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Short Communication

Infrared barriers as a detection tool to reduce human–elephant conflicts

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Elephant incursions into farms represent an important challenge for local communities and farmers living around protected areas, but also for the long-term conservation of elephants. Early detection of elephants is a promising technique to reduce elephant presence in farms and human settlements reducing human–elephant interactions. In this study we investigated the potential of infrared barriers to detect African savannah elephants *Loxodonta africana*. We designed and tested battery-operated photoelectric beam sensors in 12 locations of southern Tanzania and assessed the elephant detection accuracy through camera trapping for a total of 246 days. We obtained 1803 recordings of wildlife crossing the barriers range (30 different species of mammals and several bird and bat species). Our results show that infrared barriers, when located at 1.75–2.2 m high, detect 100% of adult elephants and ~ 29% of subadult elephants. Giraffes were the only other wildlife species detected by the barriers. Interestingly, large vehicles were also detected, which might be helpful to prevent motorized poaching. Given the gregarious behaviour of elephant families, and the limited access for vehicles, infrared barriers may represent an interesting and cost-effective detection system for early warning strategies in elephant-dominated areas of Africa and Asia or for other large-sized visitors.

Keywords: early warning systems, human–wildlife conflict, *Loxodonta africana*, photo-trapping, wildlife detectors

Introduction

When wildlife and human populations overlap in a particular area, their interactions and competition for resources sometimes lead to increasing negative impacts or threats to human livelihoods (Thirgood and Woodroffe 2005, Baral et al. 2021). These negative situations involving humans and wildlife are broadly known as human–wildlife conflicts (HWC) and represent an important threat for the conservation of the wildlife species involved, due to habitat destruction and wildlife killings as a form of retaliation (Mariki et al. 2015). In particular, human–elephant coexistence presents numerous challenges for conservation and human livelihoods across the elephant species range

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in Africa and Asia (LaDue et al. 2021, Gross et al. 2022). Elephants are known for using risk avoidance strategies such as travelling at night and moving faster in human populated areas (Graham et al. 2009). However, crops offer high nutritional intake comparing to wild plants (Rode et al. 2006), and in some cases elephants trade off safety for the gain associated with crop raiding (Chiyo et al. 2011). Therefore, when elephants enter the farms, they negatively affect human sustenance by foraging in the crops (Drake et al. 2021), but also threaten human and elephant lives by creating unsafe situations when humans are surprised by elephants in their farms or when trying to chase them away (Prakash et al. 2020).

Although these challenges have been reported for centuries, they have recently become more prominent due to increasing habitat conversion from human impact (Köpke et al. 2021, de Silva et al. 2023). In particular, human agricultural expansion is reducing and fragmenting elephant habitats (Ripple et al. 2015) and increasing the overlap of human activities and elephants´ ranges (Hoare 1999). To reduce the interaction between humans and elephants, several initiatives may arise, highlighting: land use planification based on elephant needs and movements (Hoare 2015), use of physical barriers and deterrents (acoustic, visual or olfactory) to separate humans and elephant spaces (Branco et al. 2020), and early warning systems such as watching towers (Sitati and Walpole 2006) or 'virtual fences' (Slowtow 2012). Early warning systems aim to alert of elephant presence to farmers, guards or wildlife rangers before they enter crops or human settlements (Sitati and Walpole 2006, Hedges and Gunaryadi 2010). The alerts provide a time window that allows people to find a safe refuge, or plan and execute actions to chase away the elephants.

'Virtual fencing' is a technique used as early warning systems that instead of creating a physical barrier creates a 'virtual' barrier that only affects specific species, allowing other species to move freely and maintaining the majority of the ecosystem structures and functions (Jachowski et al. 2014). When those target species, in this case elephants, cross the 'virtual fence', a wide variety of alarms (e.g. sounds, lights) can be automatically activated to scare away the elephants and alert the human population. In some cases, those systems can also alert wildlife authorities or local communities by sending notifications and exact location of the animals by SMS or radio, facilitating a quick response to chase elephants away from human settlements. Well-known examples of virtual fences are the establishment of 'geofences' in the landscape, based on GPS collared animals (Slotow 2012). However, this method can be very costly, only gives information of the collared animal and involves chemical immobilization to collar the target individuals, which can be risky.

'Virtual fences' and any other early warning system are based on detectors. The sensitivity of the detectors to spot the target animal is a key aspect that strongly determines the accuracy and therefore the effectivity of the warning system engineering. The perfect detector would have a broad range of detection, detect every elephant that passes, not have false alarms and be affordable.

