

# “Human-Elephant Conflict along the Eastern Boundary of the Udzungwa Mountains National Park, Tanzania”

Evaluating the effectiveness of a beehive fence in reducing crop raiding by elephants



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## **Cover photographs:**

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## **Keywords:**

African elephant, human- wildlife conflict, elephant crop damage, beehive fence, mitigation methods, Udzungwa Mountain National Park, Tanzania

Leeuwarden, June 2014

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## **Preface**

This report is written within the scope of my final thesis of the study of Animal Management at Van Hall Larenstein, University of Applied Science in Leeuwarden, The Netherlands. During this study, I specialized in wildlife management with an interest in zoological and conservation research.

In order to seek ways of reducing conflicts between farmers and elephants, in 2008, the Southern Tanzania Elephant Project (STEP) was established (formerly Udzungwa Elephant Project). With funding assistance from FFI/UNESCO Rapid Response Facility and the STEP, a farmers group called 'Njokomoni' was able to construct (in 2011) chili-oil and beehive fences along the border of the Udzungwa Mountain National Park. Both fences were aimed at deterring elephants from crops, but the beehive fence, for practical and financial reasons, was preferred by the farmers. The need for an evaluation of the effectiveness of the beehive fence along this border of the National Park was raised by Dr. Katarzyna Nowak (Scientific Advisor of STEP).

I warmly thank STEP's Trevor Jones and Katarzyna Nowak, for giving me the opportunity to carry out my final thesis in collaboration with the project and for allowing me to use the project's previously collected data.

Furthermore, I would like to express my very great appreciation to the field assistants Paulo Mndeme and Joseph Kidibule. Assistance in organizing the data provided by Christopher Reusch was greatly appreciated. Also, thanks to Emanuel Martin, from the Tropical Ecology, Assessment and Monitoring (TEAM) project (which is part of the Udzungwa Ecological Monitoring Centre (UEMC)), for allowing me to use GIS data from the study area. Statistical advice given by Henry Kuipers has been a great help. Thanks to all the farmers in Mang'ula A and Mang'ula B for granting permission to enter their farmland for data collection. Last but not least, thanks to my supervisors Berend van Wijk and Hans Bezuijen, for their patient guidance, encouragement and useful critiques of this research. Katarzyna Nowak made helpful edits and comments on several previous versions of this report.

I hope this report will contribute to a sustainable mitigation plan for human- elephant conflicts along the eastern boundary of the Udzungwa Mountains National Park, Tanzania in the future.

Leeuwarden, June 2014

Ciska Scheijen

## Summary

A major concern for wildlife management and rural development initiatives across Africa are conflicts between elephants and people. In most African regions, wilderness is fenceless and elephants move outside of protected areas. Because of this, and the lack of a true buffer zone, between the Udzungwa Mountains National Park and the farms to the eastern border of the park, human-elephant conflict (HEC) occurs also in this area of southern Tanzania, the focal site of this study. Long-term effects of HEC include negative attitudes of local people towards elephants, because these elephants can threaten their livelihoods. This can lead to elephant kills, snaring and poaching, to compensate or seek revenge for the damage that the elephants have caused. This also applies to the Udzungwa study area.

In 2011, the Southern Tanzania Elephant Project (STEP) established in collaboration with the Njokomoni Farmers Group, 500 meters of beehive fencing, intended to reduce crop-raiding by elephants. The fence consists of hives linked to each other with a strong wire based on a formula developed in Kenya by Dr. Lucy King of the NGO Save the Elephants. Whenever an elephant passes through the fence the hives swing, after which disturbed bees (which elephants fear) fly out. The idea is that the disturbed bees will become agitated, and keep the elephants at bay from the farmland. Another advantage of this fence is that farmers gain money from the honey they harvest, which compensates at least partially for crop damage. The fence was placed at what Kapebele (Udzungwa park ecologist at the time)(2011); identified as a hotspot of elephant crop-raiding in the area.

Before extending the existing fence along the border of the Udzungwa Mountain National Park (and thereby spending time and money), it is important to understand the effect the fence has on the extent of crop damage and frequency of elephant raiding behavior. The goal of this study was therefore to evaluate the effectiveness of the beehive fence.

Data on the extent of elephant crop damage and elephant raiding frequency was collected by STEP and Kapebele in the pre-fence period (2010-2011) and in the post-fence period (2011-present) in collaboration with STEP. The extent of crop damage and elephant raiding frequency were analyzed at two levels: total farms and individual farms. Characteristics for individual farms such as farm size, perimeter, distance to park boundary and distance to road were measured and taken into account as independent variables. Season (dry/wet) and fence (yes/no) were taken into account as independent variables for both scales, total farms and individual farms.

There was a weak correlation found between elephant raiding frequency and the extent of crop damage, this suggests that these two variables should not necessarily be used interchangeably. Therefore both variables were used in this study.

To determine the effectiveness of the beehive fence, Linear Mixed Models and Generalized Linear Models were used to analyze data from the wider study area (approximate size of 0.35 sq. km) and for the hotspot area (approximate size of 0.09 sq. km). Ten models were constructed with the two dependent variables (elephant raiding frequency and extent crop damage) combined with several spatial (total farms/ individual farms) and temporal aspects (whole period/only fenced period).

In the wider study area (WA) and in the hotspot area (HA) the extent of farm damage (WA  $P < 0.001$ , HA  $P = 0.002$ ) and elephant crop-raiding frequency (WA  $P = 0.001$ , HA  $P = 0.021$ ) both decreased after the fence was placed, when analyzing data in the multiple rather than single subject design. The beehive fence did not have an overall significant effect on the total damage inflicted on farms, or on elephants' raiding frequency when taking into account the total farmed area under study (single subject design). Likewise, neither season nor the interaction between season and fence affected total farm damage or raiding frequency. These results held for the wider study area, and also for the hotspot area. Because for the individual farms, there was used a multiple subject design (the individual farms), it was possible to correct for farm-related variables (e.g. distance to the park

boundary, farm size and farm perimeter). Besides, the number of observations that differ between the single subject design (N=41 for the wider and for the hotspot area) and multiple subject design (N=955 for the wider study area and N= 312 for the hotspot area), also the other factors taken into account with the multiple subject design can influence the significance. Despite the observation that crop-raiding by elephants actually increased at some farms after the fence was placed, the overall results of this study indicate that the beehive-fence is at least partly effective. A reason why particular farms undergo more damage could be because of a broken wire and because elephants walked around the fence.

Whereas for the multiple subject design, season did not have a significant effect on the elephant raiding frequency, it did have an effect on the extent of crop damage. In wet season the extent of damage was higher than in dry season. This is consistent with the first finding that elephant raiding frequency and extent of crop damage are not synonymous. Also the interaction between fence and season showed a different result between the two dependent variables. The beehive fence reduced the mean damage more during wet season, the mean frequency reduced more during the dry season. A possible reason for this is crop availability and the low quality of wild grasses in wet season. This is evidence that these two dependent variables cannot be used interchangeably in studies of HEC.

Because the beehive fence in this study had mixed results depending on the level and scale of analysis, careful monitoring of deterrent effectiveness is needed prior to application, expansion or modification of deterrent methods. Questions which still need to be addressed are: 1) did the absence of people (because of canceling permission for local inhabitants to collect firewood) along the UMNP border since June 2011 increase elephant raiding frequency and extent of damage, and 2) does the presence of beehives (and thus bees) in the crop area actually increase crop yield because of a pollination service, and hence a seeming increase in elephant raiding frequency and extent of damage at the level of the wider study area?

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## **List of acronyms and abbreviations**

<b>HEC</b>	Human Elephant Conflict
<b>STEP</b>	Southern Tanzania Elephant Project
<b>UMNP</b>	Udzungwa Mountains National Park
<b>PAC</b>	Problem Animal Control
<b>WA</b>	Wider Study Area
<b>HA</b>	Hotspot Area

## Introduction

The African elephant (*Loxodonta africana*) has an important influence on the structure and composition of the African (rain) forest (White et al., 1992). Their role in the ecosystem is paramount (White et al., 1992; Stephenson, 2007) because elephants are the only seed dispersers of plant species (White et al., 1992; Campos-Arceiz, 2011) such as the *Sclerocarya caffra*, and the *Balanites wilsoniana* (Campos-Arceiz, 2011), and in turn, they maintain suitable habitats for many other taxa (Campos-Arceiz, 2011; Stephenson, 2007). While this may be especially apparent for forest elephants in Central Africa, relatively little is known about forest-dwelling savanna elephants such as those in the Udzungwa Mountains of Tanzania, or Mt. Kenya, Kenya and Knysna, South Africa (Jones and Nowak, in press).

Poaching for elephant ivory in the 1970s and 1980s led to a substantial decline in elephant populations across Eastern and Central Africa (Lemieux et al., 2009; Douglas-Hamilton, 1987). Moreover, poaching for meat, habitat destruction as well as drought and disease exacerbated elephant mortality rates (Douglas-Hamilton, 1987). Over this period, the population of elephants in Africa declined from 1.3 million to approximately 600,000 (Nelson et al., 2003). This decline was also recognizable in the Udzungwa Mountains of south-central Tanzania (Nowak et al., 2010).

Very little reliable data on numbers and distribution of the African elephant were available before the mid '70s (Douglas-Hamilton, 1987), but it is assumed that before the '60s and '70s, a healthy population of elephants inhabited the Udzungwa Mountains and other Eastern Arc forests (Jones and Nowak, in press). In the '80s and '90s, after severe population declines attributed to poaching for ivory, the Udzungwa elephant population decreased until there were no longer elephants reported in the area (Nowak et al., 2010). Since 1992, after the Udzungwa Mountains National Park (UMNP) was gazetted, the population has been slowly recovering (Nowak et al., 2010). Currently, the population size of elephants in the Udzungwa Mountains is estimated at less than 2000 resident elephants, with some movement still taking place between Udzungwa and the Selous Game Reserve, and Mikumi and Ruaha National Parks (Jones & Nowak, in press; Jones et al., 2009). Between 2009 and 2011, dung diameter measurements were used to estimate the ages of elephants in the Udzungwa Mountains (Nowak et al., 2010; Kabepelle, 2011). The population appeared to be young, which fits with the area's poaching history and recent population recovery (Nowak et al., 2010).

A major concern for wildlife management and rural development initiatives across Africa are conflicts between elephants and people (Osborn et al., 2003). Human-elephant conflict (HEC) is "any human-elephant interaction which results in negative effects on human social, economic or cultural life, on elephant conservation or on the environment" (Parker et al., 2007, p.11). Because there are human settlements and farms around the edges of the UMNP, there exists no true buffer zone between the forest and the farms (Nowak et al., 2010). In this area, former elephant corridors have been blocked (Jones et al., 2012), and, as a possible result, HEC has increased (Nowak et al., 2010). Corridors are usually narrow areas where animals pass to move from one geographical area to the other (Nahonyo, 2009; Jones et al., 2009). These areas connect different habitats or protected areas (Nahonyo, 2009; Jones et al., 2009).

