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REVIEW

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Two decades of One Health in action: Enabling sustainable wildlife conservation and livestock production in southern Africa

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Abstract

The AHEAD (Animal & Human Health for the Environment And Development) program was launched in 2003 at the IUCN World Parks Congress in Durban, South Africa. We defined our mission as serving as "a convening, facilitative mechanism, working to create enabling environments that allow different and often competing sectors to literally come to the same table and find collaborative ways forward to address challenges at the interface of wildlife health, livestock health, and human health and livelihoods." We continue on this mission more than 20 years later, convening stakeholders, helping delineate conceptual frameworks to underpin planning, management and research, and providing technical support and resources for projects stakeholders identify as priorities. As one of the first applied One Health programs, our work is premised upon the fact that the challenge of managing transboundary animal diseases (TADs) often lies at the heart of whether transfrontier conservation areas (TFCAs) will succeed or fail in their aspirations to become the ecologically resilient land-use entities required for long-term delivery of poverty alleviation and related development as well as biodiversity conservation benefits. As the Kavango Zambezi Transfrontier Conservation Area's (KAZA's) remaining key wildlife corridors, needed for wildlife populations to survive and thrive for generations to come, continue to be blocked by veterinary cordon fences, the urgency of improving regional animal disease management cannot be overstated. This is especially relevant for those European donors to TFCAs whose nations set up the veterinary cordon fencing-based disease management system in the first place – starting in the 1950s when today's KAZA partner countries were European colonies or protectorates. The prevailing veterinary fencing paradigm is rooted in the colonial era, but with impacts on KAZA's wildlife that have persisted on up to the present. If we fail to help all countries within a given TFCA actually co-manage disease threats to the livestock sector that all value highly – culturally, economically, and politically – then how can we expect significant progress in terms of fostering habitat connectivity across international boundaries? When a given country fears diseases they believe or know are across the border, how can we lower the perceived or actual risks of the vision of restoring wildlife migrations through removal of segments of the most environmentally damaging fences? The AHEAD program continues to work on these challenges, with recent progress on sectorally integrative approaches providing reasons for cautious optimism.

One Health impact statement

What was arguably the first applied One Health program, AHEAD (Animal & Human Health for the Environment And Development) was launched in 2003 at the IUCN World Parks Congress in Durban – a year before one of us led the drafting of *The Manhattan Principles on 'One World, One Health'* (Cook *et al*., 2004). As AHEAD has recently marked its 20th anniversary, some introspection certainly seems prudent. Our goal, our *raison d'etre*, has been to serve as 'a convening, facilitative mechanism, working to create enabling environments that allow different and often competing sectors to literally come to the same table and find collaborative ways forward to address challenges at the interface of wildlife health, livestock health, and human health and livelihoods' (available at: http://cornell-ahead.org). We continue on our One Health mission to convene stakeholders, help delineate conceptual frameworks to underpin planning, management and research, and provide technical support and resources for projects stakeholders identify as priorities. AHEAD's One Health framing recognises the need to look at health, disease, and the environment together, while always taking a given region's socio-economic, political, and policy context into account.

Keywords: wildlife, livestock, interface, One Health, connectivity, habitat, migration, transfrontier, conservation, fencing, foot and mouth, disease, veterinary, policy, environment, livelihoods, sustainability

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Introduction

The *SADC Protocol on Wildlife Conservation and Law Enforcement* (SADC, 1999), signed by the heads of 14 member states on 18 August 1999 in Maputo, Mozambique, has as one of its specific objectives "to promote the conservation of shared wildlife resources through the establishment of transfrontier conservation areas." Since the *Protocol*'s adoption, a number of transfrontier conservation areas (TFCAs) have been established in the region, the Kavango Zambezi Transfrontier Conservation Area (KAZA TFCA or simply KAZA) being the largest and encompassing three spectacular World Heritage sites: the Okavango Delta and the Tsodilo Hills in Botswana, and Mosi-oa-Tunya (Victoria Falls) shared between Zambia and Zimbabwe. The Falls are also listed as one of the seven natural wonders of the world (available at: https://www.kavangozambezi.org). KAZA is actually the world's largest terrestrial conservation landscape, at 520,000 km^2. It represents a bold commitment on the part of five African nations (Angola, Botswana, Namibia, Zambia and Zimbabwe) to conserve biodiversity at scale, in the hopes that nature-based tourism will be an engine for sustainable rural economic development. At the heart of KAZA, also home to the world's largest remaining population of African elephants (~228,000) (Taylor *et al*., 2024), lies the wildlife-rich area of Ngamiland in northern Botswana, an area of AHEAD program focus (Fig. 1).

Since the late 1950s, hundreds of thousands if not millions of the region's wild animals have died along fences that have cut off their ancient migratory routes, needed for seasonal access to, for example, grazing and fresh water. Those fences were put up largely because wild species like the African buffalo (*Syncerus caffer*) carry the foot and mouth disease (FMD) virus, which shuts down a country's beef exports if it gets into cattle. Our policy work has included a focus on the way beef is actually processed in order to keep products virus-free for international sale, aka commodity-based trade or CBT, now endorsed by the Southern African Development Community[1] (SADC, 2012; SADC and AHEAD, 2021) – an approach that does not completely depend on fences, and that is reinforced by good herding practices. Unless these vast fences are addressed, the entire premise of habitat connectivity that underpins the economic and biodiversity conservation promise of this globally important transboundary conservation landscape will remain out of reach.

Wildlife numbers in the region have been declining over at least the last three decades (Grimaud *et al*., 2022). The complexity of achieving and assuring resilience and sustainability of protected areas was captured by Cumming *et al*. (2015b), who described them as socio-ecological systems that are strongly influenced by the needs and perceptions of the affected human population. The TFCA principle of multiple resource uses recognises that assuring a positive attitude towards conservation depends on improving the livelihoods of people living in proximity to wildlife and that not all of them will directly reap the benefits of conservation, like revenues from nature-based tourism. Improving market access for livestock farmers living in areas that are not free of FMD due to the presence of wildlife can contribute significantly to tolerance for wildlife and the sustainability of biodiversity conservation in TFCAs like KAZA (Thomson *et al*., 2013a).

As several of us wrote after more than a decade of AHEAD work (Cumming *et al*., 2015a, p. 243):

> The formerly open rangelands and savannahs of the world are increasingly being enclosed by boundaries that demarcate smaller and smaller parcels of land. The resulting changes in the scales at which these landscapes are managed have impacts on both ecological and social processes, and ultimately on system health and human health and well-being. A One Health approach provides a novel conceptual framework within which to examine the issue of fragmentation in southern African rangelands.

The chapter cited above provides details on the recent fragmentation of formerly vast open landscapes in southern Africa by manmade barriers such as roads, railways, and numerous fences, including veterinary cordon fences. Wire fences have a short history of 150 years in the region, where they were first instituted in South Africa to demarcate farm boundaries. Over the past several decades, southern African countries have been working collaboratively to recreate large, ecologically connected landscapes through the establishment of TFCAs (Osofsky *et al*., 2005; Andersson *et al*., 2013). However, many fences remain, with Botswana's veterinary

Fig. 1. Map showing location of southern Africa's KAZA TFCA (in green) across its five constituent countries.

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fences, erected largely to separate wildlife from livestock in order to enable beef exports from the zones thus demarcated as free from FMD, having had particularly detrimental impacts on the region's formerly abundant and unique wildlife populations (Cumming *et al*., 2015a, p. 246):

> Botswana [the British Protectorate of Bechuanaland until independence in 1966], a semi-arid country of some 600,372 km^2, was mostly an open system almost devoid of fences, but since the building of the first veterinary cordon fences in 1954 and 1955, and the 300 km Kuke fence in 1958, the management of FMD in the country has been dominated by fences. The fences serve to control animal movements and so create and maintain FMD-free areas to meet the requirements of a subsidized beef export industry (Osofsky *et al*., 2008; Gadd, 2012). Whilst successfully meeting the requirements of the beef industry, the fences contributed to the collapse of populations of wild ungulates by interfering with their seasonal movements and blocking access to water in dry years (Osofsky *et al*., 2008; Gadd, 2012). For example, between 1978 and 2003, formerly abundant mobile populations of wildebeest and red hartebeest in the Kalahari system in western Botswana declined by an order of magnitude (Perkins, 2010). Wildebeest declined from 315,000 to 16,000 and hartebeest from 293,000 to 45,000 as a result of fragmentation of their range by game fences. Similar impacts occurred in the Makgadikgadi system as a result of cordon fencing (Perkins, 2010). Fencing around the western, southern and south-eastern edges of the Okavango Delta presently constrains seasonal dispersal of wild ungulates from the delta at the onset of the rainy season. The result is increased pressure on habitats within the delta that may be contributing to the decline of several antelope species (e.g. Mbaiwa and Mbaiwa, 2006; Hamandawana, 2012).

This intersectoral conundrum has compromised diversification of land uses that involve wildlife and nature-based tourism, and as a result system health, resilience and human well-being (Cumming *et al*., 2015a).

The main economic activities in KAZA are nature-based tourism and agriculture. In Botswana and Namibia, with semi-arid to arid climates, livestock production is by far the most important agricultural activity (Mendelsohn, 2006; Atkinson *et al*., 2019). Before the COVID-19 pandemic severely albeit temporarily constrained travel and tourism, income from nature-based tourism in Botswana far exceeded that from agriculture, but the latter remains the backbone of the rural economy and provides household income and livelihoods for a much larger number of people (Atkinson *et al*., 2019), as relatively little direct income from tourism reaches local communities (Mbaiwa, 2017). However, for those living in proximity to wildlife usually viewed as the source of transboundary diseases (especially FMD), the economic potential of their livestock has for decades been severely limited by international regulations restricting trade in livestock commodities from countries or zones not free from diseases like FMD (Perry *et al*., 2005; Thomson *et al*., 2013a, b). Botswana and Namibia are the major beef exporters in southern Africa, but exports from both countries have been declining (Thomson *et al*., 2013a). Furthermore, as most of the cattle in southern as well as East Africa are produced in areas that are not free of FMD, the amount of beef available for export is limited, and the regions are consequently not competitive (Thomson *et al*., 2013a).

There are other problems for farmers living in close proximity to wildlife, such as crop destruction and livestock predation (Atkinson *et al*., 2019; Meyer and Börner, 2022), and other manifestations of human-wildlife conflict that result from competition for resources like grazing, water and land overall. Human-wildlife conflict is, of course, a complex problem that is not likely to be fully resolved, but it needs to be mitigated to the greatest extent possible to permit integrated land use that includes both agricultural production and wildlife conservation (du Toit *et al*., 2017). Multiple stakeholders are involved in various efforts to improve both wildlife conservation and human livelihoods in KAZA through integrated land-use options like community conservancies to ensure greater income benefits from wildlife-based activities (Meyer and Börner, 2022). This approach is comprehensively described in a collection of chapters edited by Grimaud *et al*. (2022), but although low prices for livestock products and lack of marketing opportunities are identified as challenges, the issue of limitations on opportunities caused by transboundary animal diseases and associated restrictive disease control measures is not discussed. This is likely because the focal countries of that study, Zambia and Zimbabwe, although subject to these constraints, do not have FMD-free zones. The need for countries that do have such zones to protect them to maintain beef exports to the EU and other higher-end markets exacerbates the inequality between cattle farmers in these priority zones and those in contiguous FMD-infected (or "red") zones that have historically been excluded from accessing higher-value markets.

More details on the regional history of FMD and related issues are provided in Supplementary Material 1.

Engagement via a One Health approach

The World Organisation for Animal Health (formerly OIE, now called WOAH) provides standards under World Trade Organization auspices for its 183 member countries related to international trade in commodities (including beef) that are a potential source of animal disease agents. In 2015, based on more than a decade of science-based advocacy work by AHEAD and regional partners (e.g. Osofsky *et al*., 2005; Beauty and the Beef (https://www.youtube.com/watch?v=lLZ-uhy_JeQ); SADC, 2012; SADC and AHEAD, 2012), WOAH updated its Terrestrial Animal Health Code and made it possible for African countries with wild species like buffalo that naturally harbour FMD viruses to be able to trade beef *without necessarily requiring the physical separation of wildlife and livestock through the extensive veterinary cordon fencing* that has characterised animal disease management in southern Africa since the colonial era. While there is still much to be done to make new value chain approaches to safe beef production a routine option, as per our *Guidelines* that have now been released as an official SADC document (SADC and AHEAD, 2021), this policy change facilitated the unprecedented possibility of access to new beef markets for southern African farmers and pastoralists as well as unlocked the potential for restoring migratory movements of wildlife, thus enhancing prospects for long-term wildlife population viability within individual countries and in transboundary landscapes like KAZA. This new flexibility represents a true 'win-win' for sustainable and diversified land use and livelihoods, especially given the likelihood of ongoing worsening of droughts as per regional climate change models (Steinberg, 2023).

