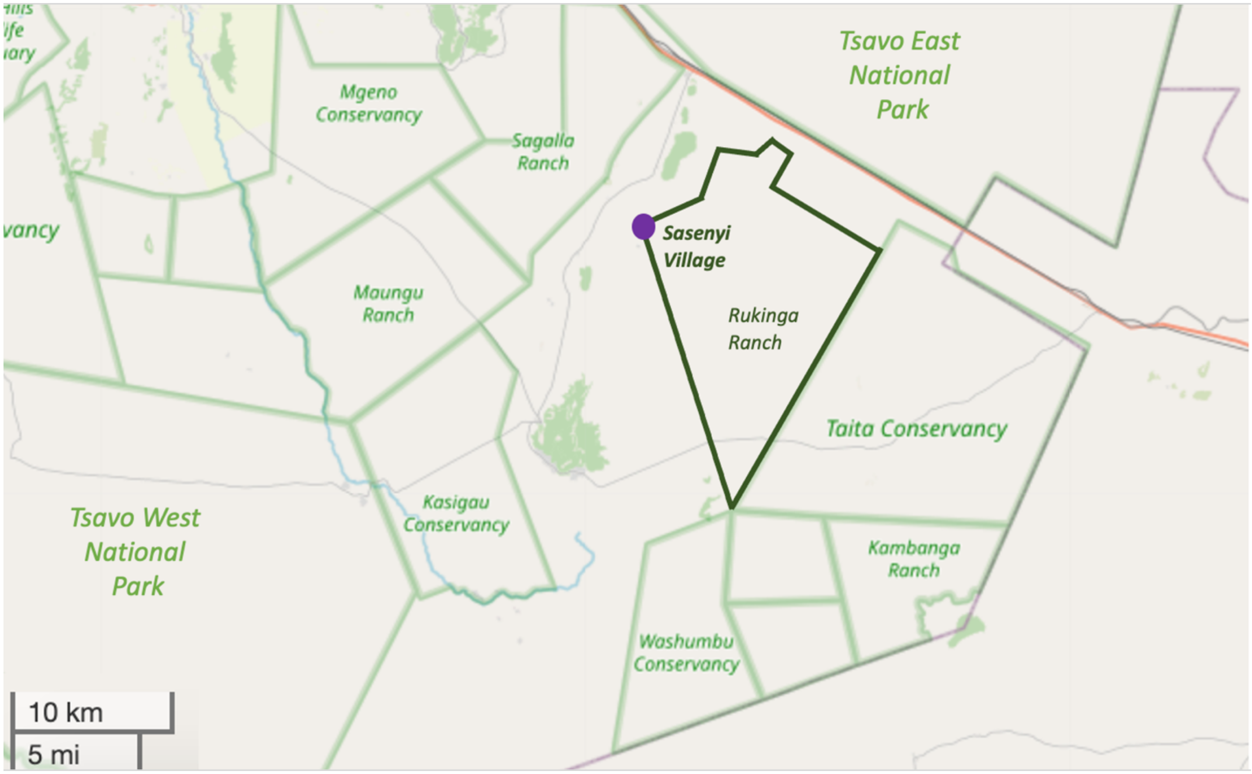

Figure 3. A map of the study site (purple pin) within the Kasigau Wildlife Corridor, Kenya. Map obtained through OpenStreetMap.

Experimental Design

In 2016, a section of land located along the Sasenyi border was chosen for the main study site of ESAK. In 2017 the four main blocks (blocks 1-4, 8 fields per block) were demarcated around agricultural land that was already in use by farmers. The owners of each block agreed to participate in this study. Field dimensions were measured using a tape measure and stakes were placed in the ground to mark placement of fence posts. The fence line for each field was constructed with 12 posts that were 8 m apart. An alleyway of 6 m separated each field as well as a 6 m buffer at the ends of each block to prevent spill-over of deterrent effect across fields (Von Hagen 2021). Fence posts of locally sourced wooden stakes were cut to an approximate height of 2 m and a circumference of 26 cm. Each post was given an identification number including block and field number to allow for easier identification of where elephants entered fields, which was recorded in the crop raiding database.

From 2017 to 2022, deterrent fences were erected around these participating farmers' fields closest to the wild habitat in the KWC to conduct experiments on their ability to deter approaching elephants from entering fields. Two trials were conducted per year over five years, resulting in ten trials total by 2022. Each trial tested up to 4 different experimental deterrents and their respective controls in the main four large blocks (each 310 m x 16 m). In 2018, an additional 4 blocks (blocks 5-8, each 82 m x 16 m) along the same road as the main blocks were leased and added to the project. These blocks were divided into two fields each following the same dimensions as the original fields in the 4 main blocks and were used to test beehive fences and their controls over the past eight trials with one experimental and one control field per block. Over the ten trials, a total of 11 deterrent types were tested around the 32 m x 16 m fields (Table 1).

Table 1. Experimental (e) deterrent fences tested during trials 1-10 from 2017-2021 in the KWC, Kenya. Each fence was paired with a matching control (see Table 2, corresponding number with letter "c"). Eight fields (four experimental, four control) were present in each of the four main blocks. See Table 2 for explanation of Fence Type. This table is organized chronologically.

Fence Type	**Trial 1 2017**	**Trial 2 2017**	**Trial 3 2018**	**Trial 4 2018**	**Trial 5 2019**	**Trial 6 2019**	**Trial 7 2020***	**Trial 8 2020***	**Trial 9 2021**	**Trial 10 2021**
1e) Metal Strip (MS)	X	X	X	X	X	X	X	X	X	X
2e) Acacia[1]	X	X	X	X						
3e) Chili	X	X	X	X						
4e) Chili + MS	X	X								
5e) False chili + MS[2]			X	X						
6e) Cloth + MS					X	X	X	X	X	
7e) DBL MS					X	X	X	X	X	X
8e) Active bee[3]			X	X	X	X	X	X	X	X
9e) Cloth									X	
10e) Active bee + MS									X	X
11e) DBL MS + cloth									X	

[*] Reliable data were not collected during trials 7 and 8 due to the COVID-19 pandemic.

[1] The traditional barrier used by local farmers to deter elephants from entering crop fields.

[2] Was transformed into the cloth + MS fence after trials 3 and 4 by including cloths of varying colors

[3] Beehive fences were erected in plots separate from the four blocks of eight fields each.

Table 2. Legend of abbreviated deterrent fence types used in the KWC, Kenya. This table is organized in order with Table 1. Experimental (e), Control (Co), Metal Strip (MS), and Double (DBL).

Abbreviation	**Deterrent Type + Explanation**
1e) MS	Metal fence. A single wire with hanging metal strung between fence posts.
1c) MS Co	Metal control fence. A single wire strung between fence posts.
2e) Acacia	Acacia. A border of acacia placed around the field.
2c) Acacia Control 1c) Grand Control	Overall control fence. Fence posts, with no wire between them. Used as control when MS erected in two fields per block.
3e) Chili	Chili fence. A rope strung between fence posts with cloths dipped in motor oil and ground chili peppers.
3c) Chili Co	Chili control fence. A rope strung between fence posts.
4e) Chili +MS	Chili + metal fence. A single wire and a rope strung between fence posts with cloths dipped in chili oil and metal strips
4c) Chili +MS Co	Chili + metal fence control. A single wire and a rope strung between fence posts with plain cloths and no metal strips.

Abbreviation	**Deterrent Type + Explanation**
5e) False Chili +MS	False chili + metal fence. A single wire with hanging metal strips and rope with hanging black cloths strung between posts. (Were later renamed as cloth + MS for trials 5-9 and incorporated cloths of different colors)
5c) False Chili +MS Co	False chili + metal control fence. A single wire and a rope strung between fence posts.
6e) Cloth + MS	Cloth + metal fence. A single wire and a rope strung between fence posts with colored cloths and metal strips
6c) Cloth + MS Co	Cloth + metal fence control. A single wire and a rope strung between fence posts.
7e) DBL MS	Double metal fence. Two wires with hanging metal strips strung between fence posts.
7c) DBL MS Co	Double metal control fence. Two wires strung between posts.
8e) Active bee	Active beehive fence. A single wire holding a yellow painted wooden box beehive strung between fence posts.
8c) Active bee Co	Active beehive fence control. A single wire holding up a yellow painted wooden block strung between fence posts.
9e) Cloth	Cloth fence. A rope strung between fence posts with a colored cloth. Only tested in trial 8 and was removed for trial 9.
10e) Active bee + MS	Active beehive fence + metal strips. A single wire holding a yellow painted wooden box beehive strung between fence posts. In front of this is a barrier line of metal strip fences along the road. Distance was given between the two as to not disturb the bees.
11e) DBL MS + Cloth	Double metal strip + cloth fence. Two wires and a single rope strung between fence posts with colored cloths and metal strips. Only tested in trial 8 and was removed for trial 9.

To create a partial randomized experimental design, each field was randomly assigned a deterrent type (Von Hagen et al. 2021). Each block consisted of 8 fields each, 4 experimental and 4 control. A paired control design was used to control for randomization in elephant approaches, in which the deterrent types were randomly assigned to a field, and their controls were erected in the field adjacent (Von Hagen et al. 2021) (Figure 4).

Figure 4. Deterrent fences used in block 2 in the KWC Kenya study site for trial 9. Satellite image obtained from Google Earth.

Two growing seasons occur each year. The first growing season runs from April to August, and the second growing season from October through February of the subsequent year. These seasons coincide with the rains and thus the wet and dry seasons (Wato et al. 2018). Starting in 2017 and continuing through to 2022, once a growing season began, camera traps were mounted strategically on fence posts to maximize coverage of wildlife that approached the fences. Camera traps were taken down ten days after the last elephant was caught on camera trap and all the crops had been harvested in the experimental fields. The only year in which camera traps were not used since 2017 was in 2020 due to the COVID-19 pandemic.

Deterrent Construction

Each deterrent was chosen because of their hypothesized ability to stimulate multiple sensory modalities (Table 3). Deterrent fences were designed and erected in 2017 following the methods laid out in Von Hagen (2018) and summarized below.

Table 3. Sensory stimulus of each of the experimental deterrent fences tested during trials 1-10 from 2017-2021 in the KWC, Kenya. Each fence, aside from the grand control, was chosen because of their ability to stimulate one or multiple sensory systems in the crop raider. Acacia is the traditional barrier used by farmers. Multiple "X" means that the fence is able to stimulate that sensory system via two deterrent types.

Deterrent Type	**Tactile**	**Auditory**	**Olfactory**	**Visual**
Grand Control				
Acacia	X			
Cloth		X		X
Chili	X	X	X	
Cloth + MS	X	XX		XX
MS	X	X		X
DBL MS	XX	XX		XX
Active bee	X	X	X	X
Chili + MS	XX	XX	X	X

Kasaine Metal Strip Fences

The Kasaine metal strip fence (MS) (Figure 5) was included in testing in 2017 because of its presence in the study area as a popular local design created by Mr. Simon Kasaine but one that lacked scientific testing of effectiveness. This fence relies on providing a negative tactile, visual, and auditory stimulus to approaching elephants. Wind or physical impacts cause the strips to collide and create noise which has been postulated to frighten the elephants; in addition, the sharp edges of the strips are likely to be uncomfortable to the touch (Von Hagen et al. 2021). The reflection of light off the strips may also alert the elephants to the presence of the fence (Von Hagen 2018). Testing on these fences has continued to the present because of their continued promise as a highly effective deterrent.

Figure 5. Kasaine metal strip fence built and erected in the farming community of Sasenyi, Kenya. Photo taken by Sophia Corde.

To build the MS fence, locally sourced binding wire was cut to 12 m per panel of fence, 12 panels total per field. Metal was acquired from locally sourced Mibati metal rolls, which are commonly used in the area for roofing. Strips were cut from the metal rolls with the dimensions of 0.50-0.80 m long and 0.10-0.12 m wide. A hole was poked through the metal using a nail and hammer, and the strips were threaded along the wire. Pliers were used to twist the wire at 1 m intervals, and after each twist, 3-4 strips of metal were strung. The twists prevented the metal strips from sliding together. The metal strip panels were attached to fence posts at approximately 1.5 m high. The control for this fence was constructed using the same methods for the fence posts and the wires but excluding the metal strips.

