Chapter 9
Barriers, the Beef Industry and Unnatural Selection: A Review of the Impact of Veterinary Fencing on Mammals in Southern Africa

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Introduction

History and Purpose of Veterinary Cordon Fences

Veterinary cordon fences (VCFs) zigzag across the southern African savannah. The fences are intended to separate disease-free livestock from infected livestock and their closest wild relatives, buffalo *Syncerus caffer* and to restrict the movement of antelope that could carry diseases of concern. Livestock production is an important aspect of many African nations, economically and culturally, locally and nationally, for both subsistence and commercial producers. However, the fences do not discriminate between targets and non-targets, and create obstacles for many large mammals.

Over the past 130 years, fences have been constructed at various times to control Foot-and-Mouth Disease (FMD), Contagious Bovine Pleuropneumonia (CBPP), trypanosomiasis, rinderpest and other diseases that can affect livestock (see Taylor and Martin 1987; Bengis et al. 2002; Hargreaves et al. 2004; Kock 2005; Mapitse 2008; Osofsky et al. 2008).

Some diseases pose a serious threat to livestock and, in turn, to food security and human livelihoods. Others, particularly FMD, do not significantly affect livestock production nor suitability for human consumption, but are controlled in order to meet conditions set by the World Organization for Animal Health (OIE, formerly the Office International des Epizooties) for trade on the more lucrative international market. The actual losses caused by FMD to subsistence pastoralists are low (Kock 2005), but financial losses to cattle exporters are high because of stringent

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processing and handling requirements (Taylor and Martin 1987; Mapitse 2008). European policies and tariffs have buoyed cattle export from some African countries, and have subsidised further fence building; the 1976 Lomé Convention and its successor, the 2000 Cotonou Agreement, gave Botswana preferred trading status for beef, guaranteeing prices 25% higher than the global average (Environmental Investigation Agency 2004; Nair 2007; Mapitse 2008). Donors have funded fences under the guise of poverty alleviation and economic development, but evidence indicates that the majority of revenue from beef export is captured by elites (Perkins 1996; Nair 2007; Mapitse 2008; Scoones and Wolmer 2008).

FMD is particularly challenging to control in situ. The virus that causes FMD is hardy and may be spread through the air (when infected or carrier animals cough or sneeze), through fomites (inanimate objects or substances) and possibly by feeding in the same area (when grazing mammals feed on grass that has been fed on by an infected animal). The virus enters hosts by inhalation or ingestion. Weather is also believed to be a factor, spreading more readily during cool, damp spells (du Toit 2005). However, aerial transmission is unlikely in southern Africa under the prevailing dry, hot weather (Sutmoller 2002). The virus can be found in a diverse range of hosts including hedgehogs, artiodactyls, primates, armadillos and rodents. Cattle *Bos taurus* and *Bos indicus*, pigs *Sus scrofa*, sheep *Ovis aries* and goats *Capra hircus,* are the domesticated species most seriously affected (Bengis et al. 2002). In Africa, impala *Aepyceros melampus,* kudu *Tragelaphus strepsiceros,* wildebeest *Connochaetes taurinus* and sable *Hippotragus niger* have low to negligible mortality from the FMD virus, but are known to carry it (Kock 2005). Buffalo have historically been regarded as the most important wild host for FMD virus and the most likely to interact with livestock and transmit infection, which led to the intentional extermination of buffalo in many cattle-producing areas in Zimbabwe (Taylor and Martin 1987), Namibia (Martin 2005) and Botswana (Albertson 1997). Cattle and buffalo become long-term carriers of FMD viruses, whereas antelope do not (Hargreaves et al. 2004). In order to satisfy OIE trade conditions, many southern African nations employ a combination of fences and vaccination regimes. In countries that have secured disease-free zones, outbreaks are controlled with slaughter of livestock to confine and eradicate the disease before it becomes economically devastating.

Fence Purposes and Designs

Veterinary cordon fences vary in strength and penetrability depending upon the disease targeted. Simple wire-strand cattle fences, 1–2 m high, suffice for CBPP control, and are built to restrict the movement of cattle and buffalo only. Most veterinary cordon fences are comprised of horizontal wires only, without the vertical or subterranean mesh that would be required to stop crawling or digging animals.

Stronger double-cordon fences are constructed to reduce the transmission of FMD. FMD fences are intended to exclude potentially infected or reservoir species, and to create a mammal-free gap of 10 m or more between the infected zone and animals in vaccination or quarantine zones (Taylor and Martin 1987). Vegetation between the fences is cleared manually or mechanically, and roads to facilitate maintenance or patrolling are cut along one or both sides of the fence. To reinforce the role of the fences in preventing disease transmission, trespassing livestock are destroyed. When animals that could be disease transmitters get on the "wrong" side of fences, well-financed wildlife departments may actively chase the animals back into wildlife areas (e.g. Kruger National Park in South Africa [F. Jori pers. comm.] and along the Northern Buffalo fence in Botswana [Albertson 1997]). More often, countries cull potential carriers that manage to get through (instituted in Zimbabwe [Taylor and Martin 1987] and Botswana [Albertson 1997]). Some countries have proposed "shoot to kill" policies for all wild animals that cross cordons, regardless of whether they are disease risks or not, as proposed for a 300-km fence along Namibia's border with Angola (see Gadd 2007). Because of the wide swath of bush that has to be cleared, the height, and the double rows of fencing, FMD-fences create a greater hurdle to wildlife than simple cattle or game fences.

The third and strongest type of fence prevalent in southern Africa along international borders serves multiple purposes, including preventing illegal movement of people and restricting animal (livestock and wildlife) movement. Long stretches of the borders shared by Botswana, South Africa, Mozambique, Zimbabwe and Namibia are fortified with razor wire or electrified, carrying 7–12 kV of electricity (enough to deter elephants and to jolt humans), and may be actively patrolled.

Southern African countries have experienced an upsurge of disease outbreaks in recent years (FAO 2005), including within fenced zones. Although the efficacy of fences has long been questioned (Owen and Owen 1980; Ross 2003), fences are still regarded as an essential component of disease control because they provide partial protection: "the rate of spread of disease is proportional to the amount of animal traffic, which fences facilitate holding to a low level" (Taylor and Martin 1987). This paper does not aim to examine the efficacy of veterinary cordon fences in controlling diseases nor the economic costs and benefits of fencing. Nor does it address the social impact of fencing on human residents whose movements and livelihoods may be adversely affected (Albertson 1997; Gupta 2004; Mapitse 2008; Pierson and Gadd 2008). Instead, the following pages focus on the ecological costs of veterinary cordon fences, with an eye to anticipating future ramifications. Expected impacts on various ecological levels (individual, population, species, community and ecosystem) are outlined. A review of observed effects is presented, limitations of existing data are evaluated and general trends are summarised. Approaches that could improve our understanding of the impact of fences and actions that could lessen detrimental effects are highlighted.

Trend Towards More and Stronger Fencing

Fences are already a prominent feature of southern African rangeland and fencing is increasing exponentially across Africa for myriad reasons: increasing human population, shifting from pastoralism to agriculture, changing land ownership policies (including privatisation and redistribution), sub-division of existing large blocks of land into smaller privately owned fragments, and escalating human-wildlife conflict. Globally, livestock numbers are expected to increase dramatically to satisfy the increasing demand for meat worldwide (due to growing human populations and increasing wealth per capita, enabling more people to afford meat). Africa is projected to be a net supplier to meet this increasing demand, and more regions will undoubtedly seek to control diseases that diminish production or jeopardise their ability to export to international markets (Kock et al. 2002).

Disease outbreaks, increasing instability in neighbouring countries, and increases in fence breakage (by people and by wildlife) have triggered the fortification of existing VCFs. Fences are being heightened, electrified and elephant-proofed, which substantially increases the obstruction they pose to wildlife. In 1995, an outbreak of CBPP among cattle around Botswana's northern border with Namibia precipitated the hasty construction of three parallel east–west fences (Samochimo, Ikoga and Setata) to try to limit the spread (Ross 2003). In spite of these measures, the disease quickly jumped the fences (by means of illegal cattle movement through the fences) and the government culled all 320,000 cattle in Ngamiland district to prevent an even more costly spread of the disease to export zones further south. To prevent incidents of this magnitude, Botswana upgraded and electrified its Caprivi fence to better barricade against livestock covertly entering from Namibia and Angola (Weaver 1997; Albertson 1998; Martin 2005). More recently, as Zimbabwe's government disintegrated and its ability to maintain disease controls came into question, Botswana took steps to defend its eastern border, adding a second row of fencing and electrifying it to prevent breakage by elephants (Gadd 2001).

