International Elephant Foundation Final Report 2021

Elephant deterrent effectiveness in light of ecological and agricultural variation

Principal Investigators

PI: Bruce A. Schulte, Western Kentucky University (WKU)

Contact: bruce.schulte@wku.edu

Co-PI: Mwangi Githiru, Wildlife Works (WW)

Co-PI: Urbanus N. Mutwiwa, Jomo Kenyatta University of Agriculture and Technology

Co-Investigators: Sophia Corde, MSc candidate, WKU

Dakota Vaccaro, MSc candidate, WKU

Simon Kasaine and Bernard Amakobe, WW

R. Lynn Von Hagen, Ph.D. Candidate, Auburn University (AU)

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2. Conservation Needs and Progress of Project in 2021

Our study is set in the Kasigau Wildlife Corridor (KWC) located between Tsavo East and Tsavo West National Parks and includes 14 Group Ranches covering ca. 2000 km^2 (Figure 1). The ranches are conserved under a REDD++ (Reduce Emissions from Deforestation and forest Degradation) scheme that provides financial incentives by tapping into the carbon market to protect forests, a process by which Wildlife Works provides benefits to the community. Most of the biological aspects of the IEF funded study occur within or adjacent to the Rukinga Ranch Wildlife Sanctuary (RRWS) (30,000 ha).

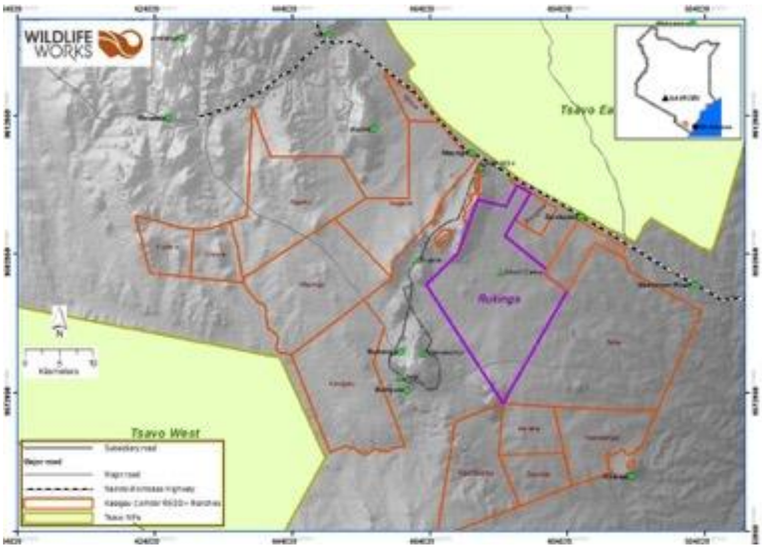

Figure 1. Map of project site showing Rukinga Ranch and the remainder of the KWC ranches in the REDD++ Project. Kivuli Camp is the project's main base.

The elephant's natural habitat continues to be encroached upon by human settlements and agricultural developments. The increased overlap of human and elephant habitat results in negative encounters between the two species, leading to issues of human elephant conflict and a challenge for coexistence. This conflict was exacerbated over 2021 due to an extreme 7-month drought that led to a complete failure of crops during the April-July growing season, and scarce natural food sources for the elephants until Mid-December. Elephants entered farmlands with high frequency in search of crops and shade but turned back after being chased or the lack of food caused by the drought. To aid in resolving this growing conflict, the major conservation needs on which this project continues to focus are as follows:

1. **Crop Raiding.** Crop raiding is a major issue in farming communities where families rely heavily if not solely on their crops for economic and food security. Farmers can lose their entire harvest in a single crop raiding event, and will occasionally retaliate, putting both themselves and the elephants in danger. The KWC region is home to approximately 100,000 people with 15,000 elephants in the Greater Tsavo Ecosystem. The subset of this population in the Kasigau Corridor REDD+ Project area is about 2000 with some 300-500 resident around Rukinga. The resource overlap between humans and elephants results in negative encounters with wildlife, especially elephants (e.g., from 1995-2017, 24,032 human-elephant conflicts were reported, comprising 61.6% of all human-wildlife conflicts in the region). A high conservation priority for our project is to identify sustainable and affordable means for preventing elephants crop raiding events from occurring. We have continued our focus on experimental examination of deterrents and have tested two new deterrent combinations this year, as well as continued testing of previous deterrents.
2. **Associated Practices of Early Warning and Elephant Identification.** Research from this project is laying the scientific foundation for an early warning system in part by collecting elephant population demographics, elephant caused tree damage, and species diversity trends. Giving farmers time to prepare for potential crop raiding events can prevent damage to crops and

structures and protect people and elephants from harm. Understanding which elephants are causing problems can be useful for designing deterrents as well as informing people of behaviors to avoid personal conflicts. An expansion to this aspect of the project requires additional funding. We submitted a proposal to the US Fish and Wildlife African Conservation Fund this past round to this end, but our proposal was not funded. We will continue to seek out sources to support this avenue.

3. **Environmental Variables.** The abiotic factors of moon phase (coupled with cloud cover) and precipitation (i.e., dry and wet seasons) are known to affect the behavior of elephants and other wildlife. By tracking these variables, we are evaluating whether crop raiding in our region is correlated with moon phase or seasonality. This knowledge can be used to improve the readiness of farmers for potential elephant incursions.
4. **Crop and Wild Habitat Quality.** The Food and Agriculture Organization (FAO) of the United Nations defines climate-smart agriculture (CSA) as "an approach that helps to guide actions needed to transform and reorient agricultural systems to effectively support development and ensure food security in a changing climate." Food security is achieved by increasing productivity (e.g., retain nutrients in soil), building resilience to climate change (e.g., enhance water storage and use efficiencies), and reducing greenhouse emissions (e.g., reduce charcoal production and burning). As seen in the KWC in 2021, drought has a massive effect on the food security of the local subsistence farmers in the area, as none of the experimental plots yielded a harvest during the April-July 2021 growing season. This drought had an extreme effect on the elephants this season as well, leading to extensive damage done to canopy trees. This damage can influence the presence of large birds and mammal species in the area. The damage done to these trees such as extensive branch breaking, bark stripping, and uprooting, resulted in heavy tree mortality this season. These trees serve as habitat for many species living in the KWC, contributing to the biodiversity of the area. However, in areas like the KWC where the elephant's natural habitat has been fragmented by human presence, higher tree mortality by elephants can lead to lower biodiversity. Through promoting CSA techniques, the tracking of tree damage, and the assessment of large bird and mammal occurrence, we can further our understanding on the balance between crop and natural productivity, particularly during these extreme weather scenarios. Using a biological cost-benefit approach, we want to determine conditions when crop raiding is likely to be prevalent.
5. **Community Outreach.** Elephant conservation will only be achieved in a long-term, sustainable fashion if the people who share the same habitat are advocates for elephant survival. Due to COVID-19, we have not been able to have as direct of an interaction with the local families through visits to the local primary school. However, to maintain the push for advocacy we have continued to have a solid presence in the community through the continued implementation and testing of deterrent fences, communication and understanding of concerns of local farmers through long distanced communication, and the creation of a solid relationship between the local people and the Wildlife Works park rangers to help facilitate a harmonious relationship with their habitat and the animals that live within it. Advocacy will not occur if elephants remove food (and water) security, thus we have continued to work to improve the reliability of lunches and clean water to school children as they are the future farmers and conservation-minded citizens. The need is to remove the perception that humans require exclusive access to resources to survive. We cannot overemphasize the importance of

