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SHOCKING ELEPHANTS: FENCES AND CROP RAIDERS IN LAIKIPIA DISTRICT, KENYA

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Abstract

Electric fences and other barriers to prevent movement of elephants onto arable land are increasingly important conservation tools in Africa, as elephant populations become isolated by areas of increasing human settlement. In Laikipia District in Kenya, crop raiding by elephants is a serious problem, and many different types of elephant barriers have been built over the last 30 years. In order to assess the importance of different design factors, an experimental fence was built along the boundary of Ol Ari Nyiro Ranch in western Laikipia in 1992, and the response of the elephants was monitored.

Comparison of different fences showed that there was no clear relationship between effectiveness of fences, and factors such as design, construction and voltage. Some high-specification fences have proved ineffective against elephants, while other simple fences have worked well for a long period. The previous experience of elephants with electric fences in a particular area, and shooting of fence-breakers are considered to be more important than any design criteria. Electric fences should be thought of as demarcations of 'no-go' areas for elephants rather than as real physical barriers, and conservation efforts should concentrate more on improved active management, rather than attempting to design fences that are effective under all circumstances.

Keywords: African elephant, *Loxodonta*, management, fences, crop-raiding.

INTRODUCTION

The issues of primary concern in African elephant conservation have changed greatly over the last 30 years. In the 1960s, debate centred on local overpopulation of elephants in national parks (Buechner & Dawkins, 1961; Laws, 1970; Laws *et al.*, 1975), while in the 1970s and 1980s the main issue was the degree of impact of illegal hunting for ivory on elephant populations (Douglas-Hamilton, 1987: Parker & Graham, 1989). Following the decline in the price of ivory and the ivory trade ban in 1989, a new problem has emerged: that of conflict between elephants and man.

The conflict between elephants and people which results from the destruction of crops, damage to property, and killing of humans by elephants is a serious conservation issue in many parts of Africa and Asia (Bell & McShane-Caluzi, 1984; Seidensticker, 1984; Sukumar, 1989). The problem is becoming more severe, as increasing human populations encroach onto elephant range, and elephant populations are compressed into restricted areas. Traditional methods for deterring crop-raiding elephants, such as the use of fires, brush fences and loud noises, have generally failed, except where farms were close together (Bell & McShane-Caluzi, 1984). In the past a variety of barriers were constructed to exclude elephants from farming areas, but electrified fences are now considered to be the best solution to the problem. Electric fences, designed to stop elephants, have been erected in Kenya (Woodley & Snyder, 1978), Malawi (Bell & McShane-Caluzi, 1984: Mkanda, 1992), Zimbabwe (Taylor, 1993), Namibia (Sukumar, 1989), Sri Lanka (Katugaha, 1992), Malaysia (Blair *et al.*, 1979), India (Schultz, 1988; Sukumar, 1989) and China (Santiapillai, 1991). Large-scale elephant fencing projects are planned in several countries. For example, the Kenya Wildlife Service (KWS) has plans to erect up to 1500 km of wildlife fencing, the majority of which will be designed to stop elephants (Kenya Wildlife Service, 1990).

Not all elephant fences have worked; some have been so ineffective that they have been abandoned, while others have reduced, but failed to eliminate, the problem of crop raiding (Mkanda, 1992; Osborn, 1993). Despite the large sums of money invested in capital and recurrent costs of fencing, there has been very little information published on the success or failure of different fences, and the factors (such as design, voltage, level of maintenance and the incentive for elephants to cross the fence line) that may determine whether a particular fence is effective or not. Part of the reason for this is that the high costs of fencing (in Kenya usually at least US $2000/km) make it impractical to carry out controlled experiments, and instead designs and management procedures evolve by trial and error. The absence of accessible documentation of case studies means that there is little interchange of experience between regions, and this is a serious constraint to development of new management techniques (Seidensticker, 1984).

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This paper describes experiences with electric fencing and other barriers to elephant movement in the vicinity of Laikipia District, which is a part of Kenya where human–elephant conflict has become a major problem because of human settlement in existing elephant range, and an influx of elephants from more arid areas to the north (Thouless, 1994). The first part of this paper describes the evolution of elephant barriers in Laikipia and surrounding areas, and the second part analyses in more detail the successes and failures of fences and other barriers in the district. An experimental fence and stone wall were erected along the boundary of Ol Ari Nyiro Ranch, on the western side of the district, to test the effectiveness of different designs, and results from this experiment are discussed.

STUDY AREA

Laikipia District covers 9723 km^2 and lies on the Equator. It is bounded to the east by the lower slopes of Mount Kenya, to the south-west by the Aberdares Range, and to the west by the Rift Valley escarpment (Fig. 1). The Laikipia plateau is an area of rolling low hills at an elevation of 1700–2000 m, bisected by the Ewaso Ngiro (river). To the north is low-lying arid pastoralist country of Samburu and Isiolo Districts.

Cattle ranches, generally in excess of 5000 ha, occupy the majority of Laikipia District. Following independence in 1963, ranches in the south of the district were bought for settlement schemes and subdivided into 0·5–2 ha farms. Initially these were confined to areas of high agricultural potential, but later, with an increasing human population, more arid regions were settled. The unplanned nature of subdivision meant that some settlement schemes were surrounded by ranches supporting substantial wildlife populations (Kohler, 1987).