Double Kasaine Metal Strip Fence

The double Kasaine metal strip fence (DBL MS) was included in testing in 2019 due to a hypothesis of increased effectiveness from heightening sensory load through the inclusion of two panels of metal strips. Like its single counterpart, this fence also relies on a negative tactile, visual, and auditory stimulus from wind or physical impacts making a loud noise. In addition, the connection with the fence leads to contact with the strips whose sharp edges are likely to cause discomfort (Von Hagen et al. 2021). Testing on these fences has also continued to the present.

The DBL MS fence was created using the same locally sourced binding wire and Mibati metal rolls to create the panels. This fence used two panels of strung metal strips. One strip was placed at 1.5 m of height and the other at 1.4 m of height to keep them from tangling (Figure 6). The control for this fence was constructed using the same methods for the fence posts and the wires but without the metal strips.

Figure 6. Kasaine double metal strip fence built and erected in experimental block 2 during trial 8 in the farming community of Sasenyi, Kenya. Photo taken by Sophia Corde.

Active Beehive Fence

Trials on the beehive fence (Figure 7) began in 2018. The active beehive fence was chosen because of its performance as an effective deterrent in many areas against both African and Asian elephants including: the Meru North District in Northern Kenya, Kerala, India, and the Kilombero Valley of south-central Tanzania (King et al. 2011; Nair and Jayson 2016; Scheijen et al. 2019). The beehive fence uses the elephants' natural fear of African honeybees, which attack in swarms and will sting sensitive areas of the elephant such as the eyes, ears, and inside the trunk (King 2007), thus providing a negative tactile, auditory, and olfactory stimulus to the elephants.

The active beehive fence was created using the guidelines provided by Dr. Lucy King (2017) following the Langstroth Beehive design. To suspend the beehives, the same locally sourced binding wire was used (Figure 7). The control for this fence was constructed using the same methods, however, rather than hanging hives, the control solely hung wooden planks painted yellow to match the beehives in the active fence.


Figure 7. Active beehive fence during trial 8 in the farming community of Sasenyi, Kenya. Photo taken by Sophia Corde.

<u>Chili Pepper Fences</u>

The chili pepper deterrent fence was introduced at the beginning of the project in 2017 but was only tested for 2 years and removed after 2018. This design, much like the beehive and Kasaine metal strip fences, relies on causing a negative tactile and olfactory stimulus. The chili and motor oil mix causes discomfort to those that contact it, as well as an unpleasant smell, leading to elephants being deterred from entering fields. This fence, though effective in other parts of the world against both African and Asian elephants (Chang'a et al. 2016, Davies et al. 2011), performed poorly in our study site, potentially due to the very dry and arid conditions of the KWC, causing the oils to dry on the cloths, thus not enacting the desired negative stimulus upon contact (Von Hagen et al. 2021). The preparation and maintenance issues of this fence also made it impractical in our area.

Construction of this fence followed the methods laid out in Von Hagen et al. (2021). 100% cotton black cloths were purchased from Wildlife Works and cut to 0.6 m X 0.6 m squares. Sisal rope was used to string the cloths between fence posts at 1.5 m high. Mixtures of crushed chilies and motor oil were applied to the cloths and ropes. A single cloth was attached at the center of the rope by tying 30 cm of rope to each corner of the cloth, and then tying these to the connecting rope between the fence posts. The control for this fence was constructed using the same methods for the fence posts, cloths, and motor oil, but removing the chili oil from the applied concoction.

Chili + MS

The combination chili + MS fence was included and tested in 2017 but was removed after 2 trials, as it performed poorly in our study site and had additional logistical issues. This fence relied on auditory stimulus from the metal strips, and a negative tactile and olfactory stimulus from the chilis. Construction of this fence followed the same methods as the chili pepper fence explained above. In addition to the chili oil covered cloths, a panel of metal strips was strung between the posts as stated above; however, this line was hung at 1.4 m high to allow room between these two deterrents. The control for this fence was constructed using the same methods for the fence posts and the wires, but without the metal strips, and without the chili oil in the applied concoction.

Cloth + MS Fence

The cloth + MS fence (Figure 8) was included in testing in 2018, after the chili pepper and chili pepper + MS fences failed to perform in our study site. This design relied on causing a negative tactile stimulus with the MS, and a negative visual stimulus with the bright colored cloths (these were initially introduced as just black cloths for the first 2 trials and then changed to include colored cloths in subsequent trials in 2019). As with all fences using cloth, the cloths will flap in the wind, but this is not a stimulus necessarily related to the presence of elephants or their interaction with the fence.

Figure 8. Cloth + metal fence in block 1 of trial 8 in the farming community of Sasenyi, Kenya. Photo taken by Sophia Corde.

Construction of this fence followed the same procedure as the chili pepper fence, just omitting the chili and motor oil application, which reduced construction and maintenance issues. Rather than using solely black cloths, locally source 100% cotton cloths of varying colors were purchased from Wildlife Works. A panel of metal strips was strung between the posts as stated above; however, this line was hung at 1.4 m high to allow room between these two deterrents. The control for this fence was constructed using the same methods for the fence posts, wires, and rope but without the metal strips or the cloths.

Cloth Fence

Testing of the cloth fence only occurred during trial 9. The cloth fence relies solely on the visual stimulus of colored cloths. Due to logistics with repair and upkeep, and low efficacy in our study site, the testing of this fence was terminated after 1 trial. This fence relied on the visual stimulus of the colored cloths, thus not providing a negative stimulus upon approach or contact with the fence other than a potential warning through the colored cloths. Construction of this fence followed the same methods as the cloth + MS fence, just omitting the application of the MS panel to the fence posts. The control for this fence was constructed using the same methods for the fence posts and ropes, but without the cloths.

Double Kasaine Metal Strip + Cloth

The double Kasaine metal strip + cloth fence (DBL MS + cloth) was tested only for trial 9 and was subsequently removed from the project because it constantly needed maintenance from being tangled within itself, ripping off the cloths, and causing the metal strips to get stuck in place, no longer emitting a sound. This fence was hypothesized to provide a negative tactile and auditory stimulus from the two lines of metal strips, and a visual stimulus from the cloths.

Construction of this fence followed the same methods as laid out above for the cloth + MS fence. After these panels of fencing were added, a second line of MS was added below these deterrents at 1.3 m high. Due to low sample sizes, this fence was not included in analysis. The control for this fence was constructed using the same methods for the fence posts, ropes, and wires but without the metal strips or cloths.

Active Bee + MS

Testing on the active bee + MS fence started in 2021 during trial 9. The idea of this fence stemmed from the idea to create a double deterrent using two effective fence types. This fence relies on negative visual (reflection of moon light off metal strips, yellow beehives), auditory (collision with metal strips, buzzing of bees), tactile (sharp edges of metal strips, stings from disturbed bees), and olfactory (scent of occupied beehive) stimuli.

This deterrent was constructed using a layered deterrent fence design. Two beehive fence blocks with the deterrent already constructed were used for this fence. At a distance of 10 m away, a second layer of fencing was constructed using the methods described for the metal strip fence. The length of this layer extended along the road and stopped at the alleyway, without closing off the section between the active beehive fence and the metal strip barrier. This fence was not included in analysis because of low sample sizes. The active beehive fence acted as the control for this fence design.

Acacia Fence

At the start of the study in 2017, the acacia fence was tested because of its use as a traditional deterrent in the study area. Many farmers will place thorny acacia branches harvested from the wild around their fields to keep out potential grazers, including elephants (Chang’a et al. 2015). The use of the acacia fence was terminated at the end of 2018 because it did not perform significantly better than the grand control of just fence posts (p = 0.39), the desire by the researchers to stop the harvesting of acacia from the wild lands, and to serve as an example for the local farmers to protect the neighboring wild habitat (Von Hagen et al. 2021). The control for this fence was constructed using just fence posts (see Grand Control section).

Grand Control

The grand control fence was included in testing from the inception of the project and is continuing to be used as the overall control for the project. This fence provides no stimulus to the crop raider, as this field solely consists of fence posts spaced 8 m apart around the length and width of the field.

Recording Crop Raiding Events

The effectiveness of the deterrents was determined by assessing approaches and breaches of the deterrent fences by elephants, fence damage, plant damage, footprints, and reports from farmers. Identifying what species caused the damage was accomplished through monitoring camera trap images and supplemented with identifying footprints and acquiring first-hand sightings by locals. 25-31 Moultrie Spy A-5 Gen2 & A30i series infra-red camera traps were placed on posts for each fence type to include the field as well as the road that divides the farms from the wild lands in their image frame. This angle was chosen to capture behaviors elephants present when encountering the fence, as well as their approach from the wild area across the road. Each camera was placed inside a protective camera cage, nailed to a fence post at about 2 m height, secured with a Master Lock python cable, and then locked to prevent theft. Cameras were mounted once the growing season began and deterrent fences were active and taken down when the crop raiding season had ended, and no elephants were present in the area for 10 days. Camera traps were set to take 3 consecutive images spaced out by 15 seconds and were triggered by motion detection. Camera trap images were recorded on SD cards, which were changed out every 5-10 days depending on how many pictures the cameras took. Batteries were also changed at least once per season depending on how many pictures the cameras took.

To review camera trap pictures, images were loaded onto computers. Images containing wildlife or domestic animals were saved to the computer and organized by camera trap number, block, field, and pole numbers. Species, number of individuals, field, and deterrent type was recorded with each picture. Whether the deterrent was active, if there was maize present, if there was structural fence damage, if the animal(s) were being chased, and approximate distance to the field were also recorded. Distance was approximated using the 8 m distance between fence posts and 6 m distance between fields.

Camera trap data were corroborated with footprint and report evidence from local farmers. Farmers were employed as fence attendants to monitor the fields daily for wildlife interactions. The US based team checked the fields at least once a week while in the field during the crop raiding season. When the US team was not in the field, Wildlife Works employee Simon Kasaine monitored the fields and camera trap images biweekly.

On occasions where wildlife entered the fields, the extent of damage to the crops was recorded based on whether the crops were trampled or consumed. To obtain an accurate assessment of crop growth level for each field, and whether this impacted raids, a ranking system developed by Hoffman-Karimi & Schulte (2015) was used to determine the average growth phase condition score (CS) of each crop. These condition scores were assigned to a field once a week by the research team. This was not possible during trials 7-10 due to COVID-19 and the 2021 drought causing delayed rains. Once fields reached a growth rank above a 2, the crop yield was estimated by the research team. This allowed for an easier estimate of the number of crops damaged in crop raiding events, and final yield at the end of the season. Any plants lost from causes other than elephant crop raiding events, such as raids done by other species, or crop failure due to pests or drought, were also recorded. Again, because of the pandemic and other personnel issues, harvest data were not reliably collected and therefore not used in analyses.

Data Analysis

Although I joined the project in 2019, I conducted analysis on past data and data from my time in the field in 2021 for a complete analysis of fence performance. Nineteen fence types were tested over the course of 10 trials (11 experimental and eight control) from 2017 – 2022. Because testing on the active beehive + metal and the double metal + cloth fences were not started until 2021, they were not included in analyses. The false chili + MS and cloth + MS deterrents were combined into one cloth + MS deterrent for analysis due to low sample size and non-significant differences between their performance at deterring approaching elephants. Thus only 8 of the original 11 experimental deterrents tested were analyzed, the MS, DBL MS, active bee, chili, chili + MS, cloth + MS, cloth, and acacia.

Due to the COVID-19 pandemic, we were not able to deploy camera traps in 2020 (trials 7 and 8). Our partnering local farmers and Wildlife Works employees also limited contact with others by visiting the farms less frequently to prevent the spread of COVID-19 in this rural region. Deterrent fences remained up and functioning during this time, however, the lack of human presence around the farms led to effectiveness of deterrents only being assessed after crop raiding events had occurred, leading to trials 7 and 8 having unreliable data in comparison to the other 8 trials. Because of this, trials 7 and 8 were removed from the analysis, and only trials 1-6, 9, and 10 were used.