the Kenyan team members, Wildlife Work employees connected to the project, and the local farmers, other village members, and the chiefs in facilitating all aspects of this project and especially the outreach components.

3. Goals and Objectives of Project in 2021

(1) Continued testing of existing deterrent fences

a. Deterrent Fences in Main Experimental Blocks. For the past four years **we have established and used actual farmers' fields in the Sasenyi community to conduct controlled experiments on deterrent fences.** We have four sets of matched experimental and control fields in the configuration shown in Figure 2. In 2021, we tested new combinations of fences (see section 4). Due to the drought, no crops grew in the experimental fields during trial 8 and lead to minimal data collected on these new configurations. Trial 9 is ongoing with harvest expected during February; however, some plots also failed in 2021-22 because of the late arrival of rain (December 2021).

Figure 2. An example trial block with crop land in the upper left half and wild space (Rukinga) in the lower right half with a dirt road between the wild space and the fences (field 8 to right).

b. Beehive Fences. In addition to the main experimental blocks, we have four sets of beehive fences with matching empty hive controls along the same road. At two of these blocks, we made the addition of a barrier metal strip fence along the road. During 2021 we continued testing these fences to increase our sample size and investigate practices that encourage honey harvest. Though, due to the drought, sample sizes were incredibly small for trial 8, and the dry weather negatively affects hive survival.

***(2)* Associated practices to deterrent fences**

a. Elephant Database. We are determining **to what extent crop raiding occurs in our area by the same or different elephants** by establishing an identification database.

b. *School Visits*. Due to COVID-19, our US team was not able to make any **visits to the local primary school** as we have in the past with EarthWatch volunteers to assist with educational information on elephants and conservation. However, members of our Kenyan based team did visit the school when it was safe to do so and otherwise stayed in contact with the administrators, teachers, and students. In addition, former volunteers have continued to contribute funds to supply food to the school throughout 2021 and into 2022. However, due to the pandemic, many are not able to make as large of a financial contribution to the school as in previous years. This has led to us not having enough funds this coming academic season to supply the school children with lunches. We are doing our best currently to promote a fundraiser to try and obtain funds to continue this program.

(3) Crop and Wild Habitat Quality

a. *Climate Smart Agriculture*. Our soil sampling from 2018 by Dr. Urbanus Mutwiwa revealed **poor soil nutrients, which can reduce overall crop success**. As part of a renewed focus on the drivers of HEC, the team constructed a test plot with climate smart agricultural (CSA) practices using micro water catchments, zai pits (an agricultural technique that involves digging down to the topsoil and adding manure to improve soil quality), and drought and/or elephant resistance crops accompanied by a control plot. We have conducted CSA plots over four trials with clear results of the success of treated plots versus controls. The CSA plots were maintained in 2021, but because of the pandemic and related fewer personnel to facilitate expansion, additional plots were not initiated. We hope to do so in 2022 if we can secure sufficient funding.

b. *Tree Damage*. We are **determining damage caused by elephants to tree species** in the study area. We are using this information to assess the timing and degree of damage relative to crop raiding. We are testing the hypothesis that escalating tree damage could be used as an indicator of impending crop raiding. An alternative hypothesis is that higher tree damage reflects the preference for browse over crops by elephants (especially considering the higher costs of raiding when crops are protected). Due to the COVID-19 pandemic, we were not able to collect tree damage data in 2020. This data collection was restarted in 2021 and is planned to continue in 2022. Due to the drought this year, extensive tree damage was recorded including a remarkably high mortality rate. In coming years, we plan to add new trees to the database. We also will be examining the relationship between tree damage and surveys of large birds and mammals (see next).

c. *Mammal & Bird Diversity Surveys.* Using **surveys of mammals and higher trophic level birds** (primarily raptors) we are assessing biodiversity of the study region. We are testing the hypothesis that one or more of these species could serve as indicators of elephant presence and degree of activity, such as impending crop raiding. Thus, such species could provide a biotic early warning system. In addition, we will be exploring how the transect data could inform us on climate change and elephant activity impacts.

(4) Community Outreach

a. *Village Surveys and HEC Mitigation*. A **community outreach program is part of the PhD thesis of Lynn Von Hagen**. Please see the 2021 final report by Von Hagen for updated information.

b. *HEC Mitigation.* The results of the survey combined with GIS information will be used to plan the **placement of appropriate mitigation measures** for each of the six villages involved in the surveys (See Von Hagen IEF final report).

c. *US Fish and Wildlife African Elephant Fund.* This aspect of our project was a major thrust for our 2021 proposal (not funded). We will **inquire if IEF is interested in a collaborative proposal next round** bringing in more regional partners with IEF's assistance.

4. Specific Actions Taken to Achieve Objectives in 2021

(1) Continued testing of existing deterrent fences

a. *Main Experimental Blocks***.** With US travel restrictions lifted and our team fully vaccinated, we arrived in Kenya at the end of May 2021. We were able to erect two new deterrents during the April-July growing season. However, due to the drought, these fence types did not obtain a large enough sample size to fully be tested. During this period, it was also found that these new combinations proved to be harder to maintain than originally hypothesized, and thus were removed for the next growing season (December 2021 – February 2022). As part of her MSc project, Ms. Sophia Corde was in Kenya monitoring the crop fields and surrounding deterrents and has continued analyzing data from all trials.