METHODS

Information on the history of fencing was collected from old Game Department records, and from interviews with people concerned with the early development of

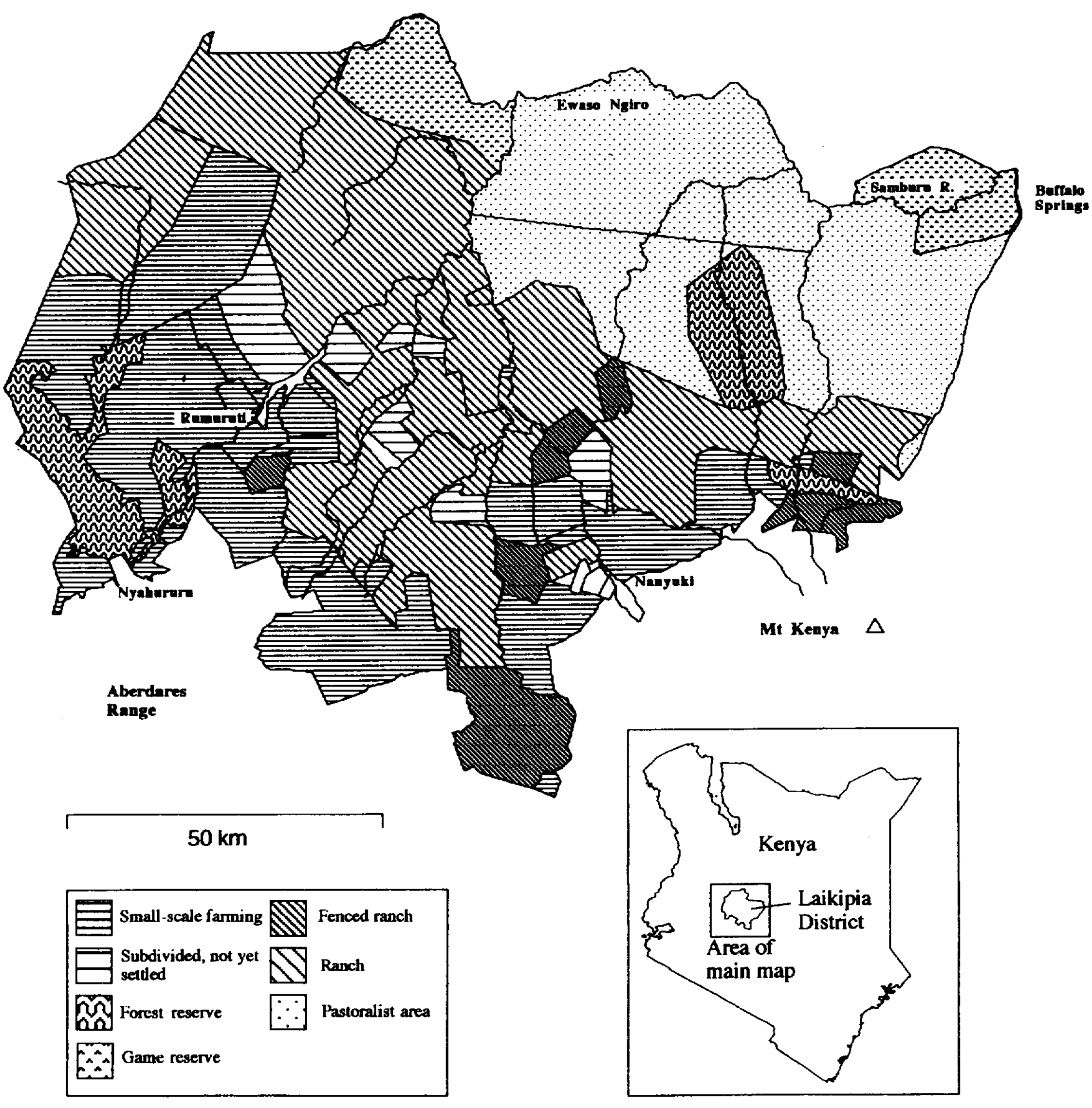

Fig. 1. Laikipia District and adjoining parts of Samburu and Isiolo Districts, Kenya, showing land use. Land use map boundaries from Kohler (1987).

fencing projects. Information came from files held at KWS Headquarters, Maralal Game Station, and the National Archives in Nairobi.

All the existing electric fences in Laikipia District were visited, and information was collected on fence design, voltage, location and length of the fences, and the degree of elephant pressure. Interviews were conducted with people responsible for maintenance in order to determine effectiveness.

Elephant pressure was defined as: (1) light pressure, with the fence separating similar areas of ranch land, supporting low to medium elephant densities; (2) medium pressure, with the fence on a main elephant movement route, but not immediately adjacent to cropland; and (3) heavy pressure, with the fence separating medium to high-density elephant range from cropland. Effectiveness was defined as: low, fences broken at least once per week, or frequently broken, and irregularly maintained; medium, occasional fence breaks; high, fence not broken by elephants more than twice per year.

Before, during and after construction of the experimental fence on Ol Ari Nyiro Ranch, 33 km of the ranch boundary was patrolled every morning for at least 10 days per month to look for elephant footprints and fence breaks. Elephants were assumed to have crossed the fence if damage to posts, wires and insulators was accompanied by footprints on the fence line. When elephant footprints were sighted within 5 m on either side of the fence line. but the fence was not broken, this was recorded as an unsuccessful challenge. Sex composition of the elephant group was determined from footprint dimensions (Western *et al.*, 1983).