Across trials 1-6, 9, and 10 a total of 429 groups of elephants (1071 individuals) approached within 12 m of the experimental fields. Two hundred and thirty-five (235) groups of elephants (603 individuals) breached the fences, and 194 groups (468 individuals) were deterred.

The size of all the groups that approached or breached ranged between 1-13 individuals with an average group size of 2.56 ± 1.8 (breached) and 2.44 ±2.0 (deterred).

All data were recorded in Microsoft Excel and all analyses were conducted using R studio ver 1.3.1073. To quantify the number of approaches, breaches, and successful crop raiding events for each fence type, the data from trials 1-6, 9, and 10 were combined. An approach was recorded as any elephant that came within 12 m of the deterrent fences. 12 m was used as the approach distance because it is the furthest distance where presence of wildlife could be reliably defined through camera trap images while minimizing potential influence by a neighboring deterrent, which are estimated to have a spillover effect of about 6 m (Von Hagen et al. 2021). A breach was recorded as any time an elephant came within 0 meters of the deterrent fences, meaning that they broke the deterrent fence boundary. Successful deterrence was calculated as the number of deterred elephants divided by the total number of approaches for that fence.

To assess the effectiveness of the modern deterrent types in comparison to traditional deterrents, generalized linear mixed models were fitted to the data (Kiffner et al. 2021). Deterrent fence type was considered as a fixed effect. To account for variances in elephant presence from differences in the experimental design of the beehive blocks and the main experimental blocks and potential variances across trials, fields, and block and trial interactions, block, trial, field, and block*trial were set as random effects. Approaches and breaches were used as the response variable for the model: breach of the deterrent fence line (came within 0 m of the deterrent fence) yes [1] or deterred [0] (came within 1-12 m of the deterrent fences) using the *lme4* package in R (Bates et al. 2015). Models varying in complexity through the removing of different random effects were compared using analysis of variance. The resulting lowest AIC value was compared to each model to ensure the best model was used to compare the data. These same methods were used to compare all modern deterrents to all modern deterrent controls and all deterrents containing an olfactory stimulus to those without. Only olfactory deterrents were used for the comparison of combined stimulus due to limitations in sample size for comparison of the other stimuli (auditory, tactile, visual). These same methods were used to assess the effectiveness of the single deterrent types in comparison to double. Only the single deterrents that had double deterrent counterparts were included in this analysis (MS and DBL MS, chili and chili + MS, cloth, and cloth + MS). All tests used an alpha value of 0.05 for significance.

The randomized block design was instituted to avoid location specific issues with evaluating fence effectiveness. The design was maintained over the eight trials under analysis in this study. To determine if the variances in time (trial number), location (block number and field number), and the interaction between the block and trial (trial*block) had an influence on the results, these variables were labeled as random in the generalized linear mixed models. The significance of these factors was tested using an rANOVA test. The random factors of trial ($p = 0.76$), block ($p = 1.00$), field ($p = 0.09$) and the interaction between block and trial ($p = 0.10$) had no significant effect on the model.

RESULTS

I hypothesized that modern fence designs would deter elephants significantly better than traditional, such as the acacia fence, and that modern deterrents would perform better than their matched controls due to their ability to stimulate sensory systems upon contact. I also hypothesized that double deterrents would deter elephants significantly better than their single counterparts due to their ability to provide a negative stimulus to multiple sensory systems, and/or at higher intensities.

Effectiveness of Deterrents

Over the eight trials analyzed (2017-2019, 2021-2022), the acacia and grand control fences were the least effective at deterring approaching elephants when comparing the proportion of deterred elephants to total number of approaches to each fence individually (Figure 9). When elephants approached within 12 m of fence, they were deterred from entering fields surrounded by the acacia fence 4 of the 21 times (19% effective). Over 10 trials, elephants were deterred from entering fields guarded by the grand control 20 of the 74 times (27%).

The most effective fences at deterring approaching elephants were the double MS fence and the active beehive fence (Figure 9). Elephants were deterred from entering fields surrounded by the double MS fence 24 of the 34 times (70.5%) in 4 trials, while the active beehive fence deterred 50 of the 57 (87.7%) approaching elephants over 6 trials. Overall, the modern fences performed better than the grand control at deterring elephants (Table 4 and Figure 9).

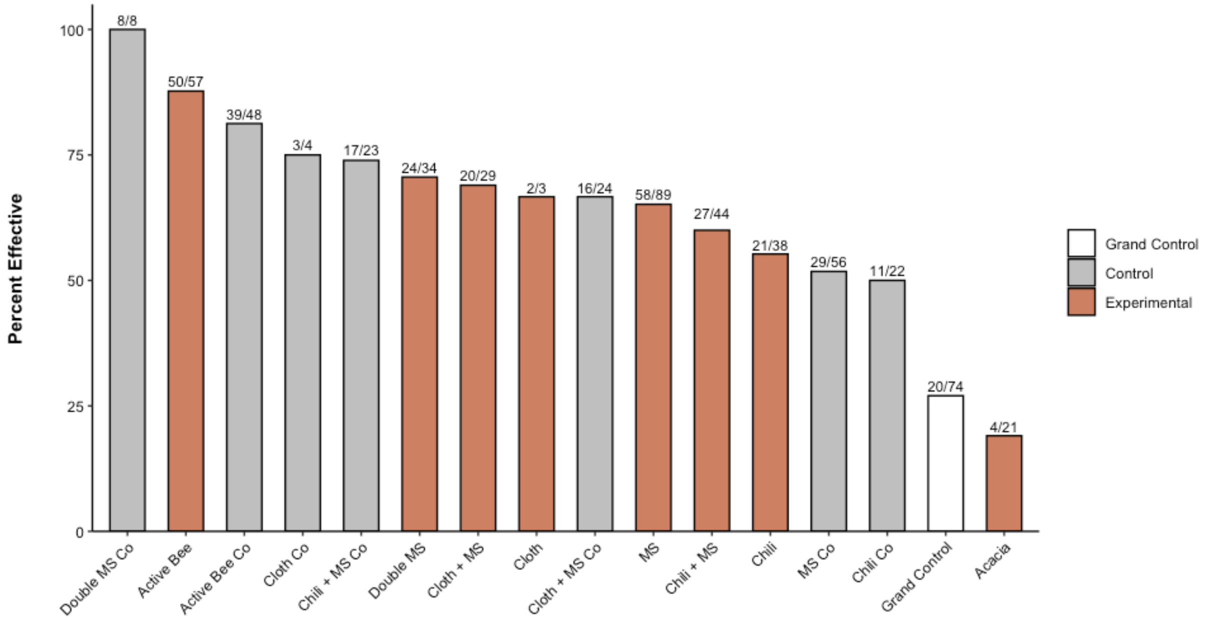

Figure 9. Effectiveness of each deterrent (deter/approach within 12 m, value above bars) at the experimental crop fields in KWC Kenya. Brown bars are experimental fences and gray bars are control fences. The white bar is the grand control (fence posts only).

Table 4. Modern and traditional fence effectiveness in comparison to the grand control (fence posts only) at the KWC Kenya using generalized linear mixed models.

Deterrent	**#Trials**	**Approaches (B+D)**	**Estimate**	**Std. Error**	**z value**	**p value**
Acacia	1-4	Breached: 17 Deterred: 4	0.52	0.60	0.86	0.39
Active bee	3-10	Breached: 7 Deterred: 50	-2.86	0.53	-5.42	**5.93e-8**
Active bee Co	3-10	Breached: 9 Deterred: 39	-2.23	0.49	-4.57	**4.85e-6**
Chili + MS	1-2	Breached: 6 Deterred: 9	-1.60	0.58	-2.77	**0.005**
Chili + MS Co	1-2	Breached: 6 Deterred:17	-1.83	0.56	-3.27	**0.001**
Chili	1-4	Breached: 17 Deterred: 21	-1.09	0.43	-2.50	**0.01**
Chili Co	1-4	Breached: 11 Deterred:11	-1.01	0.49	-2.05	**0.04**
Cloth	3-4, 9	Breached: 1 Deterred: 2	-1.81	1.28	-1.42	0.16

Deterrent	#Trials	Approaches (B+D)	Estimate	Std. Error	z value	p value
Cloth Co	3-4	Breached: 1 Deterred: 3	-2.37	1.18	-2.02	**0.04**
Cloth + MS	5-9	Breached: 9 Deterred: 20	-1.60	0.49	-3.27	**0.001**
Cloth+ MS Co	5-9	Breached: 8 Deterred: 16	-1.66	0.52	-3.17	**0.002**
DBL MS	5-10	Breached: 10 Deterred: 24	-1.38	0.41	-3.34	**8.31e-4**
DBL MS Co	5-9	Breached: 0 Deterred: 8	-18.23	2.03e3	-0.01	0.99
MS	1-10	Breached: 31 Deterred: 58	-1.47	0.35	-4.27	**2.00e-5**
MS Co	1-9	Breached: 27 Deterred: 29	-0.97	0.38	-2.55	**0.01**

To test whether the component of the fence that resulted in greater effectiveness was the negative stimulus included in each of the experimental deterrents, the experimental deterrents were compared to their controls. From this group analysis it was found that no fence performed significantly better from their control (row 2 Table 5). No experimental deterrent performed better than their matched control (Table 5).

Table 5. Results of generalized linear mixed models run on the deterrent fence data in comparison of the modern deterrents to their respective matched controls, see Methods.

Deterrent	Estimate	Std. Error	z value	p value
Experimental vs Control (Excluding GC)	-0.04	0.21	-0.20	0.84
Active bee	0.15	0.49	0.31	0.24
Chili	-0.22	0.51	-0.43	0.66
Chili + MS	-0.25	0.68	-0.37	0.71
Cloth	0.72	10.26	0.07	0.94
Cloth + MS	0.31	0.57	0.55	0.59
DBL MS	-18.51	724.08	-0.03	0.98
MS	0.31	0.39	0.78	0.44

However, when deterrents were grouped by stimulus type (ability/inability to provide a negative olfactory stimulus), deterrents that provided an olfactory stimulus performed significantly better than those that did not (Table 6).

Table 6. Results of generalized linear mixed models run on the deterrent fence data in comparison of the deterrents able to provide an olfactory stimulus (active beehive, chili + MS) to those that cannot (DBL MS, MS, Cloth + MS)

Deterrent	**Estimate**	**Std. Error**	**z value**	**p value**
Olfactory Stimulus Present	-1.05	0.38	-2.77	**0.006**

Effectiveness of Single vs. Double Deterrents

I hypothesized that double deterrents would perform better at deterring elephants than their single deterrent counterparts because of their ability to stimulate sensory systems at a higher strength and intensity. The eight deterrents analyzed included five single deterrents (acacia, metal strip, chili, cloth, and active beehive) and three double deterrents (double metal strip, chili + metal, and cloth + metal). To analyze the difference in effectiveness of single verses double deterrent fences, only the single deterrents that had double deterrent counterparts were analyzed. As stated above, the active beehive + metal fence was not included in the following analysis due to low sample size as testing only started in 2021. Of all approaches within 12 m of the deterrent fences over the past 10 trials, 62.5% of them were to single deterrents, and only 37.5% were to double deterrents.

When deterrent effectiveness was compared between the single and double deterrent fences, the single deterrent fences were 62.3% effective, and the double deterrent fences were 68% effective (Figure 10). There was no significant difference in their ability to deter elephants from entering crop fields (row 2 Table 7).

