Testing the Short-Term Effectiveness of Various Deterrents for Reducing Crop Foraging by Primates

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ABSTRACT

Crop foraging by wildlife is a major driver of negative interactions between farmers and wildlife, and yet there are few published examples of effective solutions to deter wildlife from crops. Here we investigate the effectiveness of six different methods to deter primates from crop foraging on commercial farms in South Africa. Model snakes and bioacoustic sounds had no effect on chacma baboons (*Papio ursinus*). A leopard model and the sound of bees reduced the foraging duration at bait stations of vervet monkeys (*Chlorocebus pygerythrus*) and baboons, respectively. Human sounds appeared to reduce the number of days baboons visited a bait station, but not their foraging duration. Only an electric fence was effective at keeping both baboons and vervets out of a crop field. We encourage modifications to electric fence designs to avoid electrocution of smaller animals and make recommendations for other deterrent methods which require further investigation.

Key words: crop damage, crop farming, crop raiding, Limpopo, South Africa, mitigation, baboon, vervet, wildlife management.

INTRODUCTION

Crop foraging by wildlife is a driver of negative interactions between farmers and animals and a key conservation concern. Crop damage can impact livelihoods and reduce food security for people (Hill, 2000; Naughton-Treves, 1997), while increasing stress levels and the risk of injury or death for animals (Ahlering et al., 2011; Boulton et al., 1996; Strum, 1994). A variety of deterrent techniques are widely used in an attempt to reduce crop damage by wildlife (Dickman, 2010; Osborn & Hill, 2005; Treves, 2008), but this does not mean that they are necessarily effective (Hockings, 2016). Very few of these techniques have been systematically evaluated under field conditions (Hill, 2018; Junker et al., 2020).

Primates are often cited as the species that cause most crop damage (Adedoyin et al., 2018; Linkie et al., 2007; Naughton-Treves, 1997; Rao et al., 2002), and they can also be very difficult to control (Fehlmann et al., 2017; Hill, 2005). Their intelligence and adaptability often renders control techniques unsuccessful (Strum, 1994), while their dexterity and diverse modes of locomotion render barriers such as fences ineffective (Hoffman & O'Riain, 2010, but see Howlett & Hill, 2017). Primates are also particularly effective at habituating to novel stimuli (Wallace & Hill, 2016), leaving many deterrent strategies effective for only a short period.

A crop protection technique aims to impede, repel, deter or alert farmers to crop foraging, and includes any activity that reduces the severity or frequency of crop foraging (Wallace & Hill, 2016). An effective deterrent will increase the costs and risks of crop foraging to offset the nutritional benefits (Lee & Priston, 2005; Strum, 2010).The deterrent must also be cost effective, easy to source, use and maintain, and be culturally appropriate and locally acceptable to the farmers who will be implementing it (Hill, 2000).

Mitigation strategies can be classified into different categories (Wallace & Hill, 2016; Zimmermann et al., 2009), including alarms (alerting farmers to the presence of approaching wildlife or those already in the field), barriers (impeding or excluding wildlife access to crops), repellents (warding off or repulsing wildlife), planting strategies (deciding on where, when and what crops to plant to reduce attractiveness to foragers) and lethal methods (killing of the problem wildlife); most are not mutually exclusive. In this paper, we investigate deterrents falling within the categories of barriers and repellents.

Barriers are designed to prevent animals entering a particular area, but can be ineffective against animals that climb or dig (Hoare, 1992). However, if properly designed and maintained, electric fences have proven effective against such species (Gates et al., 1978; Honda et al., 2009; Kaplan, 2013). Electric fences aim to create more of a psychological than physical barrier for wildlife, through learned avoidance (Hoare, 1992). This situation occurs when an animal initially receives an electric shock the first few times it comes into contact with the fence, followed by avoidance of the fence, sometimes even after the electricity is switched off (Hayward & Kerley, 2009; Reidy et al., 2008). In this instance, habituation to the electric fence improves its effectiveness, rather than decreasing it, as is usually the case with other deterrents.

Various studies mention the current use of electrical fencing by farmers to protect crops (Burger & Branch, 1994; Kesch et al., 2015; Knight, 1999; Nahallage et al., 2008; Nyirenda et al., 2011; Pahad, 2010; Sapkota et al., 2014; Silva & Srinivasan, 2019), while others assert that electric fences are too expensive for many farmers, particularly in developing countries (Kioko et al., 2008; Ndava & Nyika, 2019; Osborn & Hill, 2005; Silva & Srinivasan, 2019). While it is true that the capital cost of electric fencing can be high, there is evidence to suggest that it is economical in the long-term (Findlay, 2016; O'Connell-Rodwell et al., 2000), while recent advances in technology and solar power can be used to reduce the costs (Hayward & Kerley, 2009; Macdonald, 2000).

There are a number of published studies reporting mixed results from testing the effectiveness of electrical fencing at excluding wildlife. Electric fencing was successfully used to exclude elephants (*Loxodonta africana*) in Laikipia District, Kenya and Namibia, bears (*Ursus* spp.) in the USA and Japan, dingoes (*Canis famililiaris*) in Australia and primates in Japan and South Africa (Clark et al., 2005; Gates et al., 1978; Honda et al., 2009; Huygens & Hayashi, 2000; Kaplan, 2013; O'Connell-Rodwell et al., 2000; Thouless & Sakwa, 1995). However, they were found ineffective at excluding jaguar (*Panthera onca*) in Brazil, elephants in the Amboseli region of Kenya and Sri Lanka and baboons (*Papio cynocephalus*) in Kenya (Altmann & Muruthi, 1988; Cavalcanti et al., 2011; Kioko et al., 2008; Silva & Srinivasan, 2019). A number of other studies on brown bear (*Ursus arctos*), hippopotamus (*Hippopotamus amphibius*), black-backed jackal (*Canis mesomelas*) and feral pigs (*Sus scrofa*) report varying levels of effectiveness (Gard, 1971; González et al., 2017; Heard & Stephenson, 1987; Reidy et al., 2008).