To be clear, this work is not about "removing all fences," but this new, more flexible policy paradigm represents a vitally important opportunity for the wildlife and livestock sectors to work together on collaborative land-use planning, knowing that removing specific fences or fence sections impacting important wildlife habitat corridors is now an option – since beef export market access can be attained utilising new meat-processing value chain-based approaches, regardless of whether buffalo or other wildlife live in or near a particular locality or not. There is now, for the first time in several generations and based on our One Health approach (Cook *et al*., 2004), an opportunity to find ways to optimise land-use choices in the interest of system resilience and diversified livelihood opportunities. Neither the livestock nor wildlife sectors should seek to dominate the other. Instead, it is time to make land-use decisions that will be socially, ecologically and economically sustainable for generations to come (Osofsky, 2019).

Based on the expectation that CBT implementation will continue to progress, the Government of Botswana reconvened its high-level (Director- and Deputy Director-level) interagency fencing committee in 2018 (aka, the National Committee on Cordon Fences). This platform is meant to coordinate developments with regard to the evaluation, construction, maintenance, realignment, as well as

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removal or decommissioning of fences in the country. Importantly, it enables constructive engagement between historically competing sectors (such as wildlife and livestock), and more informed decision making on fences which have had long-standing environmental and socioeconomic impacts. AHEAD provides administrative and technical support to and has a seat on this committee.

AHEAD and regional partners have been reviewing the original intent of key veterinary cordon fences, many of which were constructed decades ago in response to disease threats that may or may not still be relevant. In collaboration with key veterinary and wildlife officials from Botswana and Namibia, AHEAD and regional partners have also collated historical and recent veterinary disease prevalence and outbreak data from areas where there are major fences. This consortium, working under the auspices of the official KAZA Animal Health Sub Working Group, has just finalised a qualitative livestock disease risk assessment exploring a range of veterinary cordon fence scenarios (Rosen *et al*., 2024), including comparing the status quo with removal of specific fence sections previously identified as most damaging to key wildlife movements (Atkinson *et al*., 2022), with a focus on FMD and CBPP (contagious bovine pleuropneumonia). Peste des petits ruminants (PPR), a viral disease of small livestock, was also considered. This new analysis delineates in detail how *the risk of important livestock diseases might change, or not, if these specific fence sections were removed to promote habitat connectivity across the greater KAZA landscape* (Rosen *et al*., 2024). Our critical next step is to focus on supporting more widespread adoption of managed livestock herding as a key disease risk mitigation approach (as per the *Herding for Health* model, e.g. https://www.clawsbotswana.org/what-we-do/, accessed 12 July 2024), along with community consultations with respect to specific fence sections that Botswana and Namibia government stakeholders have acknowledged could be removed (Fig. 2) if, for example, improved community livestock herding can be demonstrated, based on the fencing scenarios disease risk assessment work just completed (Rosen *et al*., 2024). Anticipated positive outcomes would include improved national and regional economic development as underpinned by sustainable, sectorally integrated (i.e., taking advantage of livestock and wildlife) land uses.

At this point in time, with AHEAD having been launched in 2003, it seems prudent to ask ourselves how we and our many critical partners across the SADC region and around the world are doing in terms of addressing this quintessential One Health challenge. One pivotal milestone, as described above, has been WOAH's acceptance of CBT of beef as a new way for even the poorest of farmers living closest to wildlife to be able to access new markets and better prices for their beef without a geographic (fence-based) approach to FMD risk mitigation. With less dependence on fences to mitigate risks of FMD (because CBT focuses on how beef can be safely produced along value chains rather than worrying about whether any buffalo are in the neighbourhood), communities in places like northern Botswana or Namibia's Zambezi Region are simultaneously on the verge of having new opportunities to expand their participation in wildlife economies. Specifically, if CBT has indeed created an enabling environment to revisit veterinary fencing policy, as we believe it has, then ecologically meaningful transfrontier conservation in a landscape like the five-nation KAZA

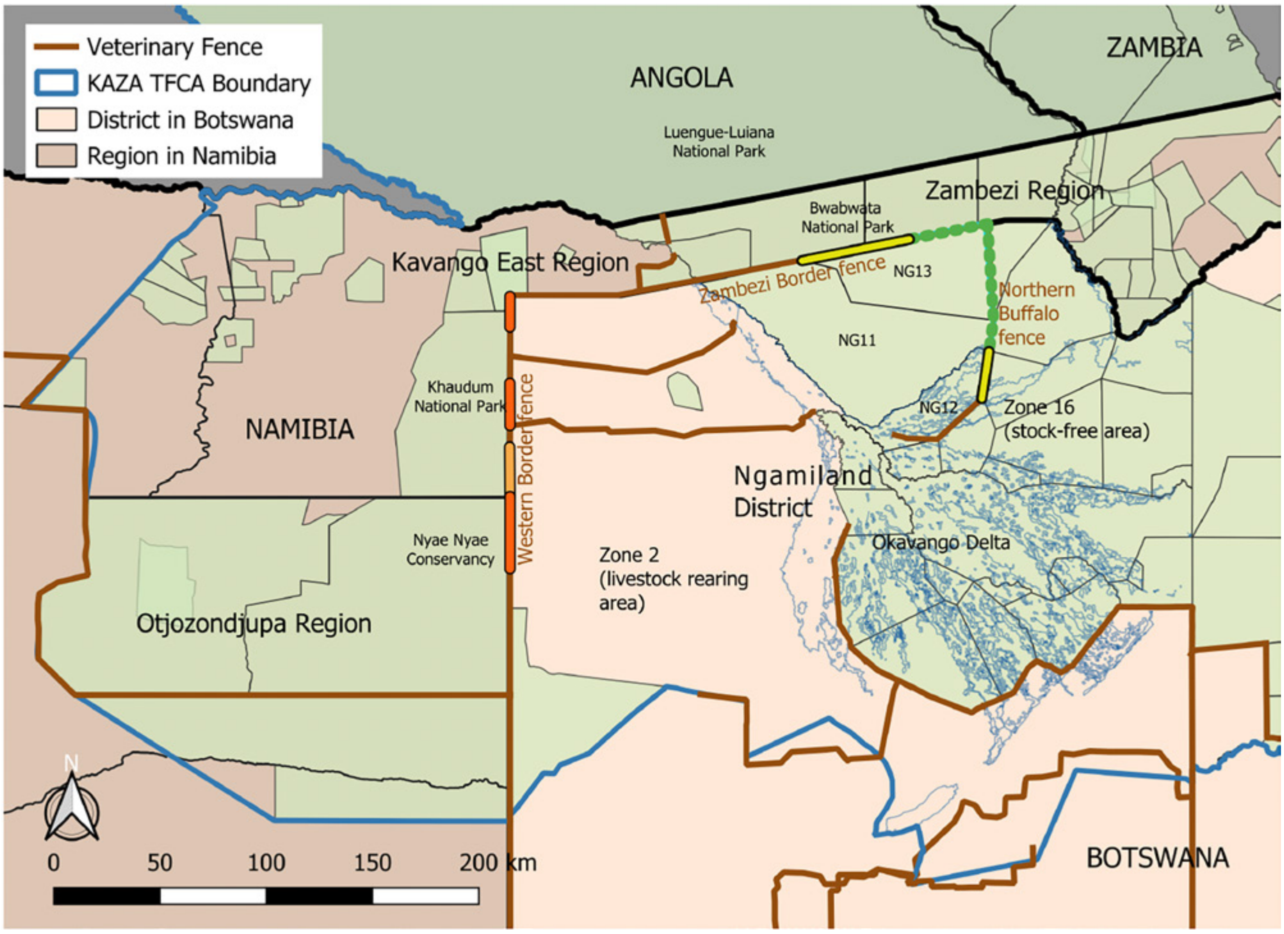

Fig. 2. Fence sections recently recommended for northern Botswana community consultations on potential removal (green) with risk mitigation, or re-evaluation in future (yellow) based on bilateral (Botswana and Namibia) consideration. Sections of the Western Border fence (dark and light orange) were not recommended for removal at this time, though one 23-km section (light orange) was highlighted as being a potential candidate in the future pending further CBPP-related information (courtesy of Rosen *et al*., 2024).

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TFCA can finally become a reality. In short, with the advent of CBT and now with a detailed analysis that shows that several key fences are no longer mitigating disease risks as originally envisioned (Rosen *et al*., 2024), the veterinary officials of key, contiguous KAZA partner states have agreed, based on sound epidemiological principles, that there is an opportunity to reopen wildlife corridors to allow for migrations that had been the norm for millennia, long before veterinary fencing began blocking them starting in the 1950s. We believe such restoration would reinforce system resilience.

But what are the ongoing obstacles to a more sectorally integrated approach to land-use planning? Perhaps the most significant one is the basic fact that, across any given TFCA, different member states may each experience, perceive and manage animal disease risks somewhat differently compared to their neighbours. Of course, a TFCA needs to be recognised and managed as one epidemiological unit, meaning that decision makers have to recognise that successful management of an animal disease problem of concern to any one country is likely going to require the active collaboration of all other countries comprising that TFCA.

The good news is that the leaders of departments of veterinary services across a TFCA like KAZA all now recognise and acknowledge this, as does the KAZA Treaty itself (KAZA TFCA Treaty, 2011), which has as one of its objectives 'to promote and facilitate the harmonisation of relevant legislation, policies and approaches in the area of transboundary animal disease prevention, surveillance and control within the KAZA TFCA,' along with the SADC Livestock Technical Committee. Transboundary animal disease management requires transboundary coordination and ideally harmonisation in terms of surveillance, data-sharing, animal movement requirements, vaccination programs, and emergency response. Again, all of our colleagues leading departments of veterinary services in KAZA know all of this – the KAZA Animal Health Sub Working Group, which AHEAD helps to steward in support of the KAZA Secretariat, has been a valuable platform for KAZA's five partner countries to utilise to consider and co-plan on these critical issues.

One of the most basic remaining challenges to harmonising disease risk mitigation across a TFCA like KAZA is a pervasive lack of resources (human and financial) combined with a lack of applied cost-benefit analysis, a problem certainly not unique to southern Africa (Bucher *et al*., 2023). For any given KAZA partner country, adequate funding for robust surveillance, data management, vaccination programs, and emergency response is often elusive. Scale those needs across the five KAZA countries, and the challenges, including those related to inadequate staffing, become even more clear. Yet, if we fail to help all countries within a given TFCA actually co-manage the disease threats to the livestock sector that all value highly – culturally, economically, and politically – then how can we expect significant progress in terms of fostering wildlife habitat connectivity across international boundaries? How can we lower the actual (or perceived) livestock health risks of the vision of restoring wildlife migrations by removing sections of the most environmentally damaging fences when a given country fears diseases they know (or believe) are across the border? Even for diseases like CBPP, in which wildlife plays no role, fences are seen as a vital way to separate "my cattle" from "your cattle." What to do?

After two decades of applied science policy work, we urge the conservation community (particularly the largest donors based in Europe) to finally recognise that the challenge of successful transboundary animal disease management often lies at the heart of whether specific TFCAs will ever reach their aspirations to become the ecologically resilient land-use entities required for long-term delivery of sustainable poverty alleviation and biodiversity conservation benefits. Tens of millions of dollars to address conservation as well as climate change are currently flowing into KAZA, but virtually none are available for helping the five countries collaboratively control key animal diseases, which can actually only be done successfully if the five countries are all able to work together in a coordinated manner, and which requires considerable resources. As KAZA's remaining key wildlife corridors, needed for wildlife populations to survive and thrive for generations to come, continue to be degraded and blocked, the urgency of donors recognising that they must help improve regional animal disease control cannot be overstated. This is especially true for those European donors to TFCAs whose nations set up some of the veterinary cordon fencing-based disease management systems in the first place, starting in the 1950s when today's KAZA partner countries were colonies or protectorates. Relatedly, if today's European consumers were aware that some of the imported beef they buy was produced at huge environmental cost to southern Africa's wildlife, they would demand nothing less than a righting of what is arguably an historical wrong with roots in the colonial era but with impacts on KAZA's wildlife that have persisted on up to the present – and that threaten the future.

