Research Article Gajah 49 (2018) 11-19

A New Type of Elephant Fence: Permeable for People and Game but Not for Elephant

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Abstract. Asian elephants around Bardiya National Park (lowland Nepal) regularly raid crops in the park's buffer zone and occasionally kill people. Retaliatory killing has been absent till now but emotions run high, and people requested a fence or a concrete wall. We designed an electric fence that allows people and livestock to pass freely but stops elephant. The fence has a single electrified wire, 9000 V, with electrified braces and 'whiskers' placing the poles out of reach of trunks. The design was tested experimentally, and after breach of the prototype, the final design has not been breached to date.

Introduction

The problem of the conflict between wildlife and people is serious especially when people are killed by wild animals and retaliatory killing results in the death of wildlife (Acharya *et al*. 2016; Ling *et al*. 2016). Many initiatives have been carried out at many different places to address human-wildlife conflict (Davies *et al*. 2011). Perhaps the earliest have been the digging of trenches (Brown 1968), or the planting of thorny hedges (Lendelvo *et al*. 2015; Staley *et al*. 2015). More recent examples are preventive and reactive shooting, netting or poisoning of game, often on a large scale (Treves & Naughton-Treves 2005). At many places, in Asia, Europe, America and Africa this resulted in 'wildlife deserts' where conflicts between wildlife and people were solved by entirely removing species from the landscape. In the Netherlands, for example, the last wolf hunts in the 18th and 19th century comprised placing game-capturing nets over a length of some 80 km in which wolves were driven and then killed through the concerted action of men from many villages.

In Africa and Asia too these enormous concerted game eradication actions by local people have been documented (Kissui 2008), and also resulted in wildlife-free land where farming became possible (see, e.g., Badenhorst 2015). Yet, not everywhere humans succeeded in this, either for religious reasons or because conservation became a new dominant discourse. In Nepal and India, nobility and despots (whether local or foreign) maintained tiger and elephant for the pleasure of the hunt on lands that by all means could have been viewed as commons but became privatized and off-limits for the general population (Bhatt 2003). Reduced tiger numbers led to increased numbers of prey such as wild boar, to the detriment of farmers but to pleasure of the leisured class. Also the Asian elephant (*Elephas maximus*) was not fully eradicated because domesticated elephants were needed as beasts of burden (and still are used commonly in places were the monsoon is vigorous) (Pradhan *et al*. 2011). At many places in Asia, both the domesticated and the wild elephant are held in high esteem because they were seen as a manifestation of the God Ganesh (Sukumar 2003).

This resulted in 'pockets' of wild elephant populations, one of which maintains itself in the lowland forests of the western Terai of Nepal (Pradhan *et al*. 2011). In the last 60 years, people have quickly and extensively colonized this area since malaria was eradicated from the area. After the Nepali Civil War between 1996 and 2006, tens of thousands of people find themselves living in an area where elephant are protected once again by the Government of Nepal, and a hundred-odd elephant find themselves confronted with agriculture in areas where formerly they

Manuscript Editor: Prithiviraj Fernando

held sway. River embankment, improved irrigation, road building, the use of GMO-crops and mechanisation of agriculture all lead to the development of a strong 'pull factor' attracting wild elephant. Harvests now take place three times a year, and high quality food is much on offer. Indeed, a major human-elephant conflict developed in recent years, with much damage to agriculture and loss of human life. Retaliatory killing has not yet been called for by local communities, but suffering attacks has become a daily phenomenon (Prins *et al*. in prep.).

