

Barriers, the beef industry and unnatural selection: a review of the impacts of veterinary fencing on mammals in southern Africa

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ABSTRACT

Thousands of kilometers of veterinary fences crisscross Southern Africa, dividing habitat and blocking the movement of terrestrial animals, and hundreds of kilometers of new fences are proposed or under construction. Although the primary targets of these fences are livestock and wild ungulates carrying diseases that could threaten livestock, the fences are not selective and create substantial physical barriers for many wildlife species. The ecological cost of these fences is often overlooked, but the evidence from 34 published and unpublished reports amounts to significant ongoing damage ranging from loss of life to the disappearance of entire migrations. Fences have adverse effects on wild mammals at the individual, population, and species levels, and alter community structure and ecosystem productivity. They disrupt individual daily movements and may lead to death by starvation, dehydration or entanglement. Fencing can divide populations, prevent recolonization and render sub-populations prone to the risks faced by small populations. Large-bodied, migratory ungulates and elephants *Loxodonta africana* have been the most severely affected. Fences can worsen negative interactions between people and wildlife: examples show that fences facilitate poaching and that fencing which disrupts the movement of large mammals, especially elephants, can increase conflict with local people. In light of current challenges (especially climate change) and opportunities (e.g. restoring degraded areas or re-connecting conservation areas), fences should be considered carefully for their role in impeding or altering events essential to species persistence, like dispersal, seasonal movement, and range expansion.

INTRODUCTION

History and purpose of VCFs

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, Cape 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 Bengis *et al.*, 2002; Hargreaves *et al.*, 2004; Kock, 2005; Mapitse, 2008; Osofsky *et al.*, 2008; Taylor & Martin, 1987).

Some diseases pose a serious threat to livestock and, in turn, to food security and human livelihoods. Others, particularly Foot-and-Mouth Disease (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 processing and handling requirements (Mapitse, 2008; Taylor & Martin, 1987). European policies and tariffs have buoyed cattle export from some African countries, and have subsidized 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 (EIA, 2004; Mapitse, 2008; Nair, 2007). 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 (Mapitse, 2008; Scoones & Wolmer, 2008; Nair, 2007; Perkins 1996).

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 (DuToit, 2005). However, aerial transmission is unlikely in southern Africa under the prevailing dry, hot weather (Sutmoller *et al.*, 2002). The virus can be found in a diverse range of hosts including hedgehogs, artiodactyls, primates, armadillos and rodents (Federation of American Scientists, 1997). 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

Syncerus caffer 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 & 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 Foot-and-Mouth Disease (FMD). FMD fences are intended to exclude potentially infected or reservoir species, and to create a mammal-free gap of 10m or more between the infected zone and animals in vaccination or quarantine zones (Taylor & 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 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 & 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 300km 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 kilovolts 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 & 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 & 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 impacts of fencing on human residents whose movements and livelihoods may be adversely affected (Albertson, 1997; Gupta, 2005; Mapitse, 2008; Pierson & 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 summarized. 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 privatization and redistribution), subdivision 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 jeopardize their ability to export to international markets (Kock *et al.*, 2002).

Disease outbreaks, increasing instability in neighboring 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 in 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 (FAO, 2003). To prevent incidents of this magnitude, Botswana upgraded and electrified its Caprivi fence to better barricade against livestock covertly entering from Namibia and Angola (Albertson, 1998; Martin, 2005; Weaver, 1997). 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 (Figure 1). For example, Botswana's perimeter is less than 3700 km but within the country (including border fences), more than 5000 km of fenceline protect the cattle industry (calculated from Williamson 2002, EIA 2004, 2005, 2007). Fences span hundreds of kilometers without any openings or gaps to allow passage of wildlife (e.g. Botswana's 300 km Kuke fence [Ross, 2003] or Zambia's proposed 1000 km fence along Angola [Anon, 2003]).