RESULTS

Historical review

One of the main tasks of the Game Department during the colonial era was to shoot crop-raiding elephants, rhino and buffalo. Elephants only occurred on the periphery of Laikipia District, coming into farmland on the lower slopes of Mt Kenya and the Aberdares, and moving along the forested hills on the edge of the Rift Valley in the west of Laikipia (Kenya Colony, 1926). The elephants in western Laikipia were regarded as a serious problem because they raided newly established arable farms (Kenya Colony, 1927) and in the late 1920s 20–30 elephants were shot per year (Kenya Colony, 1929). In August 1932 the elephant problem became severe, with elephants in larger numbers than ever before and widely dispersed through the area (Kenya Colony, 1934). A full-time control officer was recruited in December. He shot 80 elephants during 1934, and the situation was again brought under control. Another 35 were shot in 1935 (Kenya Colony, 1935), and this movement route was no longer used by elephants. The control officer was himself killed by an elephant in the following year.

As human settlement increased in proximity to elephant populations, control shooting became less effective and other methods of containing wildlife populations were sought. Early types of electric fencing used in the Nairobi, Tsavo and Aberdare National Parks in the early 1950s were failures (Jenkins & Hamilton, 1982) and attention turned to the construction of moats or ditches.

Moats were constructed in Laikipia, and along the boundaries of the Aberdares and Mount Kenya, and also in Meru National Park, Tsavo National Park and the Maralal Forest Reserve. Simple ditches along the Aberdare Salient failed because elephants learnt how to break down the walls of the moat and climb through, and because other animals could jump across. However, a number of modifications were made in the Aberdares, incorporating fences together with the ditches (Woodley, 1965). These were effective so long as good maintenance was carried out. A ditch was dug along the edge of Ol Ari Nyiro Ranch in Laikipia in 1980, but construction was plagued by corruption and incompetence within the Wildlife Conservation Management Department (WCMD): in some places it was dug to a depth of less than 1 m, and nowhere was it deep and large enough to be effective. Other ditches failed due to lack of maintenance, and none are now operational.

Until the 1940s elephants were very occasional visitors to the central part of Laikipia District. However, after 1960 there was a consistent increase in the numbers coming from the north, and by the 1970s (probably in response to increased poaching pressure in Samburu) over 1000 had become resident (Jenkins & Hamilton. 1982). Damage was done to fences on the ranches, which meant that it was difficult to manage cattle effectively using a paddock system; water pipes were ripped up, troughs destroyed, dam walls damaged and the presence of large herds of elephants endangered the lives of herdsmen and cattle in thick bush. As a result, a number of ranchers built their own solar-powered electrified fences to exclude elephants from their properties. In one case a simple fence was constructed to contain a group of 100 hundred elephants within an area of about 2500 ha in Solio Ranch. Although the elephants made repeated attempts to break out, a series of modifications was made, including electrified wires surrounding the posts, and eventually the elephants came to respect the fence and did not leave, even though they exhausted their food supply. When it was found necessary to move them, they showed considerable reluctance to cross the fence line, even when it was not electrified (Elliott, 1992).

A study was conducted by WCMD on the Laikipia elephant problem, and it was recommended that an electric fence should be built across the whole district protecting areas where wildlife was not welcome (Jenkins & Hamilton, 1982). However, a lack of funding, and the difficulty of getting agreement over the route, meant that this was not constructed. Since then the problem has changed; most of the ranchers have either fenced their properties, or accepted the presence of the elephants—indeed, the development of tourism on private land means that elephants are positively welcomed. However, in the 30% of the district that has been converted to small-scale arable farming, they are regarded as a serious menace. Each year elephants destroy large areas of crops and kill a number of people (Thouless, 1994). Many of the fences constructed recently have been designed to prevent the movement of elephants from ranches onto small-scale farming areas.

Comparison of existing elephant barriers

Simple fences

The simplest types of electric fences rely on the deterrent effect of one or more wires carrying the current, have little or no additional physical strength, and do not have properly grounded earth wires. Many of the early electric fences constructed in Laikipia incorporated a single electrified wire running along the top of a standard five-strand stock fence. Necks of soda bottles were wired to the posts as insulators. In some places an additional wire was strung along the middle of the fence to deter zebras, which are able to push underneath low wires. Other simple fences consisted of single electrified strands suspended from trees and double electrified strands on outriggers. Voltages varied from less than 2 kV to more than 7 kV, and while the higher voltage fences tended to be more effective, there was no clear relationship, since some successful fences had voltages between 3 and 4 kV.

The majority of these fences have proved ineffective (Table 1) as a result of pressure from elephants and/or lack of adequate maintenance, and several have been abandoned. For instance, the low two-strand fence on the boundary of Ol Ari Nyiro Ranch was inadequately powered; elephants learnt to disable it by dislodging the outriggers, and some bulls were large enough to step over it. However, three of these fences have proved extremely effective. All were constructed in areas where major elephant movements took place, and one was built around a small patch of irrigated crop land, in the middle of a movement route. None of these fences is maintained at high voltage, but they are respected by the elephants. When the fences were first established, 10 or more years ago, a number of fence-breaking elephants were shot in these areas.

