

**The interaction between the African elephant
(*Loxodonta africana africana*) and the African honey
bee (*Apis mellifera scutellata*) and its potential
application as an elephant deterrent**

A thesis submitted to the University of Oxford for the
degree of Doctor of Philosophy in Zoology



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Declaration:

This thesis was supported by a joint ESRC/NERC studentship grant. The proposed blend of the two research fields has been adhered to, creating an interdisciplinary thesis with a 65% emphasis on Natural Science and a 35% emphasis on Social Science.

I confirm that this thesis is all my own work, unless otherwise stated, and with the exception of three data analyses in Chapter 3. These analyses, and assistance with the data collection, were conducted by my colleague Dr Joseph Soltis from the Bioacoustic Laboratory at Disney's Animal Kingdom, Education and Science Department, Florida.

Specifically, the data analyses Dr Soltis conducted were:

Section 3.2.1. Analysis of 120 infant (0-3 year old) zoo elephant calf vocalisations from Disney's acoustic database to help us identify 0-2 year old vocalisations from our wild Samburu acoustic data set and remove them from the sample.

Section 3.2.2. Measuring and statistical analysis of the fundamental frequency, mean frequency and frequency range of vocalisations recorded from our wild Samburu elephant database.

Section 3.2.3. Shifting of the second formant in the bee rumble to represent those more typical of the white noise rumble to enable us to carry out the playback experiments as described in the remainder of Chapter 3. This includes the production of Figure 3.2.

This collaborative research described in detail in Chapter 3 enabled us to publish a joint authorship paper King *et al.*, (2010) in the journal PLoS One.

The text, excluding figure legends, tables, references and Appendix, does not exceed 45,000 words.

Signed

Date

ABSTRACT

The conceptual origin of this DPhil thesis was based on one foundation publication by Vollrath and Douglas-Hamilton (2002a) "*African bees to control African elephants*". The authors made a unique discovery that African elephants will avoid feeding on acacia trees that host beehives, either empty or occupied by African honey bees. The concept that elephants might hold a long term memory about bees that could be so negative as to evolve avoidance behaviour towards an otherwise favourite food source, was deeply intriguing and warranted further study.

Two key research questions are asked in this thesis and are reflected in the title (i) what happens when elephants and honey bees interact and (ii) how can we adapt this behaviour into a potential deterrent system for crop-raiding elephants. Hence, this is really a thesis of two halves blending both disciplines of natural and social sciences. The first three data chapters explore in detail the behavioural response of elephant families to digital playbacks of bee sounds. This technique has been used successfully by other established elephant research teams including acoustic studies on African savannah elephants conducted by scientists with the Amboseli Trust for Elephants and Cornell University studying African forest elephants. Here, I work with an unfenced savannah elephant population studied by Save the Elephants in Samburu and Buffalo Springs National Reserves, northern Kenya. I show that not only do elephants run from the sound of bees but that they emit a unique low frequency alarm call when doing so, which in turn alarms (or warns) others in the area to retreat. Although these multi-layered behavioural discoveries were groundbreaking, I go on to reveal that bee sounds alone will not be enough to deter elephants for long as they do start to habituate to the playback sounds when no negative conditioning from live bees occurs.

Turning to the application of this knowledge, I spend three chapters describing in detail the development and evolution of a unique beehive fence designed specifically for use by poor rural farmers who suffer from frequent crop depredations and damage by elephants. I rely on several rapid rural appraisal techniques to evaluate the impact of the beehive fence on efficiency and effectiveness as well as the perception of the farmers and the potential income and livelihood prospects. The adoption success of the beehive fence system in three rural communities leads to a discussion about the wider application of beehive fences on both a regional and global scale. I end with a list of recommendations for the conditions within which I predict the beehive fences will be effective.

Foundation Publication

Vollrath, F. and Douglas-Hamilton, I. (2002a) African bees to control African elephants. *Naturwissenschaften* 89: 508-511.



*The Winds II family crossing the Ewaso Ng'iro River, Samburu National Reserve
First Year of DPhil Research, 7th May 2007*

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A.2. Questionnaire Example and Data

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Chapter 1

Introduction

The point of this research in an historical context

1.1. Interactions between Elephants and Mankind – Historical Overview

African elephants (*Loxodonta africana*) are today the largest land-dwelling mammal of the order Proboscidea and one of only two living representative genera from the family Elephantidae: *Loxodonta* and *Elephas* (Gray, 1821). Historically, proboscideans occupied Africa, Europe, Asia and America but today wild elephants are only found in sub-Saharan Africa and parts of Asia. The first evidence of *Homo erectus* subsistence exploitation of proboscideans was found in the archaeological records in Olduvai Gorge, Tanzania, dating back to Palaeolithic times, 1.8 million years ago (Leakey, 1971). From this moment on, pre-historic human range expansion appeared to coincide with local proboscidean extinction events¹ (Surovell *et al.*, 2005). The archaeological records are so convincing that Surovell *et al.*, are able to conclude: “Over one million years and on five continents, *Homo* has spatially excluded and driven proboscidean taxa to extinction.....In the present and past, elephants have survived in refugia unreachd by humans or those where humans did not exist at sufficient population densities to cause local extinction.”

Although such early records suggest that raw materials from hunted proboscideans were only used for food, tools, decoration and dwelling construction (Gaudzinski *et al.*, 2005) the attractive diamond patterning of the upper incisor and the evolving mystique surrounding this ivory has since haunted elephants for millennia. It has changed the role of humans from subsistence hunters to commercial exploiters. Demand for ivory in early Roman, Egyptian and Asian cultures was thought to be responsible for widespread elephant extinctions from their northern ranges between the 4th and 7th Centuries AD but this demand only grew as Arab and European explorers began to head south to open up trading routes from Africa (Sherborn, 1935; Spinage, 1994). By the 19th Century European traders were importing up to 700 tonnes of ivory every year (Spinage, 1994) but between 1840 and 1890 the overexploitation of

¹ Surovell *et al.*, (2005) show that although climate change may have played a part in proboscidean extinctions it did not play a direct causal role as previously thought.

elephants resulted in a collapse of the ivory supply from East Africa forcing the British to establish the first game laws in 1897 (Spinage, 1973). These new laws signalled the start of the transfer of responsibility for wildlife from local people to Colonial governments. Within four decades the concept of protecting animals from people generated the establishment of the national park system in East Africa which instantly affected the regeneration of elephant populations (Laws, 1969).

1.2. Modern Day Conflicts and Exploitation

The removal of local people from national parks and reserves and an increasingly sedentary, more agricultural, human population changed the pre-colonial vision that Africans were living in a 'sea of elephants' (elephants occurred in 87% of East Africa in 1925 compared to just 27% of East Africa in 1975; Parker and Graham, 1989) to elephants living in a 'sea of people'. By 1970 Kenya's game managers were reporting that large human settlements did not overlap with large elephant populations and that the densities were inversely related; a clear sign that elephants and man were in serious competition for land and that competitive exclusion was compressing elephant range (Parker and Graham, 1989).

'The elephant problem' of the late 1960's and early 70's resulted from compressed, locally overabundant populations of elephants causing extensive conversion of woodland to savannah triggering a passionate 'to-cull-or-not-to-cull' debate amongst scientists and managers of the day (Douglas-Hamilton, 1972). Several elephant range states instigated elephant culling on a huge scale (Laws *et al.*, 1975) but in Kenya, which had delayed its decision, no culling was necessary as the country was hit by a prolonged and lethal drought in 1970-1. The starvation of thousands of elephants, particularly in Tsavo National Park (Corfield, 1973) was followed by the worst poaching era of modern times.

'The ivory crisis' that followed saw widespread, unchecked poaching across most of East Africa, apparently feeding demand in the growing economies of the West and Far East. Elephant populations fell from 17,620 to 1,438 in Uganda (1973-1989); 190,720 to 49,112 in Tanzania (1977-1989) and from 129,570 to 15,279 in Kenya between 1973 and 1989 (Douglas-Hamilton, 1989). These three core elephant range states in East Africa lost around 185,000 elephants in just 16 years. The international

outcry generated over the elephant killing resulted in an international ivory trade ban by CITES² in 1989 and a global protection of elephants by listing *Loxodonta africana* continent-wide as an Appendix I species.

Since 1989, elephants in Kenya, Tanzania and Uganda have recovered somewhat (Blanc *et al.* 2007; Thouless *et al.* 2008) but debate is still raging over whether ivory stocks should be allowed to be sold from countries with large elephant populations (Wasser *et al.*, 2010). Figure 1.1 illustrates the total elephant number estimates and overview for these three core East African states from 1973 to 2007 when the last pan-African African elephant database was produced. The graph plots ‘definite’ figures only. The figure for 1973 for Tanzania was not available so I took a conservative assumption that *at least* the number of elephants present in 1977 (190,720) would have been present in 1973 in Tanzania if the trend from the rest of East Africa could be followed which showed a decline between 1973 and 1977. Therefore, to generate this overview, I used Tanzania’s 1977 population figure for 1973. Although not strictly accurate, I am assuming this is an under estimate rather than an overestimate of Tanzania’s elephant population in 1973.

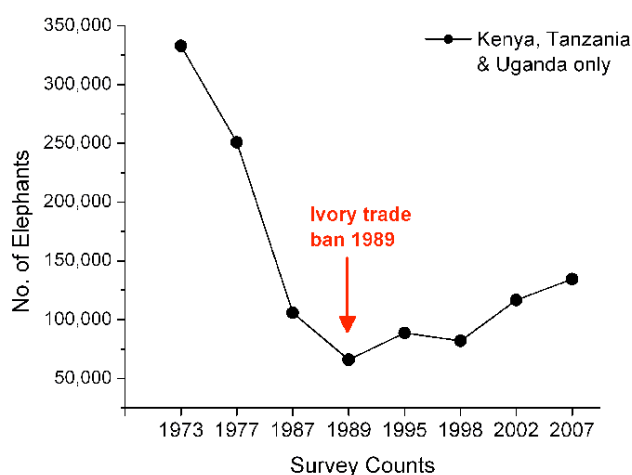


Figure 1.1. Overview of eight elephant surveys conducted in East Africa between 1973 and 2007 showing a precipitous decline until 1989 when the ivory trade ban was instigated by CITES. Data for 1973 to 1989 inclusive obtained from Douglas-Hamilton (1989) and data from 1995 to 2007 inclusive obtained from IUCN’s African Elephant Specialist Group database.

² Convention on International Trade in Endangered Species

1.3. Elephant Status in Kenya and the Emergence of Human-Elephant Conflict

Within my focal study country of Kenya, the excessive ivory harvesting saw the 1973 elephant population fall from approximately 130,000 to under 16,000 before the trade ban came into effect in 1989 (Douglas-Hamilton, 1989) and the establishment of Kenya Wildlife Service saw an approach towards more rigorous anti-poaching methods. It took some time for the decimated remnant populations to recover but by 2007 the elephant numbers had risen to 23,353 with a further 6,262 listed as probable or possible (Blanc *et al.*, 2007). Although this is a mere fraction of the original 1973 elephant population, this recovering population has had to expand into a new world, one densely populated with humans, infrastructure, agriculture and livestock.

Although Kenya has an impressive protected area network it only covers 8% of the country but at present, elephants range over at least 19% of the country (Blanc *et al.*, 2007). The migratory behaviour of elephants means they spend a significant proportion of their time outside protected areas on the search for food and water (Douglas-Hamilton *et al.*, 2005) bringing them into direct conflict with people over increasingly scarce land resources (Hoare, 2000; Sitati, 2003). With Kenya's human population, around 12 million in 1970 but now tripled to 36.3 million (2010 Kenya National Bureau of Statistics), the recovery of the local elephant populations has caused a well-documented escalation in human-elephant conflict (HEC) (Thouless, 1994; Sindiga, 1995; Omondi, *et al.*, 2004; Graham, 2007).

Conflict from living with elephants comes primarily in the form of crop depredations and human injuries or death (Ngure, 1995a). Other HEC disruptions include physical damage to water pipes, storage tanks and grain stores, livestock deaths, lower school attendance by children and a need for increased night time guarding effort that affects day time productivity (Thouless, 1994; Ngure, 1995a; Ngure, 1995b; Kiiru, 1995). Managing the local overabundance of elephants has become a significant challenge (Naughton *et al.*, 1999) particularly as elephants have complex social networks and are highly intelligent with advanced cognitive abilities (Douglas-Hamilton, 1972; Poole, 1998; Wittemyer *et al.*, 2005). Any management techniques have to be carefully thought-through for critical ethical and welfare considerations (Poole and Granli, 2005; Bradshaw *et al.*, 2005).

Although the Kenyan government is keen to protect all wildlife as a national asset that also attracts much-needed foreign exchange through tourism (Okello *et al.*, 2005), there is huge media interest and political pressure on members of parliament to tackle the unresolved issue of HEC (Adams, 2001; Balfour *et al.* 2007). If human population growth continues at the present rate, and unless cost-effective methods of limiting crop damage are implemented, the pressure on wildlife managers and governments to implement radical, ethically questionable methods (such as large scale culling) may one day become a reality. Kenya Wildlife Service (KWS) is keen to avoid this situation and regards HEC as a problem that can be tackled proactively. In their new 2010 Elephant Management Strategy (*in press*) much emphasis is being placed on developing new HEC mitigation techniques and training programs to reduce conflict at the farmer level while continuing to proactively plan for a larger, healthy elephant population. The data presented in this thesis fits into this national Elephant Management Strategy and contributes significantly to KWS' mission to utilize scientific research to improve farmer-managed elephant deterrents.

1.4. Human-Elephant Conflict Mitigation Methods – Brief Overview

Legal mitigation methods used at present in Kenya fall into four main categories: barriers, farm-based deterrents, translocations and culling (sometimes referred to as 'Problem Animal Control'). For the purpose of this thesis I will only review the first two methods as they relate directly to my research.

Conventional methods for keeping elephants away from crops are typically through the use of fortified boundaries. Stone walls are one of the simplest, low impact barriers that can often be made out of locally available material. However, elephants can push over stone walls with their chests and have proved to be widely ineffective (Thouless and Sakwa, 1995). Multi-strand, high voltage electric fences have proved to be successful in barring elephants from some human-designated areas (Hoare, 2003; Kioko *et al.* 2008) but in Kenya electrification projects have often failed due to elephants pushing over the posts, snapping the wire with their tusks, a lack of maintenance, spiralling costs, inadequate voltage and/or a lack of community buy in (Thouless and Sakwa, 1995; Thouless, *et al.*, 2002; Okello and D'Amour, 2008). De-tusking known fence breakers has also had no discernible effect at deterring determined

bull elephants (Thouless and Sakwa, 1995; B. Craig, pers. comm.). Woodley (1965) proved that well maintained, 8 foot deep, sloped ditches topped with an angled wire fence was a successful method for keeping game inside the Aberdares National Park in Kenya. However maintenance requirements were high and considerable labour was required to dig and construct the barriers.

Much recent attention and literature has focused on the effectiveness of different farmer-managed deterrents such as the use of buffer zones, fire crackers, bangers, dogs, stone throwing, shouting, watch towers or drums (Hoare, 1995; Osborn and Parker, 2003; Sitati and Walpole, 2006; Graham and Ochieng, 2008). Although results are mixed, elephants usually become habituated to such deterrents and obstacles over time and such efforts are often overwhelmed (Hoare, 2003; Omondi *et al.*, 2004; Walpole *et al.*, 2006).

To prevent habituation effects setting in, farmers and managers are beginning to focus on deterrents that have an element of pain or discomfort to the elephants. By creating a circuit of negative conditioning, the hope is that elephants will learn not to approach certain fields or crops and therefore avoid a learnt painful stimulus. The Mid Zambezi Elephant Project in Zimbabwe encourages the use of *Capsicum oleoresin* spray as an elephant deterrent following a discovery that chillies greatly irritate an elephant's sensitive trunk (Osborn and Rasmussen, 1995). The project promotes a multi-pronged approach whereby farmers can either spray the chilli irritant downwind into raiding herds, burn chilli-dung bricks or paste chilli oil onto string fences around a field of crops. The research and application of these techniques have shown some success in deterring elephants, particularly in Southern Africa test sites (Osborn, 2002; Sitati and Walpole, 2006). Unfortunately other farmers have found it time consuming and expensive (Hedges and Gunaryadi, 2010) and uptake is often poor (Graham and Ochieng, 2008). In my experience talking to Kenyan farmers who have tried this method, they complain about a number of limitations to the concept: (i) they do not have large enough land plots to grow a sufficient number of chillis to last a crop season, (ii) there is a lack of a market for excess chillies as most indigenous Kenyans do not like eating 'hot' food, (iii) the chilli oil applied to ropes around fields washes off in the rain which requires considerable maintenance and a large supply of chillies and (iv) burning of chilli bricks is painful for their children who can accidentally get caught in the smoke

cloud. Despite these negative comments from Kenyan farmers the concept of using a nature-based, painful stimulant, which is not lethal or invasive, is a good one and if these stumbling blocks could be resolved as it could over-ride the chief weaknesses of other deterrent systems, that of habituation.

1.5. Introducing the Concept that Elephants might be Scared of Bees

In the 1960's the artist Harald Pager discovered a fascinating San rock art image in Ebusingata, KwaZulu-Natal which depicts a therianthrope with a human body but elephant head, tusks and trunk. The shaman-like figure, most likely in a trance, is surrounded by bees which were considered to be full of potency and supernatural power and *"in parts of the Kalahari, San like to dance in the season when the bees swarm"* (Lewis-Williams and Blundell, 1998).



Figure 1.2. Stone Age rock art image of an elephant-man surrounded by bees from a tracing by Harald Pager reproduced here from the book *Fragile Heritage: A Rock Art Field Guide* by Lewis-Williams and Blundell (1998).

Uncovering the meaning of ancient rock art is notoriously complex to decipher and although there are translated themes, individual interpretation of images can still contribute interesting theories (Mguni, 2002). For example, in my eyes the perspective of forward motion depicted in the image could possibly represent an elephant with

features of (or perhaps even the intelligence of) a man moving away from bees. The combination of human and elephant features might also correspond to similar views held by the Samburu tribe in Kenya who believe that man and elephants are from the same clan and family (Kuriyan, 2002). Is it possible that early man was always aware that one of the greatest land mammals could be forced to move by one of the smallest insects? In reality, the presence of bees in rock art is known to represent a visual metaphor for being in a trance-like state where fluttering bees create a hallucinatory image of the trance (D. Coulson, pers. comm.).

Whilst working on Mpala Ranch, Laikipia, in 2000 Professor Fritz Vollrath from Oxford University interviewed a number of Lewaso beekeepers who revealed frequent observations of elephants running away from bee swarms (Vollrath and Douglas-Hamilton, 2002b). This local knowledge had triggered off much discussion amongst the local ranchers on whether or not bees could be used as ‘guardians’ to protect trees from the destruction caused by elephant foraging. This was tested out scientifically by Vollrath and Douglas-Hamilton (2002a) and revealed that under experimental conditions, acacia trees with beehives (either occupied or empty) did indeed have the effect of preventing elephant foraging damage to the trees. My thesis has evolved from the foundations of this published paper by Vollrath and Douglas-Hamilton (2002a) which generated so many conceptual questions about the potential use of bees as a possible natural deterrent for problem elephants.

Local knowledge, folklore or anecdotes can often reveal startling information about the natural world that has not yet reached the scientific community. Although anecdotes often come with little scientific ‘proof’ and are fallible to individual interpretation, anecdotal evidence can guide an investigation towards new hypotheses that can then be rigorously tested by science (Moore and Stilgoe, 2009). I spent some time during my first research year in Kenya talking to different local farmers, ranch managers and scientists about the concept that elephants might be ‘scared of’, or avoid, bees. The following section lists ten definitive anecdotes collected during my preliminary investigations into this concept and helped to shape the early preparations for this thesis.

1.5.1. ANECDOTES: Short accounts of personal incidents collected from interviews and discussion with people witnessing interactions between elephants and bees.

1. Origin: Professor Kigitira, Nazarene University, Nairobi

Location: Meru district, Kenya Contact: jkigatiira@anu.ac.uk

The Professor's brother lives in a community near Meru National Park and he keeps bees. His brother said "Everyone knows that elephants avoid beehives, even at night time when the bees are sleeping, they won't go anywhere near them."

2. Origin: Paul Oliver, Safari Guide, Tarangire

Location: Tarangire National Park, Tanzania Contact: safaris@paul-oliver.com

Paul was watching a young bull elephant feeding on a tree when it appeared to disturb a beehive. He thinks the bull might have sucked in a bee into its trunk in the commotion and "it went berserk, thrashing and spinning its trunk around trying to fling the bees out of its trunk". It ran off fast from the tree.

3. Origin: Mr Muchiri, maize farmer

Location: Ex-Erok, Laikipia, Kenya Contact: +254 (0)727 105439

The farmer was watching his farm at night and an elephant broke into the outer edges of his field where a beehive was hanging from the posts. The elephant appeared to knock the beehive as he walked past and the bees swarmed out and attacked him in the dark. The elephant was described as "screaming" as he ran away from the field of maize.

4. Origin: Mama Aaron, maize farmer

Location: Ex-Erok, Laikipia, Kenya Site: N 00.03437 E 036.69942

Mama Aaron had four beehives and she reported that the elephants knocked over all 4 beehives during their night raids. She could not see if the bees attacked them as it was too dark.

5. Origin: Mama Njoki, maize farmer

Location: Ex-Erok, Laikipia, Kenya Contact: +254 (0)721 475876

They had placed a few beehives along one fence line but the elephants came one night and pulled down two of the beehives from their stand. The elephants ran away that night but returned when the bees had abandoned the broken hive a few days later. She seemed to think it was the same elephants that returned a few days later.

6. Origin: Mzee David Wanjaru

Location: Mutare, Laikipia, Kenya Contact: +254 (0)721 258276

He has some beehives in some of his acacia trees and has noticed that the elephants have "never damaged those trees" despite foraging and breaking the trees on the other side of the road to his hives.

7. Origin: A very old neighbour of Joseph Wahome, Laikipia Elephant Project Scout.

Location: Laikipia, Kenya Contact: +254 (0)723 719234

The old man reported that in 2004 an elephant had walked into an apiary at night near his home bordering Ol Pejeta Conservancy. The owner of the beehives visited the apiary in the morning and found several of the beehives knocked over with elephant footprints passing through the damage. An elephant was found dead 200 'paces' away and the beekeeper assumed that the dead elephant was the one that had damaged the hives and had reacted badly to the bee stings. He could not see any signs of the elephant being stung or swollen but he suspected that the elephant had been stung "up the trunk" but he couldn't be sure.

8. Origin: Rachid, Ranch Manager, ADC Mutara Ranch

Location: Laikipia, Kenya

Contact: info@adc.co.ke

The 63,000 acre ranch has several dozen beehives set up for honey and to help with pollination. The ranch manager, Rachid, said that elephants don't touch the hives and walk around them.

9. Origin: Professor Fritz Vollrath, Oxford University and Save the Elephants

Location: Koiya Ranch, Laikipia, Kenya

Contact: fritz.vollrath@zoo.ox.ac.uk

Professor Vollrath was interviewing local beekeepers and farmers and one man, Benjamin, recounted an experience where he observed elephants running away from a bee swarm at night during a full moon.

10. Origin: Professor Fritz Vollrath, Oxford University and Save the Elephants

Location: Ol' Jogi Ranch, Laikipia, Kenya

Contact: fritz.vollrath@zoo.ox.ac.uk

A tame bull elephant was blinded by a swarm of bees stinging his eyes so badly that the swelling caused them to close completely. Administration of anti-histamine injections caused the swelling to subside (published in Vollrath and Douglas-Hamilton, 2002a).

These anecdotes recorded from discussions with local people helped to reveal a number of helpful details not forthcoming from the scientific literature. First, despite their thick skin, bees can apparently sting an elephant's trunk or eyes (Anecdotes 2,7 and 10). Second, elephants will run away from bees even if they have not been stung (Anecdotes 2, 3, 5 and 9). Finally, elephants appear to go out of their way to avoid beehives, even at night (Anecdotes 1,6 and 8). Although anecdotes, and by their very nature of being one-off eyewitness events, cannot be converted into scientific 'facts' they were extremely valuable contributions to the conceptualisation of this thesis.

1.5.2. Characteristics of *Apis mellifera scutellata*, The African Honey Bee.

Honey bees (Order Hymenoptera: family Apidea) evolved in the tropical zones of South East Asia during the Cretaceous period with the first fossil evidence found from the Eocene period 40 million years ago (Winston, 1987). The taxonomy of honey bees is extremely complex with hundreds of species and subspecies being classified under the genus *Apis*. The most recent taxonomic status (Engel, 1999) describes six clear sub-genera: *Priorapis*, *Synapis* and *Cascapis* including bees from the fossil records, and *Micrapis*, *Megapis* and *Apis* which include seven species living today. The development of cavity-nesting behaviour in two of the living species *Apis mellifera* and *Apis cerana* enabled them to expand out of the warmer tropics and spread into the more temperate zones of northern Europe and China respectively (Engel, 1999).

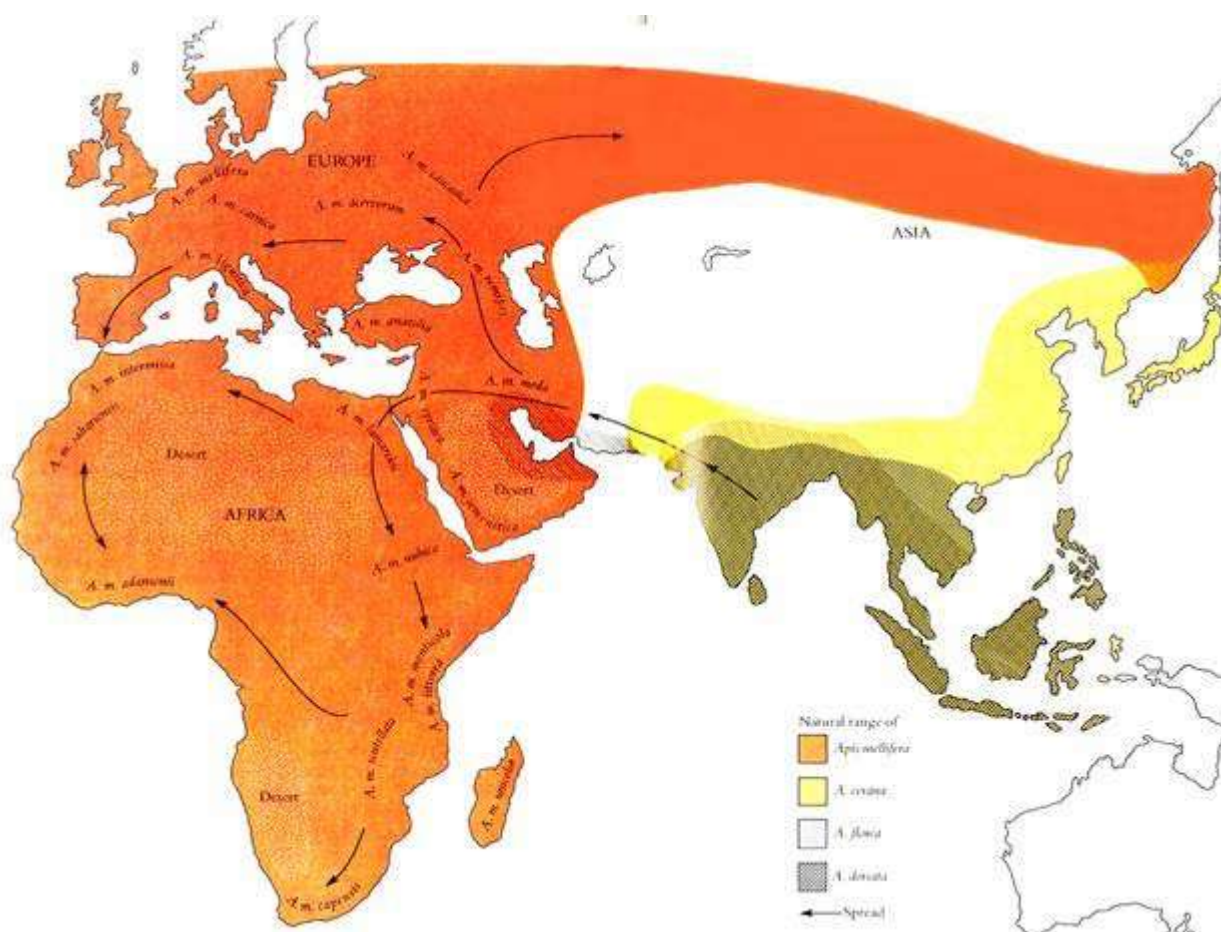


Figure 1.3. Map reproduced from Gould and Gould (1988) showing the distribution of Old-World honey bees and the spread of *Apis mellifera* (in orange) and its' many sub-species, from the Indian sub-continent, through Africa and up into Europe and north-eastern Asia.

Today, Kenya is home to three known sub-species of *Apis mellifera* from the sub-genera *Apis*: *Apis mellifera monticola*, *Apis mellifera litorea* and *Apis mellifera scutellata* which differ slightly from each other with respect to size, cubital index, abdominal banding patterns and geographical range (Raina and Kimbu, 2005). *A. m. monticola* and *A. m. litorea* have more limited geographical ranges concentrated around the coastal and high mountain regions respectively (Mbaya, 1983 as cited in Raina and Kimbu, 2005). Although the different bee sub-species overlap geographically during swarming events and hybridization has been recorded, *Apis mellifera scutellata* ranges widely in Kenya and generally occupies most of the savannah landscape (Raina and Kimbu, 2005). Although fairly small, *A. m. scutellata* is a notoriously aggressive bee that swarms frequently and lives in both open and cavity hives of up to 100,000 individuals (Winston, 1987).

The first aim of this thesis is to understand the behavioural interactions between this African sub-species of honey bee *Apis mellifera scutellata* and the African savannah elephant sub-species *Loxodonta africana africana*.

Some of the earliest evidence that man exploited honey bee products was found in Stone Age rock art paintings 6,000 to 15,000 years ago (Mguni, 2002; Gould and Gould, 1988). Honey has been much valued through the millennia as a sweetener, an alcoholic drink, a preservative and a natural medicine, with wax being used for candles, wax slates, sculptures and decoration (Gould and Gould, 1988). Today, apiculture is a traditional occupation in many African cultures where honey contributes to social and cultural status as well as providing a secondary source of income. Beekeeping is low cost, requires little physical effort and is an ideal low impact, ecologically sustainable activity which also enhances the growth of indigenous plants through pollination activities (Nel *et al.*, 2000). Beekeeping has been recognised by UNEP³ in Kenya's *National Poverty Eradication Plan 1999-2015*) as one of the activities that can enhance food security and contribute to environmental conservation. It is estimated that beekeeping has the potential to contribute US\$150 million to the Kenyan economy and provide a cash crop in arid and semi-arid areas unsuitable for agriculture.

Honey bees produce many marketable products including honey, wax, royal jelly, pollen, bee venom and propolis but optimal value can only really be obtained from more modern-day harvesting techniques (Raina, 2000). The move from bark stripping techniques and traditional log beehives towards the more efficient Kenyan Top Bar Hives (Kigatiira, 1976) has seen an increase in productivity over the last 40 years and has enabled Kenyan honey to be marketed professionally and internationally (Raina, 2000). However, traditional hives are still widely used in rural Kenya communities so a respect for the system and values of beekeeping in each community must be intimately understood before introducing new apiculture techniques (Swanson, 1976).

Beekeeping is certainly a desirable and encouraged activity in Kenya and **the second aim of this thesis** was to find out if honey bees could, in any way, become integrated into an effective defence system for farmers defending their land against crop-raiding elephants. Four research questions will attempt to fulfil these two aims.

³ United Nations Environment Program

1.6. Thesis Research Questions

The following four research questions gave structure to my research and thesis planning and required the establishment of multiple study sites.

Question 1: What behaviour occurs when elephants interact with honey bees?

➤ Data presented in Chapter 2

Question 2: Do elephants communicate about the presence of honey bees, either between themselves or to others?

➤ Data presented in Chapter 3

Question 3: How can knowledge about the interaction between elephants and bees be converted into an effective defence system for rural farmers defending their crops?

➤ Data presented in Chapters 4, 5 and 6

Question 4: What are the social and economic effects of introducing beekeeping to a rural Kenyan community as a form of elephant defence?

➤ Data presented in Chapters 5, 6 and 7

1.7. Study Areas in Kenya

The interdisciplinary research planned for this thesis was conducted in collaboration with Save the Elephants (STE), a charitable research organisation based in London, UK and Nairobi Kenya. Led by the elephant expert Dr Iain Douglas-Hamilton OBE, the organisation's aim is to use applied scientific research to secure a future for elephants. STE works closely with KWS to assist them in implementing their national elephant management plans. In Kenya, STE's study site is the vast Samburu-Laikipia region of northern Kenya and this area became the core study site for my research. All elephant behaviour research was conducted in Samburu/Buffalo Springs National Reserves. Additionally, my farm-based research was conducted with three rural communities: Ngare Mara in Isiolo/Meru North District was my main study site. Ex-Erok in Laikipia District, and Sagalla in the Tsavo-Voi region of southern Kenya, were two of my pilot study sites. For locations refer to Figure 1.4.

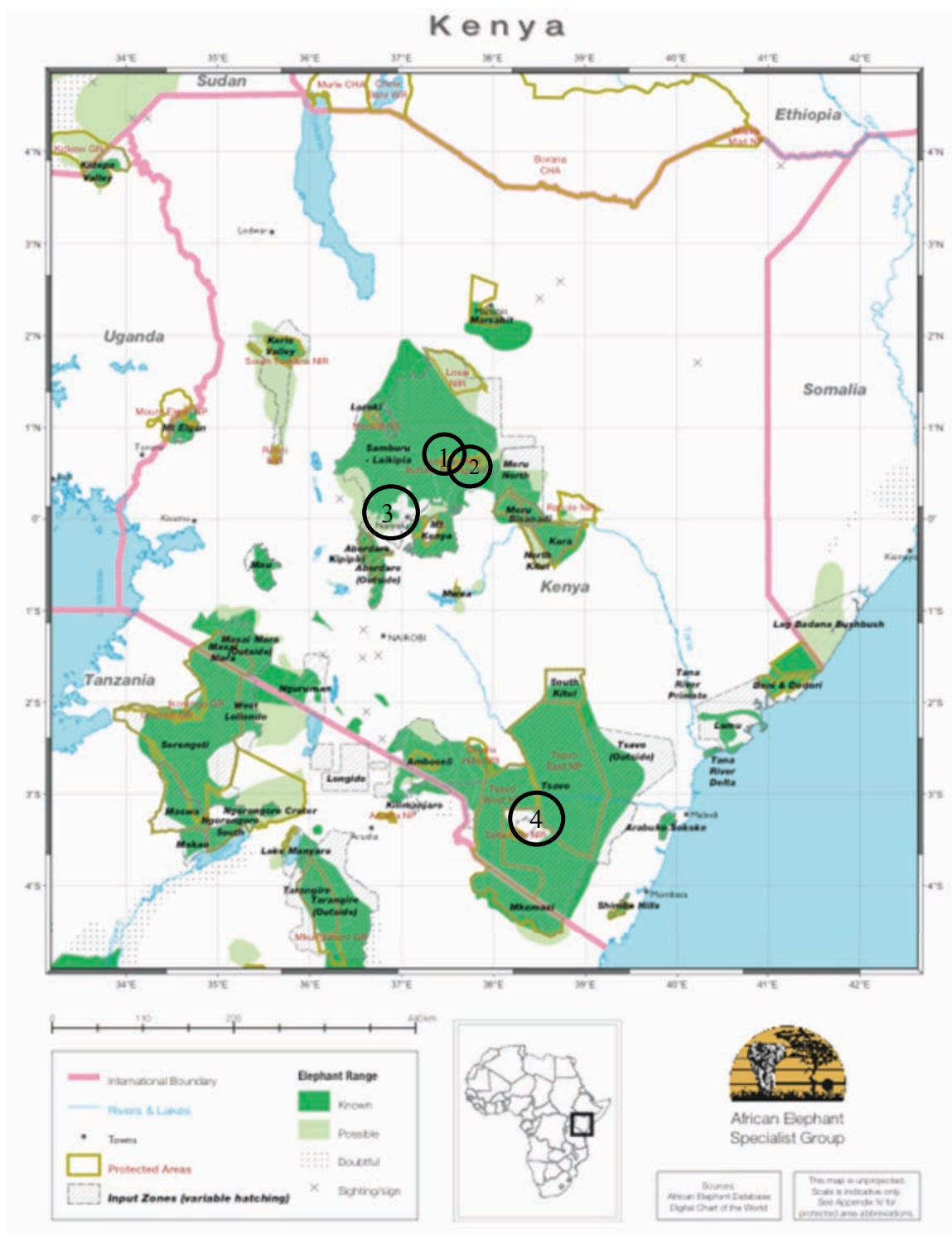


Figure 1.4. Study Sites. Map of Kenya reproduced from the African Elephant Specialist Group 2007 database (Blanc *et al.*, 2007) illustrating elephant geographical distributions across Kenya. My four study sites were based in the two largest elephant home ranges of Samburu-Laikipia and the greater Tsavo Ecosystem with specific locations numbered and circled in black. (1) Samburu and Buffalo Springs National Reserves (main site); (2) Ngare Mara community including the sub-villages of Chumviyere and Etorro (main site); (3) Ex-Erok community in Laikipia (pilot study) and (4) Sagalla community surrounded by Tsavo National Park in southern Kenya (pilot study).

1.7.1. Samburu and Buffalo Springs National Reserves

Save the Elephants' research centre is based in the heart of Samburu National Reserve, Samburu District (lat. 0.567728°; long. 37.527368°) and was the base camp for my research activities in northern Kenya. Samburu N.R. lies on the northern bank of the Ewaso Ng'iro river while to the south, Buffalo Springs National Reserve lies within Isiolo district. Although managed by different county councils, the two unfenced reserves cover an area of 336 km² and form a critical protected area in northern Kenya, particularly for elephants (Douglas-Hamilton *et al.*, 2005; Figure 1.5). The reserves lie at an altitude range of 830m to 1250m and are comprised of semi-arid *Acacia-Commiphora* savannah, typical of hot and dry conditions. Biannual rain seasons occur between March-April and October-December with variable rainfall averaging 350mm per annum (Wittemyer *et al.*, 2009). Data for chapters 2, 3 and 4 were collected from elephants living within these two reserves

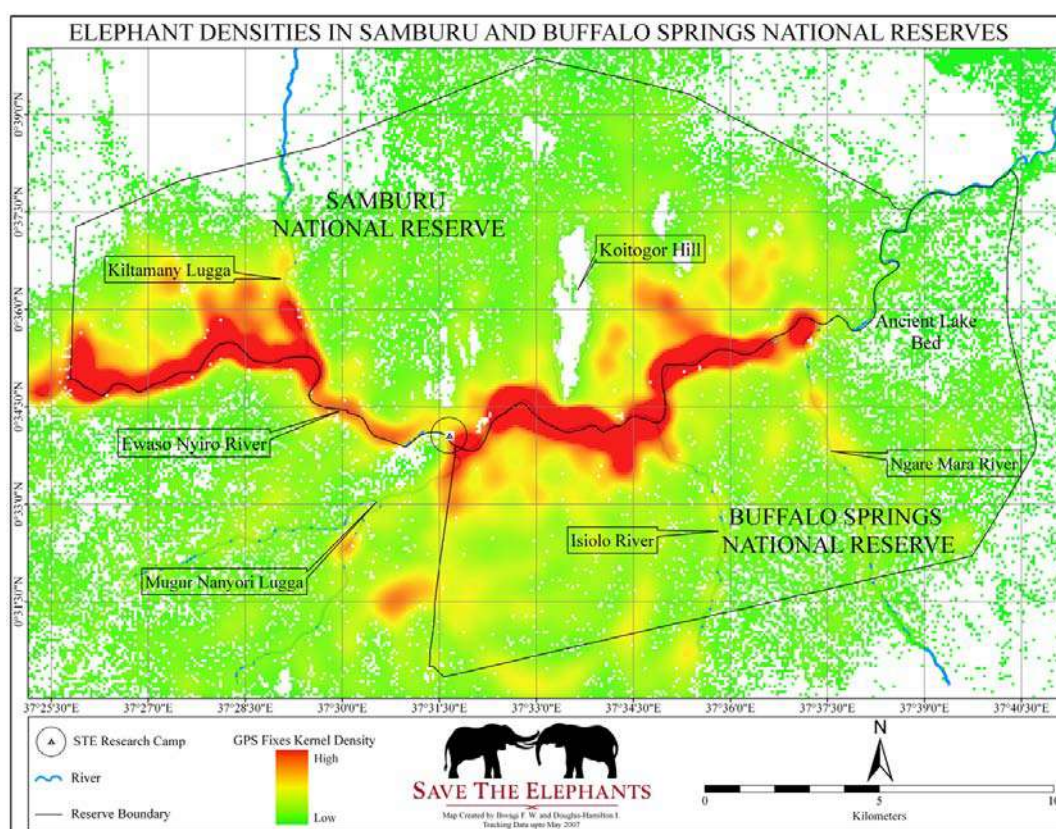


Figure 1.5. Map of the unfenced Samburu and Buffalo Springs National Reserves showing point density kernels for individual GPS and GSM fixes for 48 elephants collared and monitored by Save the Elephants between 1997 and 2007 (Ihwagi, 2007). The red shows the most overlapping kernels, and therefore illustrates the dense time usage of the riverine habitat by elephants visiting the reserve's protected section of the Ewaso Ng'iro river. (Map created by F. Ihwagi and I. Douglas-Hamilton at Save the Elephants and published in Ihwagi, 2007).

A core research activity carried out by Save the Elephants is the long term monitoring and identification of elephants within Samburu and Buffalo Springs N.R. As of May 2009, the STE team had recorded 1450 elephants and calves that, at one time or another over the previous 12 years, had visited the two reserves (unpublished data). Since 1997 a detailed photographic identification file (based on Douglas-Hamilton, 1972) has also been developed containing photographs and drawings of over 700 individual adult elephants known to frequent the reserves. This photo ID file has helped STE researchers to identify and name 63 established family groups and to generate association indices (Wittemyer *et al.*, 2005) including complex data on dominance and sub ordinance rankings (Wittemyer and Getz, 2007).

This ID file was generously made available to me to assist with my research and much effort was put into learning identification characteristics for each elephant family. This skill ensured that any experiments or sound trials conducted with any of the wild elephant families in Samburu or Buffalo Springs would not suffer from problems of pseudo replication. Key attributes for identification can be taken from markings or notches on the ears, the shape of the head, the number and shape of the tusks and sometimes the veins and scars on the skin (Figure 1.6).

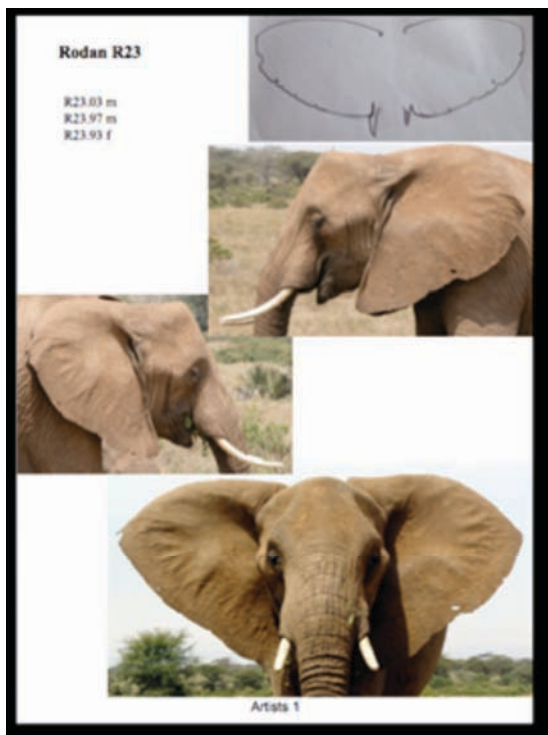


Figure 1.6. This image is an extract from STE's Identification File. It shows the page for the female elephant Rodan from the Artists 1 family, who is coded as R23. The letter R refers to her being a 'resident' female. The column of numbers under her name refers to her three calves, one female calf born in 1993, and two male calves born in 1997 and 2003. Her calves will adopt her ID number and the year of their birth will become their unique ID code for the future. Photographs and sketches like these can help to identify Rodan in the field. She can now easily be identified by the large hole in her left ear sitting above an elbow nick in the outer silhouette of her ear. Additionally we can see that she has a nick out of the top of her right ear and a distinctly pointed forehead.

1.7.2. Ngare Mara Community (Lat 0.4452; Long 37.6735).

Ngare Mara is a rural community that lies to the south of Buffalo Springs National Reserve consisting mainly of people from the Turkana tribe who moved into the area during insecurity in their homeland in the 1970's (P.Ekerri, pers. comm.). The migrating families settled into a strip of uninhabited land between Isiolo and the game reserves to the north (Figure 1.7). This event was fraught with difficulties as the Turkana had to fight both the southern Borana tribes and the northern Samburu tribes to secure the land. Additionally, the area was home to high densities of wild animals so predation by carnivores and conflicts with elephants was an ongoing battle. The Turkana were quick to kill and/or trap most wild animals on their newly acquired land and by the 1990's the community had grown to a substantial size with many sub-villages spread out along an East-West trajectory.

During the late 1990's and early into 2000, passing through the Turkana community of Ngare Mara became a notoriously dangerous activity. Multiple incidents of car-jackings and armed highway robbery occurred making the road north of Isiolo one of the most dangerous in the country, and one that tourists were advised to avoid at all costs (Kahindi, 2002). As this community gained in reputation as one of the most dangerous and fearful in northern Kenya, the authorities ruthlessly targeted the community and many individuals were arrested and jailed. In retaliation, hijacking and poaching activities in the reserves increased. Within this hostile environment a committee was formed to review the role of the local community in wildlife protection and tourism development in the area. In October 2002, members from KWS, Isiolo County Council, the Police and Save the Elephants were hosted by the Ngare Mara Community Development Committee and over 1400 members of the community turned up for the meeting representing 25 sub-villages. After two days of discussions and negotiations, solutions were found to a number of problems and disputes. In exchange for cessation of all tourist attacks, wildlife/ivory poaching and highway robberies, the police would no longer unfairly target the community and security problems in the community were to be addressed seriously by Isiolo's police. Additionally, more effort was to be made by KWS and Isiolo County Council to involve and employ members of the community in local environmental programs and activities (Kahindi, 2002).

This extraordinary meeting had its desired effect and security in the area improved over night. Once the security issues had been addressed the community's problems became clearer. Farmers complained intensely about human-wildlife conflict and the losses they suffered from living so close to the unfenced reserves. Elephants, buffalo, hippo and zebra were held responsible for crop damage, where as lions, leopard, hyena and cheetah were predated on livestock (Kahindi, 2002). Much resentment and wildlife intolerance had grown out of this conflict and the community did not receive benefits or compensation from the reserves. Save the Elephants began to monitor Ngare Mara in 2002 as part of their Monitoring the Illegal Killing of Elephants (MIKE) program and indeed found that there was a 'hotspot' of illegal elephant deaths around Ngare Mara. My second core study site was based in the heart of this hotspot in the middle of Ngare Mara community and the data is presented in Chapters 6 and 7 (Figure 1.7).

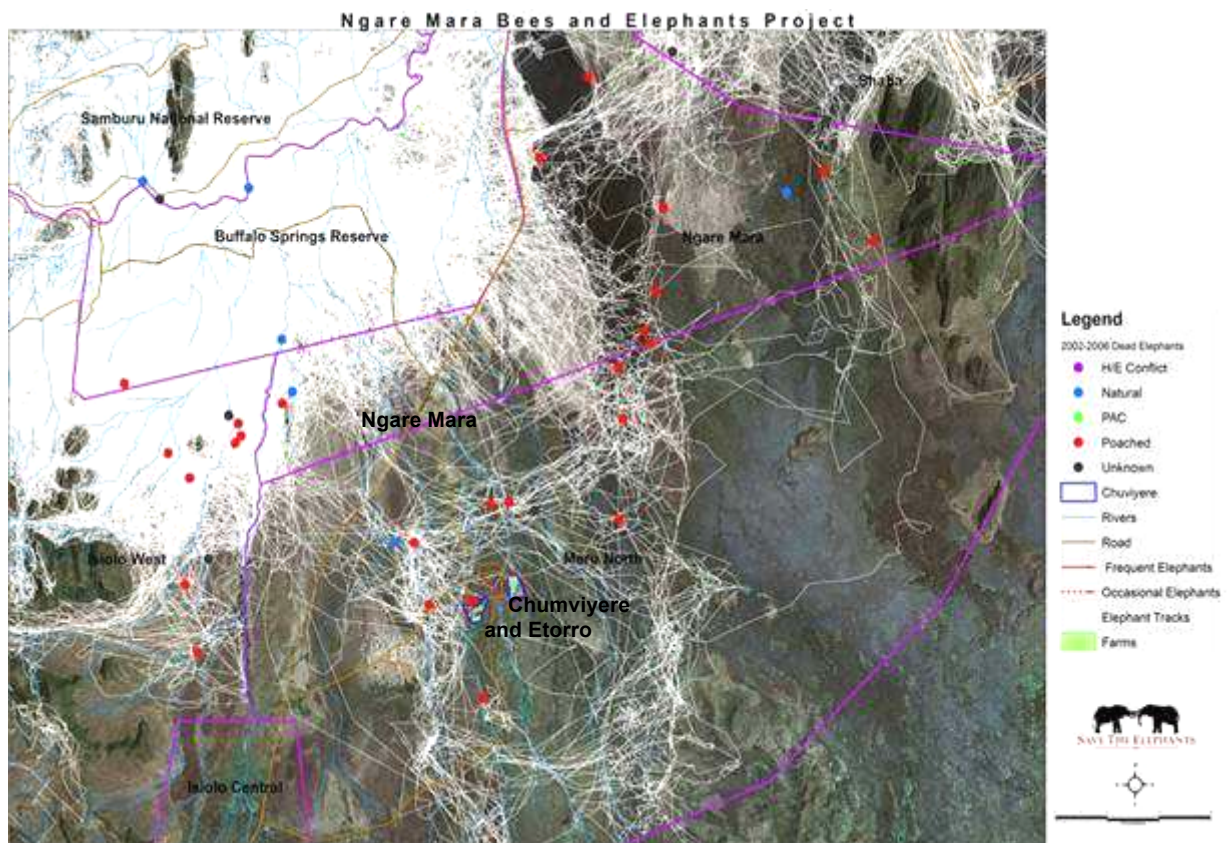


Figure 1.7. A map of Ngare Mara which is located to the south and south East of Buffalo Springs Reserve. The white lines represent tracks from 48 elephants that have been collared and tracked since STE's project began in 1997. The white tracks are very dense inside the reserves but to the south of Buffalo Springs you can clearly see a circle of tracks dotted with red circles. The circular pattern of tracks show the elephants walking around the villages of Chumviyere and Etorro, my two study sub-villages. The red dots represent the location of all the illegally killed elephants recorded by STE between 2002 and 2006. *This map was created by Barnerd Lewasopir and Lucy King using STE's tracking and MIKE data.*

1.7.3. Pilot Study Sites: Ex-Erok and Sagalla

Two communities participated in small scale pilot studies to test out the use of bees as farm-based deterrents. The first site, Ex-Erok (Lat: 0.0419°; Long: 36.7283°) was a 20,000 acre farming community based in Southern Laikipia located on the western boundary of the 90,000 acre Ol Pejeta Conservancy and on the southern boundary of the 65,000 acre ADC Mutara cattle ranch. Elephants regularly crop-raided into the community from the direction of ADC Mutara which was used as a refuge by elephants. The second site, Sagalla, was a community based around and on top of Sagalla mountain (Lat -3.52307°; Long 38.60125°) comprised of seven sub-villages. Sagalla nestles on the southern boundary of Tsavo West National Park and to the west of Tsavo East National Park. They are invaded by elephants living within the National Parks on a nightly basis and regular incidents of people being killed, by both elephants and lions, has turned this area into a hotspot for HEC. More specifics about both these pilot sites and the results of the pilot studies are presented in Chapter 5 and in the final ‘Case Study’.

1.8. Thesis Structure

This thesis has been organised into six data chapters and one case study presented as a sequence of experiments or surveys that followed the logic of the four research questions itemised in section 1.6. Important specifics of each study locations and different methodologies are described within each largely self-contained chapter. A brief ‘*Mid Script Note*’ is found after Chapter 4, that helps to link the experimental studies in the first three chapters to the farm-based trials in the last three chapters.

Chapter 2 describes the behavioural response of female-calf elephant families to the sound of disturbed honey bees using a playback method.

In *Chapter 3*, we explore the hypothesis that elephants are communicating about the ‘threat’ of bees to each other and we present data to suggest that elephants emit a unique low-frequency rumble to warn other elephants to move away.

Chapter 4 explores the habituation effects shown by elephants when they are repeatedly exposed to bee sounds with implications for the use of bee sounds alone as an effective elephant deterrent.

Chapter 5 introduces a unique barrier design that I created and coined as a ‘Beehive Fence’. The beehive fence is tested in a small pilot study in Ex-Erok community and the data presented.

In *Chapter 6*, I improve the beehive fence design and apply the concept to a larger community in Ngare Mara. The chapter explores the effectiveness of the beehive fences over two years and presents data to suggest that elephants will avoid beehive fences.

Chapter 7 explores the opinion, attitudes and activities of the local community of Ngare Mara in response to the new beehive fence technology. Socio-economic factors are considered and discussed with regard to the potential implementation of the concept to other parts of Kenya or Africa.

After *Chapter 7*, I present a short two-page *Case Study* summarising the results of the small pilot study in Sagalla community where the beehive fences were successful in keeping elephants out of two farms.

Finally, in *Chapter 8* I discuss the results from the overall thesis, any strengths and weaknesses of the research and present a conceptual argument for the inclusion of honey bees as an effective natural deterrent against crop-raiding elephants.

Chapter 2

Elephant reactions to honey bees: Playback sound experiments with known elephant families in Samburu and Buffalo Springs National Reserves, Kenya

Selected data from this chapter has been published in Current Biology:

King, L.E., Douglas-Hamilton, I. and Vollrath, F. (2007) African elephants run from the sound of disturbed bees. *Current Biology* 17: R832-3.

Abstract

Encroaching human development into wildlife rich areas is causing compression of African elephants' (Loxodonta africana) home ranges, causing increased levels of conflict between elephants and man. African honey bees (Apis mellifera scutellata) have been shown to deter elephants from foraging on acacia trees and have been proposed as a possible deterrent to keep elephants from invading agricultural crops. Here we use a sound playback experiment to study the hypothesis that elephants will avoid honey bees. In Samburu and Buffalo Springs National reserves, we played disturbed bee sounds to 32 well-known elephant families and a control sound of natural white noise to 18 families and compared their behavioural reactions. 94% of elephant families reacted negatively (immediately walking or running far away) when hearing the buzz of disturbed bees, while there was a significantly subdued response to the control. Both bee and white noise stimuli caused increased dusting, headshaking and smelling behaviour but in response to bees, elephants showed a significant correlation between the length of time in proximity to bee sounds and the number of dusting and headshaking events. Our study strongly supports the hypothesis that elephants are alarmed enough by bees to retreat quickly and far away to avoid coming into contact with the stinging insects. Increased deterrent behaviour such as dusting and headshaking supports the theory that elephants are aware about the specific painful threat of bees and such behaviour may be a method to knock the bees out of the air to prevent stinging around the sensitive eye area.

2.1. Introduction

Vollrath and Douglas-Hamilton (2002a) showed that elephant damage to acacia trees was significantly less for trees hosting either occupied or empty beehives. In Zimbabwe, elephants were observed forging new trails into experimental fields of crops to avoid beehives (Karidozo and Osborn, 2005). These data suggest that African elephants are wary around bees and hives and will avoid both, presumably to avoid stings on sensitive areas like the eyes, behind the ears and inside the trunk (Vollrath and Douglas-Hamilton, 2002a and 2002b). Despite these important published studies, and numerous undocumented anecdotes of elephants reacting negatively to bees (refer to ‘Anecdotes’ section 1.5.1), no film or scientific observations have yet been published on the behavioural interactions between elephants and bees and how they might physically respond to each other should they come into contact. Understanding this behavioural interaction is the focus of this chapter.

Designing experiments to record or film the interaction between wild animals is notoriously difficult, particularly, in this case where both wild elephants and wild honey bees cannot be captured and subjected to a laboratory setup. Both social species have the potential to be dangerous to humans and forcing a ‘meeting’ between the two is almost impossible to construct, particularly when our hypothesis is that they will avoid one another as much as possible. To overcome this barrier we designed a series of experiments using a playback method to simulate how a family of elephants might react to a disturbed beehive. Playback experiments with animals involve recording a baseline of behaviour and then comparing that baseline to behaviour recorded during and after the playback of a pre-recorded stimulus. Thus, any changes in behaviour can reveal clues as to the animals’ interpretation of the stimulus (Langbauer, 2000).

Since the discovery of low frequency vocalisation communication by both Asian (Payne *et al.*, 1986) and African elephants (Poole *et al.*, 1988), playback methods using context specific vocalisations have been used frequently in experimental elephant behaviour studies. This technique has greatly increased our understanding of the complexity and extent of savannah elephant communication networks (McComb *et al.*, 2000) including an understanding of movements by individuals in response to both musth and oestrous states (Poole, 1999). Playback experiments have also helped us

understand the number of kilometers that elephants can receive detailed auditory information (Langbauer *et al.*, 1991; McComb *et al.*, 2003) and how they respond to seismic vibrations of known individuals over long distances (O’Connell Rodwell, 2007).

Additionally, McComb *et al.* (2001) have used playback experiments to demonstrate that elephant families with older matriarchs are more adept at using auditory signals to correctly distinguish between known and unknown females. By responding appropriately to these auditory signals (which convey information on social identity) families with older matriarchs do not waste energy unnecessarily leading to greater reproductive success. Such experiments contribute significant scientific knowledge to conservation principles for African elephants. For example, evidence that older matriarchs are repositories for important social knowledge (McComb *et al.*, 2001) predicts that poaching, translocations or culling of older female elephants can have devastating consequences on the reproductive success and social structure of the rest of the family (Bradshaw *et al.*, 2005; Gobush *et al.*, 2008). Kangwana (1993) began exploring elephant behavioural responses to playback vocalisations made by other mammals, including humans, but to the best of my knowledge, no one has yet explored the behavioural responses of elephants to bees.

Playback experiments with elephants are complex and multifaceted due to their superior hearing capabilities. Elephants have much larger outer ears, pinna, ear canals and tympanic membranes than humans as well as larger sections of the inner ear containing the malleus, incus and stapes (Garstang, 2004; Soltis, 2010). The size and morphology of these structures are thought to enhance the hearing capabilities of elephants enabling a wide repertoire of audible signal detection, including low and infrasonic frequencies (Soltis, 2010). Therefore, when playing recordings back to elephants it is essential to play a sound containing the full range of frequencies of the raw stimuli and not just those frequencies audible to a human researcher’s ear. Advances in both uncompressed digital recording techniques and speaker capabilities have greatly enhanced the field of elephant playback experiments and details of the equipment we used are described in the methods.

In this chapter we used playbacks of uncompressed digital sounds recorded from a disturbed wild beehive in order to test the hypothesis (Vollrath and Douglas-Hamilton, 2002a) that elephants 'have a knowledge of' the danger of bees and respond to their sound by increased alertness and possibly even running away. We filmed all phases of the experiments and were able to compare the elephants' behavioural reactions to the bee stimulus to (i) a baseline of behaviour recorded before the playbacks began as well as (ii) to a separate control sound of natural white noise.

2.2. Method

2.2.1. Recording Sounds from a Wild Beehive

I located an established wild beehive of *Apis mellifera scutellata* inside an *Acacia tortilis* tree in Samburu National Reserve and rigged up a scaffold of wooden planks at the entrance taking care not to disturb the hive. A Steinheisser MK415 directional microphone was placed 15cm from the entrance pointing directly into the hive. The microphone was attached to a Sony MZ-RH1 Hi-Mini Disc which recorded uncompressed mono digital sound onto 1GB discs at a sampling frequency of 44100Hz. Once turned on, I threw a 4cm stone into the beehive and recorded the sound of the disturbed bees erupting out in defensive or ‘attack’ mode. The bees generated approximately six minutes of aggressive attack sounds before calming down and slowly returning to the hive. I extracted 30 seconds of the most aggressive sounds from the first minute of the recording (Figure 2.1) using Phonetic PRAAT software (version 4.5.18; Boersma and Weenink, 2007). I then spliced eight copies of this 30 second sound extract together to create a 4-minute constant bee recording (mean intensity = 66.1dB).

Stone dropped in here

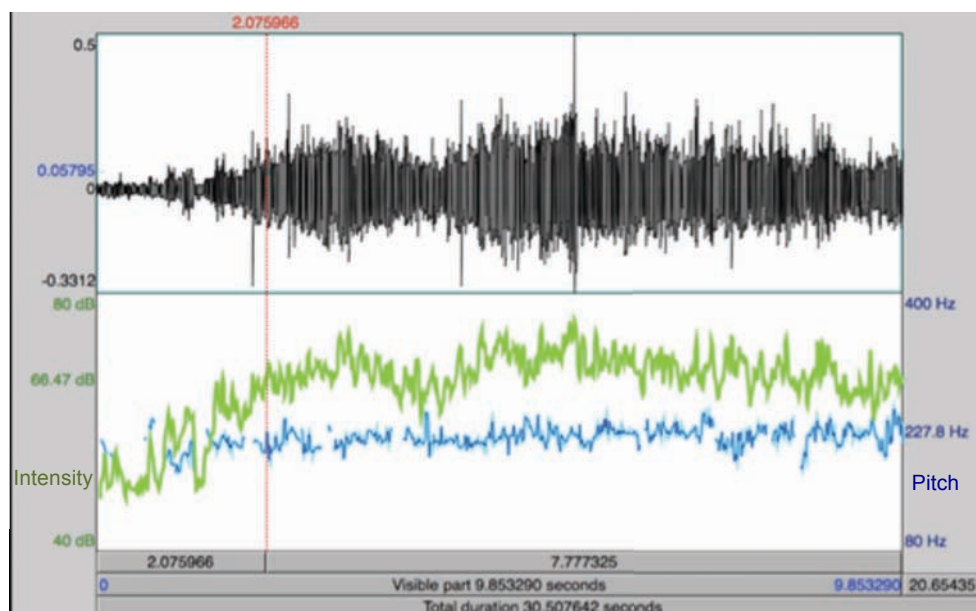


Figure 2.1. The first 10 seconds of the bee recording is illustrated graphically here. The first 2 seconds (to the left of the red marker line) shows the rapid increase in intensity (dB) in green as the bees erupt out of the hive and then settle into a loud and consistent attack mode. For this first 10 seconds of sound recording the mean pitch (or frequency) recorded in blue is 221.3Hz (range = minimum 178.3Hz; maximum 257.8Hz) and the mean intensity of sound is 65.8dB (range = minimum 48.2dB; maximum 75.7dB).

2.2.2. Control Sound of Natural White Noise

Natural white noise extracted from a forest waterfall recording served as a control (Healing Falls, www.naturesounds.ca). Natural white noise was regarded as an appropriate control as it contains all frequencies in the spectrogram of sound (0Hz to 22050Hz) but contains more random variation in those frequencies than digitally created white noise. The mean intensity of the white noise recording was almost identical to the bee recording (65.3dB) ensuring that any variation in behaviour by elephants was due to the specifics of the sound content and not variation in sound quality, intensity or loudness (Figure 2.2).

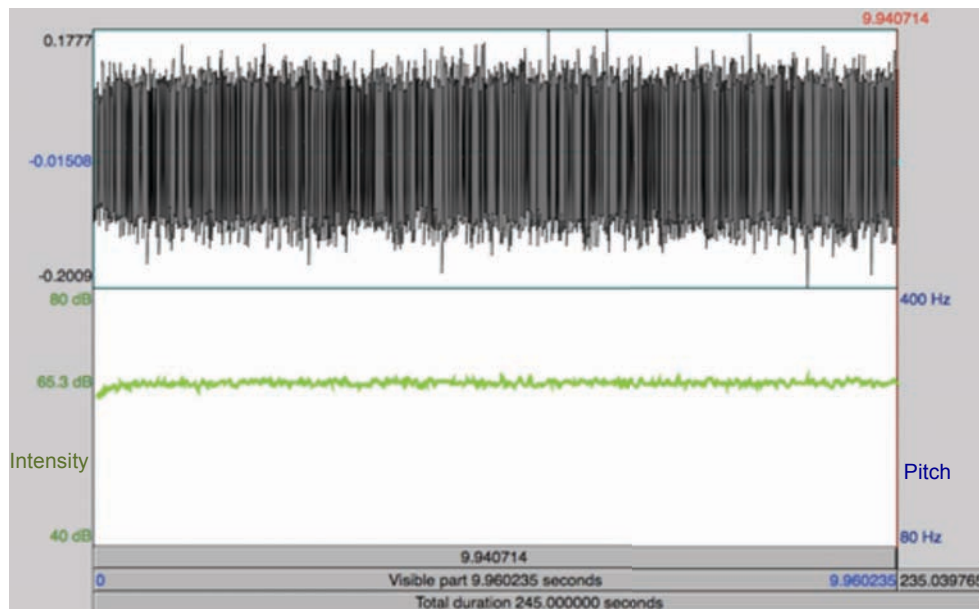


Figure 2.2. The first ten seconds of the natural white noise recordings shows a consistent mean intensity of 65.3dB throughout the recording but the equal range of frequencies from 0Hz to 22050Hz is random across the sound sample.

2.2.3. Playbacks to elephants.

The study site was the Samburu and Buffalo Springs National Reserves in Northern Kenya. Target elephants were female-calf families resting under trees during the middle of the day (11am-3pm). Before each trial began the elephant families were carefully observed and identified from ear notches and tusk shapes using Save the Elephants' detailed identification files. Elephants were counted in situ and age groups estimated including adult females, adult bulls, juveniles (2-14 years) and infants (0-2 years). The size of elephant families was consistent between test ($n=32$) and control ($n=18$) groups with an average family size of $8.06 \pm \text{StDev } 4.74$ for elephants responding to bee sounds and an average family size of $8.39 \pm \text{StDev } 2.87$ for elephants responding to white noise. This difference was not significant (Mann-Whitney U test, $U=248.5$, $p=0.43$).