Since 2008, crop-raiding in the area has escalated and elephants have become habituated to farmers and their traditional deterrent methods (Kabepelle, 2011). Kabepelle (2011) shows that over eight months, from September 2010 until April 2011, there were 291 crop-raiding events along the eastern boundary of UMNP spread out over 91 crop-raiding nights. Within one raiding night, several raiding events could take place. Every individual raiding event was considered as an incident of crop-raiding and/or damage on one farm (Kabepelle, 2011). It is possible that mainly young elephant bulls in the Udzungwa Mountains are responsible for a high percentage of Human-Elephant Conflict (HEC),

since crop-raiding tends to be carried out by young males (Kabepelle, 2011; Chiyo et al., 2012). Sub-adult males are young males which leave their family units and have just begun to be reproductively competitive (Chiyo et al., 2012; Getz et al., 2007).

Long-term effects of HEC include negative attitudes of local people towards elephants (Granados, 2011; Parker et al., 2007), because these elephants can threaten their livelihoods (Parker et al., 2007). This gives local people less incentive to conserve elephants, and can lead to elephant kills, snaring and poaching, to compensate or seek revenge for the damage that the elephants have caused (Granados, 2011; Parker et al., 2007; Kabepelle, 2011). The carcass of the elephant which is killed often goes to the people of the affected community and provides protein in the form of wild meat (Nelson et al., 2003). However, shooting a problem elephant is only a short time solution as many crop-raiding elephants are occasional raiders and thus their removal does not eliminate the problem (Chiyo et al., 2012; Smit, 2013). "Problem" individuals are also difficult to accurately identify (Chiyo et al., 2012).

This also applies to the Udzungwa study area, where local inhabitants have little incentive to conserve elephants (Mndeme, pers.comm 2013). This is not only because elephants damage crops, but also because local people do not directly benefit from the established protected area through e.g. revenue sharing. In addition, since July 2011, people are prohibited to collect firewood from inside and along the edges of the UMNP (Nowak, pers. comm, 2013). This firewood collection ban has resulted in tension between local people and the UMNP authorities. Besides, farmers see the national park as responsible for the elephants and their behavior (Mndeme, pers.comm 2013). Between May 2009 and August 2012, four Problem Animal Control (PAC) incidents took place. Two of them were legal actions (carried out by the District Game Officer) whereas one elephant was most likely poisoned by villagers, and one bull was shot in his leg by an unknown person (Jones, pers. comm., 2013). Recent analysis of camera trapping data suggests that crop-raiders are not particularly habitual, and may instead be occasional and seasonal visitors. Using camera trap data collected by STEP between 2010 and 2013, Smit (2013) identified confidently a minimum of 73 crop-raiding individuals, of which only thirteen individuals were repeat raiders. This shows that removal of one "problem" individual will not alleviate crop-raiding (Smit, 2013). Up to this day, farmers along the eastern border of the Udzungwa Mountains National Park (UMNP) are trying to keep elephants away by use of local mitigation methods such as noise, dogs and fire. Some farmers use a locally conceived mitigation method, a mixture of elephant dung and water, which is then spread over the crops (Jones et al., 2012). The effectiveness of the dung method remains untested, but it seems to be the method of choice preferred by some farmers, who believe that elephants are coprophobic (Jones, pers. comm., 2013).

To protect both elephants and farmers, it is important to have long-term plans and strategies for conservation (Nelson et al., 2003). A mixed conservation strategy that combines wildlife management (protection and deterrence of raiders from crops) with income-generating activities (such as honey production) for local people is more effective than any one single strategy (King et al., 2011).

Because of the increase in HEC close to the border of the UMNP, the "Southern Tanzania Elephant Project (STEP)" was founded in 2008 (formerly Udzungwa Elephant Project). One of the project's activities is to seek ways of reducing conflict between farmers and elephants in the Udzungwa Mountains of Tanzania (Southern Tanzania Elephant Project<sup>1</sup>, 2013). In one of their studies, the STEP discovered that the elephants in the area feed on crops year-round (Southern Tanzania Elephant Project<sup>2</sup>, 2013), which is in contrast to seasonal crop-raiding at other sites, such as in and around the Sengwa Wildlife Research Area and in the Sebungwe region of Zimbabwe (Osborn, 2004). The elephants along the eastern border of the Udzungwa Mountains feed on more than 30 different crops (Southern Tanzania Elephant Project<sup>2</sup>, 2013).

In the middle of the dry season (September to December), there is an increase in the number of farms raided with a peak occurring in mid-December. This applies also to the wet season (January to April) when there is a raiding peak in mid-March (Kabebele, 2011). To try to reduce conflict between farmers and elephants, the STEP started to work with a group of farmers which eventually formed a cooperative called “Njokomoni Farmers Group” (Southern Tanzania Elephant Project<sup>2</sup>, 2013). This is a group of 15 farmers, who all experience problems with elephant crop-raiding. They currently have 500

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Figure 1 STEP employee is monitoring the beehive fence (Christopher Reusch, 2014).

Fences were not trailed to more distant farms, because of a lack of knowledge about the effectiveness of the fences and a lack of funds to build them (Nowak, pers.com, 2013).

HEC studies often conclude that there is not one perfect deterrent method. Most times they recommend equipping and educating farmers with various deterrent methods (King et al., 2011). To combine or rotate different methods may have more effect than relying on any one method alone (King et al., 2011; Hoare, 2012).

The 500 meters of beehive fence along the eastern border of the UMNP is made up of 50 Kenyan Top Bar hives at approximately ten meters apart. These hives are linked to each other with a strong wire. Whenever an elephant passes through the fence, the hives will swing, which disturbs the bees (King, 2011). Well-known is that honey bee colonies respond aggressively on disturbance or attack (Alaux et al., 2009). The African honey bees (*Apis mellifera scutellata*) are the most intensely engaged in colony defense (Schneider et al., 2003; Alaux et al., 2009; Pearce et al., 2001). Their response can vary from a few bees, to hundreds or even thousands of individuals (Alaux et al., 2009). Since elephant crop-raids occur during the night (Chiyo et al., 2012; Lamarque et al., 2009; Hanks, 2006), and bees are less active at night as they can rest for several hours (King et al. 2011), this could reduce the effectiveness of the beehive fence. But not all bees rest at the same time, some bees will spend time cleaning the hive and feeding the brood (Kaiser, 1988; King et al. 2011). And there is a continuous sound of buzzing bees (King et al. 2011). In addition, the African bees can forage successfully during moonlit nights (Fletcher, 1978).

In 2007, a study in Northern Kenya demonstrated that elephants avoid disturbed African honeybees (King et al., 2007). During a prior pilot study, beehives themselves without fencing were observed to be an effective elephant deterrent (King et al., 2009). Elephants were observed to not only run away from the bees (King et al., 2011), but also to alert family members by making an alarm call to

oil fencing (Appendix 1), which was placed in parallel to the beehive fence (Fig. 1) (Southern Tanzania Elephant Project<sup>2</sup>, 2013).

The intended effect of these fences is to reduce crop-raiding by elephants. These fences were funded by the FFI/UNESCO Rapid Response Facility and the STEP (Southern Tanzania Elephant Project<sup>2</sup>, 2013). The fences were placed at what Kabebele, 2011 identified as

keep them away from a possible bee threat (King et al., 2009). During this study in Kenya, 32 events of crop-raids were analyzed. There was only one bull which went through the beehive fence (King et al., 2011). Also King et al. 2011 observed that there were several attempts by elephants to enter the farmland but the elephants turned away. These elephants either left the area, or walked along the fence to find an easier entry (King et al., 2011). Furthermore, the elephants avoided the beehive fences when they left the farmlands after crop-raiding. Elephants also approached the beehive fences less often than thorn bush fences, within the same area, which indicates that the elephants either could see the beehives from a distance, or they recognized the shape of the beehives, and chose another way to avoid encountering bees (King, et al., 2011). Finally, elephants can purportedly smell occupied beehives from a distance; their sense of smell is one of the best in the animal kingdom (Osborn et al., 1995). Another advantage is that farmers can harvest the honey from the bees and sell it (King et al. 2011).

Fences are only successful if they are encircling the area, as otherwise elephants will walk to the end and around the fence (Hoare, 2012). This is because elephants seek the easiest way to enter farmland (King, et al., 2011). Therefore, to keep elephants away from farms, the fence has to encircle the whole area and daily maintenance of the fences is necessary. In order to make this possible, additional efforts are needed from farmers (Hoare, 2012).

Community-based methods are recognized as necessary for sustainable management of HEC (Hedges et al., 2009). Farmers often feel powerless, and believe wildlife managers are responsible for crop losses and therefore expect compensation (Osborn et al., 2003). Shifting the responsibility to the farmers themselves, by providing them with tools and knowledge will have more impact than compensation schemes (Osborn et al., 2003). The best way to include local farmers affected by HEC is to involve them in management strategies (Nelson et. al., 2003). Especially if there are high maintenance needs and requisite skill acquisition, it is important to involve farmers in solutions (Nelson et. al., 2003). Success depends on the willingness and capacity of local people to co-exist with wild animals in the long-term (McLennan et al., 2012). It is of great value to convince farmers that they can, and should take responsibility for protecting their farmland (Hedges et al., 2009), instead of waiting for governmental or NGO-led interventions. Less crop- raiding by elephants improves food security and maintains the tolerance of local communities towards wild animals (Sitati et al., 2005).

Before extending the existing fences along the border of the Udzungwa Mountain National Park (and thereby spending time and money), it has great significance to know the extent to which the beehive fencing is having the desired effect of reducing the amount of crop damage by deterring elephants. Until now, no evaluation of the effectiveness of the fences has been carried out. In order to develop a suitable management strategy, it is also important to understand other factors influencing elephant crop-raiding behavior and/or crop damage. It is integral to gain insight into the realized effectiveness and benefits of the fences as well as the efforts of maintaining the fences, not only in order to be able to decide whether it is useful to extend the fence, but also to be able to create a sustainable mitigation plan.