Table 1. Experimental (e) deterrent fences tested over trials 1-9 from 2017-2021. Each fence was paired with a matching control (see Table 2, corresponding number with letter "c"). Eight fields (four experimental, four control) were present in each of the four blocks. See Table 2 for key to Fence Type. Table 1 is organized chronologically. Table 2 is organized to align with the x-axis of Figures.

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

[1]The overall experimental control of no fence (only fence posts) was used for this second metal strip fence once the acacia fence was no longer erected. [The 'no fence control' was the matched control for the acacia fence in the early trials.] [2]Beehive fences were erected in plots separate from the four blocks of eight fields each. [3]The overall experimental control of no fence (only fence posts) was used as the control for this second double metal strip fence once the second single metal strip fence was no longer erected. [4]The metal strip fence was used as the control for the double metal strip fence.

Table 2. Legend of abbreviated deterrent types. Order aligns with x-axis of Figures.

Abbreviation	Deterrent Type + Explanation
8e) Active Bee	Active Beehive fence. A single wire holding a yellow painted wooden box beehive strung between fence posts.
8c) Control Bee	Control Beehive fence. A single wire holding up a yellow painted wooden block strung between fence posts.
1e) Metal Strip (MS)	Metal fence. A single wire with hanging strips strung between fence posts.
3c) Acacia Co 1c) Grand Co	Metal No Control fence. Fence posts, with no wire between them. Used as control when MS erected in two fields per block.
1c) MS Co	Metal Control fence. A single wire strung between fence posts.
6e) False Color C+MS	False color Chili + Metal fence. A single wire and a rope strung between fence posts with colored cloths and metal strips.
6c) False Color C+MS CO	False color Chili + Metal Strip fence control. A single wire and a rope strung between fence posts with a plain cloth.
5e) False C+MS	False Chili + Metal fence. A single wire with hanging metal strips and rope with hanging cloths strung between posts.
5c) False C+MS Co	False Chili + Metal Control fence. A single wire and a rope strung between fence posts.
7e) DBL MS	Double Metal Strip fence. Two wires with hanging metal strips strung between fence posts.
7c) DBL MS CO	Double Metal Control fence. Two wires strung between posts.
3e) Acacia	Acacia. A border of acacia placed around the field.
2c) Chili Co	Chili Control Fence. A rope strung between fence posts.
2e) Chili	Chili Fence. A rope strung between fence posts with cloths dipped in motor oil and ground chili peppers.
4e) Chili +MS	Chili + metal fence. A single wire and a rope strung between fence posts with cloths dipped in chili oil and metal strips
4c) Chili +MS Co	Chili + metal fence control. A single wire and a rope strung between fence posts with plain cloths and no metal strips.
9e) Cloth	Cloth fence. A rope strung between fence posts with a colored cloth. Only tested in trial 8 and was removed for trial 9.
10e) Active Bee + MS	Active beehive fence + metal strips. A single wire holding a yellow painted wooden box beehive strung between fence posts. In front is a MS fence along the road separated to avoid disturbing the bees.
11e) DBL MS + Cloth	Double metal strip + cloth fence. Two wires and a single rope strung between fence posts with colored cloths and metal strips. Only tested in trial 8 and was removed for trial 9.

b. *Beehive Fences.* Due to the drought, beehive occupancy was low during the early 2021 season. Farmers have not received a harvest of honey since the start of using beehive fences. We are continuing to conduct cleaning and other practices to encourage honey yields. New water containment structures, designed by one of our community farmers, Chimanga, have been placed at each beehive (Figure 3). This has greatly improved the amount of clean accessible water for the bees; however, due to the drought, there were no flowers in the study area during most of this season, leading to low hive occupancy. We are hoping for a stronger season next year with continued use of the modified water containment structures and hopefully more rain.

Figure 3. New water containment structure designed by local farmer, Chimanga, for the beehive fences.

a. *Aeolian Harp Design*. Ms. Corde tested the efficacy of the use of Aeolian harps and variations of the design across trees during her time at Kivuli camp. The Aeolian harp is a musical string instrument that is played through wind driven vibration of strings (Figure 4). This vibration is then amplified through a larger body. For our purposes, the harps were activated by wires that vibrate hanging sticks when pushed against by elephants, causing a drumming sound like that of drums used by local people to scare off elephants. Due to the drought, we were not able to test this innovative design during 2021, but plan to implement it during 2022 growing seasons.

Figure 4. An example of an Aeolian harp built by Ms. Corde using 40 lb. test fishing line, and a recycled water bottle. *{NOTE: photograph is proprietary; please do not distribute or otherwise share publicly}.*

(2) Associated practices to deterrent fences

a. *Early Warning System.* We have made new connections with Arribada and ZSL Whipsnade Zoo to field test their Human-Elephant Alert Technologies (HEAT) thermal cameras as part of our early warning alert system. Field tests require additional funding (and our 2022 IEF proposal was not funded).

b. *Elephant Database.* We have created an elephant identification database using photos taken in elephant encounters on the ranch and camera trap images to identify elephants. This is the first time that elephants have been catalogued in the KWC and our catalog continues to grow. Age class, sex, and identification are determined through analysis of photographs taken by researchers and volunteers. Age and age class are determined by comparing the height of the individual in question to that of the average height of an elephant of the same sex in that age and age class. The decision of age and age class of an individual typically follows the guidelines of a calf 0-4 years old, juveniles 5-9 years, young adults 10-14 years, subadults 15-19 years, and adults ≥ 20 years. The identification of the individual is determined based on physical characteristics such as scars, tusk shape and markings, and variety in the ears.

(3) Environmental Variables

As a part of her MSc thesis, Ms. Sophia Corde has been examining the relationship between the trends of abiotic environmental factors of moon phase and season in the KWC and has been testing for correlations between these with elephant crop raiding events. This, along with biotic environmental factors that will be analyzed by new graduate student Ms. Dakota Vaccaro, will be compounded together to aid in the creation of an ecological crop raiding prediction system. This system will help farmers better predict when crop raiding events are more likely to occur.

a. *Moon Phase.* Other studies have shown that elephants tend to crop raid more frequently during the new moon when there is less light. Using a lunar calendar, moon phase was determined for every day of each year over the study period. Crop raiding incidents in the form of approaches and breaches to crop fields were compared by moon phase to test whether the correlation between the new moon and higher crop raiding events is present in the KWC as well.

b. *Dry and Wet Seasons.* In other studies, crop raiding events were highest in the transition phase between the wet and dry seasons. Rainfall data were obtained from "aWhere" for the village of Sasenyi from 2017 - 2021. The daily rainfall was used to create data bins to delineate dry and wet seasons. Crop raiding incidents in the form of approaches and breaches of crop fields were compared by season to test whether the correlation between the transition phase of the wet and dry seasons and higher crop raiding events is present in the KWC.