Rethinking the cost/benefit of fences

The need to reassess the costs and benefits of fences across both the wildlife and livestock sectors is being increasingly recognised (Osofsky *et al*., 2005; Woodroffe *et al*., 2014; Osofsky, 2019; Naidoo *et al*., 2022). In simple terms, the costs of adequate fence maintenance are now largely beyond the means of governments due to the high level of fence damage caused by elephants, vandalism and flooding, and a marked increase in FMD outbreaks over the last two decades suggests little benefit of the fences in terms of disease control (Vosloo and Thomson, 2017; Babayani and Thololwane, 2022). Changing patterns of FMD from a sporadic disease of cattle attributable largely to wildlife contact to a disease that circulates independently in cattle point to a situation that can no longer be managed by cordon fencing. More important preventive tools will consist of better husbandry (especially herding) combined with strategic vaccination of cattle, with fencing being used where it really is needed to mitigate transboundary animal disease or human-wildlife conflict. Protection of livestock from predation and theft is best achieved by professional herding and well-designed mobile enclosures (i.e. kraaling at night) that can enhance grazing and rangeland management. A cost-benefit analysis should also take into account that both nature-based tourism and premium-yielding wildlife-friendly beef production can result in increased income that can likely cover the costs of improved livestock management. With less reliance on fencing, savings resulting from markedly reduced fence maintenance costs could also contribute to improving livelihoods in areas that are not free of FMD. Managed herding itself (as underpinned by planned grazing) is already starting to demonstrate the potential for an extraordinary number of co-benefits in the region, including but not limited to healthier livestock in better condition, an on-ramp to successful CBT of wildlife-friendly beef, preferential beef pricing from local tourism operators, improved vaccination coverage, improved animal identification and thus traceability, decreased losses from predators (with less retaliatory killing of carnivores), avoidance of buffalo and other wildlife by herders, less cattle theft, improved rangeland condition/restoration (good for livestock and wildlife), and enhanced soil carbon sequestration (Heermans *et al*., 2021).

Integrative approaches by definition should ensure that conservation and tourism activities provide income for populations living with wildlife through the establishment of community-based conservancies (Lindsey *et al*., 2009; Weaver *et al*., 2013; du Toit *et al*., 2017; Osofsky, 2019). In the face of climate change, it is particularly important in areas that are already arid or semi-arid to manage rangelands in the best possible way and to allow wild herbivores to range over a wide enough area to sustainably access necessary grazing (Naidoo *et al*., 2014; Hering *et al*., 2022). Strategic management of livestock is crucial to ensuring a synergistic rather than a competitive relationship with wildlife in shared rangelands (Fynn *et al*., 2016; Pozo *et al*., 2021).

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To reiterate, the trajectory of holistic progress envisioned is not about "removing all fences." But we are at the point of an exciting new enabling environment based upon two key facts: (1) expanded beef market access can be attained in unfenced areas utilising meat-processing value chain-based approaches, regardless of whether buffalo or other wildlife live in or near a particular locality or not, and (2) fencing can no longer be assumed to be an effective livestock disease risk mitigation option, especially given the multiple benefits of a return to a culture of managed herding.

Conclusion

Of course, with great opportunity comes great responsibility. A collective investment in earnest stewardship of natural resources must be made by all sectoral stakeholders dependent on southern Africa's precious land-base. There is now, for the first time in several generations, an opportunity to find ways to optimise land-use choices in the interest of system resilience and diversified livelihood opportunities. Neither the livestock nor wildlife sectors should seek to dominate the other. Both are critically important to and valued by local communities. Instead, it is time to make land-use decisions that will be socially, ecologically and economically sustainable for generations to come (Osofsky, 2019).

There is, of course, still much to do, including proactively developing specific criteria that better define "wildlife-friendly beef" for the marketplace, in partnership with the full range of stakeholders. Ongoing work with southern African partners needs to include further sensitisation of key local, national and regional entities (in both the livestock and wildlife sectors, *et al*.) as to the significance of CBT as a landmark change in international beef trade standards. Communities living in FMD-endemic zones such as northern Botswana must be consulted on their perceptions of fences (past, present and looking to future scenarios) so that their knowledge and concerns can help inform any deliberations regarding specific fence sections that might be able to be removed.

Science-based risk assessments have started to demonstrate that some fences or sections of fences are, today, doing more economic, ecological and/or social harm than good. *We owe it to future generations to take such findings seriously*, before it is too late for KAZA to truly become the resilient source of poverty alleviation and biodiversity conservation it was originally meant to be when the KAZA Treaty was signed by five heads of state more than ten years ago. We are closer to reconciling animal disease-related conflict at the livestock-wildlife interface than we have ever been before, as we continue a One Health journey without parallel in the region.

CONFLICT OF INTEREST

The authors have no conflict of interest.

ETHICS STATEMENT

All ethical issues related to the preparation of this manuscript have been fulfilled.

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AUTHOR CONTRIBUTIONS

All authors contributed to the development of this manuscript.

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DATA AVAILABILITY

Not applicable.

SUPPLEMENTARY MATERIAL

The supplementary material is available in the online version of this article.

Note

[1] The SADC Regional Economic Community is comprised of 16 member states: Angola, Botswana, Comoros, Democratic Republic of Congo, Eswatini, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, United Republic of Tanzania, Zambia and Zimbabwe.

References

Andersson, J.A., de Garine-Wichatitsky, M., Cumming, D.H.M., Dzingirai, V. and Giller, K.E. (2013) *Transfrontier Conservation Areas: People Living on the Edge*. Earthscan Publishers, London.

Atkinson, S.J., Bing, M., McNutt, J.W., Marshall, C., Masedi, M., Osofsky, S.A. *et al.* (2019) Gap Analysis on the Implementation of Commodity-Based Trade of Beef in Ngamiland, Botswana. Report prepared in consultation with the Government of Botswana's Department of Veterinary Services. AHEAD Programme, Cornell University. Available at: http://wcs-ahead.org/kaza/rpt-cbt-gapanalysis-ngamiland-final-190912.pdf.

Atkinson, S.J., Albertson, A., Naidoo, R., Ramsden, N., Songhurst, A. and Osofsky, S.A. (2022) *Veterinary Fences in Botswana's Portion of the KAZA TFCA: Assessment of Status and Impacts on Wildlife. Unpublished Report Prepared for the KAZA TFCA Secretariat*. AHEAD Programme, Cornell University.

Babayani, N.D. and Thololwane, O.I. (2022) A qualitative risk assessment indicates moderate risk of foot-and-mouth disease outbreak in the Lower Okavango Delta because of interaction with buffaloes. *Transboundary and Emerging Diseases* 69, 2840–2855. DOI: 10.1111/tbed.14436.

Bucher, A., Dimov, A., Fink, G., Chitnis, N., Bonfoh, B. and Zinsstag, J. (2023) Benefit-cost analysis of coordinated strategies for control of rabies in Africa. *Nature Communications* 14, 5370. DOI: 10.1038/s41467-023-41110-2.

Cook, R.A., Karesh, W.B. and Osofsky, S.A. (2004) The Manhattan Principles on 'One World One Health.' Available at: http://www.oneworldonehealth.org/sept2004/owoh_sept04.html (accessed 12 July 2024).

Cumming, D.H.M., Osofsky, S.A., Atkinson, S.J. and Atkinson, M.W. (2015a) Beyond fences: Wildlife, livestock and land use in southern Africa. In: Zinsstag, J., Schelling, E., Waltner-Toews, D., Whittaker, M., Tanner, M. (eds) *One Health: The Theory and Practice of Integrated Health roaches*. CABI International, Wallingford, UK, pp. 345–357.

Cumming, G.S., Allen, C.R., Ban, N.C., Biggs, D., Biggs, H.C. *et al.* (2015b) Understanding protected area resilience: A multi-scale, socio-ecological approach. *Ecological Applications* 25(2), 299–319.

du Toit, J.T., Cross, P.C. and Valeix, V. (2017) Managing the livestock-wildlife interface on rangelands. In: Briske, D.D. (ed) *Rangeland Systems: Processes, Management and Challenges*. Springer Nature, Berlin, pp. 395–425. DOI: 10.1007/978-3-319-46709-2_12.

Fynn, R.W.S., Augustine, D.J., Peel, M.J.S. and de Garine-Wichatitsky, M. (2016) Strategic management of livestock to improve biodiversity conservation in African savannahs: A conceptual basis for wildlife-livestock co-existence. *Journal of Applied Ecology* 53, 388–397. DOI: 10.1111/1365-2664.12591.

Gadd, M.E. (2012) Barriers, the beef industry and unnatural selection: A review of the impact of veterinary fencing on mammals in southern Africa. In: Somers, M.J. and Hayward, M.W. (eds) *Fencing for Conservation: Restriction of Evolutionary Potential or a Riposte to Threatening Processes?* Springer Science; Business Media, Berlin, pp. 153–186. DOI: 10.1007/978-1-4614-0902-1_9.

Grimaud, P., Gumbo, D. and Le Bel, S. (eds) (2022) *Towards Sustainable Wildlife Management – An In-Depth Study for the Promotion of Community Conservancies in Zambia and Zimbabwe*. FAO; CIRAD; CIFOR; WCS. DOI: 10.4060/cb9082en.

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Subject to the CABI Digital Library Terms & Conditions, available at https://cabidigitallibrary.org/terms-and-conditions

Hamandawana, H. (2012) The impacts of herbivory on vegetation in Moremi Game Reserve, Botswana: 1967–2001. *Regional Environmental Change* 12, 1–15.

Heermans, B., van Rooyen, J., Fynn, R., Biggs, D., Lewis, M. and McNutt, J. (2021) Husbandry and herding: A community-based approach to addressing illegal wildlife trade in northern Botswana. *Frontiers in Conservation Science* 2, 675493. DOI: 10.3389/fcosc.2021.675493.

Hering, R., Hauptfleisch, M., Jago, M., Smith, T., Kramer-Schadt, S., Stiegler, J. and Blaum, N. (2022) Don't stop me now: Managed fence gaps could allow migratory ungulates to track dynamic resources and reduce fence-related energy loss. *Frontiers in Ecology and Evolution* 10, 907079. DOI: 10.3389/fevo.2022.907079.

KAZA TFCA Treaty (2011) Treaty between the Government of the Republic of Angola, the Government of the Republic Botswana, the Government of the Republic of Namibia, the Government of the Republic of Zambia and the Government of the Republic of Zimbabwe on the establishment of the Kavango Zambezi Transfrontier Conservation Area. https://tfcaportal.org/system/files/resources/KAZA%20TFCA%20Treaty_SIGNED.pdf.

Lindsey, P.A., Romañach, S.S. and Davies-Mostert, H.T. (2009) The importance of conservancies for enhancing the value of game ranch land for large mammal conservation in southern Africa. *Journal of Zoology* 277, 99–105. DOI: 10.1111/j.1469-7998.2008.00529.x.

Mbaiwa, J.E. (2017) Poverty or riches: Who benefits from the booming tourist industry in Botswana? *Journal of Contemporary African Studies* 35, 93–115. DOI: 10.1080/02589001.2016.1270424.

Mbaiwa, J.E. and Mbaiwa, O.I. (2006) The effects of veterinary fences on wildlife populations in the Okavango Delta, Botswana. *International Journal of Wilderness* 12, 17–24.

Mendelsohn, J. (2006) *Farming Systems in Namibia*. Research & Innovation Services of Namibia, Windhoek, Commissioned by the Namibia National Farmers Union.

Meyer, M. and Börner, J. (2022) Rural livelihoods, community-based conservation, and human-wildlife conflict: Scope for synergies. *Biological Conservation* 272, 109666. DOI: 10.1016/j.biocon.2022.109666.

Naidoo, R., Du Preez, P., Stuart-Hill, G., Beytell, P. and Taylor, R. (2014) Long-range migrations and dispersals of African buffalo (*Syncerus caffer*) in the Kavango-Zambezi Transfrontier Conservation Area. *African Journal of Ecology* 52(4), 581–584. DOI: 10.1111/aje.12163.

Naidoo, R., Beytell, P., Brennan, A., Kilian, W., McCulloch, G. *et al.* (2022) Challenges to elephant connectivity from border fences in the world's largest transfrontier conservation area. *Frontiers in Conservation Science* 3, 788133. DOI: 10.3389/fcosc.2022.788133.

Osofsky, S.A. (2019) The global burden of (how we manage) animal disease: Learning lessons from southern Africa. *Journal of Wildlife Diseases* 55(4), 755–757. DOI: 10.7589/2019-01-024.