Alignment of fencing

Secondly, 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 250km 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, nor dispersal of adolescent animals leaving their natal territories. Fences often join at acute angles, unintentionally funneling 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 (DuToit, 2005; Mapitse, 2008; Osofsky *et al.*, 2008). The recently established Kavango Zambezi Transfrontier Conservation Area (KAZA), spans more than 250,000 km² 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 compartmentalize 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 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 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 subdivide 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 & Cushman, 2002). Patches isolated by fences could function as land-locked islands, subject to the predictions of island biogeography theory (MacArthur & 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 chance (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 colonization or re-colonization events re-establish subpopulations) (reviewed in Hanski, 1994), fences prevent the re-colonization and recovery of satellite subpopulations. 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 & 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 subdivision 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 & Hobbes, 2004).

METHODS

Meta-analysis

I categorized the effects of veterinary cordon fences on wildlife from 34 published and unpublished reports (Table 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, summarizing 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 (SWRC/EDG, 2000). The vast majority of documents assessed impact during or after fence construction (Albertson 1997, 1998, 2005, 2007; Gadd 2001, 2003; Gupta 2005; SWRC/EDG 2000). 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 fencelines in specific regions, but these are now more than ten years out of date (Ross, 2003; Williamson 2002: Botswana fences constructed prior to 1997, Martin, 2005: Namibia, Botswana and northwestern Zimbabwe fences constructed prior to 1996), cover limited locations and did not specify fence type.

Limitations

Ideally, ecological experiments should have replicated, controlled, paired samples (Hurlbert, 1984; McGarigal & 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 fenceline and counting spoor or carcasses was the most common method employed. In five cases, aerial surveys were flown (Child 1972; Knight 1995; Spinage & Mathlare 1992; Williamson & Mbano, 1988; Williamson & Williamson 1981). Unfortunately, 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 (SWRC/EDG 2000), recommendations on optimal alignment were ignored (Albertson, 2007; EIA, 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 traveled 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 one year (Booth, Hoare, & Mackie, 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% (416/790) 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 2007). Upon encountering a newly electrified fence, elephants in eastern Botswana walked alongside it for several kilometers, until they reached the last white insulator and then broke through (Gadd 2001). In another study, 60 to 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 amphibius*, 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 fencelines 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 (Booth *et al.*, 1998; Hoare 1992; 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 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 & 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 camellus*, have been found with necks, wings

or legs entangled in fences (Albertson, 1998; Kavadinba, 1998; Taylor & Martin, 1987). Tortoises can become stuck under the lowest wires of fences (pers. obs., photograph at Boteti, Botswana, EIA).

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 burchelli*, 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 fencelines on paths to water, families were seen on separate sides of fences, individual elephants paced fencelines or walked kilometers to find a gap (Albertson, 1998; Gadd, 2001), and high concentrations of elephants were found against fencelines. In other circumstances, particularly where rewards on the other side of fences are high, elephants doggedly find ways through fences: short-circuiting them 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., FL 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, 2007). 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 (FL 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 & Slotow, 2003). Domestic dogs in Kenya used game fences to corner a zebra (pers. obs.). Numerous cases were documented where humans capitalized 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 & Owen, 1980; Williamson & Mbanjo 1988), hunting on foot with dogs (Owen & Owen 1980) or shooting from vehicles (Albertson, 1998). Veterinary fences provide inroads for poachers from other areas in community owned hunting areas (Albertson, 1998; Kavadinba 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 six-month period, 2000 snares were picked up in the Chirisa Safari Area, all made from the nearby tsetse control fence (Conway, 1984 in Taylor & 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 (Knight, 1995; Spinage & Mathlare, 1992), roan, sable, and tsessebe in the Caprivi, Namibia (Martin 2005; Weaver 1997), 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 (DuToit, 2005).