(4) Crop and Wild Habitat Quality

a. *Climate Smart Agriculture.* Test plots in Zai pits in the Sasenyi farms have continued to be constructed and planted. Zai pits are an agricultural technique that involves digging down to the topsoil and adding manure to improve soil quality (Figure 5).

Figure 5. Zai pit construction and successfully planted pits that help to retain nutrients and water.

b. *Tree Damage.* All 240 elephant-favored trees were located and tagged in the first year of the project and have been rechecked in the second, third, and fifth years (2018, 2019, and 2021). The rechecks of each tree were to assess how elephant damage (bark stripping, branch breaking, uprooting) has changed since the inception of the monitoring. Because of the pandemic, we were unable to re-check the trees in 2020.

c. *Wildlife Surveys.* Because of the pandemic, we were unable to conduct wildlife surveys in 2020 or early 2021. We were able to restart these at the beginning of June 2021. Briefly, at least one observer accompanied by a driver collected these data. At the start of each transect, the time of day, the date, the GPS location, the temperature, the cloud cover, and the wind condition/direction were recorded. The car drove along one of six designated transect routes, and observers looked out of their respective sides of the car. When a mammal or large bird was spotted, the driver stopped the car and the time of the sighting, the GPS location, the species, the number of individuals spotted, the age/sex when possible, and the distance of the group or individual from the road were recorded. At the end of each transect, the end time, the GPS location, and the duration of the transect were recorded.

(5) Community Outreach

a. *School Visits*. Because of the pandemic, no school visits were possible in 2020 or 2021.

b. *School Providing Program*. We established a fund to help feed school children and provide school supplies to assist in improving the relationship between the local community and scientists/conservation managers. The school often runs out of water during the drought season, as water douser trucks cannot make it up the badly eroded road, and so the storage tanks at the school dry up. Donations by the volunteers facilitated the connection of the school's storage tanks to the municipal water system to provide water year-round.

c. *Village Surveys & Workshops.* See Von Hagen et al. 2021 complimentary final report to IEF.

5. Modifications of Actions

The COVID-19 pandemic modified our plans for 2021. Ms. Sophia Corde and Lynn Von Hagen originally planned to travel to the study site in March 2021. This was delayed due to the pandemic until the end of May 2021. Because of this, camera traps were only able to be up in the experimental fields for the last half of the crop raiding season. Wildlife transects were also only collected during the last half of the crop raiding season. Due to the drought, many crops failed and no farmers in experimental plots were able to harvest. The failed crops led to low elephant traffic during this trial and thus we had low sample sizes for the deterrents being tested.

6. Conservation Outcomes to Date

(1) Crop Raiding: Testing of existing deterrent fences (Main and Beehive Plots)

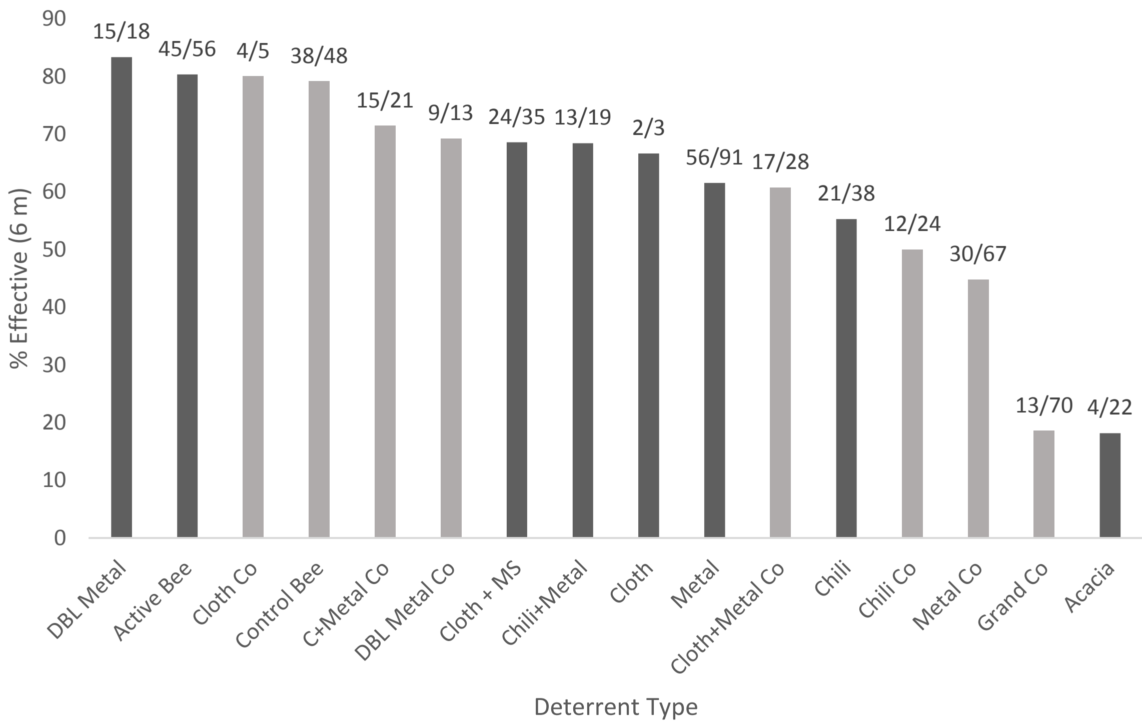

Figure 6. Percent effectiveness (deter/approach) for each deterrent where approach is within 6 m and deter is not crossing fence line into crop field. Dark bars represent experimental fences while shaded ones are control fences. The acacia is a traditional barrier of branches laid on the ground. ***{Proprietary and not yet unpublished, so please do not share publicly}***

The most effective fences at deterring elephants that have approaches within 6m were the double metal strip fence and the active beehive fence (Figure 6). We use 6 m as our approach distance, as these are in line with our field and alley sizes. During the growing seasons of 2020, we were not able to deploy our camera traps, and thus we were solely relying on written reports by our partners in the villages. For the first growing season of 2021, crop failure was quite high due to drought. Elephant presence around our experimental plots were low, so we were unable to obtain much data from these trials.

