Summer 2018

An Evaluation of Deterrent Methods Utilized to Prevent Crop Raiding by African Elephants (Loxodonta Africana) in the Kasigau Wildlife Corridor, Kenya

Rebecca Lynn Von Hagen
Western Kentucky University, lvonhagen@comcast.net

AN EVALUATION OF DETERRENTS TO PREVENT CROP RAIDING BY AFRICAN ELEPHANTS (*LOXODONTA AFRICANA*) IN THE KASIGAU WILDLIFE CORRIDOR, KENYA

A Thesis
Presented to
The Faculty of the Department of Biology
Western Kentucky University
Bowling Green, Kentucky

In Partial Fulfillment
Of the Requirements for the Degree
Master of Science

By
Rebecca Lynn Von Hagen

August 2018

AN EVALUATION OF DETERRENTS TO PREVENT
CROP RAIDING BY AFRICAN ELEPHANTS (*LOXODONTA AFRICANA*)
IN THE KASIGAU WILDLIFE CORRIDOR, KENYA

Date Recommended MAY 11 2018

Bruce A. Schulte, Ph.D., Director of Thesis

Nancy A. Rice, Ph.D.

Michael Stokes, Ph.D.

Dean, Graduate School 7/19/18
Date

ACKNOWLEDGEMENTS

The chance to return to academics after such a long absence has truly been the dream of my life, and I have so many people to thank. First and foremost is my husband, without whom none of this would be possible. When he found out it was my desire to return to school and finish my education, he simply made it happen. He has been my rock, enduring long months without me, keeping our home going while I was in Africa chasing elephants and dreams. My friends and family have been more than supportive of me, especially when the way was tough. Dr. Schulte took a chance accepting a non-traditional student into his lab, and his enduring support, patience and genius have caused me to thrive in this academic environment, and I hope we continue to collaborate. My committee of Dr. Nancy Rice and Dr. Michael Stokes have also been a source of inspiration and knowledge, and I have appreciated their input. The graduate school and administrative staff at WKU (ahem, Jessica Dunnegan!) were always there to help with logistics and paperwork, and with over a year spent in Africa, that was no small task. Samantha Thomas also helped keep me sane while navigating the statistical analyses.

With such an expansive project, there are several partners to express my undying gratitude toward. I feel the need to point out the irony and pride of being an Earthwatch team member, after spending my teenage years wistfully dreaming while flipping through their catalogs. Stan, Caroline, Kim, & Mary of Earthwatch were helpful beyond measure. In addition, funding from the International Elephant Foundation made this project possible, and I hope our research contributes to the amazing work they continue to support on behalf of the elephants. I also appreciate the support of the

WKU Graduate School Research Grant committee, the WKU Center for Biodiversity Studies, and the WKU Sisterhood for their financial support.

A special thanks to my colleagues in Kenya at Wildlife Works, Dr. Mwangi Githiru, Simon Kasaine, and Bernard Amakobe who constantly taught me about their homeland and culture. Simon allowed me to invade his home for two months when I first arrived and kept a watchful eye to make sure I was safe, while constantly challenging my scientific preconceptions and becoming my dear friend. Jamie, Keith, and Cara, also of Wildlife Works, were the perfect hosts, making sure our team had everything they needed to be successful, including some fun. The rangers of Rukinga Ranch always made sure I felt safe and welcome, especially Joseph, my constant companion during fieldwork. A huge thanks to all my big brothers at Kivuli Camp that kept watch over me and made sure I had everything I needed from such an amazing place, including companionship and snake removal. Thanks also to Dr. Lucy King and her team from Save the Elephants for their collaboration and assistance with our beehive fence project.

The Kenyan people, including our participating farmers, made me feel the most welcome and safe of any place I have ever been. I learned from them every day, even if I did not speak the same language. Their resilience and kindness will never be forgotten. Despite the challenges involved in a project like this, the one thing that always grounded me were the times that I was privileged to have close encounters with the elephants. As someone who got a second chance, I will make sure that my work in the future makes a positive contribution towards elephant conservation, while aiding the people that live amongst them.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

AN EVALUATION OF DETERRENTS TO PREVENT
CROP RAIDING BY AFRICAN ELEPHANTS (*LOXODONTA AFRICANA*) IN THE KASIGAU
WILDLIFE CORRIDOR, KENYA

R. Lynn Von Hagen August 2018 107 pages

Directed by: Bruce A. Schulte, Nancy A. Rice and Michael Stokes

Department of Biology Western Kentucky University

Escalating human elephant conflict (HEC) continues to be a contributing factor towards elephant decline, and crop raiding is the most common form of negative human-elephant interactions. For communities that cannot reverse or prevent crop raiding, it is necessary to contain HEC events through deterrent measures. Few deterrent measures exist that combine practicality and affordability while also preventing habituation by elephants. This project focused on comparing the efficacy of deterrent methods to assess which was the most successful at preventing elephants from entering crops in the farming community of Sasenyi, Kenya. In this paired-control study, four deterrent methods were evaluated: acacia fences, chili-pepper fences, a new metal strip fence, and a combination of a chili and metal strip fence. Of the over 400 visits by elephants to individual fields containing crops recorded during two field seasons, elephants entered farmer fields in the experimental area on 33 occasions (<10%). Analysis of incidents when elephants approached at less than 50 m revealed that the chili + metal fence and the metal fence were significantly more effective than no deterrent. Following further verification of its effectiveness, this new deterrent method could be a powerful new tool to alleviate elephant crop raiding and reduce HEC.

INTRODUCTION

Human wildlife conflict (HWC) occurs across the globe whenever wildlife and people have negative interactions, often in competition over resources (Decker & Chase, 1997; Madden, 2004; Songhurst, 2017; Treves et al., 2006). As anthropogenic activities and human dispersal continue to increase, so do negative encounters with elephants (Bel et al., 2010; Hoffmeier-Karimi & Schulte, 2015). These interactions may result in conflicts that lead to injury or death, biodiversity loss, destruction of property or holdings, and the creation of management concerns for government agencies; thus, they can be detrimental to conservation efforts (Barua et al., 2013; Bond, 2015; Moss, 1988; Sitati et al., 2003; Treves et al., 2009). Additional consequences to local people from HWC include compromises to physical or mental health, loss of employment or livelihood, and exposure to social inequities (Barua et al., 2013; Bond, 2015; Treves et al., 2006).

Schulte (2016) identifies three factors that continue to escalate HWC: (1) species are being driven out of their native habitats for anthropogenic usage, (2) modern agricultural developments have selected for nutrient-dense plants whose natural defenses have been lost, and (3) livestock or domestic pets now occupy spaces where wildlife once freely ranged. Other factors such as habitat loss, fragmentation, and climate change exacerbate the situation (Desai & Riddle, 2015; Karidozo & Osborn, 2015; Nelson et al., 2003). The same factors that contribute to HWC also have serious implications toward elephant conservation. African savannah, *Loxodonta africana,* African forest, *Loxodonta cyclotis*, and Asian elephants, *Elephas maximus* are showing an overall decline primarily from human elephant conflict (HEC) and poaching for their ivory (Chase et al., 2016; Graham et al., 2009; Hoare & Toit, 1999; Vollrath & Douglas-Hamilton, 2002; Wittemyer et al., 2014). The need for conservation of these species provides further incentive towards mitigating the factors that contribute to HEC.

HEC occurs most commonly in the form of crop raiding, in which groups or individual elephants feed on crop fields, primarily at night when their movements are cloaked by darkness (Graham et al., 2009; Le Bel et al., 2007; Smith & Kasiki, 2000). This results in partial or complete loss of crops due to consumption, trampling, and/or dung deposition (Kagwa, 2011; Sitati & Walpole 2003). A typical six-ton African elephant (5443 kg) can consume up to 7% of its body weight each day and expends up to 17 hours per day in search of food and water (Ruggiero 1992). Instead of foraging in their natural habitats, elephants, often males, can maximize their nutrient and mineral intake by raiding crops, which is especially beneficial to reproductive success (Chiyo, et al., 2012). The principles of optimal foraging theory demonstrate that animals will minimize energy spent traveling to forage by seeking out areas containing the greatest nutritional benefits (Sinervo, 2013). With the advent of agriculture, humans have introduced elements that have interrupted the natural foraging patterns and migration routes of elephants. Instead of moving from one natural area to another, elephants turn to agricultural fields and commonly return to areas where they have previously successfully raided (Chiyo & Cochrane, 2005; Sitati et al., 2003), creating an ongoing conservation issue.

Rural farmers in Africa have difficulty predicting and managing crop raiding incidents, and they can suffer loss of livelihood because of crop destruction by elephants (Chiyo et al., 2005; O'Connell-Rodwell et al., 2000). Prevention is one of the most important ways to alleviate crop raiding (Chiyo & Cochrane, 2005; R. Hoare, 2012; Swan et al., 2017), and studies have shown that the most frequently raided farms are located near the boundaries of national parks or community ranches (Chiyo et al., 2005; Naughton-Treves & Treves, 2005; Sitati et al., 2003). However, moving established homesteads or fields further from these boundaries is rarely practical, which makes these areas prone to high incidents of HEC.

Farmers and conservationists may attempt to contain crop raiding incidents, sometimes resorting to risky and often dangerous attempts to scare away elephants (Desai & Riddle, 2015; Graham et al., 2012; Kagwa, 2011). Crop raiding incidents involving elephants usually result in anger and resentment from the community and can leave negative impressions of conservation efforts (Lee, 2010; Naughton-Treves & Treves, 2005; Smith & Kasiki, 2000). In addition, rural farmers are often left with the monumental task of defending their crops without assistance from government wildlife agencies or Non-Governmental Organizations (NGOs) (Graham & Ochieng, 2008).

Since the 1990s, efforts have been made to reduce instances of HEC through non-lethal mitigation techniques, and research is on-going to determine which techniques are the most successful. Effective deterrents will increase the risks (or costs) of crop raiding to elephants to a level greater than the nutritional benefit (Hoare, 1999 & 2012). These deterrents should satisfy three criteria: affordability, practicality (including safety), and most importantly resistance to habituation (Figure 1). With limited resources, rural farmers are often challenged to meet these criteria; poverty makes many deterrent measures unattainable and lack of basic conveniences such as water and/or electricity make erecting and maintaining some deterrents impractical. Other key components to crop raiding deterrent solutions are proper implementation and cooperation from farmers and the community (Graham & Ochieng, 2008; O'Connell-Rodwell et al., 2000).

Deterrent measures utilize signal theory, in which humans are attempting to honestly convey a message to elephants that entering the crop would be detrimental, and thus the elephant should modify their behavior and move away (Searcy & Nowicki, 2005). Sometimes the most difficult challenge is elephants' intelligence, as they can devise ways to overcome deterrent measures. Unless punishment is sometimes received that will create a negative association when an elephant encounters a deterrent method, elephants can habituate and become unafraid or accustomed to the method(s). Even if elephants do circumvent a deterrent, a method can still be successful if it provides some type of residual discomfort or intermittent defense that causes the elephant to leave quickly. Minimal amounts of crop damage could be a sign that elephants were too uncomfortable to remain long enough to do substantial damage, which is a type of deferred success.

Fences are sometimes used as a basic line of defense against crop raiding animals. Farmers that erect traditional wire or metal fences may find them to be ineffective as elephants can easily break through unless they are made of barbed wire, which inflicts pain (Sitati et al., 2005). Once inside a fence, if there is no residual deterrence, elephants can do large amounts of damage. Electric fences can be effective deterrents, but they can be financially unobtainable or suffer from unreliable electricity sources (Connell-Rodwell et al., 2000; Kioko etal.,2008). Solar fences, which negate the necessity for electricity obtained from a power plant, are an alternative (Davies et al., 2011) but can be very costly. Elephants can sometimes overcome electric fences by laying logs across them, removing electric components, or using their tusks to snap the wires (Kioko et al., 2008; Mutinda et al., 2014). For fencing projects to be successful, regular maintenance and freedom from theft and vandalism are also necessary.

Traditionally, rural farmers have used low-technology methods such as banging drums, spotlights, digging ditches, burning fires, guarding or patrolling, and owning dogs to deter elephants. For example, acacia thorn fences have been used as livestock bomas or spread around crops to prevent goats and cows from entering fields (Chang'a et al., 2015; McKnight, 2004), but their efficacy as an elephant deterrent has not been explored [African acacias have been reclassified in the genus *Vachellia* or *Senegalia* but will be colloquially referred to as acacia throughout this document (Dyer, 2014)]. Elephants may find acacia painful because of sharp thorns and choose to enter unprotected farms. Some deterrent efforts can be dangerous and/or result in loss of sleep or absence from school or work for farmers and their families due to increased vigilance at night (Barua et al., 2013; Hill, 2004; Le Bel et al., 2007). Many traditional techniques are affordable or practical and initially show promise but lose their effectiveness as elephants habituate to them over time, or adjust their raiding habits to avoid them (Goodyear & Schulte, 2015; O'Connell-Rodwell et al., 2000).

Some modern deterrent techniques incorporate aspects of multi-modal, often unpleasant stimuli that alert elephants of their presence. Bee hive fences have emerged as a promising deterrent method (Figure 4), and experiments have shown them to be up to 80% effective (King et al., 2017). Habituation is low, as every time the beehives are disturbed, bees emerge and attempt to sting, creating a recurring negative association. Success using bee hive fences reinforces the concept of multi-modal signals coupled with positive punishment as an effective elephant deterrent, since elephants are less likely to habituate to or overcome these techniques, and the punishment strives to reduce the undesired behavior. In 2017, the Sasenyi area experienced a severe drought and bee colonies could not be established. Thus, beehive fences were deemed the least practical for immediate evaluation, but their incorporation in the future is anticipated.

Another such negative element that elephants encounter is capsaicin (the active component of chili peppers), which stimulates the trigeminal nerve, causing irritation to the mucus membranes as well as other sensitive areas (Le Bel et al., 2010; Osborn & Rasmussen, 1995). Capsaicin is only fully soluble in an oil, and researchers have discovered that it has deterrent properties when mixed with used engine oil. Farmers use ground chili peppers mixed with the oil and applied to rope to form a crop raiding deterrent fence (Figure 2) (Chang 'a et al., 2016; Karidozo & Osborn, 2015). In addition to the noxious odor, potential crop raiders must deal with moving cloths and ropes coated in irritating motor oil that must be broken through or avoided to gain entry. It is unknown at what distance elephants can detect this mixture, and it may have residual deterrent effects if an elephant breaks through a chili fence and gets the mixture on its skin. While these fences have been found to be effective in many areas, the mixture requires regular reapplication, and farmers often abandon the method unless it is part of a managed program (Davies et al., 2011; Graham & Ochieng, 2008; Hoare, 2012). The use of a visual and/or a moving barrier plus the irritating nature of chili peppers coupled with the noxious odor of motor oil is an example of a (sometimes) successful way to construct a multi-modal deterrent fence.

Novel and successful deterrent methods are rare but advancing the science behind crop raiding deterrence is a crucial component of elephant conservation. Mr. Simon Kasaine, a project collaborator from Wildlife Works in Kenya, invented a new technique made from locally available materials composed of lightweight metal strips cut from mabati metal strung on binding wire (Figure 3). When the wind blows, or the fence is contacted, the strips clatter together and sound like a rudimentary wind chime. In addition to being slightly sharp, the strips are also highly reflective in the sun, and on bright moonlit nights. This provides a physical, auditory, and visual signal to elephants of the fence's presence. Any sound or reflection could prevent elephants from approaching closely, and the metal pieces strung on a wire could make entry difficult. The intermittent and multi-modal signals signifying the presence of the fence and the negative consequences of trying to break through the fence may make this technique resistant to habituation. For example, a startling sound when the wind blows or when an elephant contacts the wire may prevent elephants from entering, but if they initially break through the fence, the intermittent nature of the startling noise and the potential annoyance of the sharp metal may cause them to spend less time in the field, therefore minimizing damage. The materials for the metal strip fence are relatively inexpensive, the fence requires little maintenance, and it can easily be repaired if broken. The metal fence has been deployed as a simple boundary fence and observers have noted that elephants go out of their way to detour around, yet no experiments have quantified the effectiveness of this technique. Because the metal fence is practical and affordable, evaluation may reveal if metal strip fences complete the requirements of an ideal deterrent method by being resistant to habituation.

The main purpose of the present study was to investigate the efficacy of four deterrent methods utilized to alleviate crop raiding in the Kasigau Wildlife Corridor of Southern Kenya, Africa: a chili pepper fence, an acacia fence, a new metal strip fence, and a combination of chili + metal fence. These deterrents were selected due to the lack of experimental evaluation (acacia or metal fence) and the opportunity to test three modern multi-modal deterrents (chili, metal, and chili + metal). I hypothesized that deterrent methods that combine techniques such as the chili + metal fence and those that have multi-modal alerting features and defenses, that is the chili or metal fences, would be the most effective, while the acacia fence with only the visual signal and physical deterrence of the thorns would be the least effective. More specifically, fields protected by the chili + metal (C+M) fence will have lower incidents of crop raiding than all other deterrent types. The metal strip fence compared to the chili fence will have insignificantly different efficacies but be more effective than the chili control (C Co), metal control (M Co), acacia (A), and acacia control (A Co). The A and A Co would be the least effective of all deterrents. The null hypothesis, H(0) is that there will be no significant differences between the success of deterrent methods at preventing elephants from entering protected crops.

METHODS

Study Area

The study area is located in southern Kenya, Africa in Taita Taveta county in the Kasigau Wildlife Corridor at approximate latitude -3.70585S longitude 38.77668E (Figure 5) within Rukinga Ranch Wildlife Sanctuary. The area is a vital wildlife corridor between Tsavo East and Tsavo West National Parks, which contains Kenya's largest population of more than 12,000 elephants (Chase et al., 2016; McKnight, 2004). The Kasigau area is home to several community or privately-owned ranches within a mixed acacia and commiphora forest, interspersed with agricultural developments and villages. Research partners at the site were from Wildlife Works (WW), the world's leading Reducing Emissions from Deforestation and Degradation (REDD+) developer, dedicated to stopping the destruction of the world's forests through conservation, community, and carbon offset programs (Wildlife Works, 2018). WW was recruited as a research partner through the association of former WKU student Simon Kasaine, and the group maintains a research camp and a tourist lodge (Kivuli Camp) on the ranch. Housing was at the research camp during 2016 and at Kivuli Camp for the remainder of the project. The Sasenyi farming community was chosen as the location of the crop raiding experiments because of high incidents of HEC (Kagwa, 2011; King et al., 2017; Omondi et al., 2008; Smith & Kasiki, 2000), and the shared boundary with Rukinga Ranch, which serves as an area of refuge for wildlife.

Initial logistics, preliminary observations, and an initial experimental design were started from May to July of 2016. Design implementation and collection of thesis data was conducted from May 2017 to mid-January 2018. Earthwatch, a non-profit travel and citizen scientist organization, provided advice, partial funding, and volunteers to assist with the project.

Study Design

Four different deterrent methods were tested to deter elephants from crops. The experimental design was based on a modified randomized block design with replication in four areas of Sasenyi. The four methods being tested were acacia fences, chili pepper fences, metal strip fences, and a combination of the metal + chili fences, each with a paired control. The design of the blocks were contrived to incorporate beehive fences in future trials and was intended to cover as much length of the boundary between Rukinga Ranch and Sasenyi as possible to maximize elephant encounters. This equated to 8 fields per block measuring 16 X 32 m each, with gaps (alleys) of 6 m in between (Figure 6). These alleys were established to separate the deterrent methods and provide an avenue for people and wildlife to pass. To ensure that each block design was balanced, a buffer was added on each end. This made the total size of each block 16 X 310 m. The placement of the deterrents in each block was randomized, but the controls were always placed next to their respective deterrent and the order of whether the control or active deterrent came first was maintained after the first deterrent or control was randomly selected. The first field was a control in blocks 2 and 4 and was experimental in blocks 1 and 3 to balance the design.

Experiment construction

During 2016, scouting occurred for block sites at the Sasenyi border that would accommodate 310 consecutive meters without being interrupted by roads, homes, or non-arable land. Four such plots were located, each having already been used for agriculture. The owners of each block agreed to participate, and construction was initiated in the 2017 field season. Homes were in close proximity to some of the fields, but each family reported elephants approaching closely, so this proximity did not appear to be a confounding factor.