Failure to recolonize/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, *Antidorcas marsupialis*, once migrated across the Karoo ecosystem. 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; Spinage, 1992; Owen & Owen, 1980; Williamson & Mbanjo, 1988). 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 fenceline hundreds of kilometers, 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, 1963-64, 1970, and 1982-83. 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 1982-83 (Parry 1987; Williamson & 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 fencelines 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 (Ross, 2003; Spinage, 1992; Spinage & Mathlare 1992), 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) (Knight, 1995; Spinage & Mathlare, 1992).

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 (1833 kg/km^2 vs. 439 kg/km^2) (Williamson & 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, no date).

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 fencelines caused local habitat degradation in Zimbabwe (Taylor & 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 recolonization 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 (Gadd, 2001; Taylor & Martin, 1987). 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 & 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; Gadd, 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

(DuToit, 2005; Taylor & Martin, 1987) 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 & Owen, 1980; Williamson & Mbano, 1988; Spinage, 1992). Fences and drought contributed to the declines of hartebeest and zebras in the Kalahari in the 1980s (Ross, 2003; Spinage, 1992). 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, no date). 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 the strengthened section and quickly learned to use the 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 fenceline 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 210km 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 2007). In spite of these successes, Botswana's Department of Animal Health reversed itself in 2007 and made the unilateral decision to rebuild the Setata fence (EIA, 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 organization (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, migratory large 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, favoring 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, like 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 minimize 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 & Wollmer, 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 & Wollmer, 2008; Thomson, 2008). International trade agreements with consumer countries, aid from developed nations, and policies within African countries that encourage subdivision 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 publicize 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.

Mitigation

Several simple steps could improve our understanding of existing fences. Firstly, we need to take stock of the existing fences. An accurate, centralized, 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 prioritizing 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 fifty 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 that prevent the passage of cattle and buffalo, elephants and other wildlife could move across, unimpeded. The planned 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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References cited

- AHEAD (2003) Animal Health, Environment and Development Working Group Notes. In World Parks Conference, Durban, South Africa.
- Albertson, A. (1997). Botswana: death by cattle.
- Albertson, A. (1998). Northern Botswana Veterinary Fences: Critical Ecological Impacts.
- Albertson, A. (2005). Removal of decommissioned veterinary fences in Ngamiland District, Botswana. Funded by Sierra Club, Kalahari Conservation Society and The Wild Foundation.
- Albertson, A. (2007). A report to the Ministry of Agriculture's Proposal to re-erect the Setata fence: points for urgent consideration.
- Bengis, R.G., Kock, R.A., & Fischer, J. (2002) Infectious animal diseases: the wildlife/livestock interface. *Rev. sci.tech. Off. Int. Epiz.*, **21**, 53-65.
- Berry, H. (1983) The blue wildebeest problem at Etosha National Park. *African Wildlife*, **39**, 192-197.
- Blake, S., Deem, S.L., Strindberg, S., Maisels, F., Momont, L., Isia, I.-B., Douglas-Hamilton, I., Karesh, W.B., & Kock, M.D. (2003) Roadless wilderness area determines forest elephant movements in the Congo Basin. *PLoS ONE*, **3**, 1-9.
- Boone, R.B. & Hobbs, N.T. (2004) Lines around fragments: effects of fencing on large herbivores. *African Journal of Range & Forage Science*, **21**, 147-158.
- Booth, V., Hoare, R.E., & Mackie, C. (1998) Use of electric fences in communal areas of Zimbabwe. In Southern Africa regional workshop on fences (ed K. Ross), pp. 14-32. Conservation International, Maun, Botswana.
- Brashares, J.S. (2003) Ecological, behavioral, and life-history correlates of mammal extinctions in West Africa. *Conservation Biology*, **17**, 733-743.
- Brook, B.W., Sodhi, N.S., & Bradshaw, C.J.A. (2008) Synergies among extinction drivers under global change. *Trends in Ecology and Evolution*, **23**, 453-460.
- Caughley, G. (1976) The elephant problem - an alternative hypothesis. *East African Wildlife Journal*, **14**, 265-283.