Multistrand fences

In recent years a number of electrified fences have been built in their entirety, rather than converted from existing stock fences. Most of these have had as their objectives the restriction of movements of elephants and other game, and control of grazing. They are more than 2 m high, with several electrified strands, and earth wires connected to the ground through metal pegs. Voltages are generally in excess of 6 kV. Several have been made to a new design which incorporates PVC piping insulators running through fence posts, rather than using insulators attached to the outside of the posts. Although this has disadvantages from the view of electrical efficiency. and is more time-consuming to repair in the event of a break, it does have the advantage that the conducting wires contribute to holding up the posts in the event that one is broken, and thus, unlike the earlier electric fences, it forms a physical barrier.

One fence which surrounds the Ngare Ndare Forest in eastern Laikipia (Fig. 2), with the intention of protecting neighbouring wheat and maize farmers from crop-raiding elephants, has been a success. It has been challenged on several occasions, but has not been

Table 1. Electric fences in Laikipia

Location	Purpose	Design	Length	In[a]	Out[a]	EP[b]	Eff[c]
Mogwooni	Game movement/illegal grazing	Stock fence with hot wire	20–30 km	R	R/Sq	1	High
Ngare Ndare Forest	Game movement from inside	11-strand electric	> 30 km	F	A/R	3	High
Kisima Rumuruti arable	Game movement from outside	Stock fence with hot wire	< 5 km	I	R	2	High
Kisima Timau	Security	Stock fence with hot wire	10–20 km	A	A	1	High
Ol Jogi Sanctuary	Rhino sanctuary	High-security electrified	10–20 km	S	R	1	High
Borana	Game movement from inside	11-strand electric	5–10 km	R	R/A	1	High
Ngare Sergoi	Rhino sanctuary	23-strand high-security	10–20 km	S	R	1	High
Sweetwaters	Rhino sanctuary	High-security electrified	20–30 km	S	R/A	2	Medium
Marmar	Game movement/illegal grazing	5-strand electric	5–10 km	R	R	1	Medium
Kifuko	Game movement from outside	Stone wall	10–20 km	R/A	R	2	Medium
De Weck	Game movement/illegal grazing	Stock fence with hot wire	10–20 km	R	R/Sq	1	Medium
Loldaiga	Game movement/illegal grazing	11-strand electric	10–20 km	R	R/Sq/A	1	Medium
Tharua	Game movement from outside	Stock fence with hot wire	10–20 km	R	R/A	2	Medium
Old Ol Ari Nyiro boundary	Game movement from inside	Two-strand electric	20–30 km	R	A	3	Low
Ol Ari Nyiro crops	Game movement from outside	12-strand electric	10–20 km	R	R	3	Low
Mutara	Game movement from outside	Stock fence with hot wire	20–30 km	R	R/A	2	Low
Segera	Cattle management	Stock fence with hot wire	20–30 km	R	R	2	Low
Lewa woods	Protection of trees	Single hot wire	< 5 km	R	R	3	Low
Jessel	Game movement from outside	Stock fence with hot wire	< 5 km	I	R	2	Low
Nanyuki Ranching	Game movement/illegal grazing	Stock fence with hot wire	10–20 km	R	R	1	Low
Ngobit Women's Group	Game movement from outside	Single hot wire	< 5 km	I	R	3	Low
Ol Ari Nyiro boundary	Game movement from inside	3–6-strand electric	20–30 km	R	A	3	Low
Ol Ari Nyiro boundary	Game movement from inside	Stone wall	< 5 km	R	A	3	Low
Mugie	Illegal grazing	6-strand electric	20–30 km	R	R	n/a	n/a
Lewa perimeter	Illegal grazing/rhino sanctuary	11-strand electric	> 30 km	R	R/A	n/a	n/a
Kisimi Rumuruti perimeter	Illegal grazing	Stone wall	10–20 km	R	R	n/a	n/a
Ol Pejeta	Game movement from inside	Stock fence with hot wire	> 30 km	R	A/R	3	var

[a]In/out, Land use within and outside fence area; R, ranch; S, rhino sanctuary; A, arable area; I, irrigated; F, forest; Sq, squatter area.
[b]EP, Elephant pressure; scale from 0–3 of increasing pressure, n/a for fences with game gaps.
[c]Eff, effectiveness.