Members of the Himalayan Tiger Foundation and Wageningen University were called to investigate the conflict and to advice local authorities (the Nepal National Parks Service, the Nepal National Trust for Nature Conservation, the Nepal Army), the local village councils and the local people on finding mitigating measures. After many consultations, the advice was to erect an electrical fence. Of course, elephant can be prevented from marauding crops by other means than fences: very deep ditches can be dug, concrete walls built, or fences strong enough to withstand the most persistent elephant. Yet, these solutions are costly, or take too much land away from farming, hamper people in their movements, or are quickly eroded in the riverine environment where monsoon impact is strong. However, electric fencing has proven to be mostly ineffective during past efforts in the area, and tens of kilometres of electric fence that had been constructed in the last years had been breached by elephant or broken by people. Hence, a new approach was needed to find a solution that is effective and proportional to the problem at the same time. Partly funded by WWF Netherlands and WWF Nepal, we then developed a new type of fence.

Requirements

Together with the named groups, we formulated the following requirements; we focussed both on needs of wild animals and of people. We had four meetings with village heads, and three with large groups of local people, both men and women. Men in general promoted the view that a fence should be more-or-less like an impenetrable wall. Women vocally supported the idea that it was them who carried firewood and fodder, so that a barrier would lead to an increased burden on them. At the end, nine points were agreed to:

1. Villagers should not become 'prisoners' behind fences, because villages are situated in a 'buffer zone' of a National Park.
2. Poor people and women depend more on sources for firewood and grass than rich people do, and their burden is already high; the electric fence should not force them to walk even more than they already have to do, so access to surrounding lands should be unhampered.
3. Since elephant is responsible for about 80% of all damage resulting from human-wildlife conflict only elephant should be excluded, and no other wildlife (such as deer, wild boar or rhino that do relatively little damage in the area).
4. Materials used in the fence should have no use for poaching, and should not be sought after by thieves.
5. Because of government policy on minimizing the spending of foreign currency, materials should be preferably available on local markets, and readily obtainable.
6. Because of the remoteness of the area and unreliable utilities, self-sufficiency is important.
7. The fence should pose no harm for humans or animals, including roosting birds.
8. It should be possible for local people to perform regular maintenance on the fence, and local technicians should be able to perform basic troubleshooting and repair.
9. Since self-reliance is important, and dependency on donors should be minimized, the costs of building, inspecting and maintaining the fence should be low and affordable.

Consequences of the requirements

At first sight, the points 1, 2 and 3 may be at loggerheads. Yet observations on the average height of local people provides an answer: what is needed is a fence that ensures elephant to be stopped but that allows especially women to pass underneath, even with a load of firewood or fodder.

Indeed, measurements led to the conclusion that a fence at about 160 cm above ground level would allow women (on average 151 cm in Nepal: http://www.averageheight.co/average-female-height-by-country), cattle, ox carts (tested by ourselves), and deer pass unhindered, but could stop Asian elephant (average adult shoulder height 2.4 m for cows and 2.7 m for bulls) and One-horned rhino (adult shoulder height 1.7–2 m). Given the fact that most damage is caused by adult bull elephant, none out of 271 interviewees reported damage caused by rhino, and juvenile elephants do not venture far from their mothers on their own, stopping adult elephant would be sufficient (Prins *et al.* in prep.). It was not our intention (nor that of the villagers) to fence out rhino; they rarely visit farmlands in the area of study.

An electric fence does not rely on its strength to deter animals, but on the energy it carries. A strong electric shock is a force unknown to animals and creates a psychological response of fear, as the source of the shock is not apparent. Because aluminium conducts electricity nearly as well as copper, is lightweight (thus reducing the structural needs of the construction) and is not affected by corrosion as much as steel or iron, we selected an aluminium wire. Furthermore, theft of copper is notorious all over the world, because of high prices, which ruled copper wire out. Steel and iron wires, although cheap, have another disadvantage: it can be easily used at any farm and is very suited for making snares due to its tensile strength and its pliability. Aluminium is a softer material and strong when applying a linear force, but it will break quickly from metal fatigue when bent, making it useless for making snares. Since a conservation programme should not facilitate theft and poaching, we selected aluminium cable as our preferred medium for carrying the electricity. The disadvantage of deploying aluminium is that wire (and braces) of this metal is currently not available on the local market in Nepal; this makes meeting requirement point 5, above, currently impossible so we decided to drop it for this experiment.