Osofsky, S.A., Cleaveland, S., Karesh, W.B., Kock, M.D., Nyhus, P.J., Starr, L. and Yang, A. (2005) *Conservation and Development Interventions at the Wildlife/Livestock Interface: Implications for Wildlife, Livestock and Human Health*. International Union for Conservation of Nature (IUCN). Available at: https://wcs-ahead.org/wpc_launch.html.

Osofsky, S.A., Cumming, D.H.M. and Kock, M.D. (2008) Transboundary management of natural resources and the importance of a 'One Health' approach: Perspectives on southern Africa. In: Fearn, E. and Redford, K.H. (eds) *State of the Wild 2008-2009: A Global Portrait of Wildlife, Wildlands, and Oceans*. Island Press, Washington, DC, pp. 89–98.

Perkins, J. (2010) Fences and landscape scale degradation. In: Ferguson, K. and Hanks, J. (eds) *Fencing Impacts: A Review of the Social, Economic and Environmental Impacts of Game and Veterinary Fencing in Africa with Particular Reference to the Great Limpopo and Kavango-Zambezi Transfrontier Conservation Areas*. Mammal Research Institute; University of Pretoria, Pretoria, pp. 83–95.

Perry, B., Nin Pratt, A., Sones, K. and Stevens, C. (2005) An Appropriate Level of Risk: Balancing the Need for Safe Livestock Products with Fair Market Access for the Poor (PPLPI Working Paper No. 23). International Livestock Research Institute, Nairobi, Kenya. Available at: https://ideas.repec.org/p/ags/faopwp/23773.html.

Pozo, R.A., Cusack, J.J., Acebes, P., Malo, J.E., Traba, J. *et al.* (2021) Reconciling livestock production and wild herbivore conservation: Challenges and opportunities. *Trends in Ecology and Evolution* 36(8), 750–761. DOI: 10.1016/j.tree.2021.05.0002.

Rosen, L.E., Amuthenu, N.S., Atkinson, S.J., Babayani, N.D., Elago, S.A.T. *et al.* (2024) *Veterinary fences in the KAZA TFCA: Assessment of livestock disease risks of potential removal of specific fence sections, with an emphasis on the Botswana-Namibia border*. AHEAD Programme, Cornell University on behalf of the KAZA Animal Health Sub Working Group, 300 pp. Available at: https://www.wcs-ahead.org/documents/livestock-dz-risk-assess_lo_res_final_20240917.pdf.

SADC (1999) Protocol on wildlife conservation and law enforcement. *Southern African Development Community*. https://www.sadc.int/document/protocol-wildlife-conservation-and-law-enforcement-1999.

SADC (2012) *The Phakalane Declaration on Adoption of Non-Geographic Approaches for Management of Foot and Mouth Disease*. Southern African Development Community. Available at: https://www.wcs-ahead.org/phakalane_declaration.html.

SADC and AHEAD (2012) *Proceedings of SADC TADS Project Scientific Symposium on "Foot and Mouth Disease in SADC" and Joint SADC-AHEAD Workshop on "Reconciling Livestock Health and Wildlife Conservation Goals in Southern Africa: Strategies for Sustainable Economic Development"*. Gaborone, Botswana. Available at: http://www.wcs-ahead.org/phakalane_workshop_2012/sadc_ahead_workshop_proceedings.pdf.

SADC and AHEAD (2021) Guidelines on commodity-based trade approaches for managing foot and mouth disease risk in beef in the SADC Region, 4th edn. *Southern African Development Community & Animal & Human Health for the Environment And Development*. Available at: https://www.sadc.int/sites/default/files/2022-07/Guidelines_for_implementing_CBT_2022_SADC_ENG_final_0.pdf.

Steinberg, N. (2023) Livelihood-focused climate risk assessment: Stress testing livelihood options in the world's largest terrestrial transboundary conservation area. Report to USAID from Chemonics International, Contract no. 720-674-18-C-00007. Available at: https://www.climatelinks.org/sites/default/files/asset/document/2024-11/Livelihood-focused%20Climate%20Risk%20Assessment.pdf (accessed 12 July 2024).

Taylor, R., Naidoo, R., Steel, L., Knight, M. and Osofsky, S.A. (2024) Count, connect, conserve: Southern Africa elephant survey points the way. *Mongabay*. Available at https://news.mongabay.com/2024/01/count-connect-conserve-southern-africa-elephant-survey-points-the-way-commentary/.

Thomson, G.R., Penrith, M.-L., Atkinson, M.W., Atkinson, S.J., Cassidy, D. and Osofsky, S.A. (2013a) Balancing livestock production and wildlife conservation in and around southern Africa's transfrontier conservation areas. *Transboundary and Emerging Diseases* 60, 492–506. DOI: 10.1111/tbed.12175.

Thomson, G.R., Penrith, M.-L., Atkinson, M.W., Thalwitzer, S., Mancuso, A., Atkinson, S.J. and Osofsky, S.A. (2013b) International standards for commodities and products derived from animals: The need for a system that integrates food safety and animal disease risk management. *Transboundary and Emerging Diseases* 60, 507–515. DOI: 10.1111/tbed.12164.

Vosloo, W. and Thomson, G.R. (2017) Natural habitats in which foot-and-mouth viruses are maintained. In: Sobrino, F. and Domingo, E. (eds) *Foot-and-Mouth Disease Virus – Current Research and Emerging Trends*. Caister Academic Press, Poole, UK, pp. 179–210.

Weaver, G.V., Domenech, J., Thiermann, A.R. and Karesh, W.B. (2013) Foot and mouth disease: A look from the wild side. *Journal of Wildlife Diseases* 49(4), 769–785. DOI: 10.7589/2012-11-276.

Woodroffe, R., Hedges, S. and Durant, S.M. (2014) To fence or not to fence. *Science* 344(6179), 46–48. DOI: 10.1126/science.1246251.

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Two Decades of One Health in Action: Enabling Sustainable Wildlife Conservation and Livestock Production in Southern Africa

Supplementary Material 1

Supplementary Material 1 examines the relative importance of African buffalo (*Syncerus caffer*) and cattle in the maintenance and transmission of FMD virus in KAZA and SADC more broadly, with a focus on the countries with current or historic beef exports. In order to place the evolving FMD situation in KAZA's member countries in the context of the region, relevant examples are also drawn from other countries in East and southern Africa with an FMD reservoir in buffalo. Considering the growing importance of endemic circulation of FMD virus in cattle populations, we revisit the relevance of veterinary cordon fences as a preferred tool to prevent outbreaks of FMD (CBPP having been discussed, to a lesser extent, in the main narrative), and propose a more holistic approach to balancing livestock production and biodiversity conservation.

Foot and mouth disease in the SADC context

While several transboundary animal diseases are present in the SADC region, South African Territories (SAT) serotypes of FMD virus, although arguably the mildest in terms of their effects on susceptible animals, have been the most important due to impacts on trade (Thomson et al., 2013a). International FMD perceptions and policies are based on the disease caused by the Eurasian serotypes, which spread fast and cause relatively high morbidity in outbreaks (Thomson and Penrith, 2017; Vosloo and Thomson, 2017). In contrast, the SAT viruses spread more slowly, are confined to the African continent and the Middle East, and apparent morbidity measured by animals showing clinical signs is low (Atkinson et al., 2019; Vosloo and Thomson, 2017).

The SAT viruses predominate in most of the SADC region (Maree et al., 2014). These viruses are considered to be the most ancient FMD viruses, and they evolved in African buffalo, which remain a reservoir host of the virus (Vosloo and Thomson, 2017). The Eurasian lineages diverged from them and evolved further in domestic livestock, with no wild reservoirs identified, although spill-over to wildlife has frequently been recorded (Alexandrov et al., 2013; Dhollander et al., 2016; Elnekave et al., 2016; Lignereux et al., 2020). In addition to the SAT viruses, two Eurasian FMD serotypes have a long history of circulation in East Africa, namely O and A (Dhikusooka et al., 2016; Kasanga et al., 2015; Omondi et al., 2020; Picado et al., 2011; Roeder et al., 1994; Wekesa et al., 2015; Woldemariyam et al., 2022). Type O, the most widespread of all the FMD viruses, has also established a presence in northern Zambia, where all three SAT viruses as well as type A have also caused outbreaks (Banda et al., 2021; Chilonda et al., 1999). Since 2018, type O viruses have moved southward in Zambia, and in July 2021 an outbreak of type O FMD was reported for the first time in Namibia, affecting cattle in the Zambezi Region (Banda et al., 2022). It's important to note that there is no evidence of any association of either type O or A with African buffalo in East Africa, despite the lengthy presence there (Casey-Bryars et al., 2018; Omondi et al., 2020; Weaver et al., 2013; Wekesa et al., 2015), or in southern Africa. One serological study of wildlife in Central Africa did find relatively high levels of antibodies to serotype O non-structural proteins in buffalo (Di Nardo et al., 2015).
Apart from African buffalo, no wildlife reservoirs for the SAT viruses have been identified, and to date frequent infection with possible spill-over to domestic ungulates has only been recorded for impalas (*Aepyceros melampus*), in which outbreaks have been reported to occur regularly in Kruger National Park (KNP), but there is no evidence of persistent infection (Bastos et al., 2000; Hargreaves et al., 2004; Thomson, 1995; Vosloo and Thomson, 2017), although infections that persisted longer have been reported in kudu (*Tragelaphus strepsiceros*), wildebeest (*Connochaetes taurinus*) and sable antelope (*Hippotragus niger*) (Vosloo and Thomson, 2017). Experimental infection of giraffe (*Giraffa camelopardalis*) with SAT-1 and SAT-2 viruses demonstrated that giraffe are susceptible to FMD infection but are unlikely to play an important role in maintenance or spread of the virus (Vosloo et al., 2011). Infection in other wild ungulates in southern Africa has occasionally been reported (Keet et al., 1996; Letshwenyo et al., 2006). In Uganda, a serological survey in a range of wildlife species in four national parks found high seroprevalence of FMD virus antibodies (serotypes O, SAT-1, SAT-2 and SAT-3) in buffalo, but only a single seropositive hartebeest (*Alcelaphus buselaphus*) (Ayebazibwe et al., 2010).

Relative importance of buffalo and cattle in maintaining and transmitting FMD

In East Africa, although high levels of infection with SAT FMD viruses occur in buffalo, there is considerable evidence that not only O and A but also SAT viruses circulate in cattle independently of buffalo. A study undertaken in Kenya in sympatric buffalo and cattle populations showed infection with SAT-1 and SAT-2 viruses in buffalo sampled and types O, A, SAT-1 and SAT-2 in cattle, but the SAT viruses in the cattle were of different lineages from those in the buffalo (Wekesa et al., 2015), suggesting separate evolution of the viruses in the two populations. Similarly, sampling of sympatric cattle and buffalo in an area where a high level of contact is likely yielded only FMD virus serotypes O and A in cattle and serotypes SAT-1 and SAT-2 in buffalo, suggesting that transmission between the species is rare (Omondi et al., 2020). However, examination of FMD virus sequences from a wider area revealed a close relationship between some SAT-1 and SAT-2 outbreak viruses isolated from cattle to buffalo SAT-1 and SAT-2 viruses from another area, suggesting transmission between cattle and buffalo, but the direction of the transmission could not be determined (Omondi et al., 2020). The authors concluded that their phylogenetic study did not provide evidence for separate evolution of SAT viruses in buffalo and cattle. Both above studies agreed, however, that circulation of FMD viruses in the cattle population did occur independently of buffalo, with most cattle outbreaks resulting from cattle movements (Omondi et al., 2020; Wekesa et al., 2015). Analysis of the location and distribution of outbreaks in Tanzania from 2001 to 2006 indicated that most occurred in border areas and were associated with communication networks rather than in areas with wildlife (Allepuz et al., 2015; Picado et al., 2011). Furthermore, although Tanzania has one of the largest buffalo populations in Africa as well as one of the largest cattle populations, kept under conditions that allow contact with buffalo, a study conducted in nine districts between 2011 and 2014 found no correlation between the FMD serotypes involved in endemic waves in cattle and those identified from sympatric buffalo (Casey-Bryars et al., 2018). The authors attributed low seroprevalence of serotypes O and A in buffalo to spill-over from cattle or a cross-reaction of SAT with the O assay that is known to occur (Casey-Bryars et al., 2018). A study by Dhikusooka et al. (2016) in cattle herds around Queen Elizabeth National Park in Uganda failed to provide evidence of transmission between buffalo and cattle, despite a serological survey of 207 buffalo in four national parks in Uganda, including Queen Elizabeth National Park, that found 80-90% of the samples were positive for antibodies to FMD virus non-structural proteins (Ayebazibwe et al., 2010). An analysis of FMD outbreaks in Ethiopia from 2010 to 2019, of which only 12% were serotyped, indicated increased prevalence of SAT-2 in the central parts of the country and a single sample positive for antibodies to SAT-1, with no suggestion of wildlife involvement (Woldemariyam et al., 2022).