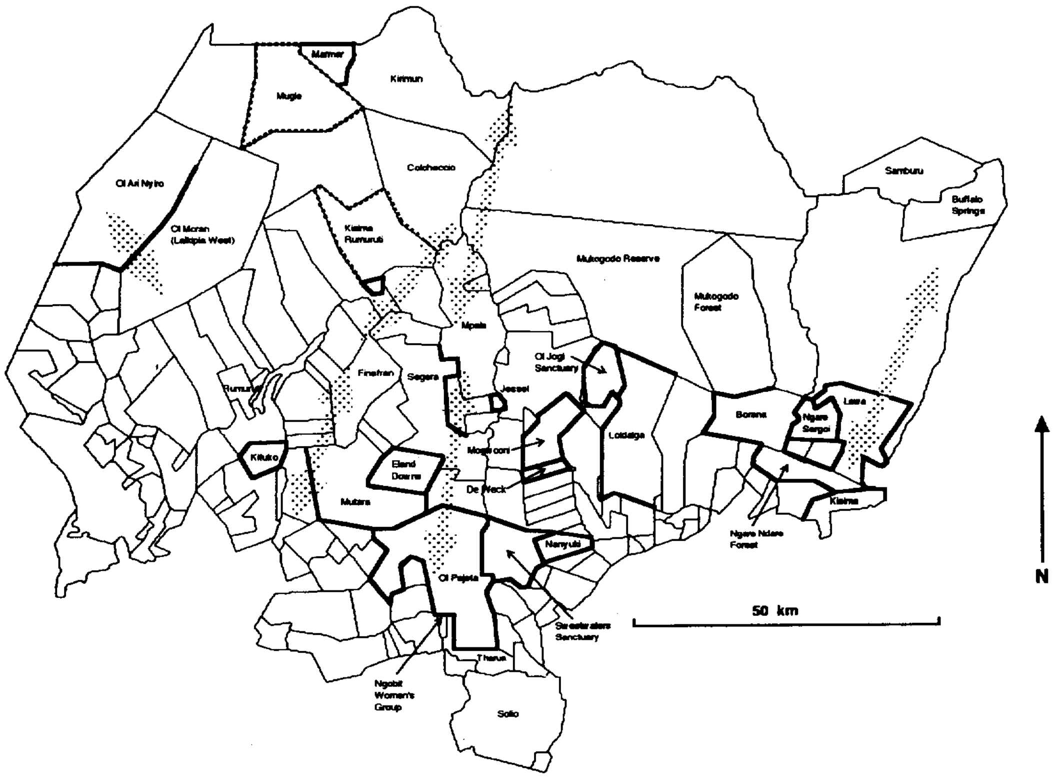

Fig. 2. Map of Laikipia showing locations of elephant barriers in thick lines. Dotted lines indicate fences with gaps to allow wildlife movement. Stippled arrows indicate main movement routes of elephants.

penetrated, although fence posts have been broken, and one elephant broke through by going under the fence where it crossed a steep ravine. Construction costs for this fence were approximately US$2500/km, and annual maintenance costs US$150/km, although this may be expected to rise as electrical components and fence posts need to be replaced. The 11-strand fence built along the edge of an arable area within Ol Ari Nyiro Ranch to the same design has been much less successful (see section on experimental fences).

High-security rhino sanctuary fences

Three rhino sanctuary fences have been built within the range of elephants on Laikipia. These are all large fences with many strands of wire and droppers, and in some cases chain link, barbed wire, and electrified out-rigger wires. Electrified wires are connected to alarms which are activated in response to a drop in current. These have generally been successful in controlling elephants, although with the exception of Sweetwaters, where elephants are contained within the fence, there is little pressure from the elephants. In Sweetwaters there have been problems with elephants breaking in. The high cost of these fences makes them impractical for controlling elephant movements alone.

Stone walls

Dry stone walls have been used in a few areas of Laikipia as farm boundaries. On one ranch they have been used as a moderately effective elephant barrier, but this has been backed up by a vigorous reaction to animals which have broken through the wall. Stone walls by themselves do not form satisfactory barriers against elephants, which can break them down by pushing with their chests. However, it is possible that under certain circumstances (which include local availability of suitable stone) stone walls with a concreted top course or with an electrified wire running along the top could provide an effective barrier. The advantages of walls is that they have minimal environmental impact, and the main costs (if stone is close enough that tractors do not have to be used) are for labour, rather than imported electrical materials.

Comparison of experimental fence designs

Five types of barriers were built on the southern and eastern boundaries of Ol Ari Nyiro Ranch in western Laikipia (Fig. 3), replacing a low-specification two-strand fence. The first three were constructed on behalf of KWS, and the other two by Sanyati Ltd for the ranch management.

(1) Stone wall. A 3·5 km long, 120 cm high, stone wall was built along the southern boundary of the ranch. The width at the base was 120 cm and at the top 75 cm. It was constructed with flat stones, at a cost of approximately US$3500/km

(2) Six-strand fence. A 6 km long six-strand fence ran along the eastern boundary, in the section which had been shown to be the main elephant movement route. Three live wires and three earth wires were attached to the inside of the 2 m posts, using plastic insulators and tacks. Construction costs were approximately US$4000/km.