Sounds were played to elephants through an AQ 863 MHz wireless speaker (frequency response 65 Hz-12 KHz, distortion $<1.5\%$) with the 100m accurate 12.5V transmitter powered by a car battery. The speaker was camouflaged 1 meter above the ground inside a fake 'tree trunk' constructed from dry reeds and a plastic rack (Figure 2.3.a). We aimed to place the speaker within 10 metres ($\pm 2\text{m}$) of the closest elephant. Both sounds were played back loudly turning on a +3db output setting on the mini disc player to help compensate for the distance of the speaker. The response of the elephants was filmed on a Sony Z1 video camera using high definition Digital MasterTM PHDVM-63DM tapes, from a distance of approximately 30m and at an angle of 45° to the speaker (Figure 2.3.b). The elephants were filmed for 2 minutes before the sound stimulus was turned on creating a "Pre-Stimulus" control phase. If the elephants moved away from the tree during this primary phase the trial was abandoned. After the 2 minute pre-stimulus phase the sound was turned on and for 4 minutes any behaviour or retreat action was filmed. If the elephants were still in sight at the end of the 4 minute "Stimulus" phase an additional 2 minute "Post-Stimulus" phase was filmed to see if the elephants changed behaviour once the sound stimulus had been turned off.

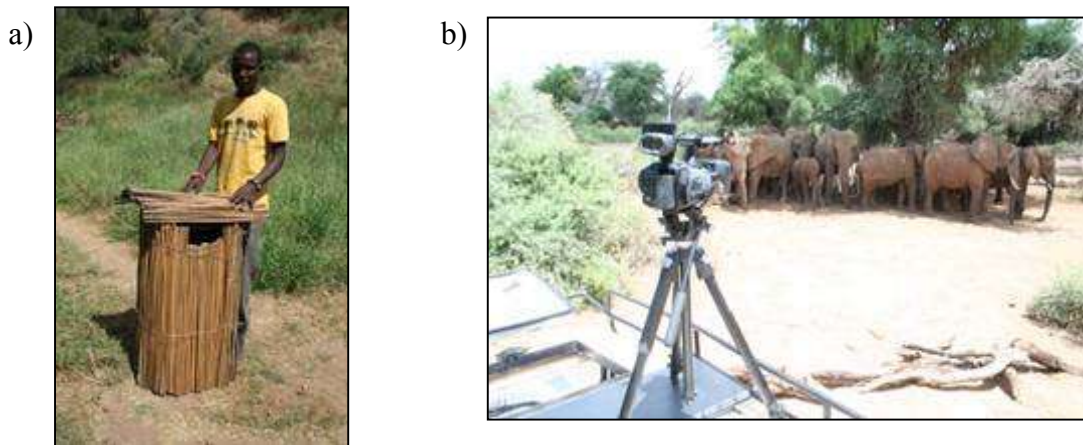


Figure 2.3. (a) The wireless speaker was hidden inside a fake ‘tree trunk’ with a hole cut into the reed camouflage to allow undistorted sound to come out of the device. (b) Playback trials were filmed using a video camera, tripod and high definition tapes to try to capture as much of the action as possible once the sound stimuli was played to resting elephant families.

2.2.4. Behavioural Analysis: Definitions and Methods

I digitized and compressed the eight minute videos into .mov movies using Apple MacBook’s iMovie program. I carefully analysed and scored each movie using each of the following behaviours and mode of retreat definitions:

‘Latency of Response’ was defined from the videotapes as the time (in seconds) between onset of the stimulus and the moment the elephants clearly decided to leave the shade of their rest tree. This did not include any ‘shuffling around’ under the tree which often occurred when elephants started to responded to the playback stimulus.

‘Distance moved’ was estimated in the field at the end of the playback trial using the 3m length of my Land Rover as a useful measuring guide for long distances. I estimated shorter distances by using a Hilti™ laser distance measurer. Due to the thickness of the bush in the study site, large distances were often hard to define due to poor visibility so I often had to drive around to find the elephants after collecting the equipment. To be as conservative as possible I limited distance moved to 100m.

‘Dusting’ was defined as an elephant picking up dust with his/her trunk and throwing that dust anywhere on the body, face, legs or behind the ears (Figure 2.4.a).

'Headshaking' events were defined by an elephant clearly throwing their head side to side by means of a slight twist to the neck that often resulted in ears flapping noisily through the air and slapping back onto the flanks of the shoulder (Figure 2.4b).

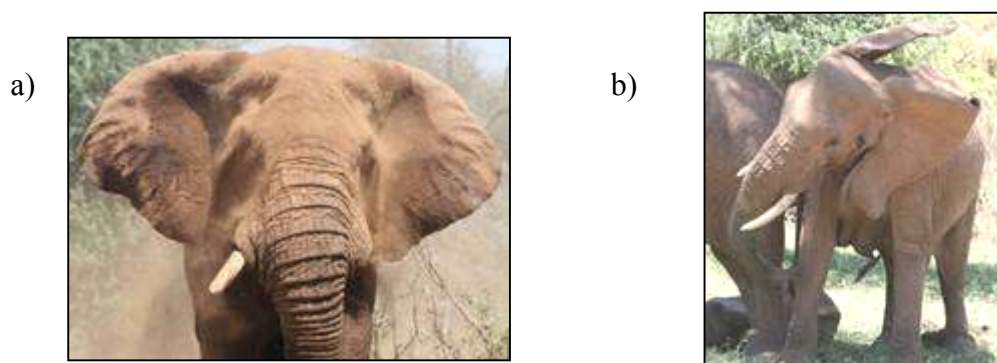


Figure 2.4. (a) Dusting events occurred when elephants actively threw a trunk full of dust over part of the head or body as demonstrated here by the adult bull Yeager; (b) Headshaking occurred when an elephant clearly threw his/her head from side to side flapping the ears in the process as demonstrated here by a female from the Winds 3 family.

During this study I observed elephants constantly smelling the air and ground with their trunks but usually the trunks were curled under the mouth or rolled up under the bottom side of the trunk. To avoid confusing 'normal' smelling with active 'alarm' smelling I defined **'Smelling'** events as the number of times the elephants raised their trunks into the air to smell, or smelt with their trunks directly out in front of their faces in the direction of interest (Figure 2.5). I cannot, of course, be absolutely certain that the elephants were smelling, I made an assumption that these trunk movements were to direct the opening of the trunk towards the area of interest to smell the air. Whether these movements were smelling events or possibly a way of signalling towards the area of interest, they were classified as smelling events for the purpose of this analysis.

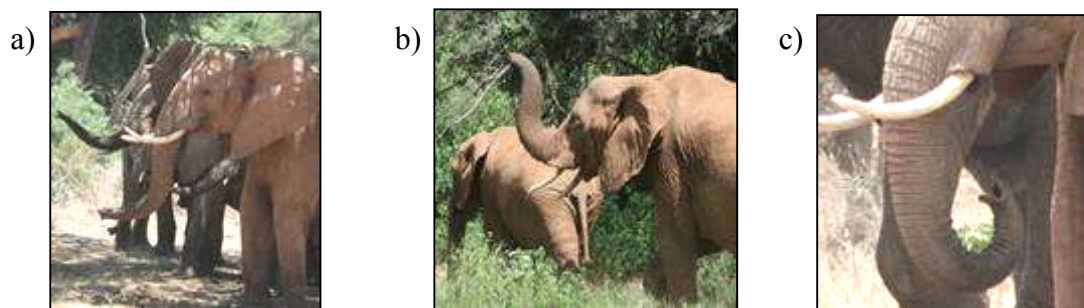


Figure 2.5. A 'smelling event' was recorded when the trunk was clearly directed in front of the elephant's face towards the direction of interest (usually towards the speaker) whether this was (a) low to the ground or (b) raised high above the head. Smelling with trunks curled under the trunk towards the body (c) were not included in the analysis.

“Running” was used to define elephants departing the area at considerable speed where I could clearly see the hindquarters bunching up which was typical of a ‘bouncing’ running gait (Ren and Hutchinson, 2007). Usually a considerable amount of dust was generated by this mode of retreat.

“Fast Walk” was used to define elephants departing the area at speed and covering the ground quickly, with heads raised but without breaking into a ‘bouncing’ run. As there is no easy distinction criteria to differentiate elephant locomotor patterns between running and walking, I used a more subjective analysis of speed variation and the ‘bouncing’ characteristic seen in running elephants to separate the two categories of ‘running’ from ‘fast walk’.

“Walk” was used to define elephants departing the area slowly or even meandering away with no obvious bouncing gait or speed element.

From video analysis I recorded dusting, headshaking and smelling events for each family but the total data scores were dependent on family size. To control for this variability I converted the data to a *“rate per minute per elephant”*. If elephants disappeared from sight before the end of the playback trial the rate per minute per elephant that was observed per family group while the elephants were in sight was used in the analysis.

2.2.5. Matched Families

I relocated 13 elephant families to which both sounds were played ensuring at least a seven day gap between playback trials (McComb, 1996) and controlling for any potential order effects. This sample enabled us to test for variation within families by comparing any differences in behaviour between sound stimuli but for the same individuals. Wilcoxon matched pairs test was used to test for significance.

2.2.6. Statistical Analysis

Statistical analyses were conducted with GenStat (version 11.1). Non-parametric, two-way statistics were used with underlying assumptions met for all tests. Results were considered significance where $p < 0.05$.

2.3. Results

2.3.1. Latency of Response and Distance Moved

Out of the 32 elephant families to whom I played bee sounds, 78.1% (25 families) left the tree under which they had been resting within 60 seconds of sound onset. Such was the speed of reaction that within just 10 seconds of sound onset we observed 34% of families (11/32) starting to move away from their resting positions. This latency of response to bees differs significantly from the response of the 18 families hearing the control sound of white noise where only one elephant family (5.5%) had moved after 10 seconds and only 6 (33.3%) had moved after 60 seconds of sound onset. Using the maximum time of the sound trials (360 seconds) as data for those elephant families classified as ‘no movers’ a significant difference (Mann-Whitney U test, $U=100.5$, $p<0.001$) was shown between the time that elephants started to move in response to bee sounds (mean = $52.84s \pm SE15.8$) compared to the control (mean = $210s \pm SE35.4$) (Figure 2.6a).

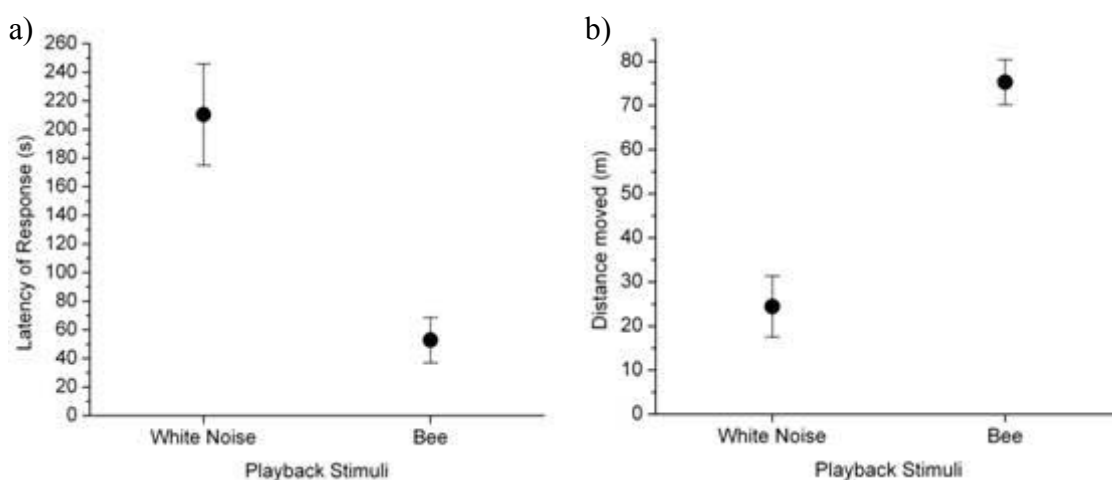


Figure 2.6: Comparison of mean \pm SE elephant family responses to white noise (n=18) and bee (n=32) playbacks showing families a) responded quicker with a shorter ‘latency of response’ and b) moved further ‘distance moved’ in response to bee sounds than white noise sounds.

Additionally, the mean distance moved (Figure 2.6b) was significantly related to the sound that was played (Mann-Whitney U test, $U=66.5$, $p<0.001$) with greater distances being taken by those families responding to bee sounds (mean = $75.31m \pm SE 5.12$) compared to control sounds (mean = $24.44m \pm SE6.91$).

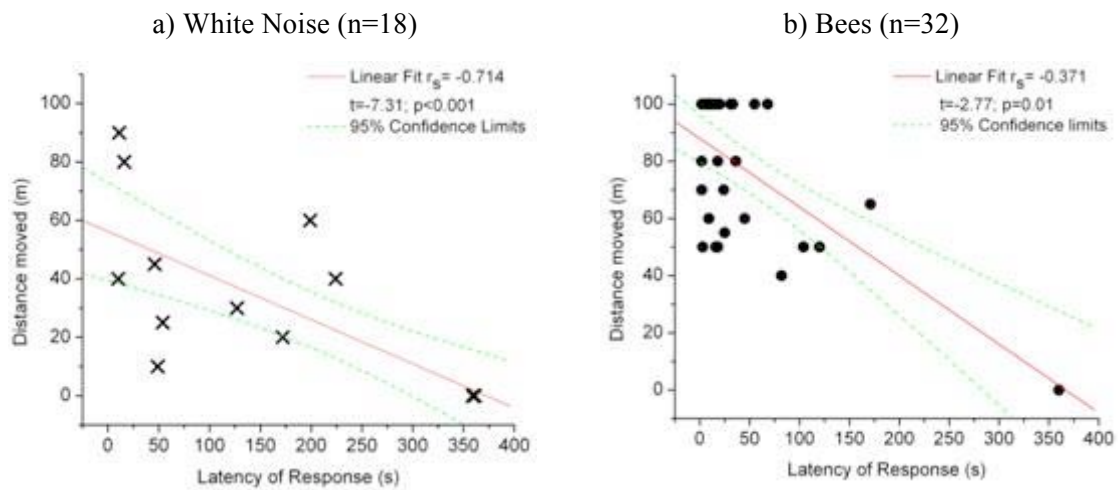


Figure 2.7: For both White Noise (a) and Bee playbacks (b) we saw a significant negative correlation between latency of response and distance moved.

Using Spearman's rank correlations I observed a significant negative correlation between the time that a family began to move away and the distance moved for both white noise ($t = -7.31$, $p < 0.001$; Figure 2.7a) and bees ($t = -2.77$, $p = 0.01$; Figure 2.7b). This indicates elephants that responded quickly and started to move away fastest to either sound also tended to move further away. Within the trials, environmental variations recorded in air pressure, temperature, time of day, altitude and number of elephants in the responding families were not significantly correlated to the retreat times of the elephants (Spearman's rank, $p > 0.05$).

2.3.2. Mode of Retreat

By the end of the 8-minute playback trials of bee stimuli 93.8% of elephant families (30/32) had moved compared to 55.6% of families (10/18) hearing the control (Maximum likelihood chi-square, $X^2 = 62.15$, $df = 3$, $p < 0.001$; Figure 2.8).

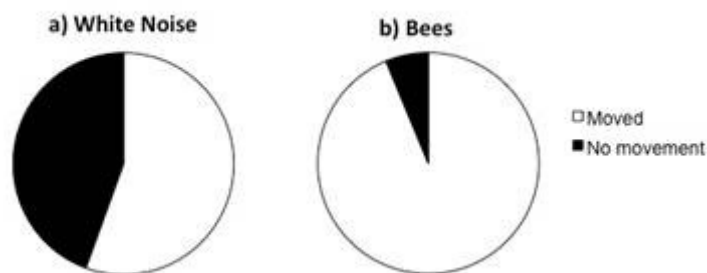


Figure 2.8. Proportion of families that had moved or did not move in response to a) White Noise (n=18) and b) Bee stimuli (n=32) after the end of the 8-minute playback trials.

Although 55.6% of elephant families responding to white noise moved away from the sound source during the 8-minute trials (Figure 2.9) the mode of retreat was consistently different from the mode of retreat chosen by elephants responding to the bee stimulus (Figure 2.9). Not one family responded to white noise by running away but a third of elephant families hearing bee sounds were seen running away. Additionally, a third walked fast away from their resting tree compared to just 5.56% walking fast away from white noise (Chi-squared Goodness of Fit test, Likelihood $X^2=133.42$, df 7, $p<0.001$).

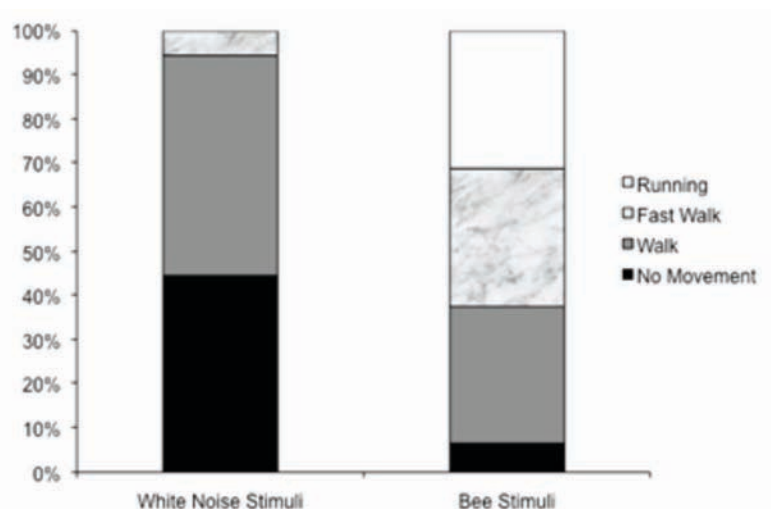


Figure 2.9. Mode of retreat for elephant families responding to white noise showed that 44.44% of families did not move, 50% of families walked away, 5.56% walked fast away and no families were seen running away from the stimuli. In contrast, families responding to bee stimuli saw only 6.7% not moving and 33.33% of families walking, walking fast and running away from the stimuli.

Retreat behaviour that was conducted at a run or fast walk showed elephants with tails in the air and backward glances towards the sound direction. In a typical flight run young calves ran directly next to their mothers with tails up, ears out and flicking their trunk from side to side. Elephants tended to bunch together when in retreat.

The retreating elephants slowed their gait as they put approximately 30-50 meters between them and the perceived ‘bees’ (the hidden speaker) and were often seen to relax and start to forage again at distances around 50 to 100 meters away from the sound source (mean distance = 75.31m \pm SE 5.12).

2.3.3. Behavioural Responses to Stimuli

Analysis of specific behaviour from video data revealed that elephants physically reacted to the stimuli when the 4-minute playbacks began. In a typical reaction to Bee stimuli elephants lifted their heads, drew their ears out on either side of the head and turned towards the speaker. (Figure 2.10 a-b) Often the elephants would to turn their heads from side to side towards the speaker as if trying to identify the location and source of the sounds. Young calves tended to come close to their mothers during this phase of response and calves or juveniles sleeping or lying on the floor would quickly get up and stand close to an adult.

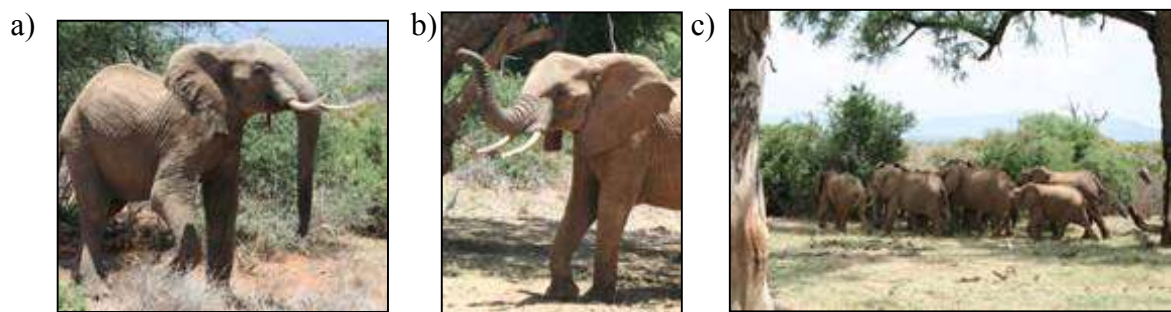


Figure 2.10. Elephant responses to bee stimuli: (a) Juvenile bull elephant stares directly towards the speaker with raised head and ears out. (b) Columbine from the Flowers family appears to be locating the sound by holding her ears out sharply from the side of her head as she raises her trunk to smell towards the direction of the sound. (c) An entire family retreats at a run from their resting tree directly in the opposite direction to the bee stimuli.

In between onset of sound and retreat, adult females were often seen to headshake towards the speaker, dust, flick their trunks around, shuffle backwards or away from the sound and smell with trunks towards the direction of sound. Usually one female would trigger a retreat and the rest of the family would follow, typically bunched together and in the opposite direction to the speaker (Figure 2.10c). This overall behavioural response differed markedly from the response to white noise where elephants usually started at the onset of sound and although often lifted their heads and paused with ears out to listen to the unusual sound, they would usually calm down quickly and resume resting. After a few minutes of listening to white noise, some families would appear “irritated” at the sound, indicated by a certain amount of shuffling around, and the elephants would start to walk off slowly, often to start foraging a few meters away (mean distance moved was just $24.44 \text{ m} \pm \text{SE}6.91$).

I analysed three of the most distinctive observed behaviours: dusting, headshaking and smelling with raised trunks. Figure 2.11 illustrates that for dusting, headshaking and smelling, elephants showed a higher mean rate per minute per elephant during the 4-minute bee stimulus phase than for white noise trials.

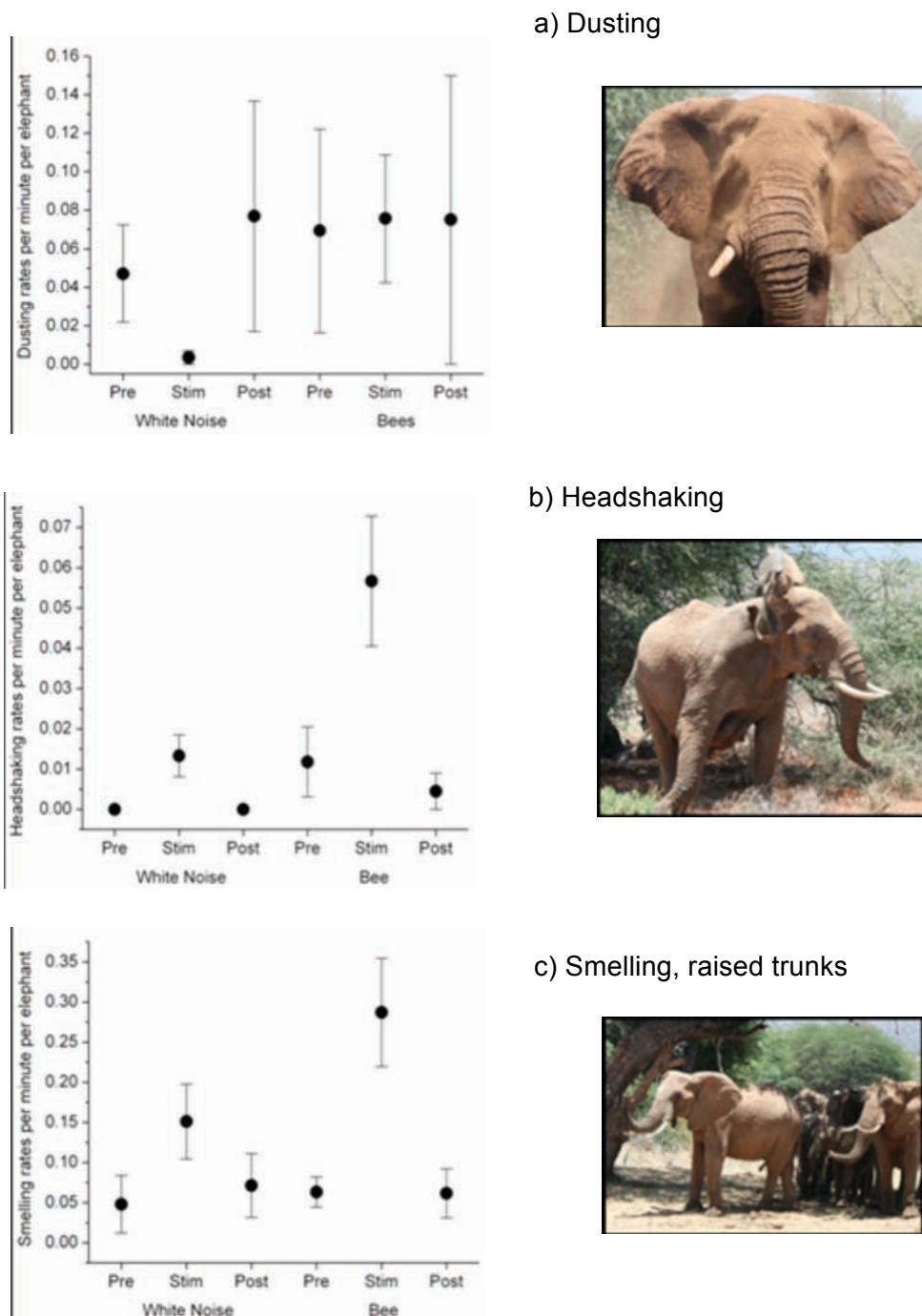


Figure 2.11. Mean \pm SE rates per minute per elephant for dusting, headshaking and smelling behaviour for families responding to White Noise and Bee stimuli. For both headshaking and smelling behaviour there was a distinctive leap in the mean occurrences to the bee stimuli.

Applying Friedman’s ANOVA to compare rates statistically across trials between pre-stimuli, stimuli and post-stimuli phases was complicated by missing data in the post-stimuli phase. 75% of elephant families responding to bee sounds had moved out of sight before the 2-minute post-stimuli phase could begin leaving only 25% of families in sight for filming behaviour in the last phase of the trial. In comparison 83% of families responding to white noise were still in sight for the post-stimuli phase where behavioural data were recorded. Table 2.1a describes the results of Friedman’s ANOVA for comparing behaviours across all trial phases. Although this test is weak, as **only 8** out of the 32 bee stimuli trials (25%) could be included in the analysis, the few trials analysed for bee playbacks showed a significant difference between trial phases for dusting and headshaking behaviour but not for smelling. In contrast families responding to white noise revealed no difference in dusting behaviour across trials but a significant variation in headshaking and smelling behaviour.

Wilcoxon matched-pairs test compared pre-stimuli behaviour scores to behaviour scores observed during the 4-minute stimuli phase (Table 2.1b). Elephants showed an increased rate of headshaking and smelling during both white noise and bee playbacks in this test and there was a trend towards an increase in dusting ($p=0.085$) in response to bee stimuli.

Behaviour	Stimuli	a) Friedman’s ANOVA	b) Wilcoxon Matched-Pairs: Pre-Stimuli vs Stimuli phases only
Dusting	White Noise	N=15, F=0.70, df 2, $p=0.247$	N=4, t=0, $p=0.125$
	Bees	N=8, F=3.06, df 2, $p=0.023$	N=13, t=28, $p=0.085$
Headshaking	White Noise	N=15, F=3.60, df 2, $p=0.002$	N=6, t=0, $p=0.031$
	Bees	N=8, F=6.81, df 2, $p=0.003$	N=15, t=7, $p=0.001$
Smelling	White Noise	N=15, F=9.03, df 2, $p=0.002$	N=15, t=1, $p<0.001$
	Bees	N=8, F=3.25, df 2, $p=0.115$	N=26, t=26, $p<0.001$

Table 2.1: (a) Results from Friedman’s ANOVA comparing dusting, headshaking and smelling rates per minute per elephant across trial phases (pre-stimuli, stimuli, post-stimuli) for White Noise (n=15) and Bees (n=8). Only trials with data within the post-stimuli phases could be included in the analysis making this a rather weak and incomplete analysis of the full dataset. (b) Wilcoxon Matched-Pairs test enabled more of the Bee response data to be statistically analysed between pre-stimuli behaviour scores and stimuli phases.

The short latency of response by elephant families responding to bee stimuli is an important factor to take into account when investigating behavioural responses to stimuli and may go some way to explain the weakness in the statistical analysis described in Table 2.1. 53% of families had disappeared from sight of the video camera before two minutes into the 4-minute bee playback stimuli (compared to only 11% for white noise). Although I controlled for this phenomenon in the analysis by comparing rates per minute per elephant, the short latency observed in response to bee stimuli had an effect on the time frame enabling elephants to dust and headshake. During my field observations I recorded that dusting mainly occurred when elephants remained under their tree kicking dust into the trunk with their feet. Likewise, headshaking occurred mainly by elephants swinging round from their stationary position to face the speaker or when appearing to hesitate about the decision to depart from the shade of the tree. Elephants with a short latency of response appeared to be in such a hurry to leave there was often no time to dust or headshake as they retreated and were often quickly out of sight of the video camera as they moved away through thick bush.

To investigate this observation further, I compared latency of response to dusting, headshaking and smelling behaviour and found that there was a significant positive correlation between the length of time an elephant remained stationary and the number of dusting (Spearman's rank $t=2.44$, $p=0.021$) and headshaking (Spearman's rank $t=2.19$, $p=0.036$) events that occurred when responding to the bee stimuli (Figure 2.12 b i-ii). In contrast, elephants listening to white noise were slower to retreat and had longer both under the tree and within full view of the camera but showed no increased dusting (Spearman's rank $t=1.01$, $p=0.328$) or headshaking (Spearman's rank $t=1.57$, $p=0.136$) the longer they listened to the noise (Figure 2.12a i-ii).

Smelling with raised trunks showed no such correlation with latency of response for either white noise (Figure 2.12 a-iii) or bee trials (Figure 2.12 b-iii) and this result was consistent with field observations where elephants appeared capable of smelling at any stage of the trial whether stationary or on the move. A quick retreat did not appear to impede the ability of elephants to smell with raised trunks and there was no difference in smelling between these fast responding elephants and those that remained under the tree for the full trial.

a) White Noise Playback Trials (n=18)

b) Bee Playback Trials (n=32)

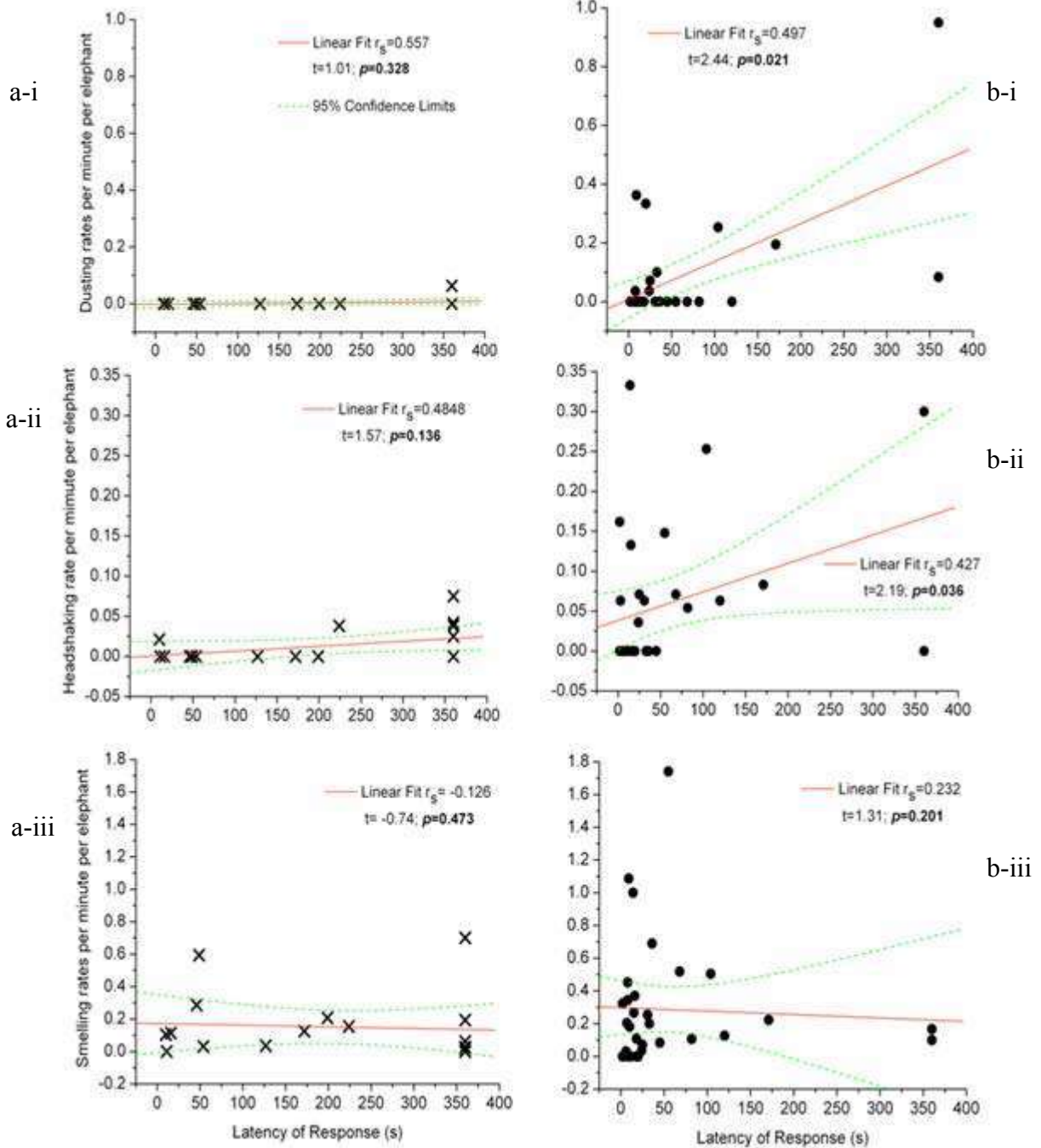


Figure 2.12. Panels a-i to iii illustrate the response of elephants to white noise and the lack of correlation between latency of response and dusting (a-i), headshaking (a-ii) and smelling rates (a-iii). Panels b-i to b-iii describe the response of elephants to bee stimuli and the significant correlation between latency of response and dusting ($p=0.0021$; b-i) and headshaking ($p=0.036$; b-ii), but not to smelling rates ($p=0.201$; b-iii).

2.3.4. Sub-sample analysis of 13 Matched Families

I played both white noise and bees to a sub-set of elephant families ($n=13$) ensuring that at least seven days were left between trials (McComb, 1996). Six Families were played bee sounds first and seven families were played white noise first. In response to bee stimulus there was no difference between the latency of response for different families played the sound first or second (Mann-Whitney U, $U=9.5$, $p=0.112$) or for distance moved (Mann-Whitney U, $U=18$, $p=0.714$) suggesting that there was no order effect caused by the playback experimental design.

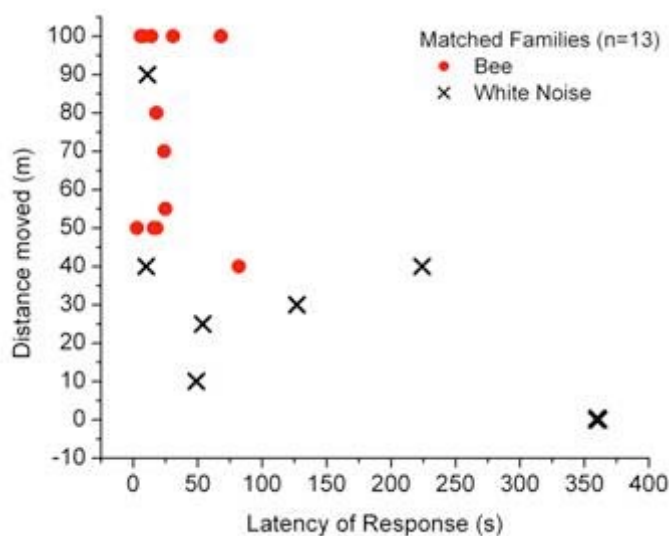


Figure 2.13. Distance moved vs latency of response for 13 matched elephant families showing that families responding to white noise were slower and moved a shorter distance than when they were played the bee stimulus. Apparent ‘missing values’ in the graph are due to overlapping data points.

I recorded a significant difference (Wilcoxon matched-pairs, $t=3.5$, $p=0.001$) between the distance moved for the same families responding to white noise (mean = $18.1\text{m} \pm \text{SE } 7.46$) and bee stimulus (mean = $76.5\text{m} \pm \text{SE } 6.83$) with families responding to bee stimulus moving on average over four times further than when moving away to white noise. I observed a similar pattern of behaviour for the latency of response which saw elephants move significantly faster (Wilcoxon matched-pairs, $t=1$, $p<0.001$) to bee stimulus (mean latency of response time = $24.6\text{s} \pm \text{SE } 6.65$) compared to white noise (mean = $230.4\text{s} \pm \text{SE } 43$) (Figure 2.13).

Additionally, families significantly changed their mode of retreat depending on which sound stimulus they heard (Chi-squared Goodness of Fit test, Likelihood $X^2=20.32$, $df\ 7$, $p=0.005$). In response to bee stimulus four families ran away compared to either walking or not moving in response to white noise and this ‘deceleration’ in mode of retreat was observed in 10 out of the 13 families (Table 2.2).

<i>N</i>	<i>Family Name</i>	<i>Mode of Retreat</i>	
		<i>White Noise</i>	<i>Bees</i>
1	American Indians	Fast Walk	Fast Walk
2	Artists 1	No Movement	Running
3	Artists 2	Walk	Fast Walk
4	Biblical Towns	No Movement	Fast Walk
5	First Ladies - Martha	No Movement	Walk
6	Native Americans 1	Walk	Fast Walk
7	Native Americans 2	No Movement	Walk
8	Rivers	Walk	Running
9	Spice Girls, Rosemary	Walk	Walk
10	Virtues	Walk	Walk
11	Winds 1	No Movement	Fast Walk
12	Winds 2	No Movement	Running
13	Winds 3	No Movement	Running

Table 2.2 Variation within elephant families as they changed their retreat behaviour in response to different playback stimuli. 10 out of 13 families jumped into a faster retreat mode category when listening to bee stimuli. The remaining three families did not change their speed of retreat.

Families responding to bee stimulus all showed a higher mean rate per minute per elephant for dusting, headshaking and smelling behaviour compared to white noise but these differences were not significant (Wilcoxon matched pairs, $p>0.05$). It is possible that because the elephants in this sub-sample moved so fast in response to the bee stimuli (mean latency was 24.6 seconds which was more than 50% lower than the total sample average of 53.9 seconds) that these families were primarily in the lower quartile end of the data set where the elephants did not have as much time to dust and headshake as their priority was to leave the area fast (refer back to Figure 2.12). Furthermore, the same families, when tested for white noise, were above average in their latency of response times (mean latency was 230.4 seconds compared to the overall average of 210.4 seconds).

2.4. Discussion

These sound playback experiments demonstrated that elephants respond to the buzz of disturbed bees with alarm and by moving away quickly from the sound source, often at a run or fast walk. The speed of response, the physical reaction of the elephant's body stances and the distance moved, all provides convincing evidence to support the hypothesis that elephants are aware of bees, that they can identify bees by sound alone, and that they hold and retain a memory about bees. This memory appears to be a negative one suggesting that elephants associate the sound of bees with a negative historical event, be it individual or collective, to which the correct response was (and is) rapid retreat to a safe distance.

Conditioning to the buzz may have been learnt either directly by (i) being stung, (ii) through observation of an elephant relative being stung or (iii) by social facilitation during a family retreat caused by buzzing bees. This study demonstrated that - overall - the elephants observed had either been negatively conditioned to aggressively buzzing bees or that they took their cues from family members that had, and therefore took flight.

Elephant skin can grow to as much as 3cm thick and is particularly thick and impenetrable, hence the phrase 'pachy-derm' or 'thick-skinned' (Sikes, 1971). However, the skin behind ears and on the forearm is much thinner than the rest of the body (Sikes, 1971). Additionally, skin around the eyes and the sensitive membrane of the inner trunk are also vulnerable spots. An anecdote recounted to me by a safari guide in Tarangire National Park, Tanzania (Paul Oliver, pers. comm) described watching a wild bull elephant accidentally crack open a wild beehive while foraging on an acacia tree. The bees erupted into his face and appeared to enter the bull's trunk causing the bull to "go berserk" as he "screamed and trumpeted loudly". He then ran away from the tree swinging his trunk from side to side as if to shake out the bees (refer back to section 1.5.1). A tame bull elephant on Ol'Jogi ranch in Laikipia, Kenya was so badly stung by bees that his eyes swelled up and closed completely. The rancher had to inject the elephant with antihistamine to reduce the swelling (Vollrath and Douglas-Hamilton, 2002a) Both these events support the likelihood that elephants do come across bees in the wild and do suffer negative reactions to being stung and these kind of unpleasant experiences must have evolved into the retreat behaviour observed in our playback

experiments. Young calves in particular have thinner skins in the early stages of development and mothers may be wary and defensive about possible attacks on their young offspring, which would warrant a rapid retreat.

I observed an increase in dusting, headshaking and smelling behaviour at the onset of bee playbacks, and headshaking and smelling behaviour at the onset of white noise playbacks. Statistical analysis of the data corresponded to field observations that elephants responding to bees often moved away so quickly (within 10 seconds) that they did not have time to stop and dust or headshake but were capable of raising their trunks to smell as a fast retreat did not impede their ability to smell the air. Elephants that took slightly longer to respond to bee stimuli were observed dusting and headshaking significantly more as their defensive behaviour appeared to increase the longer they were in the presence of the bee playback stimuli (refer back to the correlations shown in Figure 2.12). Dusting and headshaking may be specific physical reactions to the threat of bees where the dust might knock the flying insects out of the air and headshaking might throw off any bees attempting to sting the eyes or behind the ears.

Elephant families responding to white noise also had a significant increase in headshaking behaviour compared to pre-stimuli rates. However, unlike the bee playback groups, not a single headshake was observed pre-stimuli for white noise playback families, which meant that the very small increase in headshaking (mean rate per minute per elephant was only $0.013 \pm \text{SE } 0.005$ compared to 0.0 for pre-stimuli rates) resulted in a significant result. The white noise stimuli headshaking rate was not significantly different ($p > 0.05$) from the *pre-stimuli* headshaking rates observed for bee playback families (mean = $0.012 \pm \text{SE } 0.008$). Although this apparently chance anomaly in the pre-stimuli data resulted in a significant increase in headshaking behaviour for white noise trials the mean headshaking rate per minute per elephant for white noise trials (mean = $0.013 \pm \text{SE } 0.005$) was almost one fifth the rate observed for bee trials (mean = $0.057 \pm \text{SE } 0.016$) (Kolmogorov-Smirnoff two-sample test, $x^2 = 5.67$, d.f. 2, $p = 0.059$).

Two groups out of 32 did not respond to the bee playback. Both groups were sub-sections of well-known resident families and both groups were unusually small. The sub-group of the First Ladies consisted of just five elephants which was below the

average group size but an experienced, old adult female was present, Mary-Todd. Although this family did not move I recorded the highest ever dusting (n=19) and headshaking (n=6) events of any family under any trial conditions. Perhaps the hot day (39.3 °C) and large shady canopy of the tree at 1pm was too much of an attraction to leave but they ensured they were not bothered by any possible bees in the area by significantly increasing their rate of dusting and headshaking.

The second sub-group that did not move consisted of one young bull (in his early twenties), a young female (14 years old) and her calf from the Virtues family. This atypical elephant group demonstrated only one dusting event and two smelling events. However, they did not demonstrate any raising of the head, listening or retreat behaviour which suggests that these three individuals had not had (or did not remember) any direct or indirect negative interaction with bees in the past, or recent past. The young age of this group and the absence of an experienced matriarch (McComb *et al.*, 2001) may have contributed to the lack of the alarm and retreat that was so obvious in all the other thirty family groups.

Elephants like this, that fail to respond to bee buzz, could be candidates for future experiments to show how intensive an encounter with real bees is required for individual elephants to learn of their danger, either directly or indirectly. The responses of the other 250 elephants (in the other 30 experimental groups) that did take flight suggests that bee buzzing is recognised as a sign of danger at least by some elephants, which by their flight inform (i.e. alarm) the others. These observations suggest that one might be able to condition a 'bee naive' elephant family purposefully, or reinforce a bad experience by setting up an encounter with a real live beehive. Such conditioning might be useful not only to allow broadcasts of bee buzz to be deployed against crop-raiding elephants but also might serve to condition herds against entering areas of perceived danger, for example, through deployment of live beehives around fields of crops. Additionally, I often observed that non-target elephants outside of the trial family would appear through the bushes and join up with the retreating family. I heard very few vocalisations during the trials but this bunching behaviour of distant individuals led to a hypothesis that the elephants might be communicating between themselves about the threat of bees using low frequency rumbles that were beyond my hearing range. I explore this communication hypothesis in Chapter 3.

Chapter 3

Bee Threat Elicits Alarm Call in African Elephants

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Abstract

Unlike the smaller and more vulnerable mammals, African elephants have relatively few predators that threaten their survival. In this chapter we present evidence that the sound of disturbed African honey bees causes African elephants to retreat and that they produce warning vocalisations that lead other elephants to join the flight. In our first experiment, audio playbacks of bee sounds induced elephants to retreat and elicited more head-shaking and dusting, reactive behaviours that may prevent bee stings, compared to white noise control playbacks. Most importantly, elephants produced distinctive “rumble” vocalisations in response to bee sounds. These rumbles exhibited an upward shift in the second formant location, which implies active vocal tract modulation, compared to rumbles made in response to white noise playbacks. In a second experiment, audio playbacks of these rumbles produced in response to bees elicited increased headshaking, and further and faster retreat behaviour in other elephants, compared to control rumble playbacks with lower second formant frequencies. These responses to the bee rumble stimuli occurred in the absence of any bees or bee sounds. This suggests that these elephant rumbles may function as referential signals, in which a formant frequency shift alerts nearby elephants about an external threat, in this case, the threat of bees.

3.1. Introduction

Mammalian calls can reflect the internal states of animals, such as fear, but also may refer to external objects or events, such as the presence of predators (Seyfarth and Cheney, 2003). For example, arousing social contexts including social separations or encounters with strangers can result in calls of increased emotional intensity as observed in rhesus monkeys, *Macaca mulatta* (Bayart *et al.*, 1990), red fronted lemurs, *Eulemur rufifrons* (Fichtel and Hammerschmidt, 2002), baboons, *Papio cynocephalus ursinus* (Rendall, 2003), guinea pigs, *Cavia porcellus* (Monticelli *et al.*, 2004), and tree shrews, *Tupaia belangeri* (Schehka *et al.*, 2007). Typical acoustic responses to potentially threatening challenges include changes in tempo-related features (e.g. call rate and duration) and source features (e.g. increased and more variable frequency and amplitude). Filter features related to vocal tract modulations are less commonly associated with arousal, but have been observed in baboons (Rendall, 2003).

In addition to expressing internal state, mammalian vocalisations are also known to refer to external objects or events (i.e., ‘referential signaling’ (Seyfarth and Cheney, 2003)). In many cases, mammalian alarm calls vary acoustically according to specific predator species or class of predator (e.g., aerial versus terrestrial). Playback experiments with suricates, *Suricata suricatta* (Manser, 2001), and vervet monkeys, *Cercopithecus aethiops* (Seyfarth and Cheney, 2003), show that listeners react to alarm calls as if they were in the presence of an actual predator. This suggests that the acoustic structure of alarm calls can be related to specific external events, which in turn can be acted upon in adaptive ways by listeners. The complexity and variation of the acoustic cues can be seen in examples taken from three species of *Cercopithecus*, in which vervet monkeys *C. aethiops* separate their alarm calls for leopards and eagles through the location of dominant frequencies (Seyfarth *et al.*, 1980), Campbell’s monkeys *C. campbelli* separate them by call duration, fundamental frequency and dominant frequency location (Zuberbuhler, 2001) while Diana monkeys *C. diana* separate them by call rate, duration, fundamental frequency and formant frequency location (Zuberbuhler *et al.*, 1997; Zuberbuhler, 2000; Riede and Zuberbuhler, 2003). Animal alarm calls are not always predator specific, however. For example, yellow-bellied marmot, *Marmota flaviventris*, alarm calls are similar towards a range of predators but do increase in rate with level of perceived risk (Blumstein and Armitage, 1997).

Unlike the smaller and more vulnerable mammals, African elephants have relatively few predators that threaten their survival in the wild. In Kenya's Amboseli National Park, however, defensive and retreat behaviour in elephants was observed in the presence of Masaai tribesman (Bates *et al.*, 2007), who have been known to kill elephants. African elephants react similarly to sound playbacks of unfamiliar conspecifics (McComb *et al.*, 2001). Little research has been conducted on elephant vocalisations in response to specific threats, although observations of elephants 'roaring' or 'trumpeting' in response to the presence of lions is well known (Langbauer, 2000). More recently, research has demonstrated that African elephants actively avoid contact with African honey bees - with implications for the management of both species (Hoare, 2000; King *et al.*, 2009). First was the discovery that Kenyan elephants avoid feeding on trees with beehives (Vollrath and Douglas-Hamilton, 2002a). Subsequently, a playback study demonstrated that elephants retreat when hearing the sounds of disturbed bees (King *et al.*, 2007).

In order to investigate this apparent natural threat to elephants further, we recorded the vocalisations of elephants in response to playbacks of disturbed bee sounds, using an array of microphones capable of recording low frequency elephant calls. In a second playback experiment, we played the recorded "rumble" vocalisations to resting elephants in order to examine their potential function. We played natural and experimentally modified 'bee-response' calls, in order to isolate and explore the effect of a specific acoustic feature on the response of listeners, namely, the location of the second formant. Such formant location shifts are due to modulations of the vocal tract (Soltis, 2010). Thus we were able to explore how an acoustically distinctive elephant rumble produced in the presence of bees may function as an alarm call.

3.2. Methods

3.2.1. Honey Bee Stimuli Playbacks

We played the sounds of disturbed honey bees (n=15) and white noise controls (n=13) to elephant families containing known individuals resting under trees in the Samburu and Buffalo Springs National Reserves, Kenya (Wittemyer, 2001; Wittemyer and Getz, 2007). Following previously published protocols (King *et al.*, 2007; Chapter 2), we performed the playbacks from a camouflaged speaker (8-18m from the nearest subject) in the dry season of February-March 2008. In addition, three audio-recording units were deployed in an array surrounding target families to capture their vocal response (44.1 kHz sample rate). Two units (Marantz PMD670 recorder; Earthworks QTC1 microphone, 4–40,000 Hz \pm 1 dB) were deployed from the vehicle window in duffle bags 15-70 m from nearest subject (Figure 3.1), and one unit (Marantz PMD671; Earthworks QTC50, 3-50,000 Hz \pm 3 dB) and a video recorder were deployed on the research vehicle roof 15-40 m from nearest subject.



Figure 3.1. The earthworks microphones (circled) were placed as close as possible to the elephants to capture any calls or infrasonic rumbles emitted in response to the playback stimuli.

After set-up, a two minute pre-stimulus control phase began, followed by a 4-min stimulus phase (bee sounds or white noise), and a final 2-min post-stimulus phase. After each trial, the distance that the elephants travelled away from the sound source was recorded (0–100 m) (King *et al.*, 2007). Video of each trial was used to score other behaviours and group composition based on body size (age classes: 0-2 yrs, 3-14 yrs, >14 yrs). A minimum gap of 5 days was allocated before the same family was tested with the alternate sound. Every attempt was made to play both bees and white noise to the same family, randomly assigned, but some elephants left the reserve and were not seen after the first trial.

The triangular array of three microphones surrounding the elephants allowed for the identification of vocalisations produced by the target family by comparing relative amplitudes of calls on the three microphones. Identification of individual callers within families was not possible however. The number of calls (rumbles, revs, screams, trumpets (Leong *et al.*, 2002) recorded was 217 (n=160 during bee playbacks; n=57 during white noise playbacks). Low-frequency rumbles predominated (n=199). Field observations suggested that infants vocalised at random across playback trials, so infant vocalisations (0–2 yrs) were removed from the data set. We identified infant rumbles using data from African elephant infants of known age (0-3 yrs; n = 120 rumbles) at Disney’s Animal Kingdom (Wasolek *et al.*, 2009), in which infants aged 0-2 yrs produced rumbles with mean fundamental frequencies above 20 Hz and mean durations below 1.5 sec. Rumbles meeting both criteria (n=17) were removed from our dataset.

3.2.2. Acoustic measurement of rumble response

Rumbles were cut from start to end using Adobe Audition (version 1.5) and acoustic measurement of calls was performed in PRAAT (version 4.5.18, Boersma and Weenink, 2007) using automated routines. Elephant rumbles were down-sampled to a 400 Hz sample rate to analyse low frequencies. For each call, pitch floor and ceiling variables were adjusted to surround the observed fundamental frequency, replacing default software settings. From the fundamental frequency (F_0) contour, mean F_0 and F_0 range (maximum F_0 – minimum F_0) were computed. From the intensity contour, mean amplitude and amplitude range were computed. Calls were high-pass filtered (Hanning window, 10 Hz cut-off, 1 Hz smoothing) to remove background noise below the signal. A Fast Fourier frequency spectrum of the middle 0.5 s of the call was generated (bandwidth = 200 Hz), from which the first two formant frequency locations were extracted by LPC-smoothing without pre-emphasis. Duration was defined as the length of the sound file.

Signal to noise ratio was sufficient to make full measurements on 132 of the 199 rumbles (66%). After removing infant rumbles (n=12), there remained 13 pre-stimulus ‘control’ rumbles, 35 ‘white noise’ rumbles and 72 ‘bee’ rumbles. We selected for analysis all 13 pre-stimulus control rumbles and a random 20 rumbles from the ‘noise’

and ‘bee’ categories. The 13 pre-stimulus control rumbles were derived from 7 different families across 9 separate trials. The 20 noise and bee stimulus rumbles were each derived from 9 different families across 9 separate trials.

3.2.3. Rumble playbacks

We conducted a second playback experiment to determine if the class of rumbles produced in response to bees elicits different responses in listeners compared to the class of rumbles produced in response to white noise. When comparing calls of two general classes such as these, the calls are likely to vary within each class (due to inter and intra-individual variation) as well as between classes. Therefore, any difference in response by listeners to playback rumbles could be attributable to individual variation (or some other idiosyncratic attribute of the recordings), and not to between-class differences in call stimuli (McGregor *et al.*, 1992). One way to overcome this problem is to choose many different calls from each class for playbacks, so that such differences “average out”. However, in our case, we do not know the individual identity of callers, so that any observed difference in listener response could still be attributable to differences in the identity of specific callers, not to differences between ‘bee’ and ‘white noise’ rumbles.

Another means to overcome this problem, and the one we adopted here, is to experimentally manipulate calls so that the only acoustic difference between playback stimuli is the acoustic property of interest (McGregor *et al.*, 1992). The only acoustic difference between rumbles produced in response to bee sounds and those produced in response to white noise was the location of the second formant frequency, so we manipulated this feature. Rumbles used for playbacks were extracted from audio recordings of a single bee sound playback trial on a mid-ranking, resident family (Wittemyer, 2007). ‘Bee rumbles’ consisted of three post-stimulus phase rumbles (duration=9.4 sec) and exhibited second formant frequency locations typical of the ‘bee rumble’ class as a whole (Figure 3.2). To produce ‘white noise rumbles’ experimentally, the second formants of the ‘bee rumbles’ were artificially lowered (Adobe Audition, version 1.5) to mirror the formant locations observed in rumbles produced during white noise playbacks (Figure 3.2). For one sequence of two rumbles, the frequencies associated with second formants (115-168 Hz) were reduced in amplitude (-10 dB), and

lower frequencies (86-115 Hz) were amplified (+10 dB), shifting the second formant location from 132.3 to 104.5 Hz. For the third ‘bee rumble’, the 129-183 Hz band was reduced in amplitude (-10 dB), and the 78-123 Hz band was amplified (+10 dB), shifting the second formant location from 148.6 to 103.8 Hz.

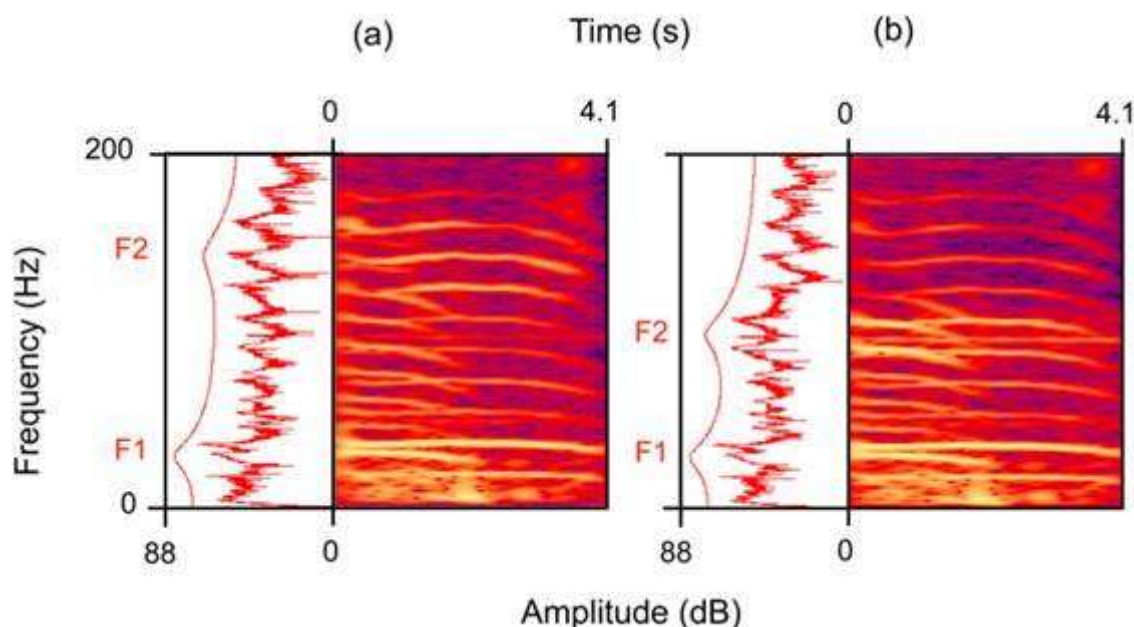


Figure 3.2. Spectrograms of elephant rumbles: (a) Unmodified African elephant rumble response to the bee playback stimulus. The Fourier frequency spectrum of the entire signal (PRAAT, version 4.6.18) with LPC smoothing showing two formants (F1, F2) and the spectrogram (44.1 kHz, Hanning window, 16384 bands; Adobe Audition, version 1.5) are shown. (b) Same signal as (a) with the frequency location of the second formants (F2) artificially lowered to match those observed in responses to white noise playbacks.

In this way, we controlled for individual differences and the problem of ‘pseudo-replication’ (McGregor *et al.*, 1992). This is because the unmodified ‘bee rumble’ stimulus exhibited high second formants that were representative of bee rumbles in general, and the experimentally modified ‘white noise rumble’ stimulus was identical in all respects (including individual identity), except that the formant locations were experimentally lowered to locations representative of the white noise rumbles in general (Figure 3.2). As a further control, three rumbles were isolated from the pre-stimulus phase of the same trial (duration=8.3 sec), designated ‘control rumbles’.

All three rumble stimuli were matched for amplitude and speaker distance during playbacks. First, all stimuli were low-pass filtered (Adobe Audition, version 1.5;

Butterworth filter, 1000 Hz cut-off), and were played from an FBT MAXX 4A speaker (frequency response: 50-20,000 Hz). Re-recording of test rumbles at 1 m showed amplitude loss below 50 Hz but frequency components were reproduced down to 20 Hz. Mean amplitudes across rumble sequences played from the FBT MAXX 4A speaker were 96.7, 96.2 and 95.7 dB (at 1 m) for the 'bee', 'white noise' and 'control' rumble stimuli, respectively (CEM DT-8852 Sound level meter data logger, slow, C weighting, sampling rate: 0.5 sec). In the field, the camouflaged speaker system was deployed 40-50 m from target families. Mean speaker distance from the nearest subject was 42.4, 43.2 and 42.2 m for the 'bee', 'white noise' and 'control' rumble stimuli, respectively.

The rumble stimuli were played back in random order until each stimulus type was played 10 times (n=30 trials) in February 2009, using the same methods described previously for bee and white noise playbacks. After set-up, a two minute pre-stimulus control phase began, followed by a 2-min stimulus phase during which three rumbles were repeated four times (either 'bee', 'white noise' or 'control' rumble stimuli), and a final 2-min post-stimulus phase. After each trial, the distance that the elephants travelled away from the sound source was recorded (0–100 m) (King *et al.*, 2007). We attempted to play all three stimuli to the same family groups but were not able to do so in all instances. Distance moved from the speaker was estimated in the field. Where partial group movement was observed, the mean distance moved was recorded. Behavioural responses and group compositions were scored from video.

3.2.4. Statistical analyses

Behaviour was compared across playback contexts using non-parametric tests (GenStat, version 11.1). MANOVA was used to analyse rumble structure across experimental contexts (SPSS, version 15.0). Type III sum of squares was employed to correct for imbalanced data (Shaw and Mitchell-Olds, 1993). We used Pearson's correlations to examine relationships between individual acoustic features and a) the distance elephants moved away from the stimulus and b) the age composition of the target family group (adults / adults + juveniles). Two tailed alpha was set at .05 for all tests.

3.3. Results

3.3.1. Honey Bee Playbacks

Confirming previous observations (Chapter 2; King *et al.*, 2007), elephants moved away in response to the playbacks of bee sounds. We performed 15 bee sound and 13 white noise playback trials to elephant families, consisting of a 2-min pre-stimulus phase, a 4-min stimulus phase (white noise or bee sounds), and a final 2-min post-stimulus phase. In 14 out of 15 bee trials (93%), families had moved away, compared to 6 of 13 white noise control trials (46%). Elephants moved away significantly further in response to bee sound playbacks ($71.67\text{m} \pm \text{s.e. } 8.46$) than to white noise playbacks ($32.3\text{m} \pm \text{s.e. } 11.5$; Mann-Whitney U test, $n_1=15$, $n_2=13$, $U=45$, $p=0.012$, Figure 3.3 a).

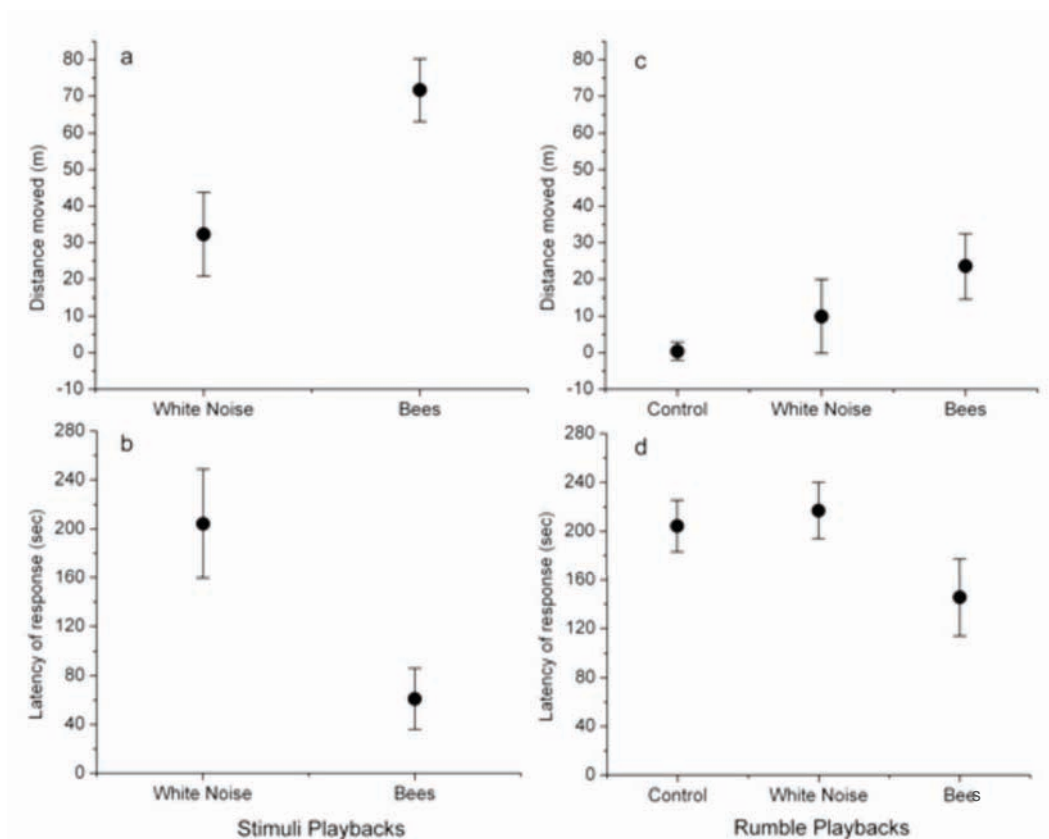


Figure 3.3. Distance moved and latency of response of elephants to sound and rumble playbacks. Mean (± 1 SE) of distance moved (a) and latency of response (b) of elephant families responding to bee sound ($n=15$) and white noise ($n=13$) playback trials. Elephants responding to bee sound playbacks moved on average over twice the distance of elephants responding to white noise playbacks (a) and were faster (b). For bee rumble playbacks ($n = 10$) elephant families moved away further (c) and faster (d) than elephant families responding to white noise or control rumble playbacks. Although rumble playbacks showed a more muted response than sound playback trials the directional pattern of behaviours were similar when comparing across experimental stimuli (a-d).

Additionally, using 360 seconds as a ceiling for families that did not move, elephants moved faster during bee sound playbacks (mean latency 61 sec \pm s.e. 25.1; median: 25 seconds) than during white noise playbacks (mean latency 204 seconds \pm s.e. 44.5; median: 207 seconds; Mann-Whitney U test, $n_1=15$, $n_2=13$, $U=56.5$, $p=0.058$, Figure 3.3b).

Upon hearing bee sounds, elephants exhibited increased headshaking and dusting behaviour during the 4-min stimulus phase of trials (Friedman's ANOVA, $n=15$, headshaking: $F=6.4$, $p=0.002$; dusting: $F=5.7$, $p=0.002$). When exposed to white noise, in contrast, headshaking and dusting were less frequent and rates did not differ across phases of the playback trials (Friedman's ANOVA, $n=13$, headshaking: $F=0.55$, $p=0.135$; dusting: $F=1.19$, $p=0.092$; Figure 3.4a and 3.4b).