The effectiveness of electric fencing depends on a number of factors, including design and proper maintenance (Honda et al., 2009; Kaplan, 2013; Kesch et al., 2015; Silva & Srinivasan, 2019), target species and individuals (Cavalcanti et al., 2011; Hoare, 1992; O'Connell-Rodwell et al., 2000; Thouless & Sakwa, 1995), local landscape (Kioko et al., 2008), value of the resource to the wildlife it excludes (Cavalcanti et al., 2011; Gard, 1971; Huygens & Hayashi, 2000; Kesch et al., 2015; Thouless & Sakwa, 1995), and whether it is combined with other deterrent methods (Huygens & Hayashi, 2000; O'Connell-Rodwell et al., 2000; Reidy et al., 2008). Despite their varying levels of success, a number of researchers and farmers have reported the electric fence to be the most effective method at keeping wildlife away from crops (Jonker et al., 1998; O'Connell-Rodwell et al., 2000; Studsrød & Wegge, 1995; Thouless & Sakwa, 1995). We therefore explored the effectiveness of electric fencing as a barrier to exclude primates from commercial crops. The other five deterrents investigated in this paper all involve types of repellents.

There are three basic types of repellents – visual, acoustic and chemical. Visual repellents, such as scarecrows, lights, moving objects and threatening images, aim to frighten away crop foraging wildlife and are the most basic form of repellent (Gilsdorf et al., 2002). Visual repellents have most often been used against birds (Conover, 1979; Osborn & Hill, 2005), but have also been used to deter mammals (Gilsdorf et al., 2002; Koehler et al., 1990) and primates in particular (Kaplan & O'Riain, 2015). However, despite the increasing number and variety of visual deterrents in use (Ango et al., 2016; Mason, 1998; Wang et al., 2006), there is very little published information on the impact of these on crop foraging primates (Hockings, 2016).

Visual stimuli that mimic natural predators are designed to elicit predator avoidance behaviour. Predator models have been used to repel birds, with some studies reporting effective use (Conover, 1982, 1984) while others report them ineffective (Belant et al., 1998). While predator models have been used in field studies to successfully elicit anti-predator behaviour in primates (Arnold et al., 2008; LaBarge et al., 2021), we have not come across any published trials of predator models as a deterrent against primate crop foraging. However, anecdotal information suggests that leopard skins effectively deterred vervet monkeys (*Chlorocebus pygerythrus*) during outdoor lunches in a hotel in Kenya (Else, 1991). We therefore tested the effectiveness of leopard (*Panthera pardus*) and snake models at deterring primates from crops. The remaining three deterrents tested were types of acoustic repellents.

Acoustic repellents, such as explosions, sirens and alarm or predator vocalisations, aim to enhance the perception of risk of foraging within a specific area (Strum, 1994). Many studies indicate the current use of acoustic repellents by farmers (Conover & Decker, 1991; Nahallage et al., 2008; Nyirenda et al., 2011; Pahad, 2010; Sekhar, 1998; Studsrød & Wegge, 1995; Ueda et al., 2018; Wang et al., 2006; Warren, 2008), but again there is little published literature on whether these are actually successful, particularly against primates (Hockings, 2016; Kaplan, 2013). Research that has been conducted, mostly aimed at deterring birds, suggests that loud sounds are more aversive than quiet sounds, sounds with wide frequency ranges are more aversive than pure tones, and natural anti-predator sounds are more effective than artificial sounds, while continuous noises are more easily habituated to (Biedenweg et al., 2011; Bomford & O'Brien, 1990).

Bioacoustic repellents are based on the principle that a predator vocalisation or distress call alerts individuals to the presence of danger, typically eliciting a behavioural response, including fleeing from the area (Gilsdorf et al., 2002). Many field studies have successfully used bioacoustic playbacks to manipulate primate behaviour (Crockford et al., 2015; Herbinger et al., 2009; Zuberbühler, 2000), but there is limited evidence on whether this works as an effective deterrent against crop foraging. While playback of baboon alarm calls was partially successful at deterring olive baboons (*Papio anubis*) from crops in Kenya (Strum, 1994), playback of elephant sounds had no deterrent effect on elephants around waterholes in Namibia (O'Connell-Rodwell et al., 2000).

Recordings of human voices as a repellent have also been investigated in a few studies. Biedenweg et al. (2011) found that natural alarms played to western grey kangaroos (*Macropus fulignosus*) in Australia elicited a less dramatic response than anticipated, with human sounds having a greater effect. Elephants were also found to retreat from recordings of Maasai cattle due to the association made between the sounds of their cattle and the danger posed by the Maasai, who periodically hunted or injured elephants (Osborn & Rasmussen, 1995). We therefore tested the effectiveness of both bioacoustic signals and human sounds at deterring primates from crops. Since beehive fences have been effective at deterring elephants from crop fields (Branco et al., 2019; King et al., 2009), and elephants flee at the sound of disturbed bees (King et al., 2007), we also tested the effectiveness of the sound of bees as an acoustic deterrent against primates.