Table 3. Results of generalized linear mixed models run on the deterrent fence data in comparison to the breaches of the traditional fence. ***{Proprietary and not yet unpublished, so please do not share publicly}***

Deterrent	Estimate	Std. Error	z value	p value
Acacia vs GC	-0.01435	1.27744	-0.011	0.991036
Active Bee vs GC	-4.22552	0.80596	-5.243	**1.58e-7**
Chili + Metal vs GC	-19.08507	2413.92359	-0.008	0.993
Chili vs GC	-2.08729	0.80065	-2.607	**0.009134**
Cloth vs GC	-1.75799	1.10174	-1.596	0.110567
Cloth + Metal vs GC	-2.97053	0.77953	-3.811	**0.000139**
DBL Metal vs GC	-3.41749	1.06297	-3.215	**0.001304**
Metal vs GC	-2.46579	0.63932	-3.857	**0.000115**

After analysis of the data collected across 8 trials, we have found that all novel deterrent fences performed significantly better than the grand control except for the cloth fence, however, this may be due to insufficient sample size, and the chili + metal fence (Table 3). Double deterrent fences, fences using two deterrents strung between the same fence posts, did not perform significantly better than single deterrents at keeping elephants from entering crop fields ($p = 0.085$). This analysis combines all fence types, indicating that fence type is a key factor in effectiveness. Unfortunately, crops did not fare well in the beginning of 2021, and subsequently, elephants were abundant in the area. Due to the rains not coming until the end of December 2021, we are still collecting data from this last trial and will be including these new findings in future analyses.

(2) Associated practices to deterrent fences

Elephant Database. The elephant identification database has been updated through to 2021 with the last entry date in June 2021. More individuals are being added with over 152 bulls as well as recurring individuals in the area. Further analysis into the elephant database, and cross referencing it with camera trap images of crop raiders could give insight into how many repeat crop raiders are currently in KWC. So far, 8+ bulls have been identified as crop raiders, some of which have repeat offenses. Conservation benefits of maintaining a catalog include the following:

(1) Empathy often occurs when individuals know and begin to understand each other. Farmers who learn how to identify elephants and thereby recognize individuals may behave in ways that are safer for both elephant and humans. (2) We will be able to track the identity of crop raiding individuals over time, allowing us to examine if environmental conditions are related to types of individuals that crop raid (age, sex, group size). (3) Similarly, we do not know if deterrent ability of a fence is related to identity of the elephant(s) that approach, i.e., whether some deterrents work well against some types of elephants but not others.

(3) Environmental Variables

a. *Moon Phase*. Over the past 9 trials, more elephants have been present around the experimental fields during all other moon phases than the full moon phase (Figure 7). This is hypothesized to be due to the increased light and thus visibility during the full moon phase.

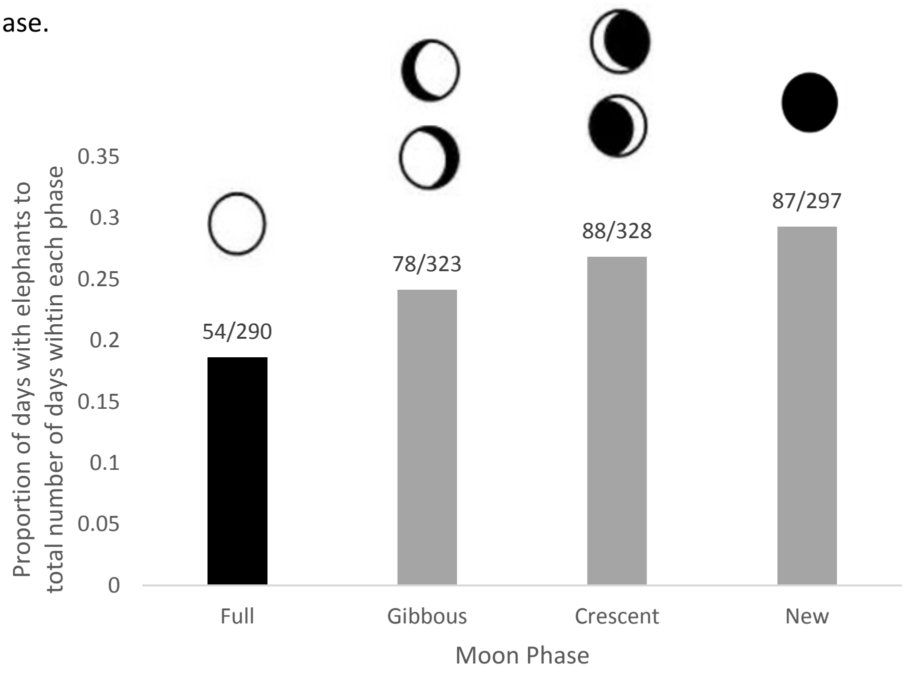

Figure 7. The proportion of elephants present per moon phase over trials 1-9. Data from trial 9 is still being collected. ***{Proprietary and not yet unpublished, so please do not share publicly}.***

b. *Dry and Wet Seasons*. Elephants were present around the experimental fields (12 m distance from the deterrent fences) less during the end of the crop growing season, when farmers were harvesting, than the middle (Figure 8).