One of the main issues we encountered during discussions with local authorities and representatives of the local communities is the absence of comprehending the principles of electricity, and how electric fences work. This is a widespread issue, not only in the communities involved but also amongst technical officers of conservation organisations. For example, previously installed electric fences were "repaired" at numerous places with metal wire that led to a short-circuit between the wire carrying current and the ground wire, and insulators were often wrongly placed or even absent, effectively turning the posts into electric grounding rods. We organized three meetings with villagers and community leaders to elucidate these issues, and assisted WWF in preparing training sessions for local communities and conservation officers.

This lack of comprehension of how electricity 'works' led to incorrect and dangerous ideas such as that a fence should have many strands, heavy concrete or iron posts, that the strands should be 'augmented' with barbed wire (which is not only against international weapon conventions but very much frowned upon since people or wildlife can get entangled and exposed to repeated electrical shocks possibly leading to death) and/or that fences should be powered by mains current (230 V AC in Nepal) (both are forbidden in, e.g., the Netherlands or the United Kingdom: Anon. 2017). It is not realised that already holding a wire with some 20 mA may lead to cramp (which makes it difficult to disengage from a wire) and at 100 mA may lead to cardiac arrest; a normal system in a household has a capacity of 40 to 60 A. In other words, the powering of electric fences from the mains, which we frequently observed, is asking for serious trouble.

After meetings with the community leaders, it was agreed that a single aluminium wire at a height of 160 cm would carry up to 9000 V and 10 Joule of energy per electric pulse was acceptable. These values are in line with international safety regulations for electric fences (Horizont 2018). We then also agreed that the Himalayan Tiger Foundation, together with WWF Netherlands would pay for a number of items that had to be imported, but that the local people should deliver the labour needed for the installation, maintenance, monitoring, repairs, etc. However, because the local community now clearly claimed co-ownership, they demanded that proper experiments were conducted on the efficiency and efficacy of the newly designed and mutually agreed fence before they would commit to a large-scale rollout.

While the testing of the new fence design was carried out, and before the outcome was known, the local village committees started erecting a fence along the trajectory that was designed by WU/HTF and agreed upon. Yet, the local committees decided to build a traditional multi-stranded fence, not made of aluminium but of traditional galvanized steel wire, with heavy steel poles, and in which the energizer is powered by both solar panels and mains power. According to the local community heads, the two main reasons for this decision were that (1) they raised money from the local communities in the form of a tax which had to be spend in the current fiscal year, and (2) that the damage caused by elephant was so high that something had to be done quickly to prevent unrest in the local communities. As electric fences with a similar design that were built in the region in the past have shown, these poles can be easily reached by elephant trunks, and pushed or pulled over.

Since the testing of the aluminium fence in an area with wild elephant now has been done for a full year, we present here our design and results. During this period, the local community repeatedly expressed their wish to learn from our design, and requested the Department of National Parks and Wildlife Conservation to maintain the experiment.

The design

One of the key requirements was that the fence should not pose a barrier for anything other than elephant. To reach this goal we had to determine the correct height of the wire so that an adult elephant would be unable to pass the fence without touching the wire carrying the electricity. To that end, we executed experiments with domestic elephants in Chitwan NP (Nepal) owned by the Edwards family (Tiger Tops Hotel). All adult elephants were female since males are rarely kept. We first discussed the question with mahouts and guides, and then placed a morsel of preferred elephant food on a pole, and asked a mahout to come forward with an elephant. Meanwhile, guides were instructed to keep a line of signalling tape horizontally in between the elephant and the food at different heights. We tested whether the elephants could reach the morsel without touching the line (Fig. 1). After the experiment, we concluded that the optimal height of the wire was between 155–185 cm, but at 160 cm any adult elephant would touch the line. From this we took that if this line would have been electrified, the elephant would always get a shock if it tried to pass underneath.