Why We Might Expect Adverse Effects on Wildlife

Extent of Fencing

The sheer extent of fencing in southern Africa makes fencing a substantial modifier of the landscape (Fig. 9.1). For example, Botswana's perimeter is less than 3,700 km but within the country (including border fences), more than 5,000 km of fenceline protect the cattle industry (calculated from Williamson 2002; Environmental Investigation Agency 2004, 2005, 2007). Fences span hundreds of kilometres without any openings or gaps to allow passage of wildlife (e.g. Botswana's 300 km Kuke fence [Ross 2003]).

Alignment of Fencing

Fences have been aligned according to political decisions, not ecological ones. Many of the fences run east–west (e.g. Botswana's Kuke fence, Namibia's existing

"Red Line" fence and its proposed 250 km fence along the border with Angola), cutting directly across habitat types, without any regard for the distribution of natural resources or wildlife. Fences cut through wilderness areas, hemming mammals into whichever side of the fence they happen to be on at the time of construction (Albertson 1997; Gadd 2001). They do not accommodate predictable seasonal movements of migratory species, nor wet season range expansion, or dispersal of adolescent animals leaving their natal territories. Fences often join at acute angles, unintentionally funnelling wildlife into blind corners with no outlet. Other fences jut out across miles of pristine wilderness before coming to an abrupt, seemingly arbitrary, end. When deciding on fence alignment around water points, wildlife usually loses out, with access to water being given to cattle owners. Countries have fenced extensive parts of their perimeters. Where these borders coincide with major river systems, e.g. the Limpopo, Shashe, and Kavango rivers, fencing must be wholly contained within one country, therefore, the water source (and, sometimes, its riparian buffer) is fenced entirely in or entirely out, separating wildlife from vital water supplies.

Fences are not amenable to changing land uses or disease patterns. Fences are sometimes built as an emergency response to an active outbreak. When the threat has passed or the fence has failed and no longer serves any disease control purpose, the fences are abandoned. Without maintenance, fences may even become more of a death trap for wildlife: unchecked conversion of wire to snares, broken dangling wires ensnaring animals, and as they decay over time, becoming less visible but equally impenetrable. Some fences go through areas of dubious disease transmission importance, with little or no cattle (Albertson 1997). In others, the value of wildlife-based industries already exceeds the value of the livestock industry. In parts of sub-Saharan Africa where wildlife is a profitable use of marginal land, some landowners are shifting away from pure livestock towards multi-species systems (du Toit 2005; Mapitse 2008; Osofsky et al. 2008). The recently established Kavango Zambezi Transfrontier Conservation Area (KAZA), spans more than 250,000 km^2 in five southern African countries and holds great promise to become a premiere tourism destination; however, it is littered with fences, particularly in its southern reaches. Tangles of active, redundant and defunct fences compartmentalise areas and prevent animals from expanding into others. For communities anxious to partake in the new wildlife-based development plans, fences thwart their hopes of mammal re-establishment and recovery.

Expected Effects

Based on theoretical ecology and on evidence observed from analogous structures elsewhere, we can anticipate certain consequences of barriers on wildlife (Table 9.1). Wherever humans occur, manmade objects interrupt and alter the landscape. Even porous objects like settlements and roads have significant effects on local ecology. A growing body of research shows the undesirable effects of roads on ecology (see

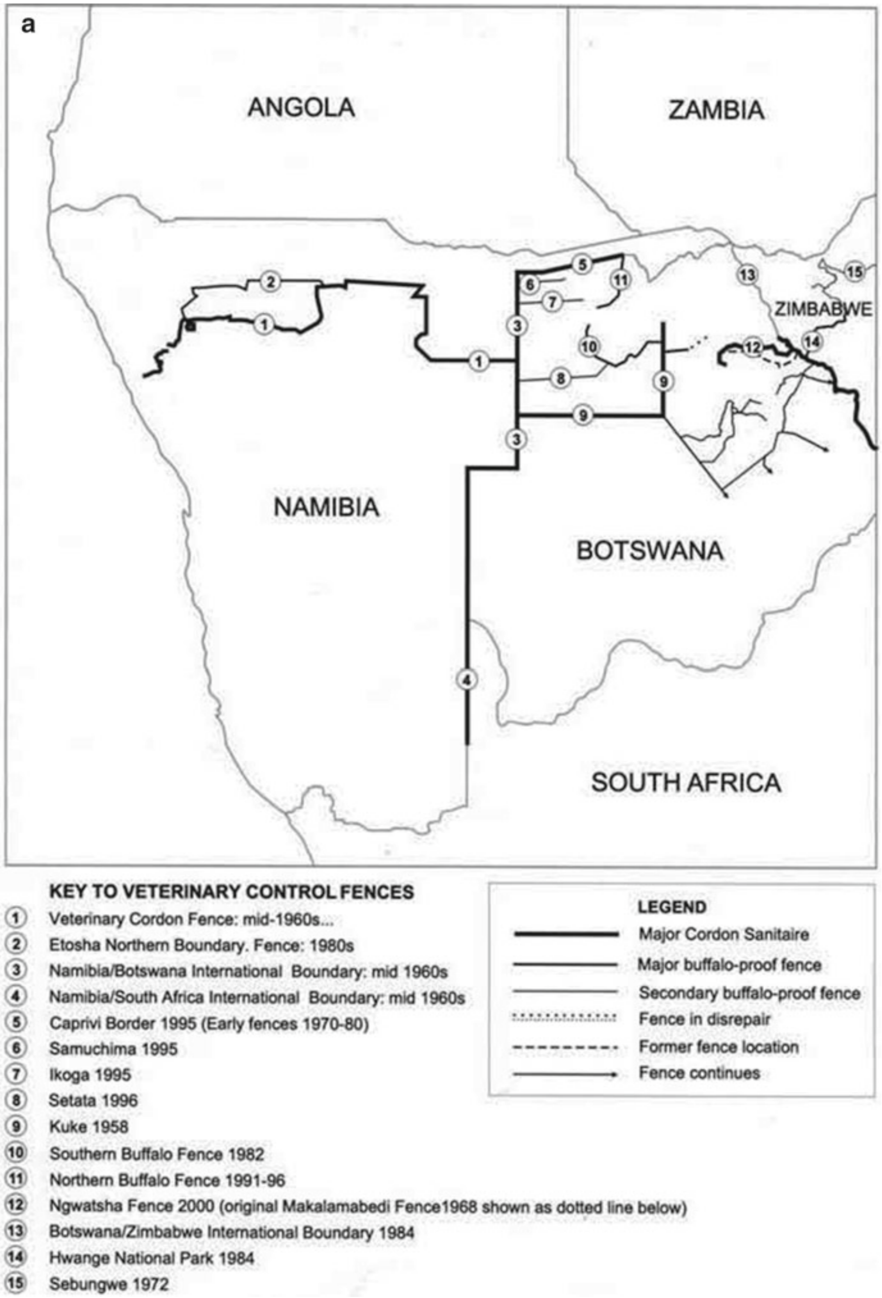

Fig. 9.1 (**a**) Major fences in southwestern Africa before 2000 (Martin 2005). (**b**) Fences in Botswana before 1997 (Williamson 2002)

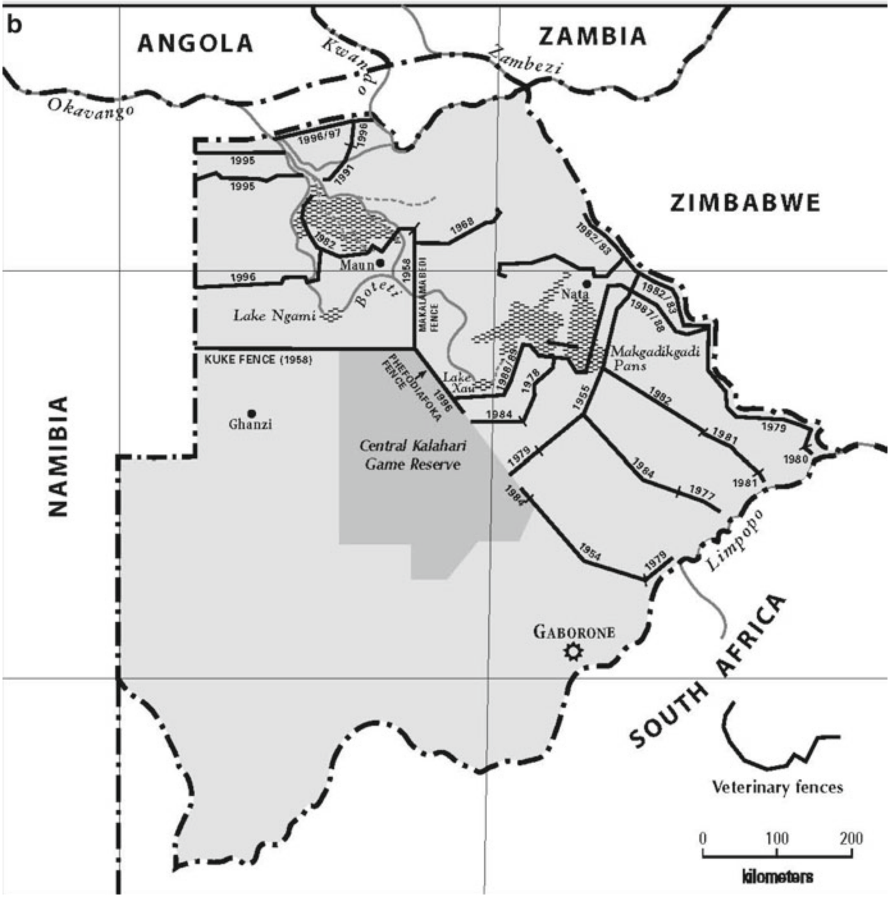

Fig. 9.1 (continued)