The most traditional and broadly used detection method to spot elephant presence in African farms consists of deploying guards on the ground or using watching towers (Sitati and Walpole 2006). This approach although it has some benefits (e.g., local communities' direct involvement) has important constraints of visibility, especially in forested areas. Furthermore, it needs motivated guards and it may imply important safety risks, mainly at night when visibility is low and the probability of injury or encountering elephants by surprise is higher. On the other hand, in some cases it might cause indirect costs such as the loss of sleep for guarding, more exposure to diseases such as malaria for being outside at night and even truancy because children remain in the farms to collaborate on guarding the crops (Hill 2000, Thirgood and Woodroffe 2005, Barua et al. 2013).

The need of detecting elephants has recently encouraged the testing and development of numerous technologies, including vocal infrasound (Thompson et al. 2010), seismic sensors of elephant footsteps (Wood et al. 2005, Parihar et al. 2021), video and camera images recognition (Zeppelzaver and Stoeger 2015) or infrared movement detectors. However, these methods are often insufficiently accurate, have generally limited ranges of detection (Sugumar and Jayaparvathy 2014), are problematic when there is background noise (Dhanaraj and Kumar Sangaiah 2021), or provide unclear images (Zeppelzaver and Stoeger 2015). For example, infrared movement detectors, even when located in high positions, can be easily triggered by birds and have reduced detection ranges (7 m radius).

One technology that has been barely explored in the literature is the use of infrared beams to detect elephants. Some studies have used infrared barriers to detect wildlife crossings but not to target specific species (Gužvica et al. 2014). Regarding elephants, to our best knowledge, the detection accuracy has only been tested in Asia on captive or domestic elephants and for small detection ranges (10–30 m) (Rathnayaka et al. 2020). In addition, theoretical designs advocates for the need of a complementary sensing tool (e.g. seismic or IR movement detection) to increase the performance of the system (Arya Singh et al. 2016, Wijesekera et al. 2021). However, more research regarding the accuracy of infrared barriers in the field (with two or more integrated beams) is needed given their potential, as they can reach nominal distance (theoretical maximum distance between receptor and transmitter) up to 250 m outdoors. The exact location of the barriers is also a key aspect, particularly the height from the ground, to better detect some wildlife species over others and be as accurate as possible depending on the target animal. In Asia, elephants are the tallest animals, and in Africa they are the second after giraffes, which are not present in most of the elephant ranges in the continent. Therefore, placing the barriers at certain height might rule out the detection of mid-small size animals while still detecting the elephants.

In this study we investigate the accuracy of detection of infrared barriers for African savannah elephant *Loxodonta africana* in a natural environment inside protected areas of southern Tanzania in both miombo woodland and woodland savannah ecosystems. We specifically test infrared barriers and their effectiveness at detecting only elephants (adults and subadults) and compare their effectiveness and costs with other alternative tools to potentially reduce human–elephant conflicts.

Material and methods

Design of the active infrared beam system

The system was designed to determine what animal species are detected in the wild by active infrared barriers located at a convenient height (between 1.75 and 2.2 m high) to detect elephants and avoid other large animals. We used two sets of battery-operated quad photoelectric beam sensors (TXF-125E, cost of ~ $450) based on TR-RE four beam simultaneous interruption that have a height of 45 cm and a nominal range up to 100 m outdoors. We selected these barriers because the batteries last around five years and their wireless attribute allowed us to easily test them in different environments and to reduce the environmental impact of the installation (no wires, no soil disturbance, no external batteries).

The system (Fig. 1) is based on a transmitter and a receiver located 1.75 cm above ground level (from the bottom of the barrier) and separated by a distance 'b'. We tried to accommodate to the environment and reduce, to the maximum, any clearing of the area to install the detectors. In addition, we used present trees to install transmitter and receiver which limited in some cases the distance between them. Similarly, we also searched for flat areas or with constant inclination angle between both parts of the barrier, as the barriers can adjust the angle of detection. The distance ('b') therefore varied in every location from 20 to 90 m, although more often the distances were 70–80 m. The receiver was connected to a USB event register (EL-USB-5+) that recorded time and date of all the 'alarm' events detected by the barriers (when the four beams are simultaneously interrupted). At the same time three camera traps (Browning Strike Force Pro XD) recorded any wildlife crossing in the area between transmitter and receiver (Fig. 1). The first camera was positioned under the receiver, the second under the transmitter (Fig. 2) and the third capturing the middle of the ground, between transmitter and receiver. The camera traps have an average 25 m of IR detection, expected to be larger in case of elephants due to their size (Tobler et al. 2008) and 36.5 m adjustable infrared IR flash for night pictures. Therefore, given the cameras position, all the medium-large wildlife crossing between transmitter and receptor were recorded.