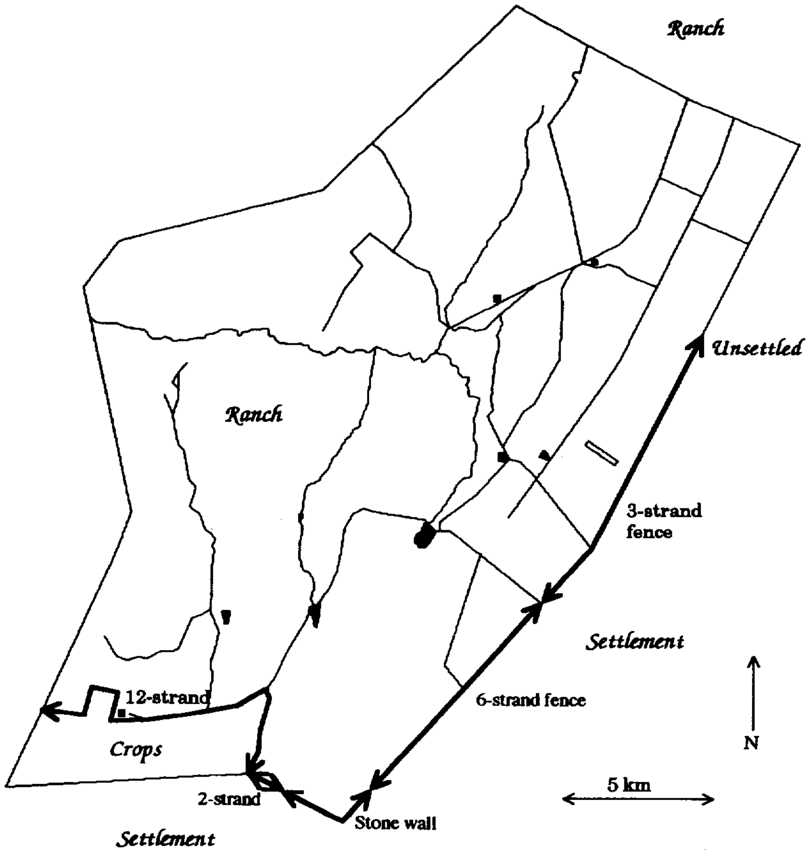

Fig. 3. Map of Ol Ari Nyiro Ranch, showing perimeter fence.

(3) Three-strand fence. A 10 km long three-strand fence of the same design as the six-strand fence, but without the lowest three wires, was constructed on the northern section. The voltages of this and the six-strand fence were maintained at 6–8 kV. The cost was similar to that of the six-strand fence.

(4) Twelve-strand fence, surrounding maize fields and paddocks within the ranch. This consisted of 3 m high posts spaced 7 m apart, with six live and six earthed wires. The wires passed through the centre of each post through heavy duty conduit piping. The voltage of this fence was maintained at 6–7 kV. Detailed records were not kept on the success of this fence, because of the lack of an access road along part of its length.

(5) Two-strand fence. This was erected later, after the failure of the stone wall, along 1 km of its length. It consisted of two electrified strands on posts extending only 30 cm above ground, and two earth wires running along the ground at a distance of 1 m metre on the inside of the fence. The live wires had 1 m lengths of wire attached at 1 m intervals, dangling perpendicularly on the inside of the fence, giving a 'hedgehog' appearance.

Effectiveness of fence designs

Elephants were able to break through all the types of barrier (Table 2). Fence posts were broken on the 12-strand fence on 49 out of the first 118 days of operation (D. Douglas–Dufresne, pers. comm.). The stone wall was particularly ineffective, and was broken so frequently that repairs were seldom carried out. The other sections were repaired nearly every day. From October to December 1992, 39 broken posts and 211 damaged insulators were replaced on the three- and six-strand fences. The three-strand fence was broken less than the six-strand one, but this was probably because it was erected along a section of boundary with less pressure from elephants. The two-strand fence seemed to work very well, but its short length (about 1 km) meant that elephants could easily go around and cross through the ineffective stone wall, so it has not been fully tested.

Table 2. Effectiveness of different barrier types
Figures given are number of breaks per kilometre per day. Total number of breaks in parentheses.

	3-strand	6-strand	2-strand	Stone wall
October	0·13(13)	0·27(32)	—	0·94(66)
November	0·06 (7)	0·11 (8)	—	0·55(23)
December	0·09 (9)	0·37(22)	0·09 (2)	0·34(12)

Elephants usually broke through the fences by kicking at the posts with their legs, or pushing them over with their tusks, so that the live wires were displaced and shorted on the earth wires. The 12-strand fence was modified by protecting the posts with electrified wires around the outside of the posts but the elephants then broke the wires between posts by pulling with their tusks. Dangling live wires were then attached along the length of the fence, but when faced with this,

Table 3. Ratio of unsuccessful challenges to fence breaks
Total number of breaks in parentheses.

	3-strand	6-strand	2-strand
October	1·5(13)	1·7(32)	—
November	2·6 (7)	1·8 (8)	0·5 (2)
December	0·2 (9)	0·1(22)	∞ (0)

the elephants just broke the fence by running at it and crashing through, accepting a 7 kV shock.

It was not realistic to quantify the reduction in the number of elephants crossing the line following the erection of the fence, because other factors changed during this period. In particular, the maize growing inside the ranch in an area where wheat had previously been grown, was a major attraction, and may have reduced the pressure on the perimeter fence. Evidence from radio tracking showed that at least one family group made a substantial shift in home range, towards the crops.

Changes in effectiveness with time

There was no detectable change in the frequency of fence breaking in the months following the erection of the fences (Table 2), despite an expected reduction in incentive for crop-raiding following the harvest in September/October. The relative number of fence breaks compared with unsuccessful challenges had increased by December, compared with the preceding months (Table 3: data for three-strand and six-strand fences combined: $\chi^2 = 30{\cdot}78$; $p < 0{\cdot}001$), indicating that elephants were learning fence-breaking techniques.

Types of elephants responsible

Most groups breaking through the fences included bulls (Table 4). Before the erection of the fence a larger proportion of groups crossing the line consisted of cows and calves only ($\chi^2 = 12{\cdot}68$; $p < 0{\cdot}001$). There was some indication that the decline in cow/calf groups crossing was because they were more frightened of the fence, as a higher proportion of cow/calf groups challenged the fence, but did not cross (Table 5: $\chi^2 = 4{\cdot}18$; $p < 0{\cdot}05$).