## Research objectives

**To evaluate the effectiveness of the beehive fence on elephant raiding frequency and the extent of crop damage at farms, and to identify other factors influencing elephant crop damage, in order to be able to create a sustainable mitigation plan in the future.**

*The sub objectives of this research are:*

- *To gain insight into the extent of crop damage done by elephants*
- *To quantify elephant raiding frequency*
- *To evaluate the realized effectiveness of the beehive fence*
- *To identify other factors influencing elephant raiding habits*

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## Research questions

**What is the realized effectiveness of the beehive fence on elephant raiding frequency and the extent of crop damage at farms and what other factors are influencing elephant crop damage?**

*The sub questions are:*

- *What is the rate of elephant raiding?*
- *What is the extent of crop damage caused by elephants?*
- *What is the realized effectiveness of the beehive fence on elephant crop damage at farms?*
- *What other factors are influencing elephant crop damage?*

## 2 Material and methods

### 2.1 Study area

The study took place along the eastern side of the UMNP, in the Kilombero Valley, south-central Tanzania. The UMNP has a size of 1990 sq. km and the mountains' highest peak is at 2576m (Bowkett et al., 2007). It lies in south central Tanzania (Fig. 2) and contains the largest and biologically richest forest blocks of the Eastern Arc Mountains (Kabepole, 2011). The Eastern Arc Mountains are a chain of mountains (10,000 sq. km) in Tanzania and Kenya, covered by rain forests and grasslands (Lovett et al., 2006; Kabepole, 2011). The UMNP is one of Tanzania's most unique wilderness mountains (Kabepole, 2011), known for its high biodiversity, wherefore it is considered to be a 'hotspot' area of biodiversity (Lovett et al., 2006; Kabepole, 2011; Bowkett et al., 2007). The park contains many endemic species (Kabepole, 2011; Bowkett et al., 2007), including two endemic primate species, the Udzungwa red colobus (*Procolobus gordonorum*) and the Sanje mangabey (*Cercocebus galeritus sanjei*), but also one near-endemic primate species Kipunji (*Rungwecebus kipunji*) (Kabepole, 2011). In the UMNP there are also thirty-six endemic and near endemic tree species and an endemic bird, the Udzungwa partridge (*Xenoperdix udzungwensis*) (Kabepole, 2011). Furthermore, the highly threatened Tanzanian endemic Abbott's duiker (*Cephalophus spadix*) inhabits the UMNP (Bowkett et al., 2007). Resident elephants within the UMNP are found up to the highest peaks of the park where they forage on bamboo and find refuge from human threats (Kabepole, 2011). The wet season (rainy and hot) spans November to May and a drier and colder period occurs from June to October (Lovett et al., 2006).

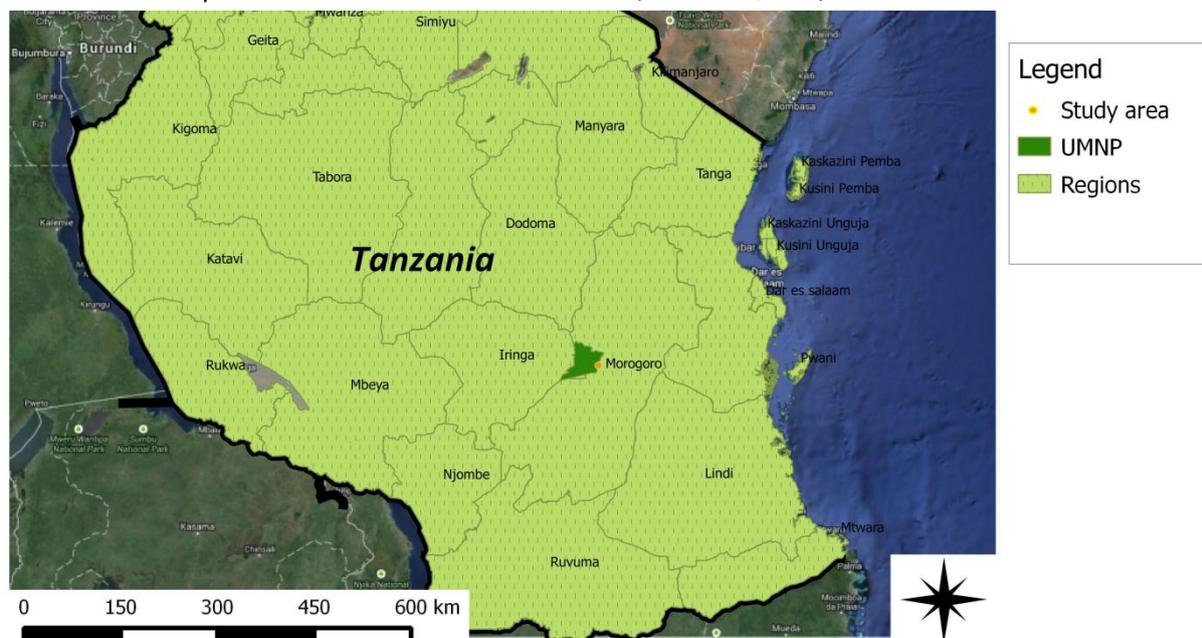


Figure 2 UMNP in south central Tanzania, and on the eastern border of the UMNP the study area (map source Google, 2014).

The focal study area covered two villages, Mang'ula A and Mang'ula B. There are more than 120 farms placed along these two villages (Fig. 3). The farms vary in size from 0.25 hectares to almost 2 hectares. Water in this area is plentiful year-round because of the rivers coming from the forested mountains. Therefore, some of the farmers in this area use irrigation by using river water (Nowak, pers.com, 2013). The farmers grow at least 32 different types of crops (appendix 2) depending on the time of year (Kabepelle, 2011). Most farmers inter-crop, and the different crops are mixed in the available space, also called 'mixed intercropping' (Sullivan, 2003). Farms contain similar combinations of crops. Almost all of these farms are affected by elephant crop-raiding. Besides crop-raiding in this area, these farmers also lose crops from trampling by elephants (Kabepelle, 2011). But not only elephants cause crop losses. Other raiders include yellow baboons (*Papio c. cynocephalus*), bush pigs (*Potamochoerus larvatus*), several other monkey species (such as Sykes' monkeys *Cercopithecus mitis*), crested porcupines (*Hystrix cristata*), birds, insects and rodents (Kabepelle, 2011). The beehive fence was placed in the southern part of the study area. This is where the elephants caused the most problems in the past, defined as the 'hotspot area of HEC' (Kabepelle, 2011) (Fig.3).

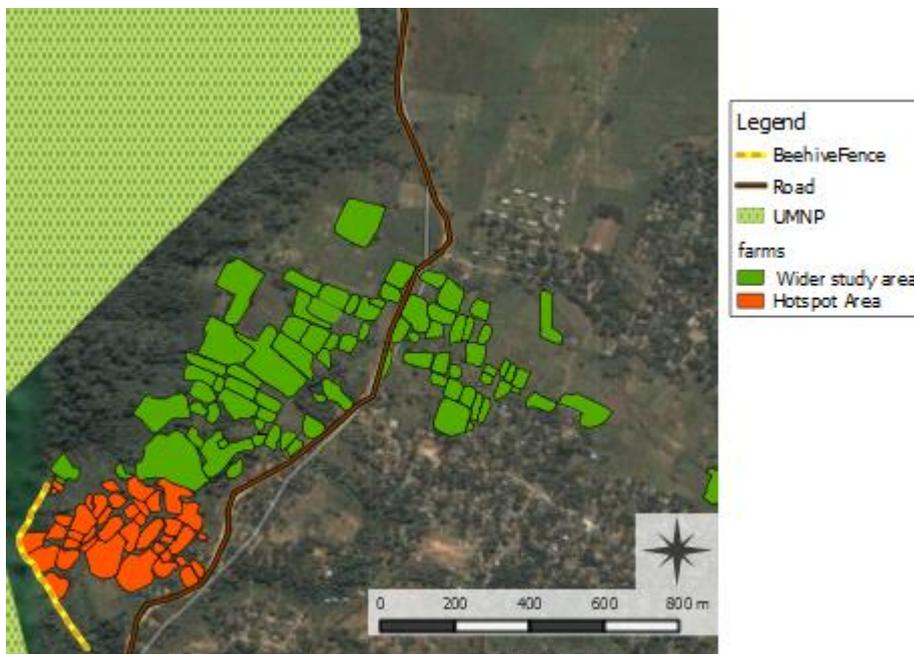


Figure 3 Study area inclusive the beehive fence and farm polygons. The orange polygons are farms within the hotspot area and the green and orange polygons together are the wider study area (map source Google, 2014).

To evaluate the effectiveness of the fence, analyses were done for the wider study area (WA) and for the hotspot area (HA). Because elephants mainly come out of the forest at the height of the hotspot area it is possible that the fence also has an effect on the farms further to the north. Therefore, the WA was taken into account. But because it is expected that the fence will be mainly effective in the HA, analysis was also done for the HA separately.

### 2.3 Data collection

In order to reduce the effect of annual variation on farmland damage and elephant raiding frequency, data were collected over a time period of three and a half years. The pre-fenced period was from the beginning of September 2010 until the end of September 2011, and a post-fenced period from the beginning of October 2011 until the end of January 2014. To see whether there was an effect of 'time of year', data were stratified per month (41 months) and by season (wet season and dry season) for a total of 8 categories (2 seasons per year).

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Every day elephants caused damage at least on one of the farms, data were collected. Researchers relied on self-reporting by farmers, who telephoned or sent the researchers a text message whenever their crops were damaged. In return, the farmers received free airtime. This method was used since September 2010. In addition to the text messages, researchers went out every day to generally survey the study area in case farmers did not notify researchers. Whenever there was no damage reported, and researchers did not see any damage, these days were considered to be days without damage.

Researchers checked affected farms to confirm that the damage was caused by elephants or if other crop-raiding species were suspected.

Measurements of damage were carried out mainly by two local trained research assistants with knowledge of the area, farming practices, crops grown and signs of elephant damage. A protocol and modified datasheet (Appendix 3) for the assessment of elephant crop damage was followed based on recommendations from the IUCN African Elephant Specialist Group (Parker, 2007).

#### *Estimation of farm size and extent of farmland damaged*

The perimeter of the whole farm was measured with a GPS. The surface area of every farm was calculated in sq. meters with the program MapSource.

The amount of crops which were raided or damaged during the night was measured by calculating the surface damaged in sq. meters. This was done by measuring the average length and average width of the damage with a measuring tape (Fig. 4). Therefore the length and width do not extend the furthest extremes of the damaged part (Parker, 2007). When the surface (in sq. meters) of the total farm and of the part damaged were both known, the percentage of the farm damaged was estimated.

Whenever there was an overall damage with small patches (width <10m) not damaged (Fig. 5A), or the damage was too close to the border of the farm (<10m) (Fig.5B), it was not possible to use a GPS (because of a standard error of  $\pm 5$  meters in open areas (Wing et al., 2005)) or tape measure. Researchers counted these areas as 100% damaged.

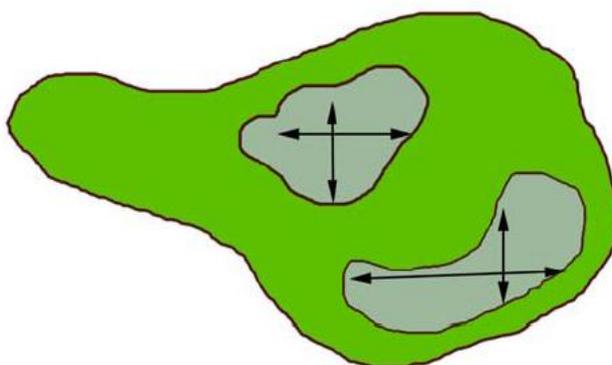


Figure 4 Estimating the area of damage by taking average dimensions. With light grey as area of damage within a farm (green) (from Parker, 2007).