Forman et al. 2003). Even though roads would appear to be a minimal obstacle to large-bodied, wide-ranging mammals like elephants, recent research on collared elephants in the Congo Basin indicates that forest elephants avoid crossing roads outside protected areas (Blake et al. 2008). Roads, and the human activities that accompany them, may artificially restrict elephant movement and sub-divide populations. We would expect fences, which are specifically designed to stop animal movement to have an even greater impact than roads, but empirical research is thin (discussed below in Methods). Like other barriers, fences may cause ecological effects directly and indirectly, immediately and over the long-term. If fences are non-porous, they may function as hard boundaries, fragmenting the landscape into small, disconnected patches. Habitat loss and fragmentation are major drivers behind the current wave of species extinctions (McGarigal and Cushman 2002). Patches isolated by fences could function as land-locked islands, subject to the

Table 9.1 Expected impacts of veterinary cordon fences

Level	Effect
Individual	Movement impeded Individual territory or home range fragmented Behavioural change to cope with fence Entrapment or inability to escape fire, flood, predation, drought Mortality: starvation, dehydration, entanglement, electrocution
Population	Social or family groups divided or fragmented Essential daily or seasonal movement prevented Effective population size reduced by mortality or by subdivision Increased predation pressure Shift in prey selection, predation success Disappearance of migratory population/persistence of sedentary population Dispersal inhibited Social interactions restricted Breeding behaviour altered Overcrowding, abnormally high density
Species	Mass mortality Cessation of migrations, selection for sedentary individuals Loss of genetic potential Disease spread in confined spaces or high densities Lack of connectivity between groups/conspecifics Loss of metapopulation function: prevention of recolonisation
Community	Change in species composition: loss of migratory individuals and species Change in disease dynamics: new species interactions at sites of limited resources Predators shifting prey species
Ecosystem	Habitat degradation due to local overabundance when animals are constrained Depressed local primary productivity Nutrient depletion Avenues for invasive species Provides access for humans to remote areas System resilience lowered: potential for recovery diminished Expansion of incompatible human land uses

predictions of island biogeography theory (MacArthur and Wilson 1967). Isolating pieces of land may result in the loss of species and eventual species relaxation, as predicted for mammals in protected areas in Tanzania (Newmark 1996) and witnessed in Ghana (Brashares 2003).

Fences physically divide contiguous populations of mammals into separate, smaller, isolated populations. Small populations are inherently more at risk of extinction via stochastic events than large populations (reviewed in Caughley 1994). Small populations are more vulnerable to demographic failures (e.g. inbreeding or inability to find mates), and are less able to recover from disasters such as drought, flood, and fire. In metapopulations (where local extirpations periodically occur and local colonisation or recolonisation events re-establish sub-populations) (reviewed in Hanski 1998), fences prevent the recolonisation and recovery of satellite sub-populations. Individual stressors may combine synergistically, pushing populations or species beyond their ability to recover, to the point of extinction. Perturbations can trigger an extinction vortex: a mutually reinforcing cycle of biotic and abiotic processes that drive population size further downward toward extinction (Brook et al. 2008).

Habitat fragmentation and physical barriers have been called "the greatest obstruction to maintaining species diversity and ecological integrity" (Clevenger and Waltho 2000). Fragmenting a landscape reduces the heterogeneity within each fragment. Confining wild or domestic herbivores in finite areas within a larger landscape reduces the variation in vegetation type, quality and quantity available to them. Empirical evidence from livestock production areas in southern Kenya indicates that sub-division of land resulted in numerous small plots of relatively uniform quality, with lower overall carrying capacity and mammalian biomass production than when it was a contiguous heterogeneous unit (Boone and Hobbs 2004).

Methods

Meta-Analysis

I categorised the effects of veterinary cordon fences on wildlife from 34 published and unpublished reports (Table 9.2). Of these, 25 contained primary data or included first-hand eyewitness accounts. Those articles that did not contain primary data were popular articles or position papers, summarising fieldwork conducted by others. In cases where the same species, events, sites and years were referred to by multiple authors, I made every effort to identify and cite only the first or original source in order to avoid double counting. Only one report was an environmental impact assessment conducted prior to fence construction, weighing various proposed fence alignment options (Scott Wilson Resource Consultants 2000). The vast majority of documents assessed impact during or after fence construction (Albertson 1997, 1998, 2005, 2008; Scott Wilson Resource Consultants 2000; Gadd 2001, 2003; Gupta 2004). One article reviewed fence strengths and purposes (Hoare 1992), and one proposed alternative fence designs and mitigation measures (Kalikawe 1997).

Attempts to correlate impact with fence type, length and age proved impossible due to the limitations of the data (see below) and incomplete details on fence attributes. Quantifying the scope and magnitude of fencing proved impossible: fence types and lengths are not available from a central, updated source. Previously published maps provided the best record of major fence lines in specific regions, but these are now more than 10 years out of date (Williamson 2002: Botswana fences constructed prior to 1997; Ross 2003; Martin 2005: Namibia, Botswana and north-western Zimbabwe fences constructed prior to 1996), cover limited locations and did not specify fence type.

Table 9.2 Known impacts of veterinary cordon fences on wildlife in southern Africa. Type of event, species affected, detail (quantification where possible), country and specific location, method, date of event, and reference

Event	Species	Detail	Country	Location	Method	Date	Source
Fence encounter/ passage rate	Buffalo	1/6 broke out of GS, 5/696 broke out of Sengwa, 1 walked around end	Zimbabwe	Gokwe South/Sengwa boundary	Spoor count, cumulative over 1 year	1992–1993	Booth et al. (1998)
	Elephants	416/790 broke out of GS, 209/988 broke out of Sengwa, 603 walked around end	Zimbabwe	Gokwe South/Sengwa boundary	Spoor count, cumulative over 1 year	1992–1993	Booth et al. (1998)
	Antelope	60–600 individuals hop over fence each year	Zimbabwe	Save valley conservancy	Interview of patrol personnel	2002	Sutmoller (2002)
Trapped between fences but alive	Elephants	Herd	Botswana	Caprivi	Direct observation	1997	Albertson (1998)
	Wildebeest	Subadult alive inside Kedia fence	Botswana	Central Kalahari Game Reserve, northern boundary	Direct observation	1997	Albertson (1998)
Death due to starvation, dehydration or entanglement	Wildebeest		Botswana	Kuke fence	Direct observation	1960s	Silberbauer (1965) in Williamson and Mbano (1988)
	Wildebeest		Botswana	Kalahari fences	Not described	1979–1980	Owen and Owen (1980)
	Giraffe, impala, sable, kudu, ostrich		Zimbabwe	Hwange and Gonarezhou	Not described		Taylor and Martin (1987)
	Flamingos	Adults and chicks entangled as water receded below fenceline	Botswana	Nata sanctuary	Direct observation	1994	Williamson (2002)
	Hartebeest, kudu, gemsbok, wildebeest, giraffe	7 giraffe, 8 gemsbok, 2 wildebeest, 2 hartebeest, 3 kudu	Botswana	Setata fence	Community report	1995	Ludbrook pers.comm. in Albertson (1998, 2005)
	Zebra, wildebeest		Botswana	Setata fence	Not described	1996	Mughogho pers. comm. in Albertson (2005)
	Giraffe, ostrich	Death by entanglement	Botswana	Setata fence	Community report	1996	Albertson (1998)
	Hartebeest, gemsbok, kudu	Death after running into fence or tripping over it	Botswana	Setata fence	Community report	1996	Albertson (1998)