Earthwatch volunteers, the research team, and two fence attendants who were employed by WW assisted with the layout and construction of each block. Field dimensions were determined using tape measures with stakes set in the ground as markers to indicate where each fence pole would be erected, leaving 8 m between each pole, except for alleys, which had a distance of 6 m. The alleys were also assigned as places that could vary in size, in order to make sure the block was following the contour of the boundary. Alleys thus became areas where the block could be adjusted or "turned" slightly if needed. Center poles were also used at the ends of each field to attach deterrents and demarcate where one field terminated and another began (Figure 7). Corners were squared across each section to assure the measurements were accurate and GPS locations of each pole location were taken with a Garmin GPSmap 60CSx and Garmin GPSmap 62 so that coordinates could be input to Google Earth (Figure 8) to construct a satellite map of each block. Holes for poles were dug to a depth of 0.46 m, and poles were locally sourced, each approximately 2 m tall, with a mean circumference of 26 cm (N=5, SD 4.7). Since termite infestation is a problem in this area, the bottom of each wooden pole was soaked in the environmentally friendly pesticide *Undertaker 480EC (Greenlife Crop Protection, Africa)* for 30 minutes. Poles were then placed in the ground, plumbed and tamped in with soil and the marker stakes removed.

After individual deterrents were erected (see below) each pole received an identification number with the block number, field number, and individual pole number marked with a Sharpie (Newell Brands, Sanford L.P.). Once crops sprouted, camera traps were deployed on fence poles to monitor for wildlife and a short layer of acacia branches were placed across the front of each block to prevent intrusions by livestock. To report exactly how animals crossed through the deterrents, a section number system was created (Figure 9) that allowed enumerators, when finding prints or damage, to report accurately the location of the incursion. The section number was consistent for each field. For example: 3 eles at S4 near B4, F3, 89, translates as three elephants crossed through section four in block four, field three next to pole number 89.

Acacia fence construction

Acacia fences were constructed using trees sourced from the nearby community that were cut down with machetes. Cut branches were placed by gloved hand in 1-2 layers around a field (Figure 10). The matching control for this deterrent was no fence, but only the poles erected in the fields. The acacia controls also served as master controls for the experiment.

Chili fence construction

Materials for the chili pepper fence were obtained and prepared ahead of fence construction following guidelines from a published study in Tanzania with up to a 100%

success rate for protecting crops from wildlife (Chang'a et al., 2015; Chang 'a et al., 2016). Black cloth (100% organic cotton) was purchased from WW and cut into 0.6 m X 0.6 m squares. A single cloth was attached to the top and bottom ropes at the middle of each fence panel. Attachments were made at each corner and the center to prevent sagging. Five kg rope (as recommended in the manual) was not available in the area, so sisal rope was purchased, and two strands were bound together for added strength. Volunteer teams joined together two 12 m sections of rope by tying a simple knot at 1 m from each end so that the rope was knotted to be secured tied when tied to fence poles. A knot was also tied at 0.25 m from the center of each joined rope on both sides. Once erected, this prevented the cloths that would be tied at the center of the ropes from sliding in the wind. Prepared ropes were wrapped in tight organized bundles so that they would unfurl easily, transport well, and not become tangled. The cloths had 30 cm rope pieces tied at each corner and top knot so they could be attached to the rope knots in the center of fence panels (Figure 11a).

I obtained the hottest local peppers available, bird's eye chili's, *Capsicum anuum* (Figure 11b), and they were dried by the local fence attendants. In the field, a traditional mortar and pestle were used to grind the chili peppers into a rough powder. Protective goggles and gloves were donned as the chili irritates the eyes and nose (Figure 11c). I procured a large supply of used engine oil from the WW garage and mixed batches of 5 L of oil with 8 handfuls of crushed chili pepper at a time. The prepped cloths and ropes were soaked in the mixture for 2 min to thoroughly coat both. The mixture was stirred often as peppers tended to sink to the bottom. The soaked cloths and ropes were transported to the assigned fields in buckets. Erected poles were marked at approximately 1.5 and 2 m, and the soaked ropes were placed at these heights and pulled taught. Chang'a's guidelines recommended a second layer of rope near the bottom if intrusions by young elephants were common, but we elected not to add them as these instances were reported as rare. The soaked cloths were secured by attaching the short ropes to the knots in the center of each panel to the already erected long ropes (Figure 11c). Some poles were naturally shorter than others and had to have their ropes lowered. The control measure for this deterrent had the same application and construction, except the oil was not combined with any chili, making the chili control fence a motor oil only fence. That would also assist with determining whether the chili peppers cause the adverse reaction or if the motor oil has deterrence capability as well. I took samples of the mixture and snippets of cloth from several panels of the deployed fences for LCMS analysis to detect the levels of capsaicinoid concentration, or Scoville Heat Units (SHU) back in the USA (See Appendix III). In accordance with recommendations from Chang a' (2015), the mixture was reapplied every 20 days or after rainfall. If time had lapsed between the reapplication process and 20 days or a rain event, I considered the deterrent to be inactive during that period, and it was excluded from analysis. This only occurred on five occasions throughout the study. Cloths and ropes were checked for damage or loosening and adjusted or replaced accordingly.

Metal fence construction

Mr. Kasaine was present to supervise construction of his invention, and some metal strip fences were already being used at Sasenyi. The remaining panels were constructed at camp and then transported to the field. Binding wire is a locally used flexible wire that rust after exposure to the elements (though the rust does not appear to compromise the integrity of the metal) and was the material upon which the metal pieces were strung. Mibati metal rolls were also readily available and this metal is commonly used as a building material for roofing and construction of roadside stands. Tin snips were used to cut approximately 0.50 - 0.80 m long X 0.10 - 0.12 m wide strips of the metal. The varying sizes seemed to assist by causing more noise than having sizes the same length when the metal pieces clattered against each other. A nail and hammer were used to pierce a hole in the top center for stringing the pieces onto the wire. A 12-m piece of binding wire was cut, and pliers were used to make a twist at about 1 m, 3-4 pieces of cut strips strung, and then another crimp 0.15 - 0.20 m from the original. This pattern was repeated until ca. 1 m from the end where a final crimp was made (Figure 3). Panels were stored until ready to be deployed at Sasenyi and then transported to the field. Marks were made on fence poles at a height of 1.5 m, and volunteers stood at each end using the binding wire to elevate the panel and pull it taught. There was some variation in the height of the center of each panel from the ground ($\bar{X}$=127.42 cm, SD=5.26 cm, N=12) because the center bowed from the weight of the fence material. Fences were checked daily for damage, and when broken, binding wire was twisted to make a patch. Occasionally metal strips would move so much that they wore down the hole and fell off, but overall maintenance was very low. The shininess of the metal also dulled with time but was still substantially reflective. The control for the metal strip fence was only the binding wire with twists (Figure 12), which were also hung at a height of 1.5 m.

Metal + chili fence construction

The fourth and final deterrent method was a combination of the chili pepper plus metal strip fence. The technique for each stayed the same, only the metal strip fence was hung at 1.4 m and the chili fence at 1.5 m heights, so that the two deterrents did not tangle. The control for this technique was a chili fence with only motor oil, and the metal wire with crimps only and no metal strips.

Data Collection & Experiment Monitoring

Twenty-seven Moultrie Spy A-5 Gen2 & A30i series infra-red camera traps (EBSCO Industries) with security cages were mounted on posts or trees to monitor species presence in the area. One was deployed 750 m from the cross roads of the Sasenyi boundary on a road used by both wildlife and people to detect when wildlife was present in the area. The remainder were deployed using a locked Master Lock python cable on the front and (sometimes) back lines of each block that contained crops. During the experimental period, one camera was damaged and seven were stolen, limiting monitoring capabilities towards the end of the experimental trials. Cameras were deployed after deterrents were activated and removed once a crop raiding season ended and no elephants were present for 10 days. Camera cages were affixed with nails at strategic positions on the fence poles, so the cameras could be removed to change batteries and storage cards easily. Cameras were numbered and mounted (Figure 7) at approximately two meters high and were set to take three consecutive images after being triggered by motion. There was an approximate 30 sec lag time in between firings. Cameras at the fields with chili cloths had to be positioned so the flapping of the cloths did not set off the cameras. Storage cards were changed every 5-10 days, depending on how many images individual units took, and images observed on a MacBook Air (2015) with the iPhoto program. Distances of wildlife from the deterrent measures were estimated by using the poles from fencing (which were six or eight meters apart) as landmarks to approximate how close animals were approaching. Any images with wildlife were retained and organized according to which block and deterrent techniques were being monitored. The images were used to estimate the distance from deterrents, type of species present, and the number of elephants in a group, all of which was corroborated through footprints.

Data were collected on approaches and entry to fields from a combination of camera images, field measurements, and visual observations. Camera traps were changed and analyzed every 7-10 days. Fence attendants monitored the fields daily to check for wildlife incursions and fields were checked by team members at least 3 times per week. Details were taken from fields that were approached or entered and input into a crop raiding database and were commonly verified by camera images. Visual surveys were also periodically performed in front of blocks to look for footprints of potential crop raiding animals which might not have entered the area of cameras. To establish a method for these visual surveys, it was necessary to determine how far away footprints could be detected with the naked eye, and it was concluded that 15 m on each side of a surveyor was the maximum reliable distance. Three participants spaced themselves at 30 m intervals with a fourth as a record taker. The first positioned themselves at 15 m perpendicular to pole number one of a block on the west end, with the other two participants at 45 m, and 75 m perpendicular. This gave each participant an area with 15 m to either side (except the person at 15 m, closest to the fence) to detect footprints. All three slowly walked parallel to the frontline of the block trying to keep distances equal between them while surveying to both sides of them. Experienced rangers or team members identified the species and notes were taken on the path of wildlife and the closest distance from specific deterrent methods were recorded.

When wildlife entered fields, it was necessary to assess the amount and type of damage, and to determine at what growth stage crops were at when damaged. A growth phase condition score (CS) was modified for each type of crop based off a system developed by Hoffman-Karimi & Schulte (2015) to rank the level of growth and to determine wildlife or elephant approaches varied predictably with crop growth (Table 1). Despite requesting that only maize be planted by farmers, some fields had up to three species of crops. Once a week, crops were assessed by each field and assigned a CS which was noted with any raiding data (Figure 13). Crop yield was estimated by the research team and volunteers once plants had grown above stage two, so that overall loss of crops could be calculated. The fence posts were used to visually divide the field into sections, moving from front to back, and counting the number of plants in each row or area. Once each section was counted, the numbers were tallied by field, buffer, or alley and then entered into the database. If fields were entered by wildlife or livestock, the number and type of plants that were damaged, and the species responsible (if discernable) were recorded, as well as whether the damage was from consumption, or trampling. Any plants lost due to pests or drought were also recorded.

Experiment timeline

Two trials occurred during the experimental period. The first (T1), shortly after the long rains, was initiated on 6/2/17 with the planting of each block with a mixture of predominantly maize, with some cow peas and lentils. Farmers were compensated for their time and efforts in both trials. There was an ongoing drought in this area and crops in blocks one and two did not survive, so deterrents were deployed only in blocks 3 and 4. In these two blocks, fields only had partial crop survival. The first wildlife appearance was on 6/28/17, with the last on 9/28/17. The second trial (T2) began with the farmers planting after the short rains by 10/23/17. One of the farmers from block four decided not to participate, and it was necessary to adjust the design accordingly by moving the first four fields to the end of the block, which also rearranged the field order (Figure 14). Farmers followed our request and planted only maize in blocks 1, 2, and 3, but all three crops were planted in block 4. There was adequate rain for this trial and at least some crops in all blocks survived to harvest. Data collection was initiated at wildlife appearance on 10/29/17 and ended on 2/16/18.

Data Analysis

All data were input and analyzed with Microsoft Excel v. 16.10 and/or R Studio v. 1.1.442. To rank the efficacy of the deterrent methods, it was necessary to quantify all the instances elephants approached and/or entered fields protected by individual deterrents. Data were combined from T1 and T2 and any alley data or instances when crops were not present were excluded from the analysis. Only blocks 3 and 4 had crops during trial one but were included in approach data, and specific fields without crops were excluded. Entry into a field was denoted by a distance of 0 m. A block that was confirmed by observation of footprints or cameras to have an elephant approach to an individual field(s) also had the remainder of the fields in that block extrapolated as approaches. Each was given an estimated distance from the known approached field rounded to the nearest meter, since elephants could have easily raided adjoining fields. For example, if an elephant was confirmed at field one (F1) 5 m away from the fence, then fields 2-7 were also added to the data set, with the distance from the confirmed field increasing at 38 m per field (the length of an entire field + alley). In trial 2, block 4 was reconfigured and the addition of spacing for a driveway was necessary, and this was considered in the estimate of elephant distances for this block only. Extrapolated distances were conservatively figured at the maximum, when it is possible that elephants were much closer. Observations of elephants near fields were noted from a combination of belt transects, observation of footprints, and camera trap images, and were grouped in categories of 50 m distances. To continue the conservative approach, all statistical analyses involved elephant presence at 50 m or less. The percentage of times elephants entered a field was determined by dividing the number of successful incursions at 0 m (Table 2, R1) by the approaches at 50 m or less, including 0 m (Table 2, R3) for individual treatments.

Deterrent methods were considered successful if they showed statistical significance when compared to no deterrent method, the acacia control. A 2 X 2 contingency table was compiled of each deterrent method with its respective matching control comparing the approaches (Table 2, R2) and successful raids (Table 2, R1). If results between a deterrent and its control are too similar, it could indicate that the key ingredient or factor attributed to the success of the deterrent is not responsible. For example, if the control for a chili fence (only motor oil) was as successful as the active fence, then the chili peppers may not play as big of a role as anticipated in the deterrent power of the technique. Fisher exact test was used because sample sizes were small, and this statistic gives an unbiased and more accurate probability than a chi square analysis with small sample sizes (Suissa & Shuster, 1985). Each deterrent method was also compared to the acacia control, which was equivalent to no deterrent measure. The p-value was considered significant at the 0.05 alpha level.

To validate the block design for this experiment and ensure it had not introduced any variability in approaches based on landscape features or other unknown variables, it was necessary to ascertain if elephants approached all fields and blocks equally. Data from both trials with all approaches at 50 m or less (including 0) were combined by deterrent measure with the different blocks as a variable, but only approaches to fields that had viable maize crops and active deterrents were used. Data were checked for normality with a Shaprio-Wilks, and then non-normal data were analyzed with non-parametric ANOVAs, using the aov function in R. If significant differences were noted from ANOVAs, a Tukey pairwise comparison of means with a 95% confidence level was performed to elucidate the specific differences. This procedure was repeated for all ANOVAs used in the experiment with non-normal data. For the approaches to specific deterrents, a box and whisker plot was created with Excel.

Significant differences between successful entries into fields compared to controls should demonstrate the efficacy level of each deterrent. However, this does not reveal a complete picture of all the factors involved that are contributing to the success of deterrent measures. Elephant group size can be compared to successful entry into a crop field to determine if there is a relationship between success and the number of individuals in a raiding group. To achieve this, the number of elephants present and group type (family or bull(s)), were part of data collected from all observations. The number of elephants were obtained from combined observations of footprints and camera trap evidence.

To quantify overall and specific types of damage by elephants, it was necessary to count viable crops, so that any damage noted could be deducted from the potential harvest. This was performed by the research team and volunteers before the raiding season began of each species planted (maize, cow peas, and lentils), and commenced after crops reached a CS score of two. Inter-observer reliability tests were performed to assure proper methodology was occurring, and when teams reached over a 90% success rate, they were allowed to assess without supervision. It has not been explored whether the amount of crop loss quantified by damage type (dung deposition, trampling, or consumption) may reveal important deterrent characteristics of specific methods. For example, low consumption rates versus high trampling, could mean that elephants left quickly because of discomfort. High consumption and dung deposition and low trampling could be an indicator of more time spent in a field in which an elephant was comfortable enough to forage extensively after breaking through the fence, thus making a specific deterrent less effective as there is no residual deterrence.

Damage was noted after each crop raid by number of plants damaged as well as the type of damage (trampling, dung deposition, or consumption). Only trial two data were used in any crop damage analysis, as reporting on trial one was limited, and the majority of crops succumbed to the drought. Percentages of crop destroyed by type of damage or total damage were calculated by taking the amount destroyed and dividing by the total amount viable + damaged. Separate two-way ANOVAs were used to examine the total, trampling, and consumption damage to determine if there was variation amongst the different deterrents by crop species (lentils, cow peas, and maize).

As elephants are known to raid more frequently as crops ripen (King et al., 2017; Naughton-Treves, 1990), monitoring of the growth level of crops in relation to elephant presence can indicate if there is a need for increased vigilance during those times and some deterrent measures may also see their efficacy wane at these times. Quantifying the overall damage to different types of crops can also reveal elephant preferences for particular crops, and farmers can plant or prepare accordingly. To assess the relationship between elephant presence and crop maturity, whenever an approach or entry occurred the condition score was noted. The condition scores were used from all elephant occurrences during trial two when crops were still present and compared by deterrent method with a two-way ANOVA. The percentage of crop loss for maize, cow peas, and lentils was achieved by dividing the total number of plants lost by the total number of plants viable for each species.

The overall percent of damage reported can illustrate how much damage elephants are responsible for in comparison to other species, drought, or invertebrate pests. It is also important to understand what other animals may be contributing to crop damages, as often farmers blame the majority of damage on elephants (Hoffmeier-Karimi & Schulte, 2015). To determine the presence of other species in the experimental area, the raw non-extrapolated data were used from both trials, excluding elephants, to compile a list of other species that could be potential crop raiders. Dates of sightings were from times when fields were monitored before and after crop raiding events and after crops had been harvested: 6/28/17-2/16/18 at 50 m or less. Cameras were not present at all times, though monitoring on foot was still being done by fence attendants, so observations are conservative.

RESULTS

Both experimental trials had elephant approaches to deterrent methods (Figure 15), and on at least one occasion fields with each of the deterrent types were entered, so no deterrent was 100% effective. The acacia control had the greatest individual number (8) of and percentage (31%) of overall breaches, with the chili + metal having the least (1 and 5%, respectively) (Table 2). Across all deterrent measures, only 16% of approaches resulted in elephants entering deterrent measures. The combined chili + metal deterrent had the lowest percentage of raids, followed by the metal strip fence, with the acacia control the greatest (Table 2, R4). This supports the hypothesis that deterrents that convey a signal of their presence and that provide a negatively reinforced association are more effective than traditional techniques. There were no significant differences when comparing the approaches versus successful raids of each deterrent method compared to its matched control but when comparing the acacia control (no deterrent) to each method, the chili + metal (*Fisher Exact Test*, p=0.023) and metal fence (*Fisher Exact Test*, p=0.040) showed a significant deterrent effect with an alpha of 0.05 (Table 3).

The randomized block design was successful in maintaining non-biased approaches by elephants to different treatment types (Tables 4), but there was a significant difference between approaches to block 4 and the other blocks (Table 5). To determine what the cause of this difference may have been, the data for trial 2 were analyzed without trial one, which also resulted in a significant difference between blocks but not deterrents. Of these two block assessments there were only non-significant approaches between blocks one and three. The combined approaches from all blocks to each deterrent method (Figure 16) showed approaches to the metal, metal control, and acacia were the most common, with the chili + metal the least (SD $\pm$ 5.90 df=7).

Camera trap images were successful at providing approach data, as well as assisting with determining how many elephants were involved in raiding parties (Table 6). However, it did not provide sufficient clarity to determine how many elephants actually entered fields when there were multiple elephants within a raiding party, thus no correlations between group sizes and successful raids were assessed. Of the 10 elephants identified as crop raiders, some of which were lone raiders and others as part of partially identified groups, two were seen twice in the community area. Thus, it is possible that some of the elephants in these results are the same elephants. Over half of all successful raids were by lone elephants, all of which were bulls, and the vast majority of raids had one, two, or three members in the raiding party. No family groups were observed crop raiding in fields, but a few were noted after crops had been harvested. The largest group number noted during the crop raiding season was eight bulls, and raids with eight members only occurred twice. It was unable to be determined how many elephants within these larger groups attempted to break through deterrents, as the photographs did not reveal how elephants interacted with the deterrents when entering. Elephants were commonly noted using open passageways to reach other areas deeper in the community. After the experimental crops were harvested, elephants continued to visit the area in search of forage, as some farmers in the community maintained a later harvest, or possibly because elephants could be headed to local water sources. After all crops were harvested in trial one, elephant presence was noted for up to 80 days afterwards, and natural forage was very limited due to drought. After trial 2, elephants still visited up to 84 days after harvest of the experimental fields. There was no evidence found that plant material such as discarded maize husks were being consumed by elephants, but farmers did allow livestock to eat what remained.