The main focus of this review is on southern Africa, which according to the UN definition is comprised of Angola, Botswana, Eswatini, Lesotho, Malawi, Mozambique, Namibia, South Africa, Zambia and Zimbabwe. All of the member countries of the KAZA and Great Limpopo TFCAs are thus part of the southern African region, and they are all also members of SADC. Close links therefore exist among all of the countries, most of which share borders with members of the KAZA or Great Limpopo TFCAs, and therefore the FMD situation in all of them will be considered, with the exception of Eswatini and Lesotho which are officially free of FMD. As in East Africa, FMD outbreaks in Malawi, Mozambique, Zambia and Zimbabwe are more likely to be related to movements of cattle than to contact with African buffalo. There is little information about FMD in Angola; isolates from outbreaks in 1974 and 1975 belonged to serotype A (Sangare et al., 2001). A recent review of FMD outbreaks in Malawi from 1957 to 2019 showed they were mostly caused by SAT viruses, although serotype O and A outbreaks occurred in the north on the border with Tanzania (Chimera et al., 2022). Although in certain instances buffalo were considered a possible source of outbreaks, a risk assessment suggested that proximity to wildlife areas was not a risk factor and that movements of live cattle and circulation within cattle populations were the main source of outbreaks (Chimera et al., 2022). A recent study in Zambia characterising FMD viruses from outbreaks in cattle between 2015 and 2020 indicated that only one of the outbreaks might have been related to buffalo contact, but in that situation movement of cattle from a neighbouring country could not be excluded; the majority of the outbreaks, many caused by serotype O, were attributed to legal and illegal movements of cattle, mainly from an eastern neighbour (Banda et al., 2021). There is little published information about FMD in Mozambique, but while a 2011 outbreak in the Gaza province was caused by a SAT-2 virus with close similarity to a buffalo virus isolated in KNP, South Africa, the infected cattle had been transported by train across the border from Zimbabwe (Jori et al., 2016). At least one previous incursion by the same route caused an FMD outbreak in the Sofala province of Mozambique (MLP, unpublished information).

In contrast to the situations in East Africa and the northern SADC countries, buffalo have been considered to be the major source of outbreaks of FMD in livestock in southern Africa (Thomson et al., 2003; Vosloo et al., 1995; Vosloo, Bastos et al., 2002). Botswana, Namibia, South Africa and Zimbabwe all established zones that were officially free of FMD, and for a long time after their establishment they remained free of FMD outbreaks. This was made possible by cordon fences separating livestock from wildlife areas with buffalo, and vaccination of cattle in areas at high risk (Vosloo, Bastos et al., 2002). An increase in fence height and strength was suggested after it was discovered that an outbreak of FMD in cattle adjacent to a double-fenced conservancy in Zimbabwe was likely to have been caused by contact with infected antelope (kudu or impala), as neither buffalo nor cattle were able to cross the fence (Hargreaves et al., 2004). It was later reported that outbreaks of FMD in impala were frequent in KNP in areas with buffalo herds, and that these antelope were able to jump fences that successfully contained larger animals, with occasional transmission of FMD virus to livestock (Vosloo et al., 2006; Vosloo et al., 2009).

An analysis of seasonal and spatial outbreak patterns in Zimbabwe from 1931 to 2016 appeared to support the contention that proximity to buffalo was a major driver of FMD outbreaks, but recognized that the information available was incomplete in important respects, including molecular genetic studies to establish relationships amongst outbreak viruses (Guerrini et al., 2019). Moreover, an increase in FMD outbreaks was recorded during periods of civil unrest and socio-economic collapse, and although lack of fence maintenance with consequent increased contact between wildlife and cattle occurred during those times (Guerrini et al., 2019), there were undoubtedly other factors such as increased cattle movement and mingling as well as climatic factors such as drought that were apparently not considered. An exponential increase in FMD outbreaks in Zimbabwe from 2000-2001 resulted in the loss of access to high value beef markets in the EU and elsewhere and suspension of the former FMD-free zone (Scoones et al., 2010). It is increasingly evident that silent circulation of FMD viruses in cattle is highly likely to occur in Zimbabwe (Brito et al., 2016; Jori et al., 2016; Miguel et al., 2013), resulting in outbreaks without the need for wildlife involvement.

In Botswana, the areas surrounding the Okavango Delta, namely Ngamiland and Chobe district, are considered not free from FMD, while the rest of the country consists of zones that are officially free of FMD (Derah and Mokopasetso, 2005). The Okavango Delta is home to a large buffalo population, as is the Chobe floodplain, these buffalo being the main reason for the infected status of the two districts, where cattle are vaccinated twice a year except in the areas deemed at highest risk of buffalo contact, where cattle are ideally vaccinated three times a year (Derah and Mokopasetso, 2005). After not experiencing any FMD outbreaks since 1980, an outbreak occurred in 2002 in a free zone that shares a border with Zimbabwe, where outbreaks had been rife in 2001 (Scoones et al., 2010). The virus isolated was closely related to a 2001 Zimbabwe outbreak virus, raising suspicions that cattle movement from Zimbabwe may have been responsible for the introduction of the virus into Botswana (Baipoledi et al., 2004; Mogotsi et al., 2016). Further outbreaks occurred along the eastern border until 2011 (Atkinson et al., 2019) and have continued sporadically up to 2022. During the same period, FMD outbreaks in Ngamiland increased, many of which were not buffalo-associated (Atkinson et al., 2019). A risk assessment for buffalo contact in Ngamiland indicated a moderate risk of buffalo-associated FMD outbreaks in the lower Okavango Delta, the region where cattle and buffalo contact was most likely to occur (Babayani and Thololwane, 2022). While FMD outbreaks in cattle close to the fence were considered likely to have been initiated by buffalo contact, it was also deemed likely that further spread by endemic circulation in cattle was responsible for outbreaks in areas without buffalo presence. The authors suggested that revised approaches to risk management based on improved cattle husbandry were required in view of the impossibility of adequate fence maintenance (Babayani and Thololwane, 2022).
Namibia has maintained its free zone due to a cordon fence that divides the country into a commercial farming area south of the fence and the communal cattle farming areas in the north, where the largest number of cattle and cattle owners live (Scoones et al., 2010). Buffalo are absent from the greater part of the Northern Communal Areas, as suitable habitats are lacking, but the eastern parts, consisting of the Kavango East and Zambezi Regions, are not free from either buffalo or FMD. Transhumance across the northern borders with Angola and Zambia is common (Atkinson et al., 2019; Scoones et al., 2010), and FMD outbreaks have occurred in both Kavango East and Zambezi that were linked to cross-border movement of cattle rather than buffalo contact (Atkinson et al., 2019). Further proof of the role of cattle was provided when the virus isolated from an outbreak in the Zambezi Region in July 2021, as previously mentioned, proved to be a serotype O virus that shared 99.5% identity with type O viruses that had been circulating in Zambian cattle since 2018 (Banda et al., 2022).

FMD in South Africa has almost always been strongly associated with KNP, which has historically been home to the only FMD-infected buffalo population in the country (Thomson, 1995). Most of the outbreaks of FMD in livestock, mainly cattle, have occurred in the area adjacent to KNP that is within the FMD protection zone (Dyason, 2010). However, more extensive outbreaks distant from KNP have three times resulted in the suspension of South Africa's free zone. In September 2000, type O FMD virus was diagnosed for the first time in a piggery in KwaZulu-Natal province after illegal feeding of swill that consisted of galley waste from the international port of Durban (Brückner et al., 2002). In November 2000, SAT-1 FMD virus was detected in cattle presented for slaughter at an abattoir in Eswatini; the cattle were traced to a feedlot in South Africa, where the same virus was isolated from the cattle (Brückner et al., 2002). This outbreak was believed to have originated from cattle illegally brought into the feedlot from the FMD protection area, and the virus shared 100% homology with viruses isolated from buffalo in KNP (Brückner et al., 2002). In 2011, FMD was detected serologically in cattle in northern KwaZulu-Natal, resulting in intensive surveillance in cattle and sampling in Ndumo Game Reserve. A SAT serotype 1 virus was isolated from cattle at one dip tank, whereas the buffalo sampled yielded a serotype 3 virus. Both viruses were reported to be related to previous isolates from buffalo in KNP (Department of Agriculture, Forestry and Fisheries, 2011). The serotype 1 virus was also isolated from cattle in a feedlot in Gauteng Province, and since 2019 South Africa has been battling outbreaks of multiple serotypes of SAT FMD in six provinces. While the first outbreaks occurred in the FMD protection zone, subsequent extensive spread has occurred through cattle movements, including to auction facilities where live cattle are sold, regardless of movement restrictions (https://nahf.co.za/update-report-foot-and-mouth-disease-outbreak-2022-2024/). The course of this epizootic, which has once more cost South Africa its free zone, has underscored the role of human activities in the spread of transboundary animal diseases.

Implications of endemic FMD circulation in cattle populations

Endemic circulation of FMD in cattle populations is a relatively new phenomenon for some southern African countries, including Botswana, Namibia and Zimbabwe. It is facilitated by a high level of direct or indirect contact in a sufficiently large or mobile cattle population that ensures a supply of new animals to infect to maintain virus circulation. Such a population that also acts as a reservoir of the virus is known as a maintenance population (Haydon et al., 2002). Large unvaccinated cattle populations in Africa are considered to be maintenance populations for FMD viruses, and buffalo only become significant when the cattle population has become epidemiologically too small to maintain the infection, for example due to effective vaccination (Haydon et al., 2002). This assessment is based on a 20-year period between 1981 and 2001 after the introduction of vaccines against FMD in southern African countries when very few outbreaks occurred, but since then the situation has deteriorated markedly (Atkinson et al., 2019; Jori et al., 2009; Vosloo and Thomson, 2017). This indicates that vaccination programs are no longer sufficiently protective, and an inadequately vaccinated cattle population has become a maintenance population (Atkinson et al., 2019).

Conditions in KAZA favour maintenance of FMD viruses in cattle populations. Countries in KAZA have subtropical to tropical climates with a dry season during which large numbers of cattle move, sometimes over considerable distances, to find grazing and water (Atkinson et al., 2019). Particularly in the drier western parts of the TFCA, these resources may be limited and this results in mixing of cattle herds in grazing areas and at watering points. In northern Namibia, annual flooding causes large-scale migrations of people and livestock to higher ground, and can also interrupt routine vaccination campaigns. Low apparent morbidity during SAT FMD outbreaks strongly suggests that many of the cattle are subclinically infected (Vosloo and Thomson, 2017), which decreases detection of infection. Vaccination of cattle prevents clinical disease but not necessarily virus circulation or shedding (Thomson and Bastos, 2004).