We first considered that an elephant trying to pass an electric fence would not try to break the line with the trunk, but would try to demolish the pole. That we had observed at many places in Nepal, and was clearly mentioned by local people. Therefore, the issue was to get the pole out-of-reach of the elephant by ensuring that it would touch the electrified wire before it could reach the pole. Again, after testing with the same domestic elephants, we found that this distance was 120 cm: the wire had to be offset at least this far before the poles were out of reach. Since wild male elephant can be bigger than domestic females, we opted for an offset of 140 cm for our design. We opted for an aluminium brace to offset the wire from the poles. To prevent elephant from simply grabbing the braces we electrified these too.

Figure 1. Trials with domestic elephant to establish correct fence height.

Another consideration was whether a separate ground wire running parallel to the live wire would need to be present. This would improve 'giving a shock' upon contacting the fence, which is potentially important in areas with rocky soils that have a high resistance. However, during prototype testing it turned out that fitting a parallel ground wire was impractical, with a high chance of the wires touching each other upon even minor interaction, leading to a short circuit rendering the entire fence inoperational. Furthermore, from our field inspections in the area we found that grounding is not a major issue. Since the area is mostly a riverine floodplain, the soil is waterlogged for most of the year, meaning good conductivity to the soil. In areas with check dams, the metal wire used to hold rocks in place acts as a grounds wire.

After taking all the requirements and observations into account, we set out to design our fence.

Design drawings and explanation

Our design is based on a stable concrete pole that serves as a mounting point for the other components. The post is 280 cm long and placed 80 cm into the ground. Depending on the type of soil, gravel may be added to stabilize the pole.

On the pole two aluminium clamps are fitted, that are insulated with 5 mm thick rubber sheets. Two bolts pass through the ends of the clamp to secure it to the pole.

One bolt on the lower clamp also serves as the mounting point for an aluminium T-profile, which serves as a brace to offset the wire.

A piece of aluminium wire, the same as used for the live fence, is attached to the top clamp and halfway along the brace, securing it in position at the correct height.

A hole at the tip of the brace allows for easily mounting the fence wire with a special type of bolt. This bolt is split down the middle, so the wire can easily be inserted and secured to the brace, thereby also ensuring adequate conductivity from the wire to the brace.

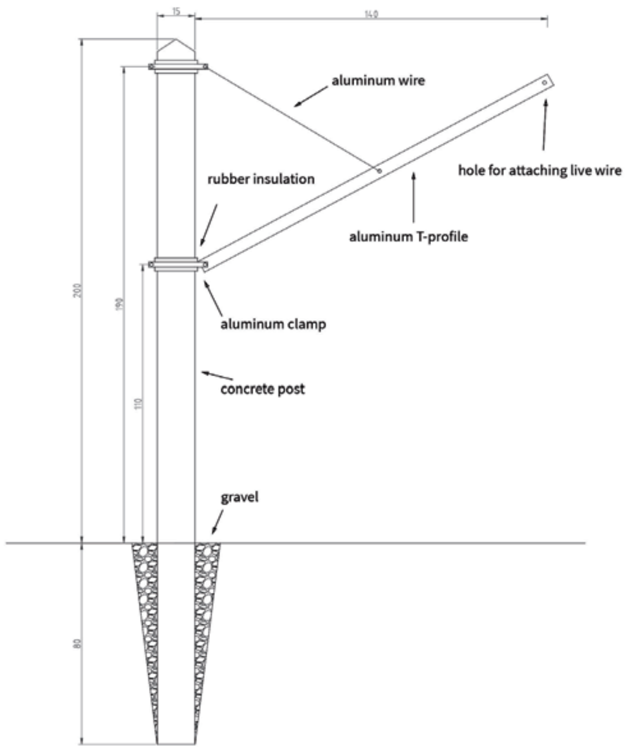

Figure 2. Cross-section drawing of design. All measurements are in cm.