In trial two, all three species of crops had trampling and/or consumption damage from elephant crop raiding, yet no dung deposition was responsible for plant death. For all crop species, consumption was responsible for more destruction than trampling (Table 7). The majority of plantings were maize, and all forms of damage to this crop were more extensive than damage to cow peas or lentils. Crops from each deterrent type except for those protected by the acacia fence experienced some form of damage, and the crops surrounded by the metal control and acacia control deterrents had the most damage (Figure 17). However, elephants would often enter fields with viable crops without doing any damage.

When examining consumption damage to all species of the crops protected by the different deterrent types, there was a significant difference detected between the types of crops (p=0.031), but not between treatment types (Table 8). The significance between crop types was between maize and lentils (Table 9). When trampling damage was analyzed in relation to the type of crop (Table 10), there were significant differences between the percent of crops trampled under protection of different types of deterrent methods (p=0.021); the metal control exhibited significant differences of incursion in pairwise comparisons against all other deterrent types (Table 11) (A Co p=0.007. Acacia p=0.002, C Co p=0.038, C + M p=0.004, C + M Co p=0.006, Metal p=0.003). Analysis of combined damage showed significance between the type of crop (p=0.029, Table 12), and maize and lentils (p=0.0121, Table 13) were damaged at different rates, which is likely due to the much greater amount of maize planted.

Surprisingly, there was no evidence for significant differences in the approaches by elephants to fields that had different crop condition score categories (Kruskall-Wallace x^2 = 6.25, df=6, p= 0.040). Thus, elephants approached all fields with no regard to the stage of growth of maize. However, when examining the percentage of crops destroyed, elephants preferred cow peas (27%), over lentils (7%) and maize (4%). Overall, farmers lost 4% of their maize crops due to elephant incursions and 5% for all crop types during trial 2 (Table 14).

Elephants were not the only animals responsible for crop raiding or visits to the experimental area (Table 15). Across both trials, both before and after harvest and camera monitoring, nine different species were noted at 50 m or less from experimental plots. Damage by any of these species were not included in the analyses. Giraffe (*Giraffa camelopardalis*) visited to feed on a specific favored tree, and spotted hyena (*Crocuta crocuta*) often visited the area in search of chickens or goats. Common duiker (*Sylvicapra grimmia*) were also noted 46 times but did no discernable damage. Of particular interest, eland (*Tragelaphus oryx*) was sighted 85 times at specific fields in trial one but only twice in trial 2.

DISCUSSION

Adding a new tool to the arsenal of deterrent methods used to mitigate HEC is a rare and exciting event for the conservation community. As expected, the multi-modal alerting and defense deterrent method of the chili + metal fence was the most effective at preventing elephants from entering crop fields. While this deterrent method had the most significant difference from the acacia control, or no deterrent, the stand-alone metal strip fence was also effective.

All deterrent methods performed better than no deterrent in preventing elephants from entering a crop field, suggesting that any mitigation efforts could have some positive effect. Despite a hypothesis of similar efficacy to the metal fence, the chili fence was bested by its control, and did not perform well compared to other successful studies (Chang a’ et al., 2016; Davies et al., 2011; Karidozo & Osborn et al., 2015). This could be due to a difference in the strength of heat of the chili peppers, a difference in experiment implementation, the windy environment in this area, or other unknown factors. However, the strength of the mixture was potent, as when it contacted human skin or eyes it caused severe discomfort. Several incursions to areas protected by both the chili and chili control method, resulted from adult elephants ducking and going under the chili flags, thus flipping the cloths over the ropes, and sometimes snapping the ropes or pulling down the poles. It was not uncommon to see elephants on camera images that had several black streaks of oil across their heads. Installation of a second lower chili rope could help prevent this behavior but was not deemed necessary since we had no young elephants that were crop raiding and the expectation was the chili would deter them from approaching too closely. Because the chili + metal strip fence performed better than any technique at keeping elephants out, it could be that the effectiveness of the metal was enhanced by having another physical barrier on top, and not the actual chili pepper mixture as the metal + chili control was the 3rd most effective. To test this hypothesis, other trials should be conducted without oil and chili solutions to see if it is the presence or movement of the ropes and cloths that are contributing to any deterrent properties.

As anticipated, the acacia and acacia control did not perform well, but the acacia was surprisingly more effective than the active chili at preventing entry. However, acacia fields had no crop damage across the trials, though they were only entered by elephants four times. It was not uncommon for elephants to enter other fields and not damage crops as well. This could be due to elephants only passing through, being scared away after entering, or other unknown factors. Therefore, using the amount of crops destroyed may not be the only or best way to assess how well a deterrent performs if damage is sometimes random. Nevertheless, this is the key factor for farmers as they would not mind if elephants or other animals entered their fields if they caused no damage. Thus, these findings also suggest that higher sample sizes are necessary to better determine the relationship between entry and consumption. Elephants were noted picking up and tossing acacia branches that blocked their way on several occasions, but this method still had half as many breaches as the acacia control. It was important to have acacia present to prevent livestock incursions and established successful measures could see increases in efficacy by adding acacia as an outer boundary.

Several factors other than overall success at deterring elephants can be indicative of the quality of a deterrent, such as the distance from which a deterrent repels elephants, whether there is residual deterrence provided, and if farmers are alerted to elephant presence. One incident of note demonstrates how important residual deterrence is when evaluating the success of deterrent methods. A group of elephants broke through the metal strip fence, ate only two cobs of maize, and then abruptly left. They were not chased by farmers, and this could be evidence that this deterrent can be affected by intermittent winds that commonly occur in Sasenyi, which increase the noise and make elephants uncomfortable. Since the noise from the metal strip fence is typically louder when being contacted than just blowing in the breeze, it could also alert farmers that something is amiss, allowing them to scare away elephants. Further tests for determining the differences in decibel levels of winds verses contact could reveal the metal fence could be an alert system for farmers. The metal strip fence is both practical and affordable and ongoing studies should work towards increasing sample sizes to clarify this effect. Other iterations of the metal strip fence, such as a second lighter strand of metal above the first, could be tested to see if the efficacy rate could go higher. In addition to the success of the metal fence, the combination of techniques proving to be effective opens the door for more research to see if various traditional and/or modern techniques can be combined to increase the efficacy of existing measures.

One unexpected result from the study was the observation that the metal fence's control had some deterrence power. Tying for 5th in its rank of effectiveness amongst the eight deterrent types, camera traps and footprints repeatedly showed 11 incidents (with and without viable crops present) of elephants approaching, contacting the metal wire, and then retreating. Our team had difficulty seeing the wire even during daylight hours, so it is possible that it is nearly invisible to elephants at night, which could startle them while they are already undertaking a known dangerous behavior. It is also possible that elephants with prior exposure to electric fences may erroneously believe this fence could be electrified. One camera observation also showed an elephant lifting the wire with his tusks, grabbing a corn from underneath, and then replacing the wire and retreating, a behavior sometimes seen in fence-breaking elephants (Mutinda et al., 2014). Kioko et al. (2008) also showed that some elephants will be deterred by electric fences even without any current. However, if elephants are aware of the presence of the wire and do not fear it, they can easily break through it. These observations also bring up the issue of biological relevance versus statistical significance. While the metal control did not show significant deterrence power, it still performed better than other or no deterrent measures. With a higher sample size, future trials may reveal that it is indeed a viable method. It also suggests that startling elephants through invisible deterrents may sometimes prevent them from entering. This method is extremely inexpensive and thus may be obtainable for extremely impoverished farmers who appreciate having any type of deterrent, even if it is not effective all the time.

Crop raiding studies in the field are usually opportunistic and take advantage of already established farmlands and crops, which makes it difficult to control for other confounding variables. Control plots are rarely used, or are simply empty fields, making statistical comparisons difficult. The blocked matching control design of this study was validated by having equal approaches by elephants across all the types of deterrent methods, though there were significant difference in the number of approaches to overall blocks. This could be due to the absence of blocks one and two in trial one due to drought, a preference seen for entry into the area from certain wildlife trails, or an imbalance of blocks sampled with walking transects to check for footprints. Higher sample sizes in future trials may isolate if there are unforeseen variables affecting which blocks elephants approach the most often. The metal and metal control also had the highest number of approaches for individual deterrents. These two results are likely skewed due to the metal and metal control fence having some of the few viable crops in trial one, which were located in block 4. This experimental model could be adapted for use in various parts of the world to assess a variety of questions related to crop raiding. As our team conducts future experiments in Rukinga Ranch, we could introduce different techniques within this same design, such as beehive fences. Because elephants were more easily quantified the closer they came to experimental fields, additional camera traps could also be added to cover areas further away from the farms to determine if elephants are present, but not detectable, and how they use they use the landscape.

Elephants have been known to damage crops though consumption, trampling, and dung deposition (Hill, 1997; Kagwa, 2011; Karimi, 2009), although for the entire experiment, dung was only noted within one field on one occasion, yet the approaches to the farms were often covered in dung. This presents an interesting behavioral question: do elephants purposefully restrain their defecation while crop raiding in this area? Because consumption was responsible for more damage than trampling across all treatments and all types of crops, once elephants obtained access to fields they may have been more likely to calmly feed. It was difficult to measure the potential level of overall deterrent success and levels of residual deterrence in relation to damage, because all deterrents had entries, but not all had damage, such as the acacia-protected plots. Elephants approached all deterrents equally when examining trampling damage except for the metal controls, this was likely skewed due to one specific crop raiding incident. One evening of crop raiding late in trial two involved 8 elephants destroying 150 plants (approx. 75 consumed/75 trampled) in the metal control. They were also scared away by farmers, which could have created more trampling than usual. This illustrates how rare but devastating large crop raids can be, but also how results can be skewed by large raiding incidents. The significantly different results when examining damage to crop types between maize and lentils is likely due to the exponentially greater amounts of maize planted than lentils.

While not a direct measurement of deterrent success, additional data collected on elephant groups can assist farmers with preparations to defend their fields, which is important for reducing HEC. Knowing the demographics of elephant groups (type of group, and quantity) can allow farmers to customize deterrent methods, as larger elephant groups or bulls could signify the need for sturdier deterrents, and younger elephants might gain access to certain deterrents more easily (e.g., they could get beneath fences if they are set too high). Females are often more aggressive due to having young calves in their herd (Bond, 2015; Nelson et al., 2003), and alerting farmers if there are female groups that are active crop raiders could be an important safety measure. In the current study area, family groups were not active raiders, and lone bulls were responsible for most of the raids. Thus, mitigation efforts can be customized from this knowledge, as males are much taller and larger than members of family groups (Kangwana, 1996; Shannon, et al., 2008). Males also uprooted or broke fence poles on several occasions for no apparent reason, but it could be a type of dominance display; this behavior should factor into the expenses for farmers in maintaining deterrent methods in this area.

Maize has commonly been referred to as an elephant-favored crop (Chiyo et al., 2005; Hill, 1997; Kagwa, 2011), but this experiment revealed that even though plantings of cow peas and lentils were minimal, elephants preferred these above corn. While one consistent crop (maize) was planned for a simpler analysis, this unintended information could inspire future studies to examine specific crops at a larger scale to determine if elephants are more attracted or aversive to particular types of crops in this region (Osborn, 2004). Farmers could then avoid planting these crops or increase vigilance or deterrent measures in those planted areas. One might also expect elephants to be drawn to crops that are ripened and ready for consumption, but no difference in the approaches to experimental fields was seen based on the growth condition scores of the maize. In this experiment, elephants approached all stages of growth equally and could have been checking to see if crops were ready for consumption or just passing through while embarking on raids elsewhere.

Since eland were a major participant in crop raiding events in trial one, it is necessary to assess their impact in future studies. While farmers are aware that eland in this area are partially responsible for crop raiding, they often blame elephants for the majority of damages (Kasaine & Githiru, 2016). Eland did not appear to be affected by deterrent methods such as the metal strip fence. Of note however, eland presence was rare in trial two. This could be due to the abundant amount of forage available during this period, or the increased presence of humans while guarding and burning fires.

Reducing the factors that contribute to crop raiding is difficult as human expansion, population growth, and climate change impacts are all projected to increase (Hanski, 2005; Le Bel et al., 2007; Williams et al., 2018). Restoration of natural forests or grassland can mitigate habitat loss and fragmentation (Harvey et al., 2014), but this practice is usually costly and fraught with political controversies. Establishing safe corridors for wildlife in between wild areas can rejoin fragmented landscape, but the creation of corridors is fiscally difficult for developing nations (Adams et al., 2016; van der Grift & Pouwels, 2006). A defined spatial level of vulnerability developed by Graham et al. (2010) can be used to identify areas at higher risk for these encounters, and if done before building new developments or settlements, community members can select areas that are the least vulnerable to conflicts. Conservation managers familiar with seasonal patterns can alert farmers to times when more diligence is needed to protect their crops. Despite all these potential solutions, local farmers usually resort to addressing crop raiding by traditional solutions such as deterrent measures.

Elephants with recurring crop-raiding behaviors, or those that have become habituated to mitigation techniques are sometimes culled by wildlife authorities to reduce HEC and to placate farmers (Rodwell et al., 2000). Besides being controversial (Aarde et al., 1999), culling can be ineffective, as another elephant will commonly replace the removed individual and culling can negatively impact sociological family structures (Shannon et al., 2013; Swan et al., 2017). Farmers will sometimes seek revenge against any elephant they encounter instead of the individual actually responsible for a crop raiding incident (Karidozo & Osborn, 2016). Reducing the causal factors attributed to HEC is difficult and crop raiding creates negative consequences for elephant conservation. Thus, it is crucial to develop practical and affordable deterrent methods for rural people that also prevent habituation by wildlife.

Involving the local community is vital in attempts to ascertain which HEC mitigation technique will be most successful in their area. Their input is important towards developing new deterrent methods and making steps towards resolving HEC. Regardless of the mitigation technique used, goals of programs to reduce HEC can include reducing elephant and human injury or death, easing the financial and emotional stress to farmers or villagers, improving attitudes towards conservation of elephants and bio-diversity, and engaging the community to secure interest in their livelihoods. While farmers lost 5% of their harvest to elephant raids in the experimental area, several surrounding community farms where elephants were left unobstructed to forage were mostly destroyed within one evening. Thus, the importance of developing and evaluating new techniques such as the metal strip fence and disseminating that information to rural people is crucial for elephant conservation as well as securing food resource for those that live amongst them.

FIGURES

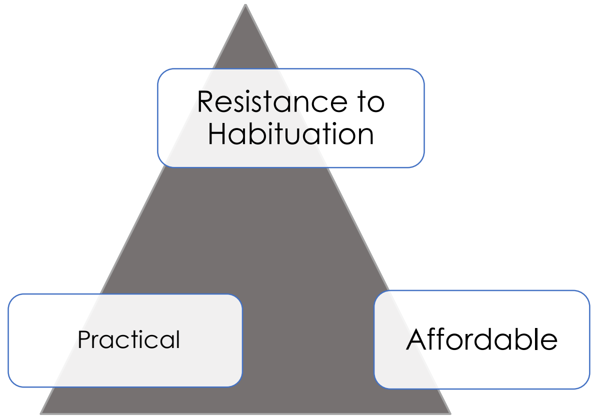


Figure 1. The author's representation of three characteristics that make up an ideal deterrent method in rural communities.

Figure 2. An example of a chili pepper fence utilized to deter elephants (Chang a' 2015).

Figure 3. A metal strip fence constructed from locally available materials deployed in the farming community of Sasenyi, Kenya.

Figure 4. An example of a bee-hive fence erected by Dr. Lucy King and her team at Save the Elephants.

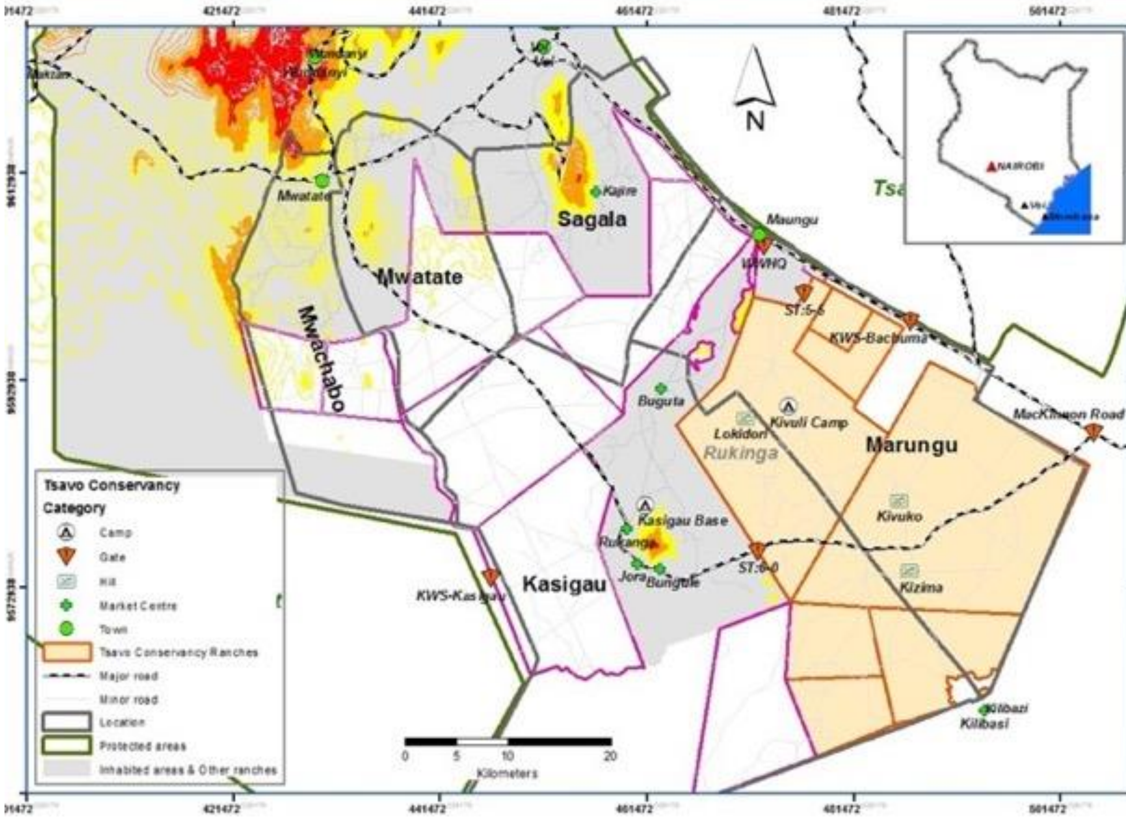


Figure 5: Map of the study area including Rukinga Ranch and Kivuli Camp with surrounding ranches, roads, and villages. Inset shows the region in relation to Kenya and the capital city Nairobi.

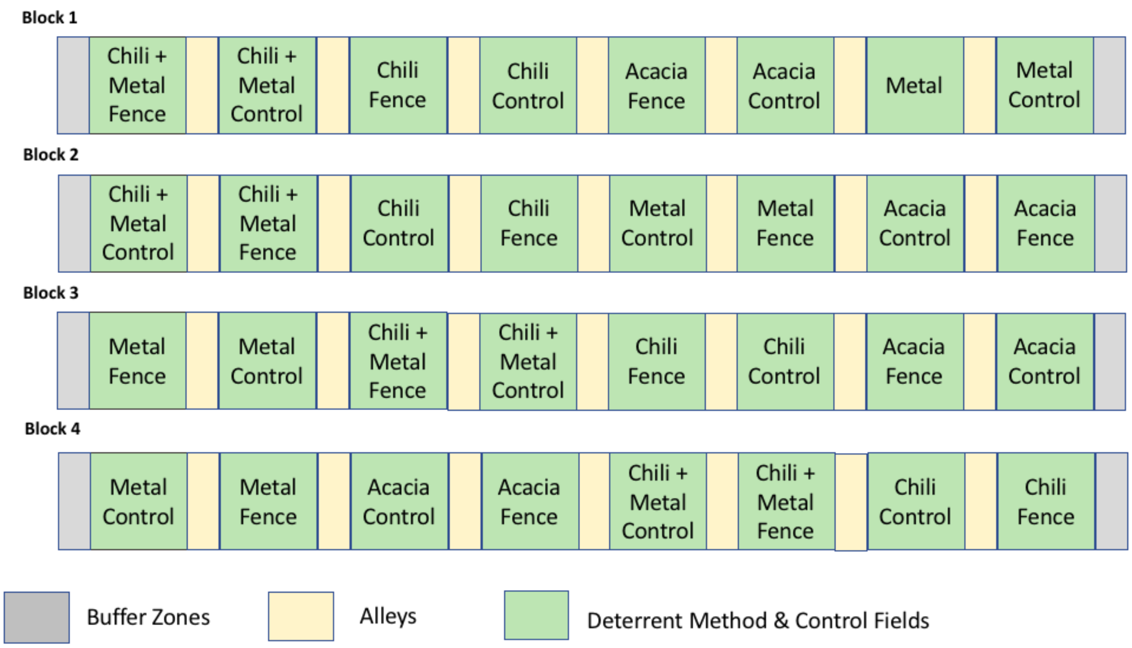


Figure 6. A visual representation of the organization and randomization of the four deterrent blocks located in Sasenyi Kenya.