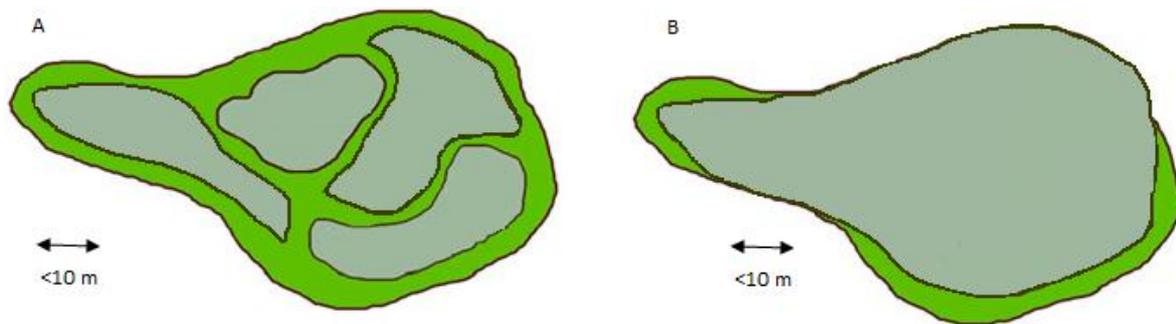


Figure 5 A) example of a farm (green) with overall damage with small patches (light grey) with a width of <10m not damaged, and B) example of a farm with damage which was too close to the border of the farm (<10m).

During the period between the beginning of December 2013 and the middle of January 2014, each time the researchers were unable to use tape measure or a GPS (as in Fig.5), the percentage damaged was estimated instead. The average percentage damage estimated in this period was 75%. Therefore, if the percentage damage for a farm was considered to be 100% before December 2013, it was adjusted to 75% to increase the accuracy of the estimated damage in the period before December 2013.

When the farmer had damage of tree crops (like mangos, coconuts, and pea trees) measuring the polygon did not represent the proportion crop losses, because the fruit productivity is dependent on the number and ages of trees (Chapman et al., 1992). Therefore these cases were not taken into account in this study. Another reason was because farmers in this area often plant trees far apart from one another, besides most farmers only had a few trees in addition to their other crops. And in most cases just one tree and sometimes only a few trees were damaged.

#### Other factors

Because elephants can smell bees (Osborn et al., 1995), it is possible that elephants walk through the fence at places where hives are not inhabited by bees. Therefore it is possible that the number of beehives occupied can have influence on the effectiveness of the fence. This can have influence on the distribution of damage by elephants. The numbers of hives occupied by bees, and their hive number were therefore recorded every month.



Figure 6 Elephant footprints on one of the farms in Mang'ula B.

Because geographical factors can also have influence on the distribution of damage, the distance from the center of the farms to the closest point of the UMNP and road were taken into account. These distances were calculated with the program QGIS Desktop 2.0.1. Furthermore, every time farmers and/or researchers have seen the elephants at the farmland, the numbers of elephants were recorded.

In December 2013 and January 2014, all the times when elephants walked through or around the beehive fence were recorded. This was accomplished by observing the raided area for footprints (Fig. 6), trails and dung.

## 2.4 Data analysis

### *Farmland damage and elephant crop-raiding frequency*

The two dependent variables used in this study were elephant crop-raiding frequency and the extent of farmland damage. Elephant raiding frequency was calculated as the number of elephant visits per unit time (per season or per month). The extent of farmland damaged was measured per farm per season in percentage, or in sq. meters for the total farmland per month. Every season had a different number of days, therefore, in order to make comparisons of raiding frequency and damage across seasons, the average frequency and extent of farms damaged per day were calculated separately for each season (Table 1).

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*Table 1 Eight seasons with time period (months, year), number of observation days, and fence status.*

Season#	Time period	Fence	Season	#Days
1	Sept- Oct 2010	No	Dry	61
2	Nov 2010 - May 2011	No	Wet	212
3	Jun - Oct 2011	No	Dry	153
4	Nov 2011- May 2012	Yes	Wet	213
5	Jun - Oct 2012	Yes	Dry	153
6	Nov 2012 - May 2013	Yes	Wet	212
7	Jun - Oct 2013	Yes	Dry	153
8	Nov 2013 - Jan 2014	Yes	Wet	84

Analyses were done on the total number of farms and for the individual farms. With the total number of farms, the whole area was counted as one area; a case study with a single subject design. In this model, to test the change in farmland damaged and elephant raiding frequency, it was only possible to take into account variables which changed over time for this whole area in total (like the placement of the fence and season). For the analysis with the individual farms there were multiple subjects (the individual farms). This way it was possible to take the changes over time into account as control variables, but also characteristics from individual farms (such as distance to park boundary, farm size, etc.). The damage and frequency were also taken into account as dependent variables per individual farm.

The relationship between farmland damaged and elephant raiding frequency was investigated using Pearson bivariate correlation coefficient. The correlation test was done on the total farms and on the individual farms, for the wider study area and the hotspot area. There was a positive correlation between elephant raiding frequency and farmland damaged, which ranged between weak and moderate ( $R^2 \leq .29$  = weak,  $R^2 \geq .30$  = moderate,  $R^2 \geq .50$  = strong) (Cohen, 1988) depending on the inputted variables (Table 2).

*Table 2 Pearson bivariate correlation between elephant raiding frequency and farmland damaged in the four situations. With the Pearsons correlation (R), the magnitude correlation (R<sup>2</sup>), the significance (P) and number of observations (N).*

	Elephant crop- raiding frequency				
	R	R <sup>2</sup>	P	N	Strength
Total farms, wider study area	.176	.03	.271	41	Weak
Total farms, hotspot area	.339	.12	.030	41	Weak
Individual farms, wider study area	.623	.39	.000	963	Moderate
Individual farms, hotspot area	.564	.32	.000	312	Moderate

This correlation indicates that when the frequency of elephant crop-raiding increases, the extent of farmland damaged also increases, as would be expected; however, the correlation is significant only when farms as a variable are analyzed at the individual level rather than total farms. Therefore, for the following analyses, both variables (raiding frequency and farmland damage) were used as dependent variables in the case that they are not always inter-related, or may indicate subtly different things (e.g. elephant behavioral patterns versus varying tendencies of different crops to sustain damage). The weak correlation suggests that raiding frequency and extent of crop damage should not necessarily be used interchangeably.

#### *Hive occupancy and lagged dependent variables*

Autocorrelation tests were done on the extent of damage, elephant raiding frequency and number of hives occupied. There was an autocorrelation found in the number of hives occupied. To correct the autocorrelation, lagged dependent variables (LDV) were used. LDV's are often used as a strategy for eliminating autocorrelations (Jorgenson et al., 2006). The dependent variable was lagged one period, this means that the first value of the dependent variable became the second value of the independent variable and so on (Table 3). This (lagged dependent) variable became the independent variable called 'number of hives correction'.

*Table 3 Example; one period lagged values of the first five months of the number of hives occupied.*

Month/year	No. Hives occupied	Lag1 no. hives occupied
Dec 2011	14	-
Jan 2012	14	14
Feb 2012	13	14
Mar 2012	17	13
Apr 2012	16	17

There was also an autocorrelation found in the extent of damage, and in elephant raiding frequency; with both variables, the length of the seasonal period was twelve months, but because this only occurred once (data was not collected long enough to see a second repeat), it was uncertain whether there was a real correlation, and therefore it was not possible to correct it.

Analyses were conducted at 2 scales: spatial (WA and HA) and temporal (pre-fence and fenced periods). To evaluate the effectiveness of the fence, all analyses included the variable 'fence' (yes/no), but varied with the other variables.

#### *Total number of farms*

Models were used on data from the wider study area and the hotspot area. The following dependent variables were used:

- total surface damage per month over the wider study area
- total surface damage per month in the hotspot area
- raiding frequency per month for the wider study area
- raiding frequency per month for the hotspot area

For these models fence (yes/no), season (dry/wet) and interaction between fence and season were treated as fixed factors. To achieve normality, total surface damaged and raiding frequencies were log-transformed using  $\text{Log}_{10}(X + 1)$ . Log transformations are used for not normal distributed dataset of positive continuous data (Keene, 1995).

### Individual farms

Analyses were carried out at farm level. Because the repeated measurements were done for every individual farm separately, farm# was considered to be the subject. Defining subjects becomes particularly important when there are repeated measurements; it is expected that the extent of damage, as well as the raiding frequency for a single farm during the study period are correlated (IBM Corporation 1989, 2011). The following dependent variables were used:

- extent of farmland damage per farm over the wider study area
- extent of farmland damage per farm in the hotspot area
- raiding frequency per farm per season for the wider study area
- raiding frequency per farm per season for the hotspot area

For these models farm# was treated as subject and season# (1-8) as the repeated variable with repeated covariance type AR(1): Heterogeneous. Autoregressive(1) (AR(1)) means that two measurements that are right next to each other probably will be correlated, and measurements further apart from each other will be less correlated (Kincaid, 2005). But the farms differ from each other (crop-type, size etc.), so there are heterogeneous variances among the different farms. Therefore, as repeated covariance type, the AR(1):Heterogeneous was used. Fence (yes/no), season (dry/wet) and fence\*season were treated as fixed factors, and farm size, perimeter, distance to road, and distance to UMNP were treated as covariates to test the effectiveness of the beehive fence for individual farms.

Many values in percentage damage were below 20%. To approach normal distribution for the percentage damage the arcsine transformation was carried out as follows:

$$\arcsine\left(\sqrt{\left(\frac{X}{100}\right)}\right)$$

This transformation is particularly recommended for datasets on percentage, if many values are below 20% or above 80% (Ahrens et al., 2001). To achieve normal distribution, raiding frequency was log-transformed  $\text{Log}_{10}(X + 1)$ .

### Fenced period

Analyses were carried out only with data after the fence was placed. This way it was possible to ascertain the effect of season on the number of hives occupied, and the effect of number of hives occupied on the raiding frequency and damage. The following dependent variables were used:

- number of hives occupied  
Here season (dry/wet) was treated as a fixed factor. Because there was an autocorrelation in the number of hives occupied, Lagged dependent variable (Lag1 no. hives occupied) was used as a covariate to correct.

- Total surface damaged per month
- Raiding frequency per month

For the two dependent variables above, season (dry/wet) was treated as a fixed factor, no. hives occupied as a covariate, and an interaction between no. hives occupied and season (dry/wet) was also explored. To achieve normality, the total sq. meters damaged and raiding frequencies were both log-transformed ( $\text{Log}_{10}(X + 1)$ ).

To determine the effectiveness of the beehive fence, Linear Mixed Models (LMM) and Generalized Linear Models (GLM) were used on data from the wider study area (approximate size of 0.35 sq. km)

and for the hotspot area (approximate size of 0.09 sq. km). Ten models were constructed with the two dependent variables combined with several spatial and temporal aspects. A third dependent variable was added to ascertain the effect of season on the number of beehives occupied (Table 4).