Study area

The study was conducted in southern Tanzania inside the paradigmatic Selous-Niassa Transfrontier Conservation Area. This area covers a heterogeneous mix of different vegetation types (e.g. miombo woodland, swamps, thicket, open wooded grassland, tracts of palmyra palms *Borassus* spp. and doum palms *Hyphaene thebaica*), and hosts important viable populations of several rare and endangered mammals and birds such as elephants *L. africana*, lions

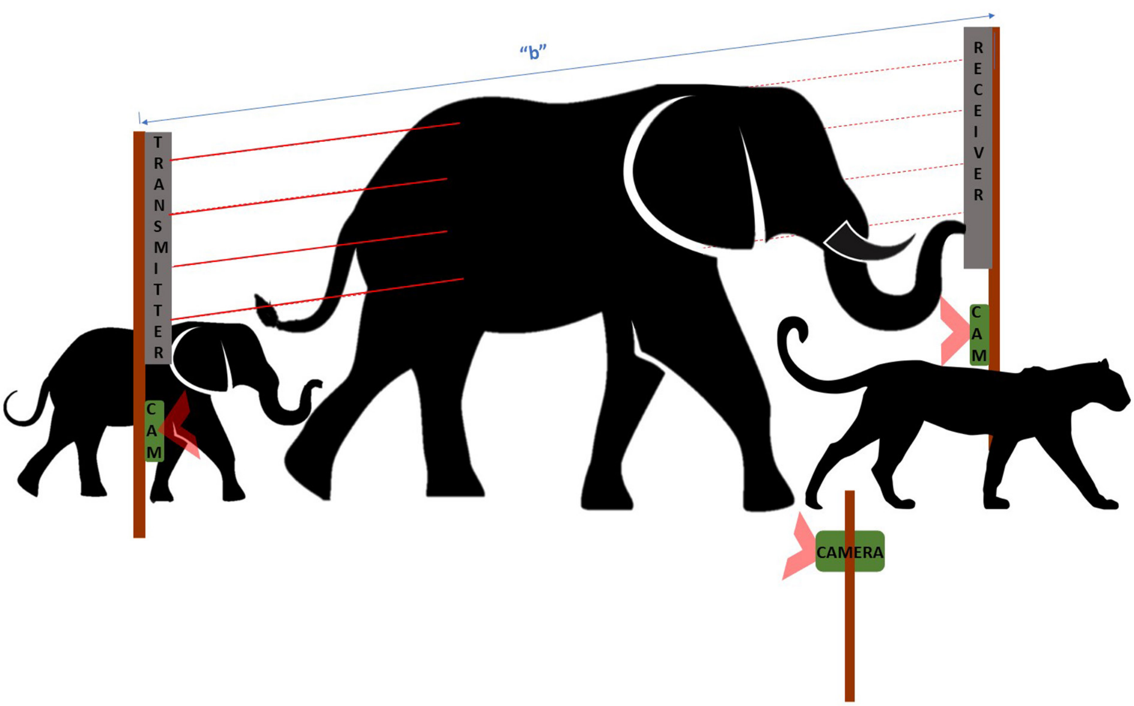

Figure 1. Design of the active infrared system with four beams. Distance 'b' refers to the nominal distance between transmitter and receiver. Note the three cameras for photo-trapping on the three poles (green color).