There is no convincing evidence that cattle that may have persistent virus in the oropharynx are able to transmit it naturally to other cattle; one cannot blame carrier animals for endemic circulation. Rinderpest provided a classic example of a disease that circulated endemically in cattle, the only maintenance host, for a long time over several continents with no carrier state ever demonstrated (Roeder, 2011). In FMD, a carrier is defined as an animal in which FMD virus persists for more than 28 days post infection in the soft palate and oropharynx (Thomson and Bastos, 2004). After infection, excretion of the virus may occur for up to four days or more before clinical signs appear, while quantifiable FMD virus is only present for two weeks or less in all except oropharyngeal secretions. Persistence of FMD virus in the oropharynx for longer than 28 days occurs in more than 50 per cent of recovered cattle, but levels will have started to decline soon post infection, and 80 per cent of cattle will have little if any virus after six months. However, FMD virus may persist in up to 20 per cent of the cattle for a year, and a small proportion remain infected for up to two or even three years (Thomson and Bastos, 2004). *In spite of this persistence, there is little evidence that these cattle transmit FMDV to in-contact cattle under natural conditions.* Persistence does not necessarily imply shedding of infective quantities of virus. A study in cattle using serotype O FMD virus reported a very short window of a few days during which large amounts of virus were shed, associated with the appearance of clinical signs (Charleston et al., 2011). The great majority of attempts to demonstrate transmission from cattle in which FMD virus persisted in the oropharynx for long periods have failed (Thomson and

Bastos, 2004). A report of recent successful transmission by direct application of material scraped from the oropharynx of a carrier at 30 days post-infection to the oropharynx of a susceptible animal (the material was homogenised prior to inoculation, but the method of inoculation is not described) (Arzt et al., 2018) fails to provide clear evidence for transmission from cattle that have been persistently infected for longer than 30 days post-infection, or even of natural contact transmission at that time. In a review of the FMD carrier state published two years later, the lead authors of that same experimental study concluded that there is consensus that "transmission from FMD virus carriers is exquisitely improbable," but they make the valid point that WOAH and the countries that enjoy official recognition of freedom from FMD would not consider survival of "carriers" to be compatible with freedom from infection (Stenfeldt and Arzt, 2020). The review also clarifies the difference between subclinical infection of a persistent nature and neoteric subclinical infection, meaning new or acute inapparent infection with virus shedding. The latter describes a situation like that observed in outbreaks caused by SAT viruses (Vosloo and Thomson, 2017), where there is low apparent morbidity but large numbers of cattle may be infected without showing clinical signs. This presents a higher risk for dissemination of the virus during the outbreak (Stenfeldt and Arzt, 2020). Importantly, it also means that surveillance based on clinical signs alone may be ineffective for early detection of outbreaks.

Designing a surveillance programme that is not based on clinical inspection is complicated and, as this would likely need to involve large scale regular sampling of populations for laboratory testing, the costs would be extremely high. As it is unusual for an outbreak to occur without a single animal showing clinical signs, although one such outbreak has been reported (Vosloo and Thomson, 2017), closer observation of herds through the use of trained herders is highly recommended. This should be combined with risk mitigation measures that minimise to the greatest possible extent the level of contact between cattle herds, which again can best be implemented by professional herding.

Fences: impacts on wildlife and role in control of FMD

Transmission of FMD virus from buffalo periodically causes outbreaks in cattle (Thomson, 1995; Vosloo, Boshoff et al., 2002; Vosloo and Thomson, 2017). Although the mechanism whereby it occurs is not fully understood, transmission likely occurs when buffalo calves lose their maternally acquired immunity and are exposed to the virus, at which point they may develop high levels of viraemia and shed large quantities of virus (Vosloo and Thomson, 2017). For this reason, cordon fences have been extensively used to prevent contact between buffalo and livestock. These fences enabled several southern African countries to create zones recognized by WOAH as officially free from FMD without vaccination (Thomson et al., 2013a). However, in addition to being detrimental to wildlife conservation and rural economies in areas outside the free zones, the approach has not been sustainable. In spite of fences around KNP in South Africa, combined with zoning, intensive surveillance and movement controls that kept South Africa free of FMD outbreaks outside the designated zones for almost half a century, in the last several decades the situation has deteriorated (Jori et al., 2009). Outbreaks of FMD occurred in South Africa when flood damage to fences around KNP in 2000 allowed buffalo to stray into the FMD control area where the cattle were not vaccinated, and sequencing of the outbreak viruses supported the epidemiological evidence that buffalo were the source of the outbreaks (Jori et al., 2009; Vosloo, Boshoff et al., 2002). This suggested that a combination of fences and vaccination were needed to prevent FMD outbreaks in cattle (Vosloo, Boshoff et al., 2002). Nevertheless, further suspensions of the free zone occurred in 2011 and 2019 when illegal movements of cattle caused outbreaks in the free area that, since 2019, have involved several provinces. And although the first outbreaks occurred adjacent to KNP, subsequent spread has been entirely due to uncontrolled movement of cattle. Furthermore, experiences in Botswana and Namibia indicate that fences and vaccination provide no guarantees. Increased numbers of outbreaks have occurred in the zones in both countries that are not free of FMD despite the deployment of fences to separate wildlife from cattle, and cattle vaccination being undertaken twice or three times annually (Vosloo and Thomson, 2017).

In Botswana, some of the outbreaks occurred in free zones (Baipoledi et al., 2004; Derah and Mokopasetso, 2005). As mentioned, Zimbabwe lost access to the EU market for its beef in 2000 due to uncontrolled FMD outbreaks (Scoones et al., 2010). Possible reasons for the increase in FMD outbreaks included fence damage by elephants and flooding, inadequate fence maintenance and vandalism (Babayani and Thololwane, 2022; Jori et al., 2009). Less than adequate protection by vaccination appears to be a central issue, and is likely due to a range of reasons, including disrespect of cold chain requirements, inadequate percentages of cattle being vaccinated and mismatches between vaccine and outbreak strains (Atkinson et al., 2019; Maree et al., 2014). It has been suggested that alternatives to reliance on fencing are essential because, among other reasons including environmental impacts, the level of maintenance required is not achievable (Babayani and Thololwane, 2022; Thomson et al., 2013a). It's noteworthy that vaccination rates are very high in Botswana's Chobe District, with very few FMD outbreaks despite a lack of veterinary cordon fencing and cattle and wildlife sharing grazing and water resources.

Veterinary cordon fences are highly controversial from the point of view of biodiversity conservation (D. H. M. Cumming et al., 2015; Ferguson et al., 2013; Gadd, 2012; Hering et al., 2022; Mbaiwa and Mbaiwa, 2006; Osofsky et al, 2005; Osofsky, 2019; Perkins, 2010; Pietersen, 2022; Sutmoller, 2002; Weaver et al., 2013). There are many studies on the adverse effects of fences on large herbivores, including ungulates and elephants, and carnivores (Bartlam-Brooks et al., 2011; Brennan et al., 2020; Chase and Griffin, 2009; Cozzi et al., 2013; Hering et al., 2022; Huang et al., 2022; Naidoo et al., 2016a; Naidoo et al., 2018). It has been observed that double electric fences can impact giraffes that can become trapped between them (Atkinson et al., 2022). However, a recent study in South Africa has highlighted the threat that electrified fences also pose to smaller species such as the highly endangered Temminck's pangolin (*Smutsia temminckii*) and several reptile species (Pietersen, 2022). The negative effects of cordon fences on biodiversity conservation have made it imperative to seek alternative ways of managing FMD (Ferguson et al., 2013; Gadd, 2012; Osofsky et al, 2005; Osofsky, 2019; Thomson et al., 2004; Thomson et al., 2013a). Paradoxically, although the purpose of veterinary cordon fences is to provide reliable separation between wildlife and domestic livestock, it does not accord FMD-free status to the farmed areas immediately adjacent to the fences, as the potential for contact is considered too high by veterinary authorities. Exclusion of livestock owners in these areas from higher value markets provides another reason for seeking alternative approaches that will provide better guarantees of safe beef and improve market access for communal farmers (Ferguson et al., 2013; Scoones et al., 2010; Thomson et al., 2013b). To achieve this, a good understanding of the epidemiology of FMD in particular contexts is needed, including the relative importance of wildlife versus cattle in terms of initiating and spreading outbreaks, and the mitigation measures needed in each context (Osofsky et al, 2005; Rosen et al., 2024; Weaver et al., 2013).

A recent study in Botswana identified several issues other than buffalo contact that are challenging for FMD management, including (for example) cross-border livestock theft and livestock owner apathy (Mogotsi et al., 2016). Furthermore, outbreaks have occurred in free zones without opportunities for buffalo contact but with proximity to potentially infected cattle via an international border (Baipoledi et al., 2004). The socio-ecological factors and economic pressures that contribute to FMD outbreaks also need to be considered and addressed (G. S. Cumming et al., 2015; Mogotsi et al., 2016; Scoones et al., 2010), as do negative impacts of FMD management approaches on biodiversity conservation (Heermans et al., 2021; Osofsky, 2019). In short, the costs and benefits of different interventions across sectors need to be considered (Barnes, 2013; Knight-Jones and Rushton, 2013; Osofsky, 2019). Fences do have purposes other than prevention of FMD, which can include protection of wildlife and prevention of human-wildlife conflict, but there is a pressing need for careful evaluation before fences are erected and also for evaluation of existing fences in terms of costs and benefits (negative versus positive effects) (Durant et al., 2015; Osofsky, 2019; Osofsky and Taylor, 2021; Woodroffe et al., 2014). The high number of veterinary cordon fences in the SADC region is a particular cause for concern, and this is emphasized in the *Phakalane Declaration on Adoption of Non-Geographic Approaches for Management of Foot and Mouth Disease* by member states which recommends, among other things, strategic realignment of fences in order to reduce their impact on wildlife (Durant et al., 2015; Osofsky and Taylor, 2021; SADC, 2012).

KAZA as a case study

Understanding wildlife migration routes and what determines them is important for planning how to support connectivity and thus secure access to suitable habitats for large herbivores over space and time, including elephants. Recent initiatives have enabled mapping of areas needed by elephants in terms of availability of water, vegetation, lack of natural and artificial barriers to migration, land-use types and levels of human activity at a range of scales (Huang et al., 2022; Shaffer et al., 2019). One of the negative results of veterinary cordon fences in KAZA is that the largest population of elephants in the world is bottled up in areas that are too small to supply the elephants' needs over time. Aerial and ground surveys and radio collaring studies have confirmed that the fences constitute a significant barrier to elephant migration, with females being more reluctant to cross the fences than males (Brennan et al., 2020; Chase, 2011; Chase and Griffin, 2009; Chase et al., 2014; Chase et al., 2018; Naidoo et al., 2022; Osofsky and Taylor, 2021). Conservation areas are surrounded by land uses that include traditional crop and livestock production, which are expanding to feed a growing human population. In particular, an increase in human and elephant populations in the Okavango panhandle has resulted in worsening human-elephant conflict, mainly due to crop damage although human and elephant fatalities also occur (Buchholtz et al., 2020; Meyer and

Börner, 2022; Songhurst, 2017; Songhurst and Coulson, 2014; Songhurst et al., 2016). Lack of market access for cattle resulted in little incentive for investments in livestock rearing (like herding) (Thomson et al., 2013a). The increasing conflict between elephants and people could be alleviated by restoring elephants' ability to move into less heavily populated areas in Namibia, Angola and Zambia (Osofsky and Taylor, 2021) through strategic decommissioning of specific fence segments as supported by science-based livestock disease risk assessments (Atkinson et al., 2022; Rosen et al., 2024).

Connectivity is the subject of considerable research in KAZA, not only to enable the elephant population to move freely (KAZA TFCA Secretariat, 2019; KAZA TFCA Secretariat, 2023; Perkins, 2019), but to protect other essential wildlife movements, including the longest migration in Africa, undertaken by zebras moving between Namibia and Botswana (Bartlam-Brooks et al., 2011; Naidoo et al., 2016a). As the problems of poaching and habitat loss due to human encroachment have been identified worldwide as the major causes for declines in elephant populations (Chase et al., 2016; Schlossberg et al., 2018; Schlossberg et al., 2020; Shaffer et al., 2019), initiatives are needed at global, continental, regional and local levels to prevent extinction. Poaching has been reported to be a growing problem in Botswana (Schlossberg et al., 2019). Enabling elephants to restore historical movement patterns could reduce pressure from poaching as well as habitat encroachment, as elephants tend to avoid close human contact as well as to actively move away from heavily poached areas (Schlossberg et al., 2019). While stronger anti-poaching measures are recommended (Schlossberg et al., 2018, 2019), holistic approaches involving multiple stakeholders including communities living at the interface with wildlife are being undertaken in KAZA to promote sustainable biodiversity conservation. Reducing human-wildlife conflict and enabling communities to benefit from wildlife conservation and thus incentivizing active protection of wildlife are key to sustainable livelihoods as well as biodiversity conservation. One initiative that originated in Zimbabwe was the well-documented Communal Areas Management Programme for Indigenous Resources (CAMPFIRE) program (CAMPFIRE Association, 2024; Child and Barnes, 2010; Murombedzi, 2001; Taylor, 2009). Lessons and experiences were subsequently adapted and developed in Zambia and Botswana, and in Namibia with the establishment of communal conservancies (Jones and Erdmann, 2013; Naidoo et al., 2016b; Weaver and Petersen, 2008). In spite of challenges related to governance, benefits sharing and sustainability, such community involvement remains key to the success of TFCAs, and problems that arise need to be investigated and solutions found (Mudzengi et al., 2021). One such solution may lie in performance-based wildlife premium mechanisms for communities that conserve ecosystem services, for example by maintaining wildlife corridors (Dinerstein et al., 2012). Another promising contribution to community-based conservation is the Herding for Health (H4H) model, which has been piloted in northern Botswana and elsewhere, to improve livestock-derived livelihoods and reduce or eliminate illegal wildlife consumption and trade (Heermans et al., 2021) while also mitigating livestock disease risks.