Table 4 Summary of variables tested in LMM and GLM in order to determine the effectiveness of the beehive fence. PB=Park Boundary

Dependent variable	Model used	Spatial aspects		Temporal aspect	Subject	Repeated variable	Fixed factor(s)	Covariate(s)
Extent of farm damage	GLM	Total farms	WA				-Fence (yes/no) -Season (dry/wet) -Fence*season	
	GLM	Total farms	HA				-Fence (yes/no) -Season (dry/wet) -Fence*season	
	LMM	Individual farms	WA		Farm#	Season#	-Fence (yes/no) -Season (dry/wet) -Fence*season	-Farm size -Perimeter -Distance to road -Distance to PB
	LMM	Individual farms	HA		Farm#	Season#	Fence (yes/no) Season (dry/wet) Fence*season	-Farm size -Perimeter -Distance to road -Distance to PB
	GLM	Total farms	WA	Fenced period			Season (dry/wet)	No. of hives occupied
Frequency of crop-raiding	GLM	Total farms	WA				-Fence (yes/no) -Season (dry/wet) -Fence*season	
	GLM	Total farms	HA				-Fence (yes/no) -Season (dry/wet) -Fence*season	
	LMM	Individual farms	WA		Farm#	Season#	-Fence (yes/no) -Season (dry/wet) -Fence*season	-Farm size -Perimeter -Distance to road -Distance to PB
	LMM	Individual farms	HA		Farm#	Season#	-Fence (yes/no) -Season (dry/wet) -Fence*season	-Farm size -Perimeter -Distance to road -Distance to PB
	GLM	Total farms	WA	Fenced period			Season (dry/wet)	No. of hives occupied
No. of hives occupied	GLM	Total farms	WA	Fenced period			Season (dry/wet)	No. of hives correction*

\*WA = Wider study Area/ HA= Hotspot Area

\*No. Hives correction = the LDV (lag1) of the no. of hives occupied

### Statistical modeling

Statistical modeling was only done for analysis done with the LMM.

The Akaike's Information Criterion (AIC) was used to compare the models (with the same dependent variable, but different numbers of parameters). The best fitting model has the smallest AIC (Akaike, 1979; Burnham & Anderson, 2002). To minimize the loss of information by just choosing the model with the lowest AIC, the Akaike Weight ( $W_i$ ) for each model was calculated (Burnham & Anderson, 2002).

To compare the different models, first the Delta AIC ( $\Delta_i$ ) for every model was calculated. The  $\Delta_i$  showed which model was relatively the best model and was calculated as

$$\Delta_i = AIC_i - \min AIC$$

Here the  $AIC_i$  is the AIC value for model  $i$ , the min AIC is the AIC value from the 'best fitting' model with the smallest AIC. Models with  $\Delta_i < 2$  suggests essential evidence,  $\Delta_i =$  between 3 and 7 can be considered as less essential and  $\Delta_i > 10$  indicates that the model is very likely not essential (Burnham & Anderson, 2002).

With the  $\Delta_i$  for each model, the Akaike Weight ( $W_i$ ) per model can be calculated. The  $W_i$  represents the ratio of the  $\Delta_i$  values per model to the whole set of candidate models:

$$Akaike\ weight = W_i = \frac{\exp(-\frac{\Delta_i}{2})}{\sum_{r=1}^R \exp(-\frac{\Delta_r}{2})}$$

The Akaike Weight indicates the chance (in percentage) that a model is the best one compared to the set of candidate models. The sum of all  $W_i$  together equals 1. Only the models with the highest  $W_i$  were taken into account, until the sum of these models counted a  $W_i \geq 0.95$ . Models with a  $\Delta_i > 3$ , were not taken into account. Therefore it was possible that the sum of the  $W_i$  did not always reach  $\geq 0.95$ . From the models taken into account, the model-averaged estimate of the regression per model per parameter, the model averaged P-value, and the Unconditional SE of the SE per model were calculated as follows

$$Model_{averaged} estimate = \hat{\vartheta} = \sum_{i=1}^R W_i \hat{\vartheta}_i$$

$$Unconditional\ SE = \sum_{i=1}^R W_i \sqrt{\hat{V}ar(\hat{\vartheta}_i | g_i) + (\hat{\vartheta}_i - \hat{\vartheta})^2}$$

### Identifying other factors influencing elephant raiding behavior

To understand better what influences the raiding behavior of elephants, independent sample t-tests were used. For both seasons (dry and wet), farms were divided into two groups; farms with more damage after the fence was placed and farms with less damage after the fence was placed. This was also the grouping variable which was used for the analysis; the change in damage (0 = less and 1 = more) per farm combined with the temporal aspect 'season'. Perimeter, size, distance to road, distance to park boundary, distance to fence, x-coordinate and y-coordinate per farm were treated as independent variables.

### 3 Results

#### 3.1 Characteristics of elephant crop-raiding along the border of the UMNP

Crop-raiding incidents occurred 94 times (out of 396 observation days) before the fence was placed and 99 times (out of 841 observation days) after the fence was placed.

Elephants visited farms mainly during hours of darkness (from 19.00 to 05.00h), but occasionally elephants visited farms earlier up to 16.00h, or stayed later until 06.30h. Elephants who visited farms varied from one individual to groups of 17 individuals, with 90% of the groups consisting of seven individuals or less (N = 57 observation days). One time an elephant pushed down a beehive which was recently occupied by bees. This was the first reported incident of an elephant pushing down a hive occupied by bees along the Udzungwa Mountains National Park boundary (Fig. 7).

Five reported elephant kills occurred at farms or near villages. The first reported kill was in May 2009 (before the study period commenced), when there was an elephant shot by a Game Officer (Jones, pers. comm., 2013).

In 2010, a dead bull (shot in his leg) was found in the forest after elephants were driven back from the farmland into the forest (by park rangers) (Jones, pers. comm., 2013). It is not known who shot the elephant. In May 2012, a dead elephant was found close to the headquarters of the UMNP. This elephant was most likely poisoned by villagers (Jones, pers. comm., 2013). In August 2012, another PAC incident took place, carried out by the Game Officer (Jones, pers. comm., 2013). And finally, in January 2014 an elephant died after it walked underneath a low hanging electricity wire near a local school (Jones, pers. comm., 2014) (Fig. 8).



Figure 7 Populated beehive toppled by elephant in the night of 7th - 8th January 2014. The damaged hive was found lying upside down almost 2 meters from its original position towards the Udzungwa Mountain National Park boundary (Picture Christopher Reusch, 2014).

#### 3.2 Total farms

All analyses were done with the Generalized Linear Model (GLM). Even though the damage decreased by a factor of 2.55 in the WA and by a factor of 1.49 in the HA (Appendix 4), the beehive fence did not have a statistical significant effect on the total damage inflicted on farms by elephants per month (WA  $P=0.188$ , HA  $P=0.648$ ). The fence also did not have a significant effect on the elephants' raiding frequency per month in the HA, but did have an effect on the WA (WA  $P=0.018$ , HA  $P=0.184$ ). Season did not affect total farm damage (WA  $P=-0.522$ , HA  $P=0.511$ ) or raiding frequency (WA  $P=0.676$ , HA  $P=0.936$ ). Furthermore, the interaction between fence and season was not significant in relation to total farm damage (WA  $P=0.584$ , HA  $P=0.331$ ) and raiding frequency (WA  $P=0.139$ , HA  $P=0.098$ ). These results held for the wider study area, and also for the hotspot area. A summary of the changes over time in the WA is shown in figure 8.

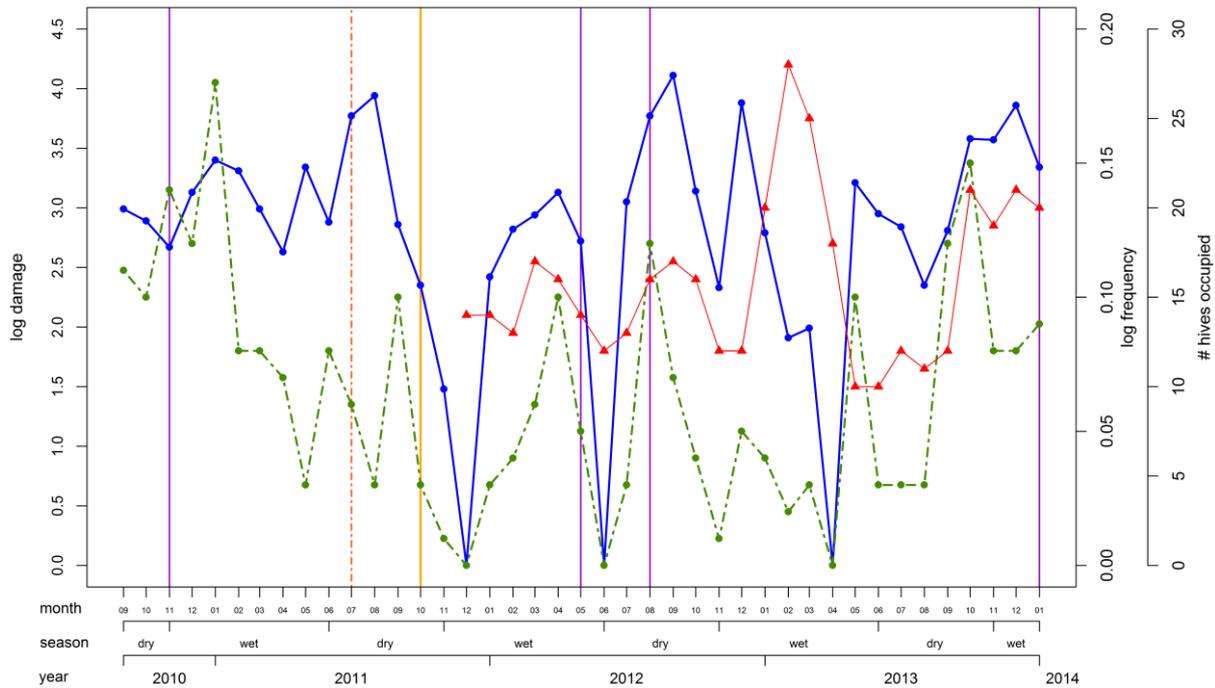
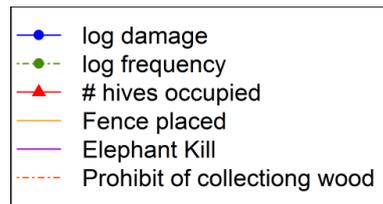


Figure 8 Summary; changes over time in the WA; in total surface damaged (log transformed), raiding frequency (log transformed) per month in the wider study area, and changes over time in number of hives occupied per month. Showing the two different seasons as well as when the beehive fence was established. In addition it shows when elephant kills occurred and from when it was prohibited for locals to collect fire wood in and along the border of the UMN.



### 3.3 Fenced period

GLM was used for analysis of data from the fenced period. The number of hives occupied did not have a significant effect on the damaged surface of the farm (WA  $P=0.982$ , HA  $P=0.366$ ). While the number of hives occupied also did not influence elephants' raiding frequency in the hotspot area (HA  $P=0.173$ ), it did have a significant effect on elephant raiding frequency over the wider study area ( $P=0.018$ ). The raiding frequency in the wider study area increased while the number of hives occupied also increased. The interaction between number of hives occupied and season (dry/wet) had a significant effect on the raiding frequency in the wider study area ( $P=0.040$ ) (Fig. 8). When the numbers of hives occupied in the wet season increased, raiding frequency also increased. Whereas in dry season the frequency decreased slightly with an increasing number of hives occupied (Fig. 9). The interaction was not significant in the hotspot area ( $P=0.070$ ). The interaction also did not have a significant effect on the sq. meters damaged in both areas (WA  $P=0.103$ , HA  $P=0.430$ ). Season did not have a significant effect on the number of hives occupied ( $P=0.62$ ).