- Caughley, G. (1994) Directions in Conservation Biology. *The Journal of Animal Ecology*, **63**, 215-244.
- Child, G. (1972) Observations on a wildebeest die-off in Botswana. *Arnoldia*, **5**, 1-13.
- Clevenger, A.P. & Waltho, N. (2000) Factors Influencing the Effectiveness of Wildlife Underpasses in Banff National Park, Alberta, Canada. *Conservation Biology*, **14**, 47-56.
- Craig, B. (2007) Final report to U.S. Fish & Wildlife Service: Wildlife Surveillance and Elephant Monitoring in Ol Pejeta Conservancy.
- Cumming, D.H.M., Fenton, M.B., Rautenback, I.L., Taylor, R.D., Cumming, G.S., Cumming, M.S., Dunlop, J.M., Ford, A.G., Hovorka, M.D., Johnson, D.S., Kalcounis, M., Mahlangu, Z., & Portfors, C.V.R. (1997) Elephants, woodlands and biodiversity in southern Africa. *South African Journal of Science*, **93**, 231-236.
- deQueiroz, J.S. (1993) Range degradation in Botswana: myth or reality? In Pastoral development paper 3b. Overseas Development Institute, London.
- DuToit, R. (2005). Foot and Mouth Disease management and land-use implications in the Zimbabwean Lowveld: the rationale for creating a Biosphere Reserve. In *Conservation and development interventions at the wildlife/livestock interface: implications for wildlife, livestock and human health* (ed S. Osofsky), Vol. Occasional paper of the IUCN Species Survival Commission, No. 30, pp. 109-111.
- EIA (2004). A line in the sand: the unsustainable expansion of Botswana's beef industry at the expense of local communities and the Okavango Delta.
- EIA (2005). Dead end: a briefing document on the construction of a game-proof fence around the Makgadikgadi National Park, Botswana.
- EIA (2007). Background and implications of the decision to re-erect the Setata fence in Ngamiland.
- FAO (2005) Foot-and-mouth disease status in southern Africa. In EMPRES Transboundary animal disease bulletin, Vol. 28, pp. 2-6.
- FAS (1997) Federation of American Scientists.
- Forman, R.T.T., Sperling, D., Bissonette, J.A., Clevenger, A.P., Cutshall, C., Dale, V.H., Fahrig, L., France, R., Goldman, C.R., Heanue, K., Jones, J.A., Swanson, F.J., Turrentine, T., & Winter, T.C. (2003) *Road Ecology* Island Press, Washington DC.
- Gadd, M. (2001). Final report to Botswana Department of Wildlife and National Parks: 2000-2001 Eastern Botswana Elephant Project. Unpublished report.
- Gadd, M. (2007). Preliminary comments on the potential effects of a new veterinary cordon fence across Northern Namibia/Southern Angola. US Department of the Interior, Interior Technical Assistance Program (ITAP) for the Millennium Challenge Corporation (MCC).
- Gadd, M.E. (2003) *Elephant ecology and conservation in African rangelands*. Ph.D., University of California at Davis.
- Gupta, C. (2005) Makgadigadi Fence impacts.
- Hanski, I. (1998) Metapopulation dynamics. *Nature*, **396**, 41-49.
- Hargreaves, S.C.F., EC Anderson, ADS Bastos, GR Thomson, NP Ferris and NJ Knowles (2004) An investigation into the source and spread of foot and mouth disease virus from a wildlife conservancy in Zimbabwe. *23 (3): 783-790. Rev. sci.tech. Off. Int. Epiz.*, **23**, 783-790.
- Hoare, R.E. (1992) Present and future use of fencing in the management of larger African mammals. *Environmental conservation*, **19**, 160-164.
- Hurlbert, S.H. (1984) Pseudoreplication and the design of ecological field experiments. *Ecological Monographs*, **54**, 187-211.