	Gemsbok, eland, kudu, ostrich, wildebeest	Vet report confirmed 2 kudu, 1 eland, 1 ostrich	Botswana	Ikoga	Community report	1996	Albertson (1998)
	Kudu, eland, sable, roan, giraffe, elephant, ostrich, duiker, steenbok	During 1997, mostly June, July: 5 kudu, 2 eland, 1 sable, 1 roan, 5 giraffe, 1 elephant, UNK ostrich, UNK duiker, UNK steenbok	Botswana	Caprivi fence	Community report	1997	Albertson (1998)
	Ostrich		Botswana	Central Kalahari game reserve, northern boundary	Direct observation	1997	Albertson (1998)
	Giraffe, buffalo, elephant, roan	During 1997: 7 giraffe, 2 buffalo, 2 elephant, UNK roan	Botswana	Northern Buffalo fence, Okavango	Community report	1998	Albertson (1998)
	Giraffe, hartebeest, wildebeest, gemsbok, ostrich	7 giraffe, 5 hartebeest, 7 wildebeest, 3 gemsbok, 2 ostrich	Botswana	Setata fence, Okavango	Community report	1998	Kavadimba (1998)
	Giraffe, gemsbok, hartebeest	4 giraffe, 1 gemsbok, 2 hartebeest	Botswana	Setata fence, Okavango	Direct observation by Ludbrook	1998	Kavadimba (1998)
	Buffalo		Namibia	Caprivi	Personal communication NAPHA chair	1988	Martin (2005)
Fragmentation of individual territory or home range	Eland, roan, sable, tsessebe, giraffe		Botswana	Northern Buffalo fence	Inference	1997	Albertson (1998)
Division of family/social groups	Wildebeest		Botswana	Kalahari fences	Not described	1979–1980	Owen and Owen (1980)
	Gemsbok, hartebeest	Exhausted calves on one side, herds on other	Botswana	Setata fence	Direct observation	1997	Albertson (1998)
	Elephants		Botswana	Caprivi fence	Direct observation	1997	Albertson (1998)
	Elephant, roan, eland, tsessebe		Botswana	Northern Buffalo fence, Okavango	Direct observation	1997	Albertson (1998)

(continued)

Table 9.2 (continued)

Event	Species	Detail	Country	Location	Method	Date	Source
	Tsessebe, giraffe	Herds seen on both sides of fence, with smaller ones on one side	Botswana	Northern Buffalo fence, Okavango	Direct observation	1997	Albertson (1998)
	Elephants	Subadults stuck on one side, all stressed and in poor condition	Botswana	Nxai Pan buffalo fence	Direct observation	1997	Albertson (1998)
Prevention of essential daily or seasonal movement	Wildebeest		Botswana	Kalahari fences	Not described	1979–1980	Owen and Owen (1980)
	Hartebeest, wildebeest	Unable to reach Limpopo River for water	Botswana	Limpopo River, between Lephepe to Dibete	Not described		Owen and Owen (1980)
	Gemsbok, eland, kudu, ostrich	Older spoor	Botswana	Ikoga	Spoor	1996	Albertson (1998)
	Elephant, sable, roan, eland, giraffe, kudu	Significant fragmentation and movement obstruction within 60 km stretch	Botswana	Caprivi fence	Direct observation	1997	Albertson (1998)
	Zebra, buffalo, wild dog	Some fragmentation and movement obstruction within 60 km stretch	Botswana	Caprivi fence	Direct observation	1997	Albertson (1998)
	Sable, zebra, buffalo, elephants	Unable to reach dry season range	Botswana	Northern Buffalo fence	Not described	1997	Albertson (1997)
	Elephants, giraffe		Botswana	Nxai Pan buffalo fence	Not described	1997	Albertson (1998)
	Wildebeest, hartebeest		Botswana	Phefodiafoka fence, northeast CKGR	Direct observation	1997	Albertson (1998)
	Elephants		Zimbabwe	Sebungwe fence at Matusadona NP			Taylor and Martin (1987)
	All mammals	Animals jump fence to get water, are shot for disease control zone	Zimbabwe	Chirisa Safari area	Interview of patrol personnel		Taylor and Martin (1987)
	Elephant		Namibia	West Caprivi Game Park (Bwabwata)	Visit to fenceline	1997	Weaver (1997)
	Elephants		Botswana	Shashe fence	Repeated spoor counts		Gadd (2001)

Forced change in migration route	Wildebeest	Migrating animals unable to reach Okavango and Boteti River, turn east to Lake Xau (not previously a migratory destination)	Botswana	Kuke, Ngamiland fences	Comparison to historical record	Post-1955	Williamson and Mbano (1988)
	Wildebeest	Tried to go north, stopped by fence and walked east	Botswana	Setata	Community report	1996	Albertson (1998)
	Zebra, wildebeest, elephants	Seasonal migration pattern changed	Botswana	Northern Buffalo fence	Comparison with recorded natural history	1997	Albertson (1998)
Fragmentation and division of populations	Wildebeest, hartebeest, eland		Botswana	Kalahari	Aerial survey, model	1980s	Spinage and Matlhare (1992)
	Gemsbok, eland		Botswana	Setata fence	Not described	1995	Albertson (2005)
	Wildebeest, hartebeest, eland, ostrich	Restriction into smaller ranges (and artificial waterpoints) increased mortality rates during droughts	South Africa	Central Kalahari	Aerial survey	1995	Knight (1995)
	Roan, sable, tsessebe		Namibia	West Caprivi Game Park (Bwabwata)	Visit to fenceline	1997	Weaver (1997)
	Roan, oribi, sable, wild dog		Botswana	Northern Buffalo fence	Not described	1997	Albertson (1997)
	Rhino		Zimbabwe	Gonarezhou, Save Valley			du Toit (2005)

(continued)

Table 9.2 (continued)

Event	Species	Detail	Country	Location	Method	Date	Source
Mass mortality event	Wildebeest	300,000 died	Botswana	Lake Xau, Mopipi Dam	Aerial survey, carcass count	1963	Child (1972)
	Wildebeest		Botswana	Kuke fence, Lake Xau	Not described	1961, 1964, 1970, 1979	Owen and Owen (1980)
	Hartebeest, wildebeest	"Thousands"	Botswana	Limpopo River, between Lephepe to Dibete	Not described		Owen and Owen (1980)
	Wildebeest	52,000 carcasses estimated at end of dry season	Botswana	Lake Xau, Mopipi Dam: 1982–1983	Carcass count on ground, sampled areas, stratified by estimated carcass density	1982–1983	Williamson and Mbano (1988)
	Wildebeest	80,000 carcasses estimated	Botswana	Lake Xau, Mopipi Dam: 1982–1983	Aerial survey, carcass count	1982–1983	Parry (1987)
	Hartebeest	10,000 hartebeest died	Botswana	Ghanzi fences	Carcass count	1981–1987	Spinage (1992)
	Zebra	60,000 died	Botswana	Kalahari fences	Not described	1980s	Ross (2003)
	Roan, elephant, and other wildlife		Botswana	Northern Buffalo fence	Not described	1997	Albertson (1998)
Population crash	Wildebeest	90% decline, from 262,000 to 16,000	Botswana	Kalahari to Okavango	Comparison with past aerial counts	1979-late1980s	Spinage (1992)
	Hartebeest	70% decline	Botswana	Kalahari to Okavango	Comparison with past aerial counts	1979-late1980s	Spinage (1992)
	Wildebeest	30,000 animals lost	Namibia	Etosha moving north			Berry and Siegfried (1979)
	Wildebeest and hartebeest	Wildebeest declined by 97%, hartebeest by 86%: drought, lack of migration and die-offs	Botswana	Central Kalahari game reserve	Aerial survey and model	1979–1986	Spinage and Matlhare (1992)
	Springbok		South Africa	Karoo: 1896	Review of historical documents	1896	Roche (2008)

Cessation of a mass migration	Springbok	Megatrek: est’d migrations ranged from 100,000–1,000,000	South Africa	Karoo: 1896	Review of historical documents	1896	Roche (2008)
	Wildebeest, hartebeest, eland		Botswana	Kalahari		1980s	Spinage and Matlhare (1992)
	Wildebeest	Estimate: 1964–1983 100,000 wildebeest lost	Botswana	Kgalagadi to Okavango, confined at Lake Xau by Kuke and Ngamiland fences	Aerial survey, carcass count		Williamson and Mbano (1988)
Entrapped and killed by fire while confined by fences	All species	Fires killed thousands of wild animals trapped against a fence	Botswana	Central Kalahari game reserve, northern boundary	Not described	1996	Albertson (1997, 1998)
Abnormally high density of animals due to confinement by fences	Wildebeest	80,000 wildebeest crowded into 125 km^2 area	Botswana	Lake Xau	Not described	1979	Owen and Owen (1980)
	Wildebeest	50,000 wildebeest concentrated in an area	Botswana	Lake Xau	Aerial survey	1983	Williamson and Mbano (1988)
Habitat degradation due to animals constrained by fences	Springbok		South Africa	Karoo fences	Review of historical documents	1896	Roche (2008)
	Elephant		Zimbabwe	Chirisa Safari Area	Direct observation	1987	Taylor and Martin (1987)
	Elephants		Botswana	Northern Buffalo fence	Direct observation	1997	Albertson (1998)
	Elephants		Botswana	Caprivi fence	Direct observation	1997	Albertson (1998)
	Elephants, eland, sable, roan, buffalo		Namibia	West Caprivi Game Park (Bwabwata)	Not described	1997	Albertson (1998)
	Kudu, wildebeest, giraffe, elephant		Botswana	Northern Buffalo fence	Spoor	1997	Albertson (1998)
	Buffalo	Overcrowding on south side of fence	Botswana	Northern Buffalo fence	Direct observation	1997	Albertson (1998)