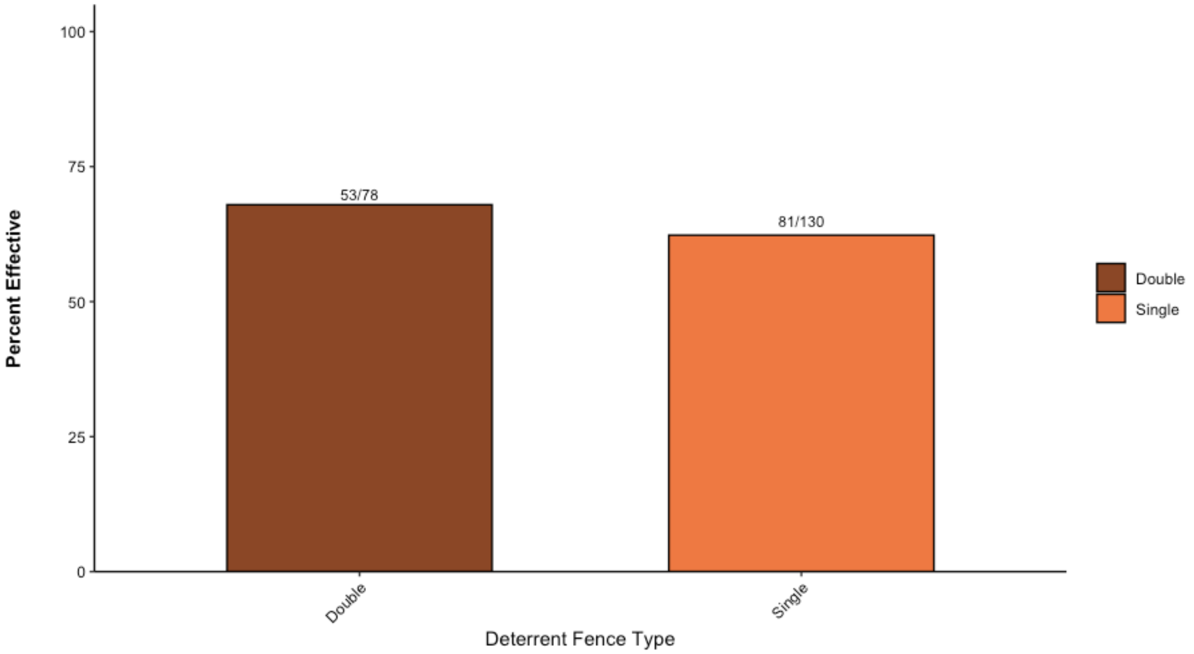

Figure 10. The proportion of elephant approaches within 12 m to single and double deterrent fence types that resulted in breaches of the fence over trials 1-6, 9, and 10 in the KWC Kenya.

Table 7. Results of generalized linear mixed models run on the deterrent fence data in comparison of the modern single deterrents to the modern double deterrents.

Deterrent	**Estimate**	**Std. Error**	**z value**	**p value**
Single vs Double	-0.13	0.30	-0.44	0.66
MS v DBL MS	0.39	0.51	0.76	0.45
Chili v Chili + MS (12m)	0.55	0.58	0.93	0.35
Cloth v Cloth + MS (12m)	0.03	1.46	0.02	0.98

DISCUSSION

My findings were consistent with others in the field of HEC in that the use of modern deterrents is often more successful at preventing crop raiding events than traditional means

(Chang'a et al. 2016, Ciska et al. 2019, Davies et al. 2011, King et al. 2011, van de Water et al. 2020, Von Hagen et al. 2021). The ineffectiveness of the acacia fence is likely attributed to acacia trees being encountered with high frequency in their natural habitat, and they are a staple food source for elephants (Dudley 1999, MacGregor & O'Connor 2004). Acacia branches are typically taken from wild areas for these deterrents, lowering forage quality in the area and potentially driving wildlife toward crop raiding because of limited forage, worsening the problem (Veblen 2013, Von Hagen et al. 2021). The use of modern experimental deterrents would decrease take from the wild lands and in turn could lessen the frequency of crop raiding events because of increased access to natural forage.

The prediction that the effectiveness of the modern deterrent fences relied on their ability to provide a specific negative stimulus to the crop raider was not supported. Across all deterrent types, no experimental deterrent performed better than their matched control. However, the percent effectiveness did differ between fence types that aligned with their ability to incite a negative stimulus. In the case of the cloth, cloth + MS, chili, and chili + MS fences, the percent effectiveness of their control was relatively similar to the experimental, and in some cases, controls performed better than their experimental counterparts. This is potentially due to their inability to incite the desired negative tactile stimulus in our study site. The negative stimulus of the cloth fences is solely visual, as these cloths are brightly colored. With the chili pepper fence, the proposed negative stimulus was the scent and stinging from the chili oil through stimulation of the trigeminal nerve (Le Bel et al. 2010), however, these did not perform well in our study site.

In comparison, the active beehive and MS fences both performed better than their paired controls and were the two most effective at deterring crop raiding events. These two deterrents also incite the strongest negative stimulus of the eight experimental deterrents analyzed. Both fences provided a negative tactile, auditory, and visual stimulus, with the active beehive fence also providing an olfactory stimulus with the presence of bees (King et al. 2011, King et al. 2007, Von Hagen et al. 2021).

When fences were grouped by their ability to provide an olfactory stimulus (active beehive and chili + MS), or not (DBL MS, MS, and cloth + MS), those that could (85.3% effective) performed significantly better than their counterparts (68.7% effective). This is potentially due to their ability to provide that stimulus from a distance, without contact being made with the fence. However, these results come from preliminary testing with relatively low sample sizes. Further testing needs to be done to acquire higher sample sizes for not only those that incite an olfactory stimulus, but tactile, visual, and auditory as well.

My third hypothesis, and original finding by Von Hagen et al. (2021), that double deterrents would perform better than single deterrents, was not supported. This is potentially because the double deterrents were all made of a combination of MS and a version of the cloth fence. Metal strips were originally added to these single fence designs to examine the hypothesis that this will hinder elephants' ability to enter crop fields by lifting the deterrent with their tusks, a behavior reported in other studies of deterrent fences (Evans & Adams 2018, Mutinda et al. 2014). The cloth fences all performed poorly at deterring elephants and did not incite an added negative stimulus. This could be the reason why all double deterrents, aside from the double MS, performed with a similar effectiveness to the single MS fence. Although the double MS did not introduce a new stimulus to the design, it provided the stimulus at a higher magnitude through its two-panel design. Further testing needs to be carried out on the double MS fence to tell if this trend persists across trials, as well as other double deterrent fences in which they consist of deterrent types that provide different negative stimuli.

The major constraints in the uptake of modern deterrent fences are affordability, practicality, and effectiveness (Osborn & Parker 2003, Sarkar et al. 2016). In our study site, testing of the chili, chili + MS, and the cloth + double MS deterrent fences was terminated because they were not practical or effective. These deterrents all showed promise during their creation, and in the case of the chili pepper fences, demonstrated effectiveness in other study sites (Chang'a et al. 2016, Davies et al. 2011, Montgomery et al. 2021). However, in the KWC the chili and chili + MS fences, though more effective than the grand control, were our lowest performing deterrents (55% and 60% effective respectively). They also required an intense amount of maintenance and were subsequently replaced with more practical deterrents. Due to the dry and arid environment of the KWC, particularly in the village of Sasenyi, the chili pepper and motor oil drenched clothes also dried quickly, consistently requiring reapplication of the oil, and leading to the chili pepper fence performing more like the cloth deterrent fence (Von Hagen et al. 2021).

Practical and affordable deterrent fences that incite a strong negative stimulus require further testing. The efficacy of fences with strong negative stimuli has been shown in studies done in areas using high-powered electrical fences and beehive fences (Sajla & Famees 2022, van de Water et al. 2020). However, although powerful and effective, these fence types are not practical for many people living in rural areas and effected by HEC because of their high demands in cost and maintenance. Although it did not work in our study area, the chili + MS fence does deserve considerations in regions where chili peppers are a viable elephant deterrent (Montgomery et al. 2021). The chili + MS has the potential to provide the same amount of negative stimulus as the active beehive fence and could be a strong and more affordable option for those who cannot afford the active beehive fence, or who struggle to keep beehives occupied.

Among the deterrent fences tested, the control for the active bee fence performed better than all except its matched experimental. The active bee control fence has the same negative visual stimulus as the cloth deterrent fence, however, has a percent effectiveness higher than even the double MS. This could be from a spillover effect of the negative stimuli associated with the active beehive fence. Without making contact, the active beehive fence still emits an olfactory and auditory deterrent when bees are present (King et al. 2007). Elephants are highly olfactorily-oriented animals (Navo et al. 2020) and have learned to be sensitive to the sound of angered bees (King et al. 2007, King et al. 2018), thus, both stimuli most likely can be sensed in the neighboring field. It would be helpful to test the active bee control fence away from the active beehive fence to tell if it truly is the spillover effect of the beehives adjacent, or if the yellow dummy hives are what is effective, or if it is a mix of both. If there is a spillover effect, this would be a great and important result for local farmers who are struggling to keep beehives occupied, especially in areas like the KWC where occupancy is difficult to keep because of the dry conditions.

Although these deterrents were designed to keep out elephant crop raiders, they have displayed effectiveness against other crop raiders as well in the region, primarily eland (*Taurotragus oryx)*. Though not as effective as against elephants, the active beehive and metal strip fences deter elands 69% and 62% of the time they approach respectively compared to the grand control (9.3%). The other deterrent fences do not have a high enough sample size of eland presence to report their efficacy. This stark difference in effectiveness against elands could show that the active beehive and MS fences could be a good mitigation method for other areas facing human wildlife conflict in the form of crop raiding (Gross et al. 2019, Mukeka et al. 2019). Although these are preliminary findings, expanding the testing of these fences beyond elephants could aid in the mitigation of other HWCs in areas like the KWC where access to electrical fencing and expensive deterrent methods are impractical.

To alleviate the effects of both crop raiding and climate change, improved agricultural practices are being learned and carried out in many areas that rely heavily on agriculture through the implementation of climate smart agriculture and kitchen gardens (Ogada et al. 2020, Aggarwal et al. 2018). The implementation of these proactive agricultural strategies will lessen the burden of HWC driven crop raiding events, and lead to more reliable food and economic security as droughts become more severe and prolonged (Lahmar et al. 2012, Partey et al. 2018). A climate smart agriculture plot has been introduced to this area, and climate smart agricultural practices have been taught to the farmers in hopes of uptake and changes to traditional methods to improve crop yield. Elephant resistant crops have also been introduced to the farmers, in hopes of uptake and transition to the growing of these rather than maize in the future (Berliani et al. 2018).

The field of conservation, particularly in the realm of human wildlife conflict, is ever changing. New methods of promoting coexistence are continually added and tested, and the faults of existing methods are found through analysis and prolonged testing in various environments. The study and reporting of the efficacy of different deterrent types in different environments across Africa and Asia is increasingly important as the uptake of these deterrent types increases among local farmers. As one deterrent, though effective in some areas at mitigating HWC, may not be the best strategy for others based on economic and environmental differences. The inclusion of local and indigenous peoples who are impacted by these conflicts continue to be included in our study in the KWC and need to be included in the creation of conservation solutions across the study of HWC. Projects in conservation need to work with the local community to gain feedback on these mitigation methods and future developments in conservation to make sure we are enacting ones that are practical and make coexistence and conservation a group effort.

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CHAPTER 2: USING CROP SEASON AND MOON PHASE TO CREATE AN ECOLOGICAL PREDICTION SYSTEM OF ELEPHANT CROP RAIDING EVENTS IN SOUTHERN KENYA

ABSTRACT

The environmental factor of lunar cycle coupled with the agricultural factor of crop season can have strong influences on animal behavior. Understanding how these factors influence behavior is necessary for mitigating human wildlife conflict (HWC). Over five years of study have been dedicated to mitigating a form of HWC, Human Elephant Conflict (HEC), in the Kasigau Wildlife Corridor (KWC) in southern Kenya, focusing on the construction of deterrent fences and the collection of environmental (moon phase) and agricultural (crop season) data around the Rukinga Wildlife Sanctuary. These data were collected to assist in the creation of an ecological prediction system due to elephants' nocturnal crop raiding behaviors and crop growth status being inversely related to the status of natural forage. Higher elephant presence around crop fields was hypothesized to occur at the end of the crop season, when natural forage quality is decreasing, and to have a negative relationship with lunar light levels. These data were compared to elephant presence within 12 m of experimental crop fields along the boundary of their wild habitat and human agricultural land to provide insight for potential crop raiding events. Elephants were present significantly less during the full and gibbous moon phases when compared to the new moon phase, and significantly more during the new and waning phases. Elephants were also present significantly more during the end of the growing season, when farmers were harvesting their crops and natural forage was dwindling, when compared to the middle of the growing season, when natural forage is most abundant. These relationships will help farmers better prepare peaceful mitigation practices; and the understanding of how animal

behavior varies with regard to these factors may have broader application in the mitigation of HWC.