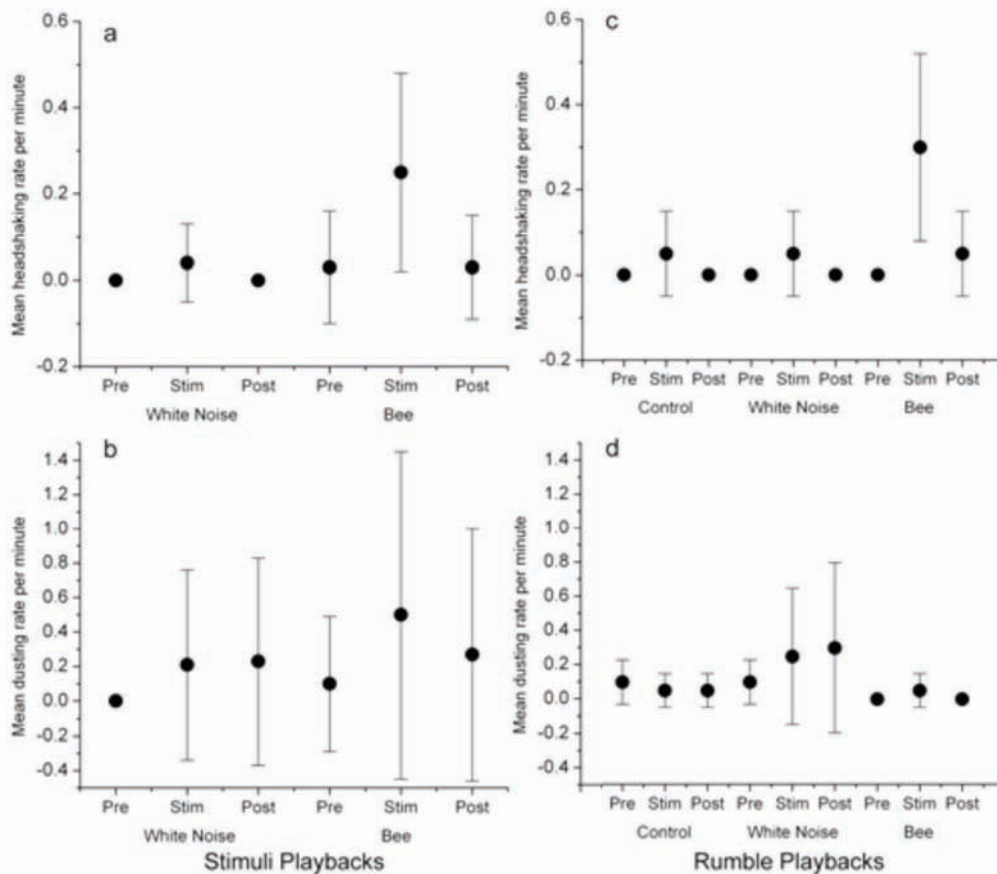


Figure 3.4. Headshaking and dusting behaviour of elephants responding to sound and rumble playbacks. Mean (± 1 SE) of headshaking (a) and dusting (b) rates per minute of elephant families responding to bee sound ($n=15$) and white noise ($n=13$) playback trials. Elephants responding to bee sound playbacks showed increased headshaking (a) and dusting (b) during the trials compared to those responding to white noise or control rumble playbacks. For bee rumble playbacks ($n = 10$) elephant families showed similar and significant patterns of increasing headshaking behaviour (c) but dusting was random across trials (d).

The total number of calls (rumbles, revs, screams, trumpets (Leong *et al.*, 2002)) recorded from the triangular array was 217, and significantly higher for the bee sound playbacks (n=15, calls = 160) than for white noise playbacks (n=13, calls = 57; Kolmogorov-Smirnov two-sample test, $\chi^2 = 10.03$, $p=0.007$) with low-frequency rumbles predominating (n=199). During bee sound playback trials, call rates among non-infants (see Methods) was lowest during the pre-stimulus phase, increased during the bee stimulus phase, and remained high in the post-stimulus phase (Friedman's ANOVA, n=15, $F=4.3$, $p=0.046$; Figure 3.5), but there was a muted response with no significant differences in call rates across trial phases for white noise playbacks (Friedman's ANOVA, n=13, $F=3.04$, $p=0.118$). There were no significant differences between white noise and bee sound playback trials for family size, age composition within each trial family, microphone distances, temperature, time of day, altitude or air pressure (K-S two-sample tests, $p>0.05$).

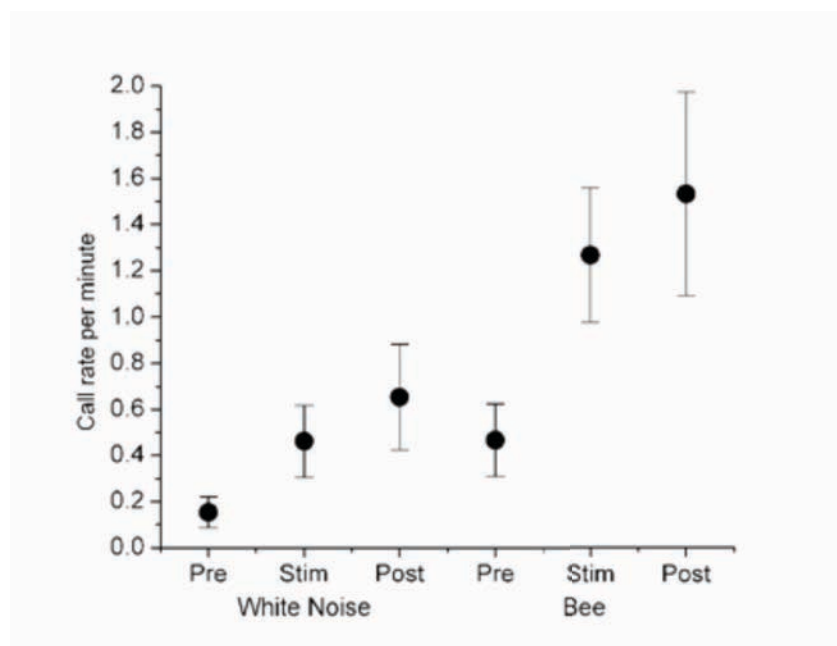


Figure 3.5. Call rates of elephants responding to sound and rumble playbacks. Mean call rates per minute (± 1 SE) recorded during the pre-stimulus, stimulus, and post-stimulus phases of bee (n=15) and white noise (n=13) playback trials. Elephants in bee playback trials responded to the stimuli with a significantly higher call rate in both the stimulus and post-stimuli phases compared to the pre-stimulus phase, but did not do so for white noise playback trials.

3.3.2. Acoustic Properties of Rumble Response

We conducted acoustic measurements on rumbles occurring during the pre-stimulus phases of all trials (n=13), during the stimulus and post-stimulus phases of bee sound trials (n=20), and during stimulus and post-stimulus phases of white noise trials (n=20; see Methods). Acoustic features measured were call duration, mean and range of the fundamental frequency, mean and range of call amplitude, and the first and second formant frequency locations (Soltis *et al.*, 2009). Formants are enhanced frequency components of a call, produced by the resonating effects of the vocal tract filter, which enhance some frequencies (called resonant frequencies or formants) and diminish others (Titze, 1994). MANOVA showed that the seven acoustic variables taken together differed across the three playback contexts (Wilks' Lambda=0.484, $F(14)=2.745$, $p=0.002$). Univariate tests showed that the mean fundamental frequency (F_o), the fundamental frequency range (max F_o – min F_o), and the second formant frequency location differed across playback contexts (ANOVA, $df=2$, mean F_o : $F=5.127$, $p=0.009$; F_o range: $F=8.479$, $p=0.001$; second formant location: $F=5.817$, $p=0.005$).

Tukey's Honestly Significant Difference pair-wise tests revealed that rumbles produced during white noise and bee sound trials both exhibited increased fundamental frequency and fundamental frequency range, compared to pre-stimulus control rumbles (F_o : white noise vs. control $p=0.009$, bee vs. control $p=0.036$; F_o range: white noise vs. control $p=0.020$, bee vs. control $p<0.001$) (Figure 3.6). Additionally, rumbles produced during bee sound trials exhibited an upward shift in the second formant location, compared to both white noise ($p=0.013$) and control rumbles ($p=0.018$) (Figure 3.6). Observed acoustic changes were not attributable to body size or physical exertion, as no acoustic measure was significantly correlated with the age composition of the target family group or the distance moved away from playback stimuli (Pearson's correlations, $p>0.05$).

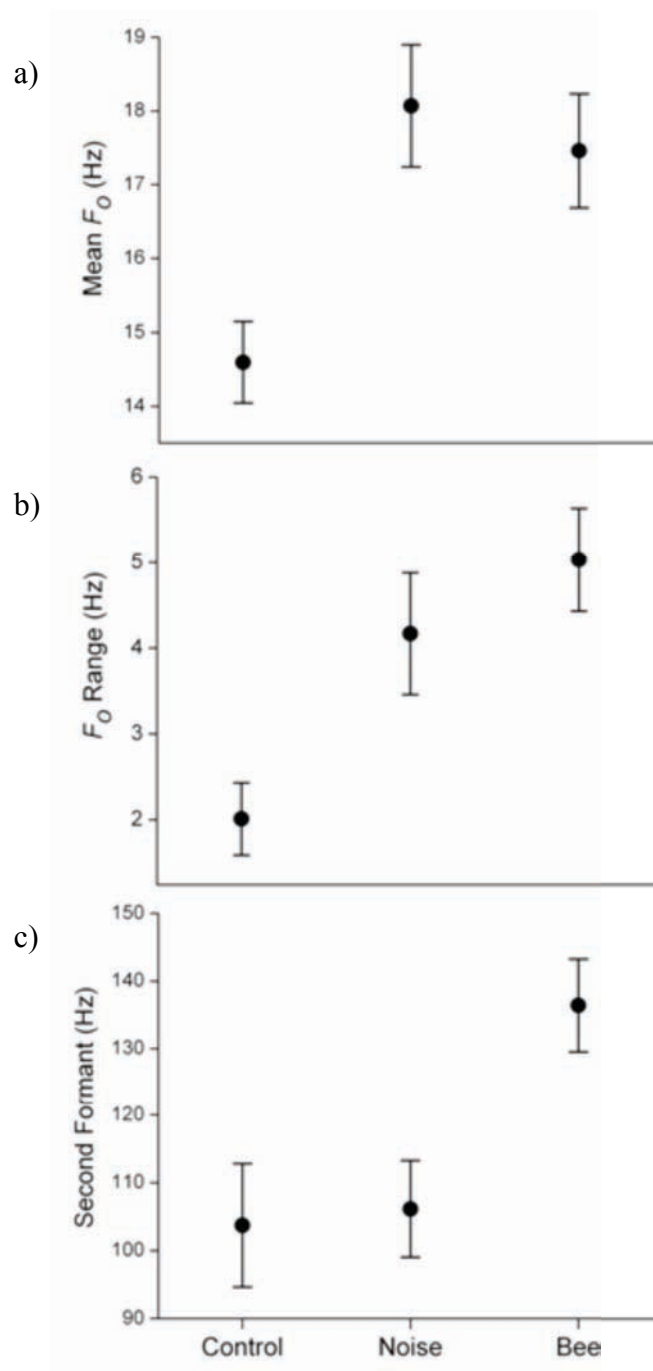


Figure 3.6. Acoustic features of rumbles emitted in response to sound playbacks. Mean (± 1 SE) for acoustic features across the three contexts (control = pre-stimulus phases of trials; noise = during stimulus or post-stimulus phases of white noise trials; bee = during stimulus or post-stimulus phases of bee trials). Results of pair-wise tests showed that bee and white noise rumbles were statistically different from controls for (a) mean F_0 and (b) F_0 range, and that bee rumbles were significantly different from white noise and control rumbles for (c) second formant frequency location.

3.3.3. Rumble Playbacks

We conducted a second playback experiment to determine if rumbles produced in response to bees elicit different responses in listeners compared to rumbles produced in response to white noise. However, we could not identify individual callers, so any differences observed in listener response to ‘bee’ and ‘white noise’ rumble playbacks could be due to individual variation of callers, not due to differences in the two classes of rumble. We overcame this problem by experimentally manipulating rumbles produced in response to bees so that they resembled rumbles produced in response to white noise, namely, by lowering the second formant frequency location. We selected three bee response rumbles that exhibited second formant frequencies that were typical of the class of bee rumbles as a whole (designated the ‘bee rumble’ stimulus). The ‘white noise rumble’ stimulus consisted of the same three rumbles, but with the second formants experimentally lowered in frequency location to resemble rumbles produced in response to white noise playbacks (Figure 3.2). Thus, all features of the two stimuli remained identical, except the one feature that distinguished bee rumbles from white noise rumbles, the second formant location (compare Figures 3.2 and 3.6). As a further control, we selected three pre-stimulus rumbles from the same trial (‘control rumble’ stimulus), matched for duration and amplitude to those of the other rumble stimuli.

Rumble playback trials followed a similar protocol as the previous sound playback experiments, consisting of a 2-min pre-stimulus phase, followed by a 2-min stimulus phase (3 rumbles repeated 4 times), and a final 2-min post-stimulus phase. We performed 10 playbacks of each rumble stimulus (‘bee rumbles’, ‘white noise rumbles’, and ‘control rumbles’) in random order for a total of 30 playback trials. In 6 of the 10 bee rumble playback trials the elephant families moved away from the speaker, compared to only 1 family moving away during 10 white noise rumble playbacks, and 2 families moving away during 10 control rumble playbacks (Table 3.1). It is possible that the order in which trials are presented can influence behavioural response, but there was no evidence for order effects in our trials. We were able to play more than one stimulus type to 11 families (Table 3.1), but there was no difference in distance moved when comparing the first and last playback trials (Wilcoxon Matched Pairs Test, $n=11$, $p=0.969$).

<i>Elephant Families</i> <i>Trials N = 30</i>	<i>Mean distance moved (m)</i>		
	<i>Bee</i>	<i>White Noise</i>	<i>Control</i>
Winds 2	60	0	12
Maya Churchill	80	-1	10
Winds 3	30	0	
Storms 2	0	0	
Spice Girls	8.6	0	
Butterflies	35	0	
Virtues: Hope	0		0
Virtues: Generosity	22		0
Artists 1	0		-18
Virtues	0		
Native Americans		100	
Winds 1		0	
First Ladies		0	0
Clouds		0	0
Artists 2			0
Rift Lakes: Baringo			0
Unknown Family			0

Table 3.1: Known elephant families tested with different rumble playback stimuli. Distance moved was relative to the speaker during each playback trial. Minus sign indicates movement towards the speaker.

To detect differences in distance moved from the speaker we conducted non-matched comparisons of the behavioural responses across ‘bee rumble’, modified ‘white noise rumble’, and ‘control rumble’ stimuli (Table 3.1). Elephant families exposed to the playback of bee rumbles moved away significantly further than elephants responding to either the white noise rumbles (Mann Whitney-U test, $n=10$, $U=26$, $p=0.041$) or control rumbles (Mann Whitney-U test, $n=10$, $U=24$, $p=0.032$), but distance moved was not different between white noise and control rumbles (Mann Whitney-U test, $n=10$, $U=47$, $p=1.0$; Figure 3.3c).

Additionally elephants listening to bees moved faster than elephants responding to white noise (Mann Whitney-U test, $n=10$, $U=26$, $p=0.042$; taking 240 seconds as the ceiling for elephants that did not move; Figure 3.3d) but a difference in latency between bee and control rumbles (Mann Whitney-U test, $n=10$, $U=31.5$, $p=0.132$) and between white noise and control rumbles (Mann Whitney-U test, $n=10$, $U=41.5$, $p=0.582$; were not significant.

Headshaking behaviour increased significantly during the stimulus phase of the bee-rumble playbacks (Friedman’s ANOVA, $d.f.=2$, $F = 3.15$, $p = 0.03$) but no

difference was observed across stimuli phases for families responding to white noise or control playbacks (Figure 3.4c). Headshaking behaviour in response to bee rumble playbacks was remarkably similar to headshaking observed in direct response to bee sound playbacks (Figure 3.4a) and appears to be one of the strongest behavioural responses to both bee and bee rumble stimuli. Dusting was observed sporadically across all rumble trials but, unlike the response to bee sound playbacks (Figure 3.4b), did not increase in response to bee rumble playbacks (Figure 3.4d).

3.4. Discussion

When exposed to the sounds of disturbed honey bees, African elephants exhibited behaviours that appear to function as defence against bees. Headshaking and dusting would knock bees away and fleeing from the area quickly would lower the risk of being stung. As elephants moved away from the sound source, they produced rumble vocalisations both during and after the bee sound stimulus. These rumbles may be simple expressions of emotional intensity (Rendall, 2003), or they may function as contact calls that coordinate group movement (Poole *et al.*, 1988; Leighty *et al.*, 2008) or as alarm calls to more distant elephants (Langbauer, 2000; Poole *et al.*, 1988). It is also possible that such calls are used in social facilitation i.e. teaching the inexperienced and more vulnerable young about a common and dangerous threat (McComb *et al.*, 2001).

The acoustic characteristics of the rumbles we examined are consistent with both increased emotional intensity of callers and with signalling to conspecifics. For example, rumbles produced in response to bees and white noise both exhibited increased and more variable fundamental frequencies, two common acoustic features associated with increased emotional intensity in other mammals generally (Rendall, 2003) and in African elephants specifically (Soltis *et al.*, 2009; Wood *et al.*, 2005). However, rumbles produced in response to bees were further distinguished by an upward shift in the second formant location, which was not observed in white noise or pre-stimulus control rumbles, and has not been observed, to our knowledge, in other emotionally arousing contexts in elephants (Soltis *et al.*, 2009). Such formant characteristics are controlled by the physical properties of the super-laryngeal vocal tract filter, which enhances resonance, or formant, frequencies. In humans, modulations

of the vocal tract filter (e.g., lip rounding and tongue position) are responsible for the production of different vowels, which convey semantic information (Titze, 1994). Our results raise the possibility that such vocal tract manipulations in elephants may function in a similar way.

When rumbles produced in response to bees (with high second formant locations) were played to other elephant families, subjects were more likely to move further away from the sound source, and showed increased headshaking compared to reactions to the same rumbles with second formants artificially lowered to resemble ‘white noise’ rumbles, and to pre-stimulus control rumbles. Since the ‘bee rumbles’ and ‘white noise rumbles’ differed only in the location of the second formant, this provides evidence that vocal tract modulation alters the formant characteristics of their rumbles when in retreat from this threat, and that rumbles exhibiting such a formant frequency shift can function as a referential signal that warns other elephants about the presence of an external threat from the environment, in this case, the threat of bees.

While we cannot conclude with certainty that this alarm call is specific for bees (more experiments are underway to compare responses to other threats), the similar behaviour patterns revealed in response to bee sound and to bee rumble playbacks (i.e., response speed, distance moved, and headshaking) make these calls good candidates for such specificity. Indeed, as elephants and bees have been interacting for millennia in the African savannah, selection pressure may have led to the evolution of an ability to communicate about such an ubiquitous threat, particularly in the light of the fact that other elephant vocalisations are situation specific (McComb *et al.*, 2003). At the very least, rumbles with upwardly shifted second formant locations may function as general alarm calls, since other elephant families retreat far from the area when exposed to such rumbles in the absence of bees or other external threats. Dusting behaviour increased in the presence of bee sounds, but did not increase during playbacks of ‘bee rumbles’, so more work is needed to reveal whether or not elephants might be trying to knock the insects out of the air with such behaviour. Understanding how elephants react to and communicate about the presence of bees will not only advance our understanding of elephant behaviour and vocal communication, but also our understanding of the potential deterrent effects of beehives on crop-raiding elephants (King *et al.*, 2009).

Chapter 4

Could bee sounds alone be an effective elephant deterrent? Habituation effects on elephant families repeatedly played bee sounds

Abstract

Acoustic deterrent devices are widely used in the aquaculture industry to deter marine predators from foraging on valuable fish stocks. The discovery that elephants will run from the playback of disturbed bees sounds has led to a discussion about whether bee sounds alone could be deployed to deter crop-raiding elephants from entering farm land. Like the use of 'pingers' in the aquaculture industry, such an acoustic deterrent method for elephants could be cheaply deployed. In this chapter I put this theory to the test by hypothesising that bee sounds alone will not be enough to deter elephants for long as other non-invasive deterrent tactics have resulted widely in habituation by elephants. I present behavioural data from 20 different elephant families living within Samburu and Buffalo Springs National Reserves to which we repeatedly played bee sound playbacks to over 13 months. I show that signs of habituation start to appear within just two playbacks for elephant families who are subjected to playbacks with a short time gap between trials but elephants with a long time gap between trials show less habituation behaviour. I conclude that although bee sounds alone will not be enough to deter elephants for long within one crop-raiding season, there may be a role for using bee sounds should a farmer choose to deploy a range of sound deterrents. Within a medley of acoustic deterrent sounds, bee sounds should be deployed with at least a five week time gap between each playback experience.

4.1. Introduction

The discovery that elephants run from the sound of disturbed bees (King *et al.*, 2007; Chapter 2) and that they emit a unique low-frequency rumble vocalization warning other elephants to retreat from bee sounds (King *et al.*, 2010; Chapter 3) has led to an important management question about the potential of using bee sounds alone to deter elephants from an area. Farmers could potentially place speakers and solar powered batteries around a field of crops and bee sounds could be played towards approaching elephants through either a manual switch or an automated triggered response using infrared trip-wires. This chapter investigates such potential.

Other non-invasive elephant deterrents have been tested in both Africa and Asia with limited success. In Luwanga valley, Zambia, white squares of cloth have been hung from string tied around fields of crops with the hope that a fluttering object might alarm approaching elephants (Osborn, 2002). In Laikipia, Kenya, cow bells have been hung around field of crops hoping that the noise of bells might alarm the elephants or at least alert the farmer to a potential crop-raiding event (Graham, 2007). In all cases, and as with many passive HEC mitigation methods, after a short period of effectiveness the elephants appeared to habituate to these passive deterrents, perhaps once they realised that there was no harmful outcome to approaching the unusual objects (Taylor, 1999).

In Maharashtra district, India, farmers tried out various more proactive techniques including explosion of firecrackers, whirling of flaming torches and the throwing of fire balls directly at the elephants. These attempts were summarized as *“It was found that elephants became accustomed to fire crackers and other scaring devices over a period of time and the techniques lost their effectiveness. New techniques have to be devised periodically to scare away elephants.”* (Kulkarni *et al.*, 2008).

In Asom district, India, a newspaper reported that the wildlife department were starting to play an audible recording of horse-neighing to try to stop elephants entering fields of crops (Guwahati State Newspaper, September 26th, 2008) but no scientific data has yet been published from this unusual idea. Extensive research in Amboseli National Park, Kenya, has revealed that playbacks of elephant rumbles (either musth or oestrous rumbles) can have the effect of attracting elephants towards or repelling elephants away

from the sound-emitting speaker (Poole, 1999) but the possible habituation effects after repeat trials was not tested. Although manipulating elephant movements through such playback techniques has been theoretically proven, to the best of my knowledge using this as an acoustic deterrent technique has not yet been field tested to deter elephants away from fields of crops.

Acoustic Deterrent Devices (ADDs) are presently widely used, and with some effect, in the aquaculture industry (Quick *et al.*, 2002) where marine mammals preying on fish (e.g. salmon) are reported to be responsible for millions of dollars loss per year (Nash *et al.*, 2000). Problem animals targeted with ADDs have included common and grey seals (*Phoca vitulina* and *Halichoerus grypus*), California sea-lions (*Zalophus californianus*), otters (*Lutra canadensis* and *Lutra lutra*) porpoises (*Phocoena phocoena*), orcas (*Orcinus orca*), Minke whales (*Balaenoptera acutirostris*) and at least five species of dolphin (Gordon and Northridge, 2002). The industry uses ADDs which are designed to produce intense sounds close to the target animal's best hearing sensitivity, usually in pulsations but generally not to generate any biological or social meaning (Gordon and Northridge, 2002). Buscaino *et al.* (2009) showed that ADDs known as 'pingers' can be effective at keeping dolphins (*Tursiops truncatus*) away from bottom gill fishing nets but the author acknowledged that habituation over time was a possibility and longer term studies were needed.

Although widely used, there is concern that the loud frequencies from ADDs may (i) damage the predators' hearing, (ii) exclude non-target wildlife from the fisheries' habitat and (iii) predatory mammals may begin to habituate to the sounds (Krauss, 1999; Cox *et al.*, 2001). In their report of ADD use in Scotland, Gordon and Northridge (2002) conclude "*ADDs may yet prove to be a useful tool for allowing an economically important activity to succeed in Scotland. However, as they are currently used, they represent the introduction of novel, powerful, yet poorly characterised, sound sources into the marine environment with a potential to detract from the conservation status of protected wildlife.*"

Within the study of animal behaviour, habituation in response to a repeated stimulus is a well-known phenomenon, particularly if the stimulus is not harmful to the study animal. In their comprehensive book *Measuring Behaviour* Martin and Bateson

(1990) describe “*the behaviour of the stimuli animals is likely to change with successive tests as they become habituated*”. Where no negative event occurs to an animal presented with a unique stimulus they can become desensitized to that stimulus over time, even if at first the stimulus caused extreme avoidance behaviour. Experience gathered from all over Africa with regards to the review of HEC mitigation methods supports this habituation theory (Osborne and Parker, 2003; Walpole *et al.*, 2006; Balfour *et al.*, 2007). As a consequence, we have no reason to predict that using playbacks of bee sounds will be any different in terms of eventually resulting in habituation by elephants, despite the extreme avoidance behaviour described in Chapter 2 from elephants hearing bee sounds for the first time.

Here I hypothesise that without the negative conditioning caused by painful bee stings from a “live” sound of disturbed bees, elephants will habituate to a playback recording of bee sound stimulus over time. I present data from 13 months of field trials to investigate this possibility.

4.2. Methods

The study site for all playback trials was the Samburu and Buffalo Springs National Reserves in Northern Kenya. Here Save the Elephants monitors all known families in the reserve keeping a comprehensive identification file of all individuals up to date. This detailed identification file was made available for our playback experiments and considerable time and effort was spent identifying core elephant families and their individual members to ensure that playback trials were done to known families. This ensured pseudo replication did not occur during these habituation trials and we can be 100% certain that the identification of each group was correct due to this invaluable resource.

Bee playback trials were conducted over three field seasons: Feb-March 2007; September-November 2007 and Feb-March 2008. These field seasons were selected as periods of high temperatures and no rainfall, giving us the greatest opportunity to find whole elephant families resting under trees during the heat of the day. By using elephant families resting, and sometimes sleeping, under shade trees we could be sure that all elephants were stationary at the start of the trial and any movement or behaviour was a result of response to the playbacks and not any other natural foraging behaviour which might cause movement.

Bee playbacks were conducted with the same method as described in detail in Chapter 2 section 2.2.2. Using a Sony Z1 video camera we filmed all behaviour and movement for 2 minutes pre-stimuli, 4 minutes during the bee sound playback followed by 2 minutes of post-stimuli behaviour (if the elephants were still in view). The core difference in method was that we attempted to re-locate each family as many times as possible within the time frame available but whilst only conducting one bee playback to the same family per day.

We had two questions we wanted answered (i) how do elephants react (or habituate) to bee sounds with a short time between playbacks and (ii) how do elephants react (or habituate) with long time gaps between trials. Much effort was made to relocate certain families within these desired time gaps but decisions on which family belonged to which group had to be opportunistic as we could not guarantee re-locating

each family within a planned timetable. As the reserves are totally unfenced, some elephant families left on their migratory journeys during the 13 months of the trials and the method had to be flexible to adapt around this natural behaviour.

Video data from each trial were carefully analysed for behavioural responses to each bee playback. Six behavioural variables were selected for analysis. Three variables looked at the movement in response to the bee sound playback: “latency of response” (the time taken for elephants to move away from their rest tree in seconds), the “distance moved” away from the rest tree by the end of the trial (in meters) and the “mode of retreat” (either no movement, walking, fast walking or running away).

Additionally three variables were selected to attempt to understand how perceptive the elephants were to the specifics of the bee sound deterrent. These were “dusting”, “headshaking” and “smelling” behaviour (see Chapter 2 section 2.2.3 for a reminder of these definitions). Recording the date between trials was important as we could observe how behaviour changes across time for elephants repeatedly played bee sounds with short or long gaps between trials.

4.3. Results

4.3.1. Data Summary

We conducted 58 bee playback trials to 20 different elephant families over three dry seasons (a period of 13 months) from early February 2007 until early-March 2008 (see raw data in Table 4.1). 20 families experienced at least two playbacks with two families, the Flowers and the Winds 2, tested as many as six times (see Figure 4.1 for repetition sample sizes).

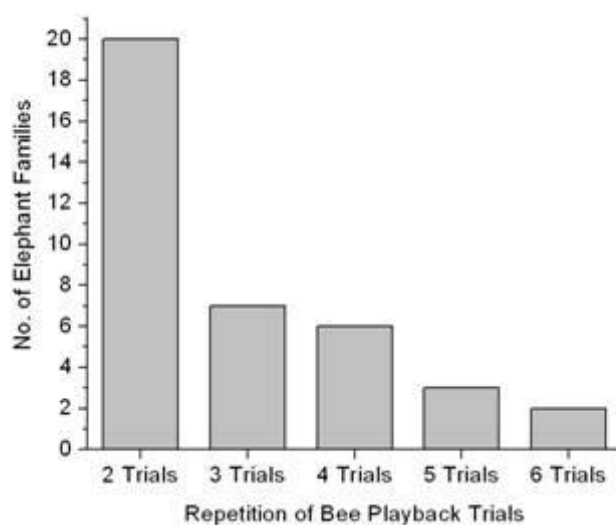


Figure 4.1. Sample sizes for bee playback repetition sound trials.

Playbacks were only conducted in the dry, hot seasons so conditions were comparable across all playbacks. However, we experienced a significant increase in temperature between the three dry seasons as the end of 2007 and early 2008 the field site was affected by a drought. The low rainfall meant an increase in temperatures from a mean of 34.2 °C in Feb 2007, rising to 39.17 °C in September 2007 and further rise to a mean temperature of 41.9 °C in Feb 2008 (Kruskall-Wallis one way ANOVA, $H=30.11$, $df=2$, X^2 $p<0.001$). However, we found no significant difference in the speed of response times from the elephants tested across the three seasons despite this increase in mean temperature (Kruskall-Wallis one way ANOVA, $H=1.67$, $df=2$, X^2 $p=0.433$) suggesting that temperature was not a deciding factor on whether or not elephants moved away quickly from the bee playback sounds.

N	Family	Behaviour	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
1	American Indians	Date of Trial	1.10.07	6.3.08				
		Latency of response (s)	3	3				
		Distance moved (m)	50	90				
		Mode of retreat	Fast Walk	Running				
		Dusting (rate per min per ele)	0	0				
		Headshaking (rate p. min p. ele)	0.063	0.016				
		Smelling (rate per min per ele)	0	0.016				
2	American Indians - Ute	Date of Trial	25.9.07	29.9.07	2.10.07	6.3.08		
		Latency of response (s)	2	30	13	3		
		Distance moved (m)	100	70	100	90		
		Mode of retreat	Running	Walk	Fast Walk	Running		
		Dusting (rate per min per ele)	0	0	0	0		
		Headshaking (rate p. min p. ele)	0.162	0.179	0.278	0.016		
		Smelling (rate per min per ele)	0.324	0.179	0.833	0.016		
3	Artists 1	Date of Trial	25.2.07	21.9.07	20.10.07	23.02.08		
		Latency of response (s)	7	10	43	8		
		Distance moved (m)	100	50	80	100		
		Mode of retreat	Running	Walk	Fast Walk	Fast Walk		
		Dusting (rate per min per ele)	0	0	0.033	0		
		Headshaking (rate p. min p. ele)	0	0	0.05	0		
		Smelling (rate per min per ele)	0.204	0	0.833	0		
4	Artists 2	Date of Trial	27.9.07	1.3.08				
		Latency of response (s)	16	156				
		Distance moved (m)	50	100				
		Mode of retreat	Fast Walk	Fast Walk				
		Dusting (rate per min per ele)	0	0				
		Headshaking (rate p. min p. ele)	0	0				
		Smelling (rate per min per ele)	0.370	0.139				
5	Biblical Towns	Date of Trial	20.2.07	2.10.07	30.10.07	3.3.08		
		Latency of response (s)	68	165	3	12		
		Distance moved (m)	100	100	30	15		
		Mode of retreat	Walk	Running	Running	Walk		
		Dusting (rate per min per ele)	0	0.016	0.075	0.017		
		Headshaking (rate p. min p. ele)	0.071	0.094	0	0.017		
		Smelling (rate per min per ele)	0.518	0.063	0.075	0.067		
6	Butterflies	Date of Trial	19.2.07	17.02.08				
		Latency of response (s)	33	360				
		Distance moved (m)	100	80				
		Mode of retreat	Running	No Move				
		Dusting (rate per min per ele)	0.1	0.35				
		Headshaking (rate p. min p. ele)	0	0				
		Smelling (rate per min per ele)	0.2	0.05				
7	Butterflies Sappiripi	Date of Trial	27.9.07	28.9.07				
		Latency of response (s)	34	2				
		Distance moved (m)	100	0				
		Mode of retreat	Walk	Fast Walk				
		Dusting (rate per min per ele)	0	0				
		Headshaking (rate p. min p. ele)	0.057	0				
		Smelling (rate per min per ele)	0	0				
8	First Ladies - Martha	Date of Trial	27.2.07	12.3.07				
		Latency of response (s)	82	50				
		Distance moved (m)	40	100				
		Mode of retreat	Walk	Fast Walk				
		Dusting (rate per min per ele)	0	0.064				
		Headshaking (rate p. min p. ele)	0.054	0.064				
		Smelling (rate per min per ele)	0.107	0.320				
9	First Ladies - Mary Todd	Date of Trial	16.9.07	20.10.07				
		Latency of response (s)	360	4				
		Distance moved (m)	0	100				
		Mode of retreat	No Move	Running				
		Dusting (rate per min per ele)	0.95	0.045				
		Headshaking (rate p. min p. ele)	0.3	0				
		Smelling (rate per min per ele)	0.1	0.045				
10	Flowers	Date of Trial	22.9.07	23.9.07	25.9.07	27.9.07	1.10.07	3.10.07
		Latency of response (s)	55	67	108	34	141	188
		Distance moved (m)	100	30	60	100	100	50
		Mode of retreat	Running	Walk	Walk	Walk	Walk	Walk
		Dusting (rate per min per ele)	0	0	0.070	0	0.156	0
		Headshaking (rate p. min p. ele)	0.148	0.065	0.140	0	0.031	0
		Smelling (rate per min per ele)	1.741	0.098	0.350	0	0.406	0.417

N	Family	Behaviour	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
11	Hardwoods - All	Date of Trial	25.2.07	21.2.08				
		Latency of response (s)	2	25				
		Distance moved (m)	100	60				
		Mode of retreat	Running	Fast Walk				
		Dusting (rate per min per ele)	0	0				
		Headshaking (rate p. min p.	0	0.036				
		Smelling (rate per min per ele)	0	0				
12	Hardwoods - Cedar	Date of Trial	21.9.07	21.02.08				
		Latency of response (s)	2	2				
		Distance moved (m)	100	60				
		Mode of retreat	Running	Running				
		Dusting (rate per min per ele)	0	0				
		Headshaking (rate p. min p.	0	0.036				
		Smelling (rate per min per ele)	0	0				
13	Planets - Duma	Date of Trial	16.10.07	20.10.07				
		Latency of response (s)	11	233				
		Distance moved (m)	100	40				
		Mode of retreat	Fast Walk	Walk				
		Dusting (rate per min per ele)	0	0.444				
		Headshaking (rate p. min p.	0	0				
		Smelling (rate per min per ele)	0	0.028				
14	Royals	Date of Trial	11.2.07	20.02.08				
		Latency of response (s)	10	26				
		Distance moved (m)	100	100				
		Mode of retreat	Fast Walk	Walk				
		Dusting (rate per min per ele)	0	0.021				
		Headshaking (rate p. min p.	0	0.021				
		Smelling (rate per min per ele)	0.182	0.313				
15	Virtues - Resilience	Date of Trial	16.9.07	21.9.07	22.9.07	26.9.07	28.9.07	
		Latency of response (s)	4	360	124	104	360	
		Distance moved (m)	100	0	100	50	0	
		Mode of retreat	Fast Walk	No Move	Fast Walk	Walk	No Move	
		Dusting (rate per min per ele)	0	0	0.070	0.253	0	
		Headshaking (rate p. min p.	0	0.036	0.140	0.253	0	
		Smelling (rate per min per ele)	0.2	0.107	0.07	0.505	0.083	
16	Virtues - R14.93	Date of Trial	12.3.07	22.9.07				
		Latency of response (s)	360	224				
		Distance moved (m)	0	30				
		Mode of retreat	No Move	Walk				
		Dusting (rate per min per ele)	0.083	0.25				
		Headshaking (rate p. min p.	0	0				
		Smelling (rate per min per ele)	0.167	0				
17	Virtues - Hope	Date of Trial	26.9.07	15.10.07				
		Latency of response (s)	8	360				
		Distance moved (m)	100	0				
		Mode of retreat	Running	No Move				
		Dusting (rate per min per ele)	0	0				
		Headshaking (rate p. min p.	0	0				
		Smelling (rate per min per ele)	0.343	0.1				
18	Winds 1	Date of Trial	13.2.07	2.2.08	15.02.08			
		Latency of response (s)	8	16	43			
		Distance moved (m)	100	100	100			
		Mode of retreat	Fast Walk	Running	Fast Walk			
		Dusting (rate per min per ele)	0.036	0	0			
		Headshaking (rate p. min p.	0	0	0.046			
		Smelling (rate per min per ele)	0	0.142	0.092			
19	Winds 2	Date of Trial	13.2.07	15.2.07	18.3.07	24.10.07	25.10.07	5.3.08
		Latency of response (s)	6	35	16	122	360	6
		Distance moved (m)	100	80	100	0	100	40
		Mode of retreat	Running	Walk	Walk	No Move	Fast Walk	Walk
		Dusting (rate per min per ele)	0	0.181	0.063	0.132	0	0
		Headshaking (rate p. min p.	0	0.014	0.031	0.059	0.000	0.118
		Smelling (rate per min per ele)	0.03	0.236	0.281	0.279	0	0.059
20	Winds 3	Date of Trial	16.4.07	21.9.07				
		Latency of response (s)	14	53				
		Distance moved (m)	100	100				
		Mode of retreat	Running	Walk				
		Dusting (rate per min per ele)	0	0				
		Headshaking (rate p. min p.	0.333	0.2				
		Smelling (rate per min per ele)	1	0				

Table 4.1. Raw data from all elephant trials conducted for our habituation tests. Six variables were compared across families: latency of response, distance moved, mode of retreat, dusting, headshaking and smelling behaviour. Date between trials was an important detail as we could observe how behaviour changes across time for elephants repeatedly played bee sounds with short or long gaps between trials.

4.3.2. Latency of Response and Distance Moved for all Trials

We observed some variation in the latency of response times from elephant families across trials with a slight upward trend ($r_s = 0.2$) showing there was an increase in the latency of response times by the 5th or 6th playback (Figure 4.2.a).

The behavioural trend for changes in distance moved by elephants was more distinctive ($r_s = -0.714$) as we observed families moved furthest away during the first playback trial and then proceeded to move away a shorter distance the more times they heard the bee playback (Figure 4.2.b).

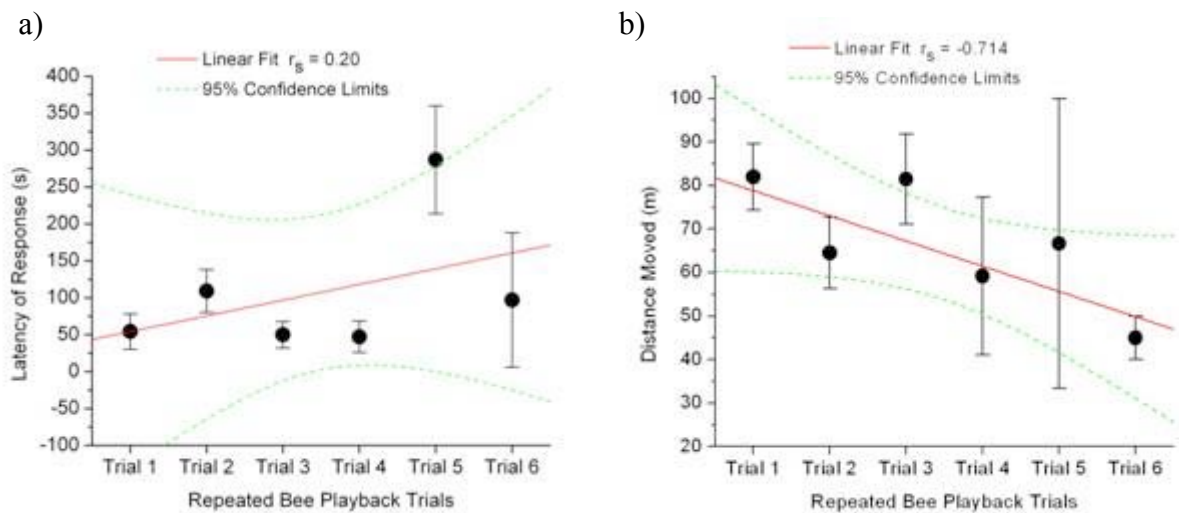


Figure 4.2. Summary of data for all 58 trials showing (a) the mean \pm SE for latency of response in seconds showed an increasing trend over time but the wide confidence limits suggest that the data did not show a strong linear relationship ($r_s = 0.2$). (b) The mean \pm SE for distance moved across trials showed that the more times elephants were tested with bee sounds the shorter distance they tended to move away from their rest tree ($r_s = -0.714$). Sample sizes for each of the six trials varied (see Figure 4.1).

4.3.3. Behavioural Responses for all Trials

We compared dusting, headshaking and smelling behaviour across trials and observed a slight negative trend for dusting ($r_s = -0.6$) and headshaking ($r_s = -0.314$) suggesting that the more often families heard the bee sound playback the less they responded with those physical responses to the sounds. There was no variation in smelling behaviour between the first and last trial ($r_s = -0.086$) that supports previous observations (Chapter 2) that smelling is not a behaviour that varies in response to playbacks of bee sounds.

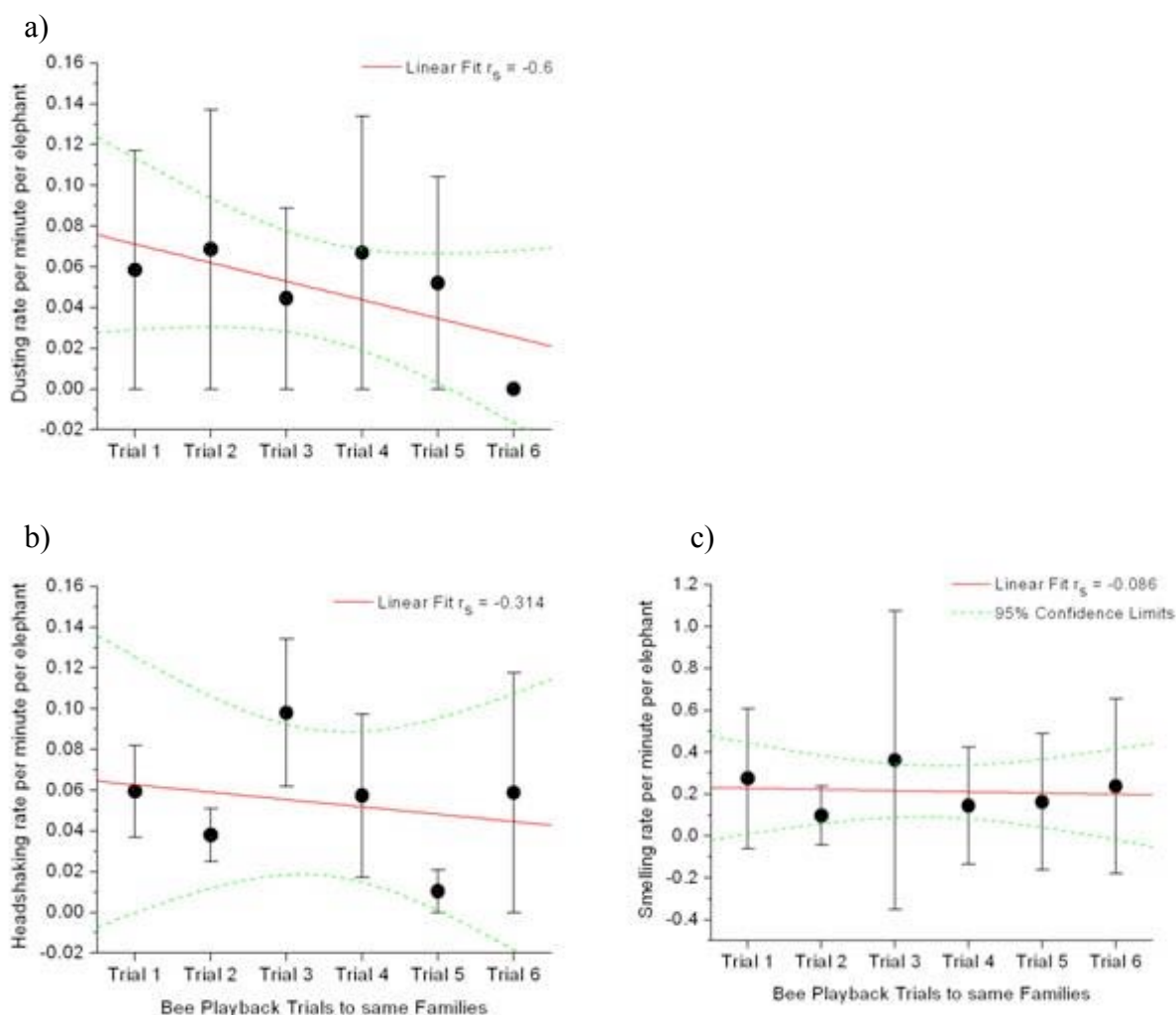


Figure 4.3. Variation in (a) dusting, (b) headshaking and (c) smelling behaviour for all elephant families across playback trials. Dusting and headshaking showed a slight trend decreasing over playback trials compared to smelling behaviour which was consistent over time.

4.3.4. Comparing Latency of Response and Distance Moved for families with long and short gaps between the first two playback trials

The data were divided into two groups, those elephant families who were tested with bee sounds for a second time with a short time gap of 18 days or less ($n=8$) and those families who had a long time gap between the first and second trial of between 5 weeks to a year ($n=12$). This data division occurred due to both a natural split in the two data groups but 1-18 days also was regarded as representative of the time period that crop-raiding elephants might frequent a farming area within a harvest season. Data for Trial 1 (the first time any family had been played bee sounds) show that there was no difference between latency of response or distance moved between short and long groups confirming that there was a consistency between response behaviour of these particular family responses for the first trial (K-S two sample tests, latency of response: $X^2 = 0.53$, d.f.2, $p = 0.766$; distance moved: $X^2 = 0.83$, d.f.2, $p = 0.659$).

Latency of Response: The data shows that elephant families who were tested twice with bee sounds in a short period of time (■) responded slower than those elephants who had a longer time gap (○) between playback trials (Figure 4.4). Of the 8 families with a short time gap between trials the mean latency of response was $25.25s \pm SE 10.39$ compared to a mean of $142.4s \pm SE 53.6$ for the second playback trial. Despite this interesting trend, there was no significant difference between the first and second playback trials (Wilcoxon Matched Pairs test, $T = 9$, $p = 0.25$).

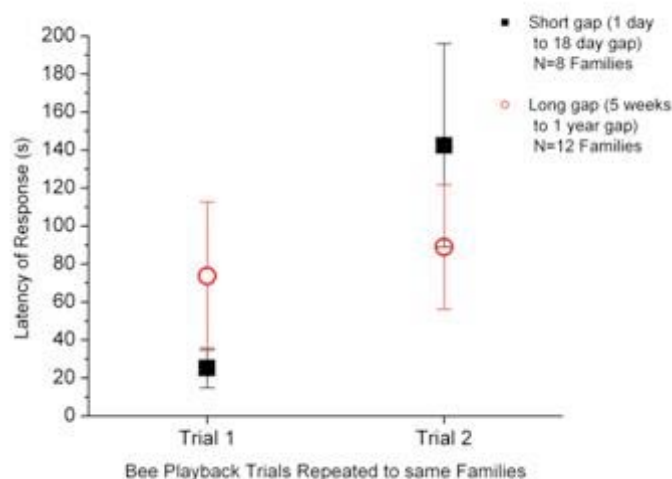


Figure 4.4. Latency of Response compared between elephant families who had a short ($n=8$) and long ($n=12$) gap between bee playback trials. The data suggest that elephants are more likely to slow their response times if they hear a second bee playback shortly after hearing a primary playback but if there is a long gap between playbacks their second response is similar to their initial response.

The mean latency of response difference for the first trial for groups tested with a long gap between playback trials ($n=12$) was $73.58s \pm SE 38.99$ compared to $88.92s \pm SE 32.75$ for the second trial. This difference was not significant (Wilcoxon matched pairs test, $T = 19$, $p = 0.184$) suggesting that elephants might react to repeated bee playbacks by moving away with the same speed if there is a large time gap between experiences of hearing bee sounds.

Distance Moved: For elephant families with a short time gap between the first and second bee playback trial we saw a significant decrease in distance moved during the second trial from a mean of $92.5m \pm SE 7.5$ in the first trial to $40m \pm SE 14.02$ for the second trial (Wilcoxon matched pairs, $t=3.5$, $p = 0.047$). As with latency of response, elephants with a long gap between trials showed no significant difference in the distance moved during the first playback (mean $75m \pm SE 11.51$) compared to the second playback ($80.83m \pm SE 7.12$) (Wilcoxon matched pairs, $t=15.5$, $p = 0.875$; Figure 4.5).

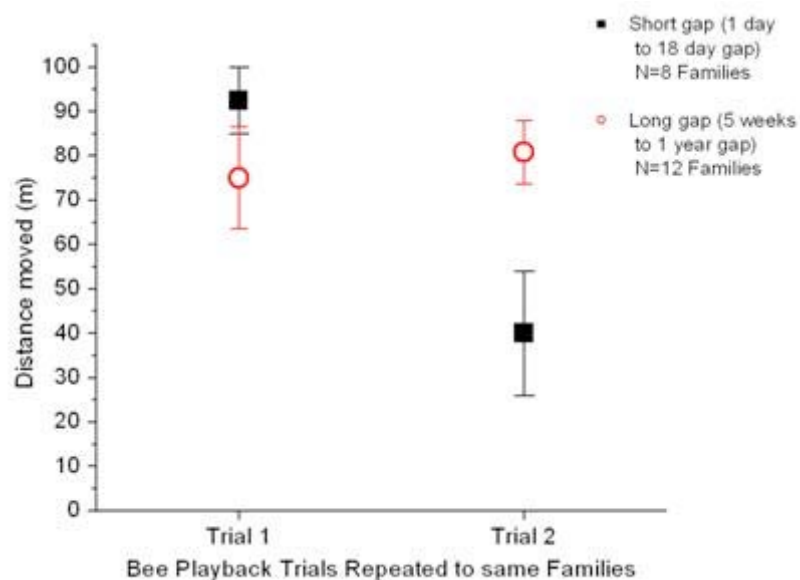


Figure 4.5. Comparing distance moved between the first and second trial playbacks we observed a significant difference ($p = 0.047$) in distance moved for families experiencing the playback with a short time gap but there was no difference between responses of elephant families with a long time gap between trials ($p = 0.875$).

4.3.5. Comparing Behavioural responses for families with long and short gaps between the first two playback trials

The behaviour of the two groups of elephant families tested with short and long gaps between trials were analysed for dusting, headshaking and smelling behaviour. Although we observed a slight trend for a decrease in all three behaviours across groups over time none of these differences were significant (Wilcoxon matched pairs tests $p > 0.05$) suggesting that elephant families were physically reacting to the bee sounds consistently between the first and second time they heard the playback. One exception was seen in dusting for families tested with a short time gap where there was an anomaly that not a single family in the 8 tested first dusted in response to the bee playback.

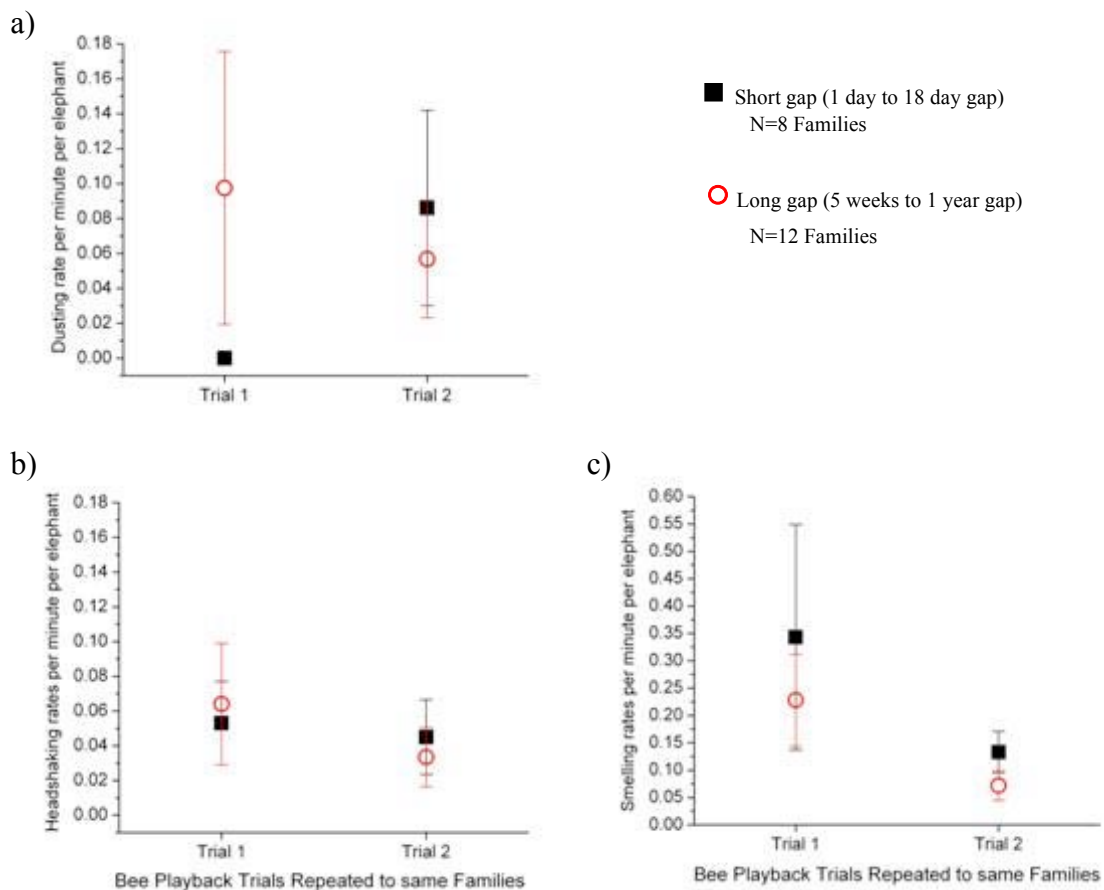


Figure 4.5. Variation in (a) dusting, (b) headshaking and (c) smelling behaviour for 20 elephant families across the first two playback trials with data divided into elephant families who had a short gap (n=8) and long gap (n=12) between trials. Headshaking and smelling behaviour showed a slight trend for decreasing over both short and long gap playback trials compared to dusting behaviour which showed the opposite trend. None of these differences were significant.

4.3.6. Comparing Mode of Retreat for families with long and short gaps between the first two playback trials

Elephant families with a short gap between playback trials showed remarkably different retreat behaviour the second time they heard the bee stimulus (Figure 4.6.a). During the first trial 50% of families ran away followed by 25% walking fast and 25% walking away. The same elephant families when tested shortly after were seen to rapidly slow down their mode of retreat and zero elephants were seen running away, with 25% not moving at all, 50% walking and 25% walking fast away.

In contrast, elephant families with a long gap between playbacks trails showed similar behaviour in their choice of retreat mode. In both the first and second trial 40% of elephants continued to run away to the bee playback. In the second playback trial more families chose to walk away (33%) compared to the first trial (8%) but there were fewer ‘no movers’ in the second trial (8%) than the first (16%).

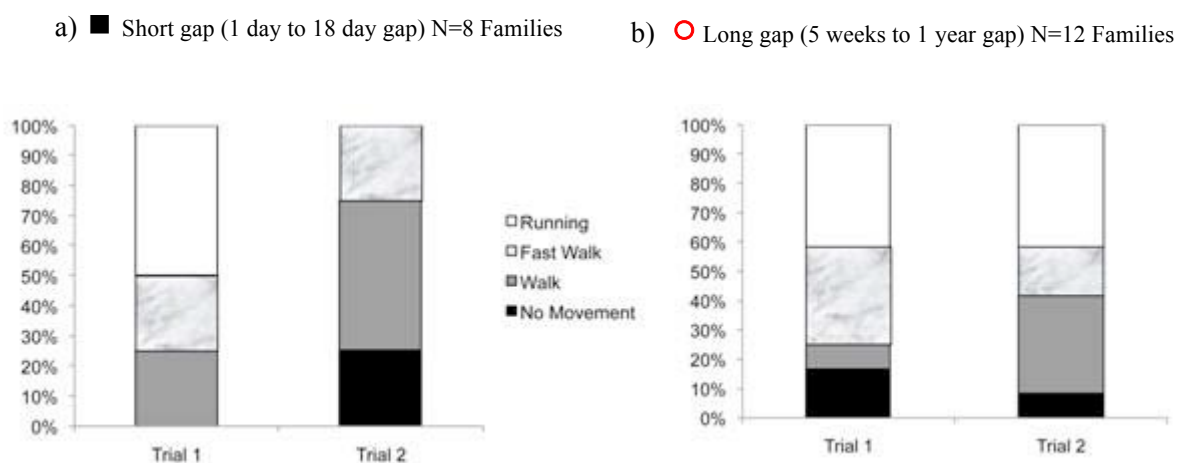


Figure 4.5. Mode of retreat choice for all 20 elephant families divided into (a) those with a short time gap (n=8) and (b) those with a long time gap (n=12) between playback trials. Elephants with a short time gap appeared to slow down their mode of retreat in response to the second playback where as those elephant families hearing bee sounds again with a long time between playbacks appeared to be just as alarmed as the first time they had heard the sound.

4.3.7. A Closer look at Individual Elephant Families

Here we take a closer look at four different elephant families who were tested between four and six times during our habituation trials. Two of these families, the Virtues and the Flowers were ‘short gap’ families (■) with all trials occurring within 13 days of each other. In both cases we saw an increase in the response times from the first to the last trial. In particular the Flowers family showed a steady increase in response times ($r_s = 0.657$) suggesting that they were becoming ‘used’ to the sound and were tempering their retreat speeds accordingly. Nevertheless, the family did continue to retreat from the area even after 6 playbacks of bee sounds. The Biblical Towns and the Artists 1 were tested four times over the period of a year (○) and we observed no slowing down of their reaction to bee sounds with the last trial causing them to retreat at a similar (if not faster) speed than the first trial (Figure 4.6).

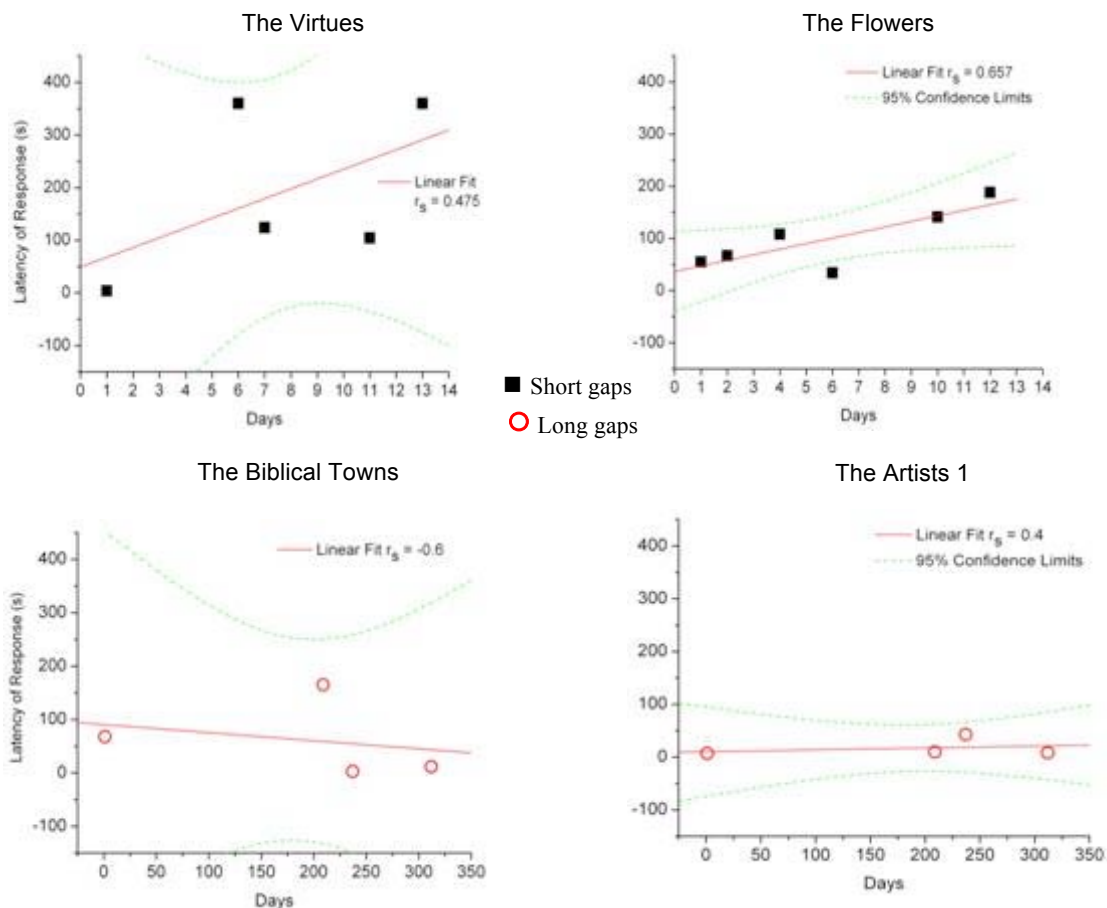


Figure 4.6. Specific latency of response data (in seconds) from four elephant families tested repeatedly with bee playback sounds. The Virtues and the Flowers were short gap families and showed a slowing of response times to bee playbacks unlike the Biblical Towns and the Artists 1 (long gap families) who showed consistently fast response times to the bee playback stimuli.

Comparing distance moved for our four families revealed that the Virtues reduced the distance that they moved in response to the first bee playback from 100 meters to 0m for the last playback trial. However, the Flowers continued to move away from the bee playback even after 6 playbacks although during the final playback they only moved 40m from their rest tree (Figure 4.7). Although the Biblical Towns had long time periods between playback trials their distance moved also decreased with every playback (Figure 4.7) even though their speed of response did not decrease (Figure 4.6). The Artists 1 moved 100m during the first bee playback and 100m during the fourth bee playback with two slightly shorter distance moved in trials two and three.

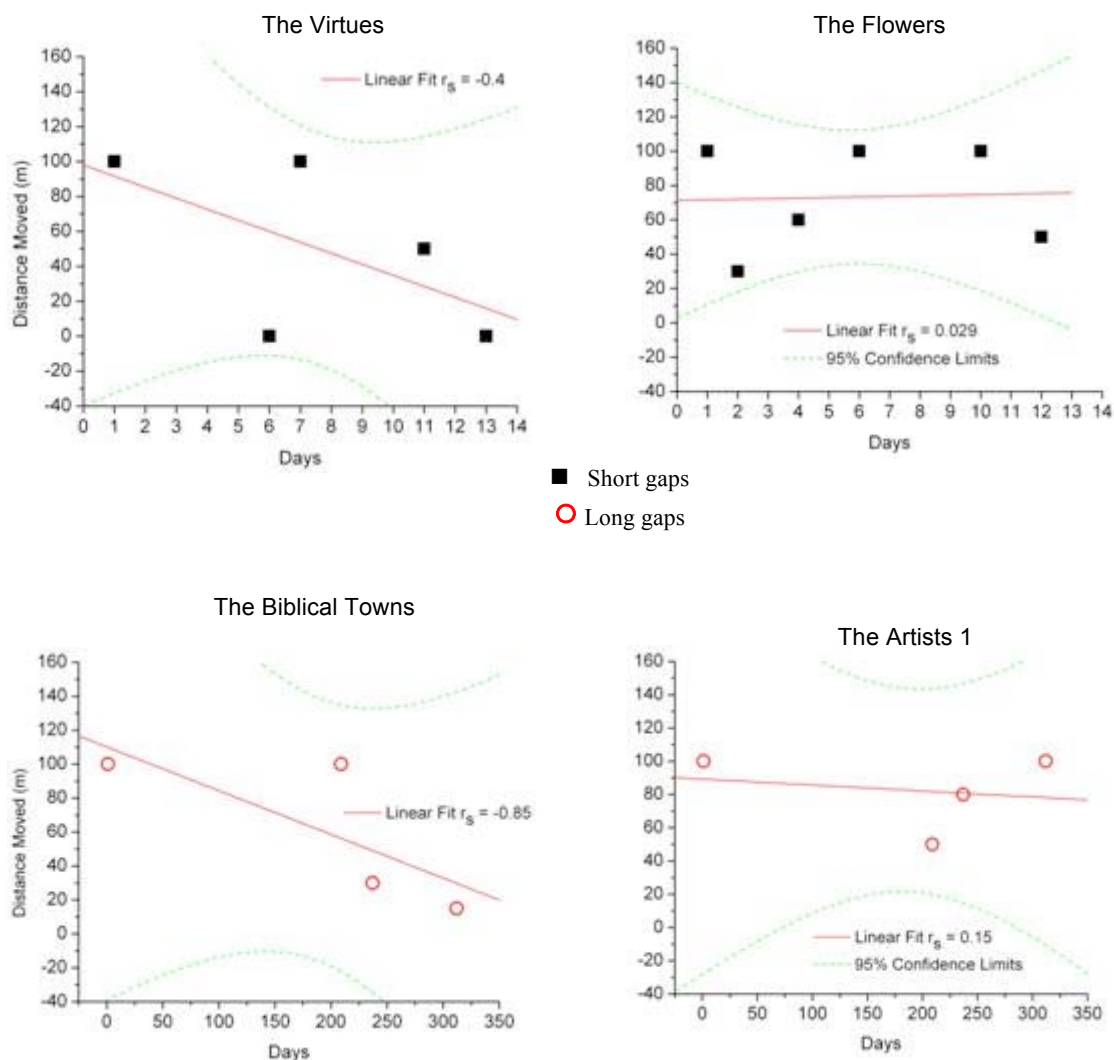


Figure 4.7. Specific distance moved data (in meters) from four elephant families tested repeatedly with bee playback sounds. The Virtues and the Biblical Towns, showed a decrease in distance moved respectively over bee playbacks whereas the Flowers and the Artists 1 showed consistent distances moved over the repeated bee playback trails. Wide confidence limits suggest more data is needed for these analyses.

4.4. Discussion

In Chapter 2 we presented data to show that elephants run from the sound of bees and in Chapter 3 we revealed that elephants communicate about the threat of bee sounds to one another causing retreat behaviour in other elephants. These exciting discoveries lead to a hypothesis that the use of recorded bee sounds alone might be deployed successfully around fields of crops to deter elephant from entering. In this chapter we attempt to repeatedly play bee sounds to 20 elephant families to see what, if any, habituation effects may occur should this potential sound deterrent be deployed in the field. We have made two important discoveries from this analysis:

Firstly, although the speed of response to bee sounds only slightly slowed down over time, elephants did significantly reduce the distance moved from their start position in response to repeated bee playbacks. This reduction in distance moved was seen both across the means of all trials and for elephants that had bee playbacks played repeatedly over a short period of time. Additionally we observed a decrease in dusting and headshaking behaviour over time that might be indicative of the elephants' increasing awareness that the threat of the bee sounds was not "real".