(continued)

Table 9.2 (continued)

Event	Species	Detail	Country	Location	Method	Date	Source
Prevention of recolonization	Eland	Population decline since 1980s. Without immigration, local extinction likely	Botswana	Central Kalahari game reserve	Aerial survey and model	1995	Spinage and Matlhare (1992)
	Roan, sable, tsessebe		Namibia	Caprivi	Inference		Martin (2005)
Isolation of national parks from one another	All, including elephants		Zimbabwe	Throughout	Comparison to historical record		Taylor and Martin (1987)
	All		Botswana	Moremi, Chobe and West Caprivi separated from wildlife areas to west and north	Inference	1997	Albertson (1997)
	All	Transboundary seasonal movement prevented	Botswana-Namibia	Caprivi fence	Inference	1997	Albertson (1998)
	All		Namibia	Caprivi parks	Inference	1997	Weaver (1997)
	All		Namibia	Western Caprivi, Mahango and Khaudum	Inference		Martin (2005)
Excess concentration of one herbivore leading to decline of another herbivore	Cattle deplete grazing, wildebeest starve		Botswana	Kuke fence, Lake Xau	Not described	1979	Owen and Owen (1980)
	Cattle deplete grazing, wildebeest starve	Grazing had been severely depleted by an enormous concentration of domestic livestock	Botswana	Lake Xau, Mopipi Dam	Direct observation	1982–1983	Williamson and Mbano (1988)
	Elephant degrading habitat for all, especially rare antelope		Botswana, Namibia	Okavango, Caprivi	Inference from declining game counts	1995, 1998, 2002 data	Martin (2005)

Shift in mammalian community composition	Wildebeest and eland will decline while gemsbok and springbok will persist	Migratory species will decline because of fencing and drought while animals that are not dependent on water will persist	Botswana	Kalahari	Aerial survey data and model		Spinage and Matlhare (1992)
	Wildebeest and eland will decline while gemsbok and springbok will persist	Species have declined because of droughts and migration routes impeded by settlement and fences. Legal and illegal offtake may alter or accelerate the decline	Botswana	Kalahari	Aerial survey data and model		Knight (1995)
Loss of nutrient input due to herbivore crash	All, especially wildebeest, hartebeest		Botswana	Khutse Game Reserve, Central Kalahari	Comparative soil samples	Unknown	de Queiroz (1993)
Decreased carrying capacity	All ungulates	Observed wild biomass 25% of expected. 439 kg/km^{-2}, vs. 1,833 kg/km^{-2}	Botswana	Kalahari	Aerial survey compared to biomass model	1980	Williamson and Williamson (1981)
Predators hunting along fence	Lion, wild dog	Lion and wild dog activity noted	Botswana	Ikoga	Community report	1996	Albertson (1998)
	Lions	Godikwa residents report increased predators attracted by congregation of game against western side of NBF	Botswana	Northern Buffalo fence	Community report	1997	Albertson (1998)

(continued)

Table 9.2 (continued)

Event	Species	Detail	Country	Location	Method	Date	Source
Hunting by humans while confined by fences	Springbok	With firearms	South Africa	Karoo: 1896	Review of historical documents	1896	Roche (2008)
	Wildebeest	Men in trucks, on horseback and on foot using packs of domestic dogs. The dogs run the herds until the exhausted wildebeest can only stand while being disembowelled	Botswana	Kuke fence, Lake Xau	Not described	1979	Owen and Owen (1980)
	Wildebeest	"Remorselessly harassed by hunters"	Botswana	Lake Xau, Mopipi Dam	Direct observation	1982–1983	Williamson and Mbano (1988)
	All species	Poaching from vehicles along the fence cutlines	Botswana	Setata fence	Spoor, animal flight distance	1997	Albertson (1998)
	All species	By poachers from other communities	Botswana	Setata fence	Community report	1998	Kavadimba (1998)
	Giraffe	Shot by government employees against fence and eaten	Botswana	Caprivi fence	Community report	1997	Albertson (1998)
	Elephants	Poaching increased because of accessibility afforded by VCF cutline	Namibia	West Caprivi Game Park (Bwabwata)	Report from professional hunter	1997	Albertson (1998)
Conversion of fences into snares	All species	2,000 snares collected between February and July 1979, all made from tsetse control fence	Zimbabwe	Chirisa Safari Area		1979	Conway (1984) in Taylor and Martin (1987)
	All species		Zimbabwe				Booth et al. (1998)
	All species		Zimbabwe	Gonarezhou			Mail and Guardian newspaper
	All species		Zimbabwe	Zambezi valley	Direct observation		L Osborne, pers.comm.
	Rhinos		Zimbabwe	Save valley, Bubye, Bubiana Conservancies	Direct observation		du Toit, pers. comm.

Escalation of human-wildlife conflict	Elephants	Crop raiding	Zimbabwe	Chirisa Safari area	Not described		Taylor and Martin (1987)
	Elephants	Crop raiding	Namibia	Caprivi fence	Community report	1997	Weaver (1997)
	Elephants	Crop raiding	Namibia	Outside western Caprivi game park, due to Caprivi fence	Community report	1997	Albertson (1998)
	Elephants	9 elephants shot by Wildlife Department for breaking a decommissioned VCF	Botswana	Nxai Pan buffalo fence	Community report	1996	Albertson (1998)
	Elephants	Crop raiding	Zimbabwe	Gokwe North, Nyaminyami, Chawarura			Booth et al. (1998)
	Elephants	Water	Botswana	Makgadigadi fence	Interview of residents	2005	Gupta (2004)
	Elephants	Water, crop raiding	Botswana	Shashe fence	Direct observation, community report		Gadd (2001)
	Lions	Godikwa residents report increased predation on dogs, horses and donkeys due to increased predators attracted by congregation of game against western side of NBF	Botswana	Northern Buffalo fence	Community report	1997	Albertson (1998)

Type of event, species affected, detail (quantification where possible), country and specific location, method, date of event, and reference

Limitations

Ideally, ecological experiments should have replicated, controlled, paired samples (Hurlbert 1984; McGarigal and Cushman 2002). Wildlife research rarely takes place under ideal conditions, and monitoring fence effects on wildlife in Africa is no exception. Unfortunately, most assessments were based on single visits. Driving or walking a portion of fence line and counting spoor or carcasses was the most common method employed. In five cases, aerial surveys were done (Child 1972; Williamson and Williamson 1981; Williamson and Mbano 1988; Spinage and Matlhare 1992; Knight 1995). Regrettably, game counts did not have optimally paired or repeated pre- and post-construction datasets. Many reports did not attempt to address and eliminate other potential causative factors, such as change in precipitation or increased livestock densities, etc.

Fences were not visited systematically, thoroughly, repeatedly, or frequently; therefore, rates of encounter and entanglement, frequency of individual and mass mortalities and total cumulative effects remain unknown. Carcass counts delineated the range of species affected, but because they were conducted only over finite areas and limited time periods, provide only the absolute minimum estimate of mortalities. Community reports and interviews with fence maintenance staff may undercount (disappearance of carcasses due to decay, scavenging or human interference) or overcount (by multiple residents reporting the same carcass or authors retelling the same event) actual impact.

The quality of veterinary fence impact studies and long-term monitoring has been severely hampered by political pressures. Biologists and conservation advocates were not informed or consulted before fence construction. Lack of communication within governments was also at play: fence construction and maintenance lie within the mandate of veterinary departments and wildlife departments are not always consulted. Fence construction was often rushed and impact assessments waived. Where assessments were conducted beforehand (Scott Wilson Resource Consultants 2000), recommendations on optimal alignment were ignored (Albertson 2008; Environmental Investigation Agency 2004, 2005, 2007). Governments discouraged or denied proposals to monitor fences. Researchers have been threatened, denied entry or expelled for their conduct related to fence effects. In some cases, government employees actively interfered with data collection: hiding, removing, burning or burying carcasses to prevent researchers from documenting wildlife mortality events (Albertson 1998). Concerns about wildlife may be downplayed for several reasons: a tendency to undervalue the contributions of wildlife to the national economy, powerful lobbying by wealthy cattle owners, pro-cattle cultural values in local and national political arenas, local support for the jobs created by fencing, a lack of interest or awareness from consumers, the desire for income generation and foreign exchange by donors and politicians, and donor preference for short-term, tangible deliverables.