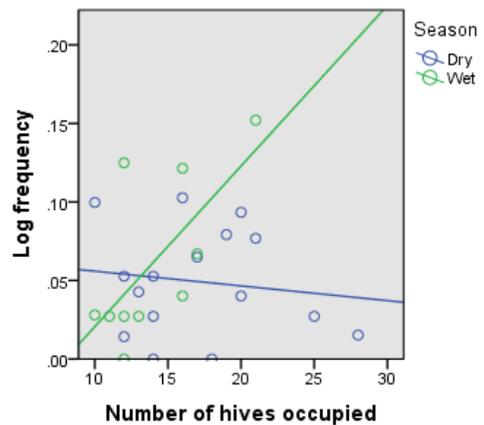


Figure 9 Elephant raiding frequency (log-transformed) as a function of number of hives occupied in relation to season in the wider study area.  $N=26$

### 3.4 Individual farms

The LMM was also used for analysis of data at the individual farm level. The beehive fence was found to have a significant effect on the percentage damage (WA  $P < 0.001$ , HA  $P = 0.002$ ) and on elephant raiding frequency per season (WA  $P = 0.001$ , HA  $P = 0.021$ ) in both areas (wider study area and hotspot area) (Table 5). The extent of farm damage and elephant crop-raiding frequency both decreased in the wider study area and in the hotspot area, after the fence was placed, when analyzing data in the multiple rather than single subject design.

There was significantly more damage in both areas during wet season compared to dry season (WA  $P < 0.001$ , HA  $P < 0.001$ ), but the frequency did not differ significantly across the seasons (WA  $P = 0.104$ , HA  $P = 0.493$ ).

The interaction between fence and season had a significant effect on the mean farm damage in the wider study area ( $P = 0.034$ ), but not in the hotspot area ( $P = 0.881$ ). This interaction also had a significant effect on the raiding frequency in both areas (WA  $P < 0.001$ , HA  $P = 0.057$ ) (Table 5). The beehive-fence led to a higher reduction of the mean damage during wet season, whereas the mean frequency was reduced more during dry season (Fig. 10).

The percentage damage ( $P < 0.001$ ) and raiding frequency ( $P = 0.032$ ) in the wider study area (longest distance in this area 1515 meters) increased significantly with decreasing distance from the farm to the park boundary; however, this did not influence elephant raiding frequency in the hotspot area (longest distance 522 meters) (appendix 5). This indicates that damage and raiding frequency only decreases with increasing the distance to the UMNP whenever farms are at least at 522 meters away from the park.

The distance from the farms to the road did not have a significant effect on the percentage damage and raiding frequency (table 5).

Table 5 Overview model averaged P-values per variable

Variable	Model averaged P- value			
	Damage WA	Damage HA	Frequency WA	Frequency HA
Fence	<0.001	0.002	0.002	0.021
Season	<0.001	<0.001	0.104	0.493
Fence*season	0.034	0.881	<0.001	0.057
Distance park boundary	<0.001	0.182	0.032	0.161
Distance to road	0.375	0.699	-	-
Perimeter	-	0.055	-	0.320
Farm size	-	-	-	0.023

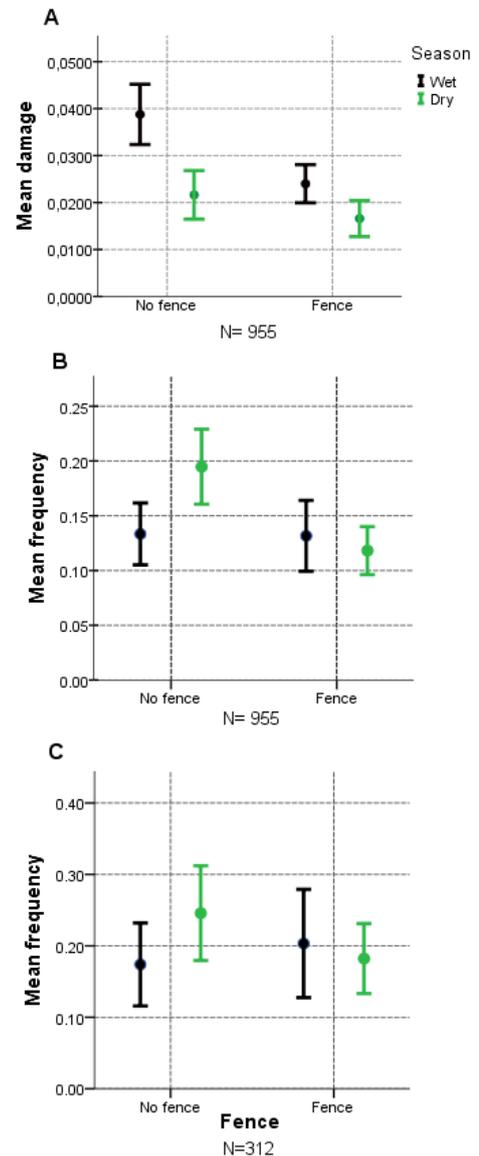


Figure 10 Interaction between 'fence (no fence/fence)' and 'season (dry/wet)' with: A. mean percentage damaged per farm for the wider study area (arcsine square-root transformation) B. raiding frequency per farm for the wider study area (log transformed) and C. raiding frequency per farm for the hotspot area (log transformed)

### 3.5 Identifying other factors influencing elephant raiding behavior

Independent sample t-tests were used to understand better what influences the raiding behavior of elephants. In dry season there was a significant difference in direction between the two groups; farms with less damage (N=78) and farms with more damage (N=43) after placement of the fence), farms with less damage were placed further north in the study area ( $P=0.016$ ). At the same time the farms with more damage were placed further to the east ( $P=0.012$ ) and further away from the park boundary ( $P=0.005$ ). Size ( $P=0.12$ ), perimeter ( $P=0.202$ ) distance to the road ( $P=0.927$ ) and distance to the fence ( $P=0.084$ ) did not significantly change among the two groups in dry season after the fence was placed. In wet season the group of farms with more damage (N=47) were significantly further east ( $P=0.009$ ), further away from the park boundary ( $P=0.05$ ) and were less far away from the fence ( $P=0.003$ ) than the farms with less damage (N=74) (Fig. 11).

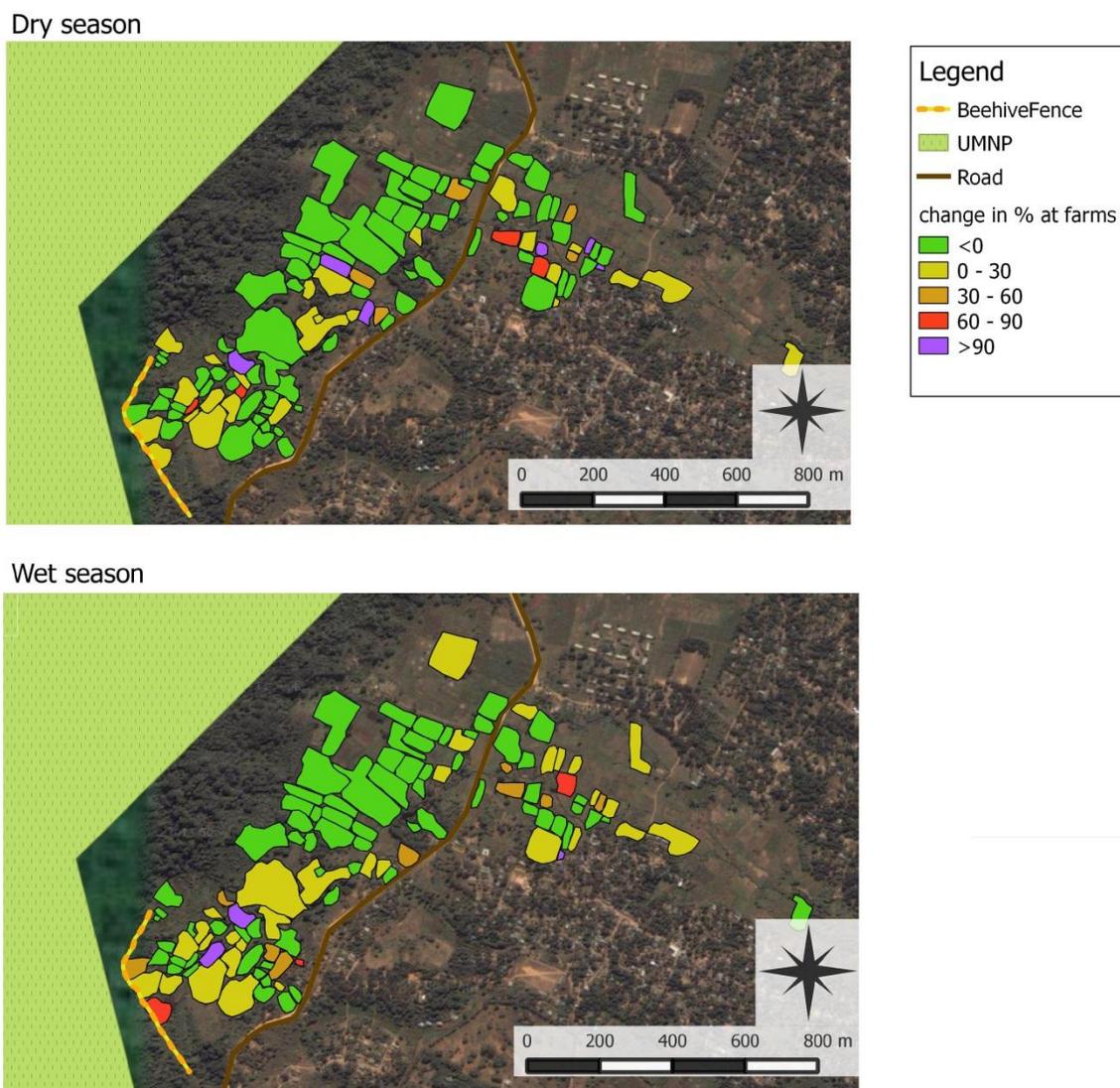


Figure 11 changes in percentage damage after the placement of the beehive fence in dry season and in wet season

## 4 Discussion

First, no clear relationship was found between extent of farmland damage and elephant crop-raiding frequency. This suggests that a high frequency of elephant crop-raiding does not necessarily result in greater crop damage, and that other factors may be at play, for example seasonal differences in crop availability.

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The results are consistent with this hypothesis as they indicate that, at the level of individual farms (multiple-subject design), elephants' frequency of raiding stayed more or less the same all year round, but there was more accrued crop damage during the wet season. Therefore, raiding frequency as measured in this study is more indicative of visit frequency but not raiding/crop consumption. These may indicate slightly different things as elephants may visit farms at a consistent rate over the entire year, but may raid more intensively during the wet season. Thus, the likely explanation is that overall crop availability and specific availability of certain types of crops is higher in the wet season (Rode et al. 2006). Another possible explanation of higher wet season damage to crops could be the decline in the quality of wild grasses particularly in (the end of) wet season making elephants more reliant on crops (while still raiding at a similar frequency to the dry season) (Osborn, 2004).