Secondly, elephants who hear the bee playback stimulus repeatedly within a short period of time displayed a trend towards a slowness in response speed, a shorter distance moved and a reduction in headshaking and smelling behaviour in response to the second playback. Elephants who do not hear the second bee playback until a number of weeks have passed appear to retain the same alarmed quick retreat behaviour as if they were hearing the sound for the first time. From analyzing all six chosen behavioural variables we can hazard a prediction that if a farmer were to repeatedly play bee sounds around a farm during one crop-raiding season the elephants are likely to habituate to the sounds. More specifically, they might start to move away shorter and shorter distances until they become aware that there are no bees present (i.e. there is no negative conditioning to the sound through painful bee stings). However, should the farmer use bee sounds as simply one deterrent amongst a range of other mitigation methods he may well have success so long as there was at least a gap of 5 weeks between bee playbacks to the same elephant groups. i.e. bee sounds could be deployed

year after year as part of a ‘package’ of deterrent sounds but we suggest from our observations that bee sounds alone will not be enough to deter elephants for long.

We did observe a reasonable amount of variation between elephant families and a closer look at four particular families demonstrated that phenomenon further. Not all elephants will respond to bee sounds in the same way and although some families, like the Flowers, appeared not to habituate to bee sounds in terms of their distance moved, they did slow down their response times. Other families, like the Biblical Towns, showed consistently fast response times but the distance moved by the family in response to repeated bee playbacks diminished. This variance in behavioural response further supports our recommendation that the use of bee sounds alone will not be enough to deter all elephants from entering a farm but as part of a package of sound deterrents it might be successful in deterring a proportion of approaching crop-raiders.

Our study was ambitious in its attempt to monitor the habituation effects on 20 different elephant groups and although the sample sizes for the third to sixth trials were much lower, the overall sample of 58 trials was regarded as a success. However, having only three and two samples for the fifth and sixth trials respectively, did limit our ability to generalize about how the overall elephant population might respond to that many playbacks. Unfortunately the matriarch of the Flowers died two weeks after the end of the sixth playback trial due to sickness and the family dispersed. Much time was spent attempting to re-locate each family within the right time frame and resting under trees during the study period, but some elephants disappeared from the reserve for months at a time or, when found, were spread out and foraging or not in an accessible place for a sound trial. Despite the difficulties and time involved in re-locating each family, we believe this sample is substantial enough to be representative of the behavioural traits displayed by the Samburu elephant population for which only a total 63 elephant families have ever been recorded.

Field Note: Preliminary Study and Evolution of Research Direction

During my first year based in Samburu National Reserve I conducted a small study where I hung 20 beehives in *Acacia* and *Kigelia* trees either side of the river where elephants regularly rested during the day. I monitored these resting trees for several months taking notes of the volume of elephant dung under the trees and comparing the dung levels to 15 empty, control trees of the same species. Unfortunately this small study was terminated due to almost 50% of the beehives being stolen over the study period which fatally disrupted the experimental design. However, I believe one notable experience from this study is worth mentioning as it seeded the idea for my beehive fence design and the following three chapters.

My assistant and I came across an elephant family resting under one of our study *Acacia tortilis* trees during the middle of the day and we stopped to observe them. The beehive hanging above in the tree branches was fully occupied although, due to the heat of the day, it was quiet with very few bees flying in and out. The odd bee did not seem to alarm the elephants and they certainly were not being stung as the hive was too high to be knocked by accident and the elephants were merely resting, not feeding on the tree or disturbing the branches in any way. It was during this moment that I realised that a hive needed to be 'disturbed' for it to have its desired effect. My assistant picked up a small stone from outside the car and miraculously threw it with such accuracy that it 'dinged' on the side of the beehive. Within a matter of seconds, the hive erupted with bees and filled the air with a loud buzzing sound and the alarmed elephant family immediately took off at a run along the riverbank kicking up dust until they were out of sight. We watched this explosion of activity in awe until the bees turned their attention to us and I had to drive off at pace to avoid being badly stung by the swarm.

This was a fascinating moment and perhaps an anecdote that may contribute to explaining the results of Vollrath and Douglas-Hamilton's (2002a) study as any disturbance of hives within tree branches during foraging activities would no doubt have similar consequences. It is not surprising that elephants would remember such a sudden and disturbing event and would learn to avoid touching or knocking a beehive in the future. This discovery helped me design the beehive fence described in Chapter 5 to ensure the hives would swing and disturb the bees should an elephant touch the wire component of the fence.

Chapter 5

Pilot Trial of Beehive Fence Concept: Case Study of Ex-Erok Community, Laikipia.

This chapter has been published in African Journal of Ecology:

Lucy E. King, Anna Lawrence, Iain Douglas-Hamilton, Fritz Vollrath (2009) Beehive Fence Deters Crop-raiding Elephants. African Journal of Ecology 47: 131–137

ABSTRACT

*Previous work has shown that African elephants (*Loxodonta africana*) will avoid African honey bees (*Apis mellifera scutellata*). Here we present results from a pilot study conducted to evaluate the concept of using beehives to mitigate elephant crop depredation. In Laikipia, Kenya we deployed a 90m fence-line of nine interconnected hives, all unoccupied bees, on two exposed sides of a square two-acre farm that was experiencing high levels of elephant crop depredation. Compared to a nearby control farm of similar status and size, our experimental farm with the “beehive fence” experienced fewer raids and consequently had higher productivity. Socioeconomic indicators suggest that not only was the concept of a beehive fence popular and desired by the community but also that it can pay for its construction costs through the sale of honey and bee products. We are calling for experiments testing this concept of a guardian beehive fence to be conducted rigorously and scientifically in as wide a range of agricultural settings as possible to jointly evaluate its effectiveness and efficiency.*

5.1. Introduction

Elephants in Kenya are not confined to National Parks and Reserves (Douglas-Hamilton *et al.*, 2005). Hence interactions with farmers, and specifically crop raiding by elephants targeting fields, pose serious social, political, economic and conservation problems in Kenya as it does in many other parts of Africa (Newmark *et al.*, 1994; Barnes, 1996; Hoare, 2000; Osborn and Parker, 2002; Balfour *et al.*, 2007). Accordingly research efforts are now focused on finding effective farmer-managed deterrents that are both socially and economically suitable especially in ‘conflict’ zones where effective electric fences to separate humans from elephants are neither feasible nor affordable (Osborn and Parker, 2003; Omondi, *et al.*, 2004).

Locals in and around our northern Kenyan study sites tell anecdotes of elephants being ‘afraid’ of bees (section 1.5.1). Vollrath and Douglas-Hamilton (2002a) experimentally tested this concept by deploying beehives in a frequently visited bush area and demonstrated that elephants avoid feeding on acacia trees hosting hives (both empty and full) of the African honey bee. Following this, King and colleagues further demonstrated in more detailed playback experiments using a recording of disturbed bee sounds that elephants associate bee-buzz with a threat and run away, a behaviour not observed in response to appropriate controls (King *et al.*, 2007). Both studies strongly support the hypothesis that bees themselves, or even evidence of their presence such as empty hives or buzzing sounds, can be used to limit crop-raiding by elephants. If indeed it were possible to use bees as an ‘eco-deterrent’ against elephant depredations then this could have important socio-economic implications. Not only would it diminish loss of farming income but would also add a diverse source of income through sales of bee products such as honey and wax (Bradbear, 2002).

Here we present results from a pilot study conducted to explore the deterrent capabilities of a unique beehive fence. Our two objectives were:

- a) To test the effectiveness of the new beehive fence design; and
- b) To assess stakeholder response and interest.

In Ex-Erok, our experimental community, bee keeping was an established practice so we used a participatory monitoring framework to reveal individual and

group reactions to the introduction of the novel technology of deploying bees to guard against elephants. Participation and inclusion in a project's decision-making fosters commitment and accountability and often leads to a sense of empowerment and ownership (Kapoor, 2001; Hellin *et al.*, 2008). Our monitoring was based on Franzel *et al.* (2002) Type 2 field trials where farmers and scientists collaborate on the execution of the trial but the researcher offers the new technology for trial and leads on the experimental design. We outline our participatory methods in detail as we consider informed and full participation a key element to this kind of study and hence important for any repeats aiming to test its validity.

While this pilot study was only preliminary (a large-scale trial is described in Chapter 6) and during the study the beehives remained unoccupied by bees, the process of working with a rural farming community and the experimental results from a unique beehive fence design were very encouraging and laid the baseline for further trials.

5.2. Methods

5.2.1. Selection of Pilot Study Site

Our study was conducted in the 20,000 acre Ex-Erok community in the southern region of Laikipia, Kenya. The 9,700 km² Laikipia plateau comprises a complex land use mosaic of large private and government cattle ranches, pastoral grazing lands and small holder farms. Historically a wildlife-rich area, large mammals still roam freely throughout the district but with increases in human immigration and the proliferation of stronger boundary fences, elephants in particular are now competing for water and food resources with local farmers (Graham, 2007). Beekeeping activities in the area are typically small scale using traditional hives, and honey is valued for both consumption and as a cash crop (Raina, 2000).

The Ex-Erok study was carried out with co-operation and assistance from rural farmers within the 17 member strong Mwireri Beekeepers Group. This area within Mutara sub-district had been identified in 2004 as a high-risk area for crop-raiding (Graham, 2007; Graham and Ochieng, 2008; Figure 5.1).

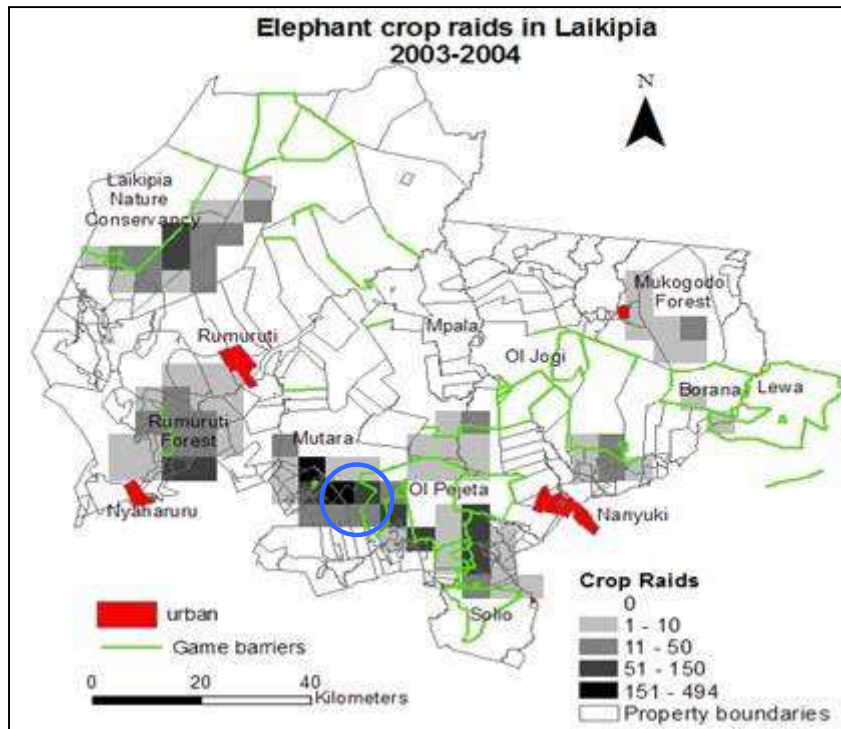


Figure 5.1. Map reproduced from Graham (2007) illustrating the crop-raiding data he collected in Laikipia from 2003-2004 showing the sub-district of Mutara as a high incident spot. Our study area of Ex-Erok used in this pilot project is circled in light blue.

After an introduction to the community by Dr Graham, we conducted pre-trial discussions with six different farmers across the Ex-Erok community. Both their answers and observations of damaged fields confirmed the area's status as a high conflict zone for crop-raiding incidents by elephants. During the pre-trial interviews we came across a group of 11 bull elephants hiding out in the thick bushes near a community farm which had been crop-raided the night before (Figure 5.2).



Figure 5.2. Photos of elephant presence and damage in the Ex-Erok farms. (a) Felix Mathenge, Farmer B, standing amongst the damage caused by elephants who had trampled and eaten his maize. (b) A traditional thorn barrier fence broken down by elephants entering the farm to crop-raid. (c) A herd of 11 bull elephants approaching a farm in broad daylight in Ex-Erok during our initial scoping visit to the area.

5.2.2. Participatory Methods

Eight farmers from the Mwireri Beekeepers Group participated consistently during the development phase of the trial. These farmers represented approximately one third of the households in the immediate trial area. Initially, two participatory activities were undertaken to help design the experimental trial. A calendar of the average year was discussed to highlight certain key activities relevant to the study. These included identifying planting, harvesting, rainy and dry seasons as well as the worst months for elephant crop raids. This calendar of seasonal activities (Figure 5.3) identified the dry harvesting season of August-September as the best period to trial the beehive fence due to the prevalence of elephant raids during this time.

Ex-Erok 26/07/07	January	February	March	April	May	June	July	August	September	October	November	December
Dry and rainy seasons	Very Hot and Dry			Rain				Dry		Some rain	Rain	
Planting Crops		Preparing land	Preparing land	Planting Maize, Beans, Potatoes				Preparing land	Preparing land	Planting Maize, Beans, Potatoes		
Harvesting Crops												
Honey Harvest												
Hardest work time (man)												
Hardest work time (wife)												
Elephant crop raiding										"Elephants always come in the rain"		
Other animal problems: Zebras												
Income or credit	Farmers said they very rarely sell their produce; they just harvest enough to eat after the elephants have finished crop raiding. Some years they claim they are left with hardly anything at all and are forced to borrow food or receive food aid from local churches.											

Figure 5.3. Participation of the farmers created a calendar of main events in Ex-Erok community illustrating the seasonal planting, harvesting and crop-raiding events. Understanding the seasonality within the community helped us select an appropriate time frame for the pilot project. Shaded boxes identify the time period where each activity is underway.

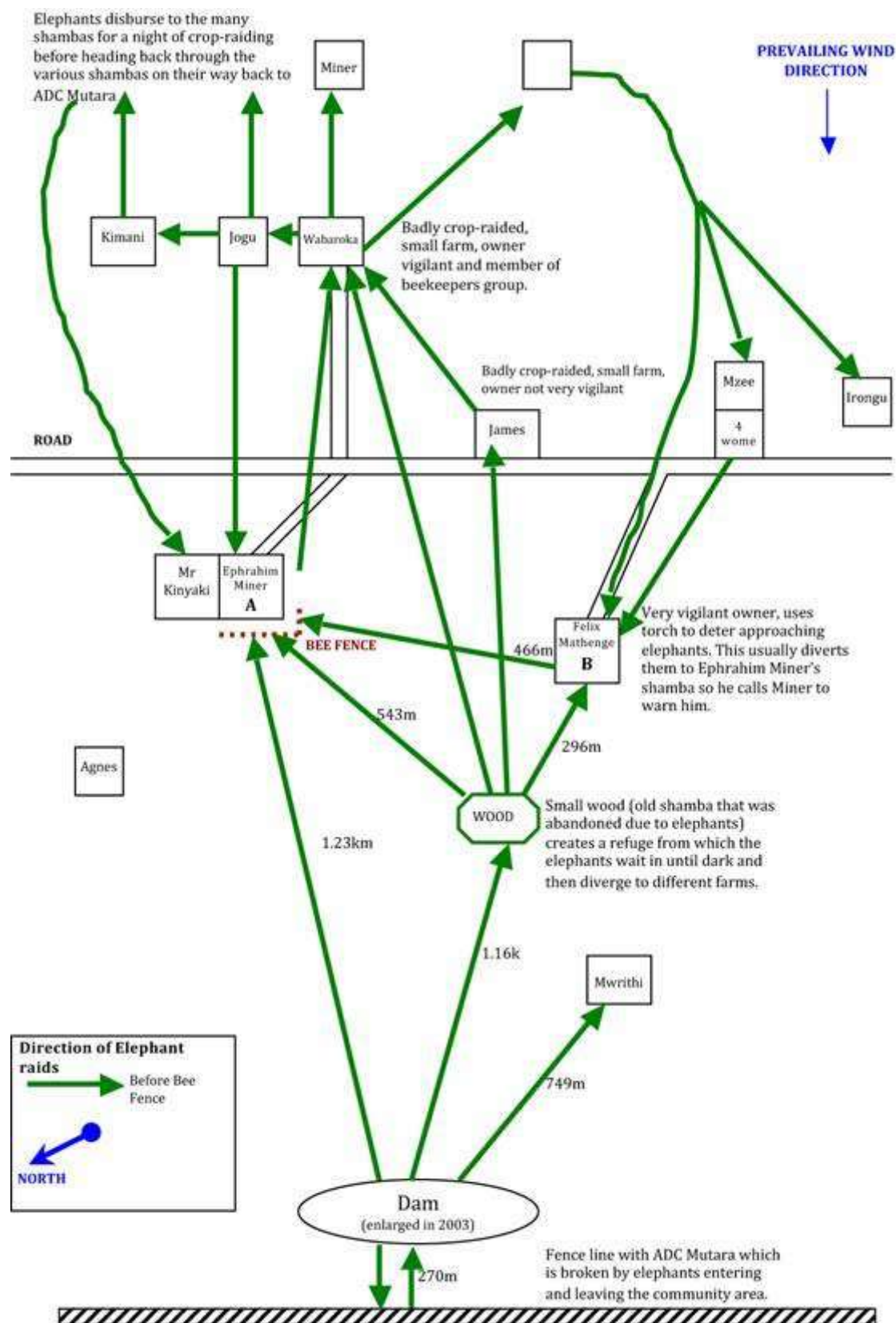


Figure 5.4. Map drawn by community farmers in August 2007 during participatory discussions and converted into a digital format. The map shows in green the path taken by elephants entering the community usually after an evening drink at the dam. The elephants walk directly into the community and usually target the first farmers' crops including Farmer Miner (Farmer A) and Farmer Mathenge (Farmer B) who were consequently chosen to participate in the beehive fence trial.

To select a site for the experimental trial of the beehive fence these eight farmers created a map of their farming area. They drew symbols for each household, dominant land features (such as roads, dams, schools) and finally the movement patterns of elephants through the landscape. This map (Figure 5.4) revealed that elephants living within the neighbouring cattle ranch of *ADC Mutara* frequently visited the community's water dam for an evening drink before entering the farmlands for a night of crop-raiding. The main elephant entrance route from the dam into the village passed between two smallholder farms either side of the 'elephant highway', a phrase used by the villagers to describe the frequently used route. The farmers identified these two farms as the worst affected by elephant crop raids and were unanimously chosen by the group for the trials.

To the east of the elephant corridor, Farm A was chosen by the group to trial the beehive fence. On the west of the corridor, 466m away, Farm B was designated a 'control' farm without a beehive fence (Figure 5.5). Both farms were approximately 2 acres and grew the same intercropped species of maize, potatoes and beans with a few scattered sorghum plants. Only two farms were used during this pilot trial to test out the new, untested design and responses from the group before extending the trial to other crop-raided farms.

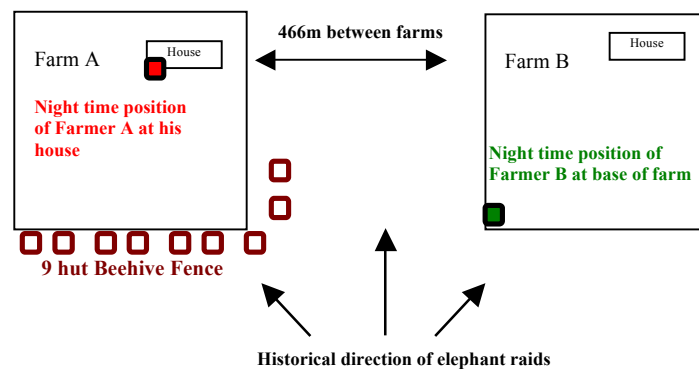


Figure 5.5. Trial layout. As Farmer A sat up at the house with only periodic nightly checks on his crops he did not record unsuccessful raids or 'visits' by elephants who might have approached his farm but turned away at the beehive fence. 466 meters away, Farmer B did record the number of elephants that approached his farm and were scared away by his deterrent tactics. Thus we were unable to directly compare the number of elephant visits that approached the beehive fence but were successfully deterred compared to those successfully deterred from Farm B.

5.2.3. Construction of Beehive Fence

Nine used but unoccupied traditional log beehives were deployed in the form of an “L” shape beehive fence along 90m of Farm A’s northern boundary cutting off all the entrance routes frequented by raiding elephants. I introduced the technical design of the fence but the resulting final structure incorporated key adjustments contributed from group members’ ideas (Figure 5.6). The fence was deployed on the outer edge of a 10m buffer zone around the crops to avoid any conflict between foraging bees and the farmer’s daily activities with his crops. The rest of Farm A was protected by a neighbouring farm on the east, a strong hedge on the west and Farmer A’s house to the south.

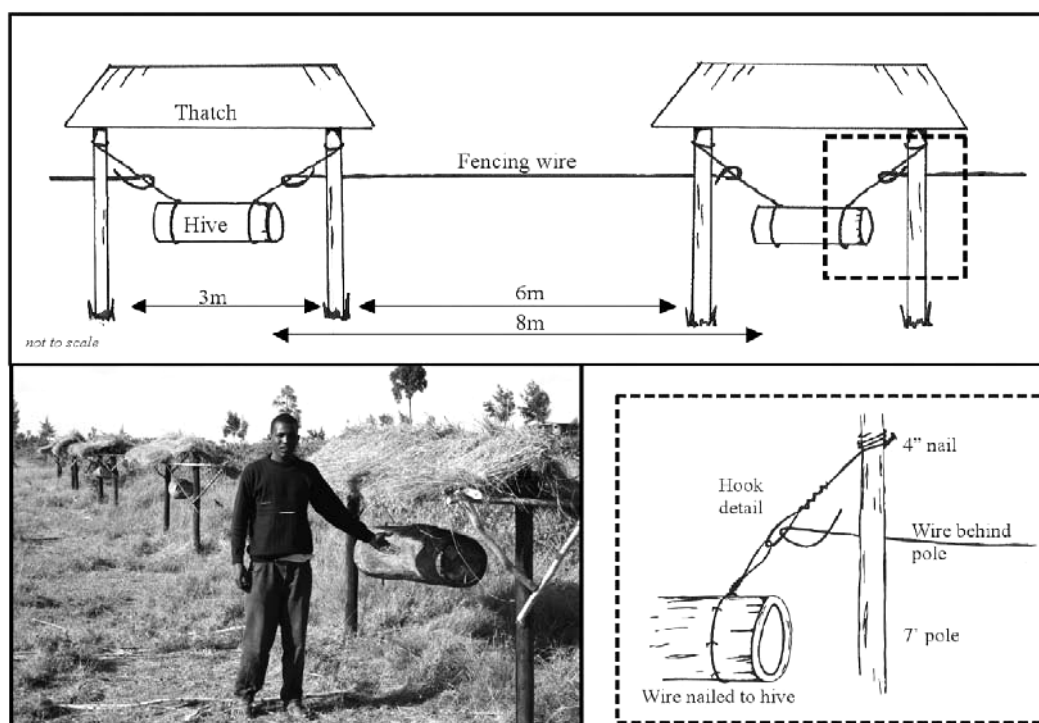


Figure 5.6: Beehive fence design. The fence is constructed with log beehives hung under small thatched roofs. The huts are spaced 6m apart allowing the hives to be spaced 8m apart. An elephant walking between huts will be less than 4m to the nearest hive, the minimum distance elephants in the study area approached solitary beehives. The beehives swing freely, suspended by tightly secured fencing wire to the top of the 7 foot poles. Each hive is linked to each other with strong, taut, fencing wire that hooks to the centre of the permanent wire of each hive and is, crucially, behind the upright poles on the crop side of the fence. An intruding elephant trying to enter the field will avoid the complex solid structure of the beehuts and will be channelled between them. As the elephant tries to push through the thigh-high wire it causes the attached beehives to swing violently, thereby disturbing and releasing the bees to irritate or sting the elephant. However, if forced, the interlinking wire will break away before the beehive is pulled down. This also prevents elephants being trapped inside the farm as they can break out without damaging the hives.

With the help of 12 people, the fence took 2 days to build using 20 kerosene treated poles, 200m of plain fencing wire, 50m thin thatching wire, two inch and four inch nails, and 1 litre of wood preservative (Figure 5.7). The beehive fence was completed in July 2007 before peak crop harvest season of August-September, but lack of occupancy meant that unoccupied hives were used for this trial.



Figure 5.7. (a) Farmer participation in the beehive fence building was consistently positive and the construction of nine ‘beehuts’ only took two days. (b) Aerial photograph of Farmer A’s plot with the 90m beehive fence clearly shown along the lower end of his farm facing the direction of invading elephants.

5.2.4. Selecting Indicators of Success

The farmers identified two indicators that would help them decide if the beehive fence was a success or not. These were:

- 1) Elephants should be kept away from damaging or eating the crops, and
- 2) The fence should be easy and cheap to maintain.

As researchers, we identified three additional indicators that were important in defining the success of the trial. These indicators were:


- 1) Identifying patterns of elephant movement behaviour around the beehive fence structures,
- 2) Identifying positive responses from the farmers, and
- 3) Realistic set-up costs of the beehive fence to ensure it could be a financially appropriate technology for other poor communities.

5.2.5. Monitoring Crop-Raiding Events and Evaluating Project Success


The farmers recorded crop-raiding events using simple data sheets, clearly explained during a training session (Figure 5.8). Farmer A recorded the number of elephants breaking through to crop-raid on his farm by noting the raid time, herd composition (when able) and movement pattern in and out of the farm. Farmer A sat up at his house with periodic checks on his crops leaving the beehive fence as his first defence. However, once on his land, Farmer A was freely available to chase the elephants away using whatever deterrent tactics he liked. Farmer B, without the beehive fence, also gathered daily data on the raid time and number of elephants successfully raiding but he also managed to record the number of elephants approaching his farm that were successfully scared away by his traditional deterrent tactics (personal vigilance, noise, fire, dogs). This data enabled us to monitor elephant movement behaviour and compare variation in crop-raids between the two farms over the same six week period of peak crop harvest time.

Elephant and Beehive Project: Incident Sheet


Date	
Time of Day	
Number of Elephants	
Bull(s) or Family?	
Notes on:	
<ul style="list-style-type: none"> - Entrance route - Exit route - Damage to hives - Damage to wire 	




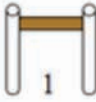
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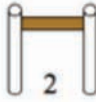
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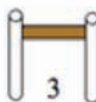





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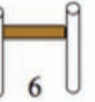
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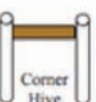
4



5



6



Corner
Hive

Figure 5.8. Copy of datasheet given to Farmer A to monitor elephant crop-raids through the beehive fence. The farmer simply had to draw on any elephant movements around the fence with a pencil and make any notes on the crop-raiding events.

To assess farmer perception of the beehive fence, I stimulated conversation about the progress of the project with both individuals and the group with all comments and actions observed during these weekly discussions recorded in a notebook. This resulting rapport enabled free flowing ideas and discussion about the beehive fence design and application.

In order to verify the local knowledge of elephant movements through the community, Save the Elephants' research team monitored for us a notorious crop-raiding bull, Genghis Khan, through the area using data from his Global System for Communication (GSM) satellite tracking collar (made by African Wildlife Tracking). This bull had been identified by Dr Graham as an Ex-Erok crop-raider between 2004 and 2006 (see blue circled area in Figure 5.9). By continuously downloading his hourly GPS movements onto Google-Earth maps using STE's tracking software (Wall, 2007) we were able to ground-truth his movements using both aerial searches and a ground tracking team for close observations during the study period of our pilot project.

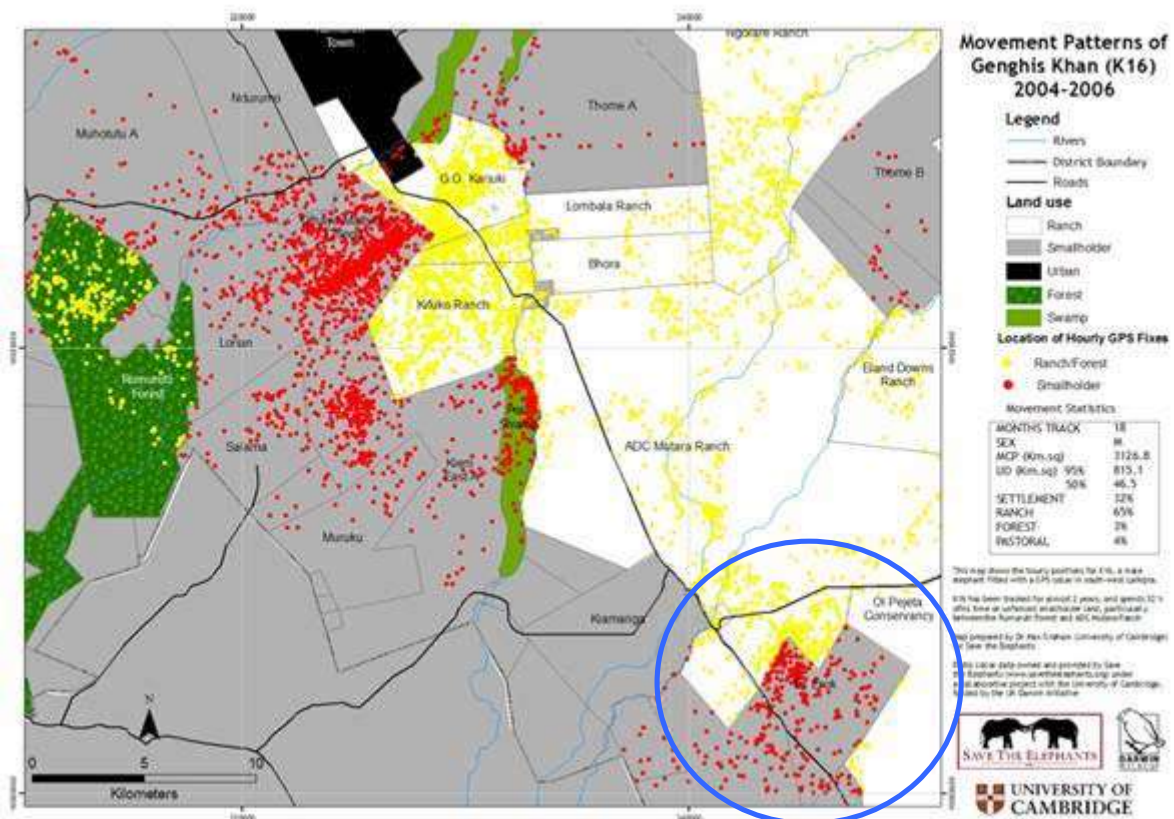


Figure 5.9. Map created by Max Graham and Save the Elephants to illustrate Genghis Khan's movements in the Mutara area between 2004-2006. The red dots inside the blue circle clearly show that this bull elephant had been a regular visitor to Ex-Erok community prior to this pilot study.

5.3. Results

5.3.1. Monitoring the Movements of Genghis Khan during the Study Period

The movement of crop-raiding elephants throughout the community was verified from monitoring Genghis Khan's GPS tracking data over the same crop-raiding season. During the study he was observed crop-raiding by several farmers and photographed from the air by IDH and by myself on the ground in the centre of a herd of 18 bull elephants coming back from crop-raids in Ex-Erok (Figure 5.10). Dung from the herd was densely littered with bean husks and maize stalks. His GPS movements closely matched the consensus map of elephant movements drawn up by the group. One major crop-raid by Genghis Khan has been graphically illustrated overleaf (Figure 5.11).

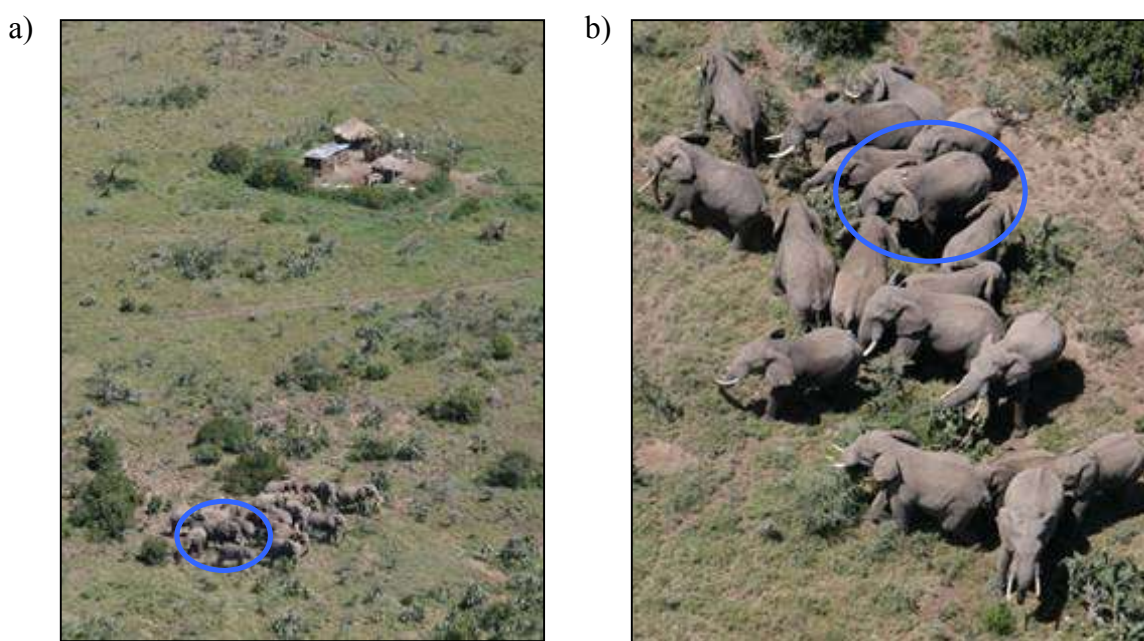
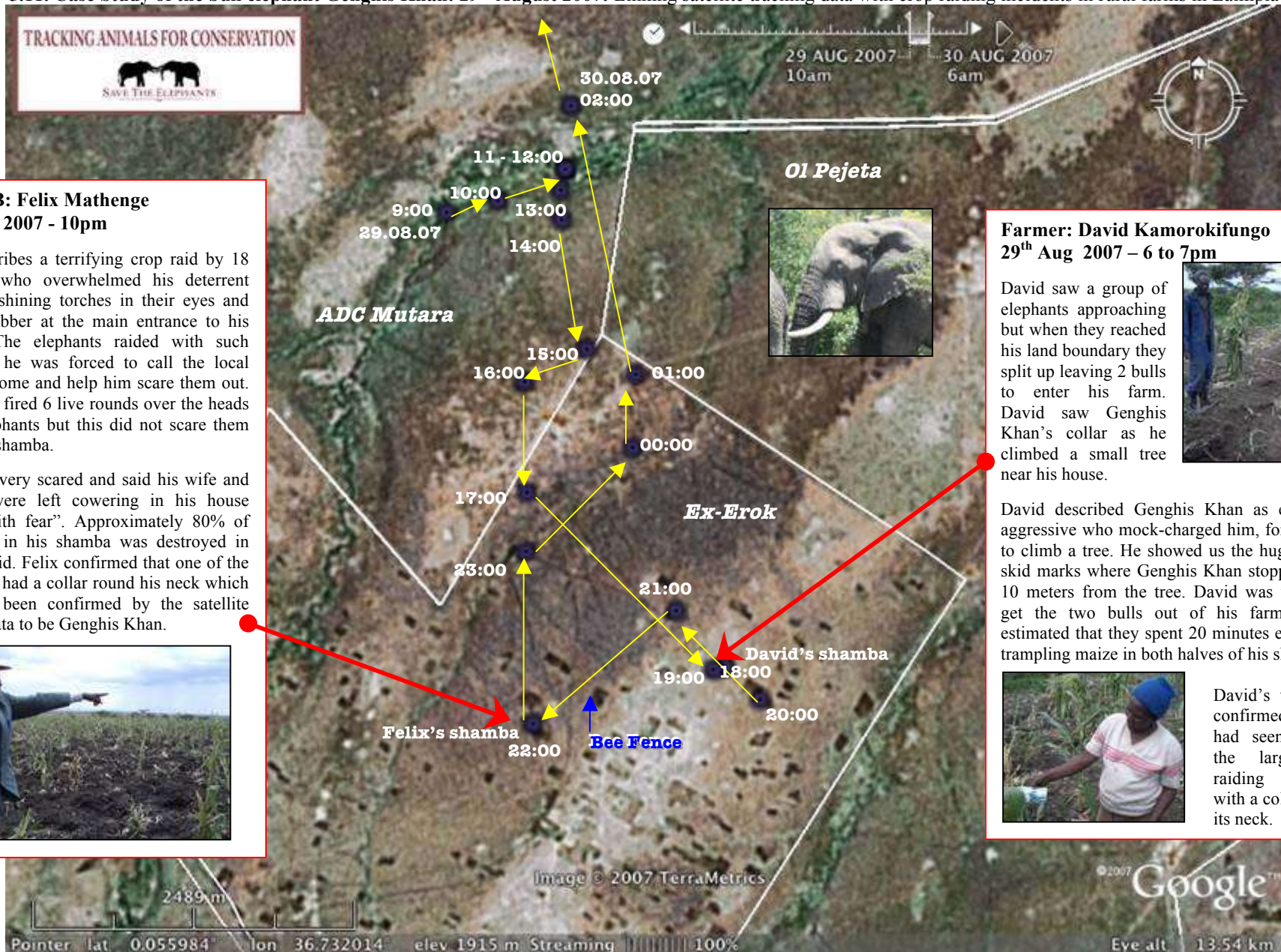


Figure 5.10. Photographs taken from the air over Ex-Erok by Dr Iain Douglas-Hamilton on the 22nd August 2007 showing Genghis Khan in the middle of a group of 18 bull elephants; Genghis is circled in blue with his tracking collar clearly showing between his ears. (a) The closeness to a homestead during the middle of the day shows how bold the elephants had become in this area. (b) Genghis is one of the largest bulls in this group mainly consisting of young to middle aged bull elephants who are perhaps relying on older bulls like Genghis to show them the best farms to raid in the community. It is highly unusual to observe 18 bulls together in the wild and this formation must be for protection and intimidation for crop-raiding events.

5.11. Case Study of the bull elephant Genghis Khan: 29th August 2007: Linking satellite tracking data with crop raiding incidents in rural farms in Laikipia



Farmer B: Felix Mathenge
29th Aug 2007 - 10pm

Felix describes a terrifying crop raid by 18 elephants who overwhelmed his deterrent tactics of shining torches in their eyes and burning rubber at the main entrance to his shamba. The elephants raided with such force that he was forced to call the local police to come and help him scare them out. The police fired 6 live rounds over the heads of the elephants but this did not scare them out of the shamba.

Felix was very scared and said his wife and children were left cowering in his house "crying with fear". Approximately 80% of the maize in his shamba was destroyed in this one raid. Felix confirmed that one of the large bulls had a collar round his neck which has since been confirmed by the satellite tracking data to be Genghis Khan.



Farmer: David Kamorokifungo
29th Aug 2007 – 6 to 7pm

David saw a group of elephants approaching but when they reached his land boundary they split up leaving 2 bulls to enter his farm. David saw Genghis Khan's collar as he climbed a small tree near his house.



David described Genghis Khan as extremely aggressive who mock-charged him, forcing him to climb a tree. He showed us the huge muddy skid marks where Genghis Khan stopped about 10 meters from the tree. David was unable to get the two bulls out of his farm and he estimated that they spent 20 minutes eating and trampling maize in both halves of his shamba.



David's wife also confirmed that she had seen one of the large crop raiding elephants with a collar round its neck.

Figure 5.11. Case Study of the bull elephant Genghis Khan: 29th August 2007: Linking satellite tracking data with crop raiding incidents in rural farms in Laikipia.

Genghis Khan's positions were tracked every hour and on the morning of the 29th August we saw that he was approaching our community study site of Ex-Erok. Between 9am and 1pm he remained in the shelter of the green belt of trees next to the river in Mutara (top left of image). Between 1pm and 5pm he started to move towards the boundary of Ex-Erok. Between 5pm and 6pm he made a fast movement into and through the community arriving at David Kamorokifungo's farm just at 6pm. Between 6pm and 7pm Genghis Khan and one other bull crop-raided David's farm (shamba) and spent about an hour around his farm trampling and eating his maize. David Kamorokifungo described Genghis as "very aggressive" and charged him when he tried to scare the bulls off his land. He ended up climbing a tree to feel safe. The GPS tracking data confirms this story as the position of Genghis is shown by two positions in a row being seen on the map right on top of his farm at 18:00 and 19:00. After crop-raiding the two bulls moved further south east to a second farm and remained there for just under an hour before passing back around David Kamorokifungo's shamba and finding another farm to enter at 9pm. From 9pm we can see that Genghis Khan and his companion passed right next to the beehive fence of Farmer A's farm but did not enter. Instead they walked directly towards and into Farmer B's (Felix Mathenge) farm where they joined forces with a further 16 elephants to crop-raid en-masse entering his farm just before 10pm. That night Farmer B estimated that he lost 80% of his maize to the 18 elephants and they "feared for their lives" and had to call the local police to shoot bullets into the air to scare the elephants away. After the gunshots the elephants started to work their way back out of the community towards Mutara but not before entering a 5th farm at 11pm. From midnight onwards we can see Genghis was moving back towards Mutara and he crossed back over between 1am and 2am and continued to march north away from the community. It is possible that the gunshots from the local police incentivised the group to move away from the farms that night, but after crop-raiding 5 farms it is also possible that Genghis and his companions had had their fill of maize and were heading back to the safety of ADC Mutara ranch. In any event, Farm A, with the beehive fence, was bypassed by Genghis Khan and his associates.

5.3.2. Evaluating Indicators of Success

After the six week trial period the data from both the elephant movements and the farmer's perceptions of elephant raids were studied in the context of each previously identified indicator. The evaluating indicators (effectiveness, efficiency, cost and perception) are briefly discussed.

Effectiveness as deterrent - Over the six week study period the two focal farms experienced 20 successful crop raids involving a total of 133 elephants where they managed to break through into the farms. Farm A, with the beehive fence, experienced 7 successful raids involving 38 elephants. Farm B experienced 13 raids (86% more than Farm A) and 95 invading elephants (150% more than Farm A; $\chi^2 = p < 0.001$, df 1) (Figure 5.12). In addition, Farmer B recorded a further 71 elephants in 8 failed raid attempts that he prevented from entering his farm using his traditional deterrent tactics. In total Farm B had 21 attempted raids by 166 elephants during the six week trial, all of which occurred less than 500m from Farm A. Most notably, by the end of the harvest season Farm B had almost no crops to harvest, with the farmer estimating that about 90% of his harvest had been destroyed or eaten by elephants, whereas Farmer A was able to harvest relatively successfully collecting a variety of sorghum, beans, potatoes and maize. This suggests that the fence was at least partially successful in deterring elephants (Figure 5.12).

Additional to the two farms A and B that were monitored during the study period two farms close to Farm A reported uncharacteristic crop raids. Farmers Kinyaki and Agnes (refer back to map in Figure 5.4) were crop raided for the first time that season as soon as the beehive fence was built around Farm A. This potential transfer of crop raids from Farm A to these neighbours warrants further study.

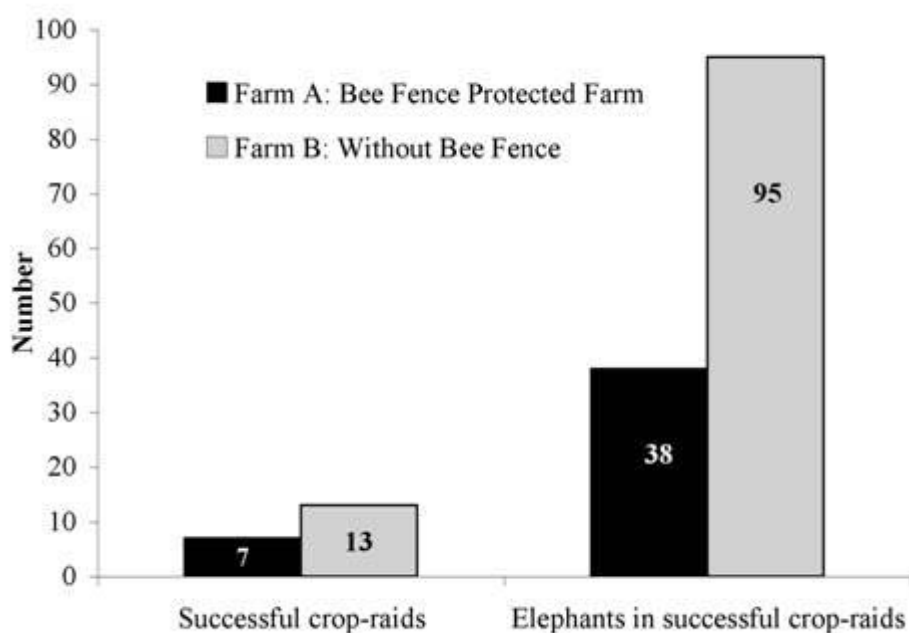


Figure 5.12. Variation in crop raiding incidents during the six week trial. Farm A, protected by the beehive fence, experienced 86% fewer successful raids and 150% fewer raiding elephants than control Farm B. However, within the seven successful crop-raids in Farm A only four inbound events occurred where elephants crossed the beehive fence and the remaining inbound events occurred from elephants walking around the fence and breaking through the thorn barriers on either end.

Efficiency of beehive fence - Within Farm A, there were 10 clustered events where elephants broke into the farm within the 7 successful raids. Of these 10 inbound events, 4 occurred between the beehuts pulling down the fencing wire and 6 occurred by elephants walking around the beehuts to make new entrances into the farm above the beehive fence line breaking down the hedge. Once inside Farm A there were 14 clustered events where elephants broke out of the Farm (either naturally or chased away by Farmer A). Of these 14 outbound events, 12 occurred between the beehive huts and 2 occurred outside of the beehive fence line. Essentially, the beehive fence did not pose a trap to the elephants inside the farm once scared off the land by Farmer A. There was no correlation in dates between all 21 attempted events on Farm B (either deterred visit or successful raid) and the 7 successful raids on Farm A.

Costs and ease of fence maintenance - The economics of the fence are an important indicator towards success or failure of the concept. Initial set-up costs will vary locally but need to include funds for: (i) the hive, (ii) a thatched roof for shade, (iii) two sturdy poles to carry hive and roof and (iv) stiff wiring to hang the hive and connect it with its neighbours. Often it will be possible to defer, or share, costs with a small local or national honey trader. During the trial our beehive fence suffered four raids when elephants broke through the fencing wire and successfully entered the farm. The wire did not break, nor did it bring down the beehives on either side so the farmer was able to simply clip the wire back into place ready for the following night. During the six weeks there were minor repairs to the bee-huts that could all be catered for from local resources at no cost (e.g. grass for thatching) or a small expense (e.g. a few nails). The fence was inspected every morning but this took away little time from the farmers' other daily chores. This suggests that a beehive fence, once erected, requires little maintenance. Of course, this will change when hives are occupied and especially when they are full of honey. Indeed, honey sales can potentially recover the cost of the hives reasonably quickly and provide a tangible incentive for maintaining the entire fence line structure.

Costs for the beehive fence based on using traditional log beehives was approximately US\$315 per 100m (Figure 5.13). In Kenya one kilogram of honey can sell for US\$2 and each traditional log hive has the potential to generate two-three annual harvests of 7-10kgs per harvest. This creates a potential income of US\$40-60 per hive per year which, if the climate were consistent, would pay back the cost of construction within two years with just a 50% hive occupancy rate. Upgrading log beehives to the more productive Kenyan Top Bar (KTBH) hives would generate more income, particularly if a queen excluder is fitted to separate the valuable honey from brood (Jones, 1999).

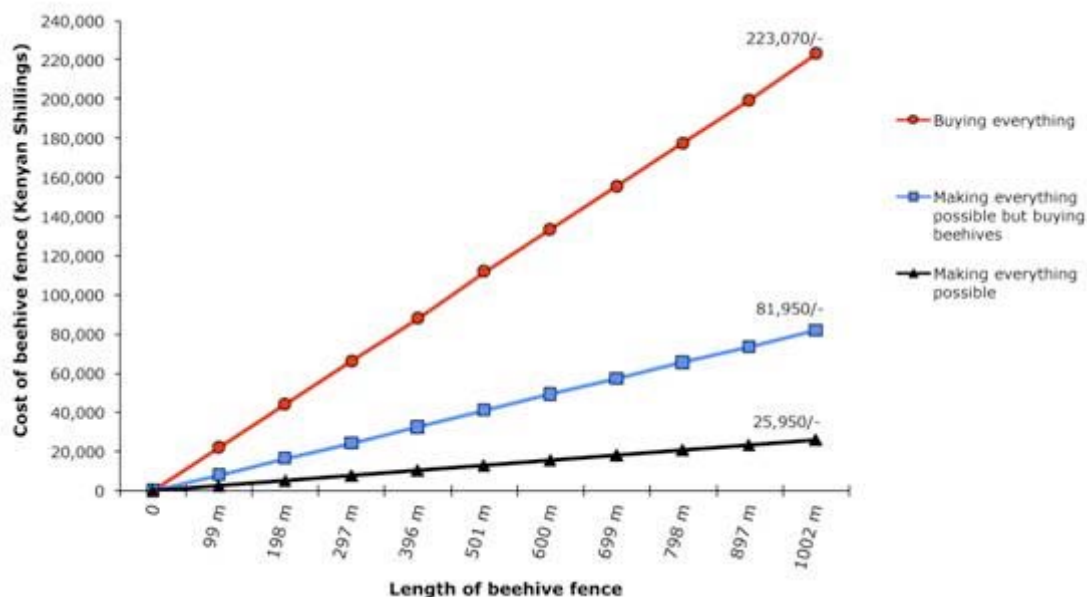


Figure 5.13. Costs of the beehive fence vary according to how many elements can be made locally or found growing naturally around the farm. If a farmer were to make all elements of the beehive fence from local materials including construction of the beehives and coppicing posts from locally available trees, the cost of a one kilometre fence would be approximately 25,950 shillings (US\$346). The main expenses remaining are funds for nails, wire and wood preservative. If the farmer chose to make everything possible but bought traditional beehives the cost of the one kilometre fence would rise to 81,950 shillings (US\$1,093). If the farmer were to purchase everything from local suppliers the cost of the one kilometre fence would rise to 223,070 shillings (US\$2,975). All costs here are accurate to the location and prices found near to Ex-Erok but are estimated to be typical for rural areas across Kenya (1USD:75Ksh). Additionally, I have made the assumption that labour costs are free as I would expect a farmer and his family to not cost in their labour expenses for a deterrent system for their own farm.

Perception by farmers - Social responses and attitudes to the project were consistently very positive throughout the trial. The following key observations were made:

(i) A consistent number of group members turned up to each meeting with a slow increase from 8 to 12. Although overall group membership increased from 17 to 24 as word of the trial spread, over half these listed group members remained curious spectators rather than integrated participants. A scout from Dr Graham's *Laikipia Elephant Research Project* commented about Farm A verbatim "You can't compare his farm to the others now. He still has crops and the others are all finished by elephants."

(ii) After the main six week study period, Farmer A extended (at his own initiative and cost) the beehive fence with two more hives to cover a new elephant entrance site above the beehive fence.

(iii) All attending members of the beekeeping group expressed a desire to have a similar fence around their farm listing the potential benefits of the fence as a) deterring elephants, b) honey production, c) improved security from cattle rustlers and d) improved sleeping patterns inside the house rather than outside in a corner of the field.

(iv) Members of the group discussed the risks of the fence i.e. increased stings (danger) for children and livestock fatalities from bee attacks. It was agreed that these risks were outweighed by the daily risk of being trampled by an elephant and hunger due to complete harvest destruction.

(v) The main disincentive for starting construction was a) cost of materials and b) knowledge that a government sponsored electric elephant fence was about to be constructed to protect the community from future elephant raids (this was completed by February 2008).

5.4. Discussion

To conduct this pilot study we used our pre-designed technology (the beehive fence) that was field tested under ‘real life’ conditions with the end users to assess effectiveness and adoption potential. Our participatory study helped to generate a sense of participant ownership and enabled the evaluation of genuine responses and attitudes to the introduced technology by both scientists and farmers.

The effectiveness of the beehive fence was remarkable as there were fewer raids and a significantly lower number of elephants in successful raids on the protected farm compared to the nearby control farm, which suffered severe (and apparently typical) damage from crop-raiding elephants during the trial period.

Equally encouraging were the positive responses from the farmers toward the concept of a beehive fence. Although there was a recognised risk from increasing the bee population so close to their living quarters, the risk was outweighed by the benefits of the fence for deterring destructive elephants plus the long term potential of generating a sustainable income through the sale of bee products. Farmers believed that the beehive fence also protected them from cattle rustlers and they predicted being able to spend more time in the house at night.

The sample size (1 experimental and 1 control farm) was small and variables such as soil type, exact hours of vigilance, crop density and variation in outer boundary defences (e.g. thickness of low protective hedges) around the two farms were not quantifiably measured. Despite these possible variations the outcome was robust with the experimental farm attracting fewer elephant raiders and consequently growing more produce. Moreover, the participants in the experiment were convinced that the deterrent worked and decided, on their own and with their own funds, to continue with beekeeping through construction of more hives to extend the fence and the planting of nectar producing vegetation. Hence, all in all, we consider this a successful pilot trial of a simple design for a guardian-bee elephant deterrent in an area of small-scale farms. Interestingly, as none of the hives were occupied during the trial the deterrent must have been due to either (or both) (i) the mental image or smell remembered by the elephants of past negative experiences with occupied hives and/or (ii) the complex physical,

moving barrier of the wires and swinging hives. In the light of other experiments (Vollrath and Douglas-Hamilton, 2002a; King *et al.*, 2007; King *et al.*, 2010) we suspect that the outcome of this study was largely due to previous ‘anti-bee’ conditioning of the elephants.

Although our hives in this experiment were not occupied, the presence of bees and honey stores in the beehive fence would enhance the benefits to the farmer through productivity of his land (fewer crop-raids, better pollination) and provide a tangible motivation for maintaining the structure for the cash benefits from selling honey. Realistic occupation rates for traditional hives lie around 50% so even at the lowest end of the productivity scale (7kgs per hive twice a year) a farmer with 9 beehives in his 90meter fence could hope to re-coup US\$126 a year from his hives. Even at this lower end of the scale the farmer would have raised enough funds to pay back a 90 meter beehive fence within two years. This type of small scale investment might be attractive to micro-finance companies or large scale honey companies looking for consistence honey suppliers.

Since the Ex-Erok community was fenced against elephants shortly after the experiments we could not expand our pilot trials to more farms in the community but instead started a major beehive fence experiment (with 62 farms) using KTBH hives in Ngare Mara (read on to Chapter 6). This first study was fundamentally important as a pilot in providing experience and new ideas for improving the beehive fence design for this next large-scale trial.

Chapter 6

Large-scale Participatory Beehive Fence Trial with the Turkana Farmers of Ngare Mara Community

Data from this chapter has been submitted to African Journal of Ecology:

Lucy E. King, Iain Douglas-Hamilton and Fritz Vollrath. Beehive Fences as Effective Deterrents for Crop-raiding Elephants: Field Trials in Northern Kenya

ABSTRACT

Increasing elephant populations in Kenya since the 1989 ivory trade ban have been widely praised as a conservation success story. However, where elephants and agricultural land overlap incidents of human-elephant conflict are on the increase. Here we present the data on a novel human-elephant conflict mitigation method, a beehive fence, deployed in a community of 62 communally run farms in northern Kenya. Participatory rapid rural appraisal methods were deployed to involve 34 Turkana farmers in every aspect of the trial. Specifically, 1700 meters of beehive fences semi-surrounded the outer boundaries of 17 farms and we compared farm-invasion events by elephants to these and to 17 neighbouring farms whose boundaries were 'protected' only by traditional thorn bush barriers. We present data from 49 invasions, or attempted farm invasions, recorded over two years. 13 groups of elephants approached the beehive fences and turned away. Of the 36 successful farm invasions only one bull elephant broke through the beehive fences. These results demonstrate that beehive fences may have a role in deterring elephants and alleviating farmer-elephant conflict. Additionally the harvesting of 106 kilograms of honey during the trial period suggests that beehive fences may have a role to play in improving crop production and rural livelihoods through pollination and honey sales.

6.1. Introduction

In Chapter 5, I describe a successful pilot study using a trial design for a beehive fence. Although small in scope, the trial framework of the pilot study involving farmers in a ‘real’ farming context was appropriate and enabled testing of the beehive fence in a rural farm setting. In this Chapter, I present data from a second trial of the beehive fence concept building on the same successful framework of participatory farm-based trials. Three key elements made this trial unique:

- (i) I upgraded my beehive fence design to replace traditional log hives with Kenyan Top Bar Hives (KTBH) to try to improve effectiveness and increase honey production;
- (ii) 34 families selected from a large community of 62 farms participated in the trial compared to just two families in Chapter 5;
- (iii) The farmers were from the traditionally pastoralist Ngisonyoka Turkana tribal group whose farming practices were relatively newly acquired and who were known to be living in a ‘hot zone’ for illegally killed elephants.

6.1.1. Theoretical Framework

The conceptual evolution and advantages of farm-based testing for new agricultural systems, technologies or crops are well documented (Byerlee and Collinson, 1980; Chambers *et al.*, 1989; Shepherd *et al.*, 1994; Douthwaite *et al.*, 2003). Although certain elements of new agricultural systems development can be achieved by station-based research (e.g. improved effects of fertilizer on a crop; Mugwe *et al.*, 2009) such tests are often biased by enhanced effort through paid labourers and access to quality equipment (Franzel, 1996) often resulting in superior yields (Mugwe *et al.*, 2009). Furthermore research stations are rarely typical of the diverse conditions encountered in farmers’ realities (Biggs 1989, Martin and Sherington, 1997). Adoption potential of new technologies and effects on livelihood strategies are regarded as critical ingredients for success and can only be truly assessed in ‘real’ farming conditions that are often sub-optimal to research stations (Franzel *et al.*, 2002; Douthwaite *et al.*, 2003). Not only may there be different biogeographical conditions on ‘real’ farms (Shepherd *et al.*, 1994) but within a potential end-use community there can be many different interests and actors who

have an influence on decision making for the community as a whole (Agrawal and Gibson, 1999; Kumar, 2005).

The use of participatory techniques can help to reveal distinctive individual and group reactions to the introduction of a new technology which may, or may not, fit into the socio-economic conditions of the community. Past studies of wildlife deterrents have shown that technically successful deterrents can still fail in application due to an unidentified social or economic constraint to the uptake of new technologies by the end users. For example, a cheap and effective explosive banger tested against elephants in Laikipia, Kenya was banned by the local authorities because the sound was so similar to gunfire that they thought it could be misused in an area where armed incidents were common (Graham and Ochieng, 2008). Hence, social conditions, conventions, limitations and historical context within a community can play a role in adoption success (Agrawal, 1999) and may not be always related to quantitative results such as yields or productivity (Scherr, 1995).

Franzel *et al.* (2002) describe in detail the benefits of different approaches to testing new technologies under realistic farm conditions, and summarise this in a typology of experimental methods:

- Type 1 are researcher designed, researcher managed trials using a strict statistical design to control for plot size and biophysical conditions.
- Type 2 are researcher designed, farmer managed trials that rely on collaboration and consultation during implementation and evaluation. Farmers remain responsible for all operations of the trials and researchers have a chance to assess both the farmers' reactions and the cost benefits of the technology.
- Type 3 are farmer designed, farmer managed trials usually suitable when farmers are working in very diverse or complex agroecosystems and social constraints to adoption mean that it is difficult for researchers to predict which technology will be appropriate. Under such conditions researchers offer a range of options, farmers select, mix-and-match or modify according to their needs and contexts.

In this study we had a pre-designed technology (the beehive fence) that needed to be field tested under ‘real life’ conditions to assess the adoption potential by possible beneficiaries. We did not want simply to test the deterrent potential of the beehive fence in a perfectly controlled field centre environment (Type 1) or offer a variety of deterrent options for farmers to try (Type 3). Hence I chose an experimental concept for this study based on Franzel and colleagues’ Type 2 field trials where farmers and researchers collaborate on the execution of the trial but the researcher offers the new technology for trial and leads on the experimental design under local conditions. This type of farmer participatory research (FPR) has also been referred to by Schulz (2000) as ‘Collaborative Participation’ and recognises that although the researcher often contributes the pre-designed technology there is an understanding that the participating farmers should feel like they have the freedom and respect to ‘fine tune’ or adapt the new system to their needs.

To identify an appropriate study community, I tried to find out as much biological, geographical, social and economic information as I could about potential study sites to locate, involve and include a community in a Type 2 field trial within the limited time available. I extracted biological data from Save the Elephants’ database of hourly elephant movements and by generating and analyzing a map of these movements (refer back to details in Chapter 1 section 1.7.2) I was able to identify this particular community ‘in the heart of’ an elephant corridor. As this community had already been identified as potentially being responsible for multiple illegal elephant mortalities in recent years and was known to have recently started agricultural practices, this community became the focus of my next stage of research.

6.1.2. Study Site

The greater Ngare Mara settlement in Meru North District (Lat 0.445345, Long 37.672749) neighbours three unfenced National Reserves and one National Park in northern Kenya. Elephants in particular migrate through the area between Shaba, Samburu and Buffalo Springs National Reserves and Meru National Park to the south (Douglas-Hamilton *et al.*, 2005). This Turkana community was established relatively recently and is not within the traditional pastoralist Turkana range. The majority of Ngare Mara’s community members are Ngisonyoka Turkana, a tribal section

originally from the southern part of Turkana District in northwest Kenya. Originating from the Jie people of Uganda approximately 300 years ago, the Turkana are traditionally pastoral nomads inhabiting the dry scrub savannah and living off livestock and the seasonality of nomadic life (Dyson-Husdon, 1999). Their ability to adapt to this inhospitable terrain enabled the Turkana to expand rapidly until European explorers first encountered them in the late 19th century. British military records described them at that time as “*an arrogant, wealthy, and warlike people, hated and feared by their neighbours and able to field an army of 2000 men*” (Dyson-Husdon, 1999).

During the 20th Century the Turkana were involved in repeated fighting with both their hated British colonialists (who demonstrated a lack of interest or understanding towards Turkana culture) and their Pokot, Samburu and Maasai tribal neighbours mostly over cattle raiding and grazing rights (Dyson-Husdon, 1999). During the 1950s – 1970s a series of intense droughts, poorly managed famine refugee camps, vicious raiding attacks, lack of infrastructure development, population growth and a brutal Government Services Unit disarming expedition in 1979 triggered some Turkana families to flee their homes in search of peace and land. It was during this period of stress in Turkana district that the original Ngisonyoka Turkana settlers migrated and arrived in Ngare Mara (P.Ekerri, pers comm.). With greatly reduced livestock numbers they settled and began to start agricultural farming. This migration was not without problems as the, seemingly uninhabited, strip of land between the town of Isiolo and the national reserves to the north was bordered by both Borana and Samburu tribal land (Figure 6.1). Both tribes initiated raiding parties on the new settlement forcing the Turkana to arm themselves for protection. A proliferation of arms, limited farming knowledge and a heavily reduced livestock bank from multiple cattle raids could have been the ingredients culminating in the security instability explained earlier in Chapter 1.

Within this context of tribal conflicts and security issues, Ngare Mara had been identified by Save the Elephants as early as 2002 as a hot spot for illegal killing of elephants as recorded by the Monitoring of Illegal Killing of Elephants program (MIKE) (Douglas-Hamilton *et al.*, 2010). Prior to the farm trials described in this Chapter, at least nine illegally killed elephants were found in the greater Ngare Mara community between 2002-2006, a clear indicator that human-elephant conflict, an intolerance for elephants and/or ivory poaching was a problem in the area. It was due to these recent bio-geographical events, relevant anthropological history and previous positive involvement by Save the Elephants' staff (refer back to Chapter 1 for history of Ngare Mara community), that I selected this study site to approach for a possible participation in a large scale trial of the beehive fence design.

Specifically, I conducted the farm-based trials in two small sub-village communities located 2kms apart, within the greater Ngare Mara community. The two sub-villages of Chumviyere and Etorro, comprising 62 farming families, are located on a rocky plateau sandwiched between the Ngare Mara and the Ngare Nite rivers. Both communities have chosen to practice communal farming on either side of the plateau on the lower flattened banks of the two rivers that are less rocky and more suitable for agriculture (Figure 6.2).



Figure 6.2. Photograph standing on the rocky plateau of Chumviyere community looking east and down towards the green maize fields. The dark line of trees at the back follow the Ngare Mara river and beyond lies the thick bush where wild elephants forage and migrate between the national reserves and parks.

6.1.3. Approaching the Community

An introduction to the community was made possible through Save the Elephants' MIKE field officer, Onesmas Kahindi. Kahindi had been STE's representative at the landmark 2002 community meeting (Chapter 1) and not only had an intimate understanding for the community's structure and problems, but he had also gained the respect of the community elders due to his involvement in the dispute settlement (Kahindi, 2002). Kahindi, and his Turkana assistant Wilson Lelukumani, had also been responsible for monitoring the illegally killed elephants in the Ngare Mara community and they were able to pass on some valuable information about the human-elephant conflict (HEC) problems suffered by the farmers of Ngare Mara.

Together, we made three visits to the community prior to initiating a large scale community meeting. These initial visits involved conducting informal discussions with members of the community including the Chief and two Chairmen of Chumviyere and Etorro. The aim of these discussions was to assess both the up-to-date HEC issues in the community and to judge the interest and enthusiasm for involvement in such a trial. We also noted that (a) a small and successful beekeeping project had begun with 20 Langstroth beehives in a neighbouring community initiated by the Ewaso North Development Trust and (b) charcoal making activities were evident all over the community.

It was apparent immediately during these scoping visits that (i) HEC was still a serious problem in the community forcing families to farm communally for better protection, (ii) the farmers voiced intolerance towards wild animals, particularly elephants, and (iii) the communities were still not receiving any benefits or being involved in any conservation initiatives from the council's wildlife department. One farmer voiced his opinion clearly when he said *"The problem with elephants is so serious here that no one can talk about how bad it is. We work so hard on our shambas [farms] and just when they are about ready to harvest the elephants come and trample and eat them."*

6.2. Method

Type 2 farm-based trials rely heavily on participation and input from participating farmers to generate an appropriate researcher-lead experimental design that often can reveal good information about (i) profitability, (ii) feasibility, and (iii) farmers' assessment of a practice (Franzel *et al.*, 2002). My methods within this framework involved the application of some Rapid Rural Appraisal (RRA) techniques to help design an appropriate experiment where the beehive fences could be tested scientifically in optimal conditions for a particular community but without artificially manipulating present farming practices.