Altogether the design is kept as simple as possible, consists of few unique components and can be put together by everyone after a few hours of training. The design is shown in Figure. 2.

The total cost of the fence is about € 2000 per km (Table 1). However, the total costs are influenced greatly by the total length of the fence, because components like the energizer are only needed every 10–15 km. The costs for this experiment were higher due to the small scale, and the inclusion of a video monitoring system. The video system is specific to this experiment and therefore left out of the breakdown.

Live experiment and conclusion

From 17th to 24th July 2017 a field experiment was set up to test the design in a real-life situation. A short circular section of fence, consisting of 10 poles, was erected around an observation tower near a waterhole at the Lamkauli grassland ('phanta') in Bardiya NP (28.52º N, 81.29º E), which according to park officials was frequently used by elephant, both mixed herds as well as solitary adult bulls. The observation tower lies some 500 m away from agricultural lands and

Table 1. Breakdown of components and costs (in €) per kilometre of fence.

Item	Amount	Unit price	Total
Energizer 4.5 joule 9 kV	1	400.00	400.00
Battery 12 V 60 Ah	4	104.00	416.00
Solar panel 100 Wp	4	70.00	280.00
Charge controller 30 A	1	90.00	90.00
Charge controller 6 A	1	30.00	30.00
Aluminum wire 10 AWG / 2 mm	1100 m	0.11	118.25
Insulated wire 5 mm	100 m	1.00	100.00
Grounding stakes 1.5 m	2	15.00	30.00
Housing for energizer + charger + solar	3	50.00	150.00
Fence voltage meter	1	80.00	80.00
Concrete post rebar 10 x 10 x 300 cm	10	100.00	100.00
Aluminum T profile 5 x 5 x 200 cm	1	11.30	11.30
Nuts, bolts, insulation, tensioners etc.	1	75.00	100.00
Transportation & import tax			50.00
Total cost per km			1965.55

villages. Local rangers and villagers recognized elephant that visited both Lamkauli and the surrounding agricultural lands. The circle had a circumference of 110 m, or diameter of about 35 m. The layout is shown in Figure 3. This was a compromise between the available open space around the tower, and the angle the wire between the poles had to make at each pole. If the angle was too acute, the minimum offset distance of 140 cm was not reached. After some tuning of the construction, the current through the fence stabilized at 8700 V, close to the target of 9000 V.

To entice elephant to try and breach the fence we placed one 40 kg bag of rice, 8 banana plants and 20 kg of 'elephant sweets' (a by-product of sugarcane) inside the fenced-off area at the beginning of the experiment. A video system with four cameras was set up from the tower with full 360^{o} coverage of the site. A schedule for routine monitoring by NTNC technicians was set up, so as to detect the presence of elephant nearby, and to download video footage after interaction of elephant with the fence.

The fence was fully operational from 27^{th} July 2017 until 20^{th} October 2017 with no elephant activity detected in the immediate area. Since elephant moves over large distances, seasonal migration may be involved and water availability is not limited in the monsoon period this was not unexpected.

The first report of interaction with the fence took place on 21^{st} October at about 01:15 hr. The fence was breached and subsequently most poles were pushed over. After closely inspecting the video footage, a team of WU/HTF/NTNC/BNP reconstructed the following chain of events: The first attack was by a medium sized bull elephant with tusks estimated at 70 cm length with a rather steep declination. The bull spent about 10 minutes close to the fence and finally made contact with the live wire, leading to the animal getting an electrical discharge, the spark of which is clearly visible in the footage. The bull then backed off but remained close by the fence, some meters away. At that moment a second much larger bull with tusks of about 90 cm, pointed forwards (thus with a much more shallow declination as compared to the other bull), appeared. Figure 4 shows both bulls standing just in front of the fence.