In areas where crop-growing is minimal and livestock farming predominates, for instance in Namibia's and Botswana's portions of KAZA, predation by large carnivores may become the most important source of conflict (du Toit et al., 2017). Providing better protection for livestock increases tolerance towards predators and enables co-existence (Cozzi et al., 2013). Secure kraaling of domestic livestock at night and herding during the day are helpful, and represent fundamental objectives of the H4H model, which focuses on rangeland, animal and community health (Heermans et al., 2021). Mobile kraals that conceal livestock from predators are used to protect cattle at night, while trained herders protect them as they graze during the day (Fynn et al., 2016). Similarly, research findings from Tanzania indicate livestock depredation can be reduced by using fortified bomas at night and vigilant herders during the day (Mkonyi et al., 2017).

Mitigating the risk of FMD by implementing commodity-based trade of beef

The concept of catalyzing market access for beef produced in areas of southern Africa not free from FMD by providing value chain-based assurance that such beef can be produced free from FMD virus was developed as an alternative to geographical (fence-based) standards that demand country or zonal freedom from FMD (Thomson et al., 2004; Thomson et al., 2013a,b). The CBT approach combines risk mitigation for FMD along value chains (FAO, 2011) and a HACCP (Hazard Analysis and Critical Control Points)-like approach to ensuring the safety of the final product, which is matured, deboned beef from which all visible lymph nodes have been removed (Thomson et al., 2013b). In spite of initial skepticism, WOAH (OIE at the time) committed to investigate opportunities to develop new standards for risk reduction for trade in livestock commodities in collaboration with international and regional organizations (Thomson et al., 2009). Based on a risk analysis performed on behalf of WOAH for FMD virus in deboned beef, Paton et al. (2010) reported a very low risk that could be reduced to negligible by adding certain upstream and downstream mitigation measures. The concept was further developed, and CBT of beef was later endorsed by member countries of SADC at a meeting in 2012 (SADC and AHEAD, 2012), where *The Phakalane Declaration on Adoption of Non-Geographic Approaches for Management of Foot and Mouth Disease* was adopted (SADC, 2012). A follow-on proposal to WOAH resulted in the birth of a new paradigm for producing beef in "red zones" (FMD-infected zones) that could actually attain broader market access. As mentioned above, in 2015, WOAH, which provides standards for its 183 member countries related to international trade in commodities (including beef) that are a potential source of animal disease agents, updated their Terrestrial Animal Health Code and made it possible for African countries with wild species like buffalo that naturally harbor FMD viruses to be able to trade beef without necessarily requiring the physical separation of wildlife and livestock through the extensive veterinary cordon fencing that has characterized animal disease management in southern Africa since the colonial era.

Implementation of CBT is underway in the Zambezi Region of Namibia and in Botswana's Ngamiland, neither of which are free of FMD due to the presence of infected wildlife, drawing from a pilot project in Namibia (Meat Board of Namibia, 2014) and a gap analysis in Botswana (Atkinson et al., 2019), among other technical assistance endeavors. Official *Guidelines on Commodity-Based Trade Approaches for Managing Foot and Mouth Disease Risk in Beef in the SADC Region* have been published (SADC and AHEAD, 2021). Specific risk mitigation measures are recommended throughout the value chain, from the farm to the final product, and include preventing livestock contact with wildlife as can be supported by trained herders, good farming practices that includes compliance with animal identification and vaccination protocols, motorized transport to a quarantine station that is under direct or indirect supervision of the official veterinary service, inspection, and motorized transport to the designated abattoir on completion of the 30-day quarantine period. At the HACCP-compliant abattoir, the animals undergo ante- and post-mortem inspection and, after a maturation period of at least 24 hours at greater than 2°C so that muscle pH drops below 6.0, the carcass is deboned and all visible lymph nodes are removed from the deboned beef before it is packed for storage and dispatch.

In Ngamiland, there are farms that are being managed as compartments through implementation of a stringent biosecurity plan, and some alternatives to the official quarantine station are being piloted, included privately owned feedlot quarantines and community-managed mobile quarantine stations. These are needed because the only functional official quarantine station is a long distance from the northern parts of the district. The mobile quarantine facilities enable the cattle to maintain good condition until they can be moved directly to an approved abattoir for slaughter.

References

Alexandrov, T., Stefanov, D., Kamenov, P., Miteva, A., Khomenko, S., Sumption, K., Meyer-Gerbaulet, H., & Depner, K. (2013). Surveillance of foot-and-mouth disease (FMD) in susceptible wildlife and domestic ungulates in Southeast of Bulgaria following a FMD case in wild boar. *Veterinary Microbiology*, 166, 84-90. https://doi.org/10.1016/j.vetmic.2013.05.016

Allepuz, A., Stevenson, M., Kivaria, F., Berkvens, D., & Picado, C.A. (2015). Risk factors for foot-and-mouth disease in Tanzania, 2001-2006. *Transboundary and Emerging Diseases*, 62, 127-136. https://doi.org/10.1111/tbed.12087

Arzt, J., Belsham, G. J., Lohse, L., Bøtner, A., & Stenfeldt, C. (2018). Transmission of foot-and-mouth disease from persistently infected carrier cattle to naïve cattle via transfer of oropharyngeal fluid. *mSphere*, 3(5), e00365-18. https://doi.org/10.1128/mSphere.00365-18

Atkinson, S.J., Albertson, A., Naidoo, R., Ramsden, N., Songhurst, A., & Osofsky, S.A. (2022). Veterinary fences in Botswana's portion of the KAZA TFCA: Assessment of status and impacts on wildlife. Unpublished report prepared for the KAZA TFCA Secretariat. AHEAD Programme, Cornell University.

Atkinson, S. J., Bing, M., McNutt, J.W., Marshall, C., Masedi, M., Osofsky, S. A., Penrith, M.-L., Ramsden, N., Ross, K.S., Thomson, G.R., van Rooyen, J., & Worobo, R.W. (2019). Gap analysis on the implementation of commodity-based trade of beef in Ngamiland, Botswana. Report prepared in consultation with the Government of Botswana's Department of Veterinary Services. AHEAD Programme, Cornell University. http://www.wcs-ahead.org/kaza/rpt-cbt-gap-analysis-ngamiland-final-190912.pdf

Ayebazibwe, C., Mwiine, F.N., Tjørnehøj, K., Balinda, S.N., Muwanika, V.B., Ademun Okorut, A.R., Belsham, G.J., Normann, P., Siegismund, H.R., & Alexandersen, S. (2010). The role of African buffalos (*Syncerus caffer*) in the maintenance of foot-and-mouth disease in Uganda. *BMC Veterinary Research*, 6, 54. https://doi.org/10.1186/1746-6148-6-54

Babayani, N.D., & Tholowane, O.I. 2022. A qualitative risk assessment indicates moderate risk of foot-and-mouth disease outbreak in the Lower Okavango Delta because of interaction with buffaloes. *Transboundary and Emerging Diseases*, 69, 2840-2855. https://doi.org/10.1111/tbed.14436

Baipoledi, E.K., Matlho, G., Letshewenyo, M., Chimbombi, M., Adom, E.K., Raborokgwe, M.V., & Hyera, J.M.K. (2004). Re-emergence of foot-and-mouth disease in Botswana. *The Veterinary Journal*, 168, 93-99.

Banda, F., Shilongo, A., Hikufe, E.M., Khaiseb, S., Kabajani, J., Shikongo, B., Set, P., Kapapero, J.K., Shoombe, K.K., Zaire, G., Kabilika, S., Quan, M., Fana, E.M., Mokopasetso, M., Hyera, J.M.K., Wadsworth, J., Knowles, N.J., Di Nardo, A., & King, D.P. (2022). The first detection of a serotype O foot-and-mouth disease virus in Namibia. *Transboundary and Emerging Diseases*, 69, e3251-e3267. https://doi.org/10.1111/tbed.14561

Banda, F., Sinkala, Y., Mataa, L., Lebea, C., Sikombe, T., Kangwa, H.L., Fana, E.M., Mokopasetso, M., Wadsworth, J., Knowles, N.J., King, D.P., & Quan, M. (2021). Characterization of foot-and-mouth disease viruses in Zambia – implications for the epidemiology of the disease in southern Africa. *Viruses*, 13, 2195. https://doi.org/10.3390/v13112195

Barnes, J.I. (2013). Economic analyses of land use policies for livestock, wildlife and disease management in Caprivi, Namibia, with potential wider implications for regional transfrontier conservation areas. Technical report to the Wildlife Conservation Society's AHEAD Programme & World Wildlife Fund. AHEAD Programme. http://www.wcs-ahead.org/kaza/ahead_wwf_caprivi_analysis_final_030613.pdf

Bartlam-Brooks, H.L.A., Bonyongo, M.C., & Harris, S. (2011). Will reconnecting ecosystems allow long-distance mammal migrations to resume? A case study of a zebra *Equus burchelli* migration in Botswana. Oryx, 45(2), 210-216. https://doi.org/10.1017/S0030605310000414

Bastos, A.D.S., Boshoff, C.I., Keet, D.F., Bengis, R.G., & Thomson, G.R. (2000). Natural transmission of foot-and-mouth disease virus between African buffalo (*Syncerus caffer*) and impala (*Aepyceros melampus*) in the Kruger National Park, South Africa. *Epidemiology and Infection*, 124, 591-598.

Brennan, A., Beytell, P., Aschenborn, O., Du Preez, P., Funston, B.J., Hanssen, L., Kilian, J.W., Stuart-Hill, G., Taylor, R.D., & Naidoo, R. (2020). Characterizing multispecies connectivity across a transfrontier conservation landscape. *Journal of Applied Ecology*, 57, 1700-1710. https://doi.org/10.1111/1365-2664.13716

Brito, B.P., Jori, F., Dwarka, R., Maree, F.F., Heath, L., & Perez, A.P. (2016). Transmission of FMD SAT2 viruses at the wildlife-livestock interface of two major transfrontier conservation areas in southern Africa. *Frontiers in Microbiology*, 7, 528. https://doi.org/10.3389/fmicb.2016.00528

Brückner, G.K., Vosloo, W., Du Plessis, B.J.A., Kloeck, P.E.L.G., Connoway, L., Ekron, M.D., Weaver, B.D., Dickason, C.J., Schreuder, F.J., Marais, T., & Mogajane, M.E. (2002). Foot and mouth disease: The experience of South Africa. *Revue scientifique et technique*, *Office international des Épizooties*, 21(3), 751-764.

Buchholtz, E. K., Stronza, A., Songhurst, A., McCulloch, G., & Fitzgerald, L. A. (2020). Using landscape connectivity to predict human-wildlife conflict. *Biological Conservation*, 248, 108677. https://doi.org/10.1016/j.biocon.2020.108677

CAMPFIRE Association (2024). Implementation of CAMPFIRE. Retrieved [February 8, 2024] from https://campfirezimbabwe.org/content/implementation-campfire

Casey-Bryars, M., Reeve, R., Bastola, U., Knowles, N.J., Auty, H., Bachanek-Bankowska, K., Fowler, V.L., Fyumagwa, R., Kazwala, R., Kibona, T., King, A., King, D.P., Lankester, F., Ludi, A.B., Lugelo, A., Maree, F.F., Mshanga, D., Ndhlovu, G., Parekh, K., Paton, D.J., Perry, B., Wadsworth, J., Parida, S., Haydon, D.T., Marsh, T.L., Cleaveland, S., & Lembo, T. (2018). Waves of endemic foot-and-mouth disease in eastern Africa suggest feasibility of proactive vaccination practices. *Nature Ecology and Evolution*, 2, 1449-1457. https://doi.org/10.1038/s41559-018-0636-x

Charleston, B., Bankowski, B.M., Gubbins, S., Chase-Topping, M.E., Schley, D., Howey, R., Barnett, P.V., Gibson, D., Juleff, N.D., & Woolhouse, M.E.J. (2011). Relationship between clinical signs and transmission of an infectious disease and the implications for control. *Science*, 332, 726. https://doi.org/10.1126/science.1199884

Chase, M.J. (2011). Dry season fixed-wing aerial survey of elephants and wildlife in northern Botswana: September – November 2010. Elephants Without Borders, Department of Wildlife and National Parks & Zoological Society of San Diego.