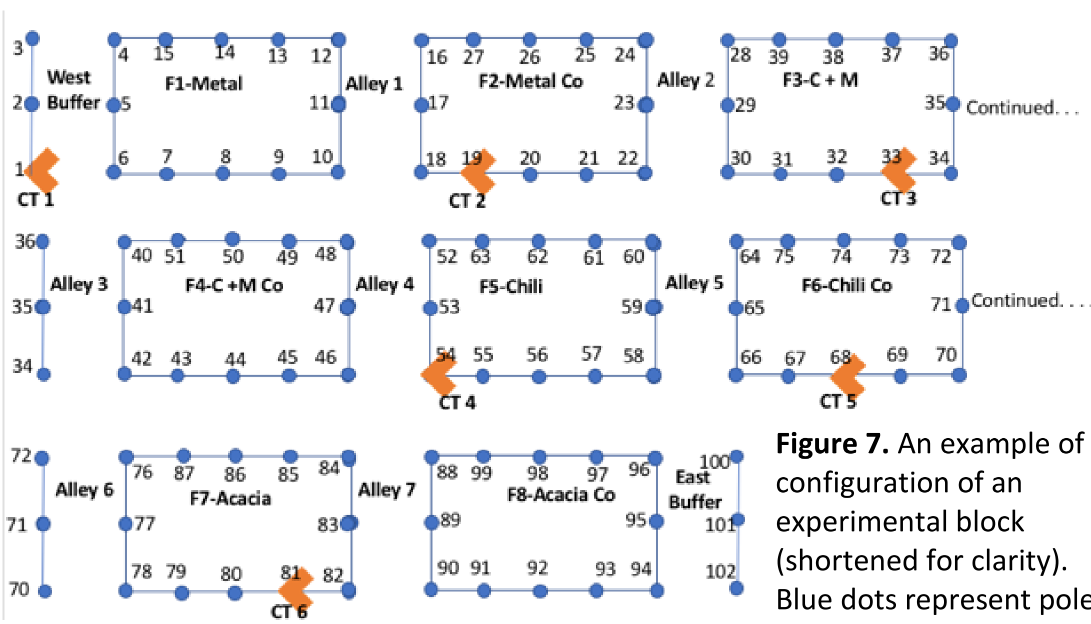
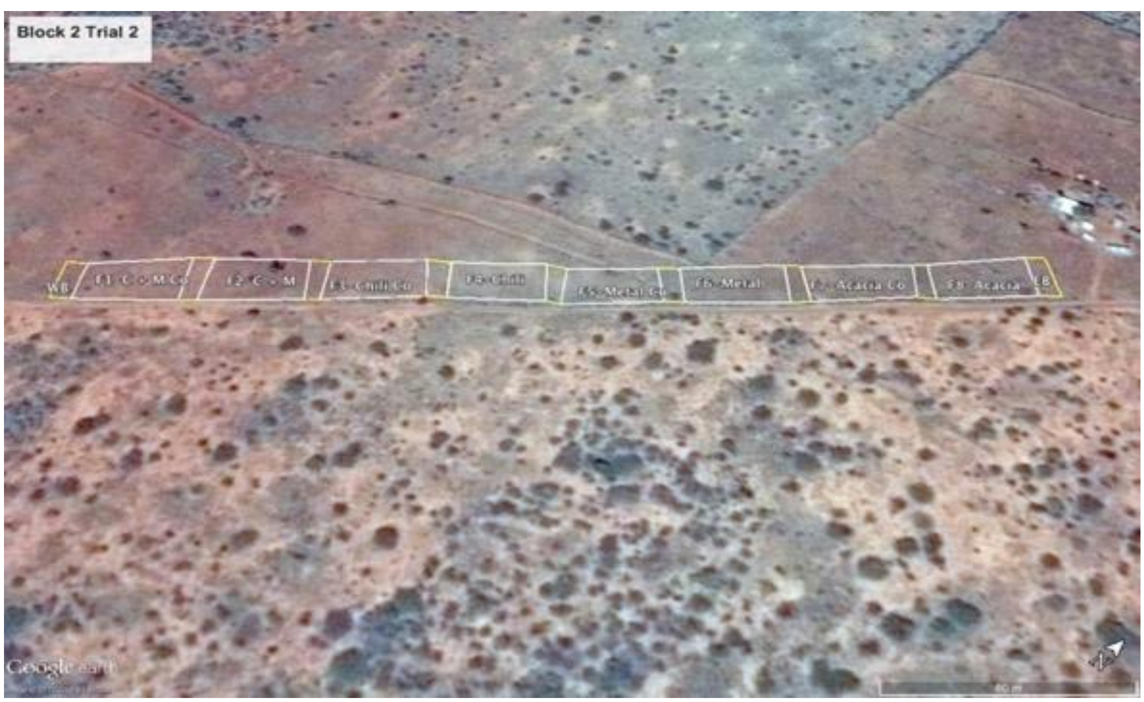


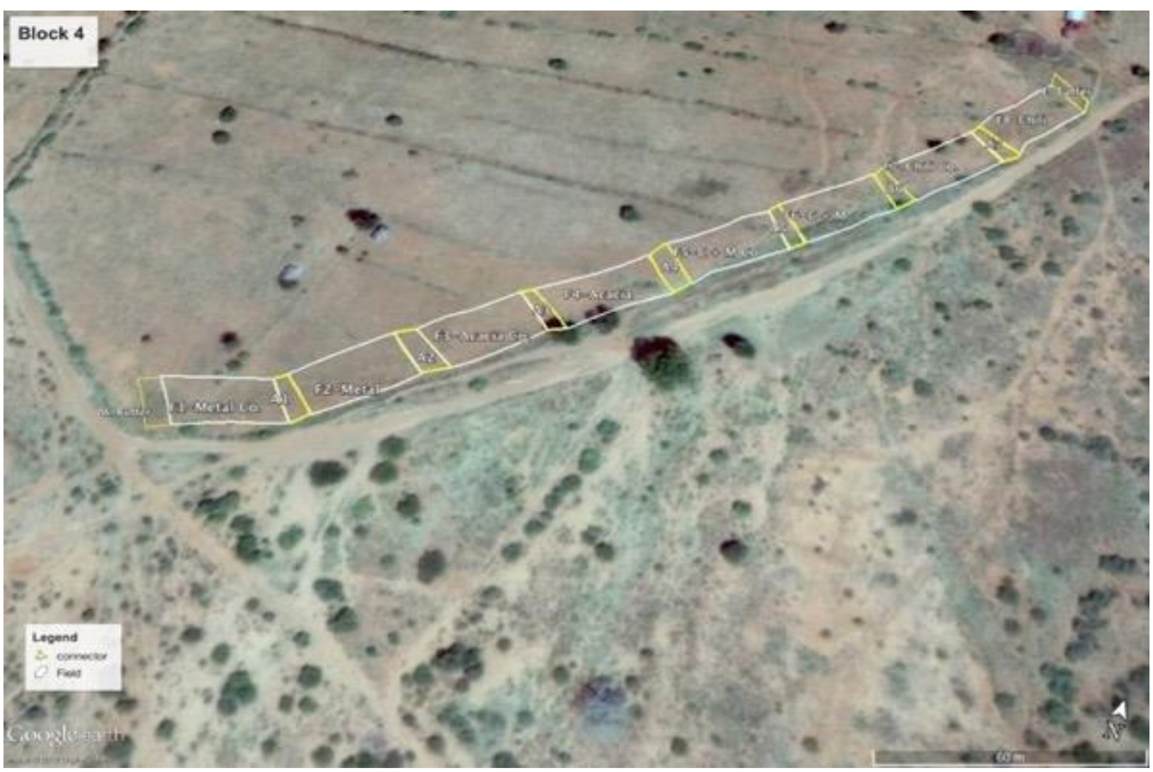
Figure 7. An example of the configuration of an experimental block (shortened for clarity). Blue dots represent poles, while orange triangles are camera trap placements

a. Block 1 used in trial 2



b. Block 2 used in trial 2

c. Block 3 used in trials 1 & 2



d. Block 4 used in trial 1

e. Block 4 new configuration after relocation in trial 2

Figure 8 (a-e). Satellite images from Google Earth with experimental blocks overlaying the topography, along with the trials they were used in. Yellow lines are alleys and buffers and white lines are experimental fields.

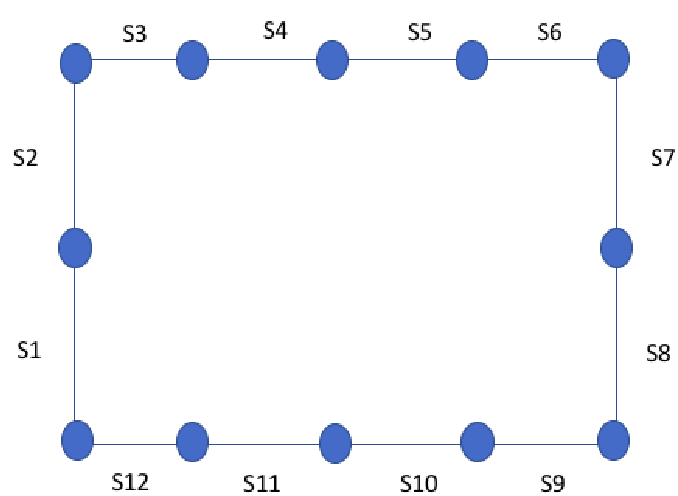


Figure 9: An example of how panels in a field are divided into section numbers which are located between numbered poles

Figure 10. An acacia fence circling an agricultural plot

a.  b.  c. 

Figure 11. Materials used in the construction of a chili pepper fence utilized to deter elephants.

(a). A deployed chili pepper fence showing panels at the corner of a field. (b). Bird's eye chili (*Capsicum anuum*) used in the experiment (c). Fence attendant Chimanga uses a traditional Kenyan mortar and pestle to crush up chili peppers.

Figure 12. The control for the metal strip fence, attached to a pole at 1.5 m.

a. Maize-CS 2 b. Lentils-CS 3 c. Maize-CS 3

Figure 13. a-c. Examples of crop condition scores (CS).

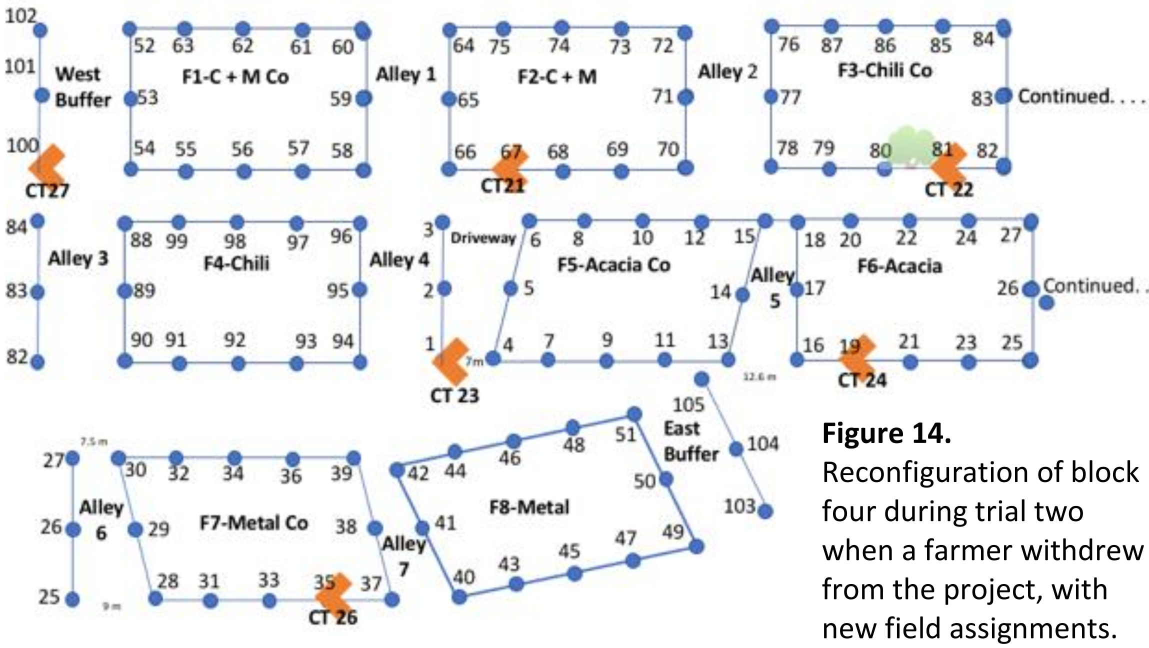


Figure 14. Reconfiguration of block four during trial two when a farmer withdrew from the project, with new field assignments.

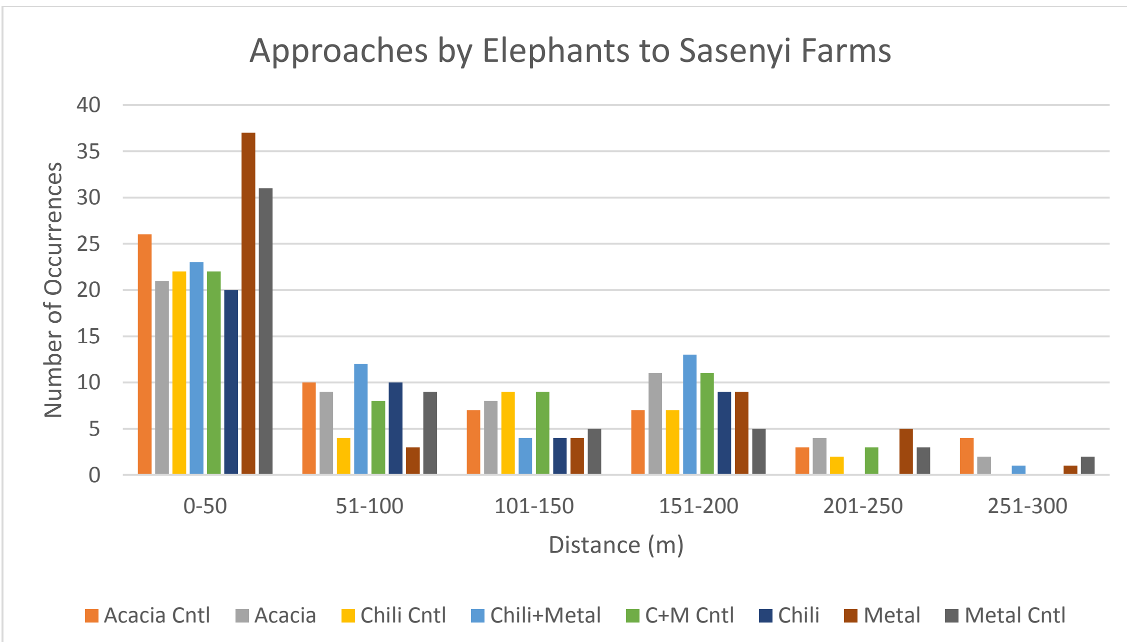


Figure 15. The 419 approaches by elephants to the Sasenyi farms experimental area. Each is categorized by the type of deterrent approached with a conservative estimated distance.

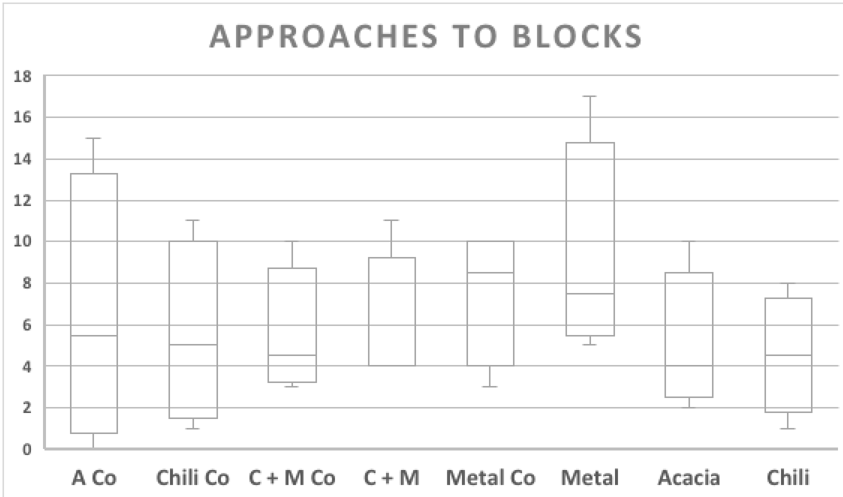


Figure 16. Elephant approaches to deterrents combined across all blocks. Median values are represented by black lines, error bars are 1 standard deviation.

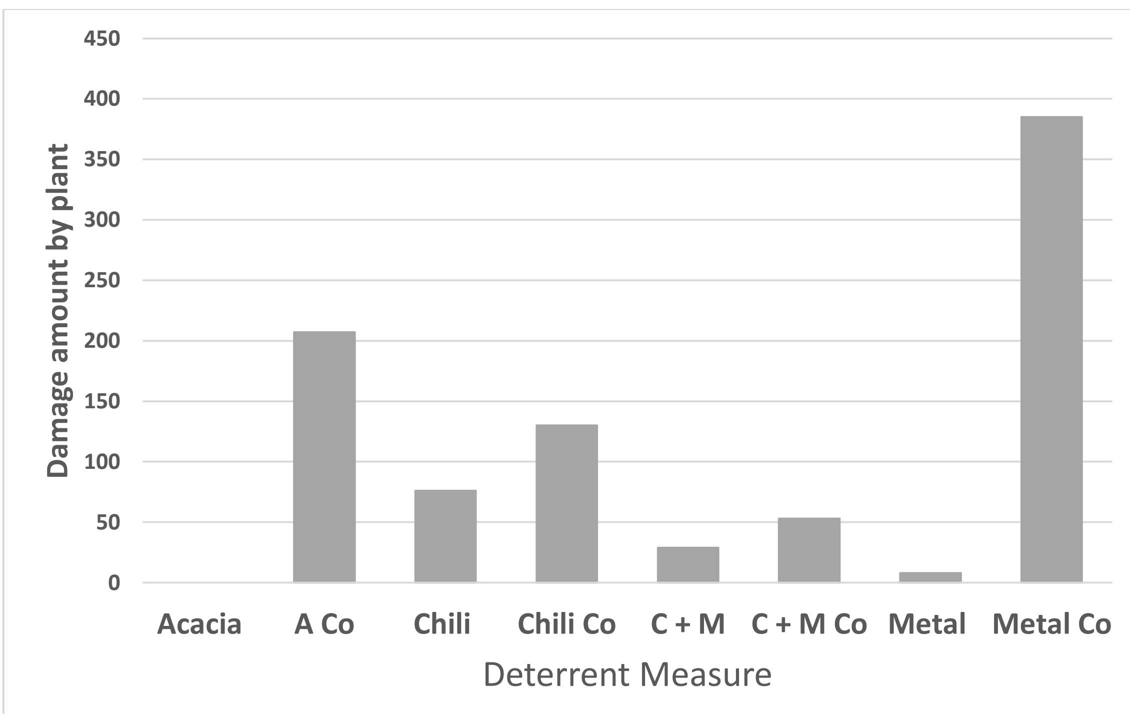


Figure 17. Histogram of the amount of damage occurring from combined trampling and consumption to experimental fields, grouped by type of deterrent measures. Damage number is by individual plant destroyed.