INTRODUCTION

The temporal effects of seasonality, including changes in rainfall and temperature, have strong influences on animal behavior. Seasonal changes in rainfall and temperature can influence access to preferred forage and breeding grounds, thus influencing migratory and spawning behaviors (Torney et al. 2017). The impacts of season can be seen in Neotropical fish (*Prochilodus costatus*), where seasonal rains provide environmental cues needed to trigger migration to favorable spawning grounds at the same time as their conspecifics (de Magalhaes Lopes et al. 2018). Rainfall events can likewise affect forage and water availability, impacting the movements of even the largest living land animals, African savanna elephants, *Loxodonta africana,* to different habitats based on changes in water and food sources (Bohrer et al. 2014).

Lunar phase also has a strong effect on wildlife behaviors due to changes in visibility (Horky et al. 2006, Perez-Granados et al. 2021). Changes in lunar light levels can influence nocturnal foraging and migration behaviors, with higher light levels during the gibbous and full moon phases, and lower light levels during the new and crescent moon phases (Chakraborty 2020, Gursky 2003, Ravache et al. 2020). The impact of lunar phase can be seen in the foraging activity of the European nightjar (*Caprimulgus europeaus*), with more activity recorded on moonlit nights because of an increase in foraging opportunities (Norevik et al. 2019). However, the choice to forage on nights with higher light levels is also weighed against their heightened visibility to nocturnal predators, thus some will also change their foraging behaviors by foraging in larger groups on moonlit nights (Gursky 2003).

When these environmentally influenced behaviors lead to an overlap with human populations, human wildlife conflict (HWC) can result (Decker & Chase 1997). HWC driven by season is often caused by its impact on foraging opportunities. In Narok County, Kenya, during the early wet season large carnivores turn to livestock depredation because of the natural decline in prey availability (Mukeka et al. 2019). In Nepal, similar effects of season on HWC were noted involving leopards (*Panthera pardus*) (Acharya et al. 2016). During the driest month of the year, leopard attacks on livestock and humans peaked in conjunction with reductions in available prey. Lunar cycle and changes in nighttime visibility influences HWC as well. In areas with high roe deer (*Capreolus capreolus*) populations, there is a higher number of deer-vehicle accidents during the full moon, when deer are more active, leading to death or injury to both the human and deer populations involved (Steiner et al. 2021). Understanding how these environmental variables influence animal behavior in terms of HWC is vital in understanding underlying drivers of these conflicts and is crucial when investigating ways of mitigating these negative interactions.

One form of HWC of particular concern in terms of food security for humans and conservation of wildlife is human-elephant conflict (HEC). HEC can result in property destruction, crop raiding, and disturbance of daily activities for many who share a habitat with African Savanna elephants (*Loxodonta africana*), African forest elephants (*Loxodonta cyclotis*), and Asian elephants (*Elephas maximus*) (Mukeka et al. 2019, Acharaya et al. 2016). The impact that elephants have on the people living in these areas is detrimental, as many of these conflicts occur in areas in which the humans rely mostly, if not solely, on their land for economic and nutritional security (Gemeda & Meles 2018). HEC can escalate and result in injury or death of the people and elephants involved (Bond 2015, Sitati et al. 2003). The retaliation on elephants by people jeopardizes elephant populations (Okello et al. 2014). Currently, all three species of elephant are on the IUCN Red List of Threatened Species ranging from endangered to critically endangered (Gobush et al. 2021a, Gobush et al. 2021b, Williams et al. 2020). In many locations, HEC rivals or is responsible for poaching as the most significant impact on elephant conservation (Mariki et al. 2015, Montez & Leng 2021, Sintayehu & Kassaw 2019)

Crop raiding is a major concern for human livelihood and elephant conservation in areas where human occupied land and elephant habitats overlap due to a heavy reliance by farmers on their crops for financial and nutritional security (Compaore et al. 2020). Farmers living in areas overlapping with elephants are more at risk of crop raiding elephants if their farms are located within natural migratory paths of elephants (Shaffer et al. 2019), if they live near national parks or near water sources (Parker & Osborn 2001), and if they do not use any elephant deterring methods (Sitati et al. 2005). In some areas of Africa and Asia, high power electric fences are used to deter elephants from entering crop fields (Gunaratne & Premarathne 2005, Thouless & Sakwa 1995). However, not all farmers have the financial ability to purchase and maintain electric fencing, thus, other means of deterring elephants are employed such as other forms of fencing, lights from bonfires and flashlights, setting off firecrackers, and digging trenches (Shaffer et al. 2019). None of these methods are 100% effective, prompting farmers to conduct nightly patrols to protect their crops. Farmers and their families that perform night patrols suffer from insufficient sleep, reduced school attendance, and enhanced exposure to malaria-carrying mosquitoes (Barua et al. 2013).

To help both the farmers and the elephants involved in this conflict, a system that allows farmers to predict when elephants are more likely to raid would inform them when to start deterrent fence construction and indicate on what nights human patrols would be most effective and efficient. Different types of early warning systems have been tested across areas of Africa and Asia, however many of these systems are technologically driven relying on cameras or sensors to inform farmers of incoming elephants (Sugumar & Jayaparvathy 2013, Zeppelzaur &

Stoeger 2015). Although helpful, many people facing HEC cannot afford or manage the upkeep of this technology; thus, the implementation of ecologically informed early warning systems provides a better solution in areas with such barriers.

The creation of an ecological early warning system is one of the objectives of the *Elephants and Sustainable Agriculture in Kenya* (ESAK) project operating in the Kasigau Wildlife Corridor (KWC) of southern Kenya (Figure 1). Many people living in the KWC are subsistence farmers and rely on their crops for both financial and nutritional security. With the location of the KWC between Tsavo East and Tsavo West National Parks, this area is susceptible to high levels of HEC, particularly in the form of crop raiding (Kagwa 2011; Von Hagen, 2018). Current work in this region through the ESAK project has supplied farmers with experimental deterrent fences along part of the border of Sasenyi village and the Rukinga Wildlife Sanctuary to test the efficacy of different deterrent fence types. This experimental testing has persisted from 2017 – 2022 and data collection is ongoing. The ecological early warning system is being developed to accompany the deterrent fence component of ESAK.

Figure 1. A map of the study site (purple) in southern Kenya. Map obtained through Online Street Map.

Elephant crop raiding is associated with timing between the wet and dry seasons (Chiyo et al. 2005, Osborn 2004). During the wet season, elephants typically have adequate forage in their natural habitat; however, in the dry season, less natural forage is available, increasingly leading elephants to raid farmers' fields for sustenance. Crop raiding predominantly occurs during the transition from wet to dry season when the grasses are starting to brown, and the elephants are beginning to browse more (Osborn 2004). Wet and dry seasons also correlate with planting and crop seasons, as many farmers rely on the rains for watering their crops. Thus, the presence of crops is correlated with the presence of adequate natural forage for most of the year. This relationship changes at the end of the growing season, between the late wet and early dry season, when farmers are planning to harvest. At this time, the rains have diminished, and the natural forage is depleted (Chiyo et al. 2005; Osborn 2004; Webber et al. 2011). This encourages crop raiding and thus potentially correlates crop raiding events to rainfall and crop season.

Moon phase also impacts the probability of elephant crop raiding events. Elephants raid farms significantly less during the full moon phase most likely because of increased detectability by humans (Gunn et al. 2013). Past studies on moon phase (Barnes et al. 2006, Gunn et al. 2013) and season (Branco et al. 2018) in relation to HEC are based on short lengths of time for data collection (1-2 years). The present study compiled the abiotic factor data for Sasenyi village in the KWC over the past five years. For moon phase specifically, past studies have focused on the main groupings of moon phases of new, waxing, full, and waning (Barnes et al. 2006, Gunn et al. 2013, Lamichhane et al. 2018), and did not take into consideration the crescent and gibbous moon phases. Therefore, in the present study the abiotic environmental factors of crop season and moon phase were chosen because of their importance in understanding and predicting animal behavior, their impact on elephant crop raiding, and their ease of collection by local farmers (Osborn 2004, Chiyo et al. 2005, Gunn et al., 2013).

The primary purpose of this study was to scientifically test the relationship between elephant crop raiding events and the variables of crop season and lunar light levels reported by local people in the KWC. I hypothesized that elephant presence around the ESAK experimental crop fields would be highest at the end of the growing season when crop presence is high, and natural forage is depleted. I also hypothesized that elephant presence would be highest during the new and crescent moon phases when lunar light levels are lowest. The information gained by furthering our understanding on the relationship between crop season, moon phase, and crop raiding events can be used to create an ecological prediction system that farmers can use to inform decisions about deterrent tactics based on the probability of crop raiding events.

METHODS

Study Site

Figure 2. A map of the study site (purple) within the Rukinga Wildlife Sanctuary (dark green outline) between Tsavo East and West National parks in the Kasigau Wildlife Corridor, Kenya. Map obtained through Online Street Map.

The study was conducted in the Kasigau Wildlife Corridor (KWC), which is located between Tsavo East and West National Parks in Taita Taveta county in southern Kenya. The KWC is home to a community of privately owned ranches, including the Rukinga Wildlife Sanctuary (RWS) and the Sasenyi farming community (Figure 2). The village of Sasenyi was chosen as the specific study site because of its proximity to the KWC protected lands that wildlife, including elephants, use as a refuge and a travel corridor between the two National Parks. Farms adjacent to the dirt road that separates the Sasenyi village from the RWS were leased and crops (mainly maize) were grown for an experimental study into elephant deterrents at the inception of the *Elephants and Sustainable Agriculture in Kenya* project in 2016 with PI's Drs. Bruce Schulte, Mwangi Githiru, and Urbanus Mutwiwa (Von Hagen 2018; Von Hagen et al. 2021).

Elephant Presence

Elephant presence at the border of Sasenyi and the wild lands was collected through the monitoring of camera trap images taken along the road dividing the farms from the wild habitat. A section of land was leased from the community and divided into four main blocks (310m x 16m each). Each block was divided into eight 32m x 16m fields. Fields were created using 12 fence posts spaced 8 m apart, with a 6 m alley way between each field. In 2018, 4 smaller blocks were added (82m x 16m each), divided into 2 fields each and following the same fence post and alley way dimensions as the main blocks. From 2017 to 2022, 25-31 Moutrie Spy A-5 Gen2 & A30i series infra-red camera traps were mounted on fence posts along these 8 blocks. Cameras were positioned to include part of the field and part of the road that divides the village from the wild land to capture elephant approaches and breaches of the fence line. Elephant caused fence damage, crop damage, footprints, and reports from local farmers along this boundary during the 10 separate trials over the course of 5 years were used to document elephant presence that was not captured on cameras (Von Hagen 2018).

To diminish the probability of double counting individuals in all forms of reporting, only elephants that were caught approaching within 12 m of the deterrent fences were used for elephant presence data. In our study site, elephants entered crop fields 74 % of the times they approached within 12 m, thus elephant presence around the fields was used as a strong indicator for potential crop raiding events (Corde 2022). If multiple groups of elephants were recorded present around the experimental fields in one night, only instances with different group numbers were included in the total number of elephants present that day to diminish the likelihood of double counting.

Environmental and Agricultural Factors

Moon phase and timing within the crop season were used to provide for potential early prediction system components. Rainfall and temperature were recorded opportunistically in the field from 2017 to 2021. When these data were not recorded, the data were supplemented with "aWhere" rainfall and temperature data for Sasenyi village (aWhere, Inc. system Accessed December 15, 2021). Daily moon phase was collected using the NASA Sky Events Calendar (NASAa. Accessed December 15, 2021).

Data Analysis

Data were collected on elephant presence from 1338 days from June 2017 - March 2022. Due to the COVID-19 pandemic, camera traps were not deployed in 2020 (trials 7-8). To limit the spread of COVID-19 into the village, local assistants also limited visits to the experimental fields. Thus, during trials 7 and 8, only instances in which elephants entered crop fields were recorded. This difference in elephant presence reporting lead to the data from trials 7 and 8 not being included in the final analysis. The deterrent fence trials occurred over the two crop seasons each year with the odd numbered trials (1, 3, 5, and 9) on average starting in June and ending in

September. The even numbered trials (2, 4, 6, and 10) on average started in October and ended in March. Over the eight trials data were collected, 256 of the 768 days had elephants present within 12 m of the experimental fields (33.3%) with a total of 861 individuals. The number of elephants visiting the farms in one night ranged between 1 and 28 individuals with an average of 3.36 ± 3.38 (N = 256).