This bull then sized up the fence, first carefully inspecting the construction with his trunk for 11 minutes. After apparently concluding that there was no safe place to make contact using his trunk, the bull attempted to crawl underneath, which also failed. Finally, the bull tried to pull the fence

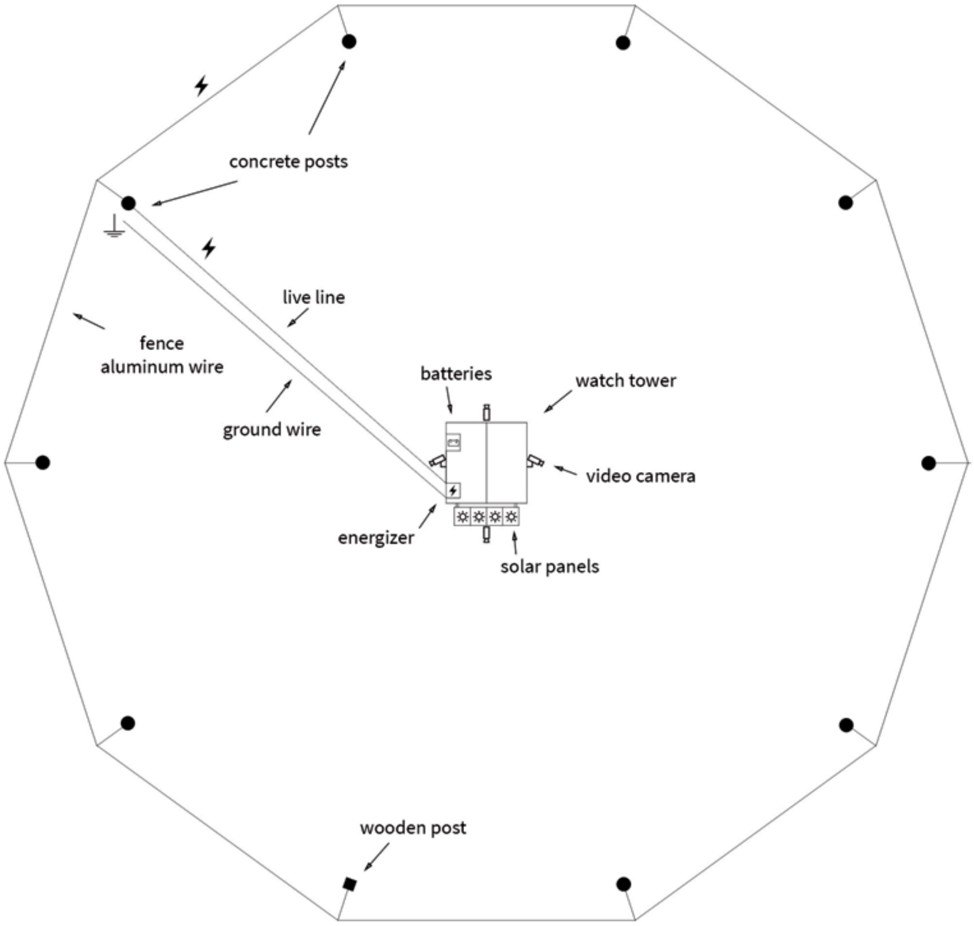

Figure 3. Schematic top-down view of the test fence. All posts but one were made of concrete (round icon), one was made of wood (square icon).

using his tusks, in which it eventually succeeded after hooking the tip of his right tusk in between the connection of the live wire and a brace. One of the concrete poles, which was locally made and of which the quality was sub-par, then collapsed and the fence wire fell to the ground. Sparks were visible on the ground, indicating that the fence was still operational at this point. During this episode, that lasted about 45 min, the other bull stayed close by. With the live wire now bested, both elephants could now have entered the site to eat the food, but neither of them did. The banana plants were alive, and the rice still available below the tower and perfectly edible. However, the elephant sweets had mostly disappeared. The largest bull came back the night after the initial attack and pulled over the remaining 9 poles that were still standing. Noteworthy is that during the entire period that the second bull interacted with the fence it did not get an electric shock once, indicating that it was very careful and systematic in its approach. We speculate that this bull might have had encounters with electric fences before.