Results

Individual

Animal Encounter/Passage Rates

How often African mammals attempt to cross fences and fail remains unknown. Heavily travelled game trails along veterinary fences indicate that animals approach the fence and are forced to turn left or right. Fence maintenance personnel in Zimbabwe visited a veterinary fence separating a designated cattle area from a wildlife area and kept a running tally of animal tracks approaching and successfully passing through the fence in either direction over 1 year (Booth et al. 1998). Buffalo rarely escaped from the wildlife area to the cattle area (691 out of 696 approaches were rebuffed). Elephants broke in and broke out of the wildlife area with some success: 20% of attempts to get out of the wildlife area succeeded (209 of 988), while 52% (416 of 790) approaches to get in succeeded. A more successful strategy was found by 603 elephants, which followed the fence to its terminus and walked around it. By contrast, only one buffalo found its way around the end. In northern Botswana, well-worn paths indicated that elephants frequently walked the length of the Nxai Pan fence to reach the open end (Albertson 2008). Upon encountering a newly electrified fence, elephants in eastern Botswana walked alongside it for several kilometres, until they reached the last white insulator and then broke through (Gadd 2001). In another study, 60–600 antelope were estimated to jump over veterinary fencing per year in Save Valley, Zimbabwe (Sutmoller 2002).

Individual Behaviour

None of the reports assessed the effects of fencing on individual mammals through focal animal observation or behavioural studies before- and after- fence construction. Anecdotal evidence suggests that hippos, *Hippopotamus amphibious,* are quick to accept the boundaries demarcated by fences (Booth et al. 1998; Hoare 1992). Others, notably elephants and buffalos, challenge fences (Hoare 1992). Elephants may “retaliate” (Hoare 1992), removing large sections of fenceposts and wire after being shocked, or after youngsters stray inside fenced areas (pers. obs.). Giraffe, *Giraffa camelopardalis,* are among the slowest to learn the risks of fencing (Goodwin 1985 cited in Hoare 1992), and also the most reluctant to cross over fence lines when wires have been removed (Albertson 2005).

The effects of fences on small, sedentary, territorial species were rarely mentioned. Small ungulates (e.g. dik dik *Madoqua* spp., steenbok *Raphicerus campestris,* duikers *Cephalophus* spp. and *Sylvicapra grimmia)* are probably adept at slipping under fences or between wires, if spaced adequately, and not electrified at low level. At an experimental fence intended to exclude wild mammals in Kenya, steenbok occurred in higher densities inside fenced areas than outside, indicating that the exclusion of predators resulted in increased survival or that individuals outside actively sought refuge or lower herbivore competition and immigrated inside (Young et al. 2005). Suids and digging animals are difficult to deter (Hoare 1992; Booth et al. 1998; Schumann et al. 2006) and may be less affected by VCFs.

How veterinary fences alter carnivore behaviour and distribution is not well documented, but many species squeeze through or dig under. Wild dogs *Lycaon pictus* in northern Botswana readily crossed veterinary fences, and lions *Panthera leo* forced their way through, although certain lions more often than others (McNutt, pers. comm.). Evidence from experimental fenced plots indicates that predators can penetrate ten-strand electrified game-proof fencing: cheetahs, *Acinonyx jubatus,* frequently went inside and lions were encountered inside once (pers. obs.). Predation incidents by lion and spotted hyena *Crocuta crocuta* remained unchanged before and after an electric fence was installed around Hwange National Park, indicating that their passage was unimpeded (Booth et al. 1998).

Impeding Movement and Dividing Groups

Wildebeest, gemsbok *Oryx gazella,* roan *Hippotragus equinus,* tsessebe *Damaliscus lunatus,* giraffe, and elephants were seen stranded on opposite sides of the fence from their conspecifics (Owen and Owen 1980; Albertson 1998). The smallest youngsters probably wandered under or through (elephants, sable, roan, eland) and adults were unable to follow. In other cases, the largest individuals may leap over, walk over, or push through and the smallest individuals are left behind.

Mortalities

Reptiles, birds and mammals were among the fence casualties. Flamingos *Phoenicopterus* spp., were entangled as they attempted to follow receding waterlines in drying pans traversed by fences (Williamson 2002). Ostriches, *Struthio camellu,* have been found with necks, wings or legs entangled in fences (Taylor and Martin 1987; Albertson 1998; Kavadimba 1998). Tortoises can become stuck under the lowest wires of fences (pers. obs. in Northern Kenya, EIA unpublished photo at Boteti, Botswana).

Mammal carcasses found along, entangled in, or trapped between fences included virtually all medium and large ungulates and sub-ungulates in the vicinity: duiker, steenbok, springbok *Antidorcas marsupialis,* impala, hartebeest *Alcelaphus buselaphus,* wildebeest, sable, kudu, zebra *Equus quagga,* gemsbok, eland *Taurotragus oryx,* buffalo, giraffe and elephants. Although not definitively known, entanglement or confinement and subsequent dehydration were probably the cause of death.

Surprisingly, veterinary cordon fences pose a serious obstacle to elephants, which are notoriously difficult to restrain. Elephant carcasses were found along fence lines on paths to water, families were seen on separate sides of fences, individual elephants paced fence lines or walked kilometres to find a gap (Albertson 1998; Gadd 2001), and high concentrations of elephants were found against fence lines.

In other circumstances, particularly where rewards on the other side of fences are high, elephants doggedly find ways through fences: short-circuiting fences with their tusks (Hoare 1992), bringing felled trees to drop across electric wires (pers. obs.), or pushing smaller elephants through. Cutlines and roads alongside VCFs may add to their barrier effect: elephants can be reluctant to cross abrupt or unnatural changes in vegetation cover (pers. obs., F.L. Osborn pers. comm.). Individual behaviour and experience may play a role: elephants that have been electrocuted on fencing elsewhere may avoid all fencing (even non-electrified) (Gadd 2001), while others become adept fence-breakers, regularly breaking out of protected areas into cultivated crops (Craig 2007).

Where fence wires have been dismantled, some animals still shy away. Giraffe and eland retreated from a section where wire had been removed, possibly due to the visual barrier of the cutline or the fence posts, or the smell of creosote-treated posts (Albertson 2005, 2008). Elephants trapped in an enclosure refused to cross the fence line even after it had been dismantled to release them (pers. obs.). Elephants are reluctant to cross manmade roads (Blake et al. 2008) and clearings (F.L. Osborn, pers. comm.) in other circumstances and may cross unfamiliar gaps only when highly motivated to do so.

Predation

Cleared cutlines alongside fences provide easy access for humans to remote areas and create opportunities for predators to track or chase and corner wildlife. Some animals charge directly into fences when startled by humans (on foot or in vehicles) (pers. obs.), but data are lacking on which species are most likely or most affected. Carnivores follow fencelines and roads, and may use fences to their advantage. In South Africa, wild dogs killed larger prey than usual (adult male kudus and waterbuck) by using Pilanesberg National Park's perimeter fences (van Dyk and Slotow 2003). Domestic dogs in Kenya used game fences to corner a zebra (pers. obs.). Numerous cases were documented where humans capitalised on "easy pickings" offered by veterinary fences: slaughtering hundreds of trapped springbok against fences in South Africa in the 1890s (Roche 2008); and wildebeest in Botswana (Owen and Owen 1980; Williamson and Mbano 1988), hunting on foot with dogs (Owen and Owen 1980) or shooting from vehicles (Albertson 1998). Veterinary fences provide inroads for poachers from other areas in community owned hunting areas (Albertson 1998; Kavadimba 1998) and in commercial safari areas (Weaver 1997). Fence maintenance personnel have also been implicated in cornering and killing wildlife (Albertson 1998). Wherever wire fences are built, snares soon follow. People deftly convert fence wire into snares for bushmeat (pers. obs., Booth et al. 1998). Over a 6-month period, 2000 snares were picked up in the Chirisa Safari Area, all made from the nearby tsetse control fence (Conway 1984 cited in Taylor and Martin 1987). How many new snares are made available annually by veterinary fences is unknown, but the practice is ubiquitous.