All data were recorded in Microsoft Excel and analyzed in R studio ver 1.3.1073. Daily elephant presence data around the experimental fields in the study site across trials 1-6, 9, and 10 were used to analyze elephant presence for each of the different environmental variables tested. All tests used an alpha value of 0.05 for significance.

Crop Season

To examine my first hypothesis, I used a linear regression (R studio) to test for a relationship between the timing within the crop season and the number of elephants present around the experimental fields. To account for differences in the lengths of growing season, I labeled each day of the crop season as its "proportion to completion" of the growing season. I calculated the proportion by dividing each day by the total number of days within the season.

Moon Phase

A total of 61 full lunar cycles were documented over the course of 5 years in the study site. Twenty-seven of these lunar cycles fell during trials 1-6, 9, and 10. I used a linear regression (R studio) to examine my second hypothesis that there is a negative relationship between elephant presence near crop fields and lunar light levels. Lunar light level was ranked using methods similar to that of Steiner et al. (2021) in that lunar days were ranked starting at 1 for the new moon and progressing to 15 for the full moon. To rank the days after the full moon, each day following was given the same rank for the corresponding same number of days to the full moon, such that 3 days after the full moon was given the same rank as three days before the full moon, or a rank of 12 (Table 1). Factors impacting moon light level such as moon-earth distance, moon-sun distance, and libration (Miller et al. 2012) were negligible due to the inclusion of a total of 24 complete lunar cycles. The total number of elephants per day were summed across all 24 lunar cycles, including a range of these factors, thus averaging them across the cycles.

Table 1. Definition of ranking of lunar light level for the study site of the Sasenyi village in southeastern Kenya from 2017-2022 for a linear regression.

Lunar Rank	Day of Lunar Cycle
1	1, 29
2	2, 28
3	3, 27
4	4, 26
5	5, 25
6	6, 24
7	7, 23
8	8, 22
9	9, 21
10	10, 20
11	11, 19
12	12, 18
13	13, 17
14	14, 16
15	15

Once a relationship was tested between lunar light levels and elephant presence, mixed effect logistic regression models fit by maximum likelihood Poisson regression were used to test whether there were significantly more elephants present during nights with minimal moon light. To account for variances in elephant presence from the difference in time (trial number) and crop season (proportion to completion of the crop season), these variables were labeled as random effects in the mixed effect logistic regression models. The significance of these effects was tested using a rANOVA test. The random effects of trial ($p = 6.3e\text{-}7$) and crop season ($p = 1.8e\text{-}4$) had a significant effect on elephant presence, thus these factors were required to include in the model as random effects to account for variation.

Lunar cycle was separated into four phases based on light level: New, Crescent, Gibbous, and Full (NASAb. Accessed March 25, 2022). The new moon phase was defined as the night of the new moon, including the three days before and 3 days after (Gunn et al. 2013). The full moon phase was defined the same, just around the day of the full moon. The crescent moon phase was defined as the 3-4 days before and after the defined new moon (days 5-7 and 23-25 of the lunar cycle). The gibbous moon phase was defined as the 3-4 days before and after the defined full moon (days 9-11 and 19-21 of the lunar cycle). The day of the First and Third Quarter moon (days 8 and 22) were included in the crescent and gibbous moon phases alternating between both, leading to an alternating range of 3-4 days for each to provide them with an equal number of half-moon days. These days were not removed from the data set as they still represent a light level. To account for variances in timing within the crop season and trial, these two variables were set as random effects in the model. Phase was set as a fixed effect. Multiple models varying in complexity through the removing of different random effects were compared using analysis of variance. The lowest AIC value of the models was also compared to ensure the use of the best model for comparing the data.

To test whether elephant presence around the experimental fields was correlated with the direction of lunar light levels, the lunar cycle was separated into four phases: new, waxing, full, and waning (NASAb. Accessed March 25, 2022) and tested again using a mixed effect logistic regression model fit by maximum likelihood Poisson regression. Again, the new and full moon phases were defined as the day of the new moon and full moon ± 3 days, respectively following the methods of Gunn et al. (2013). The waning moon phase was defined as the days following the full moon before the new moon. The waxing moon phase was defined as the days after the new moon and preceding the full moon phase. The first and third quarter days were included within the waxing and waning phases respectively. Once again, timing within the growing season and trial were set as random effects to account for variation, and models of varying complexity through the removing of different random effects were compared using analysis of variance and AIC values using the same criteria for fit to ensure the use of the best model for comparing the data.

RESULTS

Timing within the Crop Season

My hypothesis that there would be a significant positive relationship between progression of the crop season and elephant presence within 12 m of the experimental fields was supported (p = 2.65e-6) (Figure 3).

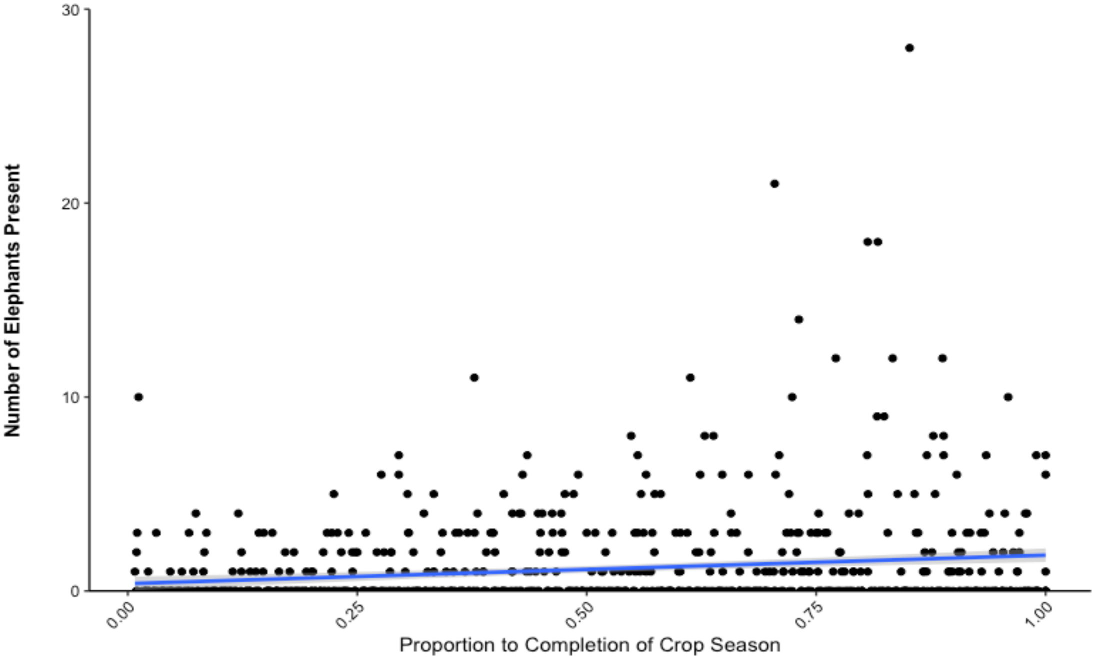

Figure 3. Weak significant positive relationship between the proportion to completion of the crop season and the number of elephants present within 12 m of the experimental fields in the Kasigau Wildlife Corridor in southeastern Kenya.

Moon Phase

The hypothesis that there would be a significant negative relationship between lunar light levels and elephant presence was not supported (p = 0.09) (Figure 4).

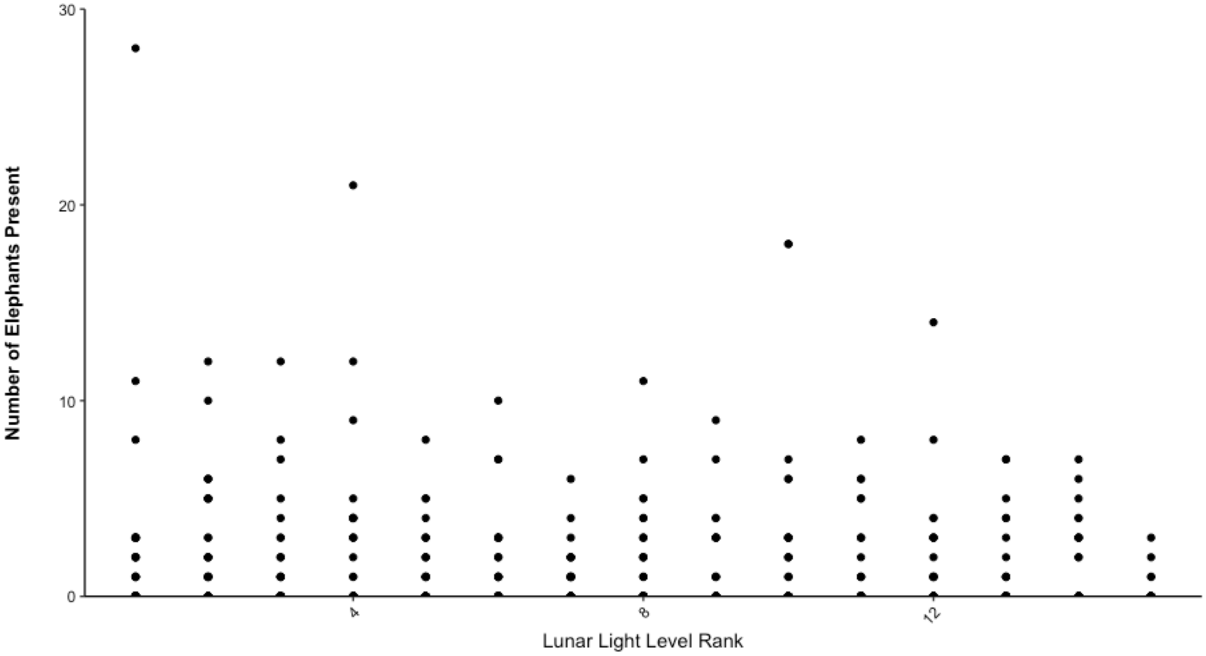

Figure 4. Negative non-significant relationship between lunar light level and the number of elephants present within 12 m of the experimental fields in the Kasigau Wildlife Corridor in southeastern Kenya.

When the four phases of the lunar cycle, namely new, crescent, gibbous, and full, were used to differentiate light levels, the distribution of the 861 elephants over the 256 days with elephants present was as follows: 242 elephants present during 68 new moon days, 267 elephants present during the 68 recorded crescent moon days, 201 elephants present during the 86 recorded gibbous moon days, and 151 elephants present during the 49 recorded full moon days with elephants present (Figure 5).