We piloted six deterrent strategies – electric fencing, two predator models (snake and leopard), and three sound deterrents (bioacoustic, human and bee sounds) on four commercial farms in South Africa. The primary aim of these experiments was to provide farmers with non-lethal, cost-effective alternatives to lethal management and guards. Experiments were short-term and conducted at the level of individual fields or baiting sites and hence generalisations to larger scale application for longer duration should be avoided. Where interventions reduced both the visit frequency and duration of time within a crop field or baiting site, we recommend further experimentation that includes the risks of both habituation and learning to circumvent interventions. For trials with negative outcomes, we recommend that these deterrents are tested no further and not used by crop farmers. In this paper, we therefore do not make any recommendations on what can be used as an effective crop foraging deterrent, but rather what shouldn't be used as well as what requires further research.

Chacma baboons (*Papio ursinus*) and vervet monkeys are considered major crop damagers within this farming landscape and most farmers in the area employ field guards to protect their crops (Findlay & Hill, 2020b). However, these methods are not 100% effective so many farmers also revert to lethal methods of control, such as shooting, which is legal in South Africa (Findlay, 2016). Our deterrent trials focus on these two species to inform future management options.

MATERIALS AND METHODS

Study area

Our trials were conducted on four commercial farms within the Blouberg District Municipality, Limpopo Province, South Africa (Figure 1). The area lies within the Limpopo Sweet Bushveld vegetation type, which is defined as plains, sometimes undulating or irregular, traversed by several tributaries and comprised of short open woodland in distributed thickets of blue thorn (*Vachellia erubescens*), black thorn (*Senegalia mellifera*) and sicklebush (*Dichrostachys cinerea*) (Mucina & Rutherford, 2006). The climate is semi-arid with warm, wet summers (October-March) and cooler, dry winters (April-September). Temperatures range from an average daily minimum of 13° C in June and July, to an average daily maximum of 33° C in November, and a mean annual temperature of 25° C. Annual rainfall is 650 mm, most of which falls during the summer months.

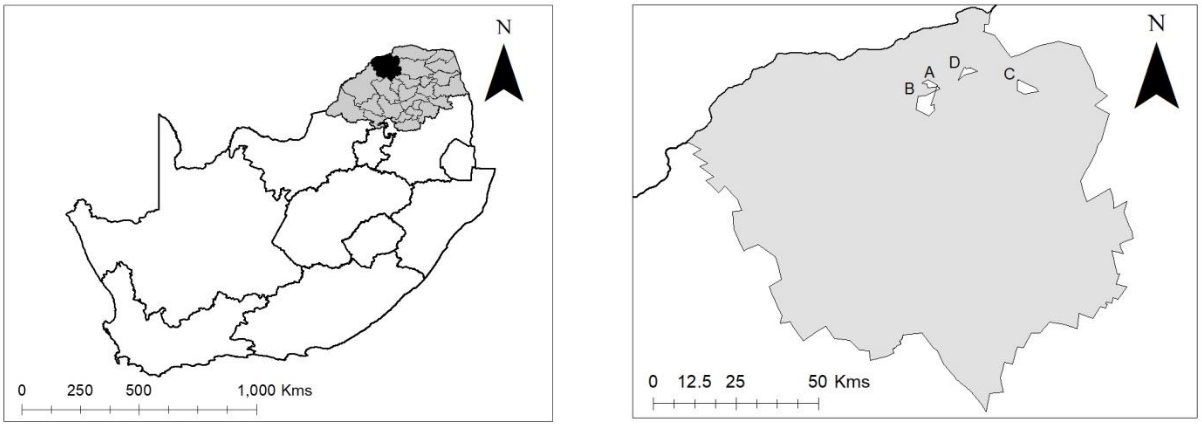

Figure 1. (a) Location of Blouberg Municipality (black) within Limpopo Province (grey), South Africa. (b) Location of commercial crop farms (white) within Blouberg Municipality (grey).

Crop production is important in the area (Tibane, 2015), with locally grown crops including tomatoes (*Solanum lycopersicum*), potatoes (*S. tuberosum*), maize (*Zea mays*), onions (*Allium cepa*), dry beans (*Phaseolus* spp.), and tobacco (*Nicotiana* spp.), as well as a variety of pumpkins and squashes (*Cucurbita* spp.), melons, and citrus fruits (*Citrus* spp.). Wildlife crop foraging occurs on the commercial farms and crop losses may be underestimated by farmers (Findlay, 2016). As well as the two primate species (Findlay & Hill, 2020a), crop foraging species also include common warthog (*Phacochoerus africanus*), bushpig (*Potamochoerus larvatus*), Cape porcupine (*Hystrix africaeaustralis*), bushbuck (*Tragelaphus sylvaticus*) and Helmeted Guineafowl (*Numida meleagris*) (Findlay, 2016).

The methods for each deterrent trial are described below. A Panasonic HC-V180 camcorder (video camera) or Browning Strike Force HD Pro BTC-5HDP trail cameras (camera traps) were deployed. Camera traps were set to take a single photo when triggered with no delay between images. The duration of each trial varied due to various logistical constraints, as well as the outcome of the experiment itself. Different crops were used between experiments, depending on the season and availability of the crops. However, all crops used were among the most preferred crops by baboons in the study area (unpublished data). Since each deterrent was tested on a small scale and for a relatively short duration, we assume that the primates visiting each site were the same individuals throughout the duration of the experiment.