Elephants primarily select the highest nutritious food available throughout the year, instead of selecting the food that is most available (Osborn, 2004). Because crops maintain the quality nutrient which elephants need, after the wild grasses become desiccated, this can motivate elephants to take more risk (and stay longer) to feed on crops (Osborn, 2004). For instance in the study area, rice is the only crop which is not grown in both seasons, it is grown in wet season only. Everything else is grown in both seasons (Mndeme and Kidibule, pers. com. 2014). Rice provides elephants with the vitamin Biotin, an important water soluble B vitamin (Sadler, 2001). Its main function is fixation of carbon dioxide in cells, which is required for some critical metabolic pathways, such as fatty acid and energy metabolism (Sadler, 2001).

Although there was no significant difference in the total surface damaged and raiding frequency before and after the beehive fence was placed (in the wider study area and in the hotspot area), a significant difference in the extent of damage and elephant raiding frequency after placement of the fence was found for individual farms. Despite the observation that crop-raiding by elephants increased at some farms after the fence was placed, the overall results of this study indicate that the beehive-fence is at least partly effective in deterring elephants. It is possible that the effectiveness of the fence was detected at multiple subject level because of the repeated variable and co-variables which were added to correct for other factors which influence the effectiveness of the fence. Furthermore the sample size for the individual farms (WA =955 HA=312) are much higher than for the total surface (41 for both areas). The sample size can have an influence on the standard error (Orme, 2010), hence the significance. After all, the damage at single subject level did decrease by a factor of 2.55 in the WA and by a factor of 1.18 in the HA, but this was not statistically significant.

A reason why particular farms undergo more damage could be because of a broken wire and because elephants walked around the fence. There are a few hypotheses that could explain why more damage occurred on these farms including 1) Elephants could pass through the fence to enter the farmland and would walk around the fence to leave the farmland, 2) elephants would walk through the fence to enter farms and took the same way back to the forest, 3) elephants walked around the

fence to enter the farmland and walked the same way back to the forest. Despite King et al. 2009 showing that the beehive fence was effective without a wire, this research indicates that it is important to keep the wire between the beehives up for the fence function to be maintained, and replace a broken wire as soon as possible or elephants will soon exploit this gap as an entrance point (suggesting that they are even prepared to walk between occupied beehives at least at night). Furthermore, it is possible that there are preferences for different crops at some of these farms which elephants then target; however, from observations, it appears that most farms contain similar combinations of crops.

In both seasons, farms which suffered more damage after the placement of the fence were located further to the east, away from the park boundary. However, farms with more damage were also found closer to the park boundary. With this research it was not possible to elucidate the reason for this. Solely in wet season elephants raided at higher extent at farms located more closely to the beehive fence, this suggests that elephants do not necessarily stay away from the beehive fence. Since King et al (2011) only found that elephant avoid disturbed bees; it is likely that elephants do not fear undisturbed bees. This gives another reason to keep the fence maintained, since bees will not get disturbed when an elephant walks through the fence without a wire.

There was a significant interaction between the beehive fence and season in the wider study area. While the damage decreased mainly in the wet season, the frequency decreased mainly in dry season after the fence was placed. This might indicate that elephants did not take additional risks anymore to increase raiding (and therefore stayed longer) in wet season than in dry season after the fence was placed. More information on the effects of season and the fence is needed to explain the interaction between the fence and season more clearly.

The results indicate that the damage and raiding frequency only decreases whenever farms are at least 522 meters away from the park. Elephants use specific areas to avoid risks (Lee & Graham, 2006); this also includes risks in human dominated landscapes (Graham et al., 2009). The further away from the park boundary, the more human settlements are found in this area. The houses of the villages are approximately placed at 800 meters from the park boundary, which possibly explains why there was no significant difference between farms close to the park boundary or further away in the hotspot area, where the farm with the longest distance is 522 meters away from the park.

The distance to the dirt road did not predict the occurrence or the extremity of farmland damaged and raiding frequency, the same result was found along the border between Kenya and Tanzania (Sitati et al. 2003). This may indicate that elephants do not necessarily experience more risk near dirt roads; however, this may change if the road is turned into tarmac in the future.

At the level of the wider study area, the number of hives occupied had a significant influence on elephant raiding frequency. The opposite than expected was found: the more hives occupied, the higher elephant raiding frequency. This was not the case in the hotspot area, here the number of hives occupied did not have influence. A possible explanation could be that elephants decided to walk more often around the fence whenever there were more hives occupied. This way, elephants would avoid the hotspot area and increase the frequency in the wider study area. But since elephants still can reach the hotspot area by walking around the fence (Hoare, 2012) this does not mean that the frequency has to decrease in the hotspot area.

Also the interaction between the number of hives occupied and season was significant at the level of the wider study area. As the number of hives occupied by bees increased in the wet season, the

frequency of elephant raiding also increased; however, this relationship was most likely not causal but correlational. Whereas in dry season elephant raiding frequency decreased slightly with an increasing number of beehives occupied in the wider study area, this interaction was not found in the hotspot area. There is a hypothesis that could explain why more damage occurred while the number of hives occupied increased also during wet season. The decline in quality of wild grasses in wet season (Osborn, 2004) causes elephants to take more risk, even when there are more hives occupied.

#### Other effects

There are more variables which can have an effect on crop-raiding by elephants. One of the things that occurred in the area is PAC and illegal hunting on elephants. This could have a short term effect on the behavior of crop-raiding elephants (Chiyo et al., 2012; Smit, 2013; Parker, 2007). Even though elephants return to places where they have successfully raided in the past (Sitati et al., 2003), many crop-raiding elephants are occasional raiders and thus their removal does not eliminate the problem (Chiyo et al., 2012; Smit, 2013). "Problem" individuals are also difficult to accurately identify (Chiyo et al., 2012).

Another variable which could have had effect was the presence and absence of people in the area. Until July 2011, locals were allowed to collect firewood along the border and to an extent, inside of the national park (Nowak, pers.com, 2013). Because elephants avoid detection by humans (Chiyo et al., 2012), it is possible that elephants stayed further in the forest whenever local inhabitants were looking for firewood (once every week). The ban and the ensuing absence of people at and just within the park boundary could have led to an increase of crop-raiding following the firewood collection ban. This possibility has actually been explicitly expressed by local inhabitants (Nowak, pers. comm. 2013).

## 5 Conclusion

Careful monitoring of deterrent effectiveness is needed prior to application, expansion or modification of deterrent methods. The beehive fence in this study had mixed success depending on the level and scale of analysis. Overall, there appeared to be no reduction in elephant raiding frequency and the extent of farm damage after the fence was constructed; however, when examining individual farms, and correcting for repeated measurements and co-variables, the raiding frequency and the extent of damage at some of these farms did indeed decrease (43 farms out of 121 in dry season and 47 farms in wet season).

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Other factors which influenced elephant crop damage included season (wet/dry), distance of farm to the park boundary, perimeter of the farm and farm size. The extent of damage was higher in wet season than in dry season in the Wider Study Area (WA) and in the Hotspot Area (HA) (WA  $P < 0.001$ , HA  $P < 0.001$ ), but the frequency did not differ significantly across the seasons (WA  $P = 0.104$ , HA  $P = 0.493$ ). The extent of damage ( $P < 0.001$ ) and raiding frequency ( $P = 0.032$ ) decreased with increasing the distance to the UMNP whenever farms are at least at 522 meters away from the park.

Furthermore there was found that elephant raiding frequency and extent of crop damage are not synonymous. This is consistent with the finding that the frequency did not differ between the seasons, but the extent of damage increased in wet season. Therefore these two variables should not be used interchangeably in studies of HEC.

## 6 Recommendations

Because there was a mixed success in the effectiveness of the fence, further research is needed. The main questions which need to be addressed are 1) why was the effect of the fence not detected at the level of the wider area, and 2) how do farms (with more damage after the fence was placed) differ in placement and other factors not taken into account in this study?

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Because this research indicates that it is important to keep the fence maintained, it is recommended that farmers responsible for maintaining the fence be supported by national park authorities and local NGOs including WWF, STEP and UEMC. At the moment, Raleigh volunteers from the UK are the main source of support to the Njokomoni farmers co-op. Reliance on foreign volunteers for support can be precarious unless a formal MoU is signed.

Future data should be collected on the status of the fence for every event of elephants passing through the beehive fence. Questions which need to be addressed when an elephant walks through the fence are: where did the elephants walk through the fence, was there a wire at the place the elephants walked through the fence, and were the hives occupied by bees? Also recommended is to observe elephants' behavior towards the beehive fence at night, in order to better understand the effectiveness of the fence at this time when elephants actually raid.

Two other questions which still need to be addressed are: 1) did the absence of people (because of canceling permission for local inhabitants to collect firewood) along the UMNP border since June 2011 increase elephant raiding frequency and extent of damage, and 2) does the presence of beehives (and thus bees) in the crop area actually increase crop yield because of a pollination service, and hence a seeming increase in elephant raiding frequency and extent of damage at the level of the wider study area?

In order to detect the cause of the increasing extent of damage in wet season two more things need some attention; to test whether elephants eat more rice in relation to other crops available in wet season, and whether the decreasing nutrients in wild grasses in wet season is important to the (more than savanna-dwelling elephants) frugivorous forest elephants in the study area.

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## **Appendices**

- Appendix 1 - Chili-oil fence
- Appendix 2 - List of all crops eaten and/or trampled by elephants
- Appendix 3 - Datasheet
- Appendix 4 - Results total farms
- Appendix 5 - Results individual farms

## Appendix 1. Chili oil fence

Chili-oil fences consist of a string hung between bamboo poles and/or existing trees, with pieces of fabric soaked in dried chilies and used engine oil (Fig.12) (Hoare, 2012). Because the capsaicin from the chili is only soluble in oils it is necessary to use chili in combination with oil. Ideally, to decrease waste, mechanical oil (gained without heating or using other resources) should be used. (Hoare, 2012) Because the chili and oil needs to be reapplied after every raining day (Hedges et al., 2009), which leads to high costs (Hoare, 2007; Hedges et al., 2009), discarded engine oil is often used (Hoare, 2012). To dissolve the capsaicin, the farmers in Udzungwa used old engine-oil mostly supplied by a local sugar company (Nowak, pers.com, 2013). Even though farmers have benefit because of the low costs for oil, there is also a disadvantage by using engine-oil. Soil contaminated by waste engine-oil contains hydrocarbons and heavy metals such as carbon, potassium and magnesium. These nutrients occur in healthy soil, but increasing the saturation, which happens in the waste engine-oil contaminated soil, can lead to a die-off of microbial life in the soil which in turn can lead to growth failure by plants and failure to germinate in seeds (Beckley et al., 2010).