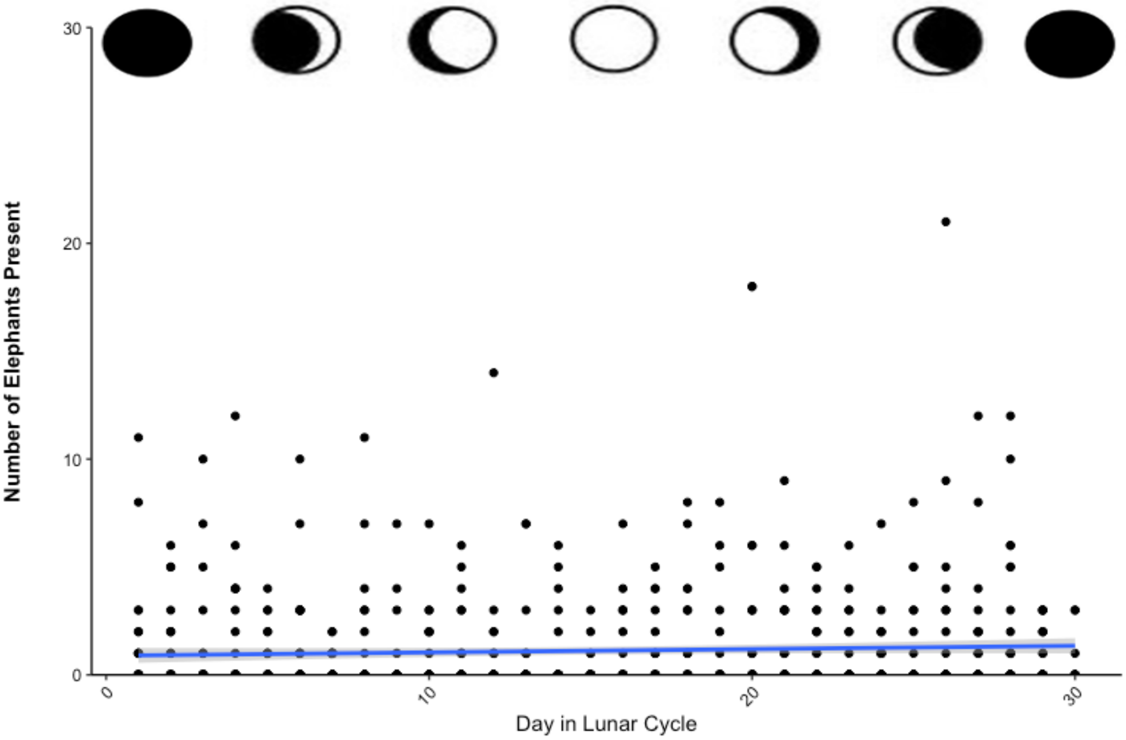

Figure 5. Total number of elephants present within 12 m of the experimental fields during each day of the lunar cycle across all 24 lunar cycles within the Kasigau Wildlife Corridor in southeastern Kenya (cycle from new moon to new moon shown, with day 15 marking the full moon).

The hypothesis that there were significantly more elephants around the experimental fields during nights with low light levels was supported (Table 2). When the number of elephants present during the new moon was compared to the number of elephants present during the full, gibbous, and crescent moon phases respectively, there were significantly fewer elephants present within 12 m of the experimental fields during the gibbous and full moon phases.

Table 2. Comparison of lunar light levels to the new moon phase (no lunar light) using mixed effect logistic regression models comparing the number of elephants present within 12 m of the experimental fields during each phase.

Moon Phase	**Estimate**	**Standard Error**	**z Value**	**p Value**
Crescent	-0.09	0.09	-1.01	0.31
Gibbous	-0.33	0.10	-3.30	**9.84e-4**
Full	-0.51	0.11	-4.73	**2.24e-6**

When assessing the trend in elephant presence within 12 m of the experimental fields to examine the relationship with the direction of lunar light (waxing and waning), there were significantly fewer elephants present within 12 m of the experimental fields during the full and waxing moon phases when compared to the new moon phase. There was no significant difference in the number of elephants present during the new and waning moon phases (Table 3). When the number of elephants present during the waxing phase was compared to the waning phase, there were significantly less elephants present during the waxing phase than the waning phase (Table 4).

Table 3. Comparison of change in lunar light levels to the new moon phase (no lunar light) using mixed effect logistic regression models comparing the number of elephants present within 12 m of the experimental fields in the Kasigau wildlife corridor in southeastern Kenya during each moon phase.

Moon Phase	**Estimate**	**Standard Error**	**z Value**	**p Value**
Waxing	-0.44	0.10	-4.22	**2.49e-5**
Full	-0.53	0.11	-4.97	**6.61e-7**
Waning	-0.09	0.09	-0.96	0.34

Table 4. Comparison of change in elephant presence within 12 m of experimental fields in the Kasigau wildlife corridor in southeastern Kenya during the waning moon phase (light levels decreasing) to the waxing moon phase (light levels increasing).

Moon Phase	**Estimate**	**Standard Error**	**z Value**	**p Value**
Waxing	-0.33865	0.10842	-3.124	**0.00179**

DISCUSSION

This study assessed the impacts crop season timing and lunar cycle have on elephant presence near crop fields as an indicator of potential crop raiding events. My results were consistent with others in that there were more elephants present around crop fields during the end of the crop season and during nights with low lunar light levels (Barnes et al. 2006, Branco et al. 2019, Chiyo et al. 2005, Gunn et al. 2013, Mukeka et al. 2019). The increase in elephant presence during the end of the crop season is congruent with the findings of Branco et al. (2019)

that there was a peak in crop raiding events during the dry season, coinciding with the decline in the quality of natural forage and the crop harvest. My findings on lunar light levels and elephant presence around crop fields align with and expand upon those of past studies (Barnes et al. 2006, Gunn et al. 2013, Lamichhane et al. 2018). Similar to Gunn et al. (2013) and Barnes et al. (2006), and in contrast with Lamichhane et al. (2018), significantly fewer elephants were present around the experimental fields in our study area during the full moon phase when compared to the other moon phases. The present study delves further into the impact of moon phase on elephant presence around farmers to inform on higher likelihoods of crop raiding events for an expanding ecological prediction system.

The hypothesis presented by Barnes et al. (2006) and developed by Gunn et al. (2013) that there are fewer crop raiding events during the full moon due to risk avoidance behaviors to lower the possibility of encountering humans was supported. Significantly fewer elephants were present within 12 m of the experimental fields during the full and gibbous moon phases than the new and crescent moon phases. However, this relationship was not linear, as when these data were analyzed using lunar light level based on the day of the lunar cycle, there was no significant relationship between elephant presence around crop fields and lunar light level.

When analyzed based on the waxing and waning moon phases to show the progression and regression of lunar light levels within the lunar cycle, no significant difference was found in the number of elephants around the crop fields between the new and waning crop phases. The impact of the waning moon phase on elephant presence expands upon a finding by Gunn et al. (2013) that there were peaks in crop raiding during the waxing and waning moon phases and provides further evidence for their hypothesis that elephants may balance the risk of detection with higher lunar light levels with the reward of improved forage and ability to use visual senses to supplement others. When elephant presence was compared between these two phases, significantly more elephants were present during the waning moon phase, when lunar light levels were decreasing. Elephant risk assessment is apparent in their inherent avoidance of crop fields during daylight hours, and nocturnal crop raiding behaviors (Jackson et al. 2008, Kiffner et al. 2021) and extends further to humans being more active and increasing guarding efforts during the full moon (Barnes et al. 2006). The patterns of elephant crop raiding behaviors align with that of ecological risk assessment (ERA) and landscape of risk. Prey, in this case elephants, alter their behaviors based on predator (humans) behaviors (Stankowich & Blumstein 2005). ERA impacts how the elephants perceive their environment in terms of cost-benefit analysis of access to better foraging and decreases in safety (Bleicher 2017, Troup et al. 2020).

The landscape of risk relies partly on predation risk based on three main factors (Brown 1999, Bleicher 2017): (1) predator activity, (2) predator abundance, and (3) prey's ability to predict a predator attack. Individuals will also take greater risks when they are faced with increased stress imposed by droughts and declines in forage quality (Riginos 2015, Branco et al. 2018). In the case of human-elephant conflict, moon phase plays a part in altering human behavior, human abundance, and elephant risk of being spotted, as well as an elephant's ability to spot humans (Barnes et al. 2006, Graham et al. 2009). Crop season influences elephant's willingness to take higher risks based on the weight of risk and reward with declining forage quality in the wild.

Elephants may be using the change in light level and not just the absolute light level to assess risk. I found no significant difference between elephant presence around the experimental fields during the new and waning moon phases, yet fewer elephants were present during the waxing phase. As the moon waxes, light levels are increasing, thus leading to increases in detectability and human activity nightly (Gunn et al. 2013). During the waning moon phases, light levels are decreasing, thus decreasing perceived risk. Timing within the crop season also has an influence on elephant presence. As crop season progresses, the wild forage declines, leading to crops becoming more desirable. These two sources together influence the landscape of risk for elephants and their probability to crop raid.

The expansion of understanding of the landscape of risk of elephants around human occupied land and their habitat assessment could be a strong factor in better understanding the impacts human behaviors have on elephants, and the creation of an ecological prediction system to better prepare and warn farmers of the likelihood of elephant crop raiding events (Troup et al. 2020). Elephants will alter their behavior around human settlements, such as not entering during daytime hours and changing the speed of their movements depending on the level of human tolerance to their presence (Graham et al. 2008). The inclusion of altered elephant behavior based on risk in mitigation efforts is crucial in finding lasting solutions to HEC that can adapt to different risk assessments of elephants depending on the changes in their surroundings. Further data needs to be collected on other environmental factors that could have an influence on elephant crop raiding events such as cloud cover and precipitation, as these can have an impact on lunar light levels and natural forage quality (Bayani & Watve 2016).

Difference in human activity during and between crop seasons and lunar cycles could also have an impact on and result in changes in the landscape of risk of elephants. Human nighttime patrols and farm guarding is a dangerous task, both with the probability to run into elephants and other dangerous wildlife (Dhakal & Thapa 2019). Livestock depredation by lions is highest on moonless night (Robertson et al. 2020), leading people to be most cautious because of increased lion presence as well as lack of visibility. The increased exposure to malaria, and the damages of sleep loss (Barua et al. 2013, Hoare 2000, Sarkar et al. 2016) are also detrimental risks from nightly patrols. The alterations in human patrolling behaviors based on risks in turn impact elephant crop raiding behaviors as well. Future studies need to document not only elephant presence in and around crop fields, but also behaviors within them over the course of the lunar cycle and crop season, to better understand how these factors are influencing risk assessment by elephants. The further understanding of elephant behavior and changes in probability of entering human occupied land will not only help farmers with guarding their crops but will also positively impact human wellbeing. Crop guarding is inherently dangerous, and better understanding of elephant crop raiding patterns and risk assessment will give farmers a better understanding of when elephants are more likely to crop raid, and thus can influence their guarding techniques to balance the risk and reward of guarding verses using other forms of HEC mitigation to limit exposure to dangers and increasing safety.

Understanding of drivers in variation in human elephant conflict can be expanded to the assessment of other human-wildlife conflicts. These conflicts come in an array of forms from crop raiding to livestock depredation to property damage (Fader et al. 2021, Long et al. 2019, Mamo et al. 2021). Human population expansion into new habitats coupled with the effects of climate change will lead to further habitat fragmentation and reductions in forage availability, heightening competition between humans and wildlife to the detriment of each (Heemskerk et al. 2020). Improved elucidation of how factors such as lunar phase and crop season impact the landscape of risk for wildlife will facilitate the means of mitigating conflicts, reducing competition between humans and wildlife.

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APPENDIX I: AEOLIAN HARPS AS A BATESEAN MIMIC FOR THE BEEHIVE DETERRENT FENCE: PRELIMINARY DETERRENT DESIGNS

INTRODUCTION

The beehive fence using the African honeybee (*Apis mellifera scutellate)* has shown to be an effective African elephant (*Loxodonta africana*) crop raiding deterrent across Africa (Elephants and Bees, elephantsandbees.com/beehive-fence/, King et al. 2011, King et al. 2009, Scheijen et al. 2019). The deterrent relies on the elephants' natural fear of bees and their behaviors to avoid being stung and thus keep them from entering crop fields (King et al. 2011). One challenge to using beehives, particularly in our study area of the Kasigau Wildlife Corridor (KWC), is the fluctuation in bee occupancy (Ngama et al. 2016). Under certain conditions, such as drought in which bees no longer have access to food and water, hive occupancy is difficult to maintain, which potentially decreases the deterrent's effectiveness (King et al. 2011). To minimize the effect of unoccupied hives on the efficacy of the fence, Schulte (2016) proposed the use of mimic beehive fences. Batesian mimicry can be used in this scenario using mimic empty hives within an active beehive fence. Whether this will work relies on the optimal ratio of occupied hives to mimic beehives. This effective ratio of active to inactive hives has not been determined; however, the number of models (active beehives) should exceed the number of mimics (Schulte 2016). Mimic beehive fences will require fewer bees and less maintenance, making the beehive deterrent more affordable and practical as well as enhance its overall-effectiveness, as human negligence in care of hives can factor in beehive fence deterrence.