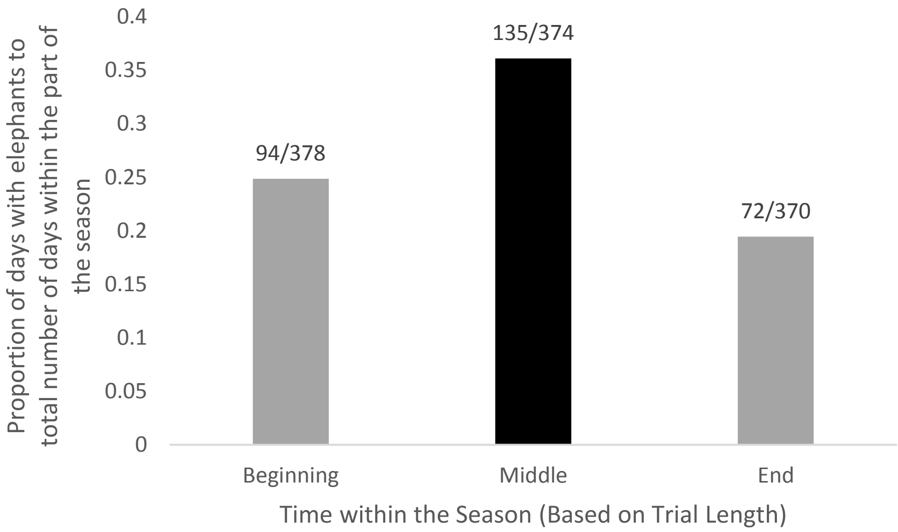

Figure 8. The proportion days with elephants present near the crop fields (12m from deterrent fences) compared between the beginning, middle, and end of the growing season over trials 1-8. ***{Proprietary and not yet unpublished, so please do not share publicly}.***

(4) Crop and Wild Habitat Quality

a. *Climate Smart Agriculture.* Control and experimental plots continue to be tested in the study site. Control plots continue to perform poorly when compared to experimental plots that include climate smart agriculture techniques. This continued through 2021 even during the prolonged drought. However, this led to intense raiding of the climate smart agriculture plots due to them containing the only food in the area.

b. *Tree Damage.* Due to COVID-19 we were not able to collect data on our 240 marked trees during the 2020 field season; however, data collection was continued in 2021. Over the past 5 years we have observed marked trees are sustaining steady and continuous increases in damage. Due to the 2021 drought, tree damage was at a high around water points due to incredibly high wildlife traffic in these areas. This damage can be seen through the increase in dead marked trees around these waterpoints. A total of 23 trees were reported as newly dead, and 4 newly reported as missing from the 2021 survey. 64% of the dead and missing trees were reported during the 2021 survey, with a grand total of 36 dead and 6 missing since the inception of the project.

c. *Mammal and Bird Surveys.* Over the past 5 years we have conducted wildlife and bird surveys weekly during the months that we were present in the field. Due to the pandemic, we were not able to continue this data collection in 2020 but were able to pick it back up in June 2021. These data have since become a large part of new graduate student Ms. Dakota Vaccaro's master's thesis. As we acquire more data, we will the correlation between the presence of mammal and birds on transects elephant caused vegetation damage, as well as elephant crop raiding events. Through these analyses we will also be able to further help mitigation of HEC through a better understanding of elephant distribution in the KWC and its relationship with crop raiding events to influence our early warning system.

(5) Community Outreach

Due to the pandemic, we were not able to conduct in person outreach or school visits. The continued presence of our Kenyan team members in the community along with the construction and preservation of fences has maintained our relationships with the people in the community. We have continued our fundraising program for the school, which has received over $25k since it was created. These funds were used to provide a permanent water supply to the school, employ local cooks, supplement teacher salaries, and purchase school supplies for the students. Only recently, due to the COVID-19 pandemic, has our funding amount dropped, leading to an inability to provide meals for the students. We are hoping, as people continue to recover from the effects of the pandemic, that we will be able to provide these funds once more.

7. Numerical Impact on Humans and Elephants

Based on the 2019 National Census, the human population in Buguta sub-location, the area closest to our experimental fields, was ca. 7,000 in 1,348 households. The region around the Wildlife Works wildlife corridor has a population of around 100,000 people. Tsavo National Parks have an estimated elephant population of 15,000. The elephant population in the Tsavo ecosystem is approximately 15,000 elephants. The subset of this population in the Kasigau Corridor REDD+ Project area is about 2000 with some 300-500 resident around Rukinga (M. Githiru, pers. comm.). Unlike in 2019, where the drought led to a high concentration of elephants in the area congregating around permanent water points, the 2021 drought resulted in the opposite. There was extremely limited food in the area from April 2021 until the middle of December. Although there was permanent water on the ranch, without any access to food or shade, most elephants appeared around water points in the cooler hours and dispersed to find shade closer to the hills during the heat of the day. Recent estimates of this population in the Kasigau Corridor REDD+ Project area is about 2000 with some 300-500 resident elephants around Rukinga.

The four main experimental farm blocks that we have continued to partner with have eight families benefiting from the leasing of their farms and the protection of their crops. We have continued our partnership with the four additional farmers who received beehive fences and participated in a workshop teaching apiculture, a skill that can be passed to future generations. Monitors have noted adverse reactions from elephants, and some farmers behind the fence are planting crops again for the first time in years. Most participating farmers had failed harvests in trial 8 due to the 2021 drought, but we are hopeful that farmers will receive some harvest during the ongoing growing season (trial 9).

8. Problems during the Project Period

See Section 5.

9. Evaluation of Success to Date

Due to the COVID-19 pandemic and the 2021 drought, there has been limited data collection over the past 3 trials. However, our team has been able to use this time to delve deeper into data analysis, and our project is continuing to make new findings. Ms. Corde and Lynn Von Hagen were able to travel to Kenya and conduct their research from the end of May through to October for Von

Hagen and the middle of December for Corde. During this time, new graduate student Dakota Vaccaro was present in the field for a month to prepare her for her upcoming 2022 field season. Dr. Schulte was present at the start of her training. During this time Vaccaro was able to meet with our team in Kenya, and conduct work in the fields which will influence her proposed research for her Master of Science degree at WKU. While not in the field, Ms. Corde and Ms. Von Hagen have been diligent about manuscript writing, revising, and submitting, and preparing data for future publications. Dr. Schulte has assisted with these endeavors. Simon Kasaine has helped with execution of the work in the field, Bernard Amakobe has provided inputs, and Drs. Mwangi Githiru and Urbanus N. Mutwiwa have helped with proposal and grand writing developments.

10. Next Steps

We will keep the deterrent aspect of the project going in 2022. Ms. Dakota Vaccaro and Dr. Bruce Schulte hope to be returning to Kenya in late May or early June of 2022. Ms. Vaccaro will be staying for 7-9 months to conduct her research and continue data collection for the project. We are hoping to begin fielding Earthwatch teams again starting in early June. If we are not able to run Earthwatch teams, we will try to continue the project with reduced funding (e.g., no support from USFWS, IEF, or the Earthwatch Institute).

11. Human Interest Story

Figure 9. Research team and WKU alums at Loki Dori at Rukinga Ranch. Simon Kasaine has arm raised and Sophia Corde is 2nd from right.