Population Effects

Isolation of Populations

Populations that were once contiguous and interbreeding have been severed by fences. Fencing is believed to be a causal factor in the long-term decline of wildebeest, hartebeest and eland in the Kalahari (Spinage and Matlhare 1992; Knight 1995); roan, sable and tsessebe in the Caprivi, Namibia (Weaver 1997; Martin 2005); and roan, oribi, *Ourebia ourebi,* and sable in northern Botswana (Albertson 1997). Fencing enforced hard edges on rhinos, *Diceros bicornis minor,* in Zimbabwe, preventing natural dispersal and intermingling and necessitating active metapopulation management (du Toit 2005).

Failure to Recolonise or Recover

Namibia's Caprivi is a thin strip of land bounded by the major rivers of the Kavango and the Zambezi. Wildlife populations in the Caprivi and in Angola were heavily depleted by war and anthropogenic pressures prior to 1990. Botswana has provided a source of recolonizing ungulates making their way north again, particularly buffalo, elephants, roan, sable, and tsessebe. However, since 1995, when Botswana's northern border fences were fortified, roan, sable and tsessebe have markedly declined. Examining all other factors (including rainfall, law enforcement, patrol effort, and human population trends), Martin (2005) concluded that the declines can be attributed to the fortified veterinary fences which prevent immigration of ungulates, and possibly, to elephant-induced habitat change.

Mass Mortalities

Mass mortality events were most common in migratory ungulates, with die-offs numbering in the tens of thousands. In South Africa, enormous herds of springbok once migrated across the Karoo region. Although the deaths of hundreds of thousands of springbok in the 1890s was previously blamed on rinderpest, an examination of newspaper reports reveals that not long after fences were constructed to protect grazing resources for domestic livestock, springbok became confined in high densities, died of starvation, and were slaughtered by settlers (Roche 2008). Shortly after Botswana's Kuke and Ngamiland veterinary fences were constructed in the late 1950s, wildebeest and hartebeest began dying in great numbers at the ephemeral Lake Xau (Child 1972; Owen and Owen 1980; Williamson and Mbano 1988; Spinage 1992). It is believed that when wildebeest and hartebeest migrating from the Kalahari Desert to the inundated Okavango Delta encountered fences blocking their traditional northerly migration, they turned east and followed the fence line for hundreds of kilometres, possibly drawn by the scent of water. In subsequent years, the wildebeest repeated their ill-fated migration to the new destination: with successive wildebeest die-offs witnessed in 1961, 1963–1964, 1970, and 1982–1983. In the dry season of 1963, an estimated 300,000 wildebeest died (Child 1972). Thirty-five years after fence construction, mass mortalities continued with a further 52,000–80,000 wildebeest dying at Lake Xau in 1982–1983 (Parry 1987; Williamson and Mbano 1988). By 1986, there was no migration, and a 1987 aerial count found only 260 wildebeest in the Central Kalahari (Ross 2003), down from 262,000 in 1979 (DHV survey data in Spinage 1992).

Selective Pressures

Eventually, the toll taken on migratory populations and species has led to a shift in animal behaviour and in community composition. As mentioned above, South Africa's largest mass migration disappeared after springbok were confined by fence-lines and died *en masse* in consecutive years in the 1890s. Within a decade, the springbok migration vanished and only small herds and scattered individuals persisted (Roche 2008). After the construction of fences across the northern boundaries of Etosha National Park in Namibia, the migration of 30,000 wildebeest disappeared. A smaller, sedentary population of wildebeest survives within Etosha, but is susceptible to episodic declines, probably due to disease outbreaks (Berry 1983). In the Kalahari, migratory wildebeest, hartebeest and zebra perished when they failed to reach their annual destination (Spinage 1992; Spinage and Matlhare 1992; Ross 2003), but some non-migratory individuals survived (Knight 1995). Within a matter of years, the repeated selection against migratory individuals has led to the predominance of sedentary individuals. Community structure may also shift, away from species reliant upon water (e.g. wildebeest and eland) to species that are not migratory or water dependent (e.g. gemsbok and springbok) (Spinage and Matlhare 1992; Knight 1995).

Ecosystem Effects

Confinement of herbivores by VCFs can lead to habitat degradation, depressed primary production and, eventually, decreased carrying capacity. Restriction of springbok, kudu, wildebeest, and giraffe by VCFs to areas of very high grazing and browsing are blamed for population declines in the Caprivi (Albertson 1998). Models using aerial survey data indicate that ungulate biomass in the Kalahari was only 25% of its predicted level after fence construction (1,833 vs. 439 kg/km^2) (Williamson and Williamson 1981). Soil samples in and around Khutse Game Reserve, Botswana linked low wildebeest and hartebeest biomass to a downward spiral in carrying capacity: free-ranging wild herbivores are necessary for nutrient input and in their absence, soil nutrition may decline (de Queiroz 1993).

Artificially high concentrations of elephants can cause rapid habitat change, so their confinement by fences can have marked effects. Elephants are keystone species, capable of causing shifts in vegetation structure and in species composition (plant and animal) (see Caughley 1976; Cumming et al. 1997; Ogada et al. 2008 for reviews). Trampling by elephants along fence lines caused local habitat degradation in Zimbabwe (Taylor and Martin 1987). Exceptionally high densities of elephants in northern Botswana may be due in part to range restriction imposed by veterinary fences (Albertson 1998). In combination with lack of recolonisation opportunities, the resulting elephant-induced changes in vegetation structure may contribute to the marked decline of buffalo, roan, sable and tsessebe in the Caprivi (Martin 2005).

Human-Wildlife Conflict

Although fences can be built specifically to curtail human-wildlife conflict, VCFs can intensify conflict. Where fences separate wildlife, especially elephants, from water supplies, human-wildlife conflict escalates (Taylor and Martin 1987; Gadd 2001). Animals denied access to natural watercourses are forced to seek water elsewhere, often resorting to waterholes in close proximity to humans and their livestock. Fences can facilitate land use practices that are incompatible with wildlife conservation. Where fences are built along the boundary of a wildlife zone, agriculture tends to expand right up to the boundary, even if a buffer zone has been designated (Taylor and Martin 1987). Fences that dead-end near agricultural settlements unintentionally funnel elephants in, increasing crop raiding (Booth et al. 1998). Fences remove incentives for people to actively herd their cattle, and cattle wander unattended, rendering them more susceptible to predation, stock theft and accidentally wandering through broken fences into disease zones (Gadd 2001). When elephants break VCFs and unaccompanied cattle escape, hostility toward elephants increases and cattle owners may demand compensation or extermination of elephants (Albertson 1998; Gadd 2001, 2003).

Benefits of VCFs to Wildlife

In addition to preventing disease spread, some veterinary cordon fences do confer advantages to wildlife. Fences made it possible to keep commercially valuable, disease-free buffalo in Zimbabwe prior to the collapse of the central government in the early 2000s (Taylor and Martin 1987; du Toit 2005) and in Namibia's Nyae Nyae Conservancy (pers. obs.). Fences can also exclude domestic stock from wilderness areas: e.g. the Southern Buffalo Fence skirts the southern edge of Botswana's Okavango Delta, keeping wildlife to the north and domestic stock to the south (Ross 2003).

Synergies

The most devastating and long-lasting impacts occurred when fences combined with other factors. Fences, disease, drought, confinement and resulting high local densities, and subsequent predation by people are blamed for the disappearance of hundreds of thousands of springbok from South Africa's Karoo (Roche 2008). Fences, loss of migration routes, and disease outbreaks depressed the wildebeest population in Etosha, Namibia to a fraction of its original size (Berry 1983). Fences, human hunting, drought and competition with cattle precipitated the demise of the Kalahari's wildebeest (Owen and Owen 1980; Williamson and Mbano 1988; Spinage 1992). Fences and drought contributed to the declines of hartebeest and zebras in the Kalahari in the 1980s (Spinage 1992; Ross 2003). Fences, provisioning of artificial waterholes and drought contributed to the decline of wildebeest, hartebeest, eland, and ostrich in Kalahari Gemsbok National Park (Knight 1995). Fences, excessively high concentration of herbivores and subsequent die-offs may cause depressed productivity in the Khutse area of the Kalahari (de Queiroz 1993). Fences, high elephant densities which depleted browsing and grazing, and the failure of immigrants to replenish northern satellite populations explain the decline of local ungulates in Caprivi, Namibia (Martin 2005). Fencing of the Shashe River, human-elephant conflict around agriculture and water points, and targeted hunting are likely to eliminate the last few dozen elephants around Mmadinare, Botswana (Gadd 2001, 2003).