A component I proposed to add to the mimic beehive fences is an Aeolian harp (Figure 1). Aeolian harps are musical string instruments that are played through the vibration of a string from the blowing of wind and amplified through a larger body. This acoustic effect coupled with the presence of the beehives could function as visual and auditory cues to alert elephants that bees are in the area. Elephants avoid trees containing beehives and will run from the sound of disturbed bees (King 2009). With low hive occupancy, Aeolian harps may help by adding the negative auditory stimulus of the humming of angered bees. Aeolian harps also require low construction cost and can be made from everyday items such as discarded plastic bottles and aluminum cans. The Aeolian harp, along with the beehive mimic fences, may keep elephants at bay while requiring fewer active beehives.

Figure 1. Aeolian harp created by using 40 lb test fishing line and a recycled 10L water bottle tested in Kivuli Camp, Kenya. Photo taken by Sophia Corde.

METHODS

Prototype construction began in March 2020 and continued into the beginning of June 2021. Multiple designs were tested though the most practical for the study site was the design shown in Figure 1.

Aeolian Harp Deterrent Construction

To build the Aeolian harp mimic, 10 L water bottles were collected locally from people wishing to discard of old water jugs. A square shaped hole was cut into the side of the bottle using a knife. The dimensions of this hole differed per water bottle depending on its length and width. Because of the differing in shapes of water bottles, there was no routine length of cutting the hole. Thus, the beginning of the hole was always cut from the middle of the bottle and up to the top of the bottle before it started to taper off. The width of the hole also differed depending on bottle shape, thus the width averaged at being cut so that the hole could only be seen from one side of the bottle, and when turned 90 degrees, could not be seen. For the 10L bottle in Figure 1, the hole was cut with a width of 22.6cm and a height of 15.5cm. Two holes were cut into the sides of the bottle using the tip of the knife to the left and right of the main. These holes were cut just wide enough to fit the fishing line through and were place just ¼ of the way up from the base of the bottle. A 12 m strand of South Bend 40 lb test monofilament fishing line, purchased in the US (approx. $4 USD for 128 m of line) and brought to the study site, was then strung through those holes.

Locally sourced binding wire was used to affix the bottles to the fence posts (approx. $2.65 USD / 1 kg). The bottle was turned upside-down so that the neck was pointing to the ground. The remainder of the fishing line on one side of the bottle was used to attach the base of the bottle to the post. Binding wire was subsequently wrapped around the neck of the bottle and then around the post to secure the bottle so that it would not move. The fishing line was pulled as tight as possible and tied securely around the adjacent fence post 8 m away so that the bottle did not move when the line was plucked.

The intensity (dB) and frequency (Hz) of the sound produced by the harps was measured upon deployment and 2 months after without any maintenance or tightening. A RISEPRO Decibel Meter as well as the Spectroid application (downloaded on android cell phone) were used to take these measurements.

RESULTS

Due to the prolonged 2021 drought, the Aeolian harp fence could not be tested in the experimental crop fields, as no crops were present. Due to the minimal sustained winds, and more abrupt forceful gusts, the Aeolian harp only produced faint high-pitched sounds within the range of human hearing periodically when there were long gusts of wind. These sounds ranged from 50.8 – 61 dB, with 83 dB on long sustained wind gusts. The frequency of the harps ranged between 646 -1787 Hz and could be detected from up to 25 m away by the human ear during prolonged wind gusts.

The harps were very resilient and were able to maintain their ability to produce sounds through high winds, rainstorms, and even visitors using the fishing line as a clothesline to dry their clothes. The strength of the harps was measured at deployment as well as after 2 months. The strength of the sound of the harps after this time only differed by 10 dB, originally measuring at 50.8 dB, and eventually measuring at 61 dB after 2 months.

DISCUSSION

The Aeolian harp mimic relies on providing a negative auditory stimulus through the association with the active beehives. Wind causes the fishing line to vibrate, thus producing a constant hum. Honeybees produce a mean buzz of 66.36dB, falling very similarly with the loudness of the Aeolian harps (Mohapatra et al. 2010). Where the two differed was in frequency. The buzzing of honeybees has a frequency falling between 435 and 531 Hz (Goodyear 2015, King et al. 2007). The Aeolian harp made sounds with a frequency falling between 646 and 1747 Hz.

The distance between ears, or size of the animal's head, is inversely related to the animal's ability to hear high-frequency sounds (Jacobson & Plotnik 2020). Asian elephants were unable to perceive sounds outside of the range 17 – 12,000 Hz with the lowest intensity being 60dB (Heffner & Heffner 1982). The combination of loudness and frequency may be a challenge for elephants to hear the designed Aeolian harp. Before re-designing, trials with elephants in zoos or those otherwise acclimated to human presence might be useful to examine their ability to hear the harps. Such a study could help improve the design before testing in the field. The ideal harp design would produce a louder sound within the range of bees buzzing when a trip wire activated by an elephant caused the harp to vibrate more than when wind blows. This would differentiate the wind- and elephant-activated frequencies, which would be a better mimic of bees buzzing when their hives are disturbed by a trip wire in the beehive fence (King et al. 2011).

Frequencies can be altered based on the tension and the thickness of the string used (Polak et al. 2018). Aeolian harps rely on extreme tension on the strings for the wind to be able to vibrate them enough to produce a tone. Thus, to tune the harps to the lower frequency emitted by bees, thicker fishing line would be useful. Increasing thickness of the fishing line would also increase strength and durability of the design. The thickest fishing line tested in our study site was 40 lb test, meaning that it can withstand 40 lb of pressure before breaking. In future studies, thicker fishing line such as 65, 75, 85, and 100 lb test need to be trialed to find the best for reaching the frequency range of honeybees. These harps can then be paired with a mock beehive fence to test and compare its effects on elephant crop raiding events. The main limitation on this fence design is the accessibility of fishing line in many of these communities. Different forms of monofilament line were tested, including thick thread used to mend shoes in the area, and binding wire, however, these did not work. Another form of more accessible locally sourced monofilament line needs to be found to enhance the practicality of this design.

Should the Aeolian harp perform successfully at producing artificial buzzing sounds at similar frequency and intensity as an occupied beehive, the incorporation of this inexpensive mimic to an active beehive fence with low honeybee occupancy would be invaluable for local farmers. Honeybees are difficult to keep (Mohammed & Hassen 2021). In the KWC, the main issues with maintaining beehive occupancy have been the lack of access to clean water and food sources. Farmers in the area have invented a new water containment system for easier access by bees using discarded plastic bottles and binding wire (Figure 2). Even with the modified water containers, many of the beehive fences have failed to obtain full occupancy, and mainly rely on 2-3 occupied hives in an entire block (82m X 16m). If the Aeolian harp could relieve the burden of maintaining at least some hive occupancy, this would potentially greatly improve the performance of the beehive fence and in turn help the local people of the KWC, and potentially others who struggle with bee occupancy in their beehive fences.

Figure 2. Modified water trough for the beehive fence invented by local farmer Chimanga in Sasenyi Village within the Kasigau Wildlife corridor consisting of a discarded water jug cut and filled with water. A rock is placed in the middle for easy access by bees to climb out in case they fall in. Photo taken by ESAK team members.

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APPENDIX II: PRESSURE ACTIVATED DRUMS AS A MEANS OF DETERRING ELEPHANT CROP RAIDERS: PRELIMINARY DETERRENT DESIGN

INTRODUCTION

Human elephant conflict (HEC) is one of the main forms of human wildlife conflict in communities where elephant habitats overlap with agricultural land (Mukeka et al. 2019). HEC takes many forms, including destruction of property, disturbance of everyday activities, and crop raiding (Bond 2015). Although there are other crop raiders present in the area, elephants (*Loxodonta africana, Loxodonta cyclotis,* and *Elephas maximus*) can do substantial damage in a single crop raiding event, leading to them often taking most of the blame (Hoffmeier-Karimi & Schulte 2015). Many of these communities have developed strategies to deter elephant crop raiders, such as human patrols (Dhakal & Thapa 2019), chemical repellents (Chang'a et al. 2016), fires (Shaffer et al. 2019), and loud noises from banging drums and shooting firearms into the air (O'Connell-Rodwell et al. 2000). Others have turned to more modern means of deterring elephants by using deterrent fences (Kiffner et al. 2021, Von Hagen et al. 2021). However, one of the main barriers in the uptake of modern elephant crop raiding deterrent fence designs is their lack of affordability. Though the word of modern deterrents has traveled to these areas, and the desire for these fences is present, many cannot afford the construction or time and maintenance of these new designs. Thus, people continue to rely on traditional deterrent methods. Traditional methods, however, are dangerous, as they often require the people to stay awake through the night and guard their crops, leading to increased exposure to dangerous wildlife, malaria, and the damages of sleep loss (Barua et al. 2013, Dhakal & Thapa 2019). An effective and affordable deterrent needs to be created that people can create using articles readily available around the home, and do not require people to stay out overnight to guard their fields.

I designed a new deterrent that will be affordable for many people facing HEC. I call this deterrent a pressure activated drum, created from discarded plastic bottles, wire, and sticks (Figure 1). The pressure activated drum relies on the already present traditional deterrent of banging drums used to scare off elephants, but removes the necessity of people being present, thus relieving danger. Based on the body of a string instrument, the deterrent relies on the strumming of strings being amplified through a larger body. Due to its low construction cost, mainly from discarded materials, this deterrent may be a solution to those facing HEC, but struggle to uptake modern deterrent designs due to the issue of affordability.

Figure 1. Pressure activated drum created by using 40 lb test fishing line, a recycled 10L water bottle, and sticks, tested in Kivuli Camp, Kenya. Photo taken by Sophia Corde.

METHODS

Prototype construction took place in the Kasigau Wildlife Corridor in southern Kenya between October 2021 – December 2021.

Pressure Activated Drum Construction

Discarded 10 L plastic bottles were collected from local people in the community and used as the resonance chamber for the drum. A 22.6cm x 15.5cm square hole was cut into the side of the bottle using a knife. If different shaped bottles were used, the height of the hole was cut from the middle of the bottle and up to the top of the bottle before it tapered off. The width was cut so that the hole could only be seen from one side of the bottle and could not be seen when the bottle was turned 90 degrees. Four holes were cut into the side of the bottle just wide enough to fit 40 lb fishing line through using the tip of a knife to the left and right of the main hole ¼ of the way from the top and ¼ of the way from the bottom of the bottle. Two 2 m strands of 40 lb test South Bend brand fishing line (purchased in the US, approx. $4 USD for 128 m of line) were fed through the holes of the bottle.

As a fence deterrent, drums would be set up between fence posts, but for trials in Kivuli Camp, I used two trees ca. 8 m apart. 12 m of locally sourced binding wire ($2.65 USD / 1 kg) was tied as tightly as possible between the two trees at 1.5 m high. The bottle was then turned upside-down, so that the neck of the bottle was facing the ground. 1 m of the fishing line fed through the two holes in the bottle to affix the bottle to the trees. Extra binding wire was also used to secure the bottle more firmly. The slack 1 m of the two fishing lines were then pulled as tightly as possible and attached to the binding wire connecting the two trees. The bottle was then tilted so that these two lines had at least 7.5 cm of horizontal space between them at their widest point. From the 8 m stretch of binding wire, two 30.5 cm long sticks were hung using extra pieces of fishing line (normal string will work as well) so that the two sticks hung freely between the two fishing lines extending from the bottle without touching either of them.

RESULTS

This fence design could not be tested against elephants in front of crop fields due to the 2021 drought at the study site. The pressure activated drum was very resilient to strong winds and rainstorms; it was even used as a clothesline to dry clothes. In all cases, it continued to perform as intended. When the binding wire is pushed, the sticks hung between the two fishing lines alternate in hitting the lines, leading to the bottle emitting a noise similar to that of a banging drum. This sound is sustained for 15 – 30 seconds depending on the amount of pressure put on the wire.

DISCUSSION

Should the pressure activated drum be successful at keeping elephants from entering crop fields, it has the potential of being a solution for farmers who cannot afford the construction or maintenance costs of other modern crop raiding deterrents. This deterrent design also has the potential of working as a warning system for farmers, as pressure on the line will cause noise, alerting farmers of the presence of elephants. Before designs can be implemented in the field, trials with elephants in captivity will be useful in examining their behaviors in response to the new deterrent, and potentially provide insights to improve the current design.

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