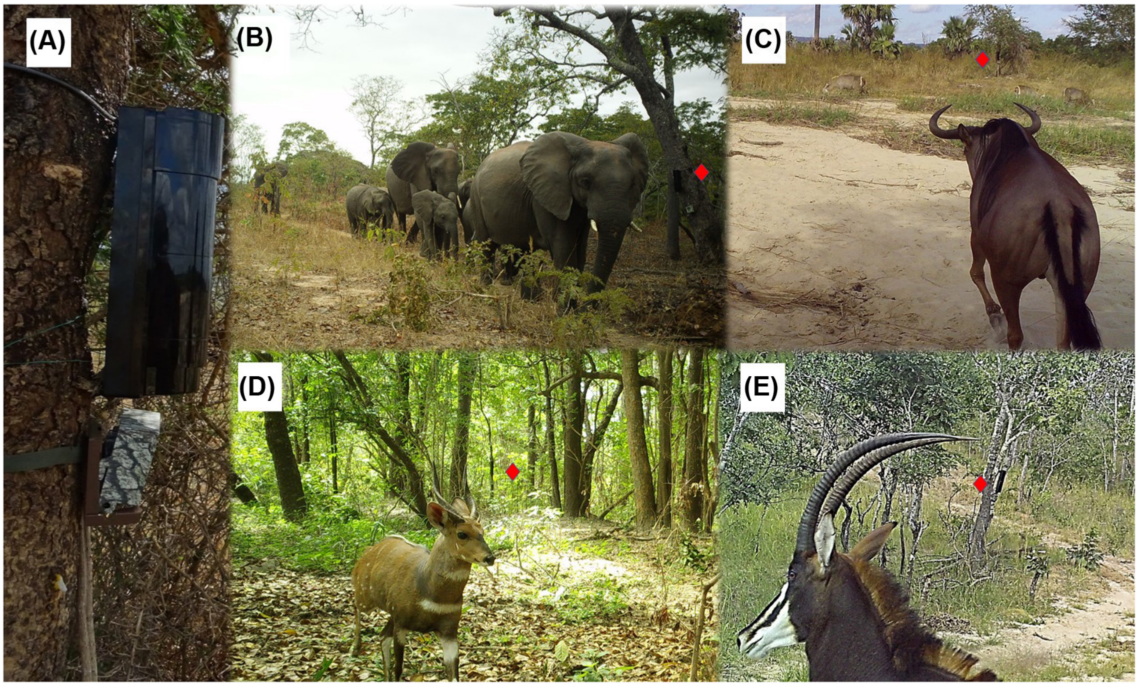

Figure 2. (A) Receiver installed in a tree with a camera trap below, (B) elephant family group crossing the IR barrier, (C) wildebeest and waterbucks crossing the IR barrier, (D) bushbuck crossing the IR barrier, (E) sable antelope crossing the IR barrier. Pictures B–E are taken by camera traps and red dots mark the position of the IR transmitter in the picture.

Panthera leo, leopards *Panthera pardus*, wild dogs *Lycaon pictus*, lesser kestrel *Falco naumanni*, Udzungwa forest partridge *Xenoperdix udzungwensis* and rufous-winged sunbird *Cinnyris rufipennis*.

The barriers were tested in 12 different locations in order to capture the maximum diversity of wildlife: six inside the Selous-Niassa Wildlife Corridor (particularly in Nalika Wildlife Management Area) and five in Nyerere National Park (one in Kalulu Sector and four in Mtemere Sector). Four of them were located along bush roads inside closed miombo forest, two between trees in closed miombo forest, one inside riparian miombo forest, two in riparian palm forest and three in wooded savannah. Both, Nalika WMA and Nyerere National Park, host similar mid-large sized wildlife species except for giraffes that are only present in northern Nyerere National Park.

Data collection

Two systems (1 system = 1 set of barriers plus three camera traps) were rotated in the landscape. We selected 12 locations across different elephant-dominated ecosystems to cover a wide spectrum of wildlife and environmental conditions. On average, a system was active on the same location for 3–4 weeks (range 10–38 days depending on the wildlife crossing frequency and logistical limitations) before changing to another location. For the 12 locations, cameras and barriers worked for a total of 246 working days (24h day^{-1}) without any disturbance, 10 days in August 2021 and 236 days from 25 May to 25 October 2022.

Results

For the total 246 days, cameras recorded 1803 crossings of wildlife (29 species of mammals and several birds and bats) and 106 vehicles (four types) all between transmitter and receiver of the infrared barriers (Table 1). Of those, only 202 triggered the barriers: 88 large vehicles, 74 elephants and 40 giraffes. As shown in Table 1, the barriers detected every adult elephant and giraffe that crossed (i.e. 100% efficacy), reducing the detection rate in case of subadult elephants (28.6%) and giraffe calves (33.3%). All elephant herds that crossed were detected. As expected, given their size, elephant calves were not detected. Figure 3 summarizes the detection accuracy and sample size of every large mammal or vehicle that crossed through the detectors.