Deterrent 1: Barrier – Electric fence

A 2.5 km electric fence was erected around 24 ha of crop fields on Farm A by the farmer in September 2014. The fence was constructed of horizontal wires spaced 10 cm apart, up to a height of 2.1 m. On the top half of the fence, every other strand was electrified. An offset was placed on the outside of the fence at 0.5 m from the ground, consisting of five wires coming off the fence at a 45^{o} angle, so that the last wire was about 5 cm above ground and 45 cm from the fence. Three of these wires, including the bottom wire, were electrified. Just above this offset, another offset was placed, consisting of one electrified wire at about 10 cm from the fence (Figure 2). Before the electric fence was erected, cameras were placed in field A A16 from 26 May – 30 June 2013, during which time butternut squash were present. Camera traps were placed 20 m apart as this was the maximum distance from the camera at which motion sensors were triggered, and five cameras were used to cover the full 100 m crop-bushveld edge of the field. This set up therefore captured all primate movements into and out of this field when this edge was used. If an animal entered and exited the field using a different edge this was not recorded, however, observational data suggest that primate crop foraging events rarely occurred where all individuals involved did not use the crop-bushveld edge (personal observation, L. Findlay). After the fence was erected, cameras were placed using the same set up in the neighbouring field A A12 (all fields now inside the electric fence) from 3 October – 7 November 2014, during which time tomatoes were present. Camera traps collected information on the frequency with which wildlife visited the fields with and without an electric fence present.

Figure 2. Photograph of the electric fence with two electrified offsets on the outside of the fence and the top half of the fence itself with electric wires.

Deterrent 2: Visual repellent – Rubber snake

Two experimental sites (A and B) were set up at a distance of 90 m apart on Farm B. These sites were both equidistant from the original provisioning site, which ensured baboons visited the area, and far enough apart for each site to be out of view from the other. Both sites were baited each morning with approximately 7 kg of butternut squash for 20 days, from 10 August – 4 September 2014. For the first 10 days, one of three rubber snakes were placed on top of the bait at site A (Figure 3), while site B contained just the bait. For the last 10 days, the rubber snake was placed on top of the bait at site B, but not site A. Data collection occurred via one camera trap placed at each baiting station, with the species visiting the bait and duration of their stay recorded.

Figure 3. (a) Model snakes used in the experiment. (b) Experimental set up with one of the snake models on top of the bait pile.

Deterrent 3: Visual repellent – Leopard model

A bait station was set up approximately 35 m north from an observation hide on Farm C. A life-sized leopard model was concealed within a second hide (Figure 4), approximately 35 m east from the bait station. A pulley system was constructed so that the observer could pull a string to drop the door of the hide, thus revealing the leopard model. The site was baited each afternoon at approximately 2 pm with a variety of available crops, including watermelon and corn. Vervet visits were video recorded. Recordings were started when vervets were seen moving towards the bait station and finished when all vervets had left the bait site and two minutes had passed without any individuals returning. Videos were coded to provide information on the frequency and duration of visits. Baseline data were collected for seven days, during which time the leopard was not revealed, followed by a 29-day experimental phase, from 31 August – 8 October 2018. During this period, the pulley system was used to reveal the leopard when vervets were observed foraging on the bait. The leopard was usually revealed once a day when vervets were present, although on five days the leopard was not revealed due to the pulley system malfunctioning.

Figure 4. Model leopard used in the experiment

Deterrent 4: Acoustic repellent – Bioacoustic sounds

A bait station was set up approximately 35 m from an observation hide on Farm C. The site was baited each morning with one crate of honeydew melons. Baboon visits were video recorded. Recordings were started when baboons were seen moving towards the bait station and finished when all baboons had left the bait site and two minutes had passed without any individuals returning. Videos were coded to provide information on the frequency and duration of visits. Baseline data were collected for nine days, followed by a nine-day experimental phase, from 15 March – 4 April 2018. During this period, one of four bioacoustic sounds – leopard call, vervet alarm call, baboon wahoo and a combination of all three – were played at random each time a baboon approached within 1 m of the bait. Sounds were played at 70 dB on an MP3 player connected to a SME-AFS Amplified field speaker hidden approximately 2 m from the observation hide.

Deterrent 5: Acoustic repellent – Human sounds

A bait station was set up approximately 35 m from an observation hide on Farm D. The site was baited each morning with one crate of honeydew melons. Baboon visits were video recorded. Recordings were started when baboons were seen moving towards the bait station and finished when all baboons had left the bait site and two minutes had passed without any individuals returning. Videos were coded to provide information on the frequency and duration of visits. Baseline data were collected for six days, during which time no sounds were played, followed by a 28-day experimental phase, from 10 July – 17 August 2014. During this period, one of four human-derived sounds – gunshot, car engine, human conversation, field guard shouting – were played at random each time a baboon approached within 1 m of the bait. Sounds were played at 70 dB on an MP3 player connected to a SME-AFS Amplified field speaker hidden approximately 2 m from the observation hide.