Tables

Table 1. Three crop species planted at experimental plots with respective scores describing maturity level

Species	CS No.	Description
Cow Pea, *Vigna unguiculata*	1	Seedling-Height < .2m
	2	Leafy but no pods
	3	Immature pods
	4	Mature pods, ready for harvest
	5	Varying-2 stages or more
Lentil *Lens culinaris*	1	Seedling-Height <.10 m
	2	Leafy but no pods
	3	Immature pods
	4	Mature pods, ready for harvest
	5	Varying-2 stages or more
Maize (corn), *Zea mays*	1	Seedling < .3m
	2	Location of ears visible, but not present
	3	Immature ears present
	4	Mature ears present on <50% of stalks
	5	Mature ears present on >50% of stalks
	6	Varying-2 stages or more
	7	Dead due to pestilence (insect infestation)
	8	Dead due to lack of water

Table 2. All approaches to individual deterrent types by elephants grouped in 50 m increments.

Distance in meters	Acacia	A Co	Chili	C Co	C + M	C + M Co	Metal	M Co	Total
(R1) **0***	4	8	5	4	1	2	3	6	33
(R2) **1-50**	17	18	15	18	22	20	34	25	202
(R3) **Subtotal (0-50)**	21	26	20	22	23	22	37	31	235
>50-100	9	10	10	4	12	8	3	9	65
101-150	8	7	4	9	4	9	4	5	50
151-200	11	7	9	7	13	11	9	5	72
201-250	4	3	0	2	0	3	5	3	20
251-300	2	4	0	0	1	0	1	2	10
Total	55	57	43	44	53	53	59	55	419
(R4) % of times field entered	19	31	25	19	5	10	9	19	16
(R5) Rank of effectiveness	5	7	6	4	1	3	2	5	

*Successful breaches of deterrent

Table 3. Comparison of deterrent methods with their respective control and deterrent method vs. the acacia control in a Fisher's Exact test result. a=0.05

Deterrent Methods	P-Value
Acacia vs. Acacia Control	0.505
Chili vs. Chili Control	0.714
Metal vs. Metal Control	0.282
C + M vs. C + M Control	0.608
Acacia Co vs. Chili	0.750
Acacia Co vs. Chili Control	0.505
Acacia Co vs. Metal	0.040**
Acacia Co vs. Metal Co	0.367
Acacia Co vs C + M	0.023**
Acacia Co vs. C + M Co	0.085*

**significant with the p-value at 0.05

* significant with the p-value at 0.10

Table 4. Non-parametric ANOVA table results of approaches by elephants examining the effect of block, and treatment (deterrent method). Column abbreviations[1]: Df=Degrees of Freedom, SS=Sum of Squares, MS=Mean Square, Rsq= R squared value.

	Df	SS	MS	Rsq	F value	Pr(>F)
Treatment	7	66.37	9.482	17.344	1.936	0.798
Block	3	329.62	109.875	0.661	22.429	0.001***
Residuals	21	102.88	4.900			
Total	31	498.88	16.093			

*** significant at 0.001 or less

[1] Applies to all ANOVA tables in results

Table 5: Tukey test for multiple comparison of means with 95% confidence intervals, examining the approaches in relation to blocks for combined trials one (T1) and two (T2) and for trial two only.

Block	P-value T1 & T2	P-value T2 Only
B2-B1	0.114	0.005**
B3-B1	0.858	0.894
B4-B1	<0.001***	<0.001***
B3-B2	0.410	0.022**
B4-B2	<0.001***	0.784
B4-B3	<0.001***	0.003**

*** significant at 0.001 or less

** significant at 0.05 or less

Table 6. The composition of elephant groups that were approaching at 50 m or less and/or successfully raiding farms at the Sasenyi experimental area.

Number of Elephants In Group	Total approaches at 50 m or less	Successful Raids (0 meters)	Unsuccessful Approaches (Elephant(s) Deterred)
1	106	14	92
2	27	11	16
3	27	4	23
4	3	0	3
5	1	0	1
7	3	2	1
8	2	2	0
Total of All Elephant Groups	**202**	**33**	**169**

Table 7. Damages to crops in trial two by crop species with all four blocks combined. Numbers represent individual plants. C=Consumption damage, T=Trampling damage, Comb=Combined Consumption + Trampling Damage

Deterrent	Maize C	Maize T	Maize Comb	Lentils C	Lentils T	Lentils Comb	Cow Peas C	Cow Peas T	Cow Peas Comb	Overall Damage
A Co	177	25	202	5	0	5	0	0	0	207
Acacia	0	0	0	0	0	0	0	0	0	0
C Co	62	48	110	0	0	0	13	7	20	130
C+M	14	15	29	0	0	0	0	0	0	29
C+M Co	31	22	53	0	0	0	0	0	0	53
Chili	28	23	51	0	0	0	20	5	25	76
Metal	0	0	0	2	5	7	0	1	1	8
Metal Co	112	80	192	20	20	40	78	75	153	385
Total	**424**	**213**	**637**	**27**	**25**	**52**	**111**	**88**	**199**	**888**

Table 8. Non-parametric ANOVA table results of crops consumed compared to the type of crop and the deterrent method.

	Df	SS	MS	Rsq	F value	Pr (>F)
Type of Crop	2	10943	5471.5	0.252	4.499	0.032*
Deterrent Method	7	15611	2230.2	0.358	1.834	0.264
Residuals	14	17026	1216.1			
Total	23	43580	1894.8			

*Significant at 0.05

Table 9: Tukey comparison of means with 95% confidence intervals for crops eaten by crop types

Crop Pairs	P-Value
Lentil Damage/CP Damage	0.821
Maize Damage/CP Damage	0.098
Maize Damage/ Lentil Damage	0.032*

*Significant at 0.05

Table 10. Non-parametric ANOVA table results of crops trampled compared to the type of crop and the deterrent method.

	Df	SS	MS	Rsq	F value	Pr (>F)
Type of Crop	2	2289.1	1144.54	0.187	6.492	0.104
Deterrent Method	7	7506.5	1072.36	0.612	6.082	0.026*
Residuals	14	2468.2	176.3			
Total	23	12263.8	533.21			

*Significant at 0.05

Table 11: Tukey comparison of means with 95% confidence intervals for crops trampled by deterrent types

Deterrent 1	Deterrent 2	P-value
Acacia	A Co	0.992
C Co	A Co	0.978
C + M	A Co	1.000
C+ M Co	A Co	1.000
Chili	A Co	1.000
Metal	A Co	1.000
Metal Co	A Co	0.007*
C Co	Acacia	0.693
C+ M	Acacia	1.000
C + M Co	Acacia	0.996
Chili	Acacia	0.985
Metal	Acacia	1.000
Metal Co	Acacia	0.002*
C + M	C Co	0.910
C + M Co	C Co	0.964
Chili	C Co	0.988
Metal	C Co	0.792
Metal Co	C Co	0.038*
C + M Co	C + M	1.000
Chili	C + M	1.000
Metal	C + M	1.000
Metal Co	C + M	0.004*
Chili	C + M Co	1.000
Metal	C + M Co	1.000
Metal Co	C + M co	0.006*
Metal	Chili	0.996
Metal Co	Chili	0.008*
Metal Co	Metal	0.003*

*Significant at 0.05

Table 12. ANOVA table results of total crop damage compared to the type of crop and the deterrent method.

	Df	SS	MS	Rsq	F value	Pr (>F)
Type of Crop	2	23153	11576.6	0.259	6.129	0.029*
Deterrent Method	7	39632	5661.7	0.444	2.993	0.140
Residuals	14	26487	1891.9			
Total	23	89272	3881.4			

*Significant at 0.05

Table 13: Tukey comparison of means with 95% confidence intervals for overall damage by crop types

Crop Pairs	P-Value
Lentil Damage/CP Damage	0.682
Maize Damage/CP Damage	0.060
Maize Damage/ Lentil Damage	0.012*

*Significant at 0.05

Table 14. A summary of total destruction by elephants of the three crops planted in trial two, and the percentage of crops that were destroyed across all fields and blocks.

	Maize	Lentils	Cow Peas
Total planted	14,724	718	748
Total destruction	637	52	199
Percentage destroyed by type of plant	4%	7%	27%
Total Plants (combined)	16,190	16,190	16,190
Total plants destroyed	888	52	199
Total destruction	**5%**	<1%	1%

Table 15. A list of species, excluding elephants noted in the experimental area during both trials at 50 m or less from deterrents.

Common Name	Species Name	Times noted at Sasenyi
Cow	*Bos taurus indicus*	11
Duiker	*Sylvicapra grimmia*	46
Eland	*Tragelaphus oryx*	87
Giraffe	*Giraffa camelopardalis*	10
Goat	*Capra hircus*	13
Kirk’s Dik Dik	*Madoqua kirkii*	9
Lesser Kudu	*Tragelaphus imberbis*	17
Slender Mongoose	*Herpestes sanguineus*	3
Spotted Hyena	*Crocuta crocuta*	3

LITERATURE CITED

Aarde, R., Whyte, I., & Pimm, S. (1999). Culling and the dynamics of the Kruger National Park African elephant population. *Animal Conservation*, *2*, 287–294.

Adams, T. S., Chase, M. J., Rogers, T. L., & Leggett, K. E. (2016). Taking the elephant out of the room and into the corridor: can urban corridors work? *Oryx*, (51)2, 1–7.

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

Blumstein, D. T. (2016). Habituation and sensitization: new thoughts about old ideas. *Animal Behaviour*, *120*, 255–262.

Bond, J. (2015). Making sense of human-elephant conflict in Laikipia County, Kenya. *Society and Natural Resources*, *28*(3), 312–327.

Chang'a, A., Omondi, R., Konuche, J., Olson, D., & DeSouza, N. (2015). *Chilli fences keep elephants out of crops! How to make and support chili fences*. Tanzania Wildlife Division, Tanzania Wildlife Research Institute, Tanzania National Parks, World Animal Protection, RESOLVE, Biodiversity & Wildlife Solutions, Mikumi & Tarangire Tembo Pilipili Teams, & the Honeyguide Foundation.

Chang 'a, A., De Souza, N., Muya, J., Keyyu, J., Mwakatobe, A., Malugu, L., Ndossi, P., Konuche, J., Omondi, R., Mpinge, A., Hahn, N., et al. (2016). Scaling-up the use of chili fences for reducing human-elephant conflict across landscapes in Tanzania. *Tropical Conservation Science*, *9*(2), 921–930.

Chase, M. J., Schlossberg, S., Griffin, C. R., Bouché, P. J. C., Djene, S. W., Elkan, P. W., Ferreira, S., Grossman, F., Kohi, E.M., Landen, K. et al.(2016). Continent-wide survey reveals massive decline in African savannah elephants. *PeerJ*, *4*, e2354. http://doi.org/10.7717/peerj.2354.

Chelliah, K., Kannan, G., Kundu, S., Abilash, N., Madhusudan, A., Baskaran, N., & Sukumar, R. (2010). Testing the efficacy of a chilli-tobacco rope fence as a deterrent against crop-raiding elephants. *Current Science*, *99*(9), 1239–1243.

Chiyo, P. I., & Cochrane, E. P. (2005). Population structure and behaviour of crop-raiding elephants in Kibale National Park, Uganda. *African Journal of Ecology*, *43*(3), 233–241.

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

Chiyo, P. I., Moss, C. J., & Alberts, S. C. (2012). The influence of life history milestones and association networks on crop-raiding behavior in male african elephants. *PLoS ONE*, *7*(2).

Davies, T. E., Wilson, S., Hazarika, N., Chakrabarty, J., Das, D., Hodgson, D. J., & Zimmermann, A. (2011). Effectiveness of intervention methods against crop-raiding elephants. *Conservation Letters*, *4*(5), 346–354.

Decker, D. J., & Chase, L. C. (1997). Human dimensions of living with wildlife: A management challenge for the 21st century. *Wildlife Society Bulletin*, *25*(4), 788–795.

Derham, K. (2014). Wire netting reduces African elephant (*Loxodonta africana*) impact to selected large trees in South Africa. *Masters Thesis & Special Projects*. Paper 1358. Western Kentucky University.

Derham, K., Henley, M.D., Schulte, B.A. (2016) Wire netting reduces African elephant (*Loxodonata africana*) impact to selected trees in South Africa. *Koedoe* 58(1), a1327. http://dx.doi. org/10.4102/koedoe. v58i1.1327

Desai, A. A., & Riddle, H. S. (2015). *Human-Elephant Conflict in Asia*. US Fish and Wildlife Service, Asian Elephant Support.

Dyer, C. (2014) New names for the African acacia species in Vachellia and Senegalia. *Southern Forests: a Journal of Forest Science*, 76(4), DOI: 10.2989/20702620.2014.980090

Goodyear, S. E., & Schulte, B. A. (2015). Habituation to auditory stimuli by captive african elephants (*Loxodonta africana*). *Animal Behaviour and Cognition*, *2*(4), 292–312.

Govind, S. K., & Jayson, E. A. (2013). Efficiency of chilli powder (*capsicum sp*.) to deter wild elephants from the crop fields in a tropical area. *Millenium Zoology*, *14*(1), 21–24.

Graham, M. D., Adams, W. M., & Kahiro, G. N. (2012). Mobile phone communication in effective human elephant–conflict management in Laikipia County, Kenya. *Oryx*, *46*(1), 137–144.

Graham, M. D., Douglas-Hamilton, I., Adams, W. M., & Lee, P. C. (2009). The movement of African elephants in a human-dominated land-use mosaic. *Animal Conservation*, *12*(5), 445–455.

Graham, M. D., Notter, B., Adams, W. M., Lee, P. C., & Ochieng, T. N. (2010). Patterns of crop-raiding elephants, *Loxodonta africana*, in Laikipia, Kenya, and the management of human–elephant conflict. *Systematics and Biodiversity*, *8*(4), 435–445.

Graham, M. D., & Ochieng, T. (2008). Uptake and performance of farm-based measures for reducing crop raiding by elephants *Loxodonta africana* among smallholder farms in Laikipia District, Kenya. *Oryx*, *42*(1), 76–82.

Hanski, I. (2005). Landscape fragmentation, biodiversity loss and the societal response. The long term consequences of our use of natural resources may be surprising and unpleasant. *EMBO Reports*, *6*(5), 388–392.

Harvey, C. A., Chacon, M., Donatti, C. I., Garen, E., Hannah, L., Andrade, A., (2014). Climate-smart landscapes: opportunities and challenges for integrating adaptation and mitigation in tropical agriculture. *Conservation Letters*, *7*(2), 77–90.

Henley, M. (2012a). Aging elephants-a practical guide. Save the Elephants.

Henley, M. (2012b). Getting to know individual elephants, ID Kit. Save the Elephants.

Hill, C.M. (1997). Crop-raiding by wild vertebrates: the farmer's perspective in an agricultural community in western Uganda. *International Journal of Pest Management,* 43(1), 77-84.

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

Hoare, R. (2012). Lessons from 15 years of human elephant conflict mitigation: Management considerations involving biological, physical and governance issues in Africa. *Pachyderm*, *51*(1), 60–74.

Hoare, R. E. (1999). Determinants of human-elephant conflict in a land-use mosaic. *Journal of Applied Ecology*, *36*(5), 689–700.

Hoare, R. E., & Du Toit, J. T. (1999). Coexistence between people and elephants in African savannas. *Conservation Biology*, *13*(3), 633–639.

Hoffmeier-Karimi, R. R., & Schulte, B. A. (2015). Assessing perceived and documented crop damage in a Tanzanian village impacted by human-elephant conflict (HEC). *Pachyderm*, (56), 51–60.

Kagwa, S. (2011). Spatial Distribution of human elephant conflict (HEC) and characterization of crop-raiding elephants in Kasigau region, Kenya. *Masters Thesis & Specialist Projects. Paper 1083.* Western Kentucky University.

Kangwana, K. (1996). Studying Elephants. African Wildlife Foundation, Nairobi, Kenya.

Karidozo, M., & Osborn, F. (2015). Community based conflict mitigation trials: Results of field tests of chili as an elephant deterrent. *Journal of Biodiversity & Endangered Species*, *3*(1), 1–6.

Karimi, R.R. (2009). An assessment of perceived crop damage in a Tanzanian village impacted by human-elephant conflict and an investigatin of deterrent properties of African elephant (*Loxodonta Africana*) exudates using bioassays. *Electronic Theses*

& dissertations. Paper 740. Georgia Southern University.

Kasaine, S., & Githiru, M. (2016). *Sasenyi Valley Baseline Household Survey: Earthwatch Institute.* Wildlife Works, Voi, Kenya.

King, L. E., Lala, F., Nzumu, H., Mwambingu, E., & Douglas-Hamilton, I. (2017a). Beehive fences as a multidimensional conflict-mitigation tool for farmers coexisting with elephants. *Conservation Biology*, *31*(4), 743-752.

Kioko, J., Muruthi, P., Omondi, P., & Chiyo, P. I. (2008). The performance of electric fences as elephant barriers in Amboseli, Kenya. *South African Journal of Wildlife Research*, *38*(1), 52–58.

Le Bel, S., Murwira, A., Mukamuri, B., Czudek, R., Taylor, R., & La Grange, M. (2007). Human wildlife conflicts in southern Africa. Riding the whirl wind in Mozambique and in Zimbabwe, in: The Importance of Biological Interactions in the Study of Biodiversity. (ed. Jordi Lopez-Pujol) pp. 283–322. Shanghai, China. Intech.

Le Bel, S, & Taylor, R., Lagrange, M., Ndoro, O., Barra, M., Madzikanda, H.(2010). An easy-to-use capsicum delivery system for crop-raiding elephants in Zimbabwe : Preliminary results of a field test in Hwange National Park. *Pachyderm*, (47)1, 80–89.

Lee, P. C. (2010). Problem animals or problem people? in: Centralizing Fieldworks: Critical Perspectives from Primatology, Biological and Social Anthropology. (eds. MacClancy, J. & Fuentes), pp. 69–83. New York/Oxford, Bergham Books.

Madden, F. (2004). Creating coexistence between humans and wildlife: Global perspectives on local efforts to address human–wildlife conflict. *Human Dimensions of Wildlife*, *9*(4), 247–257.

McKnight, B. L. (2004). Elephant numbers, group structure and movements on privately owned land adjacent to Tsavo East National Park, Kenya. *Pachyderm*, *36*(36), 44–51.

Morrison, T. A., Holdo, R. M., & Anderson, T. M. (2016). Elephant damage, not fire or rainfall, explains mortality of overstorey trees in Serengeti. *Journal of Ecology*, *3*, 409–418.

Moss, C. J. (1988). Elephant Memories. Chicago, University of Chicago Press.

Mutinda, M., Chenge, G., Gakuya, F., Otiende, M., Omondi, P., Kasiki, S.,Soriguer, R.C., Alasaad, S. (2014). Detusking fence-breaker elephants as an approach in human-elephant conflict mitigation. *PLoS ONE*, *9*(3), 1-7.

Naughton-Treves, L. (1990). Predicting Patterns of Crop Damage by Wildlife around Kibale National Park. *Conservation Biology*, *12*(1), 156–168.

Naughton-Treves, L., & Treves, A. (2005). Socio-ecological factors shaping local support for wildlife : crop-raiding by elephants and other wildlife in Africa, in: People and Wildlife: Conflict or Coexistence? (eds. Woodroffe, R., Thirgood, S., & Rabinowitz, A.) pp. 252–277. Cambridge University Press, Zoological Society of London.

Nelson, A., Bidwell, P., & Sillero-Zubiri, C. (2003). *A review of human-elephant conflict management strategies.* People and Wildlife, A Wildlife Conservation Research Unit of the Born Free Foundation partnership.

O'Connell-Rodwell, Rodwell T., Rice M., & Hart L.A. (2000). Living with the modern conservation paradigm; can agricultural communities co-exist with elephants? A 5 year case study in east Caprivi, Namibia. *Biological Conservation*, *93*, 381–391.

Omondi, P., Bitok, E. K., Mukeka, J., M, M. R., & Litoroh, M. (2008*). Total aerial count of elephants and other large mammal species of Tsavo/Mkomazi ecosystem*. Kenya Wildlife Service Biodiversity , Research & Monitoring Division.

Osborn, F.V. (2004). Seasonal variation of feeding patterns and food selection by crop-raiding elephants in Zimbabwe. African Journal of Ecology, 42(4), 322-327.

Osborn, F. V., & Rasmussen, L. E. L. (1995). Evidence for the effectiveness of an oleo-resin capsicum aerosol, as a repellent against wild elephants in zimbabwe. *Pachyderm,* 20, 55–64.

Peña-Alvarez, A., Ramírez-Maya, E., & Alvarado-Suárez, L.A. (2009). Analysis of capsaicin and dihydrocapsaicin in peppers and pepper sauces by solid phase microextraction–gas chromatography–mass spectrometry. *Journal of Chromatography,* 1216, 2843–2847.