Throughout the testing period, there was only two days of light rain but several episodes of whirlwinds, normal windy days and the falling of the miombo leaves. However, none of those episodes affected the detection accuracy of the barriers. In addition, no differences were observed on the detection accuracy comparing the different habitats or the different distances between receiver and transmitter.

In three occasions, wildlife (one hyena, one buffalo and one baboon) moved the detectors by pulling down the cable locker that attached them to the supporting trees. Exceptionally, once, the event register was activated but nothing was recorded by the camera traps for that time and date, although 10 min earlier one of the cameras recorded an elephant trunk touching the camera (by an elephant standing behind the transmitter and camera tree). Therefore, it is very

Table 1. Species/vehicles detection by infrared barriers located at 1.75–2.20 m high in twelve locations of the Selous-Niassa Trans frontier Conservation area.

	Detected	Passed	Detection (%)
Adult elephant (*Loxodonta africana*)	70	70	100.0
Subadult elephant (*Loxodonta africana*)	4	14	28.6
Elephant calf (*Loxodonta africana*)	0	42	0.0
Giraffe (*Giraffa tippelskirchi*)	39	39	100.0
Giraffe calf (*Giraffa tippelskirchi*)	1	3	33.3
Minibus	12	12	100.0
Grader	1	1	100.0
Pickup	53	64	82.8
Car (Toyota 4x4)	22	28	78.6
Eland (*Taurotragus oryx*)	0	27	0.0
Greater kudu (male) (*Tragelaphus strepsiceros*)	0	12	0.0
Greater kudu (*Tragelaphus strepsiceros*)	0	13	0.0
Buffalo (*Syncerus caffer*)	0	42	0.0
Human (*Homo sapiens*)	0	14	0.0
Sable antelope (*Hippotragus niger*)	0	3	0.0
Wildebeest (*Connochaetes taurinus*)	0	24	0.0
Zebra (*Equus quagga*)	0	7	0.0
Waterbuck (*Kobus ellipsiprymnus*)	0	4	0.0
Hippopotamus (*Hippopotamus amphibius*)	0	389	0.0
Motorbike	0	2	0.0
Leopard (*Panthera pardus*)	0	4	0.0
African wild dog (*Lycaon pictus*)	0	7	0.0
Hyena (*Crocuta crocuta*)	0	34	0.0
Bushbuck (*Tragelaphus scriptus*)	0	7	0.0
Warthog (*Phacochoerus africanus*)	0	45	0.0
Bushpig (*Potamochoerus larvatus)*	0	2	0.0
Impala (*Aepyceros melampus*)	0	733	0.0
Yellow baboon (*Papio cynocephalus*)	0	214	0.0
Serval cat (*Leptailurus serval*)	0	1	0.0
Red duiker (*Cephalophus natalensis*)	0	28	0.0
Vervet monkey (*Cercopithecus aethiops*)	0	5	0.0
Black-backed jackal (*Canis mesomelas*)	0	2	0.0
Civet cat (*Civettictis civetta*)	0	30	0.0
Southern ground hornbill (*Bucorvus leadbeateri*)	0	22	0.0
Honey badger (*Mellivora capensis*)	0	1	0.0
Porcupine (*Hystrix cristata*)	0	20	0.0
Blue duiker (*Philantomba monticola*)	0	1	0.0
Genet cat (*Genetta* spp.)	0	12	0.0
Mongoose (Herpestinae)	0	6	0.0
Hare (*Lepus capensis*)	0	12	0.0
Banded mongoose (*Mungos mungo*)	0	7	0.0
Birds/Bats (medium to small size)	0	34	0.0

likely that the barrier was triggered by the same elephant and its trunk minutes later.

Discussion

Results show that infrared barriers located at 1.75–2.20 m high only detected large animals or large vehicles. Importantly, various species of mammals and birds, some of them of large size and flying (i.e. southern ground hornbill, *Bucorvus leadbeateri*), crossed the barriers, including animals with prominent height such as male greater kudus *Tragelaphus strepsiceros* or elands *Taurotragus oryx* but they were not detected due to the high location of the receiver-transmitter with 4 beams that need to be interrupted simultaneously. The recorded animals covered most of the mid-large existing species in the study area.