From this analysis we concluded the following:

- Elephants seem not to be able to reach the posts with their trunks or crawl underneath the live wire.

Figure 4. Two bulls challenge the electric fence at the test site.

- The fence seems to be effective against non-tuskers and tuskers with short tusks or tusks that "point downwards".
- The fence is vulnerable to large 'tuskers' (90+ cm) with tusks that stick out rather level and of which more than 90 cm of ivory keeps the skin from contacting a live wire.
- Because Asian elephant are skilled at problem solving and have shown evidence of using insight learning (Foerder *et al*. 2011), it was necessary to upgrade our design.
- The focal area for improving the design was the tip of the brace, where live wire and top line are fixed. This required additional protection to place it out of reach of tusks.

In November 2017, a team consisting of WU/HTF and students from Technical University of Delft visited the site and worked on adjustments. Short pieces of wire were fitted to the tip of the brace, forming "whiskers", as shown in Figure 5. These whiskers were pointed outwards, creating a 100 cm wide electrified buffer around the brace. These are expected to prevent elephants from using their tusks to reach the brace, as the whiskers will make contact with the face of the elephant, delivering a shock.

After these adjustments, the test continued for eight months (till presently, August 2018). Although elephant had been detected by the video system four times in that period, no further interaction with the fence has been recorded, and the fence remains fully operational and stable.

Figure 5. Electrified 'whiskers' that extend from the tip of the brace protect the brace from being targeted by elephant.

After 10 months without interaction we considered discontinuing the experiment, but were held off by local people who asked us to continue the experiment. Elephant are known to dislike sudden changes in their environment but seem to accept them at some point (pers. obs., and discussions with many rangers in Africa and Asia). Habituation in elephant has rarely been studied formally but elephant readily did it when exposed to sounds in a study with African elephant in captivity (Goodyear 2015). Also in the wild it appears that after repeated exposure, elephant habituate and find solutions for skirting barriers (Davies *et al*. 2011; Hoare 2011). It is thus very well possible that elephant living in the Bardiya National Park area have reached acceptance of our test fence and will no longer easily be enticed to attempt to breach it. Another possibility is that the attractants placed at the site are not enticing enough for the elephants to attempt to breach the fence. We tried to minimize this by continuously offering them bananas, rice and 'elephant sweets' within our fence. We thus consider to continue the test in a new location, closer to local communities where crop raiding is very common. This follow-up experiment should focus more on large-scale testing so that elephant needs to pass the fence in order to reach the crops.

Acknowledgements

This work was financed by the Himalayan Tiger Foundation (HTF) and WWF Netherlands. We are grateful to the support of Femke Hilderink (WWF Netherlands), Sheren Shrestha (WWF Nepal) and of Drs Cas de Stoppelaar, Dr. Lex Raat, Eelco Dijk and Dr. Laura Bertola (all HTF). We especially want to thank Egbert van der Pol (HTF), Kumar Khadka, Umesh Paudel (both NTNC) for their continued support and enjoyable hours in the field, the local army and especially their commanding officer Lt Col. Rajendra Pant and Lt Col. Tek Bahadur Chand, the Chief Conservation Officer Mr. Manoj Shah, Assistant Conservation Officer Mr. Ashok Bhandari and former Chief Conservation Officer Mr. Ramesh Thapa, Mr. Netra Acharya, Buffer Zone Management Committee chairperson, local NTNC representative Mr. Shyam K. Thapa, Dr. Naresh Subedi, field NTNC Programme Manager, and the community leader Mr. Mahendara Chaudhary, Guruwa Rural Municipality, Head Mr. Jaman Singh KC and community people of the area. We acknowledge with gratitude the warm hospitality from Mr. Kristjan Edwards of Tiger Tops plc. both at Karnali River Lodge in Bardiya National Park and at Tiger Tops Hotel in Chitwan National Park.

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