6.2.1. Rapid Rural Appraisal (RRA) Framework

RRA's are used specifically when information is needed quickly to inform a project design, gather information and can help lead to discrete studies that can be monitored and evaluated (Schoonmaker Freudenberger, 1999). RRA's contain many of the same useful techniques of full Participatory Rural Appraisal (PRA) methods but tend to (i) lend themselves more towards collecting a combination of qualitative and quantitative data in a shorter time frame, and (ii) involve both bottom-up participatory activities and top-down researcher led activities. However, as RRA projects usually do not benefit from full participation at every stage of a project's progress and data analysis, there can sometimes be a limitation in transferring knowledge gained 'rapidly' from one indigenous project site to another (Schoonmaker Freudenberger, 1999). I chose to follow an RRA structure as it was appropriate for my relatively limited time frame (2 years) and enabled me to include participatory research activities during the first four 'stages' of the research process during the planning, set up, deployment and data collections stages. However, the scientific data analysis (5th stage) was conducted by myself without participatory involvement from the community (these stages are illustrated in section 6.2.3).

Critical to RRA methods is the creation of a 'study team', which should include members who can contribute interdisciplinary and diverse qualities to the research project. A core reason for using a study team is to minimize the potential of researcher bias. This is a phenomenon where individuals can be naturally biased

towards aspects of personal interest, which can bias qualitative data collection and ultimately a project's decision making (Schoonmaker Freudenberger, 1999). To reduce researcher bias as much as possible I used the RRA triangulation technique by involving four members in my study team during the initial two design stages of the project. Each member represented different genders, educational backgrounds and knowledge of the community. Myself as the lead, female researcher, had little knowledge of the community but full knowledge of what was needed for the practicalities of setting up a beehive fence experiment. My background as a trained zoologist and project manager meant my innate bias was more towards the elephant-beehive fence interaction but as a female I had a conscious bias to involve the women of the community in the farm-based trials as much as possible. Onesmas Kahindi, although not Turkana, held a respected position in the community, almost at elder level, and had a wealth of experience at talking to communities from other environmental projects using his professional knowledge gained from a social science masters degree. Wilson Lelukumani, a Turkana man from the area with school-leaver education, was both an 'insider' and our Turkana language translator for the team who fully understood the intricacies of the community and the Turkana tribal traditions and etiquette which were essential for interacting respectfully with this rural community. Finally Lucas Lepuiyapui, an expert Ndorobo beekeeper had experience working with both elephants and farmers in the beehive fence construction and could translate Swahili into English. Kahindi was involved for the first two design stages of the research but was not involved in the deployment and data collection phase which was more appropriately lead by our Turkana team member, Wilson.

6.2.2. Stage 1: Participatory Structure and Research Questions

Our objective for the farm-based trials was to tailor the beehive fence experiments to the needs of the community as closely as possible and to try to fit the experiments into the existing farming structure without interfering or changing any of the other farming practices in the community. Participation and involvement of the whole farming community during the first two development stages was critical so that any successes or failures of the experiment could be attributed honestly to the concept and workings of the beehive fences and not to interference from the research team. With this aim in mind, our priority for the initial introduction of the trial concept to

the community was to enable an open exchange of ideas and to listen and learn as much as possible about problems present in the community already. By doing this we aimed, as a study team, to analyse genuine responses and identify potential contributions towards the proposed beehive fence trial. Hence, the first large scale community meeting was critical and much thought by my study team went into the planning of the meeting.

61 adults participated in this first large scale meeting (25 men, 32 women, 4 study team members) representing approximately 50% of the community as a whole (Figure 6.3). We held a study team de-brief after the meeting to go over the content and extract different observations and knowledge from each of our perspectives. This process enabled us to consolidate the conceptual model and proceed with a more detailed plan for the beehive fence trial that we felt confident would be a good representation of the communities views, concerns, interests and practical information about their farming systems.

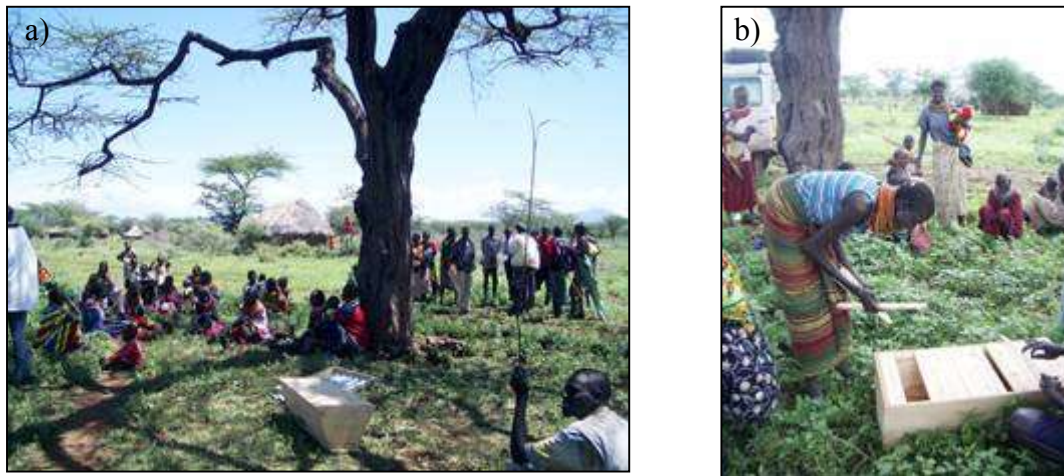


Figure 6.3. (a) During the community meeting two committees were elected from each of Chumviyere and Etorro and (b) each member was given a demonstration of how the KTBH hives worked to create an interactive forum to voice any questions or concerns about the trial.

Critical to that first Stage 1 meeting was the identification of one core research question expressed repeatedly by the community, which was ‘*will the beehive fences stop elephants from entering our farms?*’ This was the dominant discussion point and we established this research question as the main evaluating indicator of importance to the community. We identified that the prospect of honey production from the hives

was the second most important question from the community and matched our own desire to understand the livelihood improvement prospects from adoption of the beehive fence technology. Both these community questions were incorporated into the conceptual model.

We discussed indicators with the community during these meetings and identified several indicators that would enable evaluation of the beehive fence success both in terms of elephant deterrent efficiency and honey production success. The following Table 6.1. illustrates the identified indicators important to the community and to our study team and the conversion of these ideals into practical data collection methods on the ground.

Community Led Research Questions	Participatory Indicators	Methods
<i>Will beehive fences stop elephants from entering our farms?</i>	1. Comparing elephants inside bee protected farms to unprotected farms	<ol style="list-style-type: none"> 1. Participatory mapping of farms 2. Training of farmers for filling in data sheet templates for elephant movements 3. Monitoring maize growth and rainfall
<i>Will the beehive fences produce honey for us to use?</i>	<ol style="list-style-type: none"> 1. Hive occupations 2. Kilograms of honey 	Weekly monitoring team to record: <ol style="list-style-type: none"> 1. Hive occupations 2. Hive abandonments 3. Hive attacks by honey badgers 4. Honey harvesting events
Study Team Led Research Questions	Study Team Indicators	Methods
<i>How will the community respond to the new beehive fence technology?</i>	<ol style="list-style-type: none"> 1. Maintenance success 2. No. of people participating in offered beekeeping training 3. Any changes in beehive fence design 4. Theft of hives or honey 5. Attitude changes 	<ol style="list-style-type: none"> 1. Observations and discussions from weekly visits to project site 2. Beekeeping training days 3. Socio-economic questionnaire
<i>Does the beehive fence affect income and livelihood prospects?</i>	<ol style="list-style-type: none"> 1. Any changes in time management or income prospects 2. Comparing honey and charcoal income 	<ol style="list-style-type: none"> 1. Socio-economic questionnaire

Table 6.1. Summary of Stage 1: research questions highlighting the two most important to the community plus two additional research questions of interest to our study team. These are followed by evaluating indicators and methods for quantitative and qualitative data collection.

Also critical to this initial meeting was the decision to involve both communities of Chumviyere and Etorro in the trials, and the self-election of two small committees from each community (six in each committee consisting of four men and two women). The 12 committee members became my contact point in the communities and prevented the need for repetitive large scale community meetings. Two carpenters were selected to participate in a two-day KTBH beehive-making training workshop that was held immediately in the STE research camp. The community debated on a fair wage for the two carpenters and this was agreed out of the budget. A group of six women volunteered to start building a workshop in the community to house the beehive making materials and carpenters.

6.2.3. Stage 1: Conceptual Model for Field Trials

Using knowledge gained during these initial visits and meetings I constructed a conceptual model to help plan each stage of the research (Figure 6.4). Through our participatory discussions, our team had identified four core research questions of importance to both the community and ourselves which enabled me to evaluate progress, and any problems with the project, around these questions within the time frame predicted.

Question 1: *Will beehive fences stop elephants from entering farms?*

Question 2: *Will the beehive fences produce honey?*

Question 3: *How will the community respond to the new beehive fence technology?*

Question 3: *Does the beehive fence affect income and livelihood prospects?*

Due to the size and ambition of the study, Chapter 6 will deal mainly with Question 1: *Will beehive fences stop elephants from entering farms?* and Question 2: *Will the beehive fences produce honey?* Both were the core questions posed by the community throughout these early discussions and, indeed, for the entire two year trial. Chapter 7 will focus more on the two socio-economic orientated questions which leant more towards understanding the adoption potential of the new deterrent system although there is some degree of overlap.

STAGE 1		STAGE 2	STAGE 3	STAGE 4	STAGE 5	
Project Initiation	Research Questions	Preparatory Activities	Deployment	Data Collection	Data Analysis	Adoption Potential
<i>PLAN: April '08</i>	<i>April '08</i>	<i>May '08</i>	<i>May - July '08</i>	<i>June '08 – Mar '09</i>	<i>Mar-May '09</i>	<i>Discussion</i>
<i>ACTU.: April '08</i>	<i>April '08</i>	<i>May - June '08</i>	<i>June - Sept '08</i>	<i>June '08 – June '10</i>	<i>June-Aug '10</i>	<i>Discussion</i>

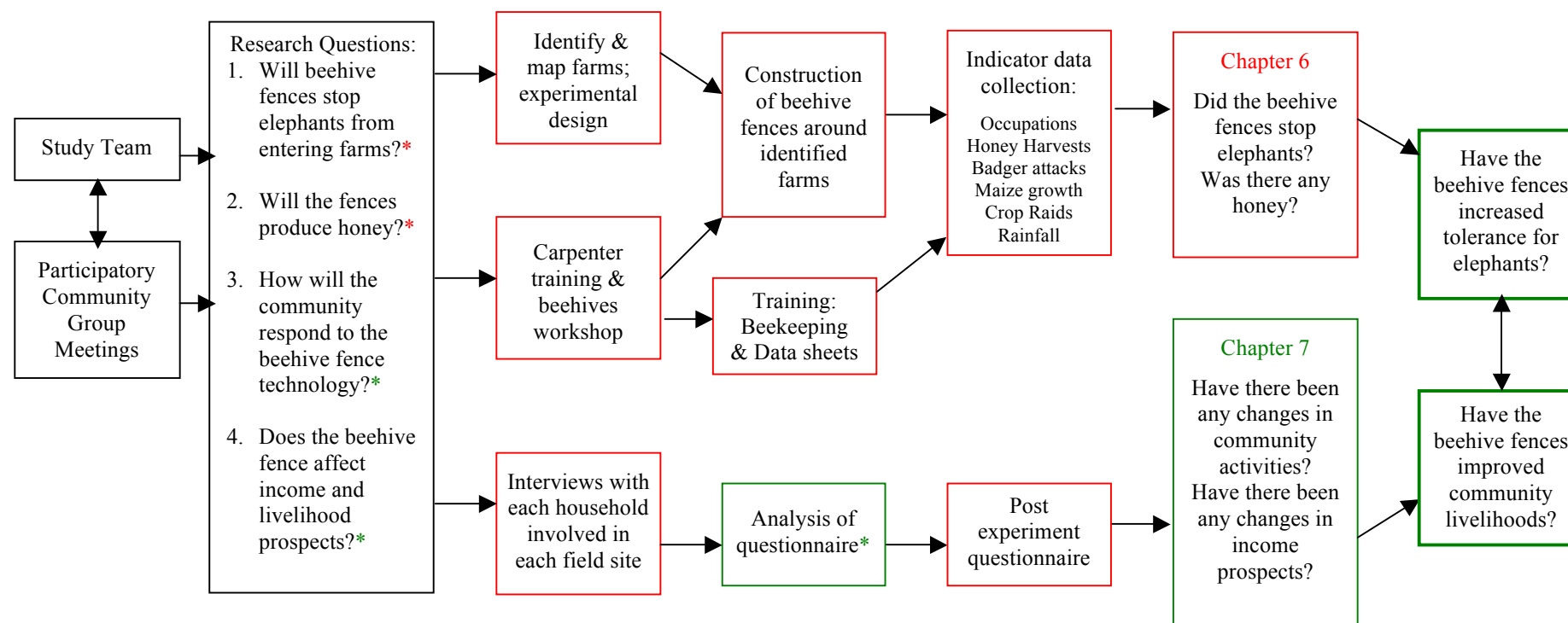


Figure 6.4. Conceptual model for beehive fence project in Ngare Mara identifying 4 core research questions which led to preparatory and deployment activities. Stages 1-4 were mostly participatory (in red*), stage 5 was mostly non-participatory (in green*). The data collection phase continued for over a year longer than anticipated due to a severe drought. The data analysis phase has been split into two manageable sections which are discussed in chapters 6 and 7.

6.2.4. Stage 2: Participatory Activities with Focus Groups

The second community meeting was held a week later with the two representative committees (our smaller focus groups). The carpenters demonstrated how the new beehives worked to the focus group, and the team of women volunteers showed us round the workshop they had built in Chumviyere to enable the carpenters to start constructing 150 beehives immediately.

Using techniques from Schoonmaker Freudenberger's RRA manual (1999) two participatory activities were conducted during this meeting to gather more specific information. (i) Participatory maps of the community were drawn showing the location of the farms, houses, rivers and the direction from which elephants came to crop-raid (Figure 6.5) and (ii) a calendar of seasonal events was created where each gender group articulated details of its particular farming or social practices to help me, the researcher, to design an experiment within the appropriate seasonal conditions (Figure 6.6). For both activities the women (n=9) and the men (n=10) were in different groups to assess any gender variation of these perspectives. Both activities helped us to define the seasonality of the communities and to start planning for where to set up the beehive fences. Additionally, I began to gather social and economic data through the medium of questionnaires both before and after a two year trial (discussed separately in Chapter 7).

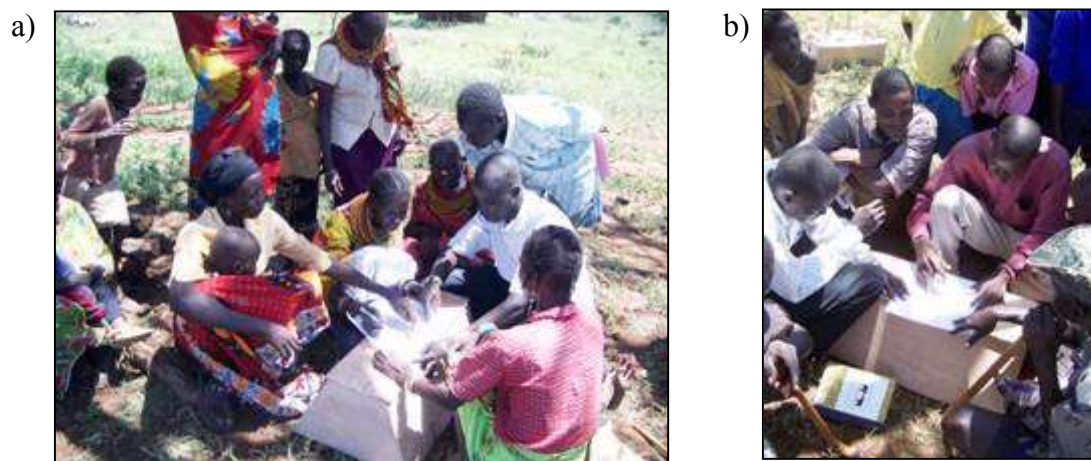


Figure 6.5. Here the (a) women and (b) male committee members are seen drawing their map of the community and their calendar on upturned beehives. A seasonal calendar of events involves ticking boxes within a template of activities listed within the months when that activity occurs. In this case the template consisted of community activities that I, as the researcher, needed to know about the community to help me design the trial plan.

Ngare Mara May 2008	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Dry and rainy seasons	Dry		Raining		Dry				Raining			
Planting Crops									♂	♀		
Harvesting Crops							♀					
Honey Harvest												
Hardest work time (man)										♀		
Hardest work time (wife)		♀		♀								
Elephant crop raiding										♂		
Other animal problems			♀			♀		♂	♂		♀	♀
Income			♀				♀		♀		♂	♂

Key: Dark Grey = consensus ♂ = male only responses ♀ = female only responses

Figure 6.6. A calendar of seasonal events was generated to help understand the seasonality within the community and to manage the beehive fence development in time for the peak crop seasons. There was considerable overlap in the two maps drawn by the men and women but small differences in opinion were interesting to note. Elephant crop raiding was identified as occurring mainly between November and June with both men and women agreeing that July-September was a quiet time for crop-raiding as this coincided with the dry season. Both men and women were fairly consistent at identifying the hardest work times and it was interesting to note that women were regarded by both genders as working hard for 8 months of the year compared to 4 for the men. The area of greatest variability in opinion was the occurrence of other problem animals and months of income. Honey harvesting was identified as happening twice a year and appeared to coincide with the end of a dry period.

6.2.5. Stage 2: Mapping the Farms and Experimental Design

Using the participatory hand drawn maps as a guide, we spent four days physically mapping the farms of both Chumviyere and Etorro. Mapping was done using a Garmin Legend GPS and notebook where the position of each corner or junction of a farm was taken and a corresponding hand drawn map was created at the same time (Figure 6.7). This notebook was an onsite data backup but it also enabled us to cross-check any seemingly inaccurate GPS positions.



Figure 6.7. Lucas and Wilson mapping the farm boundaries

The GPS data was uploaded into a computer using ArcGIS 9.2 and simple outline maps of the 62 farms were created (Figure 6.8). Through consultation with the committee members we labeled each farm with the surname of the farmer. The maps were printed off and taken back to the committees to check accuracy and to get them to re-draw the elephant movements again onto these detailed maps. These routes (marked as red arrows) represent observations and opinions of the community of where the elephants were coming from to crop-raid at night although we were unable to verify the accuracy of this information before designing the experiment.

These red routes were dominated by the pattern of elephants coming out of the thick bush towards both rivers to drink before walking up the opposite bank into the farms to crop-raid under cover of darkness. The rivers did not create any natural barrier to the elephants and instead appeared to attract elephants to the edge of the farming area. Using this local knowledge we identified and selected *all* 34 farms (55%) that were ‘on the front line’ of these historical elephant raids. The remaining 28 farms (45%) not selected for inclusion in the trial were either directly protected by another farm or were too difficult to access.

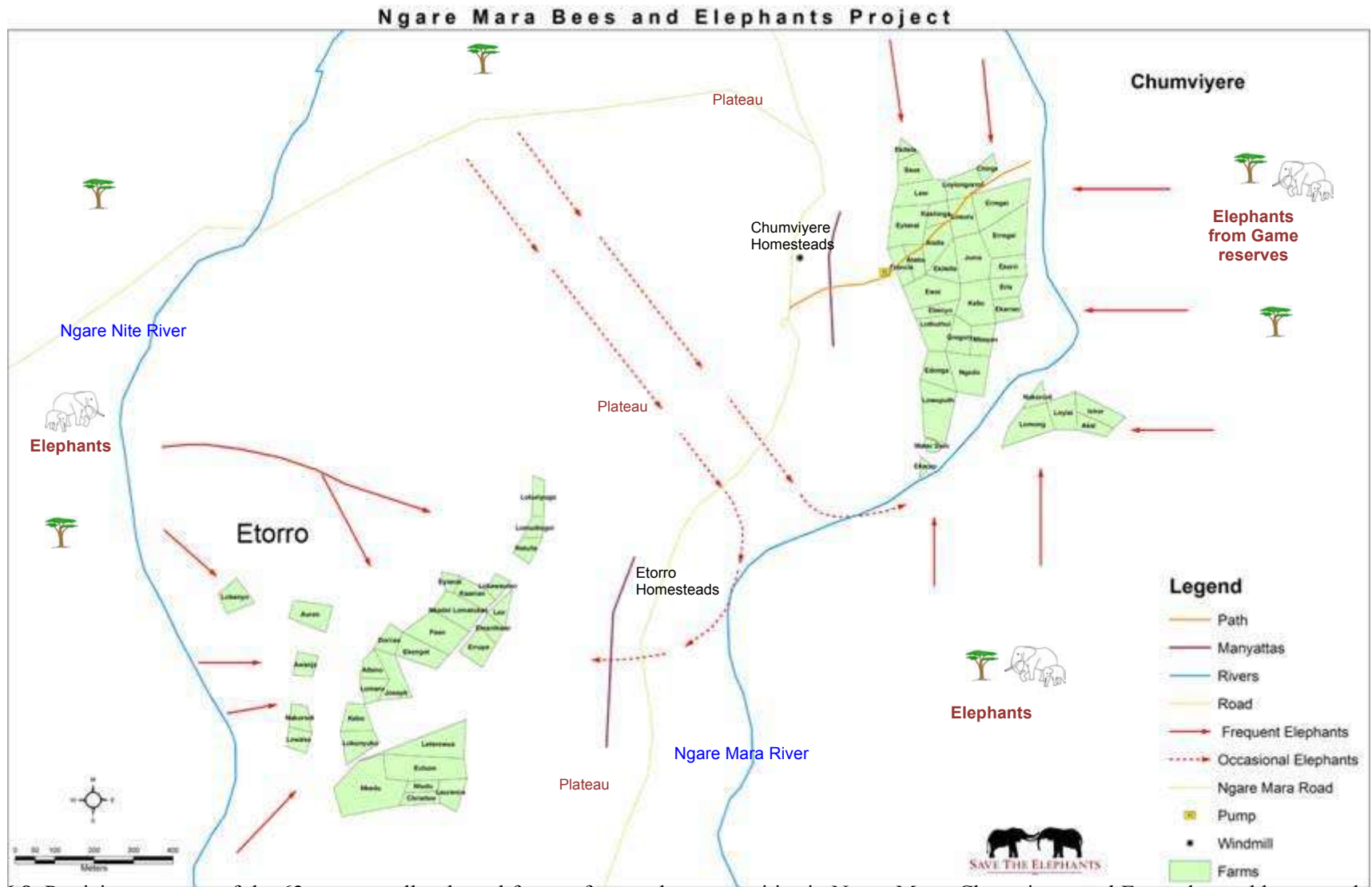


Figure 6.8. Participatory map of the 62 communally planted farms of two sub-communities in Ngare Mara, Chumviyere and Etorro located between the two rivers of Ngare Mara and Ngare Nite. Regular routes of elephants entering the farming area from the surrounding bush are drawn as red or dotted red arrows.

6.2.6. Stage 2: Beehive Construction in Community Workshop

150 of the KTBH beehives were constructed on site by members of the community between May and August '08 at a cost of US\$22 per hive. An additional 21 beehives were constructed in April 2009 at an elevated cost of US\$25 per hive due to local increases in timber costs due to fuel inflation. The hives were constructed from 8ft x 4ft sheets of 9mm plywood on a template borrowed from the manual *"Beekeeping as a business"* (Jones, 1999). I slightly modified the beehive design by reducing the length of hive from 90cm to 80cm which meant we could get exactly 3 beehives from each piece of plywood, greatly increasing the cost efficiency of the materials needed. The two carpenters constructed the hives in batches of 50 which took approximately two weeks to complete (Figure 6.9). The carpenters (who were paid a fee per finished beehive) independently employed further helpers to assist them. At the end of the workshop the two carpenters had trained at least a further 8-10 young men and women in the construction of the beehives and I regarded this skill sharing process as a positive indicator.

The hives contained a queen excluder (made from locally available coffee wire), which separated off 6 top bars from the remaining hive for the queen's brood chamber. This design ensured that the majority of the honey was kept separate from the brood enabling more efficient harvesting of 'pure honey', which was not so disruptive to the queen.



Figure 6.9. (a) The workshop became so busy that activities often spilled outside during the day where several helpers assisted the two carpenters. (b) The beehives were constructed in batches of 50 before being deployed onto the nearby farms.

6.2.7. Stage 3: Beehive Fence Construction and Deployment

The beehive fences were constructed on the template of my earlier pilot design (King *et al.* 2009, Chapter 5) but improved to include the more productive KTBH hives (Jones, 1999; see Figures 6.10, 6.11 and 6.12). The participating farmers from one farm designed a more effective, lighter flat-thatched roofing system early on during the construction of the beehive fences, and these were adopted across the field site with the help of a small group of enthusiastic volunteer farmers.



Figure 6.10. Photograph of the first 500m stretch of beehive fence using the old roofing system where long sticks were nailed to the upright posts and thatching wired onto a criss-cross of sticks to hold the thatch in place.



Figure 6.11. Photograph of a beehive hung between two posts with the new styled flat-thatched roof suspended over the hive by two pieces of wire. As the hive gets heavier with honeycomb both the beehive and the roof can be lifted up easily by just tightening the wire.

Beehive fences were constructed along 50% of the 34 most raided farms leaving the remaining 50% as control farms protected only by traditional thorn bush barriers. Each farm varied in size and therefore comparable lengths of alternate farm boundaries were used to select bee (n=17) and control (n=17) farms rather than a purely random design (Figures 6.13 and 6.14). One more 220m farm boundary with 21 beehives was included in the study in April '09 to replace 'Awanja's' farm which was never planted. In total 170 beehives were deployed around the farms with one beehive donated to the school.

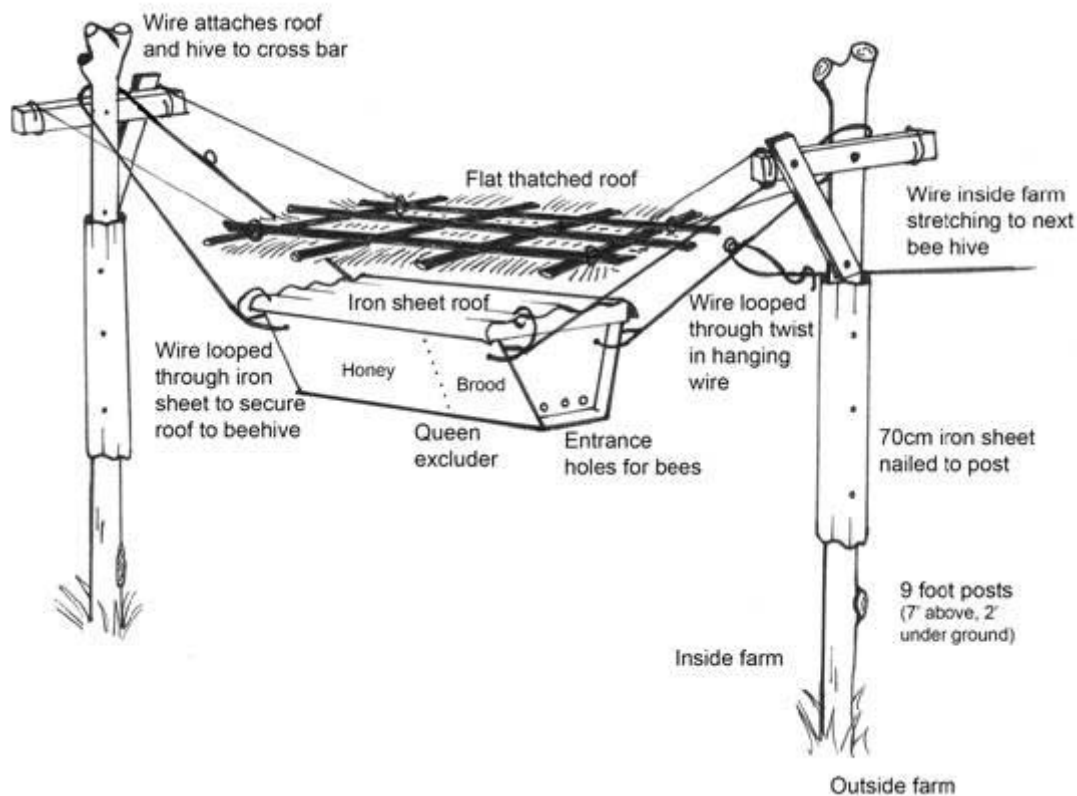


Figure 6.12: Beehut design - the key element of the beehive fence

The beehive fence is comprised of two elements, the ‘bee hut’, as seen in the diagram, and the connecting wire linking one beehive to the next with a gap of 7m between the post of one bee hut and the next. The beehut houses an 80cm long Kenyan Top Bar Hive constructed out of 9mm plywood and designed so that three beehives can be made from one large 8x4’ industrial plywood sheet. The design of the KTBH hive (taken from Jones, 1999) incorporates a queen excluder to keep the brood separate from the honey chamber, this increases the ease of harvesting and the value of the honey. The rain-proof roof is made from a cheap corrugated iron sheet and is protected from the sun by a flat-thatched roof. The new roof (designed by the farmers) is hung by thin binding wire, too thin for honey badgers to crawl down should they succeed in bridging the protective 70cm iron sheets nailed to the posts. The 9 foot posts must be coated in a cheap oil-based insecticide to prevent termites. The hive is hung by drilling small holes in the side walls of the hive and feeding through stronger plain wire. This is looped easily around the top of the upright posts and once through the hive the ends can be secured to the roof by drilling a small nail size hole in the iron roof to prevent wind blowing away the roof. A simple twist of the hive’s hanging wire on the farm side of the beehut enables a strong piece of plain wire to attach one beehive to the next beehive 10 meters away. Should an elephant attempt to enter the farm he will instinctively try to pass between the beehuts and as the wire stretches the pressure on the beehives will cause them to swing erratically and, if occupied, release the bees. The wire is only looped through the hoop, not twisted tightly back onto itself, so that excessive pressure from an elephant will release the wire rather than pulling down the hive.

The beehive fences were built with 1 beehive to every 10 meters resulting in 1700 meters of beehive fences around the boundaries of 17 community farms. A further 1700 meters of farm boundaries were allocated as ‘control’ farms where the traditional thorn bush barriers were left in place along the 17 farms (Table 6.2). The thorn bush barriers were left in place behind the beehive fences. Two long stretches of farm land boundaries at the rear of the communal farm areas were not included as ‘controls’ as the rear section of the farms backed onto the rising ridge of the plateau which was populated with houses and therefore identified by the community as an area too risky for elephants to traverse (Figures 6.13 and 6.14).

<i>Area</i>	<i>Beehive Farms</i>	<i>Control Farms</i>	<i>Total</i>
Chumviyere	9	9	18
Etorro	8	8	16
Total	17	17	34

Table 6.2. Summary of the experimental design for beehive fence experiments comparing test (n=17) and control (n=17) farms split between Chumviyere (n=18) and Etorro (n=16) communities.

Due to unforeseen events in the field site several farmers from Etorro moved away from the study site during the trials that resulted in variation in planting success. These events included a severe drought and fatal tribal conflicts between our Turkana community and the neighbouring Borana tribe (12 people were killed and several injured during two cattle raids in August 2009).

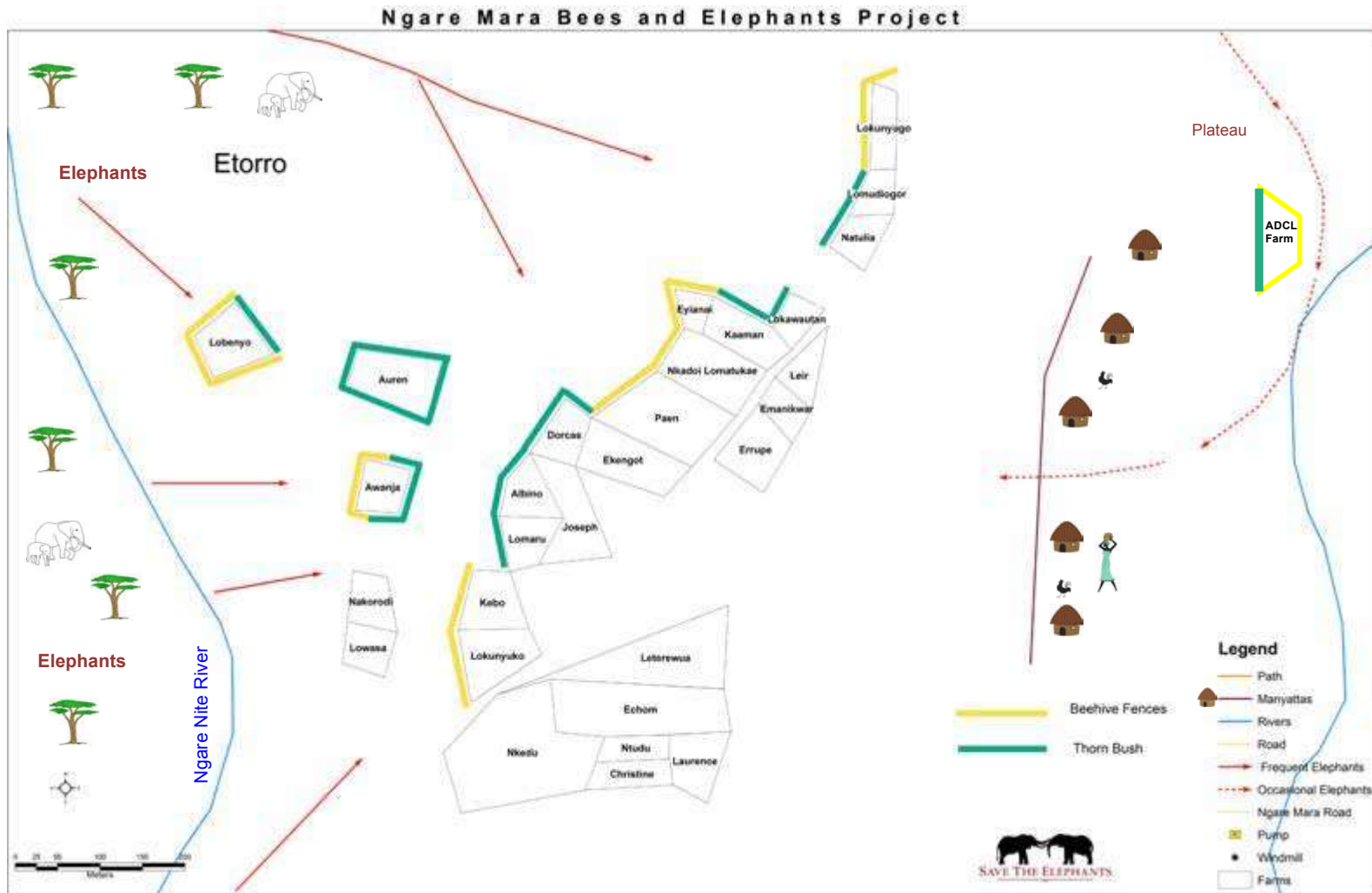


Figure 6.13. A detailed participatory map of Etorro farms showing stretches of farms protected by beehive fences and those protected just by thorn bush barriers. A further farm (ADCL Farm) was added in April 2009 to replace Awanja's farm which was never planted.

6.2.8. Stage 3: Training for Beekeepers and Data Monitors

I employed a professional ICIPE⁴ trained beekeeper to train 36 farmers during a 4 hour training session during stage 3 of the project (Figure 6.15). Furthermore, each farmer with a beehive fence section was given a personal beekeeping session with Lucas, our study team's beekeeping expert. I trained six farmers from within the two committees to fill in simple data sheet templates detailing each farm and fence layout enabling the monitors to simply draw the movements of any elephants approaching or entering a farm with details such as the time, date and number of elephants.

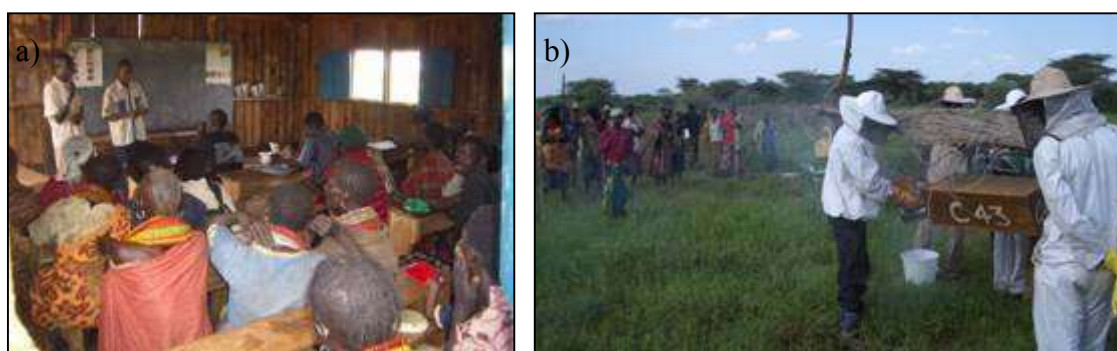


Figure 6.15. (a) As well as completing a large community beekeeping training day (36 farmers attended), each farmer was given a personal beekeeping training session (b) to help them manage their section of the beehive fence and harvest honey without destroying the brood.

6.2.9. Stage 4: Data Collecting and Monitoring

We monitored all farms over 24 months over three successive crop growing seasons. We visited the study site once a week to collect indicator data and to help with fence maintenance. We recorded hive occupations, hive abandonments, honey badger attacks, rainfall measurements, maize growth and collected information and data sheets from the farmers on elephant activities. We defined a '*farm invasion*' as an elephant, or group, crossing either a bee or thorn barrier to enter a farm and later exiting either through this or through another barrier. If those same elephants chose to re-enter a second farm across a separate barrier we recorded that second attempt as a second invasion. Elephants crossing into different farms within the communal area were not

⁴ International Center of Insect Physiology and Ecology, Nairobi

counted as separate farm invasions as there were no internal barriers between the communal farming plots. Elephants that approached a barrier and turned away was a separate event, classified as *'prevented from entering farm'*, even if those elephants were then to walk around and enter another farm at a different location on the same night (Figure 6.16).

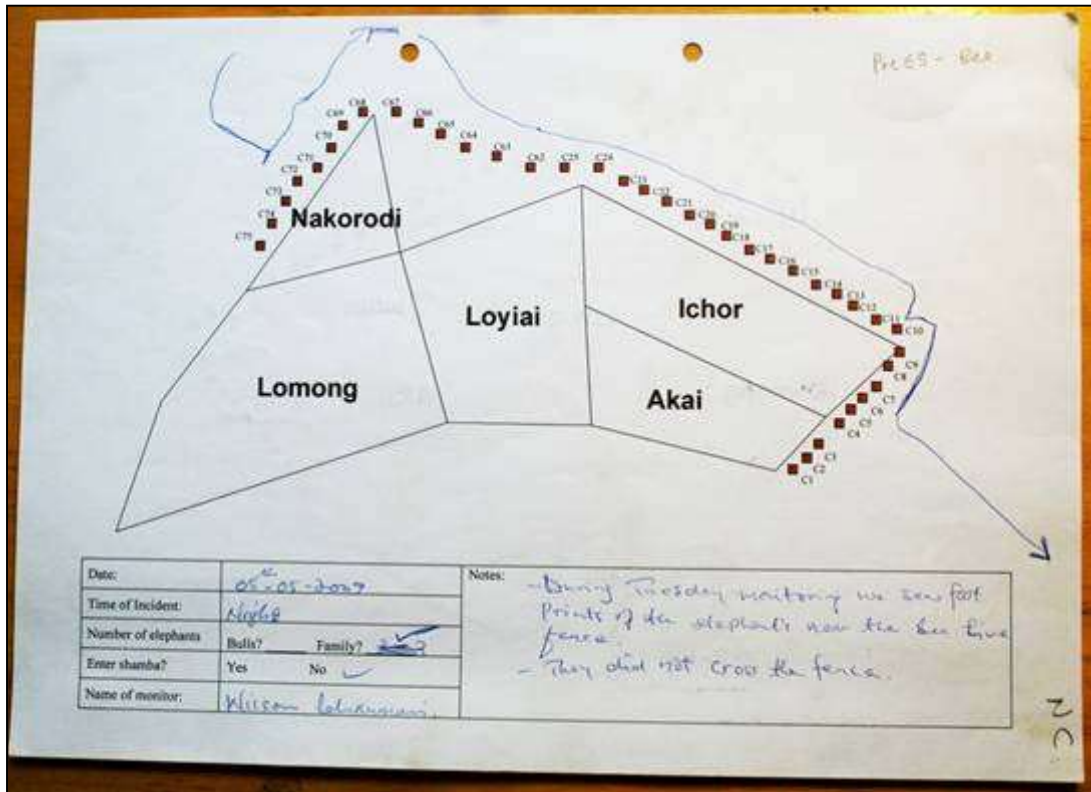


Figure 6.16. Example data sheet illustrating how a farmer drew on the movement of an elephant family around his beehive fence. In this case the elephants approached from the left and walked all around the farm without entering. Wilson was able to talk to him and translate the farmer’s observations into English in the simple data boxes.

Planting dates for each of the 34 front line farms were collected each season and weekly maize growth rates were recorded in each farm by selecting three random maize stalks and taking an average of the three (Figure 6.17). Although sampling was small, maize growth was largely consistent across a field and three measures gave enough of an indicator of the condition of each farm over the passing weeks. This allowed us to control for crop-raiding behaviour that may have been biased towards more ripe fields. Data were analysed using Genstat v.11.2 using non-parametric statistics.

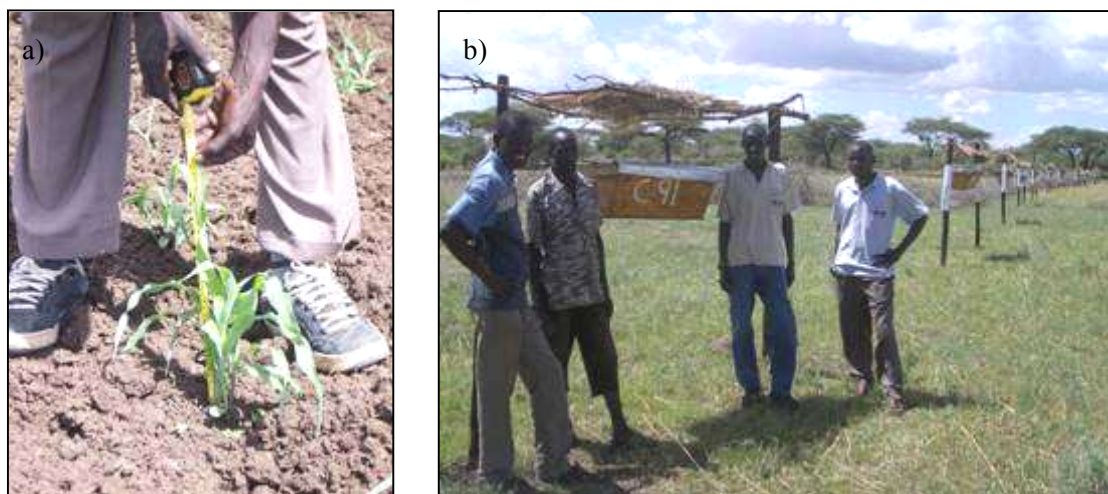


Figure 6.17. (a) Wilson measuring the growth of newly planted maize. This was done consistently by pulling the longest leaf vertically upwards and measuring from ground to tip. (b) Weekly visits to the beehive fences ensured the hives were in optimum condition for occupancy and in preparation for the rains and planting season. Active community members and at least one carpenter accompanied every visit to assist with minor repairs.

6.2.10. Stage 5: Feedback and Group Discussions of Results

During the weekly monitoring events there was ample opportunity to look over the data sheets and discuss the other indicators of success with various farmers whom we either met on our monitoring circuit or who joined us for the day's activities. During the last two months of the monitoring season (June-July 2010) we looked over all the elephant raid data sheets with a group of interested farmers in one of the carpenters' homesteads and we had a chance to discuss the patterns that were being seen. Additionally the farmers had become aware after two years of the project that the hive occupations appeared to be linked to rainfall events and the honey harvesting activities were picking up after the good rains from November 2009 – April 2010. However, the final scientific analysis of the indicators and questionnaires presented here were not conducted with the farmers.

6.3. Results

Stage 5: Analysing Indicators

Thirty four farms were carefully monitored over three crop seasons from October 2008 until March 2010. However a harsh drought occurred in northern Kenya during most of the first year of the study period severely curtailing crop growth. Thus the first crop season (October '08 - January '09) saw only 18 days of light rainfall (amounting to 1819ml that fell mostly in five days) and leading to failure of the harvest in 83% of the farms. The second crop season (March-May '09) had only seven days of rain (895ml) resulting in failure of the harvest in 100% of the farms. Finally, the third crop season (September '09 - February '10) had 34 days of rain (2417ml) spread over five months resulting in a successful harvest of crops in 50% of the farms, all in Chumviyere. Of the remaining farms, 38% failed to plant and 12% planted but the crops failed.

6.3.1. Question 1: Did the beehive fences stop elephants from entering farms?

Whether due to the unusually dry weather conditions or incidents of local insecurity, no elephants were seen in the area until April 2009. However, during the core study period (29th April 2009 - 15th February 2010) 49 elephant farm-invasions, both attempts and successful, were observed. 27 farm events were recorded where elephants entered, or attempted to enter, farms without crops (over a 259 day period) and 22 farm invasions attempts were recorded where crops were present (over an 82 day period).

We observed 36 events where elephant approached and were successful at invading the farms. Of these 36 invasions, 35 entries occurred through the thorn bush barriers and only one entry was recorded through a beehive fence ($\chi^2=40.77$, df 1, $p<0.001$; Figure 6.18). In that case a bull elephant pushed through the wire connecting the hives thus avoiding the beehive huts. His family did not follow allowing the farmer to chase the bull back out. Both beehives on either side of the entry point were unoccupied at the time (Figure 6.19).

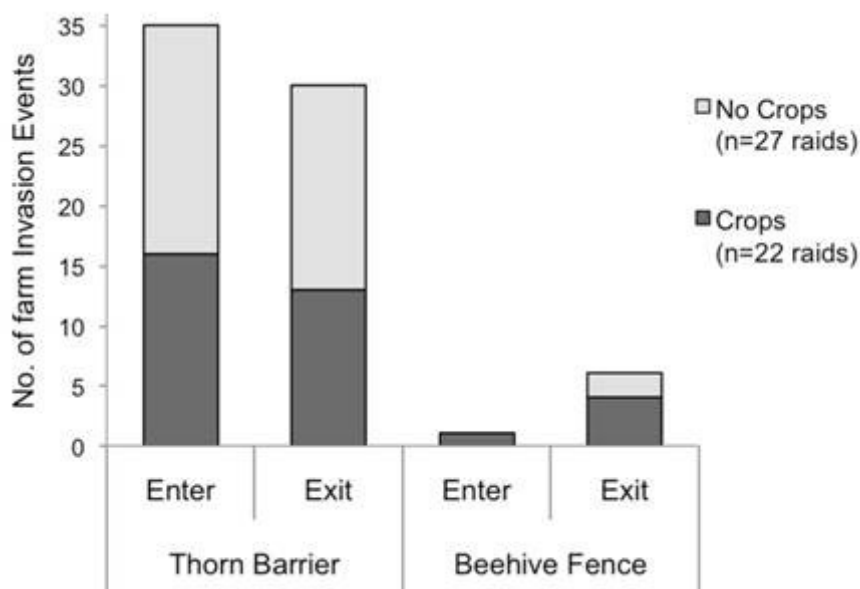


Figure 6.18: Comparing the effectiveness of beehive fences to thorn barriers in farm invasions and exits by elephants. Analysis of 36 successful farm invasions showed that 35 invasions occurred through traditional thorn barriers and only one through a beehive fence. Elephants exiting a farm after a crop-raid, or chased out by farmers, were more likely to exit through the thorn bush than the beehive fences. However there were more observations of elephants exiting through the beehive fences than when entering a farm suggesting that elephants do not necessarily get trapped inside a protected farm by a beehive fence. Elephant behaviour and deterrent effects of the barriers were similar for farms with or without crops.

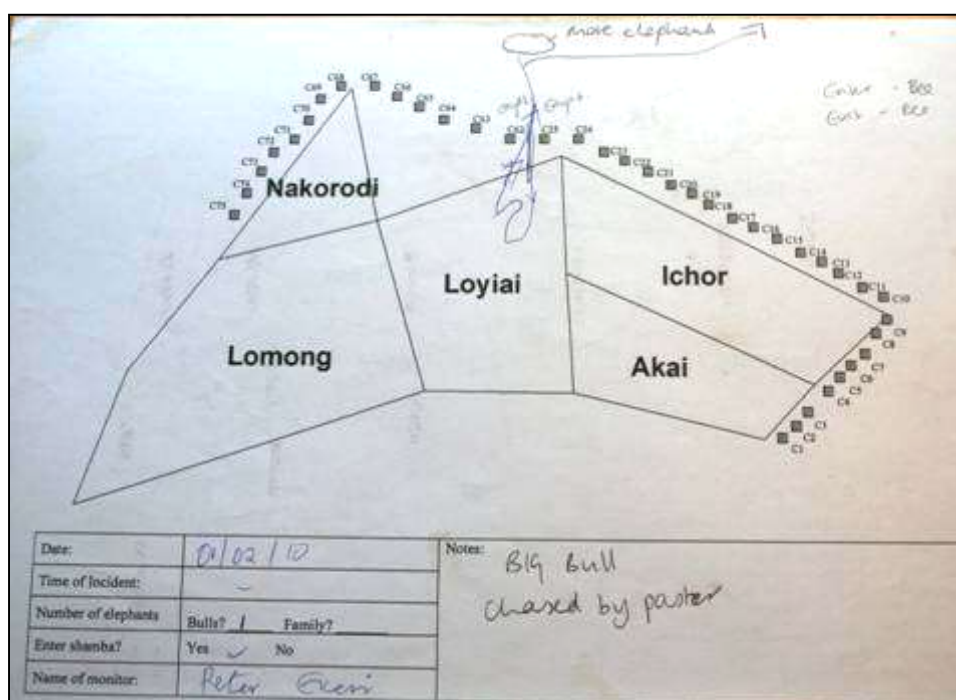


Figure 6.19. Data sheet from the one successful crossing of the beehive fence into Loyiai’s farm which did have crops in at the time. Reportedly a bull broke away from a group who were seen walking around the farm and pushed through the wire. The farmer was watching and along with some relatives they immediately chased the elephant back out of the farm and he exited through the same hole in the fence. Both beehives on either side of the break through point were unoccupied by bees at the time of entry.

We recorded 13 attempted farm-invasions where the elephants approached the beehive fences but did not push through. During eight of these 13 events the elephants (as recorded by their footprints) walked along side the length of the beehive fence structure, often approaching the wire within a meter or two and then backing away. However, in five events the elephants walked along the entire length of the beehive fences until they came to the end of the line where they broke through the thorn barriers to invade a farm (Figure 6.20). At no point did the farmers record elephants approaching the thorn bush barriers and turn away, every approach to the thorn bush barriers resulted in a successful entry to the farm.

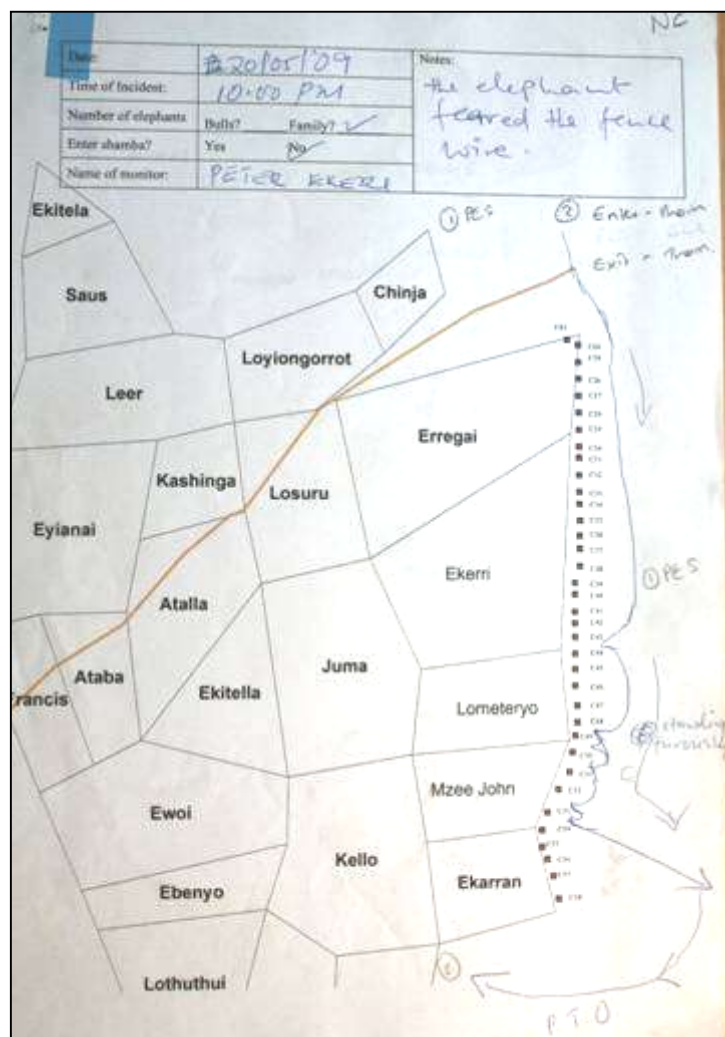


Figure 6.20. Example of a data sheet where the elephants were seen to attempt to approach and cross the beehive fences as many as six times at 10pm in May 2009 (recorded as n=1 ‘prevented from entering farm’ event). Here you can clearly see the elephants trying to get between the bee huts but turning away as they either saw or touched the wire hanging between the huts. Interestingly, the first beehive they approached, hive C44, was occupied by bees at the time the elephants approached the fence line but the remaining attempted access points occurred where the beehives were empty. Eventually they walked the whole length of the 360m fence and broke into the farm south of Ekarran through the thorn bush barriers. The farmer wrote a comment ‘standing furiously’ on the right of the sheet which was a fascinating interpretation of elephant body language by the farmer. He also noted ‘elephants feared the fence wire’.

To further examine the effectiveness of the beehive fences, we analysed five successful crop-raids that occurred within the first 10 days of February 2010, the peak of ripening time for maize in the nine central communal farms of Chumviyere. In all five cases the elephants broke into the farms at either end of the 360m beehive fence. I found that there was no significant difference in mean maize height between the five neighbouring farms protected by the beehive fence ($n=5$, mean height $229\text{cm} \pm \text{StDev } 40.7$) and the four control farms invaded at each end of the line of the beehive fence ($n=4$, mean maize height $251.7 \pm \text{StDev } 25.9$; Mann Whitney U, $U=18.5$, $p=0.647$). This strongly suggests that invasions were not due to differences in crop attraction but to differences in protection status.

This hypothesis is further supported by the observation that in the 36 successful invasions elephants also left a farm significantly more often through the thorn bush rather than through the beehive fences ($n=30$ and $n=6$ respectively; $\chi^2=17.47$, $df 1$, $p<0.001$). Indeed, in 11 events elephants already inside a farm walked along the inside of the beehive fences until reaching the thorn bush barriers where they pushed through to exit the farm. Nevertheless, in six events elephants did run through a beehive fence when chased out by a farmer (refer back to Figure 6.18). Of these six escapes, two occurred between bee huts where the wire had been removed by the farmer, three exits resulted in the wire detaching (as designed) and only once did the wire not detach effectively and the occupied beehive was brought down. This beehive was successfully harvested by the farmer producing 8kgs of honey before it was quickly repaired and reattached to the rest of the fence.

6.3.2. Question 2: Did the beehive fences produce honey?

While the beehive fences prevented elephants from entering the farms quite effectively, they also added to the productivity of a farm. Out of the 150 beehives initially deployed around the community farms 82 (55%) were occupied at least once between June 2008 and June 2010. A further 21 beehives deployed in early April 2009 had 16 occupations (76%) up until the end of monitoring in June 2010. Variation in hive occupations was most likely as a result of local abundance variation in flowering plants and water.

During the first year of the field trials we lost the honey from 38 occupied hives to honey badger attacks over a matter of a few weeks (Figure 6.21). In response to this disaster we extended the protective iron sheets from 50cm to 70cm and since that design improvement we only lost 7 occupied hives to honey badger attacks. These losses occurred when the hives hung too low due to the weight of honey and were not harvested in time by the farmer. Additionally we lost the honey from 14 hives to suspected theft but no beehives were stolen during the two year period.



Figure 6.21. Honey badger attacks were very damaging to the hives early on in the field trials. The badgers would rip open the metal roof and pull out each top bar to access the honey. They climbed up the posts, through the thatched roof and sometimes pulled the entire structure down. We solved this problem by extending the iron sheets to 70cm on the posts, which prevented them clawing their way up the posts.

I was able to compare four layers of data collected over the two year period to compare hive occupations, honey harvests and elephant events to rainfall (Figure 6.22). Beehive occupation figures appeared to closely mirror rainfall patterns as rain not only provided bees with water but it also triggered the growth of wild flowers and grasses. Honey harvests consequently followed a period of high hive occupancy and rainfall as nectar was abundant.

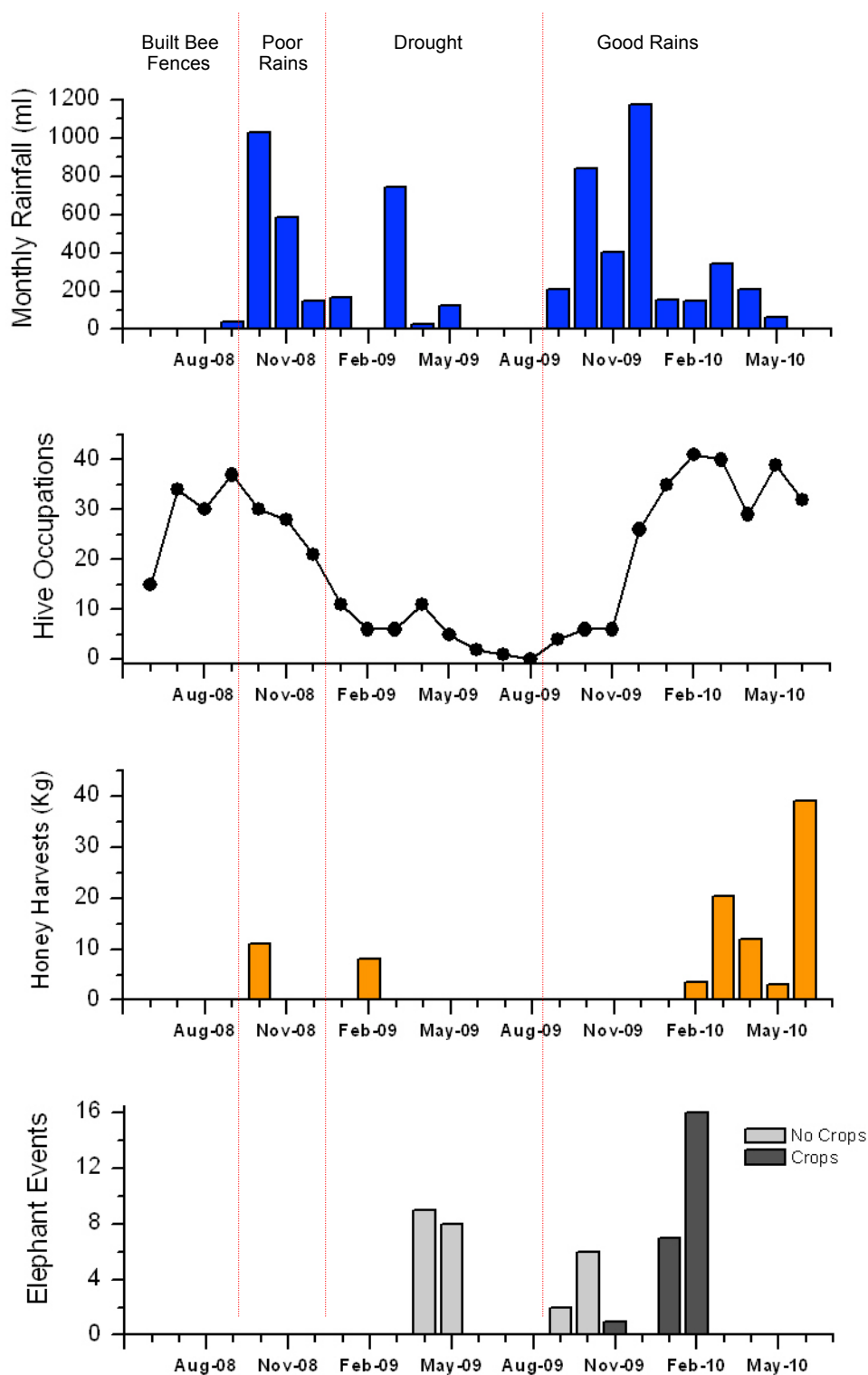


Figure 6.22. Over two years we observed that hive occupations closely followed rainfall patterns with peak occupations occurring during peak rainfall months. Honey harvests were poor during the first year and half of the project but as occupations and rainfall increased so did successful honey harvesting. Elephant events occurred mainly during harvest periods when rainfall resulted in successful crop growth. It was noticeable that elephants started to appear in the community at the same time that hive occupations were peaking.

44 out of the 98 occupied beehives were occupied more than once with some hives being occupied-abandoned-occupied as often as four times. Total occupation events within the 98 beehives were 169 revealing that previously occupied hives are more likely to attract a swarm. We found that coating the beehives with a polyurethane-based varnish not only attracted the bees but also helped protect the plywood hives from weathering. Due to a high mortality rate of bees and comb from both the drought and from honey badger attacks, only 23 beehives were successfully harvested during the trial period. Nevertheless, the total weight of “Elephant-Friendly Honey” was 106kgs with an average of 4.6kgs per hive (range from 2kgs to 15kgs) at an estimated local value of US\$290 (Figure 6.23).



Figure 6.23: “Elephant-Friendly” Honey is a significant and important output from the beehive fence deterrent. The financial benefits generated from this alternative crop encourage farmers to maintain the beehive fences and to check the hives on a regular basis. Honey does not need refrigeration and is already used for both consumption and as a medicine in traditional Turkana society. This aspect of the research is discussed in greater detail in Chapter 7.

6.4. Discussion

Here in Chapter 6, I expanded on a theoretical framework for testing out a new farming technology, a beehive fence, based on the structure of Franzel *et al.* (2002) Type 2 farm-based trials. By adopting a rapid rural appraisal technique I was able to attract the expertise and help of a small but multidisciplinary study team which was both vital and responsible for the success of this ambitious farmer participatory research project. Within our study team we held diverse attributes and skills including both genders, representatives from 3 different Kenyan tribes, one westerner, two masters level graduates (one zoologist, one social scientist), two school leavers, one ‘insider’ Turkana language speaker, two ‘outsider’ Swahili speakers, one expert beekeeper and a respected ‘elder’.

The diversity of language skills and perspectives from within our study team ensured that the first stage of the project, approaching and engaging with the whole community, was successful. This success can be attributed to the structured discussions and participatory identification of (i) research questions of importance to the community, (ii) indicators of success, (iii) community members willing to represent the community through the formation of committees, and (iv) two carpenters who volunteered to manage the construction element of the beehive fences. By going on to work closely with the two committees as focus group participants, we were able to use local knowledge to learn intricate details about (i) the different seasonal activities of the community and (ii) the historical movement of crop-raiding problem elephants around the farms. The development, training, testing and execution of a questionnaire survey is explained separately in Chapter 7 but these focus groups were helpful in formulating the question topics through open discussions. Whereas the social research in Chapter 7 deals primarily with the socio-economic implications of the trial, here I present participatory and scientific data to answer the first two research questions: *Q1: Will beehive fences stop elephants from entering farms?* and *Q2: Will the beehive fences produce honey?*

I present convincing evidence that beehive fences *can* be a useful tool for deterring elephants from entering farmland. Analysis of 36 successful crop-raids demonstrated that elephants only once broke through the beehive fences to gain access

to the crops within, and that traditional thorn barriers offer no defence at all against such invasions. We recorded 13 attempts to enter where the elephants turned away and either left the area after confronting the beehive fences or walked the length of the beehive fence to choose an easier entry point through the thorn bush. Additionally, elephants avoided the beehive fence boundaries when attempting to leave the farms after crop-raiding but if chased, an elephant would break through the wire to escape. Unexpectedly, four of the 49 farm invasions occurred with elephants entering the farms by walking between the village huts. As thorn bush barriers also protected these boundaries, these invasions were included in the analysis.

The improved design of the beehive fence structure from previous trials (King *et al.* 2009, Chapter 5) proved effective and maintenance was considerably easier using the simplified flat-thatched roof. The contribution from the farmers of the new, much improved roofing system should be regarded as a positive indicator that the farmers felt fully engaged in the research process and had spent time considering how to adapt a given technology to their needs. They identified that roof maintenance was a time consuming activity and rather than abandoning enthusiasm for the project they re-invented a simpler system to ensure the core elements of the fence remained a functioning success. Interestingly, the men delegated this roofing task the women on the farms who expressed their delight to me at being given a specific role in the beehive fence maintenance as it helped them feel engaged more in the project.

Additionally, the KTBH hives improved the quality of the honey harvested from the hives as the honey was pure (without brood) and attracted a good price at the local market. Farmers were quick to repair the damaged beehive fence from an exiting elephant, as they clearly understood the real and potential value that came from maintaining the beehives along the fence line. Farmers can get disheartened by elephants breaking through their home made barriers (Walpole *et al.*, 2006) or even give up and abandon their farms (Naughton *et al.*, 1999) but here we witnessed enthusiasm by farmers to maintain the beehive fences particularly as the new roofing system was easier to fix in this regard than the first version described in Chapter 5. The hope of a good honey harvest and protection from crop-raids appeared to be a real maintenance incentive and the socio-economic affects this had are discussed further in Chapter 7.

Although a beehive does not ‘sleep’ at night, individual bees are less active as they can rest for several hours (Kaiser, 1988) and will spend time cleaning the hive and feeding the brood, behaviour also seen during cold days (Hooper, 1997). Although this behaviour could be a limiting factor in the use of the fence (as all crop-raids occurred at night) most elephant-man interfaces in Kenya tend not to be in cold/high altitude zones. Additionally, there is a constant humming sound from fully occupied hives which may give elephants enough warning to stay away, as I showed in Chapter 2 that elephants will run from bee sounds (King *et al.* 2007). When we attempted to move a hive at 10pm at night the bees swarmed quickly out of the hive and attacked. Furthermore, species of both Asian and African bees, *Apis dorsata* and *Apis mellifera adansonii*, have been observed foraging successfully on moonlit nights (Dyer, 1985; Fletcher, 1978).

The greatest limitation of the beehive fence design here was the construction of the fence in straight or semi-circular lines in at least half of the study site. Although this design was based on participatory liaison with the community, which was able to offer advice on the most common access by elephants, it created a weakness in the design as elephants simply walked to the end of the line and entered the first unprotected farm. Farms that had more of a circular design to their beehive fences appeared to be more successful in deterring determined elephants and we recommend that any farmer testing the concept should encircle their farm land entirely for better protection. Due to the unforeseen problem of the most severe drought in 25 years (and thus two totally failed crop seasons) we were unable to monitor any changes in elephant behaviour from one season to the next. Further study is needed to assess whether or not elephants may habituate to the beehive fences, particularly to stretches of the fence that are frequently not occupied by bees.