Effect of detusking

Because (1) many of the fence breaks appeared to be done by elephants using their tusks either on the posts or pulling at the wires, (2) tusks are good insulators and

Table 4. Percentage of groups and individuals of different social groups crossing fence line outwards from ranch, before and after erection of fence (totals in parentheses)

	No. groups		No. individuals	
	Before	After	Before	After
Single bull	19·8 (88)	17·2(16)	3·6 (88)	4·0 (16)
Bull group	25·6(114)	51·6(48)	15·7 (386)	42·4(168)
Cow/calf/bull	21·8 (97)	18·2(17)	47·1(1154)	40·7(161)
Cow/calf group	32·8(146)	12·9(12)	33·6 (824)	12·8 (51)

Table 5. Social grouping responsible for the first break of the night, thus disabling the fence by breakage or shorting of live wires, and for challenging fence line without crossing

	Challenge/cross	Disable/cross	No. crossings
Single bull	1·0	0·2	23
Bull group	1·3	0·5	49
Cow/calf/bull	1·4	0·5	10
Cow/calf group	2·7	0·3	7

(3) detusking of a persistent fence-breaking elephant on Lewa Downs ranch appeared to be an effective deterrent, it was decided to remove the distal third of the tusks from eight bull elephants from groups known to cross the fence line. This operation was carried out in mid–December 1992. This had no detectable effect. There were 15 fence breaks in the 6 days preceding the detusking exercise and 20 in the 5 days following. The detusked elephants were involved, since five out of the eight were seen in a group outside the fence shortly afterwards (B. Heath, pers. comm.).

DISCUSSION

It has been suggested that the most important factors determining the success of electric fences constructed to prevent the movements of elephants are fence design, voltage, and especially the quality of maintenance (DHV Consultants, 1992). However, this paper presents examples of well-built and well-maintained fences, with adequate power supplies and good earthing, which have been broken regularly by elephants. The fact that these fences around Ol Ari Nyiro Ranch were broken does not mean that they were useless. It was not possible to make a direct comparison of numbers of elephants crossing the boundary before and after the erection of the fence, because of seasonal differences, and the changes in movement patterns that resulted from the presence of maize growing within the ranch, but the involvement of cow–calf groups in crop-raiding was substantially reduced following the erection of the fence. In India it has been found that elephant cows and calves are less willing to take risks in raiding crops than are bulls (Sukumar & Gadgil, 1988; Sukumar, 1991).

Electric fences in Asia appear to have been more effective than those in Africa (Sukumar. 1989), although Katugaha (1992) describes an unsuccessful fence in Sri Lanka. This may be because African elephants make considerable use of their tusks for fence breaking, while many male Asian elephants and all females are tuskless. Also, soil moisture tends to be higher in the range of Asian elephants than in savannah areas of Africa, and the higher soil conductivity makes electric shocks more effective.

Further modifications made to the Ol Ari Nyiro fences in 1993 reduced the level of fence breaking. It may be possible to continue upgrading fences which are under pressure, but it is likely that the elephants will learn new ways of dealing with these, as was shown with the 12-strand fence on Ol Ari Nyiro. In Asia, successive modifications have had to be made to fence design, and after a few years elephants have learnt to deal with each new modification (Rice, 1990), in some places even pulling trees onto the wires (Seidensticker, 1984).

Elephants do not always learn to break down fences. The fence around the Ngare Ndare Forest was built to a very similar design to the 12-strand fence at Ol Ari Nyiro, and in contrast to the latter has proved very successful. The difference in effectiveness is probably related to the previous experience of the different groups of elephants. Those on Ol Ari Nyiro had been used to disabling low-specification, low-voltage fencing and were well acquainted with the effects of electricity. The elephants in the Ngare Ndare Forest had much less experience, and thus the deterrent effect of the first encounter with the new fence was probably considerably greater. It is also possible that elephants in Ol Ari Nyiro were more food-limited and had a greater incentive to raid crops. Availability of natural food is believed to be a major determinant of the success of electric fencing projects in Malaysia (Rice, 1990).

Some low-specification fences have also been very successful, despite low voltage, high incentives for elephants to cross and only moderate levels of maintenance. The fences on Kisima Rumuruti and Mogwooni Ranches (see Table 1) have seldom been breached by elephants over a 10-year period. Before and during the time that these fences were being erected, a vigorous policy was adopted towards trespassing elephants, and a small number were shot each year. Despite the fact that there has been no shooting in these places for many years, the elephants still respect the fences. It appears that once the elephants learn to recognise the fence as a barrier between areas in which they are safe from areas where they may be shot then pressure on the fence will be greatly reduced. This may be enhanced by the fact that if elephants do break through, they will be in an area devoid of sign or smell of elephants. In 1991 a single bull did break into Mogwooni Ranch, from which elephants had been excluded for over 10 years, but after travelling through the ranch without stopping, it broke out again immediately afterwards.

Given the problems and expense of engaging in a prolonged 'arms race' with elephants over fence design, it may be sensible to build relatively low-specification, low-cost fences, and to concentrate on management of the elephants, treating the fences as demarcations of 'no-go' areas, rather than physical barriers. For these fences to work, it may be necessary to shoot elephants that persist in attempting to break the fence. Provided that this is done in an efficient way this will not necessarily involve the killing of large numbers of elephants. On the periphery of Tsavo National Park, raiding of sisal plantations was controlled through shooting one elephant a year (D. Woodley, pers. comm.). An efficient control shooting programme implemented at an early stage may result in considerably fewer elephants being shot over the long term. Following a period when little attention was paid to control work, 22 elephants had to be shot in Laikipia District in 1992 (Thouless, 1994). It is likely that cow–calf groups will be more easily deterred and if continued shooting is necessary it will be chiefly directed towards bulls which will have less long-term impact on elephant populations.