- Kalikawe, M.C. (1997) *Wildlife friendly fencing for Botswana: a presentation of recommended procedures, specifications and important considerations* Botswana Government Printer.
- Kavadimba, S. (1998) Community case studies: impact of fences on wildlife resource use. In Southern Africa regional workshop on fences (ed K. Ross), pp. 38-39. Conservation International, Maun, Botswana.
- Knight, M.H. (1995) Drought-related mortality of wildlife in the southern Kalahari and the role of man. *African Journal of Ecology*, **33**, 377-394.
- Kock, R. (2005). What is this infamous "wildlife/livestock disease interface?" A review of current knowledge for the African continent. In *Conservation and development interventions at the wildlife/livestock interface: implications for wildlife, livestock and human health* (ed S.A. Osofsky), Vol. 30, pp. 1-13. IUCN.
- Kock, R., Kebkiba, B., Heinonen, R., & Bedane, B. (2002) Wildlife and Pastoral Society; Shifting Paradigms in Disease Control. *Annals of the New York Academy of Sciences*, **969**, 24-33.
- MacArthur, R.H. & Wilson, E.O. (1967) *The Theory of Island Biogeography* Princeton University Press, Princeton, N.J.
- Mapitse, N. (2008). Botswana's foot-and-mouth disease and beef trade policy. Institute of Development Studies, Brighton.
- Martin, R.B. (2005). The influence of veterinary control fences on certain wild large mammal species in the Caprivi, Namibia. In *Conservation and development interventions at the wildlife/livestock interface: implications for wildlife, livestock and human health* (ed S. Osofsky), Vol. 30, pp. 27-46. Occasional paper of the IUCN Species Survival Commission.
- Mbaiwa, J.E. & Mbaiwa, O.I. (2006) The effects of veterinary fences on wildlife populations in Okavango Delta, Botswana. *International Journal of Wilderness*, **12**, 17-41.
- McGarigal, K. & Cushman, S.A. (2002) Comparative evaluation of experimental approaches to the study of habitat fragmentation effects. *Ecological Applications*, **12**, 335-345.
- Nair, M.K.S. (2007) Governance and upgrading opportunities in beef industry in Botswana: a value chain approach. In The Second International Conference on Management of Globally Distributed Work, Session 7: Capacity Management and Economics, pp. 431-440.
- Newmark, W.D. (1996) Insularization of Tanzanian parks and the local extinction of large mammals. *Conservation Biology*, **10**, 1549-1556.
- Ogada, D., Gadd, M.E., Ostfeld, R., Young, T.P., & Keesing, F. (2008) Impacts of large herbivorous mammals on bird diversity and abundance in an African savanna. *Oecologia*, **387-397**, 387-397.
- Osofsky, S.A., Cumming, D.H.M., & Kock, M.D. (2008). Transboundary management of natural resources and the importance of a 'One Health' approach: perspectives on Southern Africa. In *State of the Wild 2008-2009: A Global Portrait of Wildlife, Wildlands, and Oceans* (ed E.a.K.H.R. Fearn), pp. 89-98. Island Press, Washington, D. C.
- Owen, M. & Owen, D. (1980) The fences of death. *African Wildlife*, **34**, 25-27.
- Parry, D. (1987) Wildebeest (*Connochaetes taurinus*) mortalities at Lake Xau, Botswana. *Botswana Notes and Records*, **19**, 95-101.
- Perkins, J.S. (1996) Botswana: fencing out the equity issue. Cattleposts and cattle ranching in the Kalahari Desert. *Journal of Arid Environments*, **33**, 503-517.
- Pierson, O. & Gadd, M. (2008) To fence or not to fence: use of wildlife data to influence U.S. Government foreign assistance decision-making in Northern Namibia. In Society for Conservation Biology, Chattanooga, Tennessee.