Despite the need for more specific research into the details of habituation and the transferability of the beehive fence defence to other regions in Africa, the positive outcome of this study strongly supports the inclusion of beehive fences into the present tool box of elephant deterrents. Importantly, not only would such fences deter crop-raiding but the bees provide honey and other products for sale. If combined with other deterrents such as the use of dogs and drum beating (or should chilli grease be spread on the interlinking wires) the combination of farmer-managed activities could create a

successful elephant barrier that would be efficient, effective and be paying for itself over and above its rewards in arable products.

Chapter 7

Socio-economic considerations around the implementation of beehive fences as farm-based elephant deterrents.

Abstract

Successfully testing the adoption potential of new technologies or agricultural systems through on-farm trials relies on an appreciation of cultural, social and economic conditions within the community. Following on from our aim to field-test the beehive fence technology in a typical rural farming community, we conducted a questionnaire survey to explore the socio-economic considerations and constraints of our Turkana community before and after the beehive fence trials. Within our study community, the numbers of beehives owned by families were few with ownership correlated to families who had many children, fewer livestock and poor maize harvests. Time and money made from farm work dropped over the two year project which appeared to be related to the drought conditions during the study period. After the two year study, beekeeping was listed higher on the list for both income generation and time spent, with effort spent scaring away elephants decreasing. There was also a significant shift in opinion from the farmers to a more positive position after the trials that beehive fences are a successful deterrent for crop-raiding elephants. Both before and after the beehive fence trials charcoal making was the dominant income generator and a considerable amount of time was spent on this destructive, but income generating, activity. I consider the theoretical potential of replacing charcoal making with beekeeping activities and demonstrate that a farmer needs approximately 43 beehives to replace the mean income generated by charcoal. Although this questionnaire survey was specific to a rural Turkana community, I conclude that the results are important enough to allow some level of generalization about how other farming communities might respond to the introduction of beehive fences as elephant crop-raiding deterrents.

7.1. Introduction

The introduction of the conceptual model and theoretical framework in Chapter 6 helped to define four broad research questions relevant to understanding how a rural Turkana community responded to a new deterrent technology, the beehive fences. Here in Chapter 7, I concentrate on the third and fourth questions identified by our rapid rural appraisal research structure: *How will the community respond to the new beehive fence technology?* and *Does the beehive fence affect income and livelihood prospects?* Social research data presented here are gathered from both a detailed questionnaire survey and from discussions and observations during the two year trial. Although this chapter focuses entirely on the relevance to the socio-economic conditions of Turkana farmers, the wider implications for the potential adoption of the beehive fence technology to other communities are discussed in depth in the final chapter of this thesis.

The two Ngare Mara sub-villages of Chumviyere and Etorro could be regarded as typical representatives of emerging settlements and communities that have developed all over Kenya within the last 40 years, and within traditionally wildlife-dominated areas. During the 1970's to 1990's the ivory 'war' that caused such a precipitous decline in Kenya's elephant numbers (refer back to Chapter 1) enabled farming activities to commence in areas that would previously have been so dominated by elephants that growing crops would have been impossible. Elephant populations in the entire 21,096km² Samburu District fell so low that a 1987 survey estimated that only 372 elephants were left (Douglas-Hamilton, 1989). At a density of just 0.018 elephants per km², it was into this temporary elephant 'void' that the Turkana immigrants of Ngare Mara began to settle and farm on the southern boundary of Samburu District from 1978 onwards.

Traditionally nomadic pastoralists, the Turkana are neither natural famers nor beekeepers. The conversion from such traditional nomadic lives to the more sedentary farming community witnessed today in Ngare Mara may be caused by the competition for land squeezed between hostile neighbours and modernisation caused by the attraction of permanent access to schools and healthcare. Although the men still take their herds of cattle away in search of grazing during times of drought, the women no longer migrate and remain settled in permanent huts while their children attend primary school. I observed that the women in both Chumviyere and Etorro were well respected,

very active and were treated as equals in many aspects of community life. Attendance of women at community meetings was always equal to, if not exceeding, the number of men and their inclusion and contributions to committees were expected and evident in all our meetings.

During the period of my research, the women were involved fully in charcoal making and farm work including the hard labour of digging, planting and harvesting as well as looking after the house and cooking. In general I found most adult women in the community had little formal education with limited KiSwahili and almost no English, but the younger women and girl children were conversant in KiSwahili and all children of both genders were attending school and starting to learn English. Day to day, most adult women wore thick bands of colourful beaded necklaces and their attire consisted of bright kanga (cloth) wrap-arounds, which were used for everything from dust protectors to carrying babies and maize (Figure 7.1a). At more formal events the women donned extra necklaces and wore finely beaten, brown leather dresses with adorned leather belts. Their hair was thickly braided and matted with red coloured mud which was shown off in dancing ceremonies by shaking the head piece towards the men (Figure 7.1b).

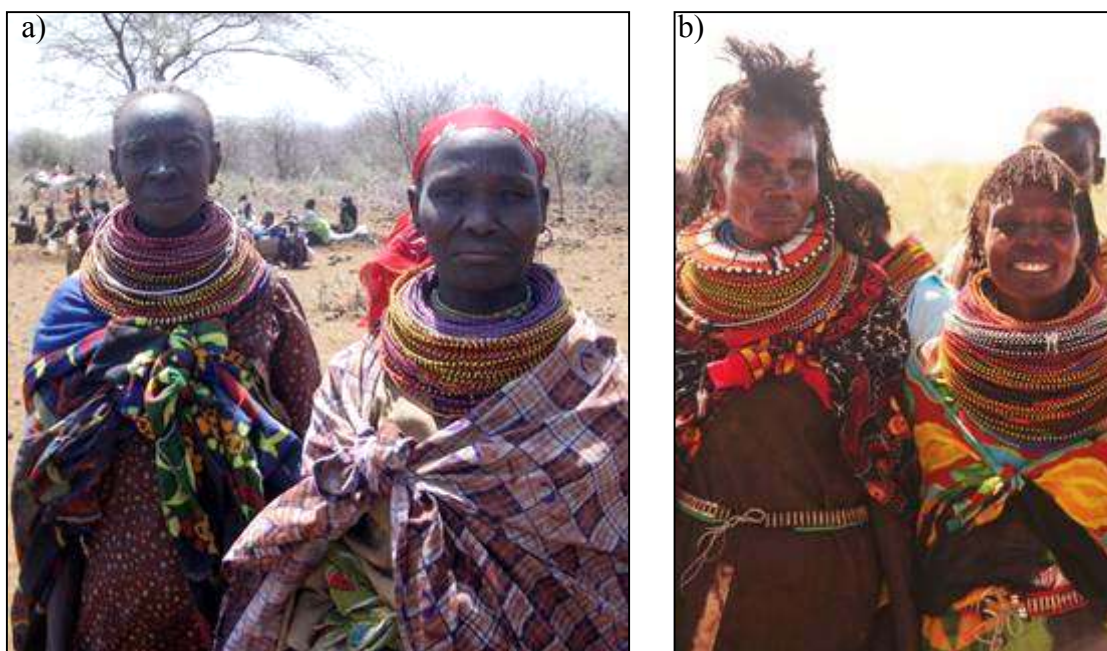


Figure 7.1. Women from the greater Ngare Mara community were dressed in colourful cloths and beads on a daily basis (a) but for special occasions (b) they would don fine leather dresses and cake their braided hair in red mud.

The men are loosely categorised into different age sets with the elders of the community being the most revered category and the age set from which the chiefs and chairmen of the area were selected (Figure 7.2). The Turkana do not circumcise either their men or women, a practice in women associated with higher sterility rates in other African populations (Rushwan, 1984). Men rich enough married more than one wife, and I was aware of one occasion where a man from Etorro seeking a new wife to wed travelled back to his ancestral home in Turkana District to select a woman from a geographically distant family. These strong connections to the ancestral home appeared to contribute to the growth of the community over the years and helped to retain their fascinating Turkana culture.



Figure 7.2. Three elders from the two communities including the chairman of Chumviyere (far right) and the chairman of Etorro (center). As with the women, discussions with elders were always extremely enjoyable and interesting and they made us feel very welcomed into the community during every visit.

The members of both Chumviyere and Etorro sub-villages live in homesteads or ‘manyattas’ which comprise of anywhere between 3-8 huts in a small compound (Figure 7.3). Typically the homesteads would be comprised of family groups with different adult family members building and occupying a hut with their children until they became old enough to build and live in their own. It was common to witness the extended family congregate around a homestead on a daily basis to share meals. In traditional Turkana society food sharing is common and is thought to not only strengthen social ties but also is a practical response to living in an unpredictable environment where each giving family knows that one day they might be on the asking end (Johnson, 1999). During our preliminary visits we observed that beekeeping was already present in the community at a very low level with just a handful of families owning beehives. Generally these were hung in the branches of trees near the home.

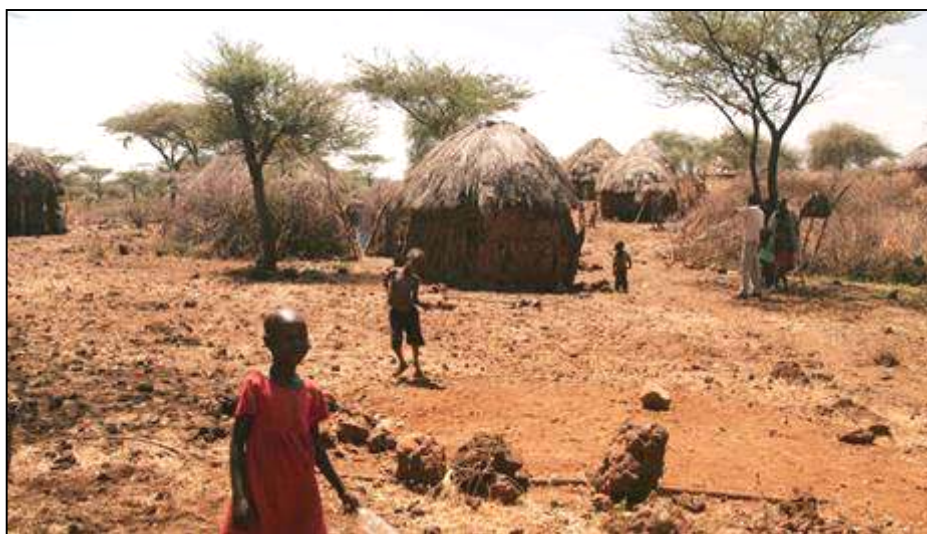


Figure 7.3. A typical community homestead comprised of several mud-walled huts with thatched roofs. No electricity or running water was present. Small thorn bomas kept livestock safe at night. Maize and bean bags were usually kept inside a hut at night for safety against theft and elephants.

In Chumviyere and Etorro the practice of communal farming works well within this traditionally supportive social network. Although each plot of land was allocated to one family, the role of deterring wild animals from the entire farming area was delegated to the young men of the community and families often helped each other at planting and harvest times. As the beehive fences were designed to protect stretches of communal farms, rather than to surround each farm independently, it was important to understand how a communally-run beehive fence system might influence socio-economic indicators within the community. This knowledge should help to anticipate how other farming communities in Kenya may respond to the new technology.

Understanding socio-economic conditions within a rural tribal community is complex and can take years, if not decades, to fully understand. With a limited time frame I chose to use a questionnaire as the quickest method to gather social information about the community by simply asking them directly about aspects of their life. Questionnaires are common methods for identifying socio-economic indicators but they have many limitations and careful planning is needed to ensure honest information is gathered. Key to their limitations are (i) the questions can often be leading, i.e. suggestive of the answer that the researcher is looking for; (ii) they can be too long and

result in boredom or resentment by the participant; (iii) the formal question setting may inhibit the expression of ideas or comments outside the strict question framework and (iv) they can be too intrusive and demanding of information which is regarded as personal or private. Aware of these pit falls in questionnaire practice, I made much effort to prepare a short, inoffensive questionnaire with both closed and open questions using our study team's fluent Turkana language speaker, Wilson, who was trained to enable the best exchange of information as possible. I used interviewing techniques described in Schoonmaker Freudenberger's (1999) manual as guiding principles to help train Wilson with his interviewing skills.

The aim of my questionnaire was to try to identify indicators within the community that would reveal information to me about (i) farming practices and harvests (ii) market information and wealth indicators (iii) the perception and attitudes towards elephants and (iv) attitudes towards beekeeping and the beehive fence. I repeated the questionnaire after two years to compare responses and attitudes before and after the beehive fence trial activities. This chapter predominately focuses on the results of these successful questionnaire surveys but takes into account my additional observations working with the farmers and villagers from 85 visits I made to the community over two years. During these visits I learnt a great deal about the culture and social activities in the community and I believe these experiences, combined with the results of the questionnaire survey, have resulted in a comprehensive understanding of how the beehive fence technology fared in this farming community.

7.2. Method

I prepared a three-page questionnaire containing 34 questions with every effort made to not ‘lead’ any answers by the style of question (see Appendix). In November 2008, after completing the beehive fence construction but before the crop-raiding season began, we randomly targeted 50% of our study farms in an attempt to gather a representative view of the community as a whole. Out of the 34 monitored farms we completed questionnaire surveys with 16 of the farmers (47% of the participant farmers). The farmers were mostly male (n=13) but three female farmers were represented in the sample. Age of respondents ranged from mid-twenties to 60+ (Figure 7.4).

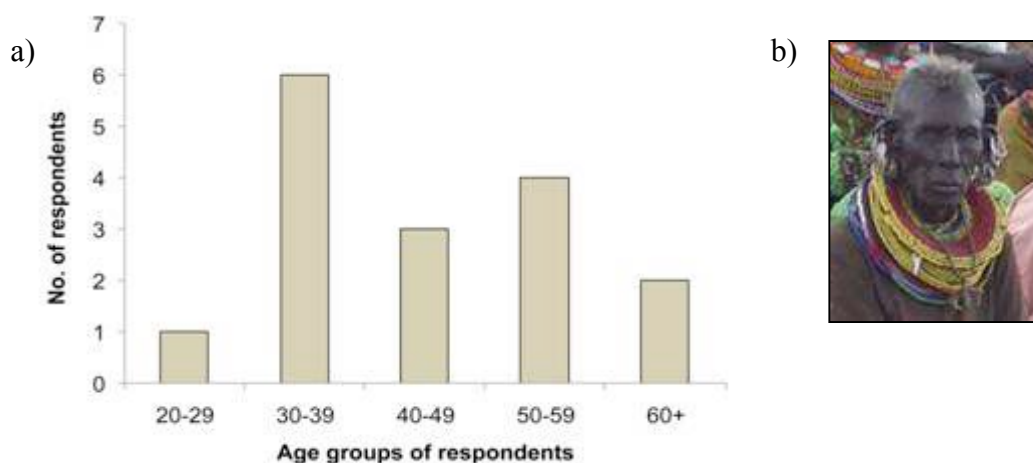


Figure 7.4. (a) Age groups of questionnaire respondents show a representation of all age groups in the community. (b) At over 70 Mama Ichor from Chumviyere was the oldest participant in the questionnaire survey.

17 questions were centred on farming activities in an attempt to understand what wild animals caused problems to farmers, how that affected their attitudes and lifestyle and more specifically what attitudes they had towards elephants. Five questions focused on market forces including the amount of charcoal a family sold and the number of livestock they owned. Questions 23 and 24 were interactive, with farmers being given a set of 11 activity cards and asked to place them on the ground in order of time spent conducting each activity and secondly, the order of income generation for any of those activities. Each card had its activity printed in English but with a descriptive photo next to the word to aid those participants who only spoke Turkana. Each card was laminated and re-used for each farmer (Figure 7.5). The remaining 9 questions were on beekeeping activities and also the attitudes of the farmers towards the proposed beehive fence project.

The majority of farmers did not speak English, a few spoke rudimentary Kiswahili but for all, their indigenous language was Turkana. My assistant Wilson Lelukumani conducted all interviews in the Turkana language. Wilson was trained as a translator by first practicing the questionnaire in English with an English speaking farmer allowing me to train his questioning techniques. As he was the only Turkana-speaking member of our team we were unable to find a second translator to accompany Wilson. We decided not to include another member from the community during each interview due to the sensitivity of some of the questions. For example, in Turkana society it is not proper to list the exact number of livestock one has so the presence of another farming family during the interview may have biased the answers due to cultural constraints (Kahindi, pers. comm.). Although Wilson was Turkana, he was from a different community two hours walk from Chumviyere and Etorro and, as head of his own family, was well regarded amongst the community.

After two years we repeated the same task with a slightly shorter questionnaire but with the core socio-economic questions asked again to see if any changes or differences in attitudes could be detected after running the beehive fence project.

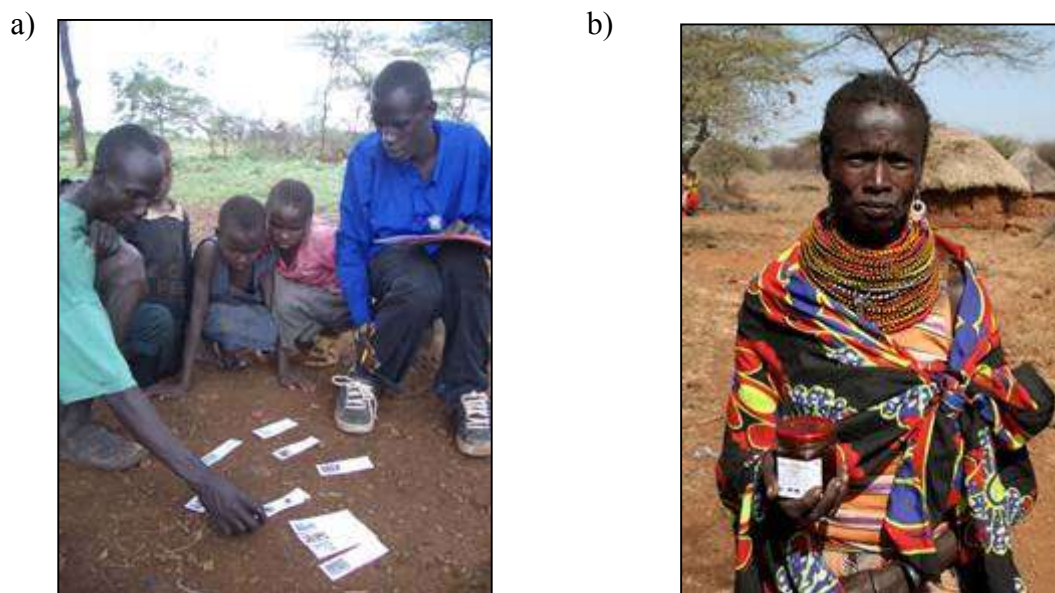


Figure 7.5. (a) Wilson (blue shirt) conducting an interview with farmer Lobenyo (green t-shirt). Here Lobenyo is placing the activity cards in order of ranking for most time spent on each activity. Lobenyo was the farmer in the community with the most beehives, ten in total, before the project began and he listed beekeeping third on his income ranking task. (b) Angelina was one of the female farmers interviewed and as she spoke no English and limited Swahili Wilson's translation was key in enabling her to become a questionnaire respondent.

7.3. Results (Refer to Appendix for raw questionnaire data)

7.3.1. Problem Animals for Farmers in 2008

The questionnaires revealed that there was an absolute consensus (100%) that elephants were perceived as the worst problem animal linked to crop-damage. Baboons were regarded as the second worst animal for crop-damage with porcupines listed as third worst (Figure 7.6). Baboons were described by the participants as “very difficult to get out” once a troop had occupied a crop field as they become “very bold” in response to stone throwing. Alternatively, porcupines caused much damage without necessarily being seen by the farmers due to their more solitary and subterfuge tactics of invading farms at night and eating maize and beans near the ground, very hard for a farmer to see or remove in the dark. Squirrels, birds and waterbuck were also mentioned as problem animals. It was not possible to verify these perceptions within the scope of our project.

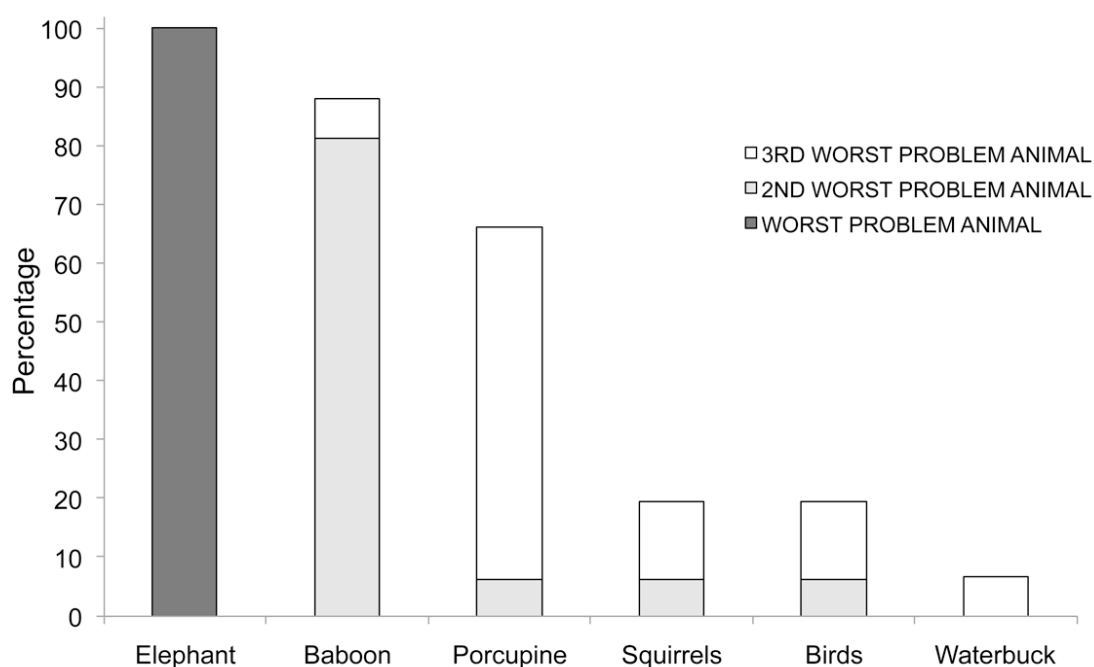


Figure 7.6. Elephants were unanimously declared the worst problem animals for crop-damage by farmers in Ngare Mara with the majority of farmers declaring baboons as the second most damaging wild animal. Other problem animals were porcupine, squirrels, birds and waterbuck.

7.3.2. Time Index in 2008

Farm work was regarded as the overall greatest time consuming activity for farmers in Ngare Mara. However, 56% of farmers regarded making charcoal as their first most time consuming activity compared to farm work (37.5%). Collecting firewood and water was also listed as time consuming and highlighted the lack of basic services available in this rural community. Scaring wildlife was listed as the fifth most time consuming activity which was much higher than the time regarded for scaring away elephants which was far down the list of activities and listed only as the eighth most time consuming activity. Beekeeping activities were listed as seventh although four of the six participants who listed beekeeping as their fifth most time consuming activity did not own any beehives perhaps indicating this listing had been confused with the recent activity around the setting up of this beehive fence project. Very little time was spent doing paid work and much time was spent at community meetings (Figure 7.7).

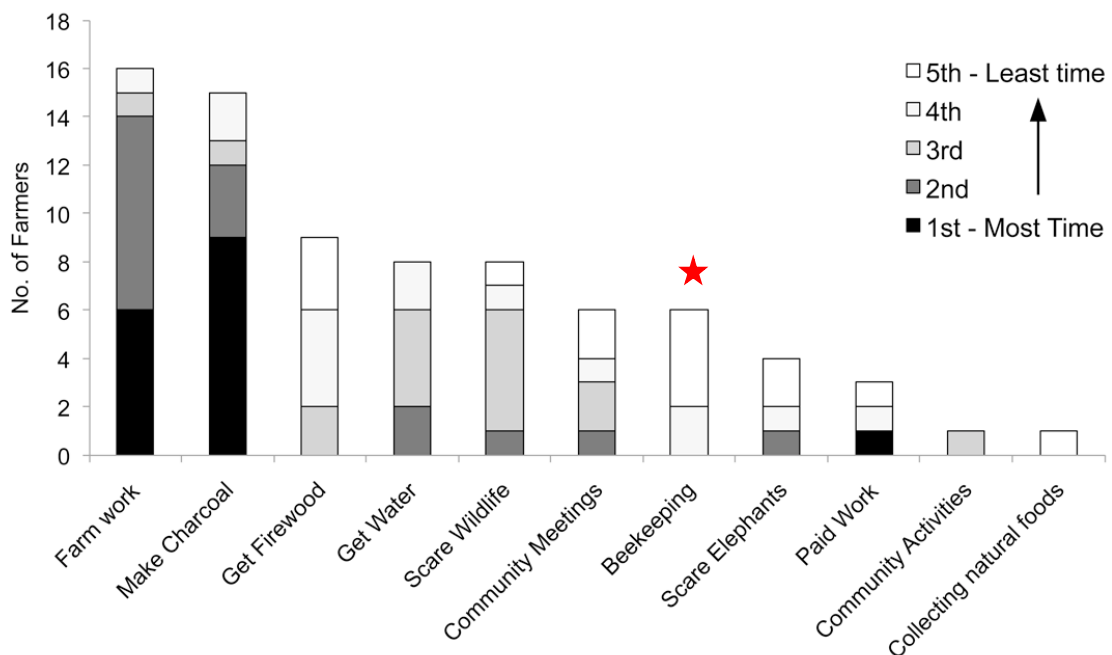


Figure 7.7. Time index for the 16 farmer respondents in Ngare Mara highlighting the first five most time consuming activities for each respondent and giving an indication of time spent on activities by the community as a whole. Beekeeping was listed as seventh most time consuming activity with scaring elephants listed eighth with only four farmers listing it in their top five most time consuming activities.

7.3.3. Income Index in 2008

Charcoal making was unanimously highlighted as the most successful income generating activity in the community. Just one participant, the head teacher of the school, listed ‘paid work’ as the activity that generated the most income for him. Farming was largely considered the second most successful income earner with paid work and beekeeping activities listed as third and fourth most successful income earner (Figure 7.8). Two farmers who did not own beehives continued to list beekeeping as a major income earner which is an anomaly not fully understood. Perhaps they were simply aware that beekeeping *is* a good income earner in general rather than specific to their family accounts. Five beekeepers listed the activity as either second or third on their list of income generating activities even though this had not been highlighted previously as a major time demand. This suggests that beekeeping is a good income earner that requires little time.

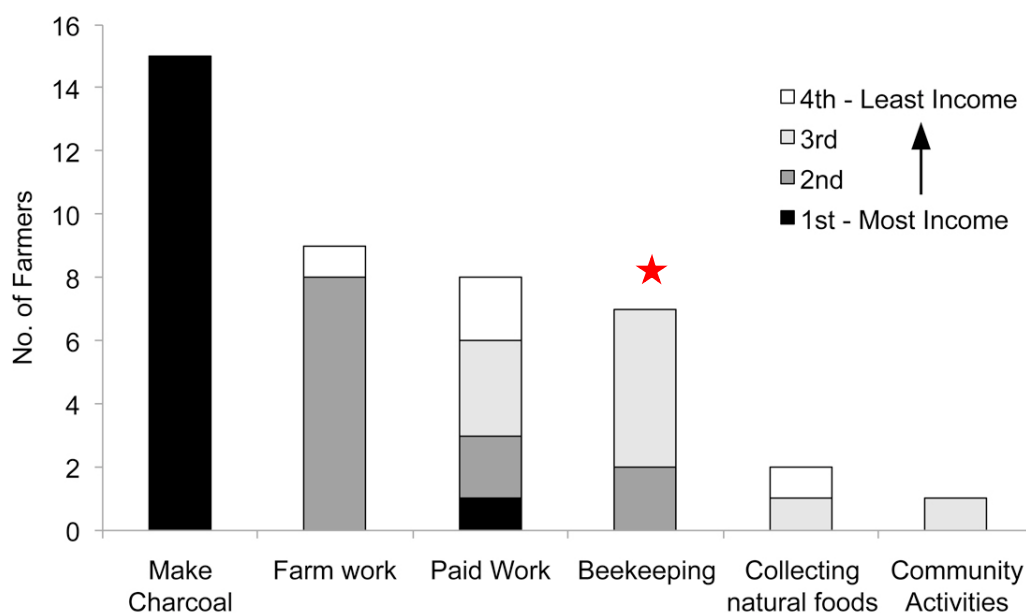


Figure 7.8. Income index for farmers in Ngare Mara was generated by asking farmers to list which activities generated the most income relative to each other rather than in absolute monetary values. This activity revealed that charcoal was the most successful activity in bringing in cash to the household. Despite being only seventh on the time demands index, beekeeping was listed as the fourth most successful income generator in the community.

7.3.4. Effects of Crop-Raiding on Sleep and Income Potential

The farmers were asked to state what time of the day or night elephants crop-raided. By combining their answers we found that, generally, the farmers experienced two peaks of crop-raiding activity between 8pm and midnight and 3am and 6am (Figure 7.9). No crop-raids occurred during the day.

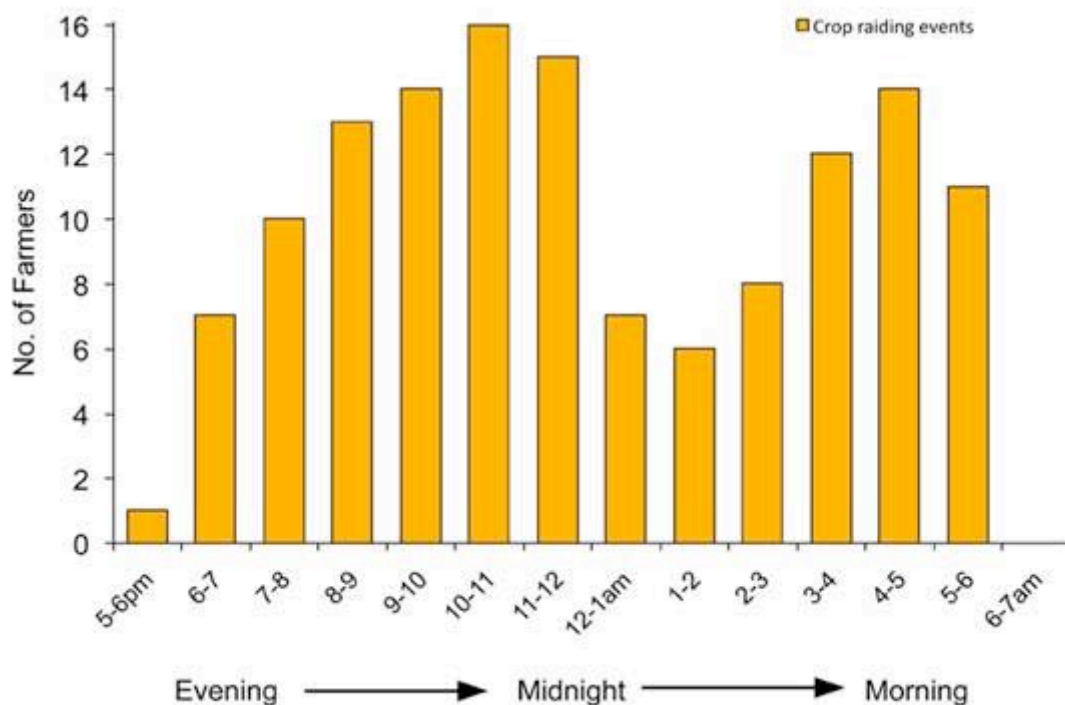


Figure 7.9. Histogram illustrating the hours reported by farmers to be the main crop-raiding times of the night by elephants. Crop-raiding started after 5pm and continued until 6am with no reports of crop-raiding during the day. Two peaks just before midnight and before dawn were noticeable.

Vigilance by farmers during the crop-growing season was very high. No farmers were vigilant for less than 4 hours every night and 44% of participants divulging that they spent between 10 and 12 hours every night down at their fields keeping guard for elephants and other wild animals (Figure 7.10a). This night time activity had a dramatic impact on their lives as each farmer reported that they had to sleep during the day for an average of 3.7 hours. Some recorded sleeping for as long as 6-7 hours (Figure 7.10b).

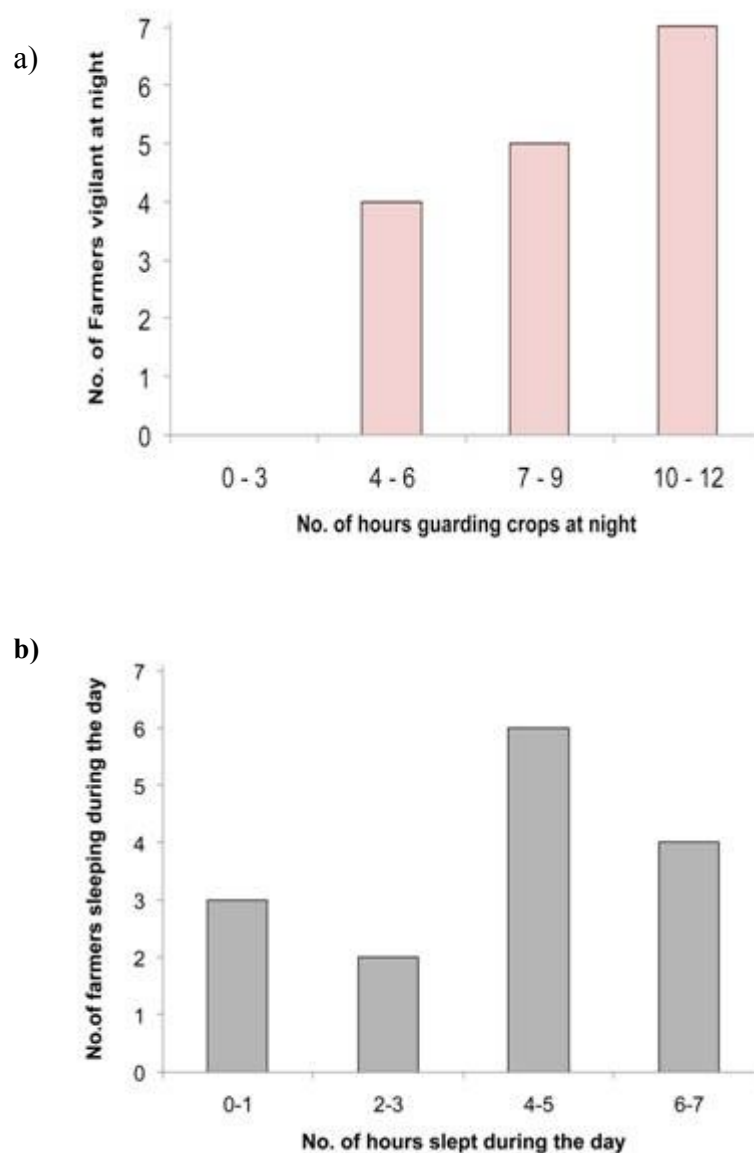


Figure 7.10. Crop-raiding by elephants and other nocturnal wildlife meant that (a) farmers were vigilant for long hours in their fields at night with 75% of farmers reporting that they spent between 7 and 12 hours guarding their fields; (b) The farmers were forced to sleep for long hours during the working day to compensate for their nocturnal efforts. The majority of farmers slept for 4-5 hours every day during the crop-raiding season.

This ability to sleep during the day was, however, correlated to the number of adult members in the household. In households with more adult members, farmers were able to sleep longer during the day, perhaps as other household chores could be carried out by other adults (Figure 7.11).

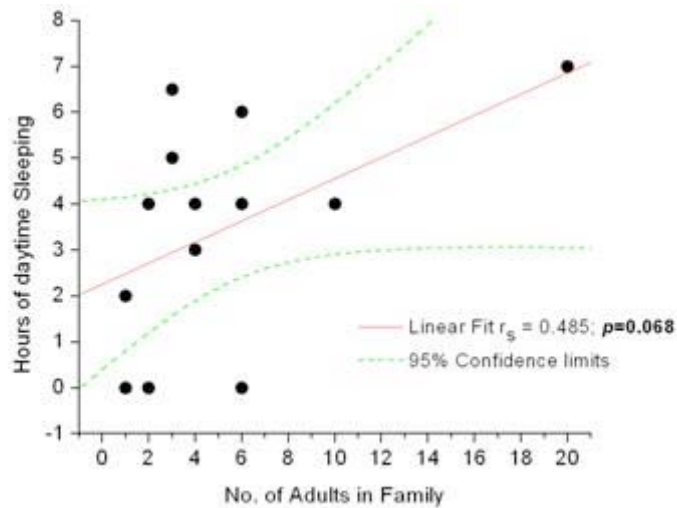


Figure 7.11. We found a positive correlation ($r_s = 0.485$, $p = 0.068$) between the number of daytime hours slept and the number of adult members in the family. Those with fewer adult helpers could not afford to sleep for long during the day due to demands of other household chores. Long vigilance during the night might therefore severely impact the daily productivity of small households.

Number of hours slept during the day was also correlated to the income generated from charcoal sales. Those farmers who slept most during the day collected less money from their efforts to sell charcoal (Regression analysis for charcoal sales vs sleep: estimate -1148, se 541, $t(13) -2.21$, $p = 0.054$). However, the result was biased by an outlier as Farmer 6 claimed to make 21,600/- per month from charcoal which was 4 times the second highest earner in the community and could have been an error in translation. When this outlier was removed there was no significant trend between sleep and charcoal income but the results suggest that more information is needed before we can rule out daytime sleep as an income suppressor (Figure 7.12).

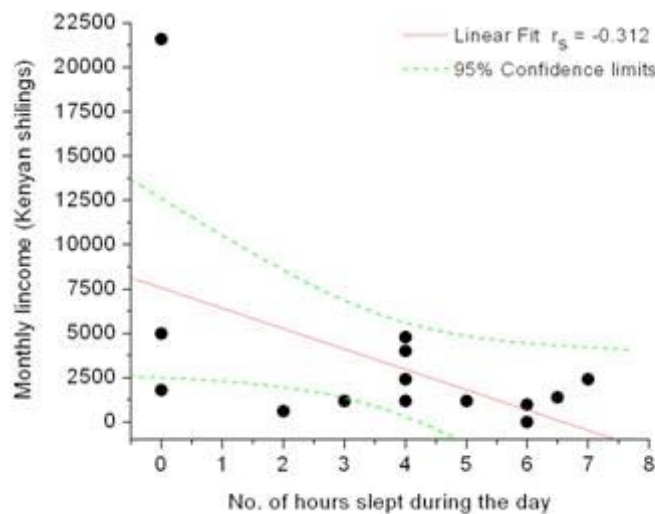
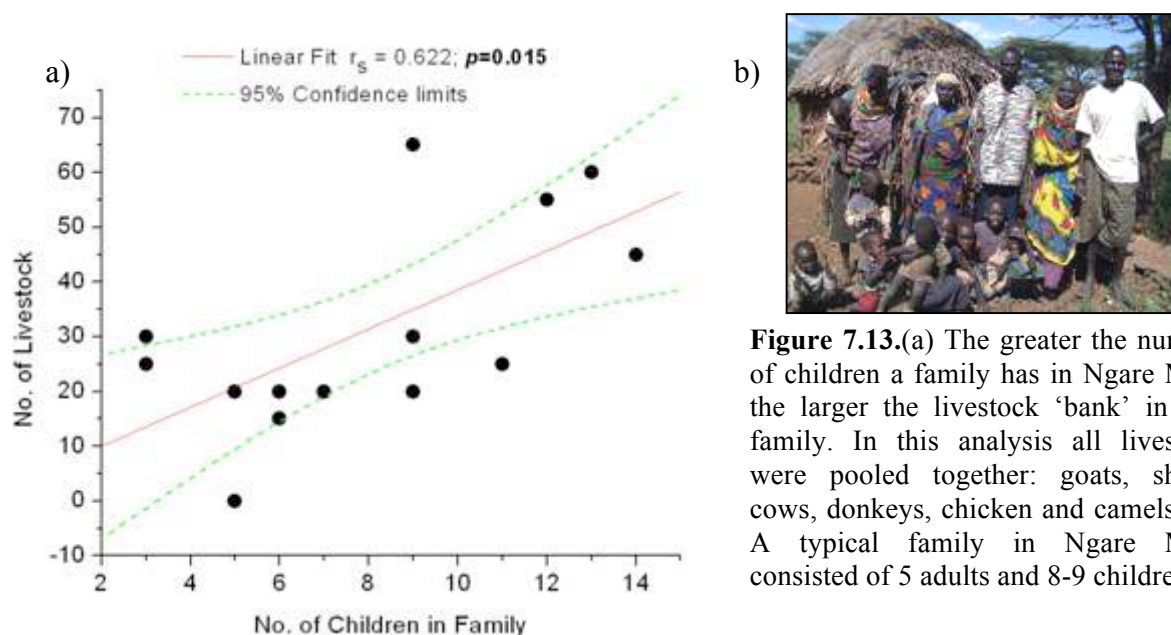


Figure 7.12. The more a farmer slept during the day in response to night time vigilance for crop-raids the less income he earned from charcoal sales.

7.3.5. Social Conditions as an Indicator of Economic Activities

The questionnaires revealed that families in Ngare Mara regularly had large numbers of children with the average from 15 respondents being 8.27 per household (\pm STDev 3.6). Although he owned a farm, the headmaster did not have his children staying with him in the community. This is comparable to a survey of 33 nomadic Turkana families by Leslie *et al.*, (1999) who found within their sample that 60.5% of men had one or two wives and the average number of children in those households was 7.9 and 7.5 respectively. Children in rural Turkana society are much valued and they help with looking after the livestock and the farm. When Campbell *et al.*, (1999) asked the question ‘how many children do you want’ to 129 Turkana women the ‘universal response’ was “*As many as possible*” or “*As many as Akuj [god] allows*”.

If the number of children in a household is not limited (either by social/cultural choice or by a lack of appropriate family planning) then other socio-economic parameters of village life are more likely to be response variates in reaction to the household size. Indeed, here we found that the number of livestock a family owned was significantly correlated to the number of children in a family (Spearman’s Rank, $r_s = 0.622$, $t = 2.81$, d.f.13, $p = 0.015$; Figure 7.13). More children herding and protecting livestock might result in less livestock predation and better fecundity due to better vigilance. Its also possible that adults are more incentivised to build up their livestock ‘bank’ if they want to have more children and to help pay for future schooling, marriages or health costs.



b)

Figure 7.13.(a) The greater the number of children a family has in Ngare Mara the larger the livestock ‘bank’ in that family. In this analysis all livestock were pooled together: goats, sheep, cows, donkeys, chicken and camels. (b) A typical family in Ngare Mara consisted of 5 adults and 8-9 children.

7.3.6. Beehives as a Response Variate to Social Conditions

Having identified that livestock numbers held by Ngare Mara families were positively correlated to the number of children, we explored the hypothesis that the number of beehives might also be a response variate to different social conditions of each family. We ran a Generalized Linear Model analysis fitting four social parameters as a possible explanatory model for the number of beehives a family had (before the beehive fence trials began) and the results were positive.

Livestock numbers ($p = 0.006$), maize harvest ($p = 0.008$) and number of children ($p = 0.029$) were significantly correlated to the number of beehives when modelled together suggesting that no single social context alone was responsible for the number of beehives. We discovered that the trio of social conditions leading to a significant increase in beehives in a family were (i) a large number of children, (ii) a smaller number of livestock and (iii) a smaller harvest of maize. The number of day time hours slept by the head farmer from each family was not correlated to the number of beehives ($p = 0.212$) suggesting that time limitations are not part of the decision on whether or not a family chooses to start beekeeping (Table 7.1).

Parameter	Estimate	s.e.	T(9)	P
Number of Beehives				
Constant	5.95	2.04	2.92	0.017
No. of Livestock	-0.2023	0.057	-3.55	0.006*
Maize bags	-0.518	0.154	-3.36	0.008*
No. of Children	0.628	0.242	2.59	0.029*
Day time sleeping	0.388	0.289	1.34	0.212

Table 7.1. Results from Generalized Linear Model explaining some of the variation in the number of beehives a family owns in Ngare Mara. Number of livestock and number of maize bags from a harvest are negatively correlated to the number of beehives where as number of children in a family is positively correlated to the number of beehives.

Hence, in Chumviyere and Etorro sub-villages, beehives are treated as an additional (or possibly alternative) income source to supplement livelihoods when a large family has a small livestock ‘bank’ and an underproductive farm. Honey was also used as (i) medicine for chest pains, (ii) for ceremonies, (iii) to make alcohol, and (iv) presented to old people for respect or blessings e.g. it was regarded as an appropriate present for a mother in law.

7.3.7. Post-Trial Analysis of Socio-Economics of Community in 2010

After two years of working in the community and monitoring the beehive fences (refer back to Chapter 6), we re-visited the same 16 farmers in June 2010 and assessed any change in their livelihood status by asking them key questions from the questionnaire again. Within the two years of the study period there had only been enough rain for one semi-successful harvest season (50% of the farmers harvested in our study fields) and we wanted to see if these drought conditions had had an impact on their social and economic conditions including any change in the status of beekeeping.

We found that there was no significant difference in the farmers' total number of livestock, number of beehives or the number of charcoal bags produced per month (Wilcoxon matched pairs tests $p > 0.05$). However, a more detailed look revealed that the total number of cows amongst the 16 farmers had dropped from 142 in 2008 to just 76 in 2010. Cows were regarded as the most valuable livestock and the loss was attributed to the severe drought and loss of grazing rather than sales. We observed a small drop in number in goats (190 in 2008 to 180 in 2010) but a small increase of chickens, sheep and donkeys amongst the farmers (a total 228 in 2008 compared to 251 in 2010) perhaps as cheaper replacements than cows. Another indicator that times were tough over the study was that in the year 2008 the 16 farmers estimated that they had sold a total of 45 goats or sheep over the previous year for income generation whereas in 2010 this number rose to 80. The farmers appeared to be dipping into their "bank" of livestock during the tough times by selling them for cash when their harvests failed.

Additionally we saw a reduction in the total number of bags of maize produced amongst the 16 farmers from 80.5 bags in 2008 to just 49.5 bags in 2010. Taking into account the model described in Table 7.1 we could predict that from this double hit of a reduction in cows and goats and a reduction in maize bags we might see a corresponding increase in the adoption of beehives amongst the farmers. In fact we saw no increase in the number of beehives belonging to each of the 16 farmers (mean $2.44 \pm$ SE 0.77 in 2008 compared to a mean of $2.31 \pm$ SE 1.079 in 2010, not significant $t = 36$, $n = 12$, $p = 0.732$). It is possible that the farmers had not had enough time to adapt to their depressed conditions by making or investing in more beehives but it is more likely

that the introduction of the beehive fences and 170 more beehives by myself suppressed any need to invest in additional personal beehives as the model predicted (Figure 7.14).

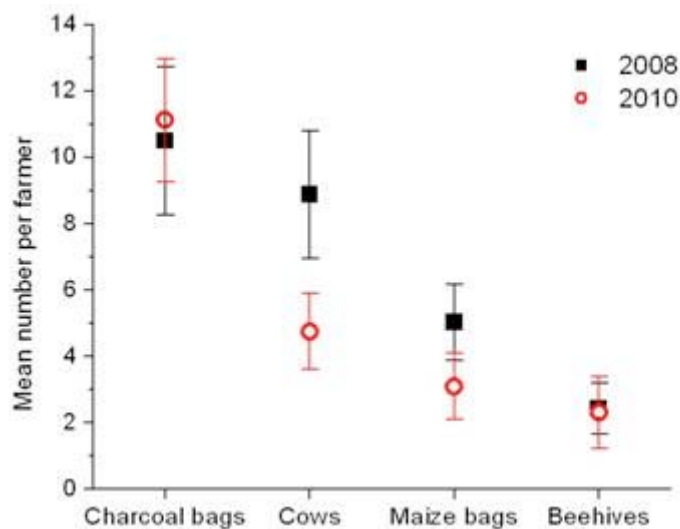


Figure 7.14. Comparing four socio-economic indicators between 2008 and 2010 showed that both the mean (\pm SE) number of cows and bags of maize decreased between the two years but the number of bags of charcoal produced monthly and the number of beehives owned by the farmers remained almost constant.

We saw a remarkable change in our time index between 2008 and 2010 (Figure 7.15). Although farm work was still first on the accumulated time index list, it had fallen from being the first or second most time consuming activity for 87.5% of farmers in 2008 to just 37.5% of farmers in 2010. Charcoal making remained second on the accumulated index but continued to be the most time consuming activity for 12 of our farmers. Beekeeping had leapt from the seventh most time consuming in 2008 activity to third behind charcoal making with 37.5% of farmers listing it second or third on their index. This can almost certainly be attributed to activity around the beehive fence project rather than any increase in personal beekeeping productivity. Scaring elephants remained very low on the list of time consuming activities and indeed had dropped from four farmers listing it as second, fourth, and fifth in 2008 to just three farmers listing it as third and fifth in 2010. It is possible that this drop in the time index could be related to success of the beehive fence but the reduction in planting success could also account for the result. The reduction could also be a more honest representation of how much effort is really spent in chasing elephants despite the perception that they are the “worst problem animal”. Considering that 75% of farmers in 2008 claimed that they spent between 7 and 12 hours every night protecting their fields from crop-raiding elephants

this time index might be a more realistic representation of how much effort is really spent scaring away elephants (Figure 7.15).

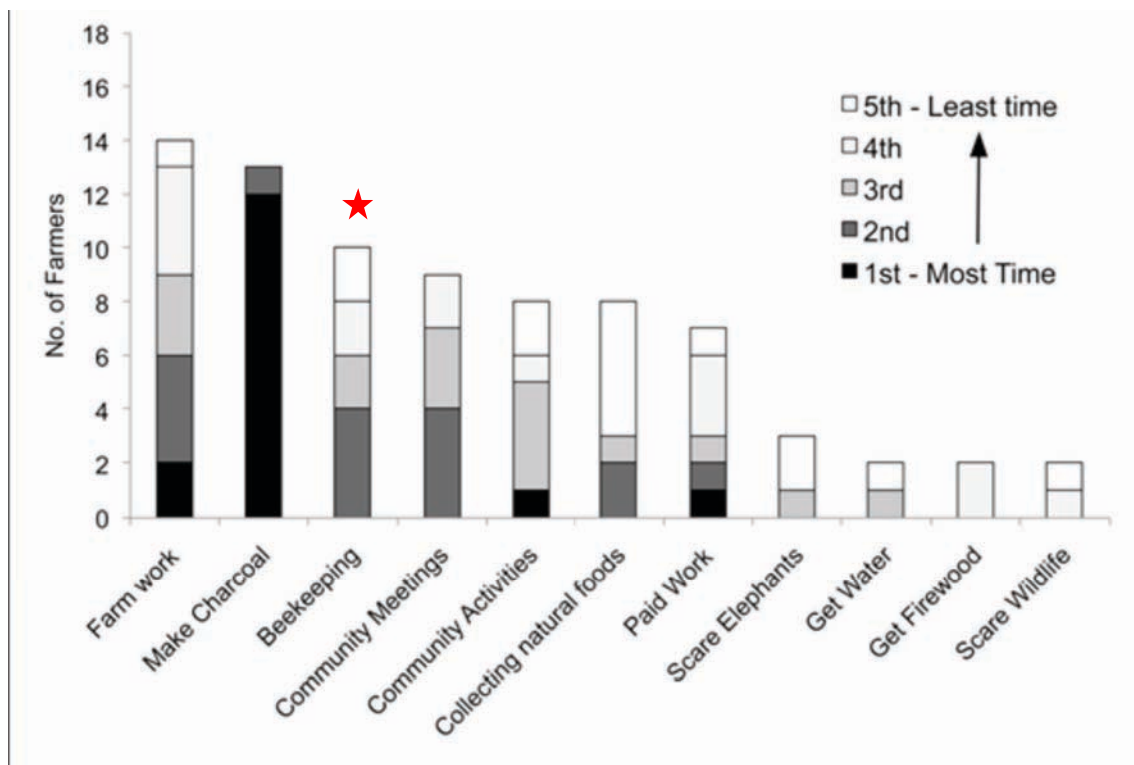


Figure 7.15. Time Index in 2010 showing how beekeeping had moved up 4 places since 2008, a feature almost certainly attributed to activity around the beehive fence project. Water collection fell by 5 places and was no doubt attributed to the improvement of the water pump and windmill system in the community by another NGO during the two year study. More farmers had also resorted to collecting natural foods during the poor harvest years to supplement meals.

Although we saw no increase in the number of beehives owned by each of the farmers we did see a change in their income index over the two years which may be a response to the harsh drought conditions over the study period and the fact that the key livestock “bank” of cows were reduced by almost half. Making charcoal remained as the top earner for the farmers but paid work and collecting natural foods leaped above farm work as greater income earners. This clearly represents the poor farming years the community had had. Interestingly, beekeeping was listed as an equal income generator next to farm work in 2010. As the number of beehives owned personally by each of the 16 farmers had not increased this elevated status of beekeeping can only be attributed to the introduction of the beehive fences from the project. Nine farmers listed beekeeping in their top four income generating activities compared to seven in 2008 (a 12.5% increase, see Figure 7.16).

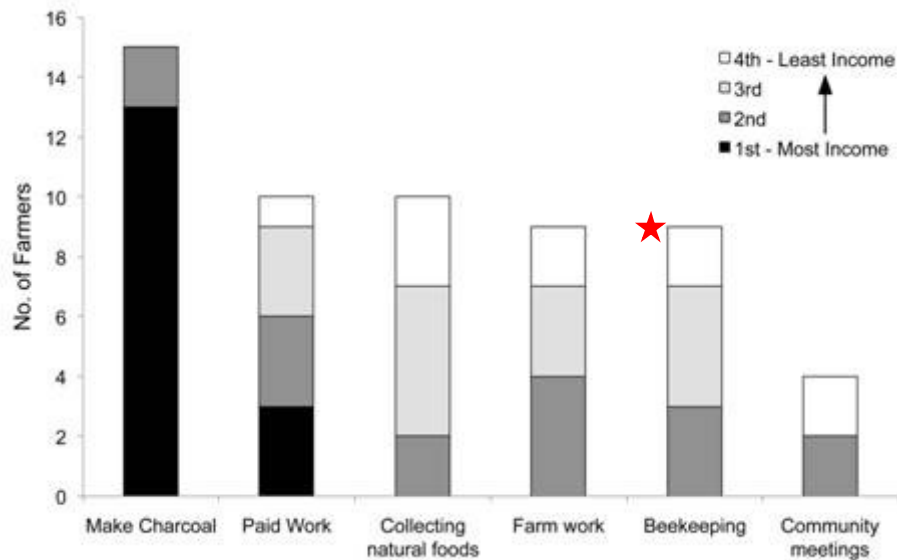


Figure 7.16. Income index taken after the trial in 2010 revealed that the two harsh drought years in the community had changed the sources of income somewhat. Charcoal remained the highest earner but farm work fell to fourth place and to an equal status as beekeeping. 62.5% of farmers were relying on collecting natural foods for sale compared to 12.5% in 2008.

Although the number of bags of charcoal did not increase significantly between 2008 and 2010 there was a significant and substantial increase in the amount of mean monthly income from charcoal sales from a mean of $3,175 \pm \text{SE } 1,282$ shillings to $5,562.5 \pm \text{SE } 927$ shillings per farmer (Wilcoxon matched pairs, $t=16$, $n=15$, $p=0.01$). This reflected the increase in mean price recorded per bag of charcoal which increased from 306.25 shillings (\$4) in 2008 to 468.75 shillings (\$6.25) in 2010 (Figure 7.17).

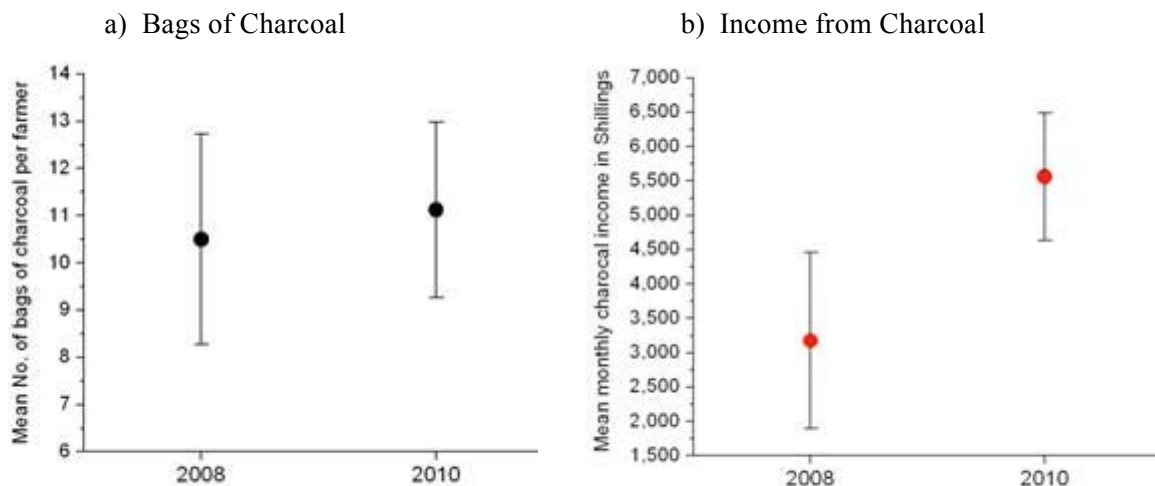


Figure 7.17 (a) Mean monthly bags of charcoal (\pm SE) produced per farmer did not significantly increase over the years but the amount of income per bag (b) did increase which significantly increased ($p=0.01$) the monthly charcoal generated income to the farmers between 2008 and 2010. (US\$ 1:75 Kenyan Shillings). This apparent income increase may also be due partly, or entirely, to high prevailing inflation rates within Kenya over the study period.

7.3.8. Opinions of Beehive Fence as an Effective Elephant Deterrent

Before the trials began we asked the farmers *two simple opinion questions*. (i) *Do you think bees can keep elephants away from crops?* and (ii) *How successful do you think the beehive fences will be at deterring elephants?* Although the trials had not begun (i.e. no crops had yet been planted) the questions were asked after the beehive fences had been built and the design explained clearly. The results (Table 7.2) revealed that in 2008 15 farmers were unsure if bees could keep elephants away, answering ‘maybe’ to question (i) with only one farmer thinking that bees could work. When the exact same question was asked in June 2010 100% of the farmers unanimously had the opinion that bees can keep elephants away from crops. Additionally, in 2008 81% of farmers were honest in sharing their opinion that the beehive fence would not be successful scoring 4 and 5 on their opinion charts. In 2010 we saw a dramatic change in opinion with 100% of farmers scoring 1 on their questionnaire stating that the beehive fences had been ‘very successful’ at deterring elephants (Figure 7.18).

<i>Do you think bees can keep elephants away from crops?</i>	2008	2010
Yes	1	16
Maybe	15	0
No	0	0

Table 7.2. Results from the questionnaire revealed a significant change in opinion from the majority of farmers unsure about whether bees could deter elephants in 2008 to complete consensus of opinion by 2010 that bees can deter elephants.

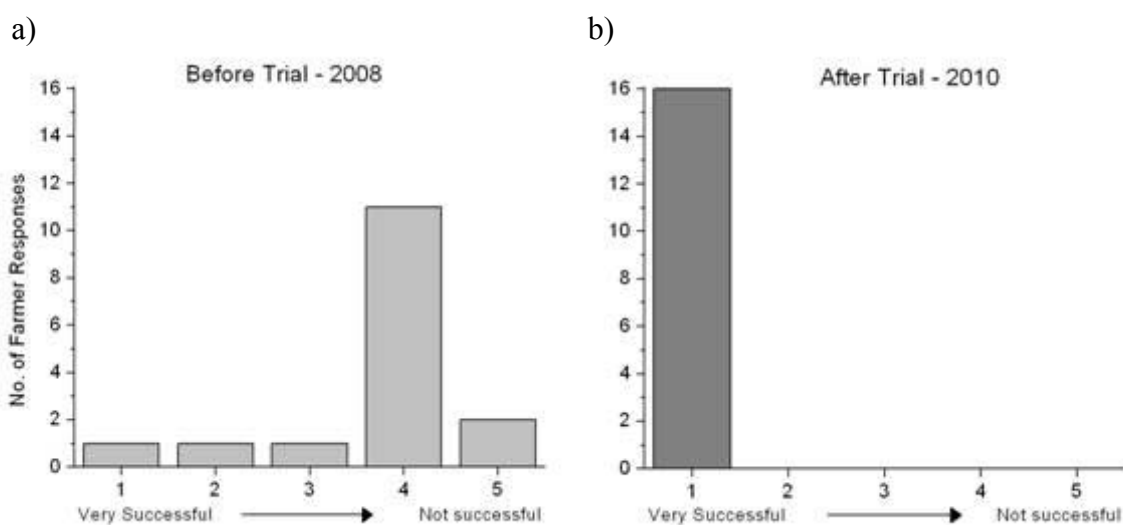


Figure 7.18. Changes of opinion about (a) the beehive fence success chances in 2008 and (b) post-trial opinions in 2010. The results were remarkably positive with a significant swing from 4 to 1 on the opinion scale.

7.4. Discussion

In this chapter we consider the social and economic conditions and constraints on a typical rural Turkana community suffering from elephant crop-raiding and consider the implications of the introduction of beekeeping (in the form of a beehive fence elephant deterrent network) into such a community. We used a simple 34 question questionnaire to gain insight into the present conditions of the community in 2008 and compared the answers to a similar set of questions taken after the beehive fence trial had been running for two years in June 2010. Understanding how beekeeping on a large scale might fit into, and hopefully benefit, a community relies on solid information about how a community is functioning in the first place. We questioned 16 farmers out of the 34 participating farms, which represented 47.1% of the study group and 25.8% of the entire 62 farm community. This was regarded as a large enough sample size to gather general information on how the community was living before and after the trial. Additionally, 85 visits to the community by myself over two years enabled an in depth insight into the culture and social context of the adoption potential of the beehive fence concept.

Not unexpectedly, and due to the polygynous nature of Turkana culture (Leslie *et al.*, 1999), we discovered that the households in Ngare Mara were large with an average farm supporting 5.3 adults and 8.3 children. This household size was comparable with other surveys of nomadic Turkana (Leslie *et al.*, 1999) and enabled us to compare the size of each family to other socio-economic conditions. However, unlike Leslie *et al.*'s study of Turkana societies, we did not extract more private details about household make up such as the number of wives per farmer or the total number of births (including child mortality figures). We deemed these questions as too personal for the context of the research questions and not essential information over and above simple household size data.

Indeed, we found that the overall size of the family was positively correlated to the number of livestock owned as well as to the number of hours slept during the day by the head farmer in charge of deterring wildlife from the farm at night. We also discovered that large families, who did not have many livestock and had an underproductive farm, were more likely to have more beehives than families with many

livestock and a healthy maize production. This discovery was very important and revealed that beekeeping in our study community was already a response activity for certain families who regarded it as an alternative, or supplementary, income generating activity when other sources of revenue were lacking. 15 out of the 16 farmers were keen to point out that honey was used to treat chest pains and they regularly gave honey to children who were not well. With an average of 8-9 children per household a beehive could be a valuable medicine cabinet for these large, low-income families.

The questionnaires revealed that 100% of the farmers regarded elephants as the worst problem animal for invading and eating or damaging the crops in their farms. This is an important perception but one we were not able to fully explore within the context of measurable damage by other crop-raiding animals. However, over 9.5 months (293 days) we only recorded 49 “events” where elephants were seen approaching and either entering or being deterred from the farms (see Chapter 6). This represents an average of only one elephant sighting every 6 days but in reality there were many months of inactivity from elephants followed by short intense raiding periods (refer to Figure 6.22).

Baboons, birds and squirrels however, were seen on numerous occasions and appeared to be a real nuisance in all areas of the community (Figure 7.19). It is not inconceivable that these smaller animals caused more consistent damage to crops than elephants but just on a smaller and more regular basis. In farms next to Kibale National Park, Uganda, Naughton *et al.*, (1999) found that although the financial damage per elephant raid was higher than any other raiding event by a pest species, the overall annual financial damage caused by goats regularly feeding within the agricultural land was higher. In hindsight it would have been valuable to record all incidents of baboon invasions to the farms to compare to elephant incidents but setting out to challenge the perception of elephants being the worst problem animal was outside the scope of our study.



Figure 7.19. It was quite common to see bird and porcupine traps being laid at the entrances to farms indicating that both species were a problem to the farmers. This traditional trap was designed to snare the legs of porcupines and ground birds that mostly walked through the crops at ground level.

75% of the farmers also claimed that they spent between 7 to 12 hours a night guarding their crops but when asked the same question via a different tactic (using the time index activity) scaring elephants was a long way down the list and featured as the seventh most time consuming activity for just four farmers.

Even though its possible that some answers relating to the severity of elephant damage and sleep patterns were over-emphasized due to my presence in the community as “an interested elephant researcher”, there was no doubt that the perception of elephants as a serious problem animal was real and the fact that Save the Elephants had recorded nine illegally killed elephants in the wider area during the five years prior to our study confirmed that elephants were a real and serious issue for this community. I was also left in no doubt that if the perception of elephants as the worst problem animal was not tackled in this community they were going to be left with no incentive to stop killing the elephants that passed through their area. To my knowledge, no outreach or compensatory funds from the National Reserves had ever reached this community. Attitudes towards the reserve rangers and Kenyan Wildlife Service were consequently negative with 100% of our respondents claiming that they did not benefit in any way from the neighbouring reserves.

The attitudes of the farmers towards the beehive fence project were positive from the outset and we consistently had a group of farmers who would come and help us with construction and maintenance throughout the study. In 2008, at the start of the project, 100% of farmers claimed that they were “very happy” to be part of the project (scoring 1 consistently on the happiness index) but were then delightfully honest with us that they thought the beehive fence would “not be successful” at deterring elephants

with 81.25% of the farmers scoring the success chances as 4 or 5 out of 5 with just one farmer thinking it could work. This result was important to me as it showed that they were answering the questions seriously and honestly and not trying to be polite. Hence, the fact that the 2010 data revealed that the remaining 15 farmers had changed their opinion and thought the beehive fences were “very successful” at deterring elephants, scoring 1 on the scale, could be considered a genuine response.

The questionnaires revealed a startlingly high dependency on charcoal within the two communities. Although the number of bags of charcoal being sold had not significantly increased over the two years the sudden increase in market value per bag and the increase in income generated by charcoal will certainly provide an incentive for increased production over the next few years. This activity is incredibly damaging to the environment and is typical of the threat to biodiversity that has been recorded when dense human settlements start to grow in species rich areas (Balmford *et al.*, 2001). Not only is the rate of tree cutting for charcoal an unsustainable activity but being so close to the unfenced national reserves means that the buffer zones for foraging elephants around the reserves are being depleted. Reductions in tree cover and forage for elephants (and other herbivores) might actually increase the potential for more crop-raiding as natural forage decreases. Additionally the destruction of tree cover and tree root networks in the community will eventually affect rainfall patterns in the area (Lal, 1997) and result in increased soil leaching and erosion with the result of even poorer agricultural productivity (Lindell *et al.*, 2010). As we have seen, poorer harvests mean greater pressures on the community to sell livestock therefore depleting their main “bank” for the future. Fewer livestock and an increasing market value for charcoal might result in a damaging spiral of local habitat destruction (Figure 7.20).