This study identifies infrared barriers as suitable detectors for adult elephants with a detection rate of 100%. On the other hand, subadult elephants and calves are barely detected which does not represent a failure for the barriers to be used as human–elephant conflict detection method, because subadult elephants and calves very rarely roam alone separated from their herd (Shannon et al. 2006). It will only be a problem in case of orphan elephants roaming around the farms as they would probably not be detected.

However, the detection of large vehicles and giraffes can represent a handicap for the barriers as early warning system

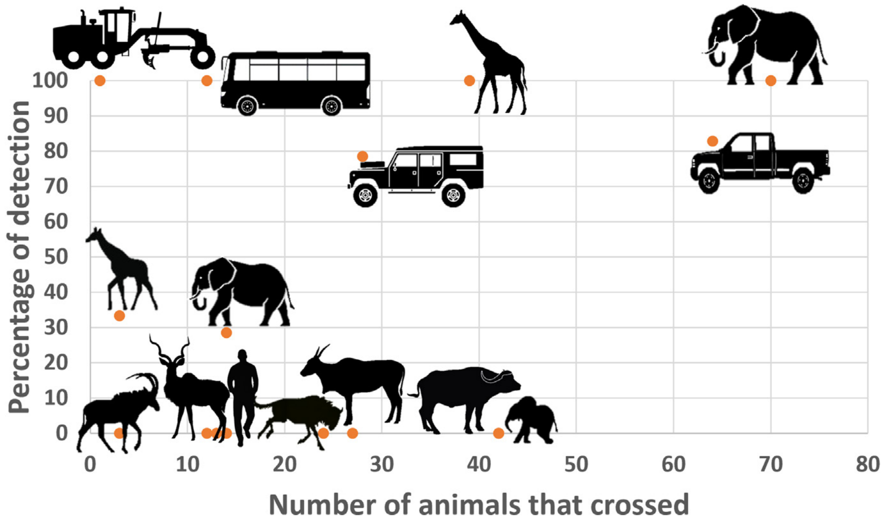

Figure 3. Large species/vehicles detection by infrared barriers located at 1.75–2.20 m high in twelve locations of the Selous-Niassa Trans frontier Conservation area.

for human–elephant conflict. In case they are connected to an instrument to send SMS alarms (e.g. a GSM modem), they would send false elephant alarms when giraffes or vehicles pass. Nevertheless, giraffes have also developed preference for some crops such as mangoes and beans and, while not as severe as elephant-related damage, in some areas conflict with farmers threatens their survival (Leroy 2009, Ahmed et al. 2021). Therefore, chasing them away before they enter the farms can be an interesting measure for giraffe conservation. In addition, in many elephant ranges there are no giraffes, as for example in southern Nyerere National Park, areas in Mozambique and Zimbabwe, Benin, Burkina-Faso, Guinea, Mali, Senegal or the whole Asia. However, more research is needed regarding the detection accuracy of forest elephant *Loxodonta cyclotis* and Asian elephant *Elephas maximus* as they are smaller in size than the savannah elephant (Smith and Fisher 2013). Nevertheless, Rathnayaka et al. (2020) reported high accuracy of Asian elephant detection (92%) by infrared barriers, when located at 1.60–2.10 m high, in controlled conditions in a zoo.

Concerning vehicles, they usually have limited access points between forest and villages, therefore, to avoid false alarms we suggest that the specific barriers that intercept roads should be complemented with a camera so the image can be sent to the ranger's team. This methodology, in case of roads that give access to protected areas, might be very useful to intercept not allowed vehicles or poaching activity. In addition, the type and size of vehicles may strongly differ from place to place and further studies should analyze the detection of other possible vehicles.

The infrared barriers tested in this study have a nominal range of up to 100 m and are relatively expensive (~ $450) due to their wireless characteristics. However, when securing an area, barriers do not need to be mobile and can be installed permanently together with a solar panel and other accessories (e.g. lights or speakers) to chase away the elephants. There are a wide variety of wired infrared barriers in the market that cost ~ $100 and reach outdoors nominal ranges up to 250 m, which would reduce considerably the cost of 'virtually fencing' a big area such as the border between farms and protected areas. In addition, when planned to be installed permanently, we recommend using permanent wooded or metal posts to hang up the transmitter and receiver and clear and level up the area between them so the maximum range can be reached.

The barriers were tested in different ecosystems and climate conditions, with no differences in their detection accuracy. This highlights their potential to be used all over Africa and Asia, with no big concerns regarding the type of ecosystem. However, they should be tested in the heavy rainy season to ensure its accuracy and range under those conditions, before broadly implementing them.