As human populations increase throughout Africa, so will conflict between humans and elephants and the erection of barriers between human and elephant populations be essential in many places to ensure the survival of the elephants. Learning how to build and manage effective barriers is essential for elephant conservation, and it is important to consider ecological and behavioural factors in addition to the technical considerations in fence building.

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REFERENCES

Bell. R. H. V. & McShane-Caluzi, E. 1984). The man–animal interface: an assessment of crop damage and wildlife control. In *Conservation and wildlife management in Africa*, ed. R. H. V. Bell & E. McShane-Caluzi. US Peace Corps, Malawi, pp. 387–416.

Blair, J. A. S. Boon, G. G. & Noor, N. M. (1979). Conservation or cultivation: the confrontation between the Asian elephant and land development in Peninsular Malaysia. *Land Dev. Digest*, 27–59.

Buechner, H. K. & Dawkins, H. C. (1961). Vegetation change induced by elephants and fire in Murchison Falls National Park, Uganda. *Ecology*, **42**, 752–66.

DHV Consultants (1992). Elephant and Community Wildlife Programme: Environmental impact of the proposed fencing programme in Kenya. Commission of the European Communities (unpublished report).

Douglas-Hamilton, I. (1987). African elephants: population trends and their causes. *Oryx*, **21**, 11–23.

Elliott, R. T. (1992). Letter to the Editor. *Tiger Paper*, **19**, 13–14.

Jenkins, P. R. & Hamilton, P. H. (1982). The Laikipia elephant problem. Wildlife Conservation and Management Department (unpublished report).

Katugaha, H. I. E. (1992). Letter to the Editor. *Asian Elephant Specialist Group Newsletter*, **8**, 56.

Kenya Colony (1926). *Game Department Annual Report 1926*. Government Stationers, Nairobi.

Kenya Colony (1927). *Game Department Annual Report 1927*. Government Stationers, Nairobi.

Kenya Colony (1929). *Game Department Annual Report 1929.* Government Stationers, Nairobi.

Kenya Colony (1934). *Game Department Annual Report 1932–4.* Government Stationers, Nairobi.

Kenya Colony (1935). *Dame Department Annual Report 1935.* Government Stationers, Nairobi.

Kenya Wildlife Service (1990). *A policy framework and development programme 1991–1996.*

Kohler, T. (1987). Land use in transition. Aspects and problems of small scale farming in a new environment: the example of Laikipia District, Kenya. *Geographica Bernensia, African Studies Series*, **A5**.

Laws, R. M. (1970). Elephants as agents of habitat and landscape change in East Africa. *Oikos*, **21**, 1–15.

Laws, R. M., Parker, I. S. C. & Johnstone, R. C. B. (1975). *Elephants and their habitats. The ecology of elephants in North Bunyoro, Uganda.* Clarendon Press, Oxford.

Mkanda, F. X. (1992). The effects of inadequate fencing along the eastern boundary of Kasungu National Park, Malawi. *Nyala*, **15**, 63–8.

Osborn, F. V. (1993). *Human/elephant conflict in the area surrounding the Sengwa Wildlife Research Area.* Department of National Parks and Wildlife Management, Zimbabwe, Report No. 2.

Parker, I. S. C. & Graham, A. D. (1989). Elephant decline (Part I). Downward trends in African elephant distribution and numbers. *Intn. J. Environ. Stud.*, **34**, 287–305.

Rice, C. (1990). Don't forget to pack the trunk. *Wildl. Conserv.*, **93**, 58–67.

Santiapillai, C. (1991). Management of elephants in the Xishuangbanna Nature Reserve. PR China. *Tiger Paper*, **18**, 1–5.

Schultz, B. (1988). *Construction and maintenance of power fences for Indian Wildlife.* Food and Agriculture Organisation of the United Nations.

Seidensticker, J. (1984). Managing elephant depredation in agricultural and forestry projects. *World Bank Tech. Pap.*, **16**.

Sukumar, R. (1989). *The Asian elephant: ecology and management.* Cambridge University Press, Cambridge.

Sukumar, R. (1991). The management of large mammals in relation to male strategies and conflict with people. *Biol. Conserv.*, **55**, 93–102.

Sukumar, R. & Gadgil, M. (1988). Male–female differences in foraging on crops by Asian elephants. *Anim. Behav.*, **36**, 1233–5.

Taylor, R. (1993). Elephant management in Nyaminyami District, Zimbabwe: turning a liability into an asset. WWF Multispecies Project Paper.

Thouless, C. R. (1994). Conflict between humans and elephants on private land in northern Kenya. *Oryx*, **28**, 119–27.

Western, D., Moss, C. & Georgiadis, N. (1983). Age estimation and population age structure of elephants from footprint dimensions. *J. Wildl. Manage.*, **47**, 1192–7.

Woodley, F. W. (1965). Game defence barriers. *E. Afr. Wildl. J.*, **3**, 89–94.

Woodley, F. W. & Snyder, P. M. (1978). Wildlife problems in Laikipia District. Wildlife Conservation and Management Department, Kenya, (unpublished report).