Figure 7.20. This image shows a typical traditional charcoal stove in Ngare Mara where trees from the surrounding area have been felled and set on fire. Sand is shovelled onto the burning logs to contain the fire. This smouldering technique allows charcoal to form without burning the wood into worthless ash.

Before this trial began, beekeeping had already been adopted by certain members of the community and particularly by farmers who had large families but few livestock and poor harvests. After the trial we saw a consensus from 100% of our farmers that they believed the beehive fences were ‘very successful’ at deterring elephants. Here we consider how many beehives a farmer might need to replace charcoal making as a chief income earner with the assumption that the beehives also form part of a beehive fence protecting his farm from elephant invasions.

Using the income figures from 2010 we have a target mean figure of 5,562 shillings (US\$ 74) generated monthly by charcoal sales from which to work from. At present raw honey (with comb) is being sold in Isiolo (the nearest market town) at the price of 200 shillings per kilogram. Therefore a farmer would have to sell a minimum of 27.8 kgs of honey per month to replace the mean income generated by charcoal. Data from our beehive fence monitoring records show that one can expect between 55% and 76% occupancy rates for beehives hung in a beehive fence. To be conservative we will use the figure of 55% occupancy. Additionally we discovered that hives are more or less ready to be harvested every four months and therefore, if harvested correctly without destroying the brood, can result in three harvests a year from each hive. Our average weight of honey harvested from our 23 hives over the last two years was 4.6kgs per hive.

Six beehives harvested per month will therefore provide enough honey to replace a farmers’ charcoal income ($4.6\text{kgs} \times 200 \text{ shillings} \times 6 \text{ hives} = 5,520 \text{ shillings}$). In order to harvest six beehives per month a farmer needs to have 24 fully occupied hives harvested on a rotational basis. If he manages to get 24 occupied hives it means that a farmer needs a total of 43 beehives to generate the same income as charcoal burning if he can rely on a 55% occupancy rate. 43 beehives will be enough to cover 430 meters of farm boundary that would, roughly, surround a 2.5 acre farm if the beehives were hung every 10 meters.

These figures can be regarded as realistic in terms of management and cost and pose a real and ecologically beneficial alternative to charcoal as an income generator. Additionally, beekeeping is regarded as an activity that takes up less time than charcoal

making (Figure 7.15) leaving more time for the farmer to work on his farm or to look after his livestock. A reduction in tree cutting combined with an increase in crop pollination from 24 occupied hives should increase agricultural productivity from his land through decreased erosion, better soil aeration and healthier harvests. More live trees will also enable the farmer to collect firewood closer to home and will provide ample natural forage for migrating elephants who are deterred from crop-raiding from the protective beehive fence.

However, set up costs for a 430 meter beehive fence are not insignificant. We spent an average of US\$315 for every 100 meters of beehive fence, excluding transport costs. Should a farmer decide to invest in a beehive fence to replace charcoal burning he would have to invest US\$1,355 for a 430 meter boundary fence if he bought, rather than made, all the materials. At an occupancy rate of 55% this would take a farmer 18 months to pay back the set up cost of the fence before he would start to see a profit. In reality, these figures are well within the range of most established micro-finance projects presently found working in Kenya and might also attract part-funding from local or national honey companies looking for a reliable honey source. 100% of our farmers declared that they did not benefit in any way from their neighbouring reserves or from elephants. Perhaps if the National Reserve and Parks' management are looking for sustainable ways to support neighbouring communities from a proportion of visitors' entrance fees this new beehive fence technology could be an ideal conduit for such community support.

Case Study of Research Potential

Introduction of two beehive fences to Sagalla Community, Tsavo

Background: The Sagalla community is located on, and around the foot of, the Sagalla Mountain on the outskirts of the Tsavo East plateau, just two hours inland from Mombasa. The people of Sagalla are a sub-tribe of the Taita tribe originating from the migration of the Bantus from the Congo Forest. During this movement towards the coast of Kenya, a small group decided to stay and commence agricultural activities when they reached this mountain. The word Sagalla means “to sit” or “to stay” in the Mijikenda language and to this day the community speak a dialect closer to Mijikenda than to their parent tribal language of Taita.

Problem: Sagalla is sandwiched between Tsavo West and Tsavo East National Parks, the largest protected area in Kenya (21,000 km²) and home to 11,696 elephants (data from 2008 KWS survey). The park’s boundary fences around Voi and the Sagalla community are presently in a poor condition, not electrified and provide no barrier at all between wildlife and the surrounding communities.



Preliminary Survey: Members of an NGO promoting better education and schooling facilities in the area, The Kileva Foundation, introduced me to Sagalla highlighting the problems the farmers were having with elephants. In August 2009 I conducted a small questionnaire survey with 10 farmers representing members from two sub-villages in Sagalla (Kirumbi and Mwukoma), which confirmed that crop-raiding by elephants in Sagalla was a problem and consequently attitudes towards elephants, the neighbouring National Parks and KWS in general were negative. 100% of our 10 participant farmers listed elephants as the worst problem animals with baboons (90%) and lions (30%) listed as second and third worst respectively. Other problem animals were buffalo, squirrels, birds, warthogs and monkeys.

The community is not known for its beekeeping activities and the farmers we interviewed confirmed that status, as only two farmers owned beehives (5 hives in total) and no farmers had ever sold honey. However, 100% of the farmers were interested in learning more about beekeeping and they all enjoyed eating honey, using it for medicine, making local brew and using it to sweeten tea. Most income was generated from working in their fields and selling maize, beans, goats and chickens in the local town of Voi. Not one farmer in Sagalla listed charcoal making first for either time or

income rankings which compared sharply to Ngare Mara (refer back to Chapter 7). Additionally, mean livestock numbers were also low and half of what we recorded in our Ngare Mara community (Sagalla mean $15.7 \pm \text{SE } 2.84$ compared to $33.5 \pm \text{SE } 4.75$ in Ngare Mara) illustrating further that this community relies heavily on agriculture as the main income generating activity.

Beehive Fence: With assistance and guidance from the community leaders we trained six carpenters to construct 36 Kenyan Top Bar beehives and 10 women were trained in constructing flat-thatched roofs. We then constructed two beehive fences around two of the ‘front-line’ farms known to suffer from frequent crop-raiding. Each farm was large (>3 acres) and so a complementary control area was established on the same farm, and with the same farmer, to enable us to compare anticipated crop-raiding events between protected vs. unprotected farm areas. Farmer A had an acre encircled by a 21 strong beehive fence and Farmer B had just under an acre encircled by 15 beehives. Additionally Farmer B had a wide opening left in one corner of the beehive fence which kept open the path he used to and from his house to the field. Each farmer was trained in how to fill out a simple data sheet enabling him to draw any elephant movements in and around the beehive fence and control areas. Additionally he was trained in simple beekeeping techniques and supplied with a beekeeping book written in KiSwahili, smoker, veil, coat, gloves and buckets.

Outcomes: In June 2010 we summarised all elephant raids and activities in the two farms encompassing 10 months of farming activity but only one core harvest season. In total there were 13 attempted raids recorded on the two farms during the study period comprising 52 elephants. Only 1 bull elephant managed to break through Farmer A’s beehive fence entering from one side of the field and breaking out through a different section of the beehive fence opposite to his entry point. The remaining 51 elephants walked around the beehive fences with at least 15 of those elephants passing through, or crop raiding, within the control areas. The farmers observed elephants walking directly towards their farm and when confronted with the beehive fence often turned 90° and either walked along the fence for a short distance or simply turned away. Both farmers were able to harvest successfully from their protected farm and although they noted some damage in the control areas we were unable to measure this quantifiably within the scope of the trial.

Summary: Although small in scale, this field trial of introducing beehive fences to a different community and tribe in southern Kenya was successful. The farmers have maintained the fences correctly and, despite a problem of wasp invasions in the hives, we hope they will soon harvest honey. Additionally, elephants in Tsavo appear to be reacting to the beehive fences with similar avoidance behaviour as shown by the Samburu elephants, which should further encourage farmers and managers tempted to try out this new deterrent in other parts of Africa.

Chapter 8

Discussion

Summary of Research Findings and Concluding Remarks

This thesis embarks on a unique investigation into the complex natural world of the African savannah elephant and the African honey bee. They both have evolved to live within the same savannah-bush ecosystem mosaic and are both, ultimately, vying for reproductive success. To the best of my knowledge, this is the first comprehensive study conducted on the behavioural interactions between elephants and bees and although, inevitably, the study has sparked off many more research questions, the data presented here have opened up a window into the relationship that has evolved between two habitat-defining social species.

8.1. Playback Techniques

The application of playback methods were a significant proportion of the techniques I deployed in my study to try to predict accurately what might happen should elephants come into contact with a disturbed live beehive. Although I was fortunate to witness one real interaction (refer to *Mid Script Field Note* on page 83) the fact that our working hypothesis was that they would avoid each other as much as possible made setting up ‘real’ interactions almost impossible without courting real danger to myself or my assistants. African honey bees are extremely aggressive and moving live beehives into the paths of elephants to test their behavioural responses was simply impractical for the sample sizes needed and too dangerous to attempt with the equipment available. It was, nonetheless, reassuring to witness one real event where the bees swarmed out of their hive and alarmed the elephants beneath. The speed of their bunched retreat, within a matter of seconds of bees filling the air, was not dissimilar to the elephant reactions I observed repeatedly when playing them a recording of disturbed bee sounds through a hidden speaker. Although I present data in Chapter 4 showing that elephants start to habituate to bee sounds after several playbacks, the data presented in Chapter 2 are only from those elephants hearing the disturbed African honey bee playbacks for the first time. I revealed that these elephants showed extreme avoidance behaviour with 67% of

elephant families physically running or walking fast away and as many as 78% of the families leaving the area within 60 seconds of sound onset.

Identifying an appropriate control sound for these playback experiments was not easy, and it may even be fair to suggest that there is no perfect control for such an unusual research question. I chose natural white noise as a control as I did not want any other animal sound to add undefined complexity to the behavioural responses of the elephants. Artificial or human-made sounds (e.g. classical music, car engines, computer generated warbles) might have no biological significance but there was a risk that such alien sounds might trigger alarmist behaviour from simply being a peculiar noise. I chose natural white noise extracted from a waterfall as the occurrence of all frequencies in the recording were naturally random and the softness of the waterfall sound was neither totally alien nor biologically significant in our study area where sizeable waterfalls did not exist.

Perhaps a more significant control was my ability to measure behaviour before either sound stimulus was emitted and to use that to define changes in behaviour for otherwise peacefully resting elephants. I chose to analyse three specific physical behaviours (dusting, headshaking and smelling with raised trunks) that I identified during field observations that might be particular to the bee sound responses. Dusting, and particularly headshaking, tended to occur more frequently by elephants listening to bee sounds than to both white noise and pre-stimulus controls, and both actions significantly increased the longer elephants remained within hearing distance of the bee sounds. I suggest that although these distinct actions occur naturally (I saw headshaking and dusting occur occasionally during pre-stimuli control periods), elephants may increase their occurrence rates to deter bees from stinging the sensitive skin around the eyes and ears, and possibly to knock bees out of the air with dust particles. The third physical response behaviour we analysed, smelling, was observed so often that it was included in the analysis but in general elephants did not smell more to bees than to white noise controls.

During my fieldwork I occasionally witnessed non-target elephants coming through the bushes from a distance to join a retreating family. Sometimes these elephants would even walk slightly towards the bee sound-emitting speaker in order to

meet up with the target family before walking off with them in a group. This field observation led to the hypothesis that the elephants were in some way communicating to each other to leave the area and, as I rarely heard any rumbles or vocalisations, I worked on the assumption that any communication may be below my hearing capabilities, within the infrasonic range of frequencies. This hypothesis was proved in Chapter 3 where my colleague Dr Soltis and I describe the acoustic structure of a typical rumble emitted during elephant responses to bee sound stimulus. The commonality between these different elephant rumbles was a high second formant location lying between 115 – 168 Hz. The location of the second formant lies in a significantly different location to those rumbles emitted in response to natural white noise despite the fundamental frequencies for both being not significantly different. This technique also allowed us to compare both the response to white noise and bee stimulus to control rumbles, those rumbles emitted naturally during the pre-stimulus recording period where the elephants were resting and socialising under trees. This revealed that, compared to the control, elephants had an elevated response to white noise as shown by their higher mean fundamental frequencies and fundamental frequency range but the distinct second formant difference between white noise and bee sound response vocalisations was clearly detected. This result suggests that white noise *was* an appropriate control as it helped to reveal different ‘grades’ of response to playback sound stimuli.

Rather than playing back different rumbles emitted to ‘bee’ and ‘white noise’ stimuli, we decided to artificially lower the second formant within the bee rumble to use as a ‘white noise’ rumble. Although this placed us at risk of pseudo replication (McGregor *et al.*, 1992), we used a trio of three typical rumbles within our call back protocol which was more than some previously published protocols (Poole, 1999) but less than others (McComb *et al.*, 2000). These rumbles were chosen from a mid-ranking resident family, the Hardwoods. The data from these rumble playbacks were fascinating and revealed that elephants hearing the ‘bee rumble’ left the area as if bees were in the location. Although we could not be certain that the ‘bee rumble’ we identified was unique to the threat of bees alone, elevated levels of dusting and headshaking could be good candidate behaviours to support such specificity.

Smelling events, on the other hand, have previously been correlated to familiarity with the caller, with older matriarchs being better able to discriminate

familiar callers (McComb *et al.*, 2001), and are likely to be influenced by dominance relationships between families. Further analysis is needed to compare smelling rates by those elephant groups subordinate to the Hardwoods to those dominant to the Hardwoods to see if that confounding variable is evident in our sample. Furthermore, we only selected three particular behavioural traits to analyse in detail but the richness of behavioural response shown by our different elephant families warrant further study. The quality of the high definition film we used should enable more in depth behavioural analyses to be conducted in the future without necessarily re-doing the experiments.

The specificity of the alarm call that we have identified is of particular interest and will be my focus for further study. Only by subjecting elephants to further threats (such as warrior voices or growling lions) will we be able to finally conclude whether the alarm call we have found is specific to bees or is more of a general ‘alarm call’ appropriate to communicate the need to retreat under a variety of circumstances.

Reacting to threats in the environment with the correct response level is crucial for elephants as responding *incorrectly* will waste valuable energy and may, over time, lead to lower reproductive success (McComb *et al.*, 2001). Learning the correct level of response for different threat types takes time, so one might predict that families with older matriarchs are better equipped to react correctly to the bee threat. Moreover, one might hypothesise that young calves and juveniles would start to learn the correct response through social facilitation as they might start to associate the sound of bees with the adults in their group becoming alarmed and retreating. Further study into both these matriarchal and calf social facilitation hypotheses would be valuable. They would require identification of matriarchs from each playback trial along with their ages and family dominance rank as well as simultaneous study of calf behaviour during repeat playbacks. This complex life history data layer is available for most of the Samburu elephant families and deserves further study.

8.2. Application of Behavioural Research

The first three chapters of this thesis delve into elephant behaviour and communication by attempting to understand the avoidance behaviour recorded towards honey bees. Whilst I recognise and indeed, go on to identify, what the next stages of the research might entail, I made a conscious decision to focus the second half of my thesis on the application of this newly discovered behaviour. My aim was to come up with an eco-deterrent that would be able to exploit this naturally occurring avoidance behaviour in elephants to help poor rural farmers protect their crops from elephant damage. Likewise, I wanted to facilitate naturally migrating elephants avoid hot spots of conflict by steering them around farmland communities. Having discovered that bee sounds alone will not deter elephants for long (Chapter 4) I turned my efforts towards designing a beehive fence that uses live bees with the hypothesis that live bees will result in a continued cycle of negative conditioning that should prevent habituation by elephants towards the HEC mitigation method.

8.3. Community Participation and Farmer Response to Beehive Fence Trials

I believe the success of the on-farm trials for testing the novel beehive fence technology was a consequence of utilising participatory techniques to involve the three communities in the trial structures. Although not every stage of the experimental trials were participatory, the early development stages of the trials were fully participatory and engaged the community and individual farmers from day one ensuring a sense of ownership and enthusiasm. I do not believe the contributions and enthusiasm I experienced would have existed to such an extent should we simply have rented farms off families for more rigorous block controlled testing.

Of course, testing a new deterrent system under real life conditions meant that the trials were affected by negative 'real life' conditions and we had our fair share of problems during the two years working within our main trial site in Ngare Mara. Not only did the project site suffer from an intense and prolonged drought but the distressed conditions at the community level meant increased tensions and security instability that led to two tragic cattle raids in August 2009. These raids resulted in many injuries and

the death of 12 people (three from our communities of Chumviyere and Etorro and nine from the neighbouring Borana community). As a consequence, some farmers left the area and only 50% of our study farms were actually planted and harvested successfully when the rains came in November 2009. However, due to the ambition and size of the project, this 50% sample (n=17 farms) still provided a wealth of information on elephant movements around the beehive fence protected farms containing crops. By combining data from elephant movements during the harvest season with elephant movements around farms that contained no crops (n=34) we generated a healthy database of events revealing the extent to which elephants would avoid crossing the beehive fences.

In all three of my study sites, Ex-Erok, Ngare Mara and Sagalla, we frequently observed elephants approaching the beehive fences and either (i) approach the fence between two of the beehives and then back away at the point where the wire hung or (ii) walk along the length of the beehive fence until the group either walked away into the bush or found the 'end of the line' and broke into a unprotected farm. This deterrent behaviour occurred consistently along the beehive fences and did not appear to be correlated to whether the beehives at the point of approach were occupied. Although we succeeded in monitoring 49 crop raids for the Ngare Mara site, the beehive fence remained a very novel, swaying, complex barrier which continued to successfully deter approaching elephants. Whether or not the barrier itself, without occupation by bees, will continue to prevent elephants from entering farms in the future should be the focus of further study in Ngare Mara.

In Ex-Erok where no bees occupied the hives during our six week pilot study in mid 2007, the beehive fence has remained in place with low occupation rates since that time. Although a new electrified elephant-proof fence was constructed in February 2008 the elephants began to return to this pilot site during 2009 when poor maintenance of the electric fence decreased its effectiveness as a barrier. During a visit to Ex-Erok in November 2010 Farmer Miner (Farmer A) confirmed that bull elephants had returned to crop raid regularly in his community but were still avoiding his farm despite low occupancy of his hives (only 2 out of 11 were occupied during my visit). The elephants avoiding Farm A over a two and a half year period suggest that the novelty of the

beehive fence barrier had not worn off although the area had been fenced off for over a year during that time.

More research is needed to understand how occupancy rates by live bees affect this decision making process for elephants. Due to the design of the beehive fence connecting the freely swinging beehives to each other with strong wire, the movement of one beehive actually causes up to three beehives on either side to swing. Is this physical, moving barrier alone enough of a deterrent? Does the occupancy of bees anywhere along the fence line increase the deterrent effect compared to completely unoccupied stretches of fence? This design feature that allows the beehives to swing might mean that bees need only occupy every 5th or 6th beehive to retain the ‘live’ ability to disturb approaching elephants and prevent habituation. If the physical barrier itself *is* the key deterrent factor, would it then be feasible to hang two ‘dummy’ beehives on the fence for every real beehive to reduce the cost of construction and to spread out valuable hive occupations? It is possible that further research could identify a balance between the success of a physical moving beehive fence barrier and the number of beehives that actually *need* to be occupied to prevent habituation to the barrier? Occupation rates by bees are certainly essential to retain the interest and enthusiasm of the farmers who might only retain their motivation for maintenance due to the financial benefits of harvesting honey from the fence.

8.4. Beehive Fence Economics

The economics of the successful beehive fence systems demonstrated in this thesis are of importance. Both the beehive fences using traditional log beehives (Chapter 5) and KTBH beehives (Chapters 6 and 7) worked out at approximately US\$315 per 100 meters. The costs of using the traditional log beehive fence were high because I bought all elements of the beehive fence including the posts and beehives. However, I demonstrated in section 5.3.2 that if a farmer were to make all possible elements of a tradition log beehive fence himself (including making hives from locally available wood) the costs of 100m of beehive fence would drop to as low as US\$35 per 100m. While I cannot advocate the practice of cutting down trees to make these log beehives, more often than not, old beehives are already present within a community and

simply need repair. If these can be re-located to hang between posts around a farm they could quickly provide a very cheap and affordable deterrent system with little effort and only the small purchasing costs of wire, nails and wood preservative. A small number of posts and thatching material are needed in the construction process but using a coppicing technique where strong tree branches are cut off for posts, rather than cutting down a whole tree, means that re-growth is highly likely and threats of localised deforestation or soil erosion becomes redundant. Beehive fences use considerably less wood, branches, planks and thorny bushes than are presently deployed around most of the rural farms in our study areas, and as these are ineffective against elephants a beehive fence may actually use less woody material than is being used at present.

Despite the minimal set up costs, there are some disadvantages of using traditional log beehives. During honey harvesting the bee brood is mixed in with the valuable honey and often gets removed or damaged during the harvesting process. This can greatly anger and disrupt African bees making them more aggressive and more likely to abandon the hive after harvesting. Such aggressiveness also means that farmers feel the need to use excessive smoke to calm the bees and this can leave a smoky flavour to the honey which makes it less desirable and less valuable at market.

The evolution of the beehive fence design to incorporate the KTBH hives was successful but the use of industrial-made 9mm plywood sheets means that materials cannot be found within most rural community areas and a financial investment is needed to install the deterrent system. Using a ratio of one beehive per 10 meters, the minimum cost of US\$315 per 100m may take the cost of the KTBH beehive fence beyond the capabilities of some farmers. However, the financial prospects of the beehive fence through pure (without brood) honey production might attract outside funding, either through micro-finance loans or through attracting large honey export companies. These companies may be willing to donate beehives in exchange for an exclusivity deal to buy back all the honey from a site, particularly if a community lives within an *Acacia* dominated savannah which produces a popular brand of honey. The characteristics of honey mean that (i) it does not need refrigeration, (ii) it cannot rot and will only lose water and viscosity if left without a lid, (iii) is a useful anti-biotic and medicine, (iv) it is universally liked as a sweetener which can replace expensive industrial sugar products, and (v) there may be a significant emerging honey market in

countries like the UK and USA as their bee colonies are under threat of collapse due to viruses and intensive agricultural practices.

During my research for this thesis, I concentrated firmly on low income farmers and I put much effort into keeping the costs of the beehive fence as low as feasibly possible whilst only using materials found locally. Costs could be further reduced by hanging ‘dummy’ beehives along the fence line which would not only be cheaper but would help to spread out the occupation of ‘live’ hives around the farms. However, it is not inconceivable that the set up costs will not be a limiting factor for some development organisations or for some wealthier farmers or ranchers. After all, beehive fences are only a fraction of the cost of electric fencing and might be more appropriate for some small localities rather than investing heavily in expensive electricity. Should more funds be available I recommend the following two suggestions to reduce maintenance:

- (i) Use nine foot metal or plastic posts (manufactured from melted recycled plastics) which should last longer and will not suffer from termite damage like the wooden posts used in this research.
- (ii) Cement the plastic or metal posts into the ground by at least 3 foot. Cement is more expensive but means the posts will not lean so much during the rains or when the hives are heavy with honey. The use of either metal or plastic posts should remove the need for nailing on iron sheets to prevent honey badgers as they should not be able to climb such a smooth, vertical feature.

8.5. Potential of Beehive Fences in Kenya’s Natural Resource Management

I believe a proactive approach could be made by Kenya’s wildlife managers and county councils to direct funding for HEC mitigation research towards farming communities willing to test out the beehive fence system. For a relatively low investment, farmers would feel a tangible benefit from the tourism revenue generated by their local reserves or national parks and this act alone could go a long way to improving the relationship between park management and neighbouring communities. The beehive fences will not stop 100% of elephant crop-raids but, if my results from

three communities may be taken as a starting point, one could predict that the successful break through crop-raiding events will remain somewhere between 14% (Ex-Erok), 8% (Sagalla) or 2% (Ngare Mara) of all potential elephant invasions within a community. The damage caused by the few elephants that do manage to break through the beehive fence deterrent system might be emotionally and financially compensated for by the income generated by honey sales. This win-win prospect might leave farmers with less of an incentive to spear, poison or shoot elephants on sight, which often leads to a lingering, painful death (pers. obs.).

Beekeeping has already been recommended as a desired activity within Kenya's *National Poverty Eradication Plan 1999-2015* and the idea of combining the merits of beekeeping and natural resource management with the chance to reduce HEC seems like an attractive proposition. Hence, if for some reason not yet identified, the beehive fences do not work in another site in Kenya (or indeed another African country) the investment into the project will not be lost as beekeeping would remain a valuable environmental and livelihood enhancing activity on its own.

The results from this thesis have triggered off more research questions in relation to the effectiveness of the beehive fences over a) a wider area and b) over a longer test period. Depending on the complexity of the farming community it is not inconceivable that there might be a saturation point in terms of the number of beehives that can realistically be occupied in a certain area. I would hazard a prediction that the saturation point (if there is one) would be lower in the dryer semi-arid areas of Kenya where wild flowers and nectar abundance are more seasonal and droughts are more common. This should be considered before a densely populated farming community in northern Kenya starts to take up the technology.

A further element to consider when predicting the potential success of the beehive fences, and something not tested here, is the question about what happens should every farmer in a community build a beehive fence? Faced with the challenge of every farm being protected, would the elephants simply walk around the farms and continue on their natural migration or would they become bolder and start to break through the fence where stretches of the hives remained unoccupied by bees?

Additionally, the ongoing success of certain HEC mitigation methods in the Mara District, Kenya, has resulted in a phenomenon where new farms are starting to encroach further into wildlife zones as the farmers appear more confident about harvesting successfully with new deterrent techniques to help (N.Sitati, pers.comm). This turn of events should lead more to questions about the application of better land planning and land use zonation systems rather than any debate about the validity of developing effective HEC methods. If Kenya continues to encourage the existence of elephants roaming freely outside of national reserves and parks, there will always be a need for effective HEC methods to retain a level of tolerance between elephants and farmers. Enforcing better land use zonation on the borders between wildlife and settlement areas is beyond the scope of this thesis but the use of government supported HEC methods should ideally only be implemented where careful land use planning is enforced.

Using knowledge gained during this thesis research, Table 8.1. summarises my predicted conditions for success levels which should be taken into consideration before deploying further beehive fences within Kenyan communities suffering from HEC. I would hope and anticipate this list to grow and to develop greater specificity as more beehive fence trial sites are set up in the future and more results are available for analysis. While I am hesitant to offer predictions for other African countries where conditions may be totally different, I expect most of these attributes could be transferrable to different geographic regions within Africa inhabited by both elephants and honey bees.

Predicted Conditions	
Higher Success	Lower Success
<p>Lower Altitudes</p> <ul style="list-style-type: none"> • Between 400m – 1200m above sea level where <i>A. m. scutellata</i> typically lives should be most effective. • Coastal regions 0 - 400m where <i>A. m. litorea</i> lives is also known to be an aggressive honey bee so results could be comparable. • Warmer conditions at night keep bees active and capable of swarming out of the hive when disturbed. 	<p>Higher Altitudes</p> <ul style="list-style-type: none"> • Above 2,500m lives <i>A.m.monticola</i>, which is a less aggressive honey bee and might have less affect when swarming out and disturbing elephants. • Cooler conditions means bees are less active at night when most crop-raiding occurs. • Snow or icy conditions may result in inactivity or semi-dormancy of bees where valuable honey stores are consumed to keep them warm and alive.
<p>Farmer/Individual Owned Beehives</p> <ul style="list-style-type: none"> • Will maintain fences due to financial incentive of honey and wax. • More likely to want to learn new beekeeping techniques and skills. • Vigilant on a daily basis for theft or elephant movements around bee fences. 	<p>Community/Group Owned Beehives</p> <ul style="list-style-type: none"> • Confusion over who is responsible for maintaining each hive. • Lack of incentive for harvesting honey if proceeds are divided amongst many. • Less accountability for stolen honey or beehives.
<p>Circular Beehive Fences</p> <ul style="list-style-type: none"> • Fully encloses farm preventing elephants from walking around the ‘end of the line’ to enter the farm. • Leave an appropriate ‘gap’ around the house or access area to prevent accidental disturbance of the hives during the day. 	<p>Straight Lines of Beehive Fences</p> <ul style="list-style-type: none"> • Applicable for communally run farms sitting side by side, but the farms at either end of the line will get crop raided more than the central farms. • Once inside a farm they can then have access to all the other farms ‘behind’ the beehive fence deterrent.
<p>Kenyan Top Bar Beehives</p> <ul style="list-style-type: none"> • Swing well between posts. • Waterproof against rain. • Brood chamber keeps queen and brood separate from honey chamber making harvesting easier and the honey more valuable. • Easy to construct and maintain. • More expensive to make but income from honey should justify initial outlay. 	<p>Traditional Log Beehives</p> <ul style="list-style-type: none"> • Often already available locally so can be easily transferred to beehive fences <i>but</i> if not available means cutting down large valuable trees to make hives. • Brood and honey chambers are mixed so harvesting can result in destroying the combs and the bees will swarm and leave. • Difficult access to honey can mean use of excessive smoke and lower quality honey due to smoky flavour.

Table 8.1. Predicted conditions for success chances when deploying beehive fences in Kenya as an elephant deterrent in locations where the African savannah elephant *Loxodonta africana* resides alongside farmland. The greatest chances of success may be found where a farmer, living below 2,500m, owns his own KTBH beehives and places them in a circular position around his farm.

8.6. What about Asian Elephants and Bees?

Although I have not tested the beehive fences in Asia I believe I can offer some tentative predictors about the chances of success using both my Kenyan experiences and from participating in a workshop with members of the Asian Elephant Specialist Group (AsESG) in Beijing in 2009. Along with elephant managers from Cambodia, India, Nepal, Laos, Vietnam, China, Sri Lanka, Bangladesh, Thailand, Malaysia and Indonesia we discussed the potential application of the beehive fences under Asian conditions. Considering the transfer of this new elephant deterrent system to test sites in Asia is worthwhile. Asian elephants *Elephas maximus* are listed as 'Endangered' by IUCN's Red List of Threatened Species as their populations are under threat from habitat fragmentation (Leimgruber *et al.*, 2003) and rising incidents of human-elephant conflict as the expanding human interface demands more space for development and agriculture (Williams *et al.*, 2001; Choudhury, 2004).

Several factors make the Asian conditions for the success of the beehive fence system quite different from those I have been studying in Kenya. Most notably, both the species of elephant and bee are different in Asia and there is no reason to expect either to behave exactly the same as their African cousins. Asia is home to three species of social honey bee, two open-nesting species *Apis florea* and *Apis dorsata* but only one hive dwelling species *Apis cerana* (Gould and Gould, 1988). The Indian honey bee *Apis cerana* is therefore the most suitable contender to inhabit a beehive fence hive and they do exhibit some of the same characteristics of African honey bees *Apis mellifera*. Studies have shown that within the hive both the Indian and African honey bee have similar auditory components to their waggle dances which result in successful recruitment of worker bees to favourable foraging sites (von Frisch, 1967; Gould and Towne, 1987). Furthermore, Indian honey bees contain the same potency of venom in their stings as African honey bees and may even inject slightly more venom per sting than their smaller African cousins (Gould and Gould, 1988). However, their lower levels of aggression mean that fewer bees may sting an intruder compared to the highly aggressive African honey bee swarms that will attack en masse with little provocation (Stort, 1975).

The AsESG workshop in Beijing revealed several characteristics of human-wildlife conflict problems in Asian countries that may pose a stumbling block to the effectiveness of deploying the beehive fences there. The results of our discussions were:

- (i) Asian elephants live predominantly in forested refuges so neighbouring farmland or plantations tend to be heavily forested or bushy rather than open savannah. This means the elephants would have less time to see the fences or the shape of the beehives as they approached the farms. Also, the beehives may get overgrown quickly with vegetation requiring greater maintenance. Wide, cleared buffer zones would be needed and this would increase labour/investment requirements.
- (ii) Rainfall can be more frequent and heavier throughout the year in many regions of Asia. This might reduce foraging time for bees resulting in poorer honey harvests that may diminish the financial incentive for maintenance. Intense humid or wet conditions may also trigger rotting of the plywood beehives more quickly than the dry conditions found in Kenya.
- (iii) Bear species from the forest refuges are attracted to honey and would be the greatest potential scavenger/destroyer of occupied hives (S. Hedges, pers. com.). Their larger size and greater reach, means that the protective iron sheets deployed effectively on the vertical posts against honey badgers in Kenya would, most likely, be ineffective and redundant in Asia.
- (iv) The Indian honey bee is known to be less aggressive and experiments are needed to understand both their hive defense characteristics and whether Asian elephants show any fear or knowledge about avoiding this species of honey bee.

Due to these potential but significant constraints, I believe that several stages of careful scientific research are needed before the beehive fences can be recommended for deployment in HEC farmland areas in Asia.

8.7. Conclusion

In this research thesis I tested several defined hypotheses and made some unique discoveries. I have presented evidence that African elephants will run from bee sounds and when doing so emit a unique low frequency vocalisation that warns other elephants in the area to retreat. To the best of my knowledge, this is the first time anyone has attempted to reveal scientifically what behavioural interactions might occur should wild elephants and honey bees come into contact. The behaviour demonstrated suggests that elephants, having come into contact with bees, retain a memory about that interaction that appears to be negative, so much so that simply *hearing* bees in the future causes extreme avoidance behaviour. How this behaviour is learnt is not yet fully understood but may be learnt through either personal experience or social facilitation. Although such avoidance behaviour could be exploited to deter elephants away from farmland, I predicted correctly that elephants would habituate to bee sounds over repeat playbacks. Rather than spending time field-testing this habituation hypothesis, I turned to testing live bees, in the form of a novel beehive fence, to keep elephants out of farmland. The beehive fence was successfully adopted by three rural farming communities, in three different districts, and by three different tribes in Kenya. Across all three sites we recorded and monitored 90 different raids or attempted raids by elephants into either test or control farms. Out of these 90 different raids only 6 incidents were recorded where elephants crossed the beehive fences (four in Ex-Erok, one in Sagalla, one in Ngare Mara). Although multi-season monitoring is needed to assess potential habituation effects, the data from these three communities are encouraging and have laid solid foundations for further research. I conclude that should a Kenyan farmer, living below 2,500 meters, invest and deploy a beehive fence fully around his farm boundary he has a very real chance of significantly cutting down damaging elephant crop raids to his farm.





Beehive Fence successfully protecting crops from elephants in Sagalla Community, bordering Tsavo National Park, Kenya. January 2010.

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APPENDIX

A.1. Published Papers - King *et al.*, (2007) Current Biology

- King *et al.*, (2009) African Journal of Ecology
- King *et al.*, (2010) PLoS One
- Wasser *et al.*, (2010) Science

A.2. Questionnaire Example and Data

ABBREVIATED TERMS

ANOVA	Analysis of Variance
AWT	African Wildlife Tracking Ltd
CITES	Convention on International Trade in Endangered Species
F ₀	Fundamental Frequency
GSM	Global Systems for Mobile Communications
GPS	Global Positioning System
HEC	Human-Elephant Conflict
Hz	Hertz
IUCN	International Union for Conservation of Nature
KTBH	Kenyan Top Bar Hive
KWS	Kenya Wildlife Service
MANOVA	Multivariate Analysis of Variance
MIKE	Monitoring the Illegal Killing of Elephants
Shamba	Farm (Kiswahili)
STE	Save the Elephants

Correspondences

African elephants run from the sound of disturbed bees

Lucy E. King^{1,2}, Iain Douglas-Hamilton² and Fritz Vollrath^{1,2}

Encroaching human development into former wildlife areas [1] is compressing African elephants into ever smaller home ranges, causing increased levels of human–elephant conflict [2]. African honeybees have been proposed as a possible deterrent to elephants [3]. We have performed a sound playback experiment to study this hypothesis. We found that a significant majority of elephants, in a sample of 18 well-known families and subgroups of varying sizes, reacted negatively — immediately walking or running away — when they heard the buzz of disturbed bees, while they ignored the control sound of natural white-noise. Whether the observed response was the result of individual conditioning or of learning by social facilitation remains to be established. Our study strongly supports the hypothesis that bees — and perhaps even their buzz alone — may be deployed to keep elephants at bay.

Two of us [3] have reported previously that the elephant damage to acacia trees was significantly less than usual when the trees hosted either occupied or empty beehives. In Zimbabwe, elephants were observed forging new trails into experimental fields of crops to avoid beehives [4]. These observations suggest that African elephants are wary around bees and hives and will avoid them, presumably to prevent being stung on sensitive areas like the eyes, behind the ears and inside the trunk [3].

In our behavioural study, we used a playback method to understand how elephants might react to a disturbed live beehive. We presented playbacks of recordings of bee buzzing sounds in order to test the hypothesis that elephants

‘know about’ the danger of bees and respond to their sound by increased alertness and possibly even running away.

The sounds of disturbed wild African bees (*Apis mellifera scutellata*) were recorded uncompressed onto a Sony MZ-RH1 Hi-Mini Disc with a Steinheisser directional microphone. Using phonetic PRAAT software [5] we extracted and multiplied 30 seconds of sound to create a 4 minute constant bee recording (dB 66.1). Natural white noise extracted from a waterfall recording served as a control (dB 65.4). Both sounds were played back to elephant families resting under trees (11am–2.30pm) through an AQ 863 MHz wireless speaker that was camouflaged inside a fake ‘tree trunk’ constructed from dry reeds and a plastic rack. This was placed within 10 metres (± 2 m) of the closest elephant. Both sounds were played back loudly at twice the recorded volume (+3 dB) to compensate for speaker distance. The elephants’ response was filmed from a distance and at an angle of 45° to the speaker before, during and following playback of the 4 minute sounds.

The study site was the Samburu/ Buffalo Springs National Reserves in Kenya. During February to April 2007, 18 well-known family groups of approximately 8 elephants per group ($x = 8.8 \pm \text{s.d.}4.2$; $n = 284$ individuals) were identified before either sound was played. After a

minimum of 7 days [6] we relocated 9 families to which both sounds were played controlling for order effect, environmental variations and family composition.

Of the 17 families, 16 (94%) left the tree under which they had been resting within 80 seconds of bee sound onset (see Table 1 in the Supplemental Data available on-line with this issue). Of these 16 families, 8 responded after only 10 seconds of sound onset. This latency of response differs from the 15 families hearing the control sound where no elephants had moved after 10 seconds and only 4 (27%) had moved after 80 seconds of sound onset (Figure 1). By the end of the 4-minute sound playback of bee buzz only one elephant family (5.9%) had failed to move compared to 8 families (53.3%) hearing the control (significant χ^2 df 3, $P = 0.041$).

Of the 9 elephant families to which both sounds were played, the elephants’ latency of response was significantly faster to bee sounds than to control sounds (Wilcoxon Matched-pairs test, $n = 9$, $P = 0.004$; using 360 seconds as data for ‘no movers’). Within these 9 families there was no significant difference between the latency of response to sounds played first or second for either bee buzz or control, suggesting the experimental design was not affected by an order effect (Mann-Whitney U test: bee sounds $n = 5(1^{\text{st}}), 4(2^{\text{nd}})$; $P = 0.127$; Control sounds: $n = 4(1^{\text{st}}), 5(2^{\text{nd}})$; $P = 0.571$).

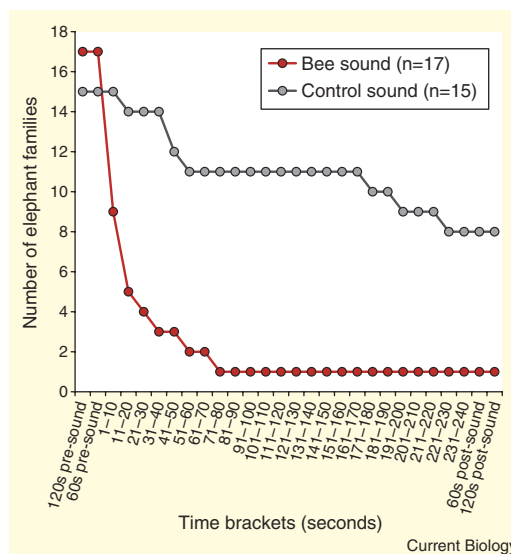


Figure 1. Number of elephant families remaining stationary in response to sound within time groupings of 10 seconds. Within 20 seconds, 70% of the herds listening to bee sounds had moved away compared to 7% in the control herds. Within 80 seconds, 94% of families had moved away from resting positions in response to bees compared to 27% of families in response to the control sound.



Figure 2. The Spice Girls family's reaction at the onset of playing bee buzz.

On hearing bee sounds, elephants demonstrated a variety of alarm behaviours [8] that appeared to ripple through the family. This included ceasing of any activity — feeding, sleeping, playing — raising of the head, ears out, slow turning of the head from side to side, headshaking and smelling with trunks both up and down towards the direction of the sound. Bunched retreat behaviour was usually led by one adult with tails in the air and backward glances towards the sound. In a typical flight run young calves were seen running directly next to their mothers with tails up, ears out and flicking their trunk from side to side. In this trial, the family took 18 seconds between onset of the sound and the start of a group retreat lead by the matriarch, Rosemary (collared individual to right of photo).

Figure 2 illustrates the group reaction to the onset of bee sounds (also see the Supplemental movie). For mode of retreat, 41.2% of families responding to bees 'ran' away, 29.4% 'walked fast' away and 23.5% 'walked' away. No 'running' or 'walking fast' behaviour was observed for the control groups, which showed 46.7% of families 'walked' away and 53.3% 'did not move'.

We observed a significant negative correlation between the latency of response and the distance moved (Spearman's rank = -0.668 , $df\ 30$, $P < 0.001$). The mean distance moved was significantly related to the sound that was played, with those families responding to bee sounds moving significantly further than those responding to natural white noise (bee: $64.2\ m \pm s.d.\ 43.3$; control: $19.7\ m \pm s.d.\ 26.1$, Mann-Whitney U, $U = 50$, $P = 0.002$). Variations in air pressure, temperature, time of day, altitude, number of elephants or number of sub-adult elephants in the responding families were not significantly correlated to the latency of response.

Our study demonstrates that elephants respond to the buzz of disturbed and aggressive bees with alarm by moving away from the sound source. The evidence suggests that elephants are aware of bees, they retain a memory about bees and they can identify bees by sound alone. Their response suggests that they remember or associate the sound of bees with a negative historical event, be it individual or collective, to which the correct response was rapid retreat. This flight informs, or alarms, the others. Conditioning to the buzz may have been learnt either directly by being stung, through observation of another elephant being stung or by social learning during a family retreat caused by disturbed bees. If social learning about a perceived threat results in such specific individual and group responses, this highlights the importance of elephant social structure in young family members' learning experiences.

One subgroup of the Virtues family did not respond to the bee sound. It was unusually small and consisted of a young bull (20 yrs),

a young female (14 yrs) and her calf. This lack of any response suggests that these 3 individuals may not have experienced (or did not remember) any direct or indirect negative interaction with bees. However, the absence in this group of an experienced matriarch [7] to provide the relevant cue (alarm) may have contributed to the atypical behaviour not observed in all 16 other groups ($n = 157$ elephants).

How well our observations — that whole family groups of elephants retreat together from the buzz of aggressive bees — can be turned to a profitable deterrent (through the protection of crops as well as the sale of honey) is now the topic of further investigations using both powerful loudspeakers and live beehives.

Supplemental data

Supplemental data including a movie clip are available at <http://www.current-biology.com/cgi/content/full/17/19/R832/DC1>

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Beehive fence deters crop-raiding elephants

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Abstract

Previous work has shown that African elephants *Loxodonta africana* will avoid African honeybees *Apis mellifera scutellata*. Here we present results from a pilot study conducted to evaluate the concept of using beehives to mitigate elephant crop depredation. In Laikipia, Kenya, we deployed a 90-m fence-line of nine inter-connected hives, all empty, on two exposed sides of a square two-acre farm that was experiencing high levels of elephant crop depredation. Compared with a nearby control farm of similar status and size, our experimental farm experienced fewer raids and consequently had higher productivity. Socioeconomic indicators suggest that not only was the concept of a beehive fence popular and desired by the community but also that it can pay for its construction costs through the sale of honey and bee products. We are calling for experiments testing this concept of a 'guardian beehive-fence' to be conducted rigorously and scientifically in as wide a range of agricultural settings as possible to evaluate jointly its effectiveness and efficiency.

Key words: African elephants, beekeeping, behaviour, crop raiding, deterrents, human–elephant conflict

Résumé

Des travaux antérieurs ont montré que les éléphants africains *Loxodonta africana* évitent les abeilles africaines *Apis mellifera scutellata*. Nous présentons ici les résultats d'une étude pilote réalisée pour évaluer le concept consistant à utiliser des ruches pour réduire la destruction des cultures par les éléphants. A Laikipia, au Kenya, nous avons installé une barrière de 90 m. de long composée de neuf ruches interconnectées, toutes vides, sur deux côtés exposés d'une ferme carrée de deux acres (arpents) dont les cultures subissaient une forte déprédation causée par les éléphants. Comparée à une ferme contrôle voisine, de

statut et de taille comparables, notre ferme expérimentale a subi moins de raids et a donc eu une meilleure productivité. Des indicateurs socioéconomiques suggèrent que non seulement le concept de barrière en ruches était populaire et souhaité par la communauté, mais qu'il peut même couvrir les frais de sa propre construction grâce à la vente de miel et autres produits dérivés. Nous sollicitons que des expériences soient faites pour tester ce concept de « clôture en ruches » de façon rigoureuse et scientifique, dans une gamme aussi étendue que possible d'installations agricoles, afin d'évaluer son efficacité et sa faisabilité.

Introduction

Elephants in Kenya are not confined to National Parks and Reserves (Douglas-Hamilton, Krink & Vollrath, 2005). Hence, interactions with farmers, and specifically crop raiding by elephants targeting fields, pose serious social, political, economic and conservation problems in Kenya as it does in many other parts of Africa (Newmark, Manyaza & Gamassa Deo-Gratias, 1994; Barnes, 1996; Hoare, 2000; Osborn & Parker, 2002; Balfour *et al.*, 2007). Accordingly, research efforts are now focused on finding effective farmer-managed deterrents that are both socially and economically suitable especially in 'conflict' zones where effective electric fences to separate humans from elephants are neither feasible nor affordable (Osborn & Parker, 2003; Omondi, Bitok & Kagiri, 2004).

Locals in and around our northern Kenyan study sites tell anecdotes of elephants being 'afraid' of bees. Vollrath & Douglas-Hamilton (2002) experimentally tested this concept by deploying beehives in a frequently visited bush area and demonstrated that elephants avoid feeding on acacia trees hosting hives (both empty and full) of the African honeybee. Following this, King and colleagues further demonstrated in more detailed playback experiments using a recording of disturbed bee sounds that elephants associate bee-buzz with a threat and run away, a behaviour

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not observed in response to appropriate controls (King, Douglas-Hamilton & Vollrath, 2007). Both studies strongly support the hypothesis that bees themselves, or even evidence of their presence such as empty hives or buzzing sounds, can be used to limit crop raiding by elephants. If indeed it were possible to use bees as an 'eco-deterrent' against elephant depredations, then this could have important socioeconomic implications. Not only would it diminish loss of farming income but would also add a diverse source of income through sales of bee products such as honey and wax (Bradbear, 2002).

Here we present results from a pilot study conducted to explore the deterrent capabilities of a unique beehive fence. Our two objectives were (i) to test the effectiveness of the new fence design and (ii) to assess stakeholder response and interest. In our experimental community, bee keeping was an established practice so we used a participatory monitoring framework to reveal individual and group reactions to the introduction of the novel technology of deploying bees to guard against elephants. Participation and inclusion in a project's decision-making foster commitment and accountability and often lead to a sense of empowerment and ownership (Kapoor, 2001; Hellin *et al.*, 2008). Our monitoring was based on Franzel *et al.* (2002) Type 2 field trials where farmers and scientists collaborate on the execution of the trial but the researcher offers the new technology for trial and leads on the experimental design. We outline our participatory methods in detail as we consider informed and full participation a key element to this kind of study and hence important for any repeats aiming to test its validity. While our study is rather preliminary (a large-scale trial is underway at another location), its results are very encouraging. Hence, on requests from farmers and wildlife managers, we are presenting the specifics of the beehive fence design and its preliminary results to enable wider trials to be conducted by willing experimenters elsewhere on the continent.

Materials and methods

Our study was conducted in the 20,000 acre Ex-Erok community in the southern region of Laikipia, Kenya. The 9,700 km² Laikipia plateau comprises a complex land use mosaic of large private and government cattle ranches, pastoral grazing lands and small holder farms. Historically a wildlife rich area, large mammals still roam freely throughout the district but with increases in human immigration and the proliferation of stronger boundary

fences, elephants in particular are now competing for vital resources with local farmers. Beekeeping activities in the area are typically small scale using traditional hives, and honey is valued for both consumption and as a cash crop (Raina, 2000).

The Ex-Erok study was carried out with cooperation and assistance from rural farmers within the seventeen member strong Mwireri Beekeepers Group. The area had been identified in 2004 as a high-risk area for crop raiding (Graham, 2007; Graham & Ochieng, 2008). After an introduction by Max Graham to the community, we conducted pretrial interviews with six different farmers across the community. Both their answers and observations of damaged fields confirmed the area's status as a high conflict zone for crop-raiding incidents by elephants.

Eight farmers from the Mwireri Beekeepers Group participated consistently during the development phase of the trial. These farmers represented approximately one-third of the households in the immediate trial area. Initially, two participatory activities were undertaken to help in designing the experimental trial. A calendar of the average year was discussed to highlight certain key activities relevant to the study. These included identifying planting, harvesting, rainy and dry seasons as well as the worst months for elephant crop raids. This calendar of seasonal activities identified the dry harvesting season of August–September as the best period to trial the beehive fence because of the prevalence of elephant raids during this time.

To select a site for the experimental trial of the beehive fence, these eight farmers created a map of their farming area. They drew symbols for each household, dominant land features (such as roads, dams, schools) and finally the movement patterns of elephants through the landscape. This map revealed that elephants living within the neighbouring cattle ranch frequently visited the community's water dam for an evening drink before entering the community lands for a night of crop raiding. The main route of elephant entrance from the dam into the village passed between two smallholder farms either side of the 'elephant highway', a phrase used by the villagers to describe the frequently used route. The farmers identified these two farms as the worst affected by elephant crop raids and were unanimously chosen by the group for the trials.

To verify this local knowledge of elephant movements through the community, Save the Elephants' (STE) research team monitored for us a notorious crop-raiding

bull, Genghis Khan, through the area using data from his Global System for Communication (GSM) satellite tracking collar (made by African Wildlife Tracking). By continuously downloading his hourly GPS movements onto Google-Earth maps using STE's tracking software (Wall, 2007), we were able to ground-truth his movements using both aerial searches and a ground tracking team for close observations.

To the east of the elephant corridor, Farm A was chosen by the group to trial the beehive fence. On the west of the corridor, 466 m away, Farm B was designated a 'control' farm without a beehive fence. Both farms were approximately 2 acres and grew the same intercropped species of maize, potatoes and beans with a few scattered sorghum plants. Only two farms were used during this pilot trial to minimize any potential risk by bees to the farming group and to test out the new, untested design and responses from the group before extending the trial to other crop-raided farms.

Nine used but empty traditional log beehives were deployed in the form of an 'L' shape beehive fence along

90 m of Farm A's northern boundary cutting off all the entrance routes frequented by raiding elephants. The field researcher introduced the technical design of the fence but the resulting final structure incorporated key adjustments contributed from group members' ideas (Fig. 1). The fence was deployed on the outer edge of a 10-m buffer zone around the crops to avoid any conflict between foraging bees and the farmer's daily activities with his crops. The rest of Farm A was protected by a neighbouring farm on the east, a strong hedge on the west and Farmer A's house to the south. With the help of twelve people, the fence took 2 days to build using twenty kerosene-treated poles, 200 m of plain fencing wire, 50 m of thin thatching wire, 2-inch and 4-inch nails, and 1 l of wood preservative. The beehive fence was completed in July 2007 before peak crop harvest season of August–September, but lack of occupancy meant that unoccupied hives were used for this trial.

The farmers identified two indicators that would help them decide if the beehive fence was a success or not. These were; (i) elephants should be kept away from

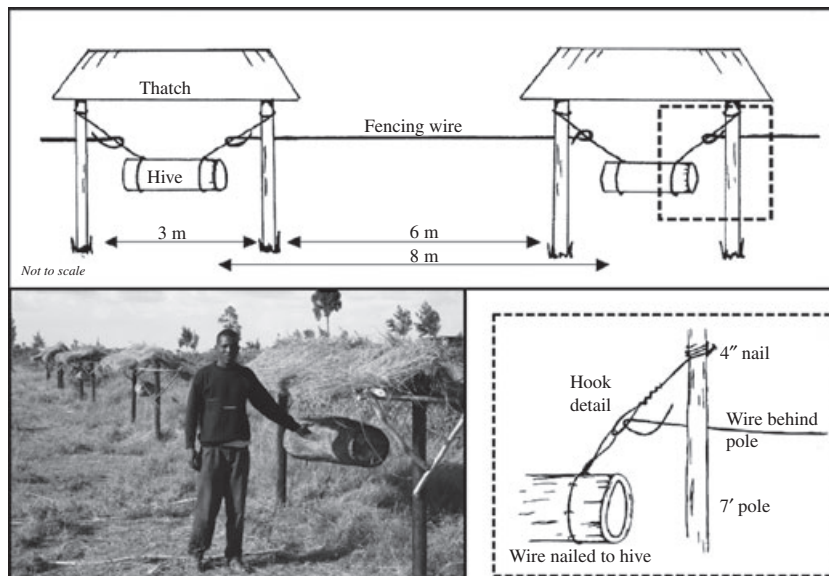


Fig 1 Beehive fence design. The fence is constructed with log beehives hung under small thatched roofs. The huts are spaced 6 m apart allowing the hives to be spaced 8 m apart. An elephant walking between huts will be less than 4 m to the nearest hive, the minimum distance elephants in the study area approached solitary beehives. The beehives swing freely, suspended by tightly secured fencing wire to the top of the seven foot poles. Each hive is linked to each other with strong, taut, fencing wire that hooks to the centre of the permanent wire of each hive and is, crucially, behind the upright poles on the crop side of the fence. An intruding elephant trying to enter the field will avoid the complex solid structure of the beehuts and will be channelled between them. As the elephant tries to push through the thigh-high wire, it causes the attached beehives to swing violently, thereby disturbing and releasing the bees to irritate or sting the elephant. However, if forced, the interlinking wire will break away before the beehive is pulled down. This also prevents elephants being trapped inside the farm as they can break out without damaging the hives. To prevent honey badger attacks, nail a 60–70 cm circular strip of iron sheet half way up the wooden post

damaging or eating the crops and (ii) the fence should be easy and cheap to maintain. We identified several additional indicators that were important in defining the success of the trial. These indicators were; (i) identifying patterns of elephant movement behaviour around the beehive fence structures, (ii) identifying positive responses from the farmers and (iii) realistic set-up costs of the beehive fence to ensure it could be a financially appropriate technology for other poor communities. Before encouraging investment in new technologies, such indicators can be vital when assessing the likelihood of uptake.

The farmers recorded crop-raiding events using simple data sheets, clearly explained during a training session. Farmer A recorded the number of elephants breaking through to crop raid on his farm by noting the raid time, herd composition (when able) and movement pattern in and out of the farm. Farmer A sat up at his house with periodic checks on his crops leaving the beehive fence as his first defence. However, once on his land, Farmer A was freely available to chase the elephants away using whatever deterrent tactics he liked. Farmer B, without the beehive fence, also gathered daily data on the raid time and number of elephants successfully raiding but he also managed to record the number of elephants approaching his farm that were successfully scared away by his traditional deterrent tactics (personal vigilance, noise, fire, dogs). These data enabled us to monitor elephant movement behaviour and compare variation in crop raids between the two farms over the same 6-week period of peak crop harvest time.

To assess farmer perception of the beehive fence, the field researcher stimulated conversation about the progress of the project with both individuals and the group with all comments and actions observed during these weekly discussions recorded in a notebook. This resulting rapport enabled free flowing ideas and discussion about the beehive fence design and application.

Results

The movement of crop-raiding elephants throughout the community was verified from monitoring Genghis Khan's GPS tracking data over the same crop-raiding season. During the study, he was observed crop raiding by several farmers and photographed from the air by IDH and by LK on the ground in the centre of a herd of eighteen bull elephants coming back from crop raids in Ex-Erok. Dung from the herd was densely littered with bean husks and maize

stalks. His GPS movements closely matched the consensus map of elephant movements drawn up by the group.

After the 6-week trial period, the data from both the elephant movements and the farmer's perceptions of elephant raids were studied in the context of each previously identified indicator. The evaluating indicators (cost, effectiveness, efficiency and perception) are briefly discussed.

Costs and ease of fence maintenance

The economics of the fence are an important indicator towards success or failure of the concept. Initial set-up costs will vary locally but need to include funds for: (i) the hive, (ii) a thatched roof for shade, (iii) two sturdy poles to carry hive and roof and (iv) stiff wiring to hang the hive and connect it with its neighbours. Often it will be possible to defer, or share, costs with a small local or national honey trader. During the trial, our beehive fence suffered four raids when elephants broke through the fencing wire and successfully entered the farm. The wire did not break, nor did it bring down the beehives on either side so the farmer was able to simply clip the wire back into place ready for the following night. During the 6 weeks, there were minor repairs to the bee huts that could all be catered for from local resources at no cost (e.g. grass for thatching) or a small expense (e.g. a few nails). The fence was inspected every morning but this took away little time from the farmers' other daily chores. This suggests that a beehive fence, once erected, requires little maintenance. Of course, this will change when hives are occupied and especially when they are full of honey. Indeed, honey sales can potentially recover the cost of the hives reasonably quickly and provide a tangible incentive for maintaining the entire fence line structure. Costs for the beehive fence based on using traditional log beehives were approximately US\$315 per 100 m. In Kenya, 1 kg of honey can sell for US\$2 and each traditional log hive has the potential to generate two to three annual harvests of 7–10 kgs per harvest. Upgrading log beehives to the more productive Kenyan Top Bar (KTB) hives would generate more income, particularly if a queen excluder is fitted to separate the valuable honey from brood (Jones, 1999).

Effectiveness as deterrent

Over the 6-week study period, the two focal farms experienced twenty successful crop raids involving 133 elephants. Farm A, with the beehive fence, experienced seven

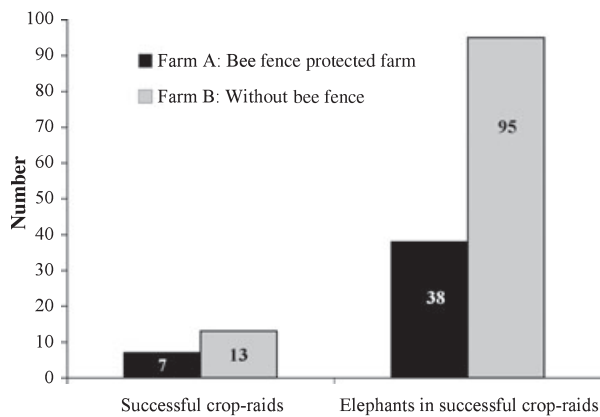


Fig 2 Variation in crop raiding incidents during the 6-week trial. Farm A, protected by the beehive fence, experienced 86% fewer successful raids and 150% fewer raiding elephants than control Farm B

successful raids involving 38 elephants. Farm B experienced thirteen raids (86% more than Farm A) involving 95 invading elephants (150% more than Farm A; $X^2 = P < 0.001$, $df 1$) (Fig. 2). In addition, Farmer B recorded a further 71 elephants in eight failed raid attempts that he prevented from entering his farm using his traditional deterrent tactics. In total Farm B had 21 attempted raids by 166 elephants during the 6-week trial, all of which occurred less than 500 m from Farm A. Most notably, by the end of the harvest season, Farm B had almost no crops to harvest, with the farmer estimating that about 90% of his harvest had been destroyed or eaten by elephants, whereas Farmer A was able to harvest relatively successfully collecting a variety of sorghum, beans, potatoes and maize. This suggests that the fence was at least partially successful in deterring elephants.

Efficiency of beehive fence

Within Farm A, there were ten clustered events where elephants broke into the farm within the seven successful raids. Of these ten inbound events, four occurred between the beehuts pulling down the fencing wire and six occurred by elephants walking around the beehuts to make new entrances into the farm above the beehive fence line breaking down the hedge. Once inside Farm A, there were fourteen clustered events where elephants broke out of the Farm (either naturally or chased away by Farmer A). Of these fourteen outbound events, twelve occurred between the beehive huts and two occurred outside the

beehive fence line. Essentially, the beehive fence did not pose a trap to the elephants inside the farm once scared off the land by Farmer A. There was no correlation in dates between all 21 attempted events on Farm B (either deterred visit or successful raid) and the seven successful raids on Farm A. Elephants deterred from one farm do not necessarily move on to raid the next closest farm.

Perception by farmers

Social responses and attitudes to the project were consistently very positive throughout the trial. The following key observations were made:

1. A consistent number of group members turned up to each meeting with a slow increase from eight to twelve. Although overall group membership increased from seventeen to 24 as word of the trial spread, over half these listed group members remained curious spectators rather than integrated participants. A scout from Dr Graham's 'Darwin-Cambridge Laikipia Elephant Research Project' commented about Farm A verbatim 'You can't compare his farm to the others now. He still has crops and the others are all finished by elephants.'
2. After the main 6-week-study period, Farmer A extended (at his own initiative and cost) the beehive fence with two more hives to cover a new elephant entrance site above the beehive fence.
3. All attending members of the beekeeping group expressed a desire to have a similar fence around their farm listing the potential benefits of the fence as (i) deterring elephants, (ii) honey production, (iii) improved security from cattle rustlers and (iv) improved sleeping patterns inside the house rather than outside in a corner of the field.
4. Members of the group discussed the risks of the fence, i.e. increased stings (danger) for children and livestock fatalities from bee attacks. It was agreed that these risks were outweighed by the daily risk of being trampled by an elephant and hunger because of complete harvest destruction.
5. The main disincentive for starting construction was (i) cost of materials and (ii) knowledge that a government-sponsored electric elephant fence was about to be constructed to protect the community from future elephant raids (this was completed by February 2008).

Discussion

To conduct this pilot study, we used our predesigned technology (the beehive fence) that was field tested under

'real life' conditions with the end users to assess effectiveness and adoption potential. Our participatory study helped to generate a sense of participant ownership and enabled the evaluation of genuine responses and attitudes to the introduced technology by both scientists and farmers.

The effectiveness of the beehive fence was remarkable as there were fewer raids and a significantly lower number of elephants in successful raids on the protected farm compared with the nearby control farm, which suffered severe (and apparently typical) damage from crop-raiding elephants during the trial period.

Equally encouraging were the positive responses from the farmers towards the concept of a beehive fence. Although there was a recognized risk from increasing the bee population so close to their living quarters, the risk was outweighed by the benefits of the fence for deterring destructive elephants plus the long-term potential of generating a sustainable income through the sale of bee products. Farmers believed that the beehive fence also protected them from cattle rustlers and they predicted being able to spend more time in the house at night.

The sample size (one experimental and one control farm) was small and variables such as soil type, exact hours of vigilance, crop density and variation in outer boundary defences (e.g. thickness of low protective hedges) around the two farms were not quantifiably measured. Despite these possible variations, the outcome was robust with the experimental farm attracting fewer elephant raiders and consequently growing more produce. Moreover, the participants in the experiment were convinced that the deterrent worked and decided, on their own and with their own funds, to continue with beekeeping through construction of more hives to extend the fence and the planting of nectar producing vegetation. Hence, overall, we consider this a successful pilot trial of a simple design for a guardian-bee elephant deterrent in an area of small-scale farms. Interestingly, as none of the hives was occupied during the trial, the deterrent must have been due to either (or both) (i) the image or smell remembered by the elephants of past negative experiences with occupied hives and/or (ii) the complex physical, moving barrier of the wires and swinging hives. In the light of other experiments (Vollrath & Douglas-Hamilton, 2002; King *et al.*, 2007; King *et al.*, in prep), we suspect that the outcome of this study was largely because of previous 'anti-bee' conditioning of the elephants.

As the site was fenced against elephants shortly after the experiments, we could not follow up our pilot trials with

more farms but instead started a major beehive fence experiment (with 60 farms) using KTB hives in another part of Kenya. Although this experiment has been taken up with comparable enthusiasm by its participants (which unlike the Ex-Erok farmers had no prior experience with bee keeping), all those farms were devastated by the 2008/2009 drought resulting in 100% loss in crops and consequently a total lack of elephant raids. As word of our Ex-Erok pilot study spread, more farmers and researchers began to question us about the concept, hence we decided to publish its details in order to allow others to independently begin rigorously testing our thesis now rather than delay by a few more years, with possibly detrimental socio-economic consequences.

Acknowledgements

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Bee Threat Elicits Alarm Call in African Elephants

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Abstract

Unlike the smaller and more vulnerable mammals, African elephants have relatively few predators that threaten their survival. The sound of disturbed African honeybees *Apis mellifera scutellata* causes African elephants *Loxodonta africana* to retreat and produce warning vocalizations that lead other elephants to join the flight. In our first experiment, audio playbacks of bee sounds induced elephants to retreat and elicited more head-shaking and dusting, reactive behaviors that may prevent bee stings, compared to white noise control playbacks. Most importantly, elephants produced distinctive “rumble” vocalizations in response to bee sounds. These rumbles exhibited an upward shift in the second formant location, which implies active vocal tract modulation, compared to rumbles made in response to white noise playbacks. In a second experiment, audio playbacks of these rumbles produced in response to bees elicited increased headshaking, and further and faster retreat behavior in other elephants, compared to control rumble playbacks with lower second formant frequencies. These responses to the bee rumble stimuli occurred in the absence of any bees or bee sounds. This suggests that these elephant rumbles may function as referential signals, in which a formant frequency shift alerts nearby elephants about an external threat, in this case, the threat of bees.

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Introduction

Mammalian calls can reflect the internal states of animals, such as fear, but also may refer to external objects or events, such as the presence of predators [1]. For example, arousing social contexts including social separations or encounters with strangers can result in calls of increased emotional intensity as observed in rhesus monkeys, *Macaca mulatta* [2], red fronted lemurs, *Eulemur rufifrons* [3], baboons, *Papio cynocephalus ursinus* [4], guinea pigs, *Cavia porcellus* [5], and tree shrews, *Tupaia belangeri* [6]. Typical acoustic responses to potentially threatening challenges include changes in tempo-related features (e.g. call rate and duration) and source features (e.g. increased and more variable frequency and amplitude). Filter features related to vocal tract modulations are less commonly associated with arousal, but have been observed in baboons [4].