Comparing with other emerging technological devices, infrared barriers have similar or lower cost and larger ranges of detection and can detect adult elephants more effectively (lower frequency of false alarms). For example, autonomous vocal sensors (~ $400) although they have a broad range of detection when triangled (350 m), they do not detect silent elephants (Thompson et al. 2010) or even some of the rumbles (Reinwald et al. 2021), and they malfunction when there is background noise (Dhanaraj and Kumar Sangaiah 2021). Seismic ground sensors ($55–85 per unit), although promising, had 82% of accuracy when used in an African context (false positives of 60% of giraffes and 30% of oryx) and detection of 93% of the elephants that accessed their detection range (Wood et al. 2005). Seismic ground sensors also have very limited linear range (120 m^2, 6 m radius) (Sugumar and Jayaparvathy 2014) although when tested with domesticated Asian elephants alone can detect 90% of the times they crossed, up to 12.5 m of distance (Parihar et al. 2021). Sensitivity of seismic geophones also varies with humidity of the soil and type of soil (Sugumar et al. 2022). Regarding video and camera detection (~ $250), although they are increasing their accuracy with machine learning, they still have reduced ranges: 1–50 m with a detection of 91% of the elephants when using video cameras (Zeppelzaver and Stoeger 2015). In addition, cameras need to have a clear view of the area, so they are not recommended for forested areas, and their accuracy depend on the light quality and position. Tests on infrared cameras ($500–1000) give an actual range of 20–30 m and are very costly (unpublished data, Arribada initiative project www.arribada.org).

Depending on the socioeconomic situation of the affected farmers, the installation and maintenance of the barriers (with or without speakers and lights associated) could be totally or partially funded by the farmers, either cooperatively or individually in their own farms. However, in a scenario of subsistence farming, as it is the case in many human–elephant conflict hotspots, this methodology should be supported by other institutions such as conservation authorities or NGOs (Davies et al. 2011, Gunaryadi et al. 2017). Depending on the size and landscape of the area to cover, the investment to establish early warning systems may strongly vary. For barriers, it will strongly depend on whether there are well known (heavily used) elephant paths to access the farms or not. Similarly, the number of barriers will be higher in areas where farms are scattered in the landscape (many more paths) or when there is need to cover the whole intersection between farms and forest. We recommend their utilization in villages where elephant presence is frequent. However, barriers used as early warning systems should be positioned at least 1 km away from the farms (Wall et al. 2014), have installed a GSM modem (to send SMS) or radio and be combined with the deployment of response teams. This will provide enough time for the response teams to organize themselves and chase away the elephants before they get the crop reward (Wall et al. 2014). If further research confirms high effectiveness in the use of barriers connected to light or speakers to automatically chase away the elephants, the distance between barriers and farms edge can be shortened and response teams would not be necessary. However, noises have been only tested in the short-term (Thuppil and Coss 2016, Wijayagunawardane et al. 2016) and lights and chili aerosols although effective in the short-term (Osborn and Rasmussen 1995, Davies et al. 2011, Shaffer et al. 2019, Adams et al. 2021) might lose effectiveness over the long-term as elephants acclimate to them (O'Connel et al. 2000). Nevertheless, the application of noise and lights linked to infrared barriers, due to their accuracy, would be limited to direct confrontation with the elephants, which might avoid habituation (Desai 2002).

We conclude that infrared barriers may represent an interesting and cost-effective detection system for large wildlife species and could be used as early warning systems in elephant-dominated areas of Africa and Asia. However, further research is needed to ensure their large-scale application in human–wildlife conflicts such as their use in the farms with other technology to remotely warn rangers and locals or their possible malfunctioning under particular environmental conditions (e.g. heavy rains, dense vegetation or the presence of other curious wildlife that may damage the device). Future research is also needed to test whether IR barriers could effectively reduce the conflicts (e.g. by performing trials on actual crop farms and analyze the effect before and after the installation).

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Author contributions

María Montero-Botey: Conceptualization (lead); Data curation (lead); Formal analysis (lead); Investigation (lead); Methodology (equal); Writing – original draft (lead). **Ramon Perea**: Funding acquisition (lead); Methodology (equal); Supervision (lead); Writing – review and editing (lead).

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Data availability statement

Data are available from the Dryad Digital Repository: https://doi.org/10.5061/dryad.jsxksn0gt (Montero-Botey and Perea 2023).

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