Mitigation

Few attempts have been made to lessen the impact of veterinary cordon fences, either by leaving openings or by designing fences that are more permeable to wildlife. Give-and-go fences that could be triggered by elephants have been suggested (Kalikawe 1997) but not field-tested. Carnivores showed some proclivity for learning where passage points were in a ranch fence in Namibia (Schumann et al. 2006). Attempts to curtail crop raiding by elephants could yield insights that could be applied to veterinary fences. Managers at Ol Pejeta Conservancy in Kenya identified points in their perimeter fence that elephants often broke through. At these breakage points, managers fortified the fences and where the property joined wildlife-friendly areas, managers removed sections of fence to encourage passage. Preliminary evidence from collared individuals and spoor counts indicates that elephants abandoned strengthened sections and quickly learned to use gaps (Craig 2007).

Progress and Restoration

Although pre-construction wildlife surveys were rarely used to decide upon the alignment of fences, governments recently agreed to remove specific sections of fence line after construction, after local and international outcry. To the acclaim of conservationists and local residents dependent on wild products and non-export livestock, Botswana's Department of Agriculture dismantled 210 km of the Setata fence (west of the Okavango) and 66 km of the Nxai Pan Buffalo Fence (east of the Okavango) in 2003 and 2004. Within weeks, elephants, zebras and wildebeest traversed the old line and moved into their former range (Albertson 2005). After being absent for decades, a hippo and a rhino made their first forays south of the old Setata line (Albertson 2008). In spite of these successes, Botswana's Department of Animal Health reversed its standpoint in 2007 and made the unilateral decision to rebuild the Setata fence (Environmental Investigation Agency 2007), selecting the alignment least recommended by the environmental impact assessment. However, progress was made again in 2008, when the Botswana government announced that it would leave a 100-km section of fence to allow wildlife to move unencumbered and would follow a less objectionable alignment option (Botswana Office of the President 2008).

Discussion

Trends Across Studies

Data on the impact of veterinary fences have been collected over finite sampling periods and covered only a fraction of the existing fences; therefore, they vastly underestimate the true toll. However, they provide incontrovertible evidence that veterinary cordon fences have played a significant role in the deaths of thousands of mammals, the disappearance of mass migrations and the collapse of local populations.

Effects have been recorded at all levels of organisation (individual to ecosystem) and across time scales (short- and long-term). With the exception of small mammals and carnivores, most mammals in the vicinity experienced individual entanglement and mortality. However, large, migratory ungulates have been the most severely affected, experiencing repeated mass mortalities and population crashes.

In the short term, animals in the immediate vicinity are separated from vital resources, family groups and conspecifics. Populations are restricted into habitat fragments and isolated into smaller populations. During drought periods, animals are unable to reach their dry season destination. Diverted by fences, animals may crowd into blind corners or confined areas, reaching unnaturally high concentrations, where they suffer exhaustion and stress and may succumb to dehydration, starvation, and predation. Human hunters take advantage of these aggregations, quickly and easily slaughtering confined, exhausted animals.

Deaths continue decades after fence construction, as new generations try to disperse, degraded habitat or climatic conditions force animals to take new paths or attempt to restore old ones. Over a few years, migratory individuals may perish, and over generations, migratory behaviours may disappear. The relict population may be more sedentary, isolated and susceptible to extinction. Community structure may shift, favouring sedentary species. In the long-term, the instinct and the ability to migrate could be lost.

Fences create feast and famine situations; too many herbivores confined on one side can lead to overgrazing, trampling, disease outbreaks, habitat degradation, starvation, and eventual decrease in carrying capacity. Too few on one side can lead to local extinctions. Fences bisect habitat and divide populations, blocking corridors and severing connectivity of metapopulations and of wildlife areas. Over time, populations dependent on inflow of new individuals from source populations may crash.

When combined with other forces, including natural environmental stressors (drought, fire, disease), competition with other herbivores (particularly cattle and elephants) and hunting by humans, fence effects can be catastrophic.

Learning from Our Mistakes

We have every reason to expect the prevalence of fences and the negative impacts of fencing on wildlife to increase in the coming years. In addition to new fences, existing fences are being strengthened to withstand disease threats and breakage by elephants in some regions and unwanted wildlife in other regions, and to resist the uncontrolled movement of people.

We should anticipate that climate change may exacerbate fence impacts. Animals will need to move in response to changing rainfall patterns and resource distribution, and will be forced to track shifting prey species or habitat distribution. Animals may find their habitat or prey species moving north or south of fences. Fence sections which have not had significant impact may suddenly be in the way of vital range shifts. Disease dynamics and animal interactions are bound to change. Existing fences may not be properly placed to accommodate changing land uses and disease control needs. There may be demand for a new generation of fences on the new frontlines of the wildlife/livestock interface; therefore, it is imperative that we have a realistic understanding of the effects of existing fences and a strategy to minimise undesirable consequences.

Improved Planning and Monitoring

For too long, disease control policies have been planned and executed in isolation. A new approach that considers economic productivity, ecosystem function, biodiversity and human health is essential (Osofsky et al. 2008). Diseases are a very real threat, but control plans should be developed at the regional level, in consultation with key stakeholders including cattle producers, veterinary departments, human health advocates, wildlife agencies and local residents.

Policies and subsidies need to be examined closely for hidden costs. It has been suggested that the standards for international trade are antiquated and that different protocols need to be explored (Nair 2007; Scoones and Wolmer 2008; Thomson 2008), which could alleviate the need for FMD fencing. For example, advocates of commodity-based trade argue that hygienically processing healthy cattle in Africa (by removing bones and lymph nodes) before export would serve the dual purpose of eliminating the risk of disease transmission and adding value to the commodity, thus removing the need for physical barriers and allowing African nations to retain more revenue from their exported beef (Scoones and Wolmer 2008; Thomson 2008). International trade agreements with consumer countries, aid from developed nations and policies within African countries that encourage sub-division and fencing, need to be examined for their unintended effects.

Conscientious Consumers and Educated Donors

Consumers are becoming more conscientious about the ecological footprint of the food they buy, yet few European consumers are aware of where their beef comes from, and even fewer are cognizant of the links to African wildlife. Campaigns to label the country of origin of animal products and to publicise the ecological cost could result in improved consumer awareness and more discerning buyers.

New fences are often paid for under the aegis of economic development. Cost/benefit analyses need to appropriately value the wildlife resources affected. Donor nations have the right, and the obligation to conduct environmental, social and economic impact assessments before fencing.

Mitigation

Several simple steps could improve our understanding of existing fences. Firstly, we need to take stock of the existing fences. An accurate, centralised, spatially explicit database of all fences (including information on key fence attributes, like type of fence, condition, etc.) is critical to understanding the current fence network and to prioritising future construction and removals.

Impediments to research need to be removed so that impact assessments can be carried out in a transparent, objective manner. Researchers have been unable to collect paired before- and after- or long-term data, and advice on minimizing impact to wildlife has been ignored. When new fences are deemed absolutely necessary, objective, independent environmental impact assessments must be conducted prior to fence construction and recommendations adhered to. At a minimum, for any proposed new fencing, mammal distribution, migration pathways, resource distribution (including vegetation types, rainfall gradient and water sources), historic knowledge of movements and migrations, altitudinal gradients, present and proposed land uses should be taken into account. Repeated, systematic paired assessments should be conducted before and after fence construction to see how wildlife distribution and abundance changes. Longitudinal studies to determine how individuals and species are affected at a given location need to be initiated. Focal animals should be studied before and after construction in order to answer questions about how individuals respond to altered resource availability, home ranges or territories, and divided social groups.

Existing fences must be managed adaptively. Fence encounter and passage rates can be calculated through simple yet systematic, frequent monitoring of fences. With regular monitoring, we can better understand mortality patterns and, most importantly, events that trigger them. By anticipating when and where essential wildlife movements are likely to happen, and where the disease control trade-off is reasonable, proactive measures like fence removal can be undertaken. Identifying locations that are likely to be used by wildlife that could be left open without compromising restriction of cattle movement would be a vast improvement. Where mammal traffic or mortality is high along VCFs or where threatened species occur, changes need to be made. In high impact areas, important corridors, or at times of year when migration is essential, alternatives to fencing must be explored.

Fence design has been relatively unchanged for the last 50 years. Simple innovations that allow the passage of some animals while preventing others could lessen the effects of fences without compromising their disease control functions. For example, where cattle and buffalo are the species of concern, cattle grids could be installed and effectively maintained. These will prevent the passage of cattle and buffalo while elephants and other wildlife could move across, unimpeded. The removal of fences within emerging transfrontier conservation areas, such as Kruger National Park's border with Mozambique, provide a unique opportunity to study how animals respond to fence removal and to test new wildlife friendly fencing sections, in a controlled, replicated manner.

For decades, the impact of veterinary fences on wildlife has been swept under the rug. It is time to take an honest accounting of the impact thus far and to take steps to prevent such unnecessary damage in future.

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