Salako, K., Azihou, A. F., Assogbadjo, A. E., Hou, D., Kassa, D., &.Kakai, R.L. (2015). Elephant-induced damage drives spatial isolation of the dioecious palm *Borassus aethiopum Mart.*(Arecaceae) in the Pendjari National Park , Benin. *African Journal of Ecology*, 54, 9–19.

Searcy, W. A., & Nowicki, S. (2005) Introduction, in: The Evolution of Animal Communication Reliability and Deception in Signaling Systems. (eds. Krebs, J.R. & Clutton-Brock, T.) pp. 1–24. Princeton University Press, Princeton, NJ.

Shannon, G., Page, B.R., Mackey, R.K., Duffy, K.J., Slotow, R. (2008). Activity budgets and sexual segregations in African elephants (*Loxodonta africana*). *Journal of Mammology*, 89(2), 467-476

Shannon, G., Slotow, R., Durant, S. M., Sayialel, K. N., Poole, J., Moss, C., & McComb, K. (2013). Effects of social disruption in elephants persist decades after culling. *Frontiers in Zoology*, *10*(62), 1–10.

Sinervo, B. (2013). Optimal foraging theory: Constraints and cognitive processes in: Behavioral Ecology. pp. 105-130. University of California, Santa Cruz CA. http://bio.research.ucsc.edu/~barrylab/classes/CHAPTER_PDFS/Chap_6_Optimal.pdf.

Sitati, N. W., Walpole, M. J., & Leader-Williams, N. (2005). Factors affecting susceptibility of farms to crop raiding by African elephants: Using a predictive model to mitigate conflict. *Journal of Applied Ecology*, *42*(6), 1175–1182.

Sitati, N. W., Walpole, M. J., Smith, R. J., & Leader-Williams, N. (2003). Predicting spatial aspects of human and elephant conflict. *Journal of Applied Ecology*, *4*(40), 667–677.

Smith, R. J., & Kasiki, S. M. (2000). *A spatial analysis of human-elehant conflict in the Tsavo ecosystem, Kenya*. Gland, Switzerland. African Elephant Specialist Group, Human-Elephant Conflict Task Force, IUCN.

Songhurst, A. (2017). Measuring human–wildlife conflicts: Comparing insights from different monitoring approaches. *Wildlife Society Bulletin*, *41*(2), 351–361.

Suissa, S., & Shuster, J.J. (1985). Exact unconditional sample sizes for the 2 X 2 binomial trial. *Journal of the Royal Statistical Society*, 148(4), 317-327.

Swan, G. J. F., Redpath, S. M., Bearhop, S., & McDonald, R. A. (2017). Ecology of problem individuals and the efficacy of selective wildlife management. *Trends in Ecology and Evolution*, *32*(7), 518–530.

Treves, A., Wallace, R. B., Naughton-Treves, L., & Morales, A. (2006). Co-managing human–wildlife conflicts: A review. *Human Dimensions of Wildlife*, *11*(6), 383–396.

Treves, A., Wallace, R. B., & White, S. (2009). Participatory planning of interventions to mitigate human-wildlife conflicts. *Conservation Biology*, *23*(6), 1577–1587.

van der Grift, E., & Pouwels, R. (2006). Restoring habitat connectivity across transport corridors: identifying high-priority locations for de-fragmentation with the use of an expert-based model, in: The Ecology of Transportation: Managing Mobility for the Environment. (eds. Davenport, J. & Davenport, J.L.) pp. 205–231. Alterra, The Netherlands. Wageningen University and Research Center.

Vollrath, F., & Douglas-Hamilton, I. (2002). African bees to control African elephants. *Naturwissenschaften*, *89*(11), 508–511.

Von Gerhardt, K., Van Niekerk, A., Kidd, M., Samways, M., & Hanks, J. (2014). The role of elephant *Loxodonta africana* pathways as a spatial variable in crop-raiding location. *Oryx*, *48*(3), 1–9.

Williams, H. F., Bartholomew, D. C., Amakobe, B., & Githiru, M. (2018). Environmental factors affecting the distribution of African elephants in the Kasigau wildlife corridor, SE Kenya. *African Journal of Ecology*, 56(2), 244-253.

Wittemyer, G., Northrup, J. M., Blanc, J., Douglas-Hamilton, I., Omondi, P., & Burnham, K. P. (2014). Illegal killing for ivory drives global decline in African elephants.

Proceedings of the National Academy of Sciences of the United States of America, *111*(36), 13117–21.

APPENDIX I: SURVEYS OF TREE DAMAGE AS AN INDICATOR TOWARDS CROP RAIDING FLUCTUATIONS

Introduction

Because elephants are generalist herbivores, they can also do extensive damage to trees. Uprooting, breaking branches, or stripping trees of bark is common (Figure A1.1), and elephant damage is a major cause of over story tree mortality in savannah areas (Morrison et al., 2016; Salako et al., 2015). Damage to local trees can become especially high in the transition from dry to wet season when elephants are browsing extensively and grasses are limited (Vollrath & Douglas-Hamilton, 2002). Property owners or National Parks incurring extensive tree damages may resort to wrapping them with wire netting to reduce their losses (Derham, 2014). Elephant activity such as this can present difficulties for deforested areas in which the ecosystem is still recovering. When resources are scarce, elephants commonly supplement their diets with bark (browsing), but little is known how this may relate to the occurrences of crop raiding in nearby areas. It is important to understand patterns of tree damage and how this may relate to temporal or seasonal patterns of crop raiding, as well as developing methods that will prevent excessive elephant damage in recovering ecosystems. As a supplementary experiment to the crop raiding study, 240 elephant-favored trees spread across six transects in Rukinga Ranch were selected and catalogued to survey changes in damage in relation to crop raiding rates. I hypothesized that tree damage would significantly increase during time periods of drought or when crops were not present in the Sasenyi farming community.

Methods

To establish transects for wildlife (Appendix II) and tree surveys, six areas across Rukinga Ranch were selected that contained major water points with easy road access. A Garmin GPSmap 60CSx or Garmin GPSmap 62GPS were used to mark locations of water points, roads, tanks, or other topographical objects of interest. These transects were put into Google Earth (Figure A1.2), as ArcGIS was not available at our study site, which provided a map for team members. The six transects covered a linear total of 84.43 km with a mean transect length of 14.07 km (Table A1.1) and covered most of the major regions of the ranch.

Within each transect, four locations were selected near water points to sample ten trees in each area (Table A1.2) near the beginning, middle and end of each transect. At each location a GPS waypoint was taken, and a number for each tree was assigned. A metal tag was stamped with the tree number as well as a number written in sharpie and was hung from a lower branch with the location noted in the database. Local tree expert Joshua Kitiro assisted with identification of all tree species. To determine the approximate height of each tree, a Simmons 801405 Rangefinder was used to estimate the distance from the observer's eye to the tree, and the distance to the top of the tree. Pythagorean's theorem ($a^2 + b^2 = c^2$) was used to extrapolate the height of the missing length and when added to the height of the observer resulted in the approximate height of the tree, rounded to the nearest meter. Later in the project, a collapsible ruler was obtained and utilized, giving a more accurate measurement. To determine canopy size, two team members visually inspected the tree and stood on the side with the widest spread of the canopy and took a measurement from the two furthest tips of the branches, and then moved perpendicular to obtain another. The final canopy size resulted from the mean of these two measurements in meters. The lowest canopy point from the ground was also noted.

African trees commonly have multiple trunks and estimating the diameter at breast height (DBH) can be complicated. The procedure used by the carbon monitoring team of Wildlife Works (WW) was adopted, and measurements were taken with a DCT120 Perfect Pi DBH Tape by encircling the tape around the trunk and reading the corresponding measurement. Trees with a single trunk were measured at 1.4 m from the ground. If there was a bulge or branch right at 1.4 m, the measurement was taken just above this area. Trees that had multiple forks that were less than 0.4 m above the ground had each measurement taken at 1.4 m. For trees that had forks above 0.4 m those forks were measured 1 m above the point where the fork occurred. For trunks that had multiple forks per trunk, if the second fork fell below 1 m after the first, it was measured below the second fork. If a tree was considered in a shrub class, the largest stem had the DBH taken and the remainder of stems counted.

Each tree was evaluated for the types and severity of elephant damage based on a classification system from Derham et al. (2016). Damage types were bark stripping (BS), branch breaking (BB), main stem breaking (MS), Uprooting-tree pushed over (UR), and main stem breaking combine with uprooting (Fell). Bark stripping and branch breaking had impact scores assigned based on the amount of damage (Table A1.3). The damage level of branch breaking was estimated by taking the percentage of branches that were disturbed in relation to the remainder of the tree and dividing by 100. Bark stripping was estimated in the same manner, but the largest stripping (if reachable) had its length, width and distance from the ground measured in cm. Each tree had overall and specific damage photographs taken and all metrics for each were entered into a tree database. Because of the increase in elephant numbers on the property from the end of November to the end of the year, follow-up checks on tree damage were not performed in 2017.

Results

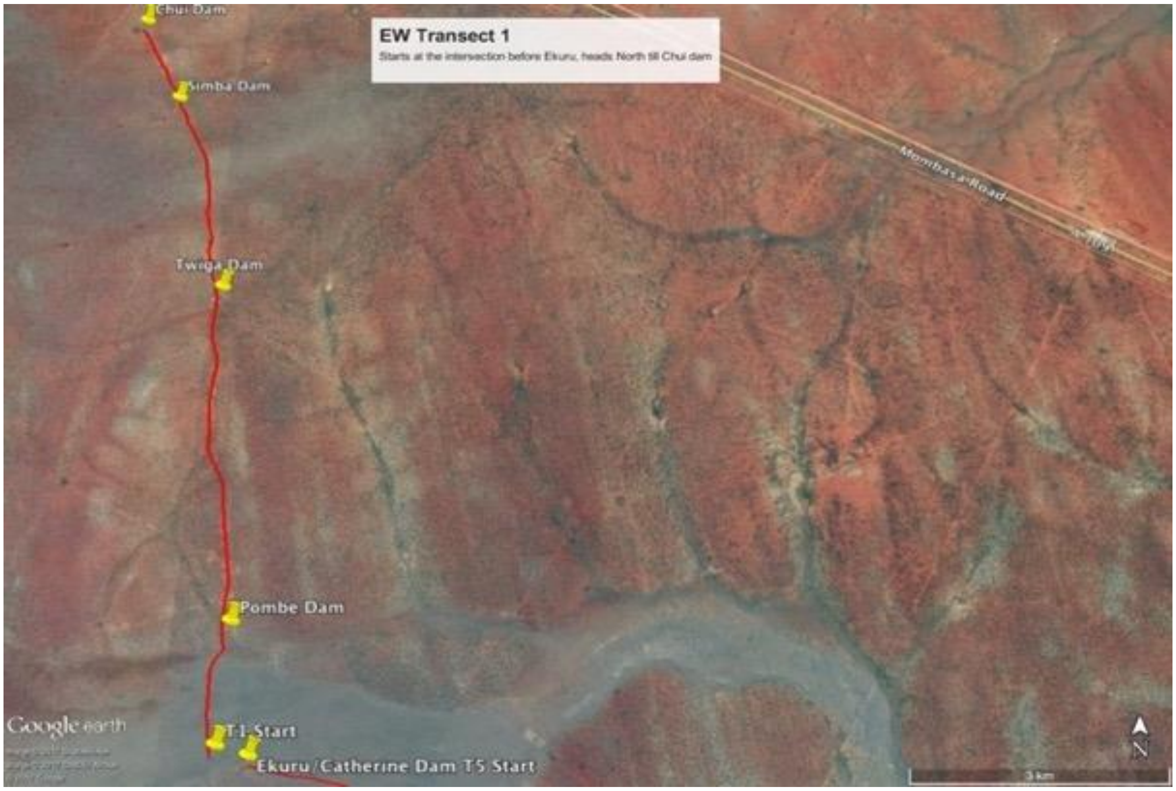
All 240 trees were successfully located and cataloged by the end of 2017. Twenty-eight different species were catalogued (Table A1.4). All damage types were found, and only 33 selected trees had no type of damage (Table A1.5). Bark stripping and branch breaking were the most common types of damage with a variety of impact scores (Table A1.6) and the majority of trees had multiple damage types.

Discussion

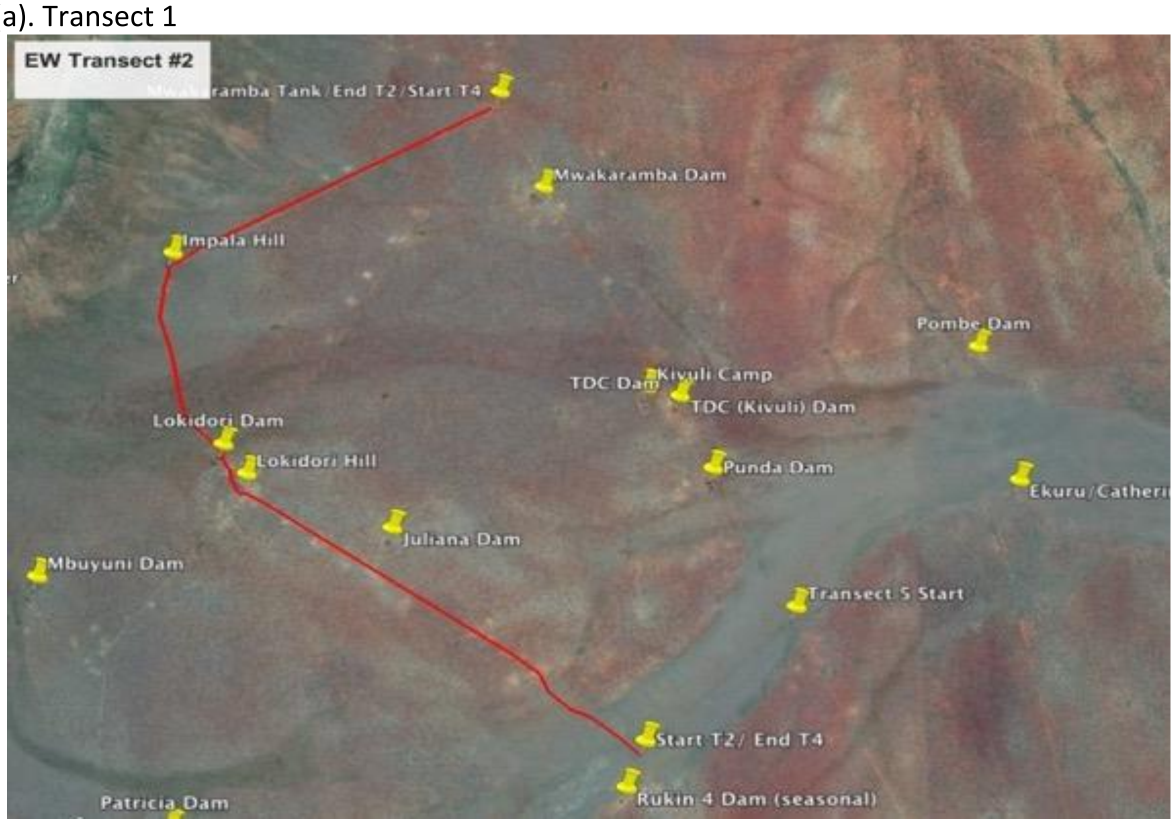
Follow up tree surveys were not able to be performed in the first field season, so no conclusions about the relationship between crop raiding and tree damage (foraging) by elephants could be drawn. However, the foundation for this multi-season survey was successfully established with the location, measurements, tagging, and cataloging of all the trees necessary to conduct this study. The assortment of elephant-favored trees selected within various locations throughout Rukinga Ranch displayed a variety of damage types and the extent of damage ranged from none to over 50%. These conditions should be ideal for ascertaining how damage to trees changes over time, and if there is a correlation between damage to trees and rates of crop raiding.