Chili-oil fences are used in different places where HEC occurs (Chelliah et al., 2010, Hedges et al., 2009) and seem to have different effects on different locations. For example, there was a significant deterrent effect found in a study on a fence with chili and tobacco powder mixed with waste oil (Chelliah et al., 2010). In contrast to that, Hedges et al., who did study on chili-grease (oil) fences in 2009, did not find a significant deterrent effect, but believed other chili-based deterrents may be effective (Hedges et al., 2009).

Before 2009, no other studies were done to identify what the contributions of chili-based deterrents are to crop defense systems (Hedges et al., 2009). This is why Hedges et al. 2009 was not able to give a general conclusion about the effectiveness of chili on crop raiding due to elephants. It is possible, that under certain conditions, chili- based methods provide deterrence (Hedges et al., 2009). Chili and tobacco powder mixed with waste oil, tested in 2010 and conducted over 2–3 months, showed significantly to be a deterrent method. During low-rainfall season it was more significant than during high- rainfall season (Chelliah et al., 2010). Due to the rain the chili and oil washes off the pieces of fabric. This makes the method expensive and time consuming (Hedges et al., 2009).



Figure 12 Villagers and community leaders visit the fence. (Southern Tanzania Elephant Project, 2013)

Because of the high expenses, the time needed to maintain the fence and the pollution with waste engine oil, the fence does not exist anymore along the border of the UMNP (Nowak, pers.com, 2013).

## Appendix 2 List of all crops eaten and/or damaged by elephants

Common English Names	Common Swahili Names	Scientific Names	Tree/ plant classified
Pumpkin	Maboga	Cucurbita maxima	Plant
Okra	Bamia	Hibiscus Esculentus	Plant
Maize	Mahindi	Zea mays	Plant
Banana	Migomba	Musa acuminata	Tree
Sugar cane	Miwa	Saccharum officinarum	Plant
Spinach	Mchicha	Spinacea oleracea	Plant
Coconut trees	Minazi	Cocos nucifera	Tree
Cassava	Mihogo	Manihot esculenta	Plant
Pawpaws	Mipapai	Asimina triloba	Tree
Black-eyed peas	Kunde	Vigna unguiculata	Plant
Chilli	Pilipili	Capsicum frutescens	Plant
African eggplant	Nyanya chungu	Solanum macrocarpon	Plant
Rice	Mpunga	Oryza sativa	Plant
American nightshade	Mnafu	Solanum americanum	Plant
Pineapples	Mananasi	Ananas comosus	Plant
Chinese Cabbage	Chainizi	Brassica pekinensis	Plant
oranges	Machungwa	Citrus sinensis	Tree
Tomatoes	Nyanya	Lycopersicon esculentum	Plant
Mangoes	Maembe	Mangifera indica	Tree
Pigeon peas	Mbaazi	Cajanus cajan	Plant
Egg plant	Biriginganya	Solanum melongena	Plant
Ethiopian mustard	Figiri	Brassica carinata	Plant
Potatoes	Viazi	Solanum tuberosum	Plant
Pepper	Pilipili hoho	Capsicum annum	Plant
Cucumber	Tango	Cucumis sativus	Plant
Taro	Magimbi	Colocasia esculenta esculenta	Plant
Avocado tree	Parachichi	Persea americana	Tree
Christmas tree	Mkrisimasi	Pseudotsuga menzietii	Tree
Groundnuts	Karanga	Arachis hypogaea	Plant
Guava tree	Mpera	Psidium guajava	Tree
Sweet potatoes leaves	Matembele	Ipomoea batatas	Plant

(Kabepel, 2011)

### Appendix 3 Datasheet

#### Elephants damage form

Form no. \_\_\_\_\_

Village/ street \_\_\_\_\_

Destruction date \_\_\_\_\_

Reporting date \_\_\_\_\_

Enumerator \_\_\_\_\_

Tot.no of sheets \_\_\_\_\_

Fences damaged No \_\_\_\_\_ YES \_\_\_\_\_

Farm(s) number \_\_\_\_\_

GPS # \_\_\_\_\_

Coordinates \_\_\_\_\_

Track- log number \_\_\_\_\_

Comments: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

#### Destroyed crops

Type of crop	Part	Age	Quality	Eaten/trodden	Destruction area	Farm #
Crop 1:						
Crop 2:						
Crop 3:						
Crop 4:						
Crop 5:						
Crop 6:						
Crop 7:						
Crop 8:						
Crop 9:						
Crop 10:						
Crop 11:						
Crop 12:						
Crop 13:						
Crop 14:						
Crop 15:						
Crop 16:						
Crop 17:						
Crop 18:						
Crop 19:						
Crop 20:						
Crop 21:						
Crop 22:						
Crop 23:						
Crop 24:						

### Appendix 4 Results total farms

The decreasing factor of the extent of damage for both areas (WA and HA) were calculated as follows;

$$F = 10^{(Mean(0)-Mean(1))}$$

Here F was the decreasing factor of the extent of damage, Mean(0) was the mean of the log damage without fence and the Mean(1) was the mean of the log damage with fence (table 6 and 7).

Table 6 SPSS Estimates output of GLM with the mean of log damage in the Wider Study Area

Estimates				
Fence	Mean	Std. Error	95% Wald Confidence Interval	
			Lower	Upper
.0	3.0831	.24723	2.5986	3.5677
1.0	2.6770	.18433	2.3157	3.0382

\* Fence 0 = no fence, Fence 1 = with fence

Therefore, for the WA the decreasing factor of the extent of damage after the placement of the fence is:

$$10^{(3.0831-2.677)} = 2.5474$$

Table 7 SPSS Estimates output of GLM with the mean of log damage in the Hotspot Area

Estimates				
Fence	Mean	Std. Error	95% Wald Confidence Interval	
			Lower	Upper
.0	2.3743	.28277	1.8201	2.9285
1.0	2.2133	.21083	1.8001	2.6266

\* Fence 0 = no fence, Fence 1 = with fence

And for the HA:

$$10^{2.3743-2.2133} = 1.4887$$

## Appendix 5 Results individual farms

### Extent farmland damaged for the wider study area

For the extent of farmland damaged in the wider study area, the best model had an Akaike Weight of 0,59, to approach  $\geq 0,95$  two models were added (table 8).

Table 8 Summary results after model averaging: effects of each parameter on percentage of farmland damaged (arcsine square-root transformation) in the wider study area.

Model	# Parameters	Delta AIC	Akaike Weight		
Fence, season	2	2.26	0,143628319		
Fence, season, distance to UMNP, distance to road	4	0.27	0,397730796		
Fence, season, fence*season	3	0	0,455217527		
Estimates ( $\pm$ unconditional SE) obtained from model averaging					
Parameter	Fence	season	Distance to UMNP	Distance to road	Fence*season
Estimates	0,8529496	-0,013001513	-0,000015	0,000007	-0,008495
Confidence interval	0,818636314 0,887263	-0,015914789 -0,01009	-0,00002284 -0,00000716	-0,00000868 0,00002268	-0,01632716 -0,00066
Model averaged P-value	1,64E-08	5,64E-14	0,000348	0,380	0,034465
Relative importance	-	1.00	0.33	0.33	0.33

\* Fence = 1 was the reference category (1=yes, 0=no)

\* season = wet season was reference category

\* season# (1-8) was insert as repeated variable

\* N= 955

**Extent farmland damaged for the hotspot area**

For the extent of farmland damaged in the hotspot area, the best model had an Akaike Weight of 0,29, to approach  $\geq 0,95$  four models were added (table 9).

*Table 9 Summary results after model averaging: effects of each parameter on percentage of farmland damaged (arcsine square-root transformation).*

Model	# Parameters	Delta AIC	Akaike Weight			
Fence, season	2	0,458	0,228437			
Fence, season, fence* season	3	2,433	0,085079			
Fence, season, distance to UMNP	3	0	0,28717			
Fence, season, distance to UMNP, distance to road	4	1,850	0,113878			
fence, season, distance to UMNP, perimeter, fence*season	5	0,334	0,243019			
Estimates ( $\pm$ unconditional SE) obtained from model averaging						
Parameter	Fence	season	Distance to UMNP	Distance to road	Fence*season	perimeter
Estimates	0,016162	-0,01151	-0,000025	0,000014	-0,00035	0,000056
Confidence interval	0,007444 0,024879	-0,01641 -0,00661	-0,00000832 0,00000832	-0,0000546 0,0000826	-0,00485 0,004149	0,00000112 0,000111
Model averaged P-value	0,002165	2,14E-05	0,182454482	0,699863	0,881004	0,055235
Relative importance	-	1.00	0.60	0.20	0.40	0.20

\* Fence = 1 was the reference category (1=yes, 0=no)

\* season = wet season was reference category

\* season# (1-8) was insert as repeated variable

\* N= 312

**Elephant raiding frequency for the wider study area**

For the elephant raiding frequency in the wider study area, the best model had an Akaike Weight of 0,51, to approach  $\geq 0,95$  one model was added (table 10).

Table 10 Summary results after model averaging: effects of each parameter on the elephant raiding frequency in the wider study area

Model	# Parameters	Delta AIC	Akaike Weight
Fence	1	0.902	0,463897225
Fence, season	2	0	0,514410215
Estimates ( $\pm$ unconditional SE) obtained from model averaging			
Parameter	Fence	Season	Fence* season
Estimates	0,045564	0,01616	-0,07416
Confidence interval	0,020463	-0,00325	-0,10977
	0,070664	0,035566	-0,03856
Model averaged P-value	0,00158	0,103562	0,000069
Relative importance	-	0.66	0.33

- \* Fence = 1 was the reference category (1=yes, 0=no)
- \* season = wet season was reference category
- \* season# (1-8) was insert as repeated variable
- \* N= 955

**Elephant raiding frequency for the hotspot area**

For the elephant raiding frequency in the hotspot study area, the best model had an Akaike Weight of 0,51, to approach  $\geq 0,95$  one model was added (table 11).

Table 11 Summary results after model averaging: effects of each parameter on the elephant raiding frequency in the hotspot area

Model	# Parameters	Delta AIC	Akaike Weight			
Fence, season, perimeter, distance to UMNP	4	2,311148	0,123881			
Fence, season, distance to UMNP, perimeter, farm size	5	1,538906	0,182261			
Fence, season, distance to UMNP, farm size	4	0	0,393427			
Fence, season, fence*season, perimeter, farm size	5	0,742864	0,271365			
Estimates ( $\pm$ unconditional SE) obtained from model averaging						
Parameter	Fence	Season	Fence*season	Distance to UMNP	Farm size	Perimeter
Estimates	0,093584	0,01476	-0,066	-0,00022	3,93E-05	-0,00013
Confidence interval	0,024321	-0,02717	-0,13226	-0,00052	9,9E-06	-0,00129
	0,162847	0,056691	0,000263	8,24E-05	6,88E-05	0,001029
Model averaged P-value	0,021153	0,492386	0,056677	0,160827	0,023116	0,319764
Relative importance	-	1.0	0.25	0.75	0.75	0.75

- \* Fence = 1 was the reference category (1=yes, 0=no)
- \* season = wet season was reference category
- \* season# (1-8) was insert as repeated variable
- \* N= 312