Deterrent 6: Acoustic repellent – Bee sounds

Two experimental sites (A and B) were set up 50 m apart on Farm C, approximately 25 m each from a baboon sleeping tree. Sixteen sessions were run at both sites across 14 days, from 16 July to 2 August 2019. Sessions were usually conducted in the early morning or late afternoon to coincide with baboons being close to their sleeping site. At the start of each session approximately 5 kg of tomatoes was placed at each bait site. At both sites, a speaker box wrapped in green shade netting was placed 2 m from the bait. At site A this box was empty, while at site B the box contained a Rocka Gideon Dual 10” trolley speaker. During each session, the speaker played the sound of swarming bees at 95 dB at site B. Data collection occurred via a camera trap placed at each bait station, and included when baboons visited the bait and duration of their stay. A camera trap was also placed at the sleeping site so that days baboons were not using the sleeping site, and therefore not within the vicinity of the experimental sites, could be removed from the analysis.

We conducted all data collection under the guidelines and approval of Durham University’s Animal Welfare Ethical Review Board (formerly Life Sciences Ethical Review Process Committee) and a permit issued from the Limpopo Department of Economic Development, Environment and Tourism. Data collection methods adhered to the American Society of Primatologists (ASP) Principles for the Ethical Treatment of Non-Human Primates.

Data Analyses

For each deterrent method we quantified the number of days a baboon or vervet group visited the sites, as well as the duration of time spent at each site during these visits. We used a

Wilcoxon rank-sum test to compare the frequency of baboon and/or vervet visits before and after the electric fence was erected. One visit included any number of the same species present at the site and 30 minutes had to pass with no sightings of this species for the next sighting to be counted as a separate visit. We also used Wilcoxon rank-sum tests to compare the duration of foraging at the bait site between the two phases of the rubber snake, leopard model, bioacoustic sounds, human sounds, and bee sounds. Durations were calculated from the time the first animal was sighted until the time the last animal of the same species was sighted; the time the last animal seen being when no other member of this species was sighted for a further 30 minutes. Where we found a significant result, we used a Spearman's rank correlation to test for habituation over time. All statistical analysis was performed using R version 4.1.0 (R Core Team, 2021).

RESULTS

Deterrent 1: Barrier – Electric Fence

Baboons entered the crop field on 16 of the 36 days (44%) during the pre-fence baseline period, while vervets entered the field on 25 of the 36 days (69%) during this time. In year 2, after the electric fence was erected, neither baboons nor vervets entered the adjacent field on any of the 36 days (0%; Figure 5a). The electric fence therefore reduced visits to the crop fields by both baboons and vervet monkeys by 100% (baboons: $W = 936$, $P < 0.001$; vervets: $W = 1098$, $P < 0.001$). The electric fence also reduced the visit frequency of other crop foraging wildlife, including porcupine ($W = 864$; $P < 0.001$) and bushbuck ($W = 1207.5$; $P < 0.001$).