Appendix I Figures

Figure A1.1 Example of elephant tree damage in Rukinga Ranch, Kenya



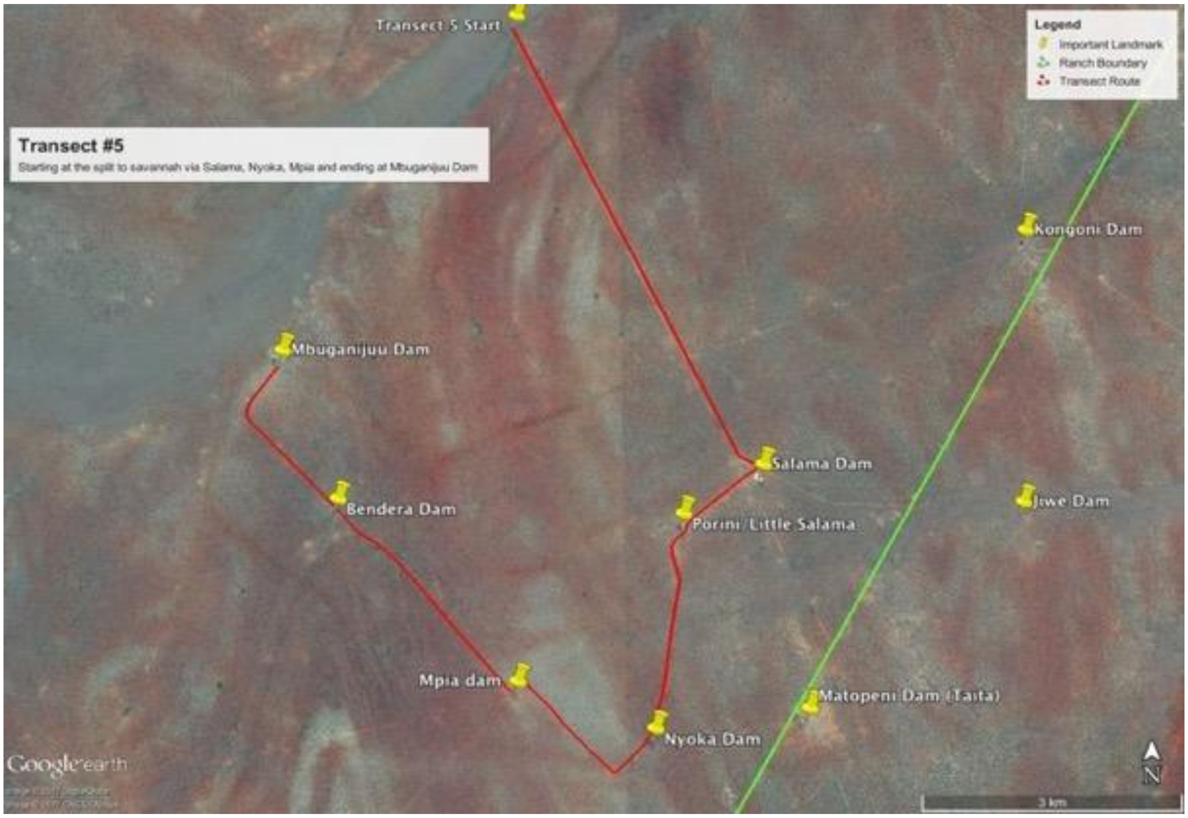
(a). Transect 1



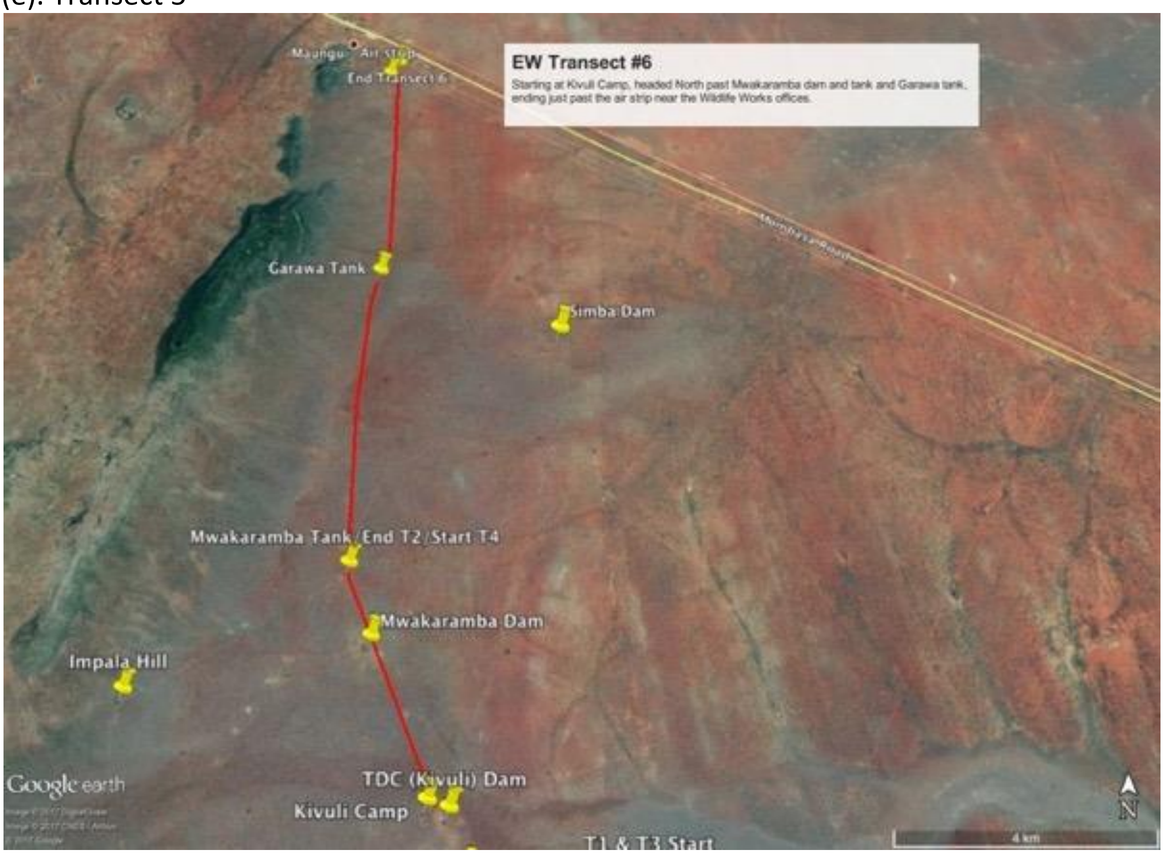
(b). Transect 2

(c). Transect 3

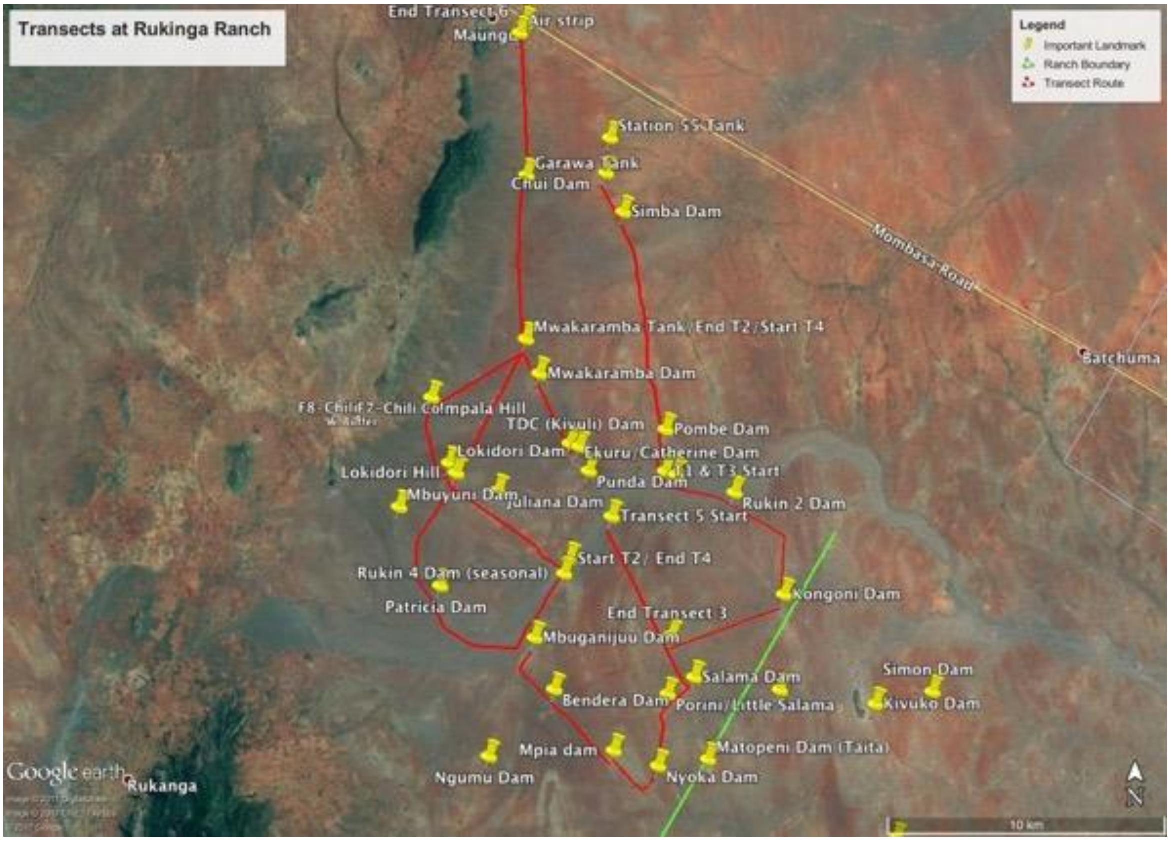
(d). Transect 4



(e). Transect 5



(f). Transect 6



(g). Combined map of all 6 transects

Figure A1.2 The six wildlife and tree transects established at Rukinga Ranch (a-f) with major land features, roads, and water points indicated, and a combined map (g) showing all transects.

Appendix I Tables

Table A1.1 The six wildlife and tree transects with route and length information.

Transect No.	Start	Route	End	Length in km
T1	Cross roads near Ekuru (Catherine)	North via Pombe, Twiga, & Simba dams	Chui Dam	11
T2	Savanna before Rukin 4 dam (seasonal)	Juliana dam, Loki-Dori hill to Impala hill	Mwakaramba Tank	12
T3	Cross roads near Ekuru (Catherine)	Kongoni Dam	Salama road	11.46
T4	Mwakaramba tank	Loki-Dori to Patricia	Savanna before Rukin 4 (start of T2)	16.98
T5	Split towards Salama and Savanna	Salama via Nyoka, and Mpia	Mbuganijuu dam	17.69
T6	Kivuli Camp	Mwakaramba tank	Road before WW office	15.3

Table A1.2: Sampling locations from the six transects established on Rukinga Ranch.

Transect Number	Sampling Location
1	Chui Dam
1	Twiga Dam
1	Pombe Dam
1	Simba Dam
2	Marungu Tank
2	Lokidorri Dam
2	Juliana Dam
2	The Savannah near start of transect 2
3	Ekuru Dam
3	Rukin 4 Seasonal Waterpoint
3	Kongoni Dam
3	Near intersection of Salama Rd.
4	Mwakaramba Tank
4	Patricia Dam
4	Mbuganijuu Dam
4	Mbuyuni Dam
5	Salama Dam
5	Nyoka Dam
5	Mpya Dam
5	Bandera Dam
6	Jojoba Dam
6	Garawa Tank
6	Mwakaramba Dam
6	TDC Dam

Table A1.3. Impact scores for elephant damage to trees for bark stripping and branch breaking.

Score Number	Percentage of Damage
1	0%
2	<1%
3	1%-5%
4	6%-10%
5	11%-25%
6	26%-50%
7	51%-75%
8	76%-90%
9	91%-99%
10	100%

Tree Species	Number Catalogued
Vachellia bussei	11
Vachellia etbaica	2
Vachellia hockii	7
Vachellia nilotica	25
Vachellia robustica	1
Vachellia tortillis	27
Vachellia zanzibarica	5
Albizia anthelmintica	2
Balanites aegyptiaca	1
Boscia coriacea	1
Boswellia neglecta	18
Carissa edulis	1
Cassia abbreviata	16
Combretum apiculatum	1
Combretum exalatum	1
Commifora africana	1
Commifora campestris	2
Commifora confusa	17
Commifora edulis	5
Cordia monoica	1
Cordia sinensis	26
Delonix elata	1
Diospyros mespiliformis	1
Grewia bicolor	5
Grewia mollis	9
Grewia similis	1
Lannea alata	16
Lannea rivae	15
Lannea schweimfurthii	11
Manilkana mochisia	2
Platycelyphium voense	2
Sterculia africana	6

Table A1.4. The 28 types of African tree species identified, tagged, and measured with the quantity of each species sampled totaling 240.

Table A1.5. The types and occurrences of damage found on elephant-favored trees that were catalogued in Rukinga Ranch. BS-bark stripping, BB-branch breaking, MS-main stem breaking, UR-Uprooting, Fell-Uprooting and main stem breakage.

Damage Type	**Number of Occurrences**
1-BS	119
2-BB	192
3-MS	36
4-UR	2
5-Fell	1
6-None	33
Total	**383**

Table A1.6. The percentage of damage to trees with BS & BB in Rukinga Ranch. The majority of trees had multiple damage types.

Impact Scores	**Bark Stripping (BS) Damage Type 1**	**Branch Breaking (BB) BB- Damage Type 2**
0 None	33	33
2 (<1%)	8	15
3 (1-5%)	38	30
4 (6-10%)	32	33
5 (11-25%)	30	65
6 (26-50%)	10	44
7 (51-75%)	1	3
8 (76-90%)	0	1
9 (91-99%)	0	0
10 (100%)	0	0

APPENDIX II: ELEPHANT IDENTIFICATION AND WILDLIFE PRESENCE

Introduction

Elephants are visually identified by size, sex, group composition, and unique ear markings such as vein patterns and rips or tears to the edges of their ears, as well as tusk condition (Kangwana, 1996). These unique characteristics can be photographed or drawn and used to identify specific elephants to which an identification number or name can be applied. Researchers must use caution and update their records often, as these characteristics can change. Using an identification system, a database can be made which catalogs presence or activities of individual elephants or groups. This database can be used to identify individuals from camera traps as crop raiders or sightings while looking for elephants. While most HEC incidents are attributed to males (Graham et al., 2010; Hoare, 1999; Mutinda et al., 2014; Von Gerhardt et al., 2014), some HEC incidents involve female groups as found in the Tsavo ecosystem (Sitati et al., 2003; Smith & Kasiki, 2000; personal observation). Since no current elephant identification was occurring on Rukinga Ranch, it was important to compile a catalog of elephants to identify crop raiders, as well as provide an overall picture of the demographics of the elephant population and their movements.

Elephants are just one component of the biodiversity found in the Kasigau Wildlife Corridor. WW conducts bi-monthly wildlife surveys and monitors species of concern such as Grevy's zebra (*Equus grevyi*) and African vultures (all species), which are endangered. However, it was important to get a more complete picture of the biodiversity found on Rukinga Ranch so that connections between crop raiding and wildlife density could be explored in future years of the project. Driving or walking transects are an important conservation tool used to monitor biodiversity commonly utilized in this area (Williams et al., 2018). To quantify the local biodiversity and catalog elephants in the area, a driving transect system was enacted to create databases that cataloged bull and family groups of elephants recorded the presence of mammals and large birds on Rukinga Ranch (Figure A1.2).

Methods

Elephant sightings were often opportunistic while in transit to other areas of the ranch or the Sasenyi farming community, and a method for quantifying these encounters was established. Specific ventures onto the ranch were also taken periodically to search for elephants, and since elephants commonly came to the waterhole just outside of Kivuli Camp, trumpeting could be heard as a sign of elephant presence. Whenever elephants were sighted, a GPS point was taken along with notes on all members in the group. Each encounter had the time of day, location, number in the group, and sex (if possible) noted, as well as any other identifying markings. Females were also noted as pregnant or nursing if ascertainable. If possible, individual photos were taken of the left and right ear, the full front with ears flared, the left and right sides, the rear including tail, tusks, and any noticeable features such as scars (Figure A2.1) in accordance with guidelines established by Save the Elephants (Henley 2012b). Elephant groups were identified as families-consisting of a matriarchal herd with females and juvenile males, lone bulls, bull groups, or mixed-family groups with temporary attending bulls. Each individual also received an age classification (Table

A2.1), which commonly took place after assessing photographs. Since the composition of bull groups changed frequently, the associates at each sighting were noted. All information was entered into a database and catalogs were maintained for family groups and individual bulls. Family groups were originally listed by date, and only after the group was seen twice were they given individual names to assure that all family members were included and there were adequate physical observations. The first group seen twice had all members with names that began with A, the second group with B and so on. Bull elephants were given a name if sufficient identifying information was present such as at least one ear with markings and tusks, or both ears. Bulls in this area usually travel alone or in small groups, are easier to approach, and tend to remain for longer periods of time. Thus, males were more reliably identified than family groups.

Wildlife survey transects coincided with those established for tree monitoring (Figure A1.2), and six transects were conducted over a two-week period, most often at three times per week. Transects were randomly selected but were not repeated within a two-week period. Each transect began between 16:45 and 17:15 and usually concluded just before dusk. Each transect used a minimum of three people. At the beginning and end of each transect, a waypoint was taken on a Garmin GPSmap 60CSx or Garmin GPSmap 62. Important abiotic data were noted such as temperature, cloud cover, and wind conditions. The driver was responsible for monitoring in front of the vehicle and to the right when possible, while one scribe, who also sat in front, monitored the left side and recorded data on the data sheet, while a third person behind the driver monitored the right side. The vehicle moved at 15 kph or less and when an animal was spotted the vehicle would pull perpendicular to the original position of the animal that was sighted regardless if it had moved. A Simmons 801405 Rangefinder was used to estimate the distance from the vehicle to the animal's original position in meters and recorded. The time, GPS waypoint, species, and number of animals in the group were all noted by the scribe, based off of observations from the team which often necessitated binoculars (Nikon, Monarch M511, 8 X 42, 6.3°). As sex and age are sometimes difficult to determine in the field, the age categories of juvenile, adult, and unknown were applied and the sex was identified as male, female, or unknown. Any special observations were also noted such as pregnancy or injuries. The time and waypoint of the completion of each transect was also recorded and all data were input into an Excel wildlife transect database. Whenever elephants were noted they were also added to the elephant ID information and catalogs, though on transects elephant observations were limited to just enough time to gather the essential data.

Results

At the beginning of the study period (May 2017), elephant observations were limited due to low presence because of drought, though during the harvest of trial one, they were commonly seen on camera traps. However, elephant presence increased steadily after rains commenced in October during trial two. Family groups were very difficult to assess as they were quite skittish, and commonly ran whenever seeing a vehicle. In contrast, males were quite subdued and would allow closer approaches, making age, identification notes, and group composition much simpler. A total of 1375 individual elephant sightings were listed in the database, with 691 sex unknown, 514 males, and 170 females within a range of age categories (Table A2.2), though most ages were indeterminate. This did include repeat elephants and some bulls were seen up to 21 times. Eighty-three separate elephants were added to the bull catalog with the majority being seen on more than one occasion. The family groups provided quite a challenge with identification, and 20 groups were added to the catalog that were partially observed or only seen once, though two full groups (A & B) were catalogued. Images from crop raiding elephants were periodically compared to the catalogs, and eight different bulls were identified as crop raiders with two being repeat offenders. All elephants at Sasenyi while crops were present and that were responsible for active raiding were bulls. Several bulls were also caught on camera that have not been added to the catalog as of yet. Females were seen at Sasenyi before and after harvest, but not while active crop raiding was occurring. During T1 a family group came 750 meters from the experimental area on 7/3/17 but did not enter the farms. After harvest, family groups were noted in the fields on 8/8/, 8/9, 8/23, 8/24, 9/11, & 9/23. In T2, no families were noted before planting, and cameras were removed shortly after harvest due to theft, so none were noted as in the previous trial.

The first wildlife transect commenced on 6/17/17 and the last was recorded on 1/10/18 for a total of 91 completed transects. A total of 3367 individuals were counted of 63 species, with three additional groups that were sometimes only identified by the family but not species: vultures, eagles, and bustards (Table A2.4). The most commonly identified age category was unknown, and males and females were identifiable at about the same rate (Table A2.5).

Discussion

Understanding the demographic populations of wildlife in a conservation area such as Rukinga Ranch is vital for management planning, especially for threatened African elephants. Since elephant family groups were more difficult to identify than bull groups, it may be necessary in this area to devote more time to waiting at areas such as waterholes. Overall, elephant sightings were high, suggesting elephants are taking advantage of this area of refuge, which could make bordering communities more susceptible to crop raiding. Further observations will continue to grow the identification catalog and identifying eight bulls as crop raiders at Sasenyi provides insight into which males are repeat offenders and could lead to developing a “typical” crop raiding elephant profile.

The method for wildlife transects proved to be successful and a wide variety of species were recorded. Certain species could serve as indicators of impending crop raiding if their population numbers shift during fluctuations in the rates of crop raiding. Future years of this ongoing project will compare wildlife densities to temporal fluctuations in elephant crop raiding to determine if there are any correlates. Methods for performing elephant identification and wildlife transects proved efficient and will continue to be used to assess the faunal biodiversity of this area.

Appendix II Figures

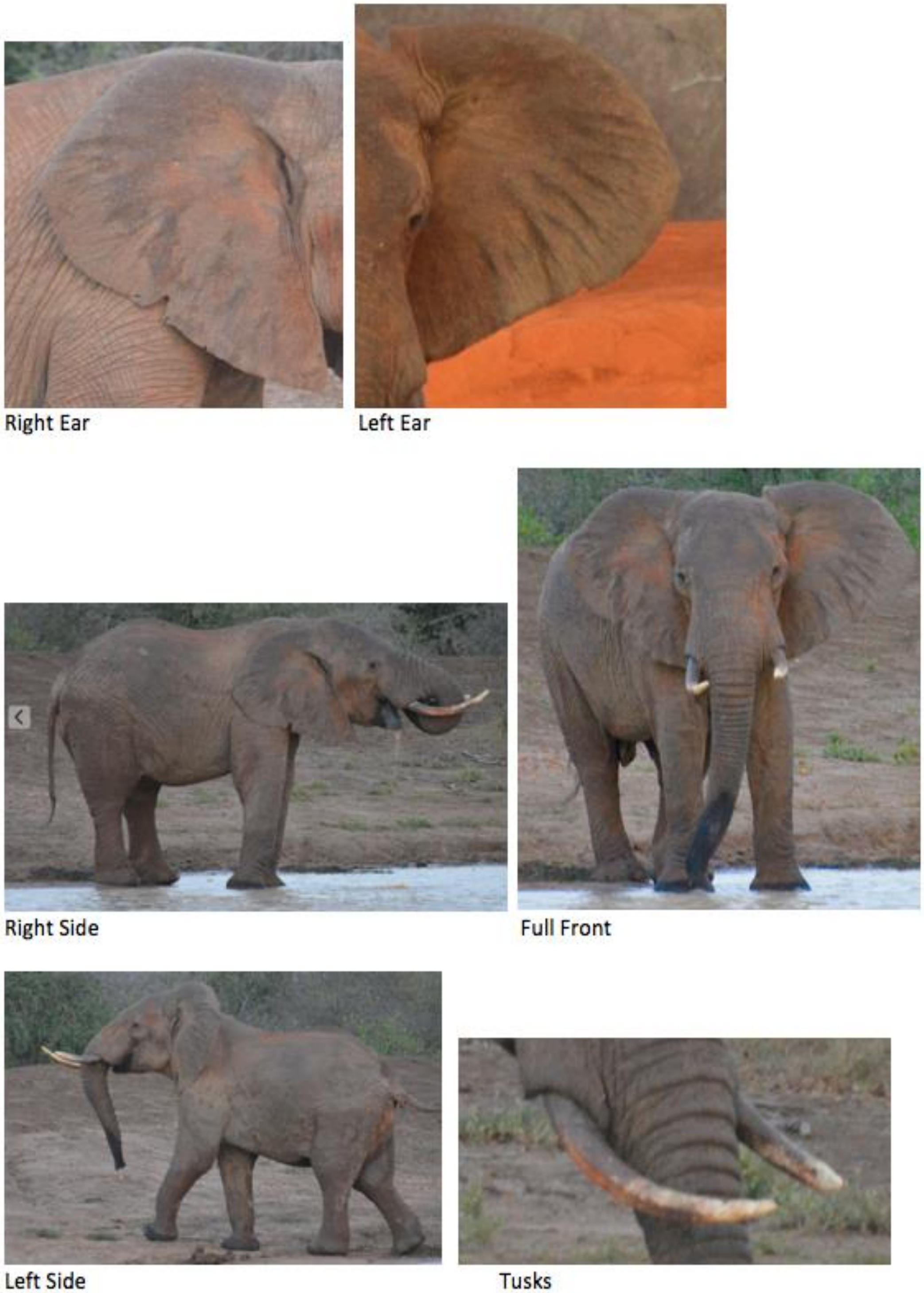


Figure A2.1 Example of the photos that were attempted for each elephant which were entered into a catalog of elephants observed on Rukinga Ranch.