Due to the COVID-19 pandemic, many plans changed and relationships with coworkers needed to be maintained online rather than in person. A notable example of this can be seen in the work that Mr. Simon Kasaine and graduate student Ms. Sophia Corde did to help in the continuation of this project through the pandemic both in and out of the field (Figure 9). In December 2019, Ms. Corde made her first trip to Kenya in which she met with Mr. Kasaine for the first time. During this trip Corde conducted field work with past student and doctoral candidate Lynn Von Hagen and prepared for her own field season to begin in April 2020. Due to the COVID-19 shut down in March 2020, Corde needed to postpone her field season a full year. During that year Corde took the time to organize and analyze past data. In doing this, she added an extra year on to her MS degree to be able to carry on with field work once it was safe to do so. During this time, Corde and Kasaine maintained contact through email. Kasaine, being based in Kenya and a Kenyan native, was in the farms carrying out the work during 2020's trial 7. Because camera traps were not set up, Kasaine visited the local record keeper and local farmers to retrieve written reports by them about elephant incursions into fields and elephant crop raiding events. These reports were relayed back to the US based team and input into the databases. It is because of Kasaine's continued dedication to the project and help in the fields during the 2020 shutdown that we were able to continue to collect data on the deterrents during trial 7. Once the travel restrictions were lifted, Corde and Von Hagen hopped on the first plane available and were on the ground in Kenya just 2 weeks later, where Kasaine picked Corde and Von Hagen up from the train station. The COVID-19 pandemic has had a drastic effect on many over the past two years, both financially and socially. Through the perseverance of all members of our team, we were able to make the most of the situation and propel the project forward.

12. Project Progress Summary (500 words)

In areas where human settlements and elephant habitats overlap, human-elephant conflict is a major issue for human livelihoods and elephant conservation. These interactions harm farmers, as crop raiding events compromise food and economic security, and elephants, as farmers may retaliate against them. Over the past four years, we tested the effectiveness of eight deterrent fence designs, including 5 single deterrents (one line of deterrent strung between fence posts), and 3 double deterrents (a combination of two strands of single deterrents). We also examined moon phase and season as environmental factors in relation to crop raiding. Supplementary to this we have also conducted wildlife and bird transect surveys and elephant caused tree damage surveys along marked routes and at water points. Due to the pandemic, our Earthwatch Institute Citizen Science Volunteer teams were cancelled, reducing our project funds and number of field assistants as well as reducing our outreach. Pandemic caused restrictions in Kenya have also impacted our ability to conduct community surveys, make school visits, and other procedures that require gathering individuals together. Fortunately, we have made progress in our study through modifications of the project during these restrictions. Aside from the pandemic, drought has also had a substantial impact on our ability to collect data over the past 2 trials; however, we were able to continue our wildlife and tree surveys. Through further data analysis we found that elephants breached fences significantly more during the waning crescent moon phase compared to the full moon through trial 7, further analysis needs to be done to include present trials. All new experimental deterrents performed better than the grand control. The acacia fence was the only deterrent tested that did not perform significantly better than the grand control at deterring approaching elephants, and the double deterrent fence designs performed no better at deterring elephants than the single ones. The double metal strip fence and the beehive fence were the most effective at deterring elephants. Our community outreach with schools and farmers has continued to benefit from our relationship locally, improving food security. The results of this study are being shared with the farmers living in the KWC as well as relevant policy makers to improve food and nutrition security, as well as enhance coexistence. Our findings may be useful to others living in high HEC areas by providing additional crop raiding mitigation strategies for coexisting with elephants.

13. Project Progress Summary (50 words)

Our project suffered setbacks from the pandemic and 2021 drought. Nevertheless, we continued experimental tests of deterrent fences for effectiveness, tracked crop raiding, maintained our elephant database, worked on an ecological prediction system, evaluated abiotic and biotic correlates to raiding, and performed community outreach in Kenya's Kasigau Wildlife Corridor.

14. Organizations involved

The International Elephant Foundation (https://elephantconservation.org/), the Richard Lounsbery Foundation (https://www.rlounsbery.org/), the Earthwatch Institute (http://earthwatch.org/), Save the Elephants', Elephants and Bees Project (http://elephantsandbees.com/), Western Kentucky University (https://www.wku.edu/), Wildlife Works (http://www.wildlifeworks.com/saveforests/forests_kasigau.php), Jomo Kenyatta University of Agriculture and Technology (http://www.jkuat.ac.ke/), and Auburn University (www.auburn.edu).

15. Financial Report – Final (February 2021)

The 2020 proposal to IEF by Schulte et al. was funded at a reduced amount ($7000; the original request was $10,000). Thus, the budget had to be revised, and all equipment / visa expenses were eliminated (Table 4). In addition, because no Earthwatch Institute groups traveled, the project also did not have access to any of these funds. All funds have been expended.

Table 4. IEF budget for 2021 – February 2022.

Item	Budget	Expenditures	Cost
International Travel	$7000.00	Per diem that includes housing, hotel stays, food, and in country travel	$7,000.00
Total	$7,000.00	All Expenses to date	$7,000.00
Remaining	$7,000.00		$0

16. Digital Images

Figure 11. Elephant approaching and being deterred from the double metal strip fence.

Figure 12. Beehive + Metal Strip Kasaine Deterrent Fence.

Figure 13. Graduate students Sophia Corde and Dakota Vaccaro assessing newly planted corn at control beehive fence.