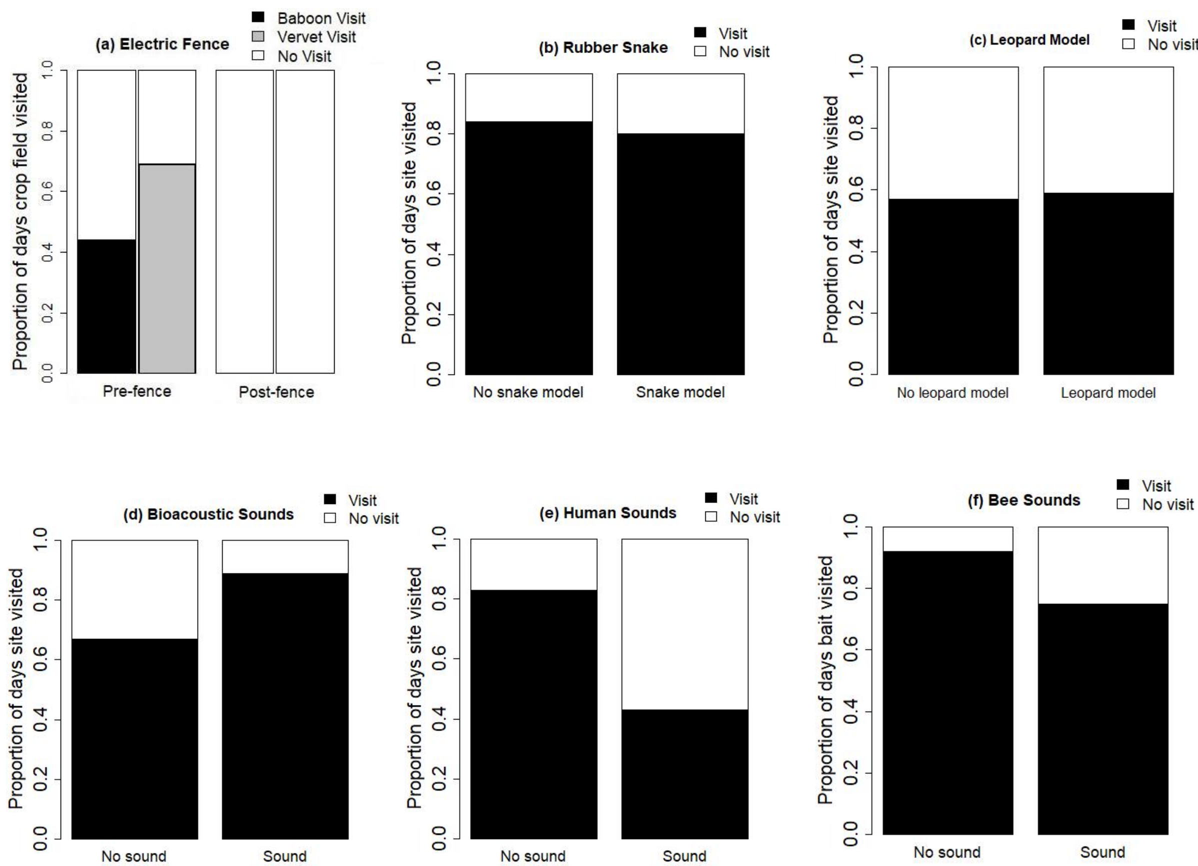

Figure 5. The proportion of days on which baboons or vervet monkeys visited the experimental sites. (a) The proportion of days on which baboons and vervets entered the crop field before (year 1) and after (year 2) the electric fence was erected. (b) and (c) The proportion of days on which baboons visited the experimental site when predator models were and were not present. (d), (e) and (f) The proportion of days on which baboons visited the experimental site when sounds were and were not played.

Deterrent 2: Visual repellent – Rubber snake

One day of 'no snake' data were removed due to the camera trap malfunctioning and no data being collected that day. Baboons visited the 'no snake' site on 16 of the 19 trial days (84%) and the 'snake' site on 16 of the 20 trial days (80%; Figure 5b). While vervets also visited, the frequency was too low to analyse (6 out of 40 trial days). When baboons visited the sites, there was no significant difference in the amount of time they spent at the bait stations whether there was a rubber snake present or not (W = 105.5, P = 0.407).

Deterrent 3: Visual repellent – Leopard model

Vervets visited the experimental site on four of the seven baseline days (57%) and 17 of the 29 experimental days (59%; Figure 5c). When vervets visited the site, they spent significantly less time at the bait station during the experimental phase (including the days when the leopard model was not revealed) than they did during the baseline phase (W = 56, P = 0.026, Figure 6a) despite no change in the availability of bait.

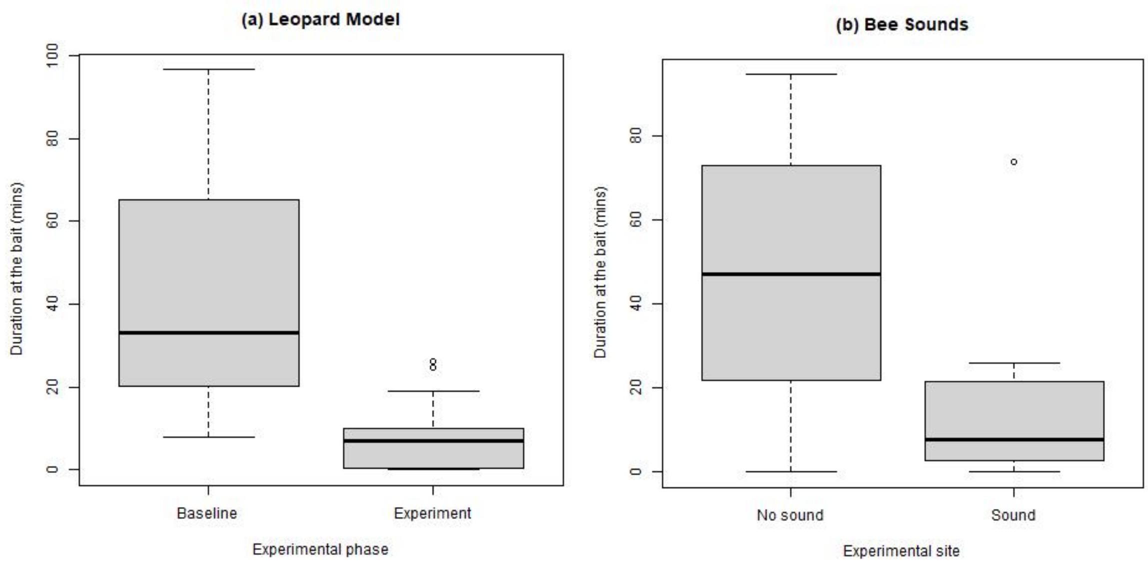

Figure 6. (a) The duration vervet monkeys spent foraging at the bait station during the baseline and experimental phases of the leopard model presentation, on days which vervets visited the experimental site, showing the medians and interquartile ranges. (b) The duration baboons spent foraging at each bait station with and without the sound of bees, showing the medians and interquartile ranges.

There was no significant increase in the duration vervets spent foraging at the bait site over time, suggesting there was limited habituation to the predator model during the experiment (rho = 0.371, n=17, P = 0.157). On seven of the 13 occasions that the model was revealed, vervets did not return to the crops on the same day. On the remaining six occasions, vervets returned to the bait site within the hour.

Deterrent 4: Acoustic repellent – Bioacoustic Sounds

Baboons visited the experimental site on six of the nine baseline days (67%) and eight of the nine experimental days (89%; Figure 5d). When baboons visited the site, there was no significant difference in the amount of time they spent at the bait station between the two phases ($W = 9$, $P = 0.060$).

Deterrent 5: Acoustic repellent – Human sounds

Baboons visited the experimental site on five of the six baseline days (83%) and 12 of the 28 experimental days (43%; Figure 5e). Although baboons appeared to visit the site with less frequency during the experimental phase, when they did visit there was no significant difference in the amount of time they spent at the bait station between the two phases ($W = 18$, $P = 0.234$).