Appendix II Tables

Table A2.1. Age classifications for family groups and bulls in years (Henley, 2012b).

Family Groups:	
< 4	Calf
5-9	Juvenile
10-19	Sub-adult
20+	Adult
55 +	Senescing adult
Bulls:	
< 4	Calf
5-9	Juvenile
10-14	Sub-adult
15-19	Young adult
20-35	Adult
35-55	Prime adult
55 +	Senescing adult

Table A2.2. The number of elephants observed during the study period categorized by sex and age class.

Sex & Class	Number Observed
FEMALES	
Calf	5
Juvenile	11
Sub-adult	22
Adult	131
Senescing	1
MALES	
Calf	25
Juvenile	24
Sub-adult	24
Young adult	30
Adult	279
Prime adult	90
Senescing adult	4
Unknown	40
UNKNOWN	
Adult	59
Calf	95
Juvenile	58
Sub adult	41
Unknown	435
Total	**1375**

Table A2.3. List and quantity of the species totaling 3367 individuals identified on Rukinga Ranch transects.

Common Name	***Scientific Name***	**Count**
Aardwolf	*Proteles cristatus*	4
African elephant	*Loxodonta africana*	238
African hawk eagle	*Hieraaetus spilogaster*	1
African white-backed vulture	*Gyps africanus*	106
Amur falcoln	*Falco amurensis*	1
Banded mongoose	*Mungos mungo*	5
Bateleur eagle	*Terathopius ecaudatus*	11
Black backed jackal	*Canis mesomelas*	5
Black bellied bustard	*Eupodotis melanogaster*	17
Black chested snake eagle	*Ciraetus pectoralis*	2
Black faced vervet monkey	*Cercopithecus aethiopis*	15
Black headed heron	*Ardea melanocephala*	3
Black shouldered kite	*Elanus caeruleus*	1
Brown snake eagle	*Circaetus cinereus*	10
Buff-crested bustard	*Eupodotis gindiana*	26
Bustard, unknown		16
Cape buffalo	*Syncerus caffer*	405
Cape hare	*Lepus capensis*	7
Cheetah	*Acinonyx jubatus*	2
Common zebra	*Equus quagga*	390
Dwarf mongoose	*Helogale undulata*	6
Eagle, unknown		5
Eastern chanting goshawk	*Melierax metabates*	70
Egyptian goose	*Alopochen aegyptiacus*	11
Eland	*Tragelaphus oryx*	92
Gerenuk	*Litocranius walleri*	30
Grant's gazelle	*Gazella granti*	96
Grasshopper buzzard	*Butastur rufipennis*	3
Grevy's zebra	*Equus grevyi*	3
Grey heron	*Ardea cinerea*	1

Hartebeest	*Alcelaphus buselaphus*	40
Hartlaub's bustard	*Eupodotis hartlaubii*	20
Helmeted guinea fowl	*Numia meleagris*	5
Impala	*Aepyceros melampus*	128
Kirk’s dik dik	*Madoqua kirkii*	255
Klipspringer	*Oreotragus oreotragus*	2
Lappet-faced vulture	*Torgos tracheliotus*	5
Lesser Kestral	*Falco naumanni*	3
Lesser Kudu	*Tragelaphus imberbis*	103
Lion	*Panthera leo*	4
Marabou stork	*Leptoptilus crumeniferus*	1
Martial eagle	*Polemaetus bellicosus*	5
Masai giraffe	*Giraffa camelopardalis*	211
Oryx	*Oryx gazella beisa*	187
Ostrich	*Struthio molybdophanes*	56
Pygmy falcon	*Polihierax semtorquatus*	2
Raptor, unknown		9
Rock hyrax	*Heterohyrax brucei*	19
Secretary bird	*Sagittarius serpentarius*	29
Serval	*Felis serval*	2
Slender mongoose	*Herpestes sanguineus*	1
Spotted hyena	*Crocuta crocuta*	2
Striped hyena	*Hyaena hyaena*	1
Tawny eagle	*Aquila rapax*	9
Unstriped ground squirrel	*Xerus rutilus*	11
Verraux's eagle owl	*Bubo lacteus*	5
Vulture, unknown		47
Warthog	*Phacochoerus aethiopicus*	77
Waterbuck	*Kobus ellipsibprymnus*	1
White bellied bustard	*Eupodotis senegalensis*	18
Woolly necked stork	*Ciconia episcopus*	2
Yellow baboon	*Papio cynocephalus*	529
Yellow necked spurfowl	*Francolinus leuoscepus*	1

AM	AF	AU	JM	JF	JU	UM	UF	UU	Total
492	478	1550	25	19	186	0	0	617	**3367**

Table A2.4. The age categories and quantities for all species found for Rukinga Ranch transects. AM=Adult Male, AF=Adult Female, AU=Adult Unknown, JM=Juvenile Male, JF=Juvenile Female, JU=Juvenile Unknown, UM=Unknown Male, UF=Unknown Female, UU=Unknown Unknown

APPENDIX III: DEGRADATION RATES OF CAPSAICIN IN CHILI PEPPER FENCES

Introduction

No studies have analyzed how capsacinoids, the suite of active compounds in chili peppers that produce the “heat” degrade over time when applied to the cloths used in chili pepper fences as utilized in this study. A typical recommendation is to reapply the chili and oil mixture after approximately three weeks or rainfall (Chang a’ et al., 2015). Experiments show that chili fences used in areas of high rainfall or rainy seasons are less effective (Chelliah et al., 2010; Govind & Jayson, 2013), yet no analyses have provided information on how capsaicin levels are affected by overall exposure to the elements (i.e. wind, rain, evaporation from the sun), which could affect the performance of fences used as an elephant deterrent method. This type of knowledge could provide concrete evidence as to the duration of the active ingredients, which could be the key to the success of the fence.

The goal of this experiment was to simulate conditions of chili pepper and oil cloths exposed to the environment in a laboratory, while analyzing the mixture to determine at what rate the capsaicinoids degraded using a Liquid Chromatrgraphy and Mass Spectrometry (LCMS) machine. It is unknown the strength of the capsaicinoids used in these fences and if any potency of the peppers is lost once mixed with the engine oil and over time. I hypothesized that the capsaicinoids in the mixture could be isolated and would have a discernable degradation rate.

Methods

To isolate the capsaicinoid levels of the chilis used in pepper fences once mixed with used engine oil, after being placed on cloths, and over time, it was necessary to create a method for passing such a mixture through a LCMS machine. There is no methodology available for using motor oil mixed with peppers with this type of process, suggesting it has not been attempted before. First, 50 mg of the analytical standard for capsaicin (cap)(Cayman Chemical, Item # 92350), and 5 mg of dihydrocapsaicin (dicap) (Sigma Aldrich, Item # 03813) were acquired as these two compounds represent over 90% of the capsaicinoids in chili peppers (Pena-Alvarez et al., 2009). To make stock standards of these two compounds, dilutions of 450 and 580 (respectively) ppm were obtained after mixing 0.0045 grams of dicap with 10 ml of acetonitrile (ace) and 0.0058 of cap with 10 ml of ace. All glassware used in the experiment were amber colored and were rinsed three times with ace whenever used to eliminate the chance of cross contamination.

To ensure the proper settings for the LCMS machine, test runs were conducted with a 2.1 X 150 mm, C120A OD-5-100/152 column from Standard Method and a guard column which were used throughout the experiment. LCMS sampler vials for the experiment were 2 ml, amber, and were also used throughout the entire experiment. 50 μl each from the cap and dicap stock standards were added into the auto sampler vials along with 450 μl of ace and 450 μl of distilled water to make a 50/50 mixture. This resulted in a 22.5 ppm concentration of dicap, and 27.5 ppm for cap. The pumps for the machine were set at 0.1% formic acid in water for A pump, and LCMS methanol was used as the organic mobile phase for the HPLC in B Pump. Flow rates, times and pump percentages as noted in Table A3.1 were used throughout the experiment. The LCMS was set to full scan, in MSMS mode which only looked for the peaks of interest: the molecular weights of cap (306) and dicap (308). Calibration curves were also performed between different runs at 1:100, 1:200, 1:400, and 1:1,000 dilutions.

To determine if there is a loss in the potency of cap and dicap once mixed with engine oil, it was necessary to get a baseline reading of the strength of the peppers or Scoville Heat Units (SHU). A common formula used by WW on chili pepper fences in Kenya is 2 kg of pepper boiled with 5 L of water and then strained to be mixed with 5 L of engine oil. This 2/5/5 ratio was scaled down and 20.06 g of commercial (Frontier Co-op), birdseye chili peppers (*Capsicum annum*), with a SHU of 130,000 were crushed into a fine powder with a commercial bullet blender. It was then combined with 50 ml of tap water and heated on a Thermo Scientific Cimarec hot plate at 230 °C and allowed to boil for 2 min After cooling, the mixture was strained to remove large pieces. A system was devised to remove all of the small particulates so that the mixture could pass through the LCMS machine by utilizing an Eppendorf 50 ml syringe which had the tip removed and by placing a Whatman grade 43 filter paper inside to push the mixture through and exclude all particles. Once thoroughly strained, 1 ml of chili/water mix was extracted with a Restek 0.22 um PTFE Luer lock inlet 13 mm syringe filter and placed into an LCMS tube and a run was performed with the previously mentioned settings. After verifying the detectability of the cap and dicap, it was necessary to determine if peaks were also discernible once mixed with motor oil. 100 ml of used engine oil mixed with chili peppers was combined with 20 ml of ace and shaken vigorously to homogenize the mixture. It was then added to a 250 ml centrifuge tube, with a counter-balance blank of the same weight. An Allegra 6 centrifuge was set with speed-2.5, timer-15 minutes, and brake-off. To get as much of the cap and dicap out of the mixture as possible, three sequential extractions occurred. After the initial spin, the mixture was separated, and all visible ace was extracted and retained. Next, 20 ml of ace was added again, and the process repeated until three samples were extracted and were processed with visible peaks.

To develop a method for detecting the amount of cap and dicap that remained after being applied to cloths, the aforementioned procedure was performed for mixing the chili with water and then straining. 50 ml of the chili + water was retained and then mixed with 100 ml of used engine oil (obtained from Valvoline Oil Change). Two 100% cotton muslin cloths were cut into 0.18 X 0.18 m squares, and soaked in the mixture and then hung to drip dry for 20 min. The cloths soaked up approximately 25 ml each of the mixture, and after drying were rolled and placed in a 50 ml clear glass centrifuge vial. Ace was added to fill the tubes to the top and then sonicated for 30 min in a Leco UC-100 ultrasonic cleaner to separate the mixture for extraction. Samples were centrifuged using the same settings and after separation, 1 ml was withdrawn from each sample and ran through the LCMS with the same settings showing discernible peaks.

Once all methods were verified as detectible on the LCMS, it was necessary to make a large quantity of chili + oil for the main experiment. 500 ml of tap water was mixed with 200.25 of chili peppers and boiled at 230°C. Boiling was prolonged, so the temperature was increased to 300°C, and a thermometer assured the temperature of the mixture achieved 100°C, which was then allowed to boil for 3 min and then removed to cool. Using the aforementioned procedures, 170 ml of chili infused water was retained and 1 ml of this was extracted for testing. A large sealable plastic tub had 500 ml of engine oil placed inside with the 170 ml of chili water added and shaken vigorously. A laboratory with a fume hood was used and an apparatus consisting of wooden poles with eyelets was constructed to hold two strands of 63" long jute ropes, which would have the soaked cloths attached. Heavy weights were placed on top of the wood pedestals to ensure the weight of the cloths would not cause the jute lines to sag, and the two strands were attached to the eyelets. The position of the eyelets assured that the cloths would not overlap and drip on each other. A plastic shelf liner was placed on the floor of the hood, so the mixture would not cause damage, and aluminum metal pans were placed underneath the jute lines to catch the dripping mixture. Eighteen cloths were trimmed to approximately 0.18 X 0.18 m with a weight of 3.5 g each. All cloths were placed inside the tub and mixed with a wooden spoon to assure they were coated equally and the tub was capped and shaken. The mixture and cloths were dumped into a pan and each cloth was hung in a progressive manner with the lower row first from left to right for a total of 9 cloths, and then the second row from left to right for the remaining 9 cloths (Figure A3.1). Each cloth was given a sample number based on the day of the experiment which it would be removed and which of the three replicates it was. Black office binder clips were used to secure the cloths, and each was spaced in a manner in which it did not overlap with the adjacent cloth, touch the dowel rods, or drip on the cloths underneath. This assisted with each cloth retaining a similar amount of liquid mixture.

The hood vent was placed on to accelerate the initial dripping of the cloths and this was the only time it was used. After the first set of cloths were no longer dripping, each was removed in sequence and weighed using a 30 g Pesola scale. To ensure consistency, each day the cloths were removed at 4:30 PM and weighed and placed in a clear glass 50 ml capped centrifuge tube. Weights were recorded with ace added to the top the tube on the day after removal. The first cloths (day 0) were removed on the initial day of the experiment and the bottom row was rearranged so that spacing was more efficient. Cloth #10 from the second row was moved down to prevent crowding, leaving C-4 thru C-10 on the bottom row and C-11 thru C-18 on the top row. The remainder of the oil/pepper mix was retained for further testing. Since no access to the lab was available on the weekends, days 4 and 5 were not be able to be tested.

For processing of the cloth samples, ace was added to equal the weight of the centrifuge blank, and each sample was sonicated, centrifuged, and extracted using the aforementioned procedures and processed in the LCMS machine. The remaining chili + oil mixture was also sampled (without cloths) to determine if any of the cap and dicap were lost when the mixture was placed on the cloths. To perform accurate calculations since the amount of oil on the cloths varied, we took a weight of one ml of the chili + oil mixture which was 0.74 g to be used in calculations.

To determine the most effective recipe for creating chili pepper fences, the recipe from Chang a' 's successful project in Tanzania (2016) was also tested. This recipe excludes the boiling of chilis in water and consists of approximately 2.5 kg of crushed peppers mixed with 10 L of used engine oil. The recipe was scaled appropriately for testing in the lab, all procedures remained the same, and three samples were extracted.

Results

The initial test of the two cloths for cap and dicap extraction resulted in retention times of 5.565 and 7.962 ppm of cap and 0.0861 and 1.639 ppm of dicap, demonstrating that the second cloth had retained more of the mixture which would need to be accounted for in all future calculations. Obtaining viable results from all LCMS runs demonstrated that the method applied for the experiment was appropriate to be able to detect cap and dicap concentrations.

The mock chili fence cloths showed a general increase in the difference in grams from the weight of the cloth from the onset of the experiment to the end, suggesting that the mixture on the cloths either continued to drip or evaporate more over time (Table A3.2). All samples processed in the experiment for cap and dicap had LCMS results as shown in Tables A3.3 and A3.4, and each phase of the tests of this portion of the project produced results.

Discussion

A successful method for extracting quantifiable cap and dicap levels from motor oil mixtures commonly used on chili pepper fences was established for the first time with this project and has laid the foundation for future LCMS studies to determine the potency of chili fences as an elephant deterrent. However, complex calculations in the laboratory will be necessary to interpret the results from the different components of this experiment and will be a part of future analysis once the field portion of the overall project is completed.

Appendix III Figures

Figure A3.1. Laboratory experiment simulating a chili pepper fence used to deter elephants to detect capsaicinoid levels.

Appendix III Tables

Table A3.1 Final pump setting for the chili and oil testing in LCMS experiment.

Time (min:sec)	% Pump A	% Pump B	Flow (µl/min)
0:00	80	20	200
2:00	80	20	200
2:30	30	60	200
12:30	30	60	200
13:00	80	20	200
16:00	80	20	200

Table A3.2. Experimental cloths infused with chili pepper and oil mixture with the day of the experiment (D0, D1, etc.), cloth number, and measured weights.

Cloth ID Number	Starting weight in grams	Initial post-drip weight in grams	Weight when removed in grams	Difference in grams
D0-C1	3.5	12	12	0
D0-C2	3.5	12.5	12.5	0
D0-C3	3.5	12.5	12.5	0
D1-C4	3.5	13.5	10.25	3.25
D1-C5	3.5	13.5	10	3.5
D1-C6	3.5	13.2	10.5	2.7
D2-C7	3.5	12.8	9.5	3.3
D2-C8	3.5	13	9.5	3.5
D2-C9	3.5	12.5	9.3	3.2
D3-C10	3.5	12	8.75	3.25
D3-C11	3.5	12.5	9	3.5
D3-C12	3.5	12.5	9.25	3.25
D4-C13	3.5	13.2	9.5	3.7
D4-C14	3.5	13.4	9.5	3.9
D4-C15	3.5	13	9.4	3.6
D7-C16	3.5	14	9.6	4.4
D7-C17	3.5	13.2	9.5	3.7
D7-C18	3.5	13	8.75	4.25

Table A3.3. LCMS results from capsaicin.

Capsaicin Sample	Amount µg/ml	Volume of ace	µg of component	Grams of oil loaded onto the cloth	µg of component/ gram of oil
Chili + Water	0.351	N/A	N/A	N/A	N/A
Chili +Oil R1	15.88	34	539.92	N/A	N/A
Chili + Oil R2	15.57	34	529.38	N/A	N/A
Chili + Oil R3	13.66	34	464.44	N/A	N/A
Chang 1	32.25	36	1161.00	N/A	N/A
Chang 2	31.63	36.25	1146.59	N/A	N/A
Chang 3	29.75	36.1	1073.98	N/A	N/A
D0-C1	12.02	35	420.70	8.5	49.49
D0-C2	8.952	33.8	302.58	9	33.62
D0-C3	11.01	34.2	376.54	9	41.84
D1-C4	10.88	39	424.32	10	42.43
D1-C5	11.87	38	451.06	10	45.11
D1-C6	10.53	37	389.61	9.7	40.17
D2-C7	12.09	40	483.60	9.3	52.00
D2-C8	10.23	38	388.74	9.5	40.92
D2-C9	11.62	38	441.56	9	49.06
D3-C10	9.423	40	376.92	8.5	44.34
D3-C11	11.05	38.5	425.43	9	47.27
D3-C12	11.03	38.5	424.66	9	47.18
D4-C13	14.15	38.5	544.78	9.7	56.16
D4-C14	13.78	38	523.64	9.9	52.89
D4-C15	14.28	38.5	549.78	9.5	57.87
D7-C16	12.63	38.5	486.26	10.5	46.31
D7-C17	12.00	39	468.00	9.7	48.25
D7-C18	11.62	39.5	458.99	9.5	48.31

Table A3.4. LCMS results from dihydrocapsaicin.

Dihydrocapsaicin Sample	Amount μg/ml	Volume of Ace	μg of component	grams of oil loaded onto the cloth	μg of component/ gram of oil
Chili + Water	0.27	N/A	N/A	N/A	N/A
Chili +Oil R1	5.84	34	198.56	N/A	N/A
Chili + Oil R2	5.99	34	203.56	N/A	N/A
Chili + Oil R3	5.28	34	179.45	N/A	N/A
Chang 1	8.39	36	301.93	N/A	N/A
Chang 2	8.69	36.25	315.09	N/A	N/A
Chang 3	12.92	36.1	466.41	N/A	N/A
D0-C1	4.63	35	162.12	8.5	19.07
D0-C2	2.87	33.8	96.90	9	10.77
D0-C3	3.85	34.2	131.67	9	14.63
D1-C4	4.21	39	164.31	10	16.43
D1-C5	4.85	38	184.19	10	18.42
D1-C6	4.39	37	162.50	9.7	16.75
D2-C7	5.05	40	202.00	9.3	9.30
D2-C8	4.07	38	154.47	9.5	16.26
D2-C9	4.35	38	165.19	9	18.35
D3-C10	3.24	40	129.56	8.5	15.24
D3-C11	3.73	38.5	143.64	9	15.96
D3-C12	4.20	38.5	161.78	9	17.98
D4-C13	4.28	38.5	164.90	9.7	17.00
D4-C14	5.03	38	191.14	9.9	19.31
D4-C15	4.62	38.5	177.99	9.5	18.74
D7-C16	3.78	38.5	145.45	10.5	13.85
D7-C17	3.59	39	140.17	9.7	14.45
D7-C18	3.33	39.5	131.69	9.5	13.86