- Roche, C. (2008) 'The fertile brain and inventive power of man': anthropogenic factors in the cessation of springbok treks and the disruption of the Karoo ecosystem, 1865-1908. *Africa*, **78**, 157.
- Ross, K. (2003) *Okavango: Jewel of the Kalahari* Struik Publishers, Cape Town.
- Schumann, M., Schumann, B., Dickman, A., Watson, L.H., & Marker, L. (2006) Assessing the use of swing gates in game fences as a potential non-lethal predator exclusion technique. *South African Journal of Wildlife Research*, **36**, 173.
- Scoones, I. & Wolmer, W. (2008). Foot-and-mouth disease and market access: challenges for the beef industry in southern Africa. Institute of Development Studies, Brighton.
- Spinage, C.A. (1992) The decline of the Kalahari wildebeest. *Oryx*, **26**, 147-150.
- Spinage, C.A. & Matlhare, J.M. (1992) Is the Kalahari cornucopia fact or fiction? A predictive model. *J. appl. Ecol.*, **29**, 605-610.
- Sutmoller, P. (2002) The fencing issue relative to the control of Foot-and-Mouth Disease. *Annals of the New York Academy of Sciences*, **969**, 191-200.
- SWRC/EDG (2000). Environmental impact assessment of the veterinary fences in Ngamiland. Funded by Department for International Development (DFID) and the Government of Botswana.
- Taylor, R.D. & Martin, R.B. (1987) Effects of veterinary fences on wildlife conservation in Zimbabwe. *Environmental management*, **11**, 327-334.
- Thomson, G. (2008). A short overview of regional positions on foot-and-mouth disease control in southern Africa. Institute of Development Studies, Brighton.
- van Dyk, G. & Slotow, R. (2003) The effects of fences and lions on the ecology of African wild dogs reintroduced to Pilanesberg National Park, South Africa. *African Zoology*, **38**, 79.
- Weaver, L.C. (1997). Background and potential impacts resulting from construction of a game and livestock proof fence by the Government of Botswana south of the West Caprivi Game Reserve. WWF/LIFE Programme.
- Williamson, D. (2002) Dimensions and dilemmas of conservation in the Kalahari. *Open Country*, **4**, 15-24.
- Williamson, D. & Mbanjo (1988) Wildebeest mortality during 1983 at Lake Xau, Botswana. *African Journal of Ecology*, **26**, 341-344.
- Williamson, D. & Williamson, J. (1981) An assessment of the impact of fences on large herbivore biomass in the Kalahari. *Botswana Notes and Records*, **13**, 107-110.
- Young, T.P., Palmer, T.M., & Gadd, M. (2005) Competition and compensation among cattle, zebras, and elephants in a semi-arid savannah in Laikipia, Kenya. *Biological Conservation*, **122**, 351-359.

Table 1. Expected impacts of veterinary cordon fences. **(attached as Excel file)**

Table 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. **(attached as Excel file)**

Figure 1 a) Major fences in southwestern Africa before 2000 (Martin 2005).

b) Fences in Botswana before 1997 (Williamson 2002). **(Below on separate pages)**

Table 1. Expected impacts of veterinary cordon fences

Level	Effect
Individual	Movement impeded
	Individual territory or home range fragmented
	Behavioral 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 behavior 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 recolonization
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

Table 2. Known impacts of veterinary cordon fences on wildlife in southern Africa							
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	1992-93	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	1992-93	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 & Mbano 1988
	wildebeest		Botswana	Kalahari fences	not described	1979-1980	Owen & Owen 1980
	giraffe, impala, sable, kudu, ostrich		Zimbabwe	Hwange and Gonarezhou	not described		Taylor & 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

Event	Species	Detail	Country	Location	Method	Date	Source
	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	1979-80	Owen & 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
	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	1979-80	Owen & Owen 1980
	hartebeest, wildebeest	unable to reach Limpopo River for water	Botswana	Limpopo River, between Lephepe to Dibete	not described		Owen & 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