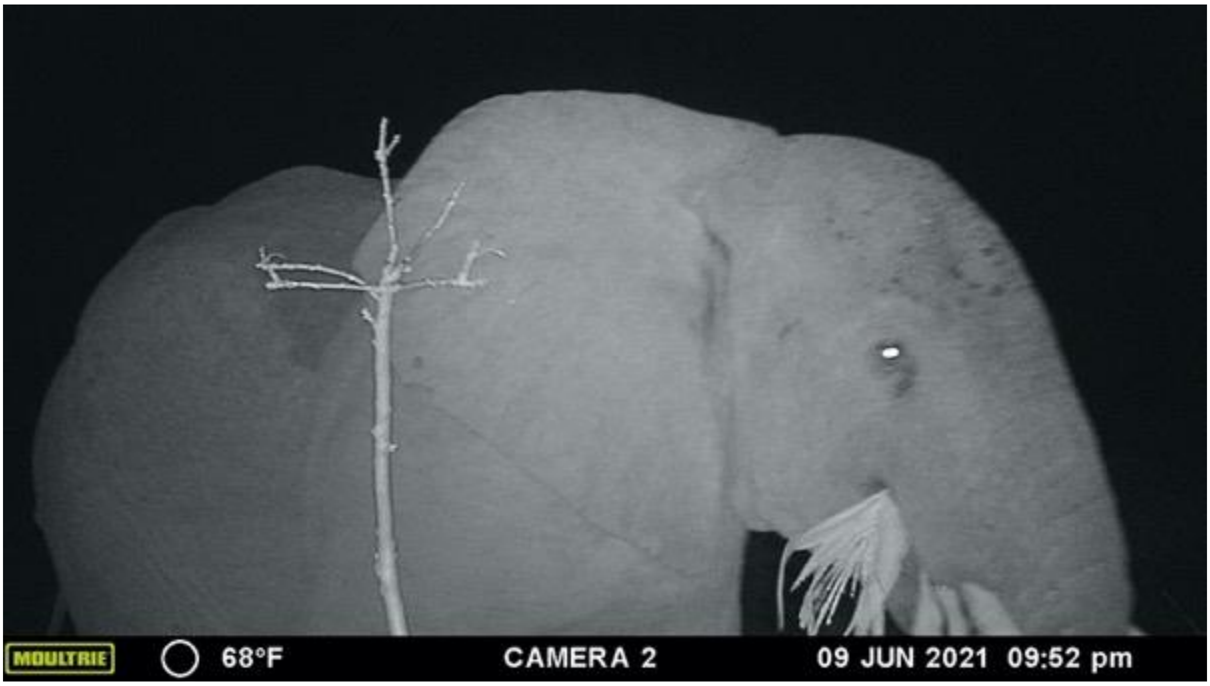

Figure 14. Elephant caught on camera trap eating maize while leaving an experimental control field.

Figure 15. Corde and Ranger Mwatate repair a double metal strip Kasaine fence.

17. Video Clip

Submitted via Dropbox: PPPS file

18. Presentation / Publication Plans

Conferences:

None in-person because of pandemic (some intended ones were canceled or postponed).

International Congress for Conservation Biology (ICCB), Virtual Meeting (December 2021):
Symposium on Decision Analysis for Conserving Biodiversity: A Global Perspective

Prakash V, Von Hagen RL, Gitzen R, Irwin E, Schulte BA, Lepczyk CA. Elephants and tigers and models, oh my! Structured decision making to mitigate negative human wildlife interactions.

Schulte BA, Irwin E. Incorporating a conservation behavior approach into the adaptive management framework.

International Elephant Foundation, Virtual Meeting (November 2021)

Schulte BA, LaDue CA. Human–elephant conflict (HEC) from a research perspective.

Corde S, Von Hagen RL, Kasaine S, Githiru M, Amakobe B, Mutwiwa U, Schulte BA. The use of deterrent fences and environmental correlates to alleviate human elephant conflict in southern Kenya.

Von Hagen RL, Schulte BA, Githiru M, Mutwiwa U, Kasaine S, Corde SC, Amakobe B, Lepczyk C. Evaluating socioeconomic drivers of human-elephant conflicts in Kenyan communities.

Chemical Signals in Vertebrates 15, Virtua Meeting (October 2021)

Schulte BA, Von Hagen RL, Githiru M, Mutwiwa U, Kasaine S, Amakobe B, Corde SC. Chemical communication and elephant conservation: Chili pepper fences and other chemo-approaches.

Animal Behavior Society, Virtual Meeting (August 2021)

Schulte BA, Corde SC, Von Hagen L, Githiru M, Kasaine S, Mutwiwa U, Amakobe B. Facilitating cohabitation of humans and elephants through a conservation behavior approach.

Student Conference on Conservation Science-NY. October 2021

Von Hagen, R.L., Schulte, B.A., Githiru, M., Mutwiwa, U., Kasaine, S., Corde, S., Amakobe, B., Lepczyk, C.A. Evaluating the impact of socio-economic drivers on community resilience to human-elephant conflict in the Kasigau Wildlife Corridor of Kenya.

American Society of Mammologists 100th annual meeting. June 2021.

Corde, S.C., Von Hagen, R.L., Kasaine, S., Githiru, M., Amakobe, B., Mutwiwa, U., Schulte, B.A. Alleviating human elephant conflict through deterrent fences and environmental monitoring in southern Kenya.

Von Hagen, R.L., Corde, S.C., Kasaine, S., Githiru, M., Amakobe, B., Mutwiwa, U., Schulte, B.A. Evaluating socioeconomic drivers of human-elephant conflict in Kenyan communities.

Published Papers:

Von Hagen RL, Kasaine S, Githiru M, Amakobe B, Multiway UN, Schulte BA. **2021**. Metal strip fences for preventing African elephant (*Loxodonta africana*) crop foraging in the Kasigau Wildlife Corridor, Kenya. African Journal of Ecology, 59, 293-298.

Von Hagen, R.L. **2020**. Chai, Chapati & Coexistence: The Essential Role of Community Engagement in Elephant Conservation. *Journal of Elephant Managers Association.* (**31**)3, 102-106.

Von Hagen RL, Norris P, Schulte BA. **2020.** Quantifying capsaicinoids from chili pepper and motor oil mixtures used in elephant deterrent fences. Chromatographia 83: 1153-1157. https://doi.org/10.1007/s10337-020-03934-8

In Preparation:

Von Hagen, RL, N Norris P, Schulte BA. Capsaicin degradation and alternative solvents for chili fences used to deter African elephant (*Loxodonta africana*) crop raiding.

Related publications:

Schulte BA, LaDue CA. **2021**. The chemical ecology of elephants: 21st century additions to our understanding and future outlooks. Animals, open access, https://doi.org/10.3390/ani11102860.

LaDue CA, Schulte BA, Kiso WK, Freeman EW. **2021**. Musth and sexual selection in elephants: a review of signaling properties and potential fitness consequences. Behaviour, open access, DOI:10.1163/1568539X-bja10120.

LaDue CA, Schulte BA. **2021**. Pheromonal enrichment in the zoo: An empirical approach with Asian elephants (*Elephas maximus*). Applied Animal Behaviour Science, 235, (article 105228). https://doi.org/10.1016/j.applanim.2021.105228.

19. Website, Blogs, Social Media Accounts

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