Deterrent 6: Acoustic repellent – Bee sounds

Four sessions were removed from the analysis due to baboons not visiting the baiting sites during those times (using information gathered from the sleeping site camera trap). When the sleeping site was used, baboons visited the bait station with no sound on 11 of the 12 (92%) sessions, and the bait station with sound on nine of the 12 sessions (75%; Figure 5f). Baboons spent significantly less time at the bait station where the sound of bees was played than at the bait station with no sound ($W = 114.5$, $P = 0.015$, Figure 6b). There was no increase in the duration baboons spent at this bait station over time, suggesting there was no habituation to the sound of bees during the experiment ($rho = -0.177$, $n = 12$, $P = 0.583$).

DISCUSSION

We piloted six different deterrent methods that could be used to keep primates out of crop fields. For each method we quantified the number of days a baboon or vervet group visited the sites, as well as the duration of time spent at each site during these visits. We did not quantify the number of individuals involved in each visit which may influence the time it takes to deplete the food source, and therefore the duration of the visit. However, given our study was of a short duration and specific to a small area, and our study species is group living, we contend that group size was likely to be constant within trials and hence the number of individuals present in each trial is likely to be similar. Consequently, if a deterrent reduced the number of days baboons or vervets visited the site or the duration with which they visited the site, we consider this as a positive result and recommend further research to explore the impacts of learning and habituation, and the scalability of each intervention. If no differences were found, we would recommend caution in further investigations, noting the limitations in the overall design may have resulted in false negatives too. The electric fence was the only method that worked effectively at deterring both baboons and vervets, although the leopard model and human and bee sounds may reduce the time primates spend at feeding sites. The rubber snake and the bioacoustic sounds had no discernible effect.

Electric fences have been used in wildlife management since the 1930s and have increased in popularity in recent decades amongst landowners (Arnot & Molteno, 2017; McAtee, 1939; Pitman et al., 2017; Storer et al., 1938). Kaplan (2013) showed that certain fence designs can be 100% effective at excluding primates from residential areas in Cape Town, South Africa, and our results suggest they can also be 100% effective at excluding primates from crop fields. Furthermore, communication with the farmer six years after the trial period revealed that the electric fence remained effective against primates. On one occasion baboons were able to navigate the fence without getting an electric shock by climbing over a non-electrified pole that held a gate in place. Primates can be particularly adept at finding 'weak' spots in the fence (Hill, 2005; Strum, 1994), but as long as farmers are vigilant to this and respond appropriately, the fences effectiveness can be maintained. Once the farmer electrified these poles, he did not see another primate in his crop fields. This highlights that maintaining electric fencing is not labour free compared to other deterrent methods, since the fence must be checked regularly and properly maintained for it to remain effective (Clark et al., 2005; Kaplan, 2013; Kioko et al., 2008).

The crop that was planted between the two experimental phases changed from butternut (before the fence was erected) to tomato (after the fence was erected), however, this is not considered to be problematic within the study design. Butternuts and tomatoes both appear to be favoured crops by baboons (unpublished data) and the authors have observed many crop foraging events by both baboons and vervets within tomato fields. It is therefore unlikely that the change in crop rather than the deterrent caused the reduction in crop foraging. While the potential effectiveness of the electric fence is a major advantage, electric fences also have some drawbacks, including mortalities caused when animals get caught between electric wires (Cunningham & Cunningham, 2007; Howerter et al., 1996; Rey et al., 2012). Tortoises (family Testudinidae) and pangolins (family Manidae) seem to be particularly at risk (Arnot & Molteno, 2017; Beck, 2008; Burger & Branch, 1994; Macray, 2017; Pietersen, 2013; Pietersen et al., 2014); after the trial period it was reported that a number of leopard tortoises (*Stigmochelys pardalis*) were found dead along the electric fence (commercial farmer, personal communication). It will be important to incorporate steps into the fence design and maintenance to minimise these mortalities, and we suggest that further investigation is required on how to do this while maintaining effectiveness at excluding crop foragers.

The snake models may have failed to deter baboons from the bait simply because they failed to move and did not represent a realistic situation. It could be argued that further investigation is required to conduct these trials with more realistic models. Field studies indicate that primates adjust their behaviour according to perceived risk of predation (Coleman & Hill, 2014; Cowlishaw, 1997a, 1997b; Willems & Hill, 2009) and that the constant threat of attack plays more of a role than actual predation events (Mikula et al., 2018). However, anti-predator behaviours often involve alarm calling, vigilance, and sometimes mobbing of the predator (Byrne, 1981), and vigilance rather than avoidance has been found to be the main anti-predator strategy in chacma baboons (Ayers, 2019). Furthermore, snakes have been shown not to impact space use in vervet monkeys (Willems & Hill, 2009) and have the weakest effect on samango monkeys (*Cercopithecus albogularis schwarzi;* LaBarge et al., 2021). If baboons incorporate extra vigilance into their behaviour repertoire rather than fleeing the site, it would likely not take long for these intelligent animals to realise that the snake is not real and does not pose a threat. This has been seen in birds, where their predator-attraction behaviour led to rapid habituation (Conover, 1979). Furthermore, when scaled up to a commercial crop field, it is unlikely that the deterrent effect of the model snakes will extend far enough for such a deterrent to be feasible for an area as large as commercial crop fields. We therefore recommend no further investigation into model snakes as a deterrent method.