In addition to expressing internal state, mammalian vocalizations are also known to refer to external objects or events (i.e., ‘referential signaling’ [1]). In many cases, mammalian alarm calls vary acoustically according to specific predator species or class of predator (e.g., aerial versus terrestrial). Playback experiments with suricates, *Suricata suricatta* [7], and vervet monkeys, *Cercopithecus*

aethiops [1], show that listeners react to alarm calls as if they were in the presence of an actual predator. This suggests that the acoustic structure of alarm calls can be related to specific external events, which in turn can be acted upon in adaptive ways by listeners. The complexity and variation of the acoustic cues can be seen in examples taken from three species of *Cercopithecus*, in which vervet monkeys *C. aethiops* separate their alarm calls for leopards and eagles through the location of dominant frequencies [8], Campbell's monkeys *C. campbelli* separate them by call duration, fundamental frequency and dominant frequency location [9], while Diana monkeys *C. diana* separate them by call rate, duration, fundamental frequency and formant frequency location [10,11,12]. Animal alarm calls are not always predator specific, however. For example, yellow-bellied marmot, *Marmota flaviventris*, alarm calls are similar towards a range of predators but do increase in rate with level of perceived risk [13].

Unlike the smaller and more vulnerable mammals, African elephants have relatively few predators that threaten their survival in the wild. In Kenya's Amboseli National Park, however, defensive and retreat behavior in elephants was observed in the presence of Masai tribesman [14], who have been known to kill elephants. African elephants react similarly to sound playbacks of

unfamiliar conspecifics [15]. Little research has been conducted on elephant vocalizations in response to specific threats, although observations of elephants ‘roaring’ or ‘trumpeting’ in response to the presence of lions is well known [16]. More recently, research has demonstrated that African elephants actively avoid contact with African honey bees - with implications for the management of both species [17,18]. First was the discovery that Kenyan elephants avoid feeding on trees with beehives [19]. Subsequently, a playback study demonstrated that elephants retreat when hearing the sounds of disturbed bees [20].

In order to investigate this apparent natural threat to elephants further, we recorded the vocalizations of elephants in response to playbacks of disturbed bee sounds, using an array of microphones capable of recording low frequency elephant calls. In a second playback experiment, we played the recorded “rumble” vocalizations to resting elephants in order to examine their potential function. We played natural and experimentally modified ‘bee-response’ calls, in order to isolate and explore the effect of a specific acoustic feature on the response of listeners, namely, the location of the second formant. Such formant location shifts are

due to modulations of the vocal tract [21]. Thus we were able to explore how an acoustically distinctive elephant rumble produced in the presence of bees may function as an alarm call.

Results

Honeybee playbacks

Confirming previous observations [20], elephants moved away in response to the playbacks of bee sounds. We performed 15 bee sound and 13 white noise playback trials to elephant families, consisting of a 2-min pre-stimulus phase, a 4-min stimulus phase (white noise or bee sounds), and a final 2-min post-stimulus phase. In 14 out of 15 bee trials (93%), families had moved away, compared to 6 of 13 white noise control trials (46%). Elephants moved away significantly further in response to bee sound playbacks ($71.67 \text{ m} \pm \text{s.e. } 8.46$) than to white noise playbacks ($32.3 \text{ m} \pm \text{s.e. } 11.5$; Mann-Whitney U test, $n_1 = 15$, $n_2 = 13$, $U = 45$, $p = 0.012$, Figure 1a). Additionally, using 360 seconds as a ceiling for families that did not move, elephants moved faster during bee sound playbacks (mean latency $61 \text{ sec} \pm \text{s.e. } 25.1$;

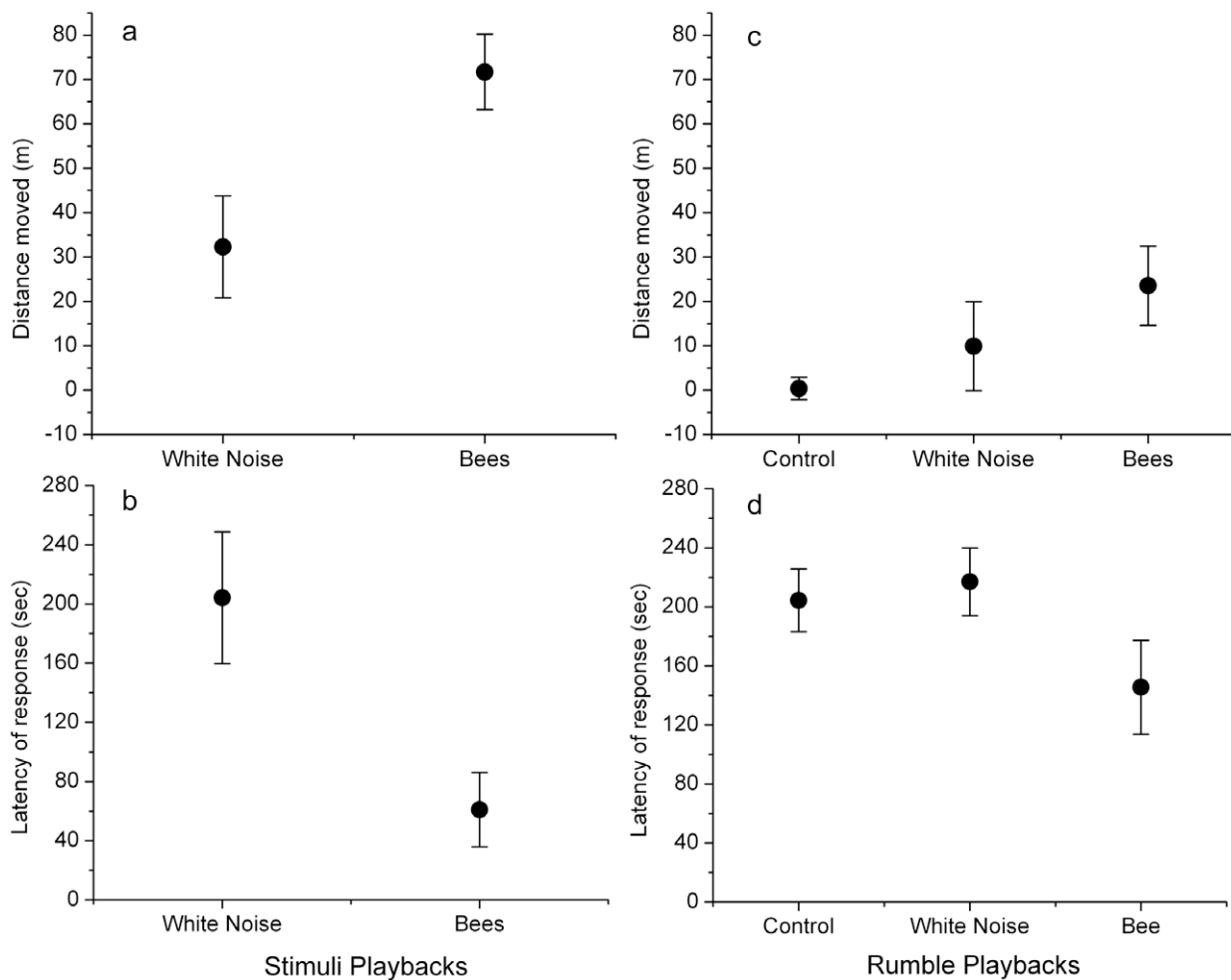


Figure 1. Distance moved and latency of response of elephants to sound and rumble playbacks. Mean (± 1 SEM) of distance moved (a) and latency of response (b) of elephant families responding to bee sound ($n = 15$) and white noise ($n = 13$) playback trials. Elephants responding to bee sound playbacks moved on average over twice the distance of elephants responding to white noise playbacks (a) and were faster (b). For bee rumble playbacks ($n = 10$) elephant families moved away further (c) and faster (d) than elephant families responding to white noise or control rumble playbacks. Although rumble playbacks showed a more muted response than sound playback trials the directional pattern of behaviors were similar when comparing across experimental stimuli (a–d). doi:10.1371/journal.pone.0010346.g001

median: 25 seconds) than during white noise playbacks (mean latency 204 seconds \pm s.e. 44.5; median: 207 seconds; Mann-Whitney U test, $n_1 = 15$, $n_2 = 13$, $U = 56.5$, $p = 0.058$, Figure 1b).

Upon hearing bee sounds, elephants exhibited increased headshaking and dusting behavior during the 4-min stimulus phase of trials (Friedman's ANOVA, $n = 15$, headshaking: $F = 6.4$, $p = 0.002$; dusting: $F = 5.7$, $p = 0.002$; Figure 2a and 2b). When exposed to white noise, in contrast, headshaking and dusting were less frequent and rates did not differ across phases of the playback trials (Friedman's ANOVA, $n = 13$, headshaking: $F = 0.55$, $p = 0.135$; dusting: $F = 1.19$, $p = 0.092$; Figure 2a and 2b).

The total number of calls (rumbles, revs, screams, trumpets [22]) recorded from the triangular array was 217, and significantly higher for the bee sound playbacks ($n = 15$, calls = 160) than for white noise playbacks ($n = 13$, calls = 57; Kolmogorov-Smirnov two-sample test, $\chi^2 = 10.03$, $p = 0.007$) with low-frequency rumbles predominating ($n = 199$). During bee sound playback trials, call rates among non-infants (see Materials and Methods) was lowest

during the pre-stimulus phase, increased during the bee stimulus phase, and remained high in the post-stimulus phase (Friedman's ANOVA, $n = 15$, $F = 4.3$, $p = 0.046$; Figure 3), but there was a muted response with no significant differences in call rates across trial phases for white noise playbacks (Friedman's ANOVA, $n = 13$, $F = 3.04$, $p = 0.118$). There were no significant differences between white noise and bee sound playback trials for family size, age composition within each trial family, microphone distances, temperature, time of day, altitude or air pressure (K-S two-sample tests, $p > 0.05$).

Acoustic properties of rumble response

We conducted acoustic measurements on rumbles occurring during the pre-stimulus phases of all trials ($n = 13$), during the stimulus and post-stimulus phases of bee sound trials ($n = 20$), and during stimulus and post-stimulus phases of white noise trials ($n = 20$; see Materials and Methods). Acoustic features measured were call duration, mean and range of the fundamental

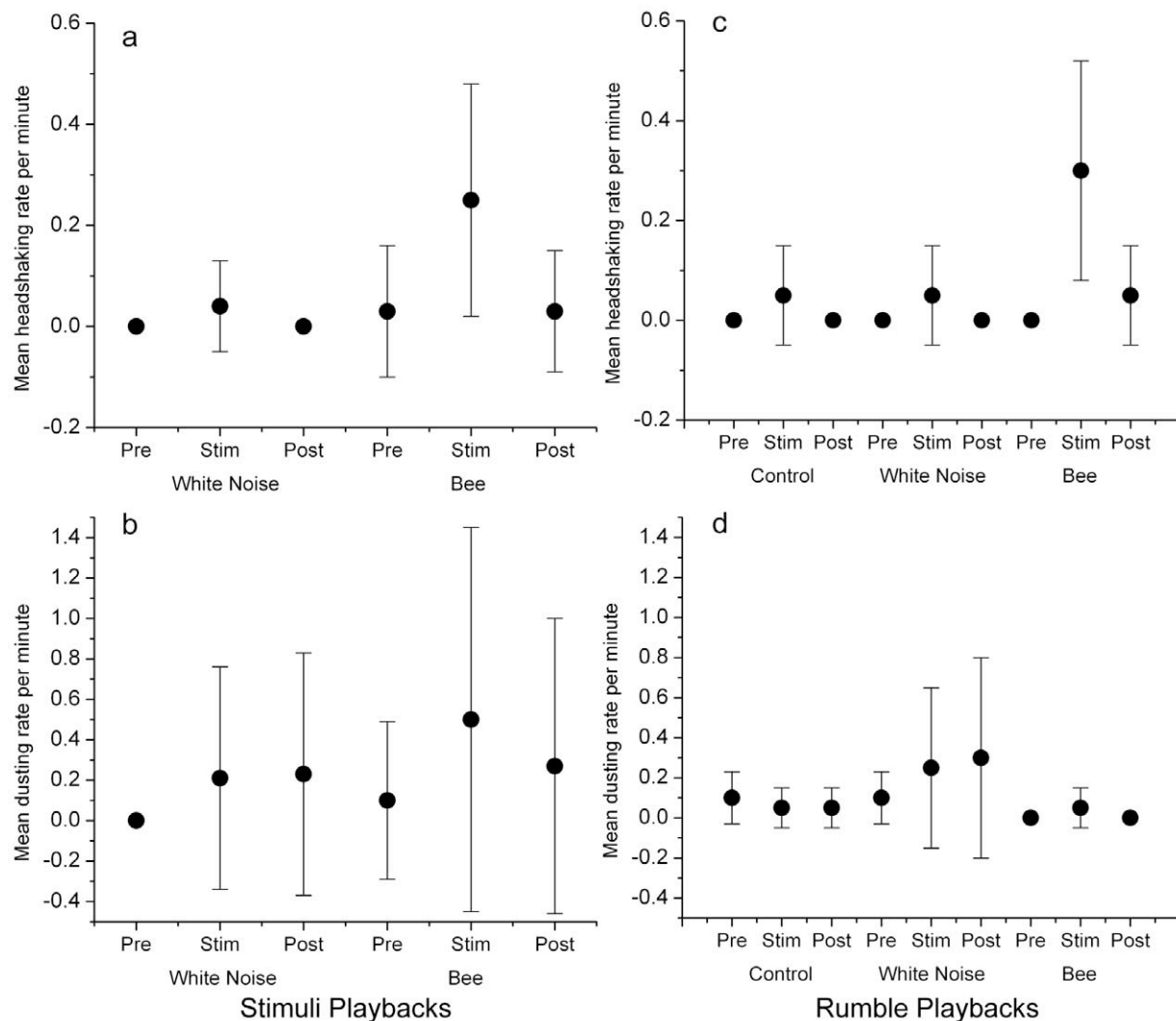


Figure 2. Headshaking and dusting behaviour of elephants responding to sound and rumble playbacks. Mean (± 1 SEM) of headshaking (a) and dusting (b) rates per minute of elephant families responding to bee sound ($n = 15$) and white noise ($n = 13$) playback trials. Elephants responding to bee sound playbacks showed increased headshaking (a) and dusting (b) during the trials compared to those responding to white noise or control rumble playbacks. For bee rumble playbacks ($n = 10$) elephant families showed similar and significant patterns of increasing headshaking behavior (c) but dusting was random across trials (d). doi:10.1371/journal.pone.0010346.g002

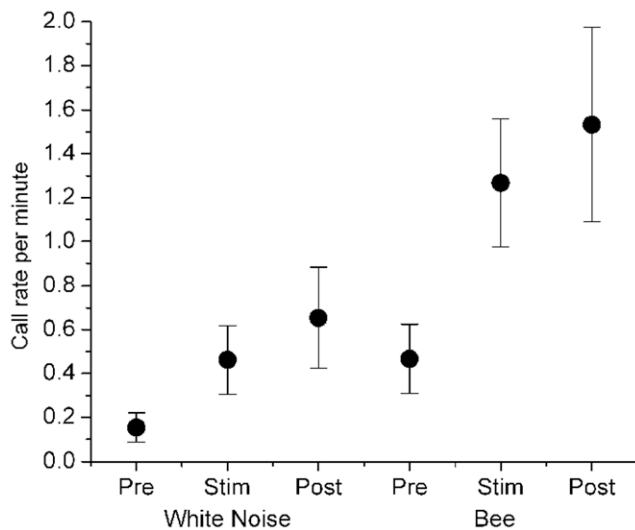


Figure 3. Call rates of elephants responding to sound and rumble playbacks. Mean call rates per minute (± 1 SEM) recorded during the pre-stimulus, stimulus, and post-stimulus phases of bee ($n=15$) and white noise ($n=13$) playback trials. Elephants in bee playback trials responded to the stimuli with a significantly higher call rate in both the stimulus and post-stimuli phases compared to the pre-stimulus phase, but did not do so for white noise playback trials. doi:10.1371/journal.pone.0010346.g003

frequency, mean and range of call amplitude, and the first and second formant frequency locations [23]. Formants are enhanced frequency components of a call, produced by the resonating effects of the vocal tract filter, which enhance some frequencies (called resonant frequencies or formants) and diminish others [24]. MANOVA showed that the seven acoustic variables taken together differed across the three playback contexts (Wilks' Lambda = 0.484, $F(14) = 2.745$, $p = 0.002$). Univariate tests showed that the mean fundamental frequency (F_0), the fundamental frequency range (max F_0 - min F_0), and the second formant frequency location differed across playback contexts (ANOVA, $df = 2$, mean F_0 : $F = 5.127$, $p = 0.009$; F_0 range: $F = 8.479$, $p = 0.001$; second formant location: $F = 5.817$, $p = 0.005$).

Tukey's Honestly Significant Difference pair-wise tests revealed that rumbles produced during white noise and bee sound trials both exhibited increased fundamental frequency and fundamental frequency range, compared to pre-stimulus control rumbles (F_0 : white noise vs. control $p = 0.009$, bee vs. control $p = 0.036$; F_0 range: white noise vs. control $p = 0.020$, bee vs. control $p < 0.001$) (Figure 4). Additionally, rumbles produced during bee sound trials exhibited an upward shift in the second formant location, compared to both white noise ($p = 0.013$) and control rumbles ($p = 0.018$) (Figure 4). Observed acoustic changes were not attributable to body size or physical exertion, as no acoustic measure was significantly correlated with the age composition of the target family group or the distance moved away from playback stimuli (Pearson's correlations, $p > 0.05$).

Rumble Playbacks

We conducted a second playback experiment to determine if rumbles produced in response to bees elicit different responses in listeners compared to rumbles produced in response to white noise. However, we could not identify individual callers, so any differences observed in listener response to 'bee' and 'white noise' rumble playbacks could be due to individual variation of callers,

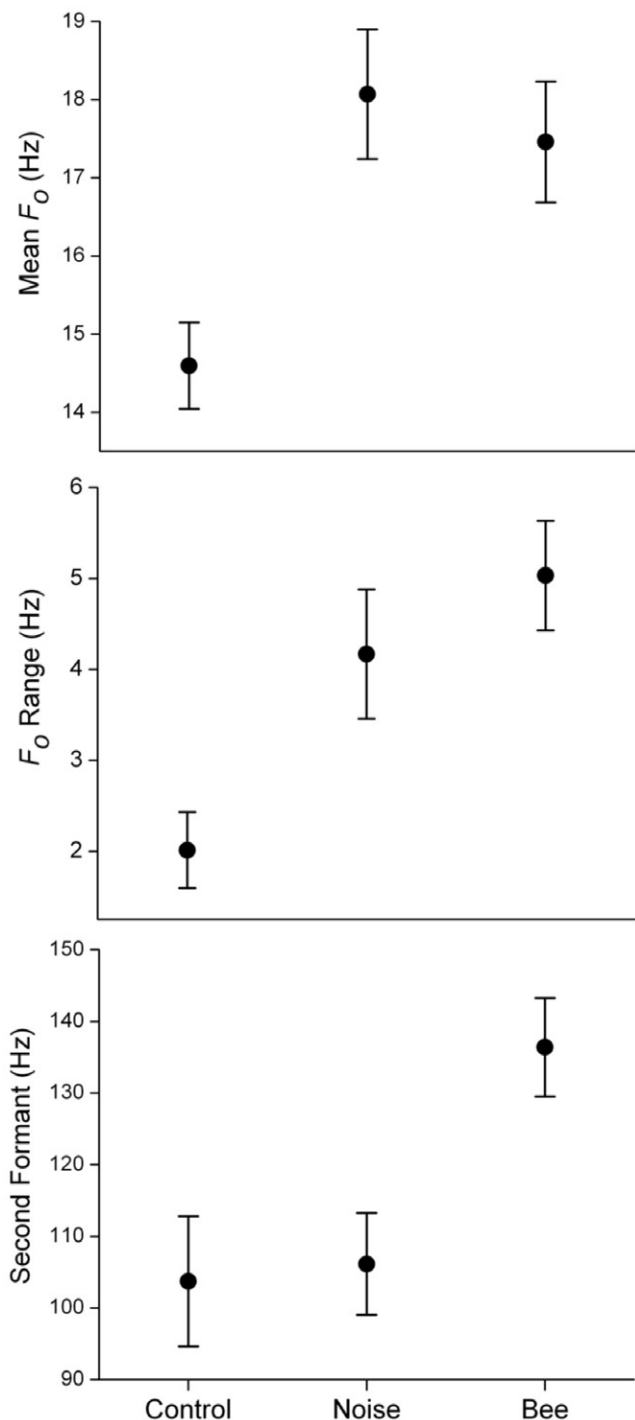


Figure 4. Acoustic features of rumbles emitted in response to sound playbacks. Mean (± 1 SEM) for acoustic features across the three contexts (control = pre-stimulus phases of trials; noise = during stimulus or post-stimulus phases of white noise trials; bees = during stimulus or post-stimulus phases of bee trials). Results of pair-wise tests showed that bee and white noise rumbles were statistically different from controls for mean F_0 and F_0 range, and that bee rumbles were significantly different from white noise and control rumbles for second formant frequency location. doi:10.1371/journal.pone.0010346.g004

not due to differences in the two classes of rumble (for details see Materials and Methods). We overcame this problem by experimentally manipulating rumbles produced in response to bees so

that they resembled rumbles produced in response to white noise, namely, by lowering the second formant frequency location. We selected three bee response rumbles (Audio S1) that exhibited second formant frequencies that were typical of the class of bee rumbles as a whole (designated the 'bee rumble' stimulus). The 'white noise rumble' stimulus (Audio S2) consisted of the same three rumbles, but with the second formants experimentally lowered in frequency location to resemble rumbles produced in response to white noise playbacks (Figure 5; also see Materials and Methods). Thus, all features of the two stimuli remained identical, except the one feature that distinguished bee rumbles from white noise rumbles, the second formant location (compare Figures 4 and 5). As a further control, we selected three pre-stimulus rumbles from the same trial ('control rumble' stimulus), matched for duration and amplitude to those of the other rumble stimuli (Audio S3).

Rumble playback trials followed a similar protocol as the previous sound playback experiments, consisting of a 2-min pre-stimulus phase, followed by a 2-min stimulus phase (3 rumbles repeated 4 times), and a final 2-min post-stimulus phase. We performed 10 playbacks of each rumble stimulus ('bee rumbles', 'white noise rumbles', and 'control rumbles') in random order for a total of 30 playback trials. In 6 of the 10 bee rumble playback trials the elephant families moved away from the speaker (see online supplementary video, Video S1), compared to only 1 family moving away during 10 white noise rumble playbacks, and 2 families moving away during 10 control rumble playbacks (Table 1). It is possible that the order in which trials are presented can influence behavioral response, but there was no evidence for order effects in our trials. We were able to play more than one stimulus type to 11 families (Table 1), but there was no difference in distance moved when comparing the first and last playback trials (Wilcoxon Matched Pairs Test, $n = 11$, $p = 0.969$).

To detect differences in distanced moved from the speaker we conducted non-matched comparisons of the behavioural responses across 'bee rumble', modified 'white noise rumble', and 'control rumble' stimuli (Table 1). Elephant families exposed to the playback of bee rumbles moved away significantly further than elephants responding to either the white noise rumbles (Mann Whitney-U test, $n = 10$, $U = 26$, $p = 0.041$) or control rumbles (Mann Whitney-U test, $n = 10$, $U = 24$, $p = 0.032$), but distance moved was not different between white noise and control rumbles (Mann Whitney-U test, $n = 10$, $U = 47$, $p = 1.0$; Figure 1c).

Additionally elephants listening to bees moved faster than elephants responding to white noise (Mann Whitney-U test, $n = 10$, $U = 26$, $p = 0.042$; taking 240 seconds as the ceiling for elephants that did not move; Figure 1d) but a difference in latency between bee and control rumbles (Mann Whitney-U test, $n = 10$, $U = 31.5$, $p = 0.132$) and between white noise and control rumbles (Mann Whitney-U test, $n = 10$, $U = 41.5$, $p = 0.582$; were not significant).

Headshaking behavior increased significantly during the stimulus phase of the bee-rumble playbacks (Friedman's ANOVA, d.f. = 2, $F = 3.15$, $p = 0.03$) but no difference was observed across stimuli phases for families responding to white noise or control playbacks (Figure 2c). Headshaking behavior in response to bee rumble playbacks was remarkably similar to headshaking observed in direct response to bee sound playbacks (Figure 2a). Dusting was observed sporadically across all rumble trials but, unlike the response to bee sound playbacks (Figure 2b), did not increase in response to bee rumble playbacks (Figure 2d).

Discussion

When exposed to the sounds of disturbed honeybees, African elephants exhibited behaviors that appear to function as defense

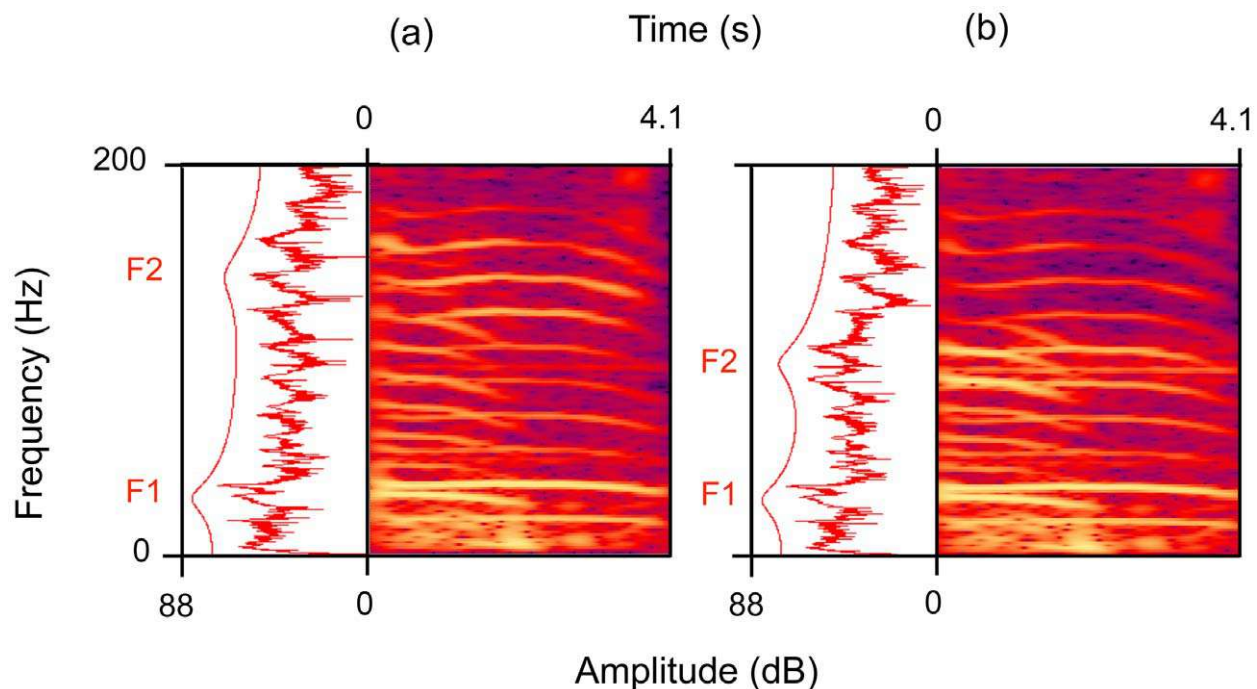


Figure 5. Spectrograms of elephant rumbles. (a) Unmodified African elephant rumble response to the bee playback stimulus. The Fourier frequency spectrum of the entire signal (PRAAT, version 4.6.18) with LPC smoothing showing two formants (F1, F2) and the spectrogram (44.1 kHz, Hanning window, 16384 bands; Adobe Audition, version 1.5) are shown. (b) Same signal as (a) with the frequency location of the second formants (F2) artificially lowered to match those observed in responses to white noise playbacks (see Materials and Methods). doi:10.1371/journal.pone.0010346.g005

Table 1. Known elephant families tested with different rumble playback stimuli.

Elephant Families Trials N = 30	Mean distance moved (m)		
	Bee	White Noise	Control
Winds 2	60	0	12
Maya Churchill	80	-1	10
Winds 3	30	0	
Storms 2	0	0	
Spice Girls	8.6	0	
Butterflies	35	0	
Virtues: Hope	0		0
Virtues: Generosity	22		0
Artists 1	0		-18
Virtues	0		
Native Americans		100	
Winds 1		0	
First Ladies		0	0
Clouds		0	0
Artists 2			0
Rift Lakes: Baringo			0
Unknown Family			0

Distance moved was relative to the speaker during each playback trial. Minus sign indicates movement towards the speaker.
doi:10.1371/journal.pone.0010346.t001

against bees. Headshaking and dusting would knock bees away and fleeing from the area quickly would lower the risk of being stung. As elephants moved away from the sound source, they produced rumble vocalizations both during and after the bee sound stimulus. These rumbles may be simple expressions of emotional intensity [4], or they may function as contact calls that coordinate group movement [25,26] or as alarm calls to more distant elephants [16,25]. It is also possible that such calls are used in social facilitation i.e. teaching the inexperienced and more vulnerable young about a common and dangerous threat [15].

The acoustic characteristics of the rumbles we examined are consistent with both increased emotional intensity of callers and with signaling to conspecifics. For example, rumbles produced in response to bees and white noise both exhibited increased and more variable fundamental frequencies, two common acoustic features associated with increased emotional intensity in other mammals generally [4] and in African elephants specifically [23,27]. However, rumbles produced in response to bees were further distinguished by an upward shift in the second formant location, which was not observed in white noise or pre-stimulus control rumbles, and has not been observed, to our knowledge, in other emotionally arousing contexts in elephants [23]. Such formant characteristics are controlled by the physical properties of the super-laryngeal vocal tract filter, which enhances resonance, or formant, frequencies. In humans, modulations of the vocal tract filter (e.g., lip rounding and tongue position) are responsible for the production of different vowels, which convey semantic information [24]. Our results suggest that such vocal tract manipulations in elephants may function in a similar way.

When rumbles produced in response to bees (with high second formant locations) were played to other elephant families, subjects were more likely to move further away from the sound source,

and showed increased headshaking compared to reactions to the same rumbles with second formants artificially lowered to resemble 'white noise' rumbles, and to pre-stimulus control rumbles. Since the 'bee rumbles' and 'white noise rumbles' differed only in the location of the second formant, this provides evidence that vocal tract modulation alters the formant characteristics of their rumbles when in retreat from this threat, and that rumbles exhibiting such a formant frequency shift can function as a referential signal that warns other elephants about the presence of an external threat from the environment, in this case, the threat of bees.

While we cannot conclude with certainty that this alarm call is specific for bees (more experiments are underway to compare responses to other threats), the similar behavior patterns revealed in response to bee sound and to bee rumble playbacks (i.e., response speed, distance moved, and headshaking) make these calls good candidates for such specificity. Indeed, as elephants and bees have been interacting for millennia in the African savannah, selection pressure may have led to the evolution of an ability to communicate about such an ubiquitous threat, particularly in the light of the fact that other elephant vocalizations are situation specific [28,29]. At the very least, rumbles with upwardly shifted second formant locations may function as general alarm calls, since other elephant families retreat far from the area when exposed to such rumbles in the absence of bees or other external threats. Dusting behavior increased in the presence of bee sounds, but did not increase during playbacks of 'bee rumbles', so more work is needed to reveal whether or not elephants might be trying to knock the insects out of the air with such behavior. Understanding how elephants react to and communicate about the presence of bees will not only advance our understanding of elephant behavior and vocal communication, but also our understanding of the potential deterrent effects of beehives on crop-raiding elephants [18].

Materials and Methods

Honeybee playbacks

We played the sounds of disturbed honeybees ($n = 15$) and white noise controls ($n = 13$) to elephant families containing known individuals resting under trees in the Samburu and Buffalo Springs National Reserves, Kenya [30,31]. Following previously published protocols [20], we performed the playbacks from a camouflaged speaker (8–18 m from the nearest subject) in the dry season of February–March 2008. In addition, three audio-recording units were deployed in an array surrounding target families to capture their vocal response (44.1 kHz sample rate). Two units (Marantz PMD670 recorder; Earthworks QTC1 microphone, 4–40,000 Hz ± 1 dB) were deployed from the vehicle window in duffle bags (15–70 m from nearest subject), and one unit (Marantz PMD671; Earthworks QTC50, 3–50,000 Hz ± 3 dB) and a video recorder were deployed on the research vehicle roof (15–40 m from nearest subject).

After set-up, a two minute pre-stimulus control phase began, followed by a 4-min stimulus phase (bee sounds or white noise), and a final 2-min post-stimulus phase. After each trial, the distance that the elephants traveled away from the sound source was recorded (0–100 m [20]). Video of each trial was used to score other behaviors and group composition based on body size (age classes: 0–2 yrs, 3–14 yrs, >14 yrs). A minimum gap of 5 days was allocated before the same family was tested with the alternate sound. Every attempt was made to play both bees and white noise to the same family, randomly assigned, but some elephants left the reserve and were not seen after the first trial.

The triangular array of three microphones surrounding the elephants allowed for the identification of vocalizations produced by the target family, by comparing relative amplitudes of calls on the three microphones. Identification of individual callers within families was not possible however. The number of calls (rumbles, revs, screams, trumpets [22]) recorded was 217 ($n = 160$ during bee playbacks; $n = 57$ during white noise playbacks). Low-frequency rumbles predominated ($n = 199$). Field observations suggested that infants vocalized at random across playback trials, so infant vocalizations (0–2 yrs) were removed from the data set. We identified infant rumbles using data from African elephant infants of known age (0–3 yrs; $n = 120$ rumbles) at Disney's Animal Kingdom [32], in which infants aged 0–2 yrs produced rumbles with mean fundamental frequencies above 20 Hz and mean durations below 1.5 sec. Rumbles meeting both criteria ($n = 17$) were removed.

Acoustic measurement of rumble response

Rumbles were cut from start to end using Adobe Audition (version 1.5) and acoustic measurement of calls was performed in PRAAT (version 4.5.18) [33] using automated routines. Elephant rumbles were down-sampled to a 400 Hz sample rate to analyze low frequencies. For each call, pitch floor and ceiling variables were adjusted to surround the observed fundamental frequency, replacing standard settings. From the fundamental frequency (F_0) contour, mean F_0 and F_0 range (maximum F_0 –minimum F_0) were computed. From the intensity contour, mean amplitude and amplitude range were computed. Calls were high-pass filtered (Hanning window, 10 Hz cut-off, 1 Hz smoothing) to remove background noise below the signal. A Fast Fourier frequency spectrum of the middle 0.5 s of the call was generated (bandwidth = 200 Hz), from which the first two formant frequency locations were extracted by LPC-smoothing without pre-emphasis. Duration was defined as the length of the sound file.

Signal to noise ratio was sufficient to make full measurements on 132 of the 199 rumbles (66%). After removing infant rumbles ($n = 12$), there remained 13 pre-stimulus 'control' rumbles, 35 'white noise' rumbles and 72 'bee' rumbles. We selected for analysis all 13 pre-stimulus control rumbles and a random 20 rumbles from the 'noise' and 'bee' categories. The 13 pre-stimulus control rumbles were derived from 7 different families across 9 separate trials. The 20 noise and bee stimulus rumbles were each derived from 9 different families across 9 separate trials.

Rumble playbacks

We conducted a second playback experiment to determine if the class of rumbles produced in response to bees elicits different responses in listeners compared to the class of rumbles produced in response to white noise. When comparing calls of two general classes such as these, the calls are likely to vary within each class (due to inter and intra-individual variation) as well as between classes. Therefore, any difference in response by listeners to playback rumbles could be attributable to individual variation (or some other idiosyncratic attribute of the recordings), and not to between-class differences in call stimuli [34]. One way to overcome this problem is to choose many different calls from each class for playbacks, so that such differences "average out". However, in our case, we do not know the individual identity of callers, so that any observed difference in listener response could still be attributable to differences in the identity of specific callers, not to differences between 'bee' and 'white noise' rumbles.

Another means to overcome this problem, and the one we adopted here, is to experimentally manipulate calls so that the only

acoustic difference between playback stimuli is the acoustic property of interest [34]. The only acoustic difference between rumbles produced in response to bee sounds and those produced in response to white noise was the location of the second formant frequency, so we manipulated this feature. Rumbles used for playbacks were extracted from audio recordings of a single bee sound playback trial on a mid-ranking, resident family [31]. 'Bee rumbles' consisted of three post-stimulus phase rumbles (duration = 9.4 sec) and exhibited second formant frequency locations typical of the 'bee rumble' class as a whole (Figure 4). To experimentally produce 'white noise rumbles', the second formants of the 'bee rumbles' were artificially lowered (Adobe Audition, version 1.5) to mirror the formant locations observed in rumbles produced during white noise playbacks (Figure 4). For one sequence of two rumbles, the frequencies associated with second formants (115–168 Hz) were reduced in amplitude (–10 dB), and lower frequencies (86–115 Hz) were amplified (+10 dB), shifting the second formant location from 132.3 to 104.5 Hz (Figure 5). For the third 'bee rumble', the 129–183 Hz band was reduced in amplitude (–10 dB), and the 78–123 Hz band was amplified (+10 dB), shifting the second formant location from 148.6 to 103.8 Hz.

In this way, we controlled for individual differences and the problem of 'pseudo-replication' [34]. This is because the unmodified 'bee rumble' stimulus exhibited high second formants that were representative of bee rumbles in general, and the experimentally modified 'white noise rumble' stimulus was identical in all respects (including individual identity), except that the formant locations were experimentally lowered to locations representative of the white noise rumbles in general (compare Figures 4 and 5). As a further control, three rumbles were isolated from the pre-stimulus phase of the same trial (duration = 8.3 sec), designated 'control rumbles'.

All three rumble stimuli were matched for amplitude and speaker distance during playbacks. First, all stimuli were low-pass filtered (Adobe Audition, version 1.5; Butterworth filter, 1000 Hz cut-off), and were played from an FBT MAXX 4A speaker (frequency response: 50–20,000 Hz). Re-recording of test rumbles at 1 m showed amplitude loss below 50 Hz but frequency components were reproduced down to 20 Hz. Mean amplitudes across rumble sequences played from the FBT MAXX 4A speaker were 96.7, 96.2 and 95.7 dB (at 1 m) for the 'bee', 'white noise' and 'control' rumble stimuli, respectively (CEM DT-8852 Sound level meter data logger, slow, C weighting, sampling rate: 0.5 sec). In the field, the camouflaged speaker system was deployed 40–50 m from target families. Mean speaker distance from the nearest subject was 42.4, 43.2 and 42.2 m for the 'bee', 'white noise' and 'control' rumble stimuli, respectively.

The rumble stimuli were played back in random order until each stimulus type was played 10 times ($n = 30$ trials) in February 2009, using the same methods described previously for bee and white noise playbacks. After set-up, a two minute pre-stimulus control phase began, followed by a 2-min stimulus phase during which three rumbles were repeated four times (either 'bee', 'white noise' or 'control' rumble stimuli), and a final 2-min post-stimulus phase. After each trial, the distance that the elephants traveled away from the sound source was recorded (0–100 m [20]). We attempted to play all three stimuli to the same family groups but were not able to do so in all instances. Distance moved from the speaker was estimated in the field. Where partial group movement was observed, the mean distance moved was recorded. Behavioral responses and group compositions were scored from video.

Statistical analyses

Behaviour was compared across playback contexts using non-parametric tests (GenStat, version 11.1). MANOVA was used to analyze rumble structure across experimental contexts (SPSS, version 15.0). Type III sum of squares was employed to correct for imbalanced data [35]. We used Pearson's correlations to examine relationships between individual acoustic features and a) the distance elephants moved away from the stimulus and b) the age composition of the target family group (adults/adults + juveniles). Two tailed alpha was set at .05 for all tests.

Ethics statement

This research on wild African elephants was reviewed from an animal welfare perspective by Disney's Animal Care and Welfare Committee, and was approved on December 12, 2007. Clearance for research was granted by the National Council of Science and Technology, Republic of Kenya (No. NCST/5/002/R/1189; 31 Dec 2006–31 Jan 2013).

Supporting Information

Audio S1 Recording of Bee Rumble. These three “bee rumbles” were recorded from an elephant family responding to bee stimuli and were used in the rumble playback experiments.

Found at: doi:10.1371/journal.pone.0010346.s001 (0.40 MB WAV)

Audio S2 White Noise Rumble. These three “white noise rumbles” were recorded from an elephant family responding to bee stimuli where the second formants were experimentally lowered in frequency location to resemble rumbles produced in response to white noise playbacks.

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Found at: doi:10.1371/journal.pone.0010346.s002 (0.36 MB WAV)

Audio S3 Control Rumbles. These three “control rumbles” were recorded pre-stimulus from the same elephant family and were matched for duration and amplitude to the other rumble playbacks.

Found at: doi:10.1371/journal.pone.0010346.s003 (0.57 MB WAV)

Video S4 Butterfly Family Response to Bee Rumble Playback. This video shows a typical response by elephants to the bee rumble playback. Here the Butterfly Family are resting under a tree when the rumble is heard to the right of the picture coming from the hidden wireless speaker. The response to move away is quick and the matriarch is seen headshaking as she walks away (in the opposite direction to the speaker) with her family.

Found at: doi:10.1371/journal.pone.0010346.s004 (3.61 MB MOV)

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Author Contributions

Conceived and designed the experiments: LEK JS IDH AS FV. Performed the experiments: LEK JS. Analyzed the data: LEK JS. Wrote the paper: LEK JS IDH AS FV.

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CONSERVATION

Elephants, Ivory, and Trade

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Trade decisions made by the Convention on International Trade in Endangered Species must place science over politics.

Tanzania and Zambia are petitioning the Convention on International Trade in Endangered Species (CITES) to “downlist” the conservation status of their elephants to allow sale of stockpiled ivory. But just 2 years after CITES placed a 9-year moratorium on future ivory sales (1), elephant poaching is on the rise. The petitioning countries are major sources and conduits of Africa’s illegal ivory (2–4). The petitions highlight the controversy surrounding ivory trade (5) and broader issues underlying CITES trade decisions.

With illegal wildlife trade in all species worth tens of billions of dollars annually (4), CITES must link decisions on legal trade in vulnerable species to (i) the species’ role in its ecosystem, (ii) adequate controls on exploitation that can be verified by independent and effective monitoring programs, and (iii) the petitioning country’s record in combating illegal trade.

Ecological Impacts

Loss of keystone species like elephants impacts the integrity of ecosystems and their services (6). Repercussions are likely to be marked in Central Africa, coinciding with major reductions in elephant populations (7–9). Local extirpation of the primary seed disperser of large trees in Central African forests may substantially affect long-term viability of the second most important carbon capture forests in the world (9, 10).

In Zambia, elephants maintain the transition zone separating the habitats of genetically distinct savannah and forest elephants. In Tanzania, they play a major role in shaping woodland structure of extensive areas like the Selous Game Reserve (SGR)—the second largest World Heritage site on Earth.



An adult female and a juvenile examine the broken tusk of a fallen elephant. Elephants often spend long periods inspecting bones of their dead.

Lack of Adequate, Verifiable Controls

Recent work strongly suggests that poaching is reducing Africa’s continent-wide elephant population (3). Elephant population declines were under way at many locations (7–9) in 2007 when CITES gave its final approval to petitions allowing South Africa, Botswana, Namibia, and Zimbabwe to sell 110 tons of stockpiled ivory to China and Japan, despite heated debate. This debate focused on one key question: Does legal sale influence levels of poaching across Africa (11)? That question could not be resolved, partly because MIKE (Monitor-

ing Illegal Killing of Elephants), created by CITES in 1997 to assess poaching rates on a continental scale, is unable to deliver data relevant to the causality mandate (12–14). With no reliable verification in place, the European Union brokered a compromise, making the 2008 sale contingent on a 9-year moratorium on future stockpile sales. The moratorium would provide time to enhance enforcement and to monitor the impact of the sales in the absence of further legal trade. CITES, however, restricted the moratorium to the four countries involved in the initial sale (1) and never addressed whether poaching levels were so serious that any further trade could ultimately jeopardize elephant survival throughout most of Africa.

Ivory Trade from Tanzania and Zambia

Tanzania and Zambia (15, 16) are exploiting this restricted moratorium in their petitions. Approval requires demonstration that their elephant populations are secure, law enforcement is effective, and sales will not be detrimental to elephants. Yet, Zambia

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and Tanzania are among the largest sources of, and transit countries for, Africa's illegal ivory (3, 4). China and Japan, the only two approved importing countries, are also among the three largest consumers of illegal ivory (2, 4). They too are failing to control illegal trade, risking legal sales becoming cover for black-market ivory.

Ivory seizures are one of the most rigorous metrics of illegal ivory markets, illustrating the scale of involvement by country. Since the ivory ban, seizures of illegal ivory peaked in 2002, 2006, and 2009 (2). Zambia and Tanzania were among the most heavily involved in this trade during each peak; they also petitioned CITES to downlist their elephants in those same years. The largest single ivory seizure since the ivory trade ban (6.5 tons in Singapore) in 2002 was shown by DNA analyses to have originated almost entirely from Zambia (3). Zambia unsuccessfully petitioned CITES to downlist their elephants that year, and other similarly sized seizures followed (17).

Tanzania shipped 41% of the seizures in the 2006 peak (11 of 27 tons) (2, 4). DNA testing on 2600 kg from Hong Kong and 5200 kg from Taiwan confirmed origins from the Selous (southern Tanzania) and Niassa (northern Mozambique) Game Reserves complex (4). Tanzania also submitted, but then withdrew, a petition to downlist their elephants in 2006, only to resubmit in 2009—when more than 14 tons of ivory shipped from Tanzania were seized (18, 19). Tanzania has the greatest average seizure size of any country in the Elephant Trade Information System (ETIS)—established by CITES to monitor trends in the illegal ivory trade. These large seizures are indicative of organized crime and suggest that Tanzania and Zambia's abilities to address these challenges are considerably compromised (2). But this was not always the case.

In 1989, Tanzania launched Operation Uhai, a highly successful antipoaching offensive by the wildlife department, police, and military. That year, Tanzania submitted one of six proposals to CITES that led to the 1989 ivory trade ban.

In recent years, Tanzania and Zambia have become less transparent about population sizes and poaching-related mortalities. Three weeks before the CITES decision, information on Tanzanian elephant population trends and mortalities was still unavailable, impeding scientific assessment. Carcass counts, often an important metric of population trends (20), were either not collected or inaccurate in many recent aerial surveys. This year, SGR's carcass count was reportedly less than 2%, low even for populations with minimal mortality (20). Transparent, scientific peer review of census

methods and results is needed for verification.

The proportion of elephant mortality attributed to illegal killing (PIKE)—an index of poaching threat (12, 21)—in Tanzania's SGR rose from 22% in 2003 to 63% in 2009 (2, 12). Recent PIKE values are unavailable for western Tanzania, where illegal killing of elephants when reported was as high as or higher than in the Selous (12), and reputedly remains so. In Zambia, PIKE is rising, with record levels of 88% in 2008 (12). Monitoring data for Zambia are deficient, with small sample sizes limiting interpretation.

CITES decisions should be based not only on national trends in population size and illegal killing but also on trends for subpopulations within ecological aggregations (some of which span national boundaries) (5, 22, 23). Tanzania shares elephant populations with Kenya (Tsavo-Mkomazi, Amboseli-Kilimanjaro, and Mara-Serengeti) and Mozambique (via the Selous-Niassa Corridor), but neither country was consulted by Tanzania on its downlisting and trade proposal.

Review of petitions is undertaken only by bodies selected by the CITES secretariat, with no engagement of the wider scientific community. The report of the Panel of (four) Experts evaluating the current petitions is a case in point. A system of peer review should be adopted, with greater reliance on knowledgeable independent experts.

Conclusion

Proceeds of a sale of Tanzania's 90 tons and Zambia's 22 tons of ivory are likely to be on the order of \$14 million and \$3.5 million, respectively, depending on ivory price at auction [~\$150/kg at average values achieved in 2008 sales (24)]. This represents less than 1% of annual tourism revenues for Tanzania (25). Ivory sales could jeopardize those revenues, either from tourist sanctions or by triggering widespread poaching.

The scale of illegal ivory trade demonstrates that most of Africa lacks adequate controls for protection of elephants. The petitioning countries are not succeeding in responsibly controlling their illegal trade, nor are the countries likely to act as buyers of the ivory. Furthermore, MIKE, the system of verification, is currently unable to meet its full mandate, and an analysis integrating data from both MIKE and ETIS is lacking (12). In the absence of data, precautionary principles should be applied.

We contend that no "one-off" ivory sales should be approved, regardless of who is the seller or buyer. Such sales split the appendix listing of a single species (which CITES itself recommends against); introduce uncertainty of supply into the marketplace, encourag-

ing poaching; and stimulate conflict among people working for effective elephant conservation. Ultimately, CITES will only meet its mandate to protect wildlife if criteria that place science above politics are applied to all CITES trade decisions. The implications reach far beyond trade species, potentially affecting ecosystem health (6), climate (10), and even the spread of zoonotic disease (26).

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Short Questionnaire for Ngare Mara Farmers

Interviewer Name: _____ Date: _____ Ques. No. _____

Other interviewers present: _____

Household or Farmer Name					Chumviyere	Etorro
Any other participants?						
Gender	Male	Female	Any Position held in community?			
Age	10-19	20-29	30-39	40-49	50-59	60+

Shamba questions

1	What year did your family move to this area? How many years have you planted in your present shamba?		
2	How many people in your family are supported/fed by this shamba?	Adults _____ Children _____	
3	What crops are you planting this year in your shamba?		
4	How many bags of maize/beans did you harvest last season?	Maize: _____ Bags _____ Kgs	Beans: _____ Bags _____ Kgs
5	Do you have a problem with wildlife eating/damaging crops?	YES / NO / SOMETIMES	
6	a) What is the worst problem animal? b) What is the 2nd worst? c) What is the 3 rd worst? Other problem animals	1: _____ 2: _____ 3: _____ _____	
7	Which person(s) in your family are involved in scaring away wildlife?		
8	During crop season, how many hours do your family members usually spend scaring away wildlife?	During the day _____ During the night _____	
9	What is the most active time during the night for elephants coming to the shambas?		

10	How many times <i>per week</i> do you see elephants during crop growing season?	
11	Do you feel at danger from elephants?	YES / NO / SOMETIMES
12	What methods do you use to keep elephants away from your crops?	
13	Do you stay/sleep down at your shamba every night?	YES / NO / SOMETIMES
14	Do you need to sleep during the day during the crop season? How many day hours do you sleep?	YES / NO / SOMETIMES _____ hours
15	Do you benefit in any way from elephants? If yes, how?	YES / NO
16	Do you benefit in any way from the nearby game reserves? If yes, how?	YES / NO
17	What do you think KWS should do about the elephants coming through this area?	

Market Questions

18	How often do you or a family member go to Isiolo per month?																																					
19	How do you usually travel there?	Walk Matatu Bicycle																																				
20	How many bags of charcoal does your family usually sell every month? How much do you sell one bag for?	_____ Bags _____ Shillings																																				
21	How many goats (or sheep) does your family usually sell in one year?																																					
22	Roughly how many livestock do you own now? (circle rough number if unhappy to discuss exact number)	<table border="0"> <tr> <td>Goats _____</td> <td>1-10</td> <td>11-20</td> <td>21-30</td> <td>31-40</td> <td>40+</td> </tr> <tr> <td>Chickens _____</td> <td>1-10</td> <td>11-20</td> <td>21-30</td> <td>31-40</td> <td>40+</td> </tr> <tr> <td>Sheep _____</td> <td>1-10</td> <td>11-20</td> <td>21-30</td> <td>31-40</td> <td>40+</td> </tr> <tr> <td>Donkeys _____</td> <td>1-10</td> <td>11-20</td> <td>21-30</td> <td>31-40</td> <td>40+</td> </tr> <tr> <td>Cows _____</td> <td>1-10</td> <td>11-20</td> <td>21-30</td> <td>31-40</td> <td>40+</td> </tr> <tr> <td>Camels _____</td> <td>1-10</td> <td>11-20</td> <td>21-30</td> <td>31-40</td> <td>40+</td> </tr> </table>	Goats _____	1-10	11-20	21-30	31-40	40+	Chickens _____	1-10	11-20	21-30	31-40	40+	Sheep _____	1-10	11-20	21-30	31-40	40+	Donkeys _____	1-10	11-20	21-30	31-40	40+	Cows _____	1-10	11-20	21-30	31-40	40+	Camels _____	1-10	11-20	21-30	31-40	40+
Goats _____	1-10	11-20	21-30	31-40	40+																																	
Chickens _____	1-10	11-20	21-30	31-40	40+																																	
Sheep _____	1-10	11-20	21-30	31-40	40+																																	
Donkeys _____	1-10	11-20	21-30	31-40	40+																																	
Cows _____	1-10	11-20	21-30	31-40	40+																																	
Camels _____	1-10	11-20	21-30	31-40	40+																																	

Activity Cards

23. Which activities take up the most of your time?

24. Can you order these cards into which generates the most income for you?

Activity (N/A= Not applicable, 1 = Highest; 11= lowest)	Time rank	Income Rank
Collecting Water		
Working in the Shamba (planting/harvesting)		
Scaring away elephants		
Scaring away other wildlife		
Collecting Firewood		
Making Charcoal		
Beekeeping activities		
Collecting natural foods (e.g. berries)		
Community Group Meetings		
Community Group Activities (e.g. handicrafts)		
Paid work (Labour etc)		

Beehive fence Questions

25	Do you like eating honey?	YES / NO
26	Do you own any beehives?	YES / NO How Many?
27	Do you have any traditional or medicinal use for honey?	
28	Have you ever sold any honey? How much for 1kg?	YES / NO _____ Shillings
29	Are you interested in learning about beekeeping?	YES / NO / MAYBE
30	Why are you interested in beekeeping?	To eat honey To sell honey for cash To help pollination of crops
31	Do you have any concerns about beekeeping? What concerns?	YES / NO
32	Do you think bees can keep elephants away from your shambas?	YES / NO / MAYBE
33	How successful do you think the beehive fence will be at deterring elephants from the shambas?	(Very successful) 1 2 3 4 5 (not successful)
34	How happy are you to be involved in this project?	(Very happy) 1 2 3 4 5 (not happy)

Finished Questionnaire. Thank you very much for your time!

QUESTIONS TO FARMERS 2008	1. Awanja	2. Lowapus	3. Loumwa	4. Lomong	5. Loylai	6. Ekitela	7. Mzee John	8. Erregai	9. Ekeri	10. Lobenyo	11. Lokunyuko	12. Leer	13. Ichor	14. Chinja	15. Paen	16. Mbayan
Area	Etorro	Chumviyere	Chumviyere	Chumviyere	Chumviyere	Chumviyere	Chumviyere	Chumviyere	Chumviyere	Etorro	Etorro	Chumviyere	Chumviyere	Chumviyere	Etorro	Chumviyere
Gender	Male	Male	Male	Female	Male	Male	Male	Female	Male	Male	Male	Male	Female	Male	Male	Male
Age	30-39	40-49	50-59	60+	30-39	30-39	50-59	40-49	20-29	40-49	50-59	50-59	60+	30-39	30-39	30-39
Position in community		Head teacher			Church leader			Chairman of area	Secretary, bee project		Chairman of area					
INTRODUCTORY QUESTIONS																
Date arrived in Village	2000	2000	1995	2003	1982	1996	1978	1978	1978	1978	1980	1978	1982	1982	1978	1980
No. of people living in homestead	6		15	7	19	6	33	7	9	19	20	16	5	9	16	17
No. of Adults	3		6	2	10	1	20	1	3	10	6	4	2	2	4	6
No. of Children	3		9	5	9	5	13	6	6	9	14	12	3	7	12	11
SHAMBA QUESTIONS																
How many times have you planted in your present shamba?	3	6	6	6	22	5	15	15	since 1978	since 1978	20	15	4	12	12	10
Bags harvested last season																
MAIZE (Kilos)	90kgs	50kgs	90	50	90	50	90	90	50	0	90	90	90	90	50	90
Maize (bags)	1.5	1	2	2	5	6	1	5	18	0	10	6	4	8	2	9
BEANS (Kilos)	25kgs	100kgs	50	25	50	50	50	50	90	0	90	90	90	50	50	90
Beans (bags)	0.5	2	2	0.5	3	5	1	3	2	0	3	2	2	4	2	2
Any problems with wildlife & crops?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
1st Worst problem animal	Elephants	Elephants	Elephants	Elephants	Elephants	Elephants	Elephants	Elephants	Elephants	Elephants	Elephants	Elephants	Elephants	Elephants	Elephants	Elephants
2nd Worst problem animal	Baboons	Squirrels	Baboons	Porcupine	Baboons	Birds	Baboons	Baboons	Baboons	Baboons	Baboons	Baboons	Baboons	Baboons	Baboons	Baboons
3rd Worst problem animal	Porcupine		Porcupine	Squirrels	Porcupine	Baboons	Birds	Squirrel	Porcupine	Waterbuck	Porcupine	Birds	Porcupine	Porcupine	Porcupine	Porcupine
Other problem animals?	Birds		Squirrels, Birds, people	Birds	Birds, squirrels		Porcupine	Hornbill	Birds, squirrels, waterbuck, buffalo	Birds, squirrels, porcupine	Birds, squirrels, waterbuck, hyena	Porcupine	Birds, squirrels	Birds, squirrels		Birds, squirrels, buffalo
Who deters wildlife?	Awanja	Children	Loumwa	Relatives	Loylai	Ekitela	Lokichokio	Fancesca	Ekeri	Lobenyo and Auren	Lokunyuko	His sons	relatives	chinja	Paen	Mbayan
Day hours spent deterring wildlife	All day	All day	3 hours	7	7	12	4	All day	12	12	morning hours	4 hours	8	morning hours	6	6
Night hours spent deterring wildlife	All night	All night	5 hours	7	7	12	7	5	12	12	7 hours	all night	11	7	4	4
Most active time of night for elephants	6.30pm-5.30am	from 10pm	All night	10pm-12pm; 3am-5am	6.30pm-5.30pm	8pm-12am	6.30pm-5am	9pm-midnight	7pm-12am; 3am-6am	7pm-12am; 3am-6am	8pm to 1am, 4am-5.30am	6.30pm-12; 3am-5am	6.30pm-5am	7.30pm-11.30pm; 4.30am-5.30am	8pm-12; 3am-5.30am	5.30pm-11pm, 3am-6am
How many times per week do you see elephants during crop season	Every day	3 times per week	every day	Only at night	Every day	3 times	2-3 times	Daily	3 to 4	4	5	2	5	3	every day	3 times
Do you feel at danger from elephants?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Methods for deterring elephants?	Throwing stones, lighting fire, torches	Lighting fire, beating drums, using torches	Torches, beating drums, lighting fire, throwing stones	Beating drums, lighting fire, throwing stones, making noise	Torch, lighting fire, clapping hands, beating drums, throwing stones	Lighting fires, beating drums, throwing stones, torches	Lighting fires, torch, stones	Lighting fires, beating drums	Fire, beating drums, clapping hands, torch.	Stones, fire, torch	Throwing stones, beating drums, lighting fire	Torches, lighting fire, hand clapping, stones	making noise, beating drums, throwing stones, lighting fire	Lighting fire, throwing stones, beating drums, noise	lighting fire, throwing stones, torches	torches, lighting fires, beating drums, throwing stones
Do you sleep at your shamba every night?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
How many hours do you sleep in the day?	5	6	6	Yes	4	0	7	2	6 to 7	4	0	4	0	4	3	4
Do you benefit from elephants?	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
Do you benefit from the game reserves?	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
What should KWS do?	Scare elephants stop them coming into our shambas	They should come and keep guard all night	Should keep guard of our shambas	KWS should transfer the elephants to the reserve and fence the park	KWS should come and scare elephants and come and stay in our shambas to protect them	Should stop eles damaging our crops, KWS should pay after damage	Should come and scare away eles	They should come every crop season to scare elephants	Scare elephants, eles are not important to us, only for their salary	Fence the reserves to stop eles entering our shambas	Stop eles damaging our crops, we get no benefit from elephants	Come and stay and keep guard, chase all eles back into protected area	Stop eles from damaging our crops	Scare away and come and stay to stop eles destroying crops	scare eles to the parks and come and stay to scare eles	To scare elephants from our area
MARKET QUESTIONS																
No. of monthly market trips		4	3	5	2	12	2	4	3 to 4	2	5	3	2	3	4	6
How do you usually travel there?	Walk	Walk	Walk	Walk	Walk	walk	Walk	Walk	Walk	Walk	Walk	Walk	Walk	Walk	Walk	Walk
How many bags of charcoal do you sell every month	12	0	10	10	12	36	4	2	3 to 4	4	10	12	4	24	12	12
How much do you sell one bag for?	100	0	100	100	400	600	600	300	350	1000	500	100	450	100	100	100

QUESTIONS TO FARMERS 2010	1. Awanja	2. Lowapus	3. Loumwa	4. Lomong	5. Loylai	6. Ekitela	7. Mzee John	8. Erregai	9. Ekeri	10. Lobenyo	11. Lokunyuko	12. Leer	13. Ichor	14. Chinja	15. Paen	16. Mbayan
AREA	Etorro	Chumviyere	Chumviyere	Chumviyere	Chumviyere	Chumviyere	Chumviyere	Chumviyere	Chumviyere	Etorro	Etorro	Chumviyere	Chumviyere	Chumviyere	Etorro	Chumviyere
GENDER	Male	Male	Male	Female	Male	Male	Male	Female	Male	Male	Male	Male	Female	Male	Male	Male
AGE	30-39	40-49	50-59	50-59	30-39	30-39	50-59	40-49	20-29	40-49	50-59	50-59	60+	30-39	30-39	30-39
Position in community		Head teacher			Church leader		Chairman of area		Secretary of bee protect		Chairman of area					
SHAMBA QUESTIONS																
NUMBER OF MAIZE/BEAN BAGS HARVESTED LAST SEASON																
MAIZE (Kilos)	0	90	50	90	135	180	0	0	0	0	0	360	90	90	0	90
Maize (bags)	0	13	1	6	1.5	2	0	0	0	0	0	4	8	6	0	8
BEANS (Kilos)	0	50	20	50	0	100	0	0	0	0	50	50	90	90	0	90
Beans (bags)	0	6	1	3	0	2	0	0	0	0	1	1	2	2	0	3
ANY PROBLEM WITH WILDLIFE AND CROPS?		Yes														
WORST PROBLEM ANIMAL?	Baboons	Elephants	Elephants	Elephants	Elephants (not this year)	Elephants	Elephants	Elephants	Elephants	Elephants	Elephants	Birds	Elephants	Elephants	Elephants	Elephants
2ND WORST PROBLEM ANIMAL?	Elephants	Baboons	Baboons	Baboons	Birds	Baboons	Baboons	Birds	Baboon	Baboons	Porcupines	Elephants	Baboon	Porcupine	Baboons	Baboons
3RD WORST PROBLEM ANIMAL?	Squirrels	Birds	Squirrels	Birds	Porcupines	Squirrels	Squirrels	Porcupines	Porcupines	Squirrels	Birds	Baboons	Porcupines	Birds	birds squirrels, porcupine	Squirrels
OTHER?		Porcupine		Porcupine		Birds, porcupine		Squirrels			Baboons	Squirrels	Squirrels	Squirrels		Porcupine, birds
WHO IN THE FAMILY DETERS WILDLIFE?	Awanja	Son	Men	Relatives	Loyai	Him	Men	son	Men	Lobenyo	him	son	Ichor	Chinja	boys	Mbayan
NUMBER OF HOURS SPENT DETERING WILDLIFE																
DURING THE DAY	3	Yes	2	12	4	2	8	3	3	6	4	12	12	4	4	12
DURING THE NIGHT	12	12	12	12	12	12	12	12	12	12	12	12	Relatives help	12	12	12
Do you sleep at your shamba every night?	Yes	no	Sometimes	Yes	Yes	yes	Sometimes	yes	sometimes	yes	yes	yes	No	Yes	Yes	No
How many hours do you sleep in the day?	4	no	6	No	4	4	8	4	05-Jan	4	4	1	No	4	4	6
MARKET QUESTIONS																
charcoal do you sell every month	12	0	6	3	20	16	6	17	2	19	22	20	5	11	15	4
How much do you sell one bag for?	500	0	500	500	500	500	500	500	500	500	500	500	500	500	500	500
How many goats or sheep do you sell last year?	6	0	0	2	4 sheep, 1 camel	12	4	4	3	2	10	10	3	8	8	4
NUMBER OF LIVESTOCK OWNED	35	75	20	10	12	20	45	25	20	25	55	55	21	10	35	50
GOATS	11 to 20	21-30	1 to 10	1 to 10	1 to 10	1 to 10	11 to 20	1 to 10	1 to 10	11 to 20	21 to 30	11 to 20	1 to 10	1 to 10	11 to 20	11 to 20
CHICKENS	1 to 10	1 to 10	1 to 10	0	1 to 10	0	1 to 10	1 to 10	1 to 10	0	1 to 10	11 to 20	1 to 10	1 to 10	1 to 10	1 to 10
SHEEP	1 to 10	21 to 30	1 to 10	1 to 10	1	1 to 10	11 to 20	1 to 10	1 to 10	0	11 to 20	1 to 10	1 to 10	0	1 to 10	11 to 20
DONKEYS	1 to 10	1 to 10	1 to 10	0	0	1 to 10	1 to 10	1 to 10	1 to 10	1 to 10	1 to 10	1 to 10	0	0	1 to 10	1 to 10
COWS	1 to 10	11 to 20	1 to 10	0	1	1 to 10	1 to 10	1 to 10	0	1 to 10	1 to 10	11 to 20	1 to 10	0	1 to 10	1 to 10
CAMELS	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1 to 10
ACTIVITY CARDS																
Time Rank 1	making charcoal	Paid work	making charcoal	Making charcoal	making charcoal	making charcoal	shamba making charcoal	making charcoal	Group activities	making charcoal	making charcoal	making charcoal	Making charcoal	Shamba	making charcoal	Making charcoal
Time Rank 2	beekeeping	Group meetings	natural foods	Shamba	group meetings	paid work	shamba making charcoal	shamba group meetings	Group meetings	beekeeping	beekeeping	natural foods	Shamba	Beekeeping	group meetings	shamba
Time Rank 3	paid work	group activities	group activities	Water	group activities	beekeeping	group meetings	group activities	shamba	shamba	group meetings	shamba	Natural foods	group meetings	beekeeping	scaring elephants
Time Rank 4	shamba	beekeeping	shamba	Firewood	shamba	shamba	beekeeping	meetings	paid work		group activities	group meetings	Firewood	paid work	paid work	scaring wildlife
Time Rank 5	scaring wildlife	shamba	scaring elephants	natural foods	beekeeping	natural foods	natural foods	beekeeping	scaring elephants		natural foods	group activities	water	natural foods	group activities	paid work