Event	Species	Detail	Country	Location	Method	Date	Source
	elephants, giraffe		Botswana	Nxai Pan buffalo fence	not described	1997	Albertson 1998
	wildebeest, hartebeest		Botswana	Phedofiafoka fence, northeast CKGR	direct observation	1997	Albertson 1998
	elephants		Zimbabwe	Sebungwe fence at Matusadona NP			Taylor & 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 & 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 & Mbanjo 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 & 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			DuToit 2005
Mass mortality event	wildebeest	300,000 died	Botswana	Lake Xau, Mopipi Dam	aerial survey, carcass count	1963	Child 1972

Event	Species	Detail	Country	Location	Method	Date	Source
	wildebeest		Botswana	Kuke fence, Lake Xau	not described	1961, 1964, 1970, 1979	Owen & Owen 1980
	hartebeest, wildebeest	'thousands'	Botswana	Limpopo River, between Lephepe to Dibete	not described		Owen & Owen 1980
	wildebeest	52,000 carcasses estimated at end of dry season	Botswana	Lake Xau, Mopipi Dam: 1982-83	carcass count on ground, sampled areas, stratified by estimated carcass density	1982-83	Williamson & Mbanjo 1988
	wildebeest	80,000 carcasses estimated	Botswana	Lake Xau, Mopipi Dam: 1982-83	aerial survey, carcass count	1982-83	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 & 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 & Mathare 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 & Mathare 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 & Mbanjo 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 125km2 area	Botswana	Lake Xau	not described	1979	Owen & Owen 1980

Event	Species	Detail	Country	Location	Method	Date	Source
	wildebeest	50,000 wildebeest concentrated in an area	Botswana	Lake Xau	aerial survey	1983	Williamson & Mbanjo 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
Prevention of recolonization	eland	Population decline since 1980s. Without immigration, local extinction likely.	Botswana	Central Kalahari Game Reserve	aerial survey and model	1995	Spinage & 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 & Owen 1980

Event	Species	Detail	Country	Location	Method	Date	Source
	cattle deplete grazing, wildebeest starve	"grazing had been severely depleted by an enormous concentration of domestic livestock"	Botswana	Lake Xau, Mopipi Dam	direct observation	1982-83	Williamson and Mbanjo 1988
	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 & 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
Decreased carrying capacity	all ungulates	observed wild biomass 25% of expected. 439kg/km-2, vs. 1833kg/km-2	Botswana	Kalahari	aerial survey compared to biomass model	1980	Williamson & 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
Hunting by humans while confined by fences	springbok	with firearms	South Africa	Karoo: 1896	review of historical documents	1896	Roche 2008
	wildebeest	using packs of domestic dogs. The dogs run the herds until the exhausted wildebeest can only stand while being	Botswana	Kuke fence, Lake Xau	not described	1979	Owen & Owen 1980
	wildebeest	"remorselessly harassed by hunters"	Botswana	Lake Xau, Mopipi Dam	direct observation	1982-3	Williamson & Mbanjo 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

Event	Species	Detail	Country	Location	Method	Date	Source
Conversion of fences into snares	all species	2000 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 & Guardian newspaper
	all species		Zimbabwe	Zambezi Valley	direct observation		L Osborne, pers.comm.
	rhinos		Zimbabwe	Save Valley, Bubyie, Bubiana Conservancies	direct observation		duToit, 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 2005
	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