The leopard model, however, appeared to reduce the amount of time vervets spent foraging on the bait when present at the site. Although not significant, there could be some habituation to the model during the 29-day experimental phase. On the first five occasions that the leopard was revealed, the vervets did not return to the crops on the same day. However, on the sixth and almost all following occasions bar two, the vervets returned to the bait within an hour. This suggests that the vervets may have started to habituate, even though they were still being cautious and not spending as much time at the bait site. Despite research showing avoidance of leopards as the strongest predictor of vervet space use when naturally foraging (Willems and Hill 2009), and that samango monkeys show greater responses to leopards than other predators (LaBarge et al., 2021), our results show that the leopard model did not deter vervets from the experimental site altogether. The failure of the leopard model as a deterrent may have been due to its lack of movement and realism. Furthermore, the effect that the model did have on the time the vervets spent at the bait site may have been due to the sound and movement of the hide door falling, rather than the appearance of the leopard itself. However, for similar reasons described for the model snake, we do not recommend further investigation into this method as a crop protection strategy for vervets. Unfortunately, baboons did not show up at the experimental site during the study period, and we were therefore unable to test the effects of this deterrent on baboons.

The bioacoustic sounds did not deter baboons from foraging on crops. It has been suggested that acoustic deterrents are unlikely to be effective against primates because of their complex communication skills that allow them to distinguish between real and false auditory threats (King & Lee, 1987). Furthermore, playback vocalisations of ambush predators, such as leopards and lions (*Panthera leo*), may not be appropriate as they are unlikely to vocalise during hunting, while primates often approach the source of predator vocalisations (Arnold et al., 2008). For these reasons, therefore, bioacoustic sounds seem ineffective, and since predator models were also of limited utility, we do not recommend these sounds as a primate deterrent.

Human sounds however were more effective. While not reducing the time spent foraging on bait when baboons did visit the experimental site, the human sounds did appear to affect the baboons returning to the site on following days, shown by the lower proportion of days baboons visited the site during the experimental phase. This is similar to Biedenweg et al.'s (2011) study on grey kangaroos in Australia, who found that human sounds, such as the crack of a whip, had a greater aversive effect on kangaroos than natural alarms, the former stopping the animals eating and eliciting flight from the area. Smith et al. (2017) also found that pumas (*Puma concolor*) in

California, USA fled more often and took longer to return to kill sites where human sounds were played, as opposed to sites where the sounds of frogs (used as a control) were played. The immediate fleeing of baboons on the first occasion they heard the human sounds, indicates that the baboons associate increased risk with these noises. Over time, habituation occurred and the sounds stopped having a deterrent effect, possibly because the baboons learned that the sounds did not come with an actual risk. We therefore recommend that these sounds are combined with field guarding to maintain their effectiveness. We predict that human sounds set off by a motion-sensor (see Suraci et al., 2017) will initially deter baboons, while the subsequent chasing by field guards will reinforce the threat of the sounds and prevent habituation occurring. This should reduce primate delay in response to chasing and therefore duration of crop foraging (see Findlay & Hill, 2020b), as well as providing the field guard with a warning system that wildlife has entered the fields. These predictions will of course need to be tested.

Acoustic deterrents work best when a variety of different sounds are used (Biedenweg et al., 2011; Bomford & O'Brien, 1990; Treves & Karanth, 2003). While we used four different sounds in this trial, it may pay to include more. Human voices appeared to elicit more fearful responses than gunshots (personal observation), so we suggest increasing the number and variety of human voices to include more than four different tracks that can be played in a random sequence, and test whether this can delay habituation. Bomford and O'Brien (1990) also suggest that moving the sound source frequently improves effectiveness, which is something we did not do and could also be incorporated into the new protocol.

The sound of bees appeared to reduce the time baboons spent crop foraging, with no habituation over the 14-day trial period. Both sites were often visited during the same time period, so we were not concerned with the possible confounding effect of assessing this deterrent at a sleeping site, where the troop was either returning to sleep with limited time available to forage and likely to be satiated or leaving the site with more time available for foraging and more likely to be hungry; both sites were visited equally within each time period. Unfortunately, due to logistical constraints we were not able to switch playing the sound of bees between the two sites to test for site biases. While we did not expect a site bias to occur because the two sites were equally distant from a sleeping tree and within 50 m from one another, we recommend that this be taken into account if conducting further research into using the sound of bees as a deterrent. We also suggest extending the trial period to establish whether habituation occurs, where it will be important to assess whether it is the same baboons visiting the site throughout the experimental period. However, regardless of whether baboons habituate, the fact that they initially spent less time at the site with the sound of bees suggests that bees themselves may be a deterrent to baboons. Bee-hive fences have been used successfully to deter crop foraging elephants (Branco et al., 2019; King et al., 2009) and our results support the idea that these may also work against primates. If baboons do habituate to the sounds of bees, beehive fences may still be effective in deterring baboons from crop fields.

MANAGEMENT IMPLICATIONS

Electric fences appear to be the most effective method at keeping primates out of crop fields, provided the right designs are used and the fence is maintained properly. However, electrocution, particularly of smaller animals, poses a real problem, and designs to reduce the number of mortalities should be incorporated into the design before electric fences are erected. The sound of bees, or occupied beehives, may prove to be an effective deterrent, but further research into this is required. Motion-activated human sounds have potential, and if combined with field guarding may prove a successful deterrent. These could also be used as an alarm system to alert guards to foraging wildlife. We do not recommend the use of animal communication playbacks or predator models to deter crop foraging primates.

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