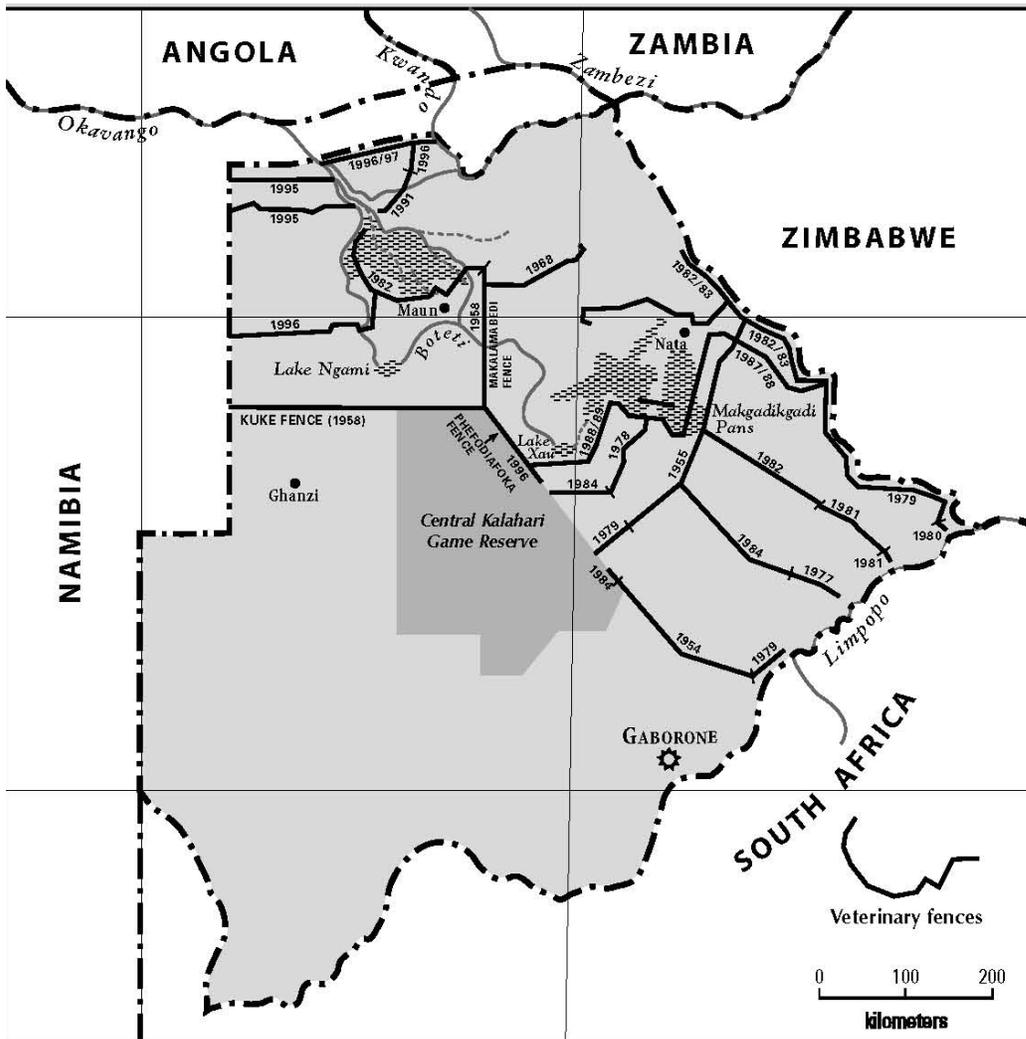
KEY TO VETERINARY CONTROL FENCES

- ① Veterinary Cordon Fence: mid-1960s...
- ② Etosha Northern Boundary. Fence: 1980s
- ③ Namibia/Botswana International Boundary: mid 1960s
- ④ Namibia/South Africa International Boundary: mid 1960s
- ⑤ Caprivi Border 1995 (Early fences 1970-80)
- ⑥ Samuchima 1995
- ⑦ Ikoga 1995
- ⑧ Setata 1996
- ⑨ Kuke 1958
- ⑩ Southern Buffalo Fence 1982
- ⑪ Northern Buffalo Fence 1991-96
- ⑫ Ngwatsha Fence 2000 (original Makalamabedi Fence 1968 shown as dotted line below)
- ⑬ Botswana/Zimbabwe International Boundary 1984
- ⑭ Hwange National Park 1984
- ⑮ Sebungwe 1972

LEGEND

- Major Cordon Sanitaire
- Major buffalo-proof fence
- Secondary buffalo-proof fence
- Fence in disrepair
- Former fence location
- Fence continues

1a)



1b)

Figure 1 a) Major fences in southwestern Africa before 2000 (Martin 2005).
 b) Fences in Botswana before 1997 (Williamson 2002).