Chase, M.J., & Griffin, C.R. (2009). Elephants caught in the middle: impacts of war, fences and people on elephant distribution and abundance in the Caprivi Strip, Namibia. *African Journal of Ecology*, 47, 223-233. https://doi.org/10.1111/j.1365-2028.2008.01017.x

Chase, M.J., Schlossberg, S., Griffin, C. R., Bouché, P.J.C., Djene, S.W., Elkan, P.W., Ferreira, S., Grossman, F., Kohi, E.M., Landen, K., Omondi, P., Peltier, A., Selier, S.A.J., & Sutcliffe, R. (2016). Continent-wide survey reveals massive decline in African savannah elephants. PeerJ, 4, e2354. https://doi.org/10.7717/peerj.2354

Chase M., Schlossberg, S., Landen, K., Sutcliffe, R., Seonyatseng, E., Keitsile, A., & Flyman, M. (2014). Dry season aerial survey of elephants and wildlife in northern Botswana: July – October 2014. Elephants Without Borders, Department of Wildlife & National Parks & Great Elephant Census.

Chase, M., Schlossberg, S., Sutcliffe, R., & Seonyatseng, E. (2018) Dry season aerial survey of elephants and wildlife in northern Botswana: July – October 2018. Elephants Without Borders & Department of Wildlife and National Parks.

Child, B., & Barnes, G. (2010). The conceptual evolution and practice of community-based natural resource management in southern Africa: Past, present and future. *Environmental Conservation*, 37(3), 283–295. https://doi.org/10.1017/s0376892910000512

Chilonda, P., Woodford, J.D., Ahmadu, B., Samui, L., Syakalima, M., & Mlangwa, J.E.D. (1999). Foot and mouth disease in Zambia: A review of the aetiology and epidemiology and recommendations for possible control. *Revue scientifique et technique, Office international des Épizooties*, 18(3), 585-592.

Chimera, E.T., Fosgate, G.T., Etter, E.M.C., Jemberu, W.T., Kamwendo, G., & Njoka, P. (2022). Spatio-temporal patterns and risk factors of foot-and-mouth disease in Malawi between 1957 and 2019. *Preventive Veterinary Medicine*, 204, 105639. https://doi.org/10.1016/j.prevetmed.2022.105639

Cozzi, G., Broekhuis, F., McNutt, J. W., & Schmid, B. (2013). Comparison of the effects of artificial and natural barriers on large African carnivores: Implications for interspecific relationships and connectivity. *Journal of Animal Ecology*, 82, 707-715. https://doi.org/10.1111/1365-2656.12039

Cumming, D.H.M., Osofsky, S.A., Atkinson, S.J., & Atkinson, M.W. (2015). Beyond fences: wildlife, livestock and land use in southern Africa. In J. Zinsstag, E. Schelling, D. Waltner-Toews, M. Whittaker & M. Tanner (Eds.), *One Health: The Theory and Practice of Integrated Health Approaches* (pp. 345-357). CABI International.

Cumming, G.S., Allen, C.R., Ban, N.C., Biggs, D., Biggs, H.C., Cumming, D.H.M., De Vos, A., Epstein, G., Etienne, M., Maciejewski, K., Mathevet, R., Moore, C., Nenadovic, M., & Schoon, M. (2015). Understanding protected area resilience: A multi-scale, socio-ecological approach. *Ecological Applications*, 25(2), 299-319.

Department of Agriculture, Forestry and Fisheries (2011, May 11). Foot and mouth disease isolated [Press release]. https://www.gov.za/news/media-statements/foot-and-mouth-disease-virus-isolated-11-may-2011

Derah, N., & Mokopasetso, M. 2005. The control of foot and mouth disease in Botswana and Zimbabwe. *Tropicultura*, 23 (Special Issue), 3-7.

Dhikusooka, M. T., Ayebazibwe, C., Namatovu, A., Belsham, G. J., Siegismund, H. R., Wekesa, S.N., Balinda, S. N., Muwanika, V., & Tjørnehøj, K. (2016). Unrecognized circulation of SAT 1 foot-and-mouth disease virus in cattle herds around Queen Elizabeth National Park in Uganda. *BMC Veterinary Research*, 12, 5. https://doi.org/10.1186/s12917-015-0616-1

Dhollander, S., Belsham, G. J., Lange, M., Willgert, K., Alexandrov, T., Chondrokouki, E., Depner, K., Khomenko, S., Özyörük, F., Salman, M., Thulke, H.-H., & Bøtner, A. (2016). Assessing the spread and maintenance of foot-and-mouth disease virus infection in wild ungulates: General principles and application to a specific scenario in Thrace. *Transboundary and Emerging Diseases*, 63, 165-174. https://doi.org/10.1111/tbed.12240

Di Nardo, A., Libeau, G., Chardonnet, B., Chardonnet, P., Kock, R.A., Parekh, K., Hamblin, P., Li, Y., Parida, S., & Sumption, K.J. (2015). Serological profile of foot-and-mouth disease in wildlife populations of West and Central Africa with special reference to *Syncerus caffer* subspecies. *Veterinary Research*, 46, 77. https://doi.org/10.1186/s03567-015-0213-0

Dinerstein, E., Varma, K., Wikramanayake, E., Powell, G., Lumpkin, S., Naidoo, R., Korchinsky, M., Del Valle, C., Lohani, S., Seidensticker, J., Joldersma, D., Lovejoy, T., & Kushlin, A. (2012). Enhancing conservation, ecosystem services, and local livelihoods through a wildlife premium mechanism. *Conservation Biology*, 27(1), 14-23. https://doi.org/10.111/j.1523-1739.2012.01959.x

Durant, S.M., Becker, M.S., Creel, S., Bashir, S., Dickman, A.J., Beudels-Jamar, R.C., ... et al. (2015). Developing fencing policies for dryland ecosystems. *Journal of Applied Ecology*, 53(3), 543-551. https://doi.org/10.1111/1365-2664.12415

du Toit, J.T., Cross, P.C., & Valeix, V. (2017). Managing the livestock-wildlife interface on rangelands. In D.D. Briske (Ed.), *Rangeland Systems: Processes, Management and Challenges* (pp. 395-425). Springer Nature. https://doi.org/10.1007/978-3-319-46709-2_12

Dyason, E. (2010). Summary of foot-and-mouth disease outbreaks reported in and around the Kruger National Park, South Africa, between 1970 and 2009. *Journal of the South African Veterinary Association*, 81(4), 201-206.

Elnekave, E., King, R., van Maanen, K., Shilo, H., Gelman, B., Storm, N., & Klement, E. (2016). Seroprevalence of susceptible wildlife in Israel. *Frontiers in Veterinary Science*, 3, 32. https://doi.org/10.3389/fvets.2016.00032

FAO. (2011). A value chain approach to animal diseases risk management: Technical foundations and practical framework for field application. FAO Animal Production and Health Guidelines, 4. FAO. https://www.fao.org/documents/card/en/c/44dbd020-212b-55ad-a7a9-37f5b9cf90ab

Ferguson, K.J., Cleaveland, S., Haydon, D.T., Caron, A., Kock, R.A., Lembo, T., Hopcraft, J.G. C., Chardonnet, B., Nyariki, T., Keyyu, J., Paton, D.J., & Kivaria, F.M. (2013). Evaluating the potential for sustainable control of foot and mouth disease in sub-Saharan Africa. *EcoHealth*, 10, 314-322. https://doi.org/10.1007/s10393-013-0850-6

Fynn, R.W.S., Augustine, D.J., Peel, M.J.S., & de Garine-Wichatitsky, M. (2016). Strategic management of livestock to improve biodiversity conservation in African savannahs: A conceptual basis for wildlife-livestock co-existence. *Journal of Applied Ecology*, 53, 388-397. https://doi.org/10.1111/1365-2664.12591

Gadd, M.E. (2012). Barriers, the beef industry and unnatural selection: A review of the impact of veterinary fencing on mammals in southern Africa. In M. J. Somers & M. W. Hayward (Eds.), *Fencing for Conservation: Restriction of Evolutionary Potential or a Riposte to Threatening Processes?* (pp. 153-186). Springer Science; Business Media. https://doi.org/10.1007/978-1-4614-0902-1_9

Guerrini, L., Pfukenyi, D.M., Etter, E., Bouyer, J., Njagu, C., Ndhovu, F., Bourgarel, M., de Garine Witchatitsky, M., Foggin, C., Grosbois, V., & Caron, A. (2019). Spatial and seasonal patterns of FMD outbreaks in cattle in Zimbabwe between 1931 and 2016. *Veterinary Research*, 50, 73. https://doi.org/10.1186/s13567-019-0690-7

Hargreaves, S.K., Foggin, C.M., Anderson, E.C., Bastos, A.D.S., Thomson, G.R., Ferris, N.P., & Knowles, N.J. (2004). An investigation into the source and spread of foot and mouth disease virus from a wildlife conservancy in Zimbabwe. *Revue scientifique et technique, Office international des Épizooties*, 23(3), 783-790.

Haydon, D.T., Cleaveland, S., Taylor, L.H., & Laurenson, M.K. (2002). Identifying reservoirs of infection: A conceptual and practical challenge. *Emerging Infectious Diseases*, 8(12), 1468-1473.

Heermans, B., van Rooyen, J., Fynn, R., Biggs, D., Lewis, M., & McNutt, J. (2021). Husbandry and herding: A community-based approach to addressing illegal wildlife trade in northern Botswana. *Frontiers in Conservation Science*, 2, 675493. https://doi.org/10.3389/fcosc.2021.675493

Hering, R., Hauptfleisch, M., Jago, M., Smith, T., Kramer-Schadt, S., Stiegler, J., & Blaum, N. (2022). Don't stop me now: Managed fence gaps could allow migratory ungulates to track dynamic resources and reduce fence-related energy loss. *Frontiers in Ecology and Evolution*, 10, 907079. https://doi.org/10.3389/fevo.2022.907079

Huang, R.M., van Aarde, R.J., Pimm, S.L., Chase, M.J., & Leggett, K. (2022). Mapping potential connections between southern Africa's elephant populations. *PLoS ONE*, 17(10), e0275791. https://doi.org/10.1371/journal.pone.0275791

Jones, B.T.B., & Erdmann, T.K. (2013). Community-based natural resource management in southern Africa: A decision-maker's guide. *United States Agency for international Development*. Retrieved from https://pdf.usaid.gov/pdf_docs/PA00JRSF.pdf. Accessed February 8, 2024.

Jori, F., Caron, A., Thompson, P.N., Dwarka, R., Foggin, C., de Garine Witchatitsky, M., Hofmeyr, M., van Heerden, J., & Heath, L. (2016). Characteristics of foot-and-mouth disease viral strains circulating at the wildlife/livestock interface of the Great Limpopo Transfrontier Conservation Area. *Transboundary and Emerging Diseases*, 63, e58-e70. https://doi.org/10.1111/tbed.12231

Jori, F., Vosloo, W., Du Plessis, B., Bengis, R., Brahmbatt, D., Gummow, B., & Thomson, G.R. (2009). A qualitative risk assessment of factors contributing to foot and mouth disease outbreaks in cattle along the western boundary of the Kruger National Park. *Revue scientifique et technique, Office international des Épizooties*, 28(3), 917-931.

Kasanga, C.J., Wadsworth, J., Mpelembe-Ngeleja, C.A.R., Sallu, R., Kivaria, F., Wambura, P. N., Yongolo, M.G.S., Rweyemamu, M., Knowles, N.J., & King, D.P. (2015). Molecular characterization of foot-and-mouth disease viruses collected in Tanzania between 1967 and 2009. *Transboundary and Emerging Diseases*, 62, e19-e29. https://doi.org/10.1111/tbed.12200

KAZA TFCA Secretariat (2019). Strategic planning framework for the conservation and management of elephants in the Kavango Zambezi Transfrontier Conservation Area. https://www.kavangozambezi.org/publications-2/

KAZA TFCA Secretariat (2023). KAZA policy brief: Elephant movements and connectivity in the Kavango Zambezi Transfrontier Conservation Area. https://www.kavangozambezi.org/download/78/kazapublications-english/1527/kaza-policy-brief-on-elephant-movements-and-connectivity-in-the-kavangozambezi-transfrontier-conservation-area.pdf

Keet, D.F., Hunter, P., Bengis, R.G., Bastos, A., & Thomson, G.R. (1996). The 1992 foot-and-mouth disease epizootic in the Kruger National Park. *Journal of the South African Veterinary Association*, 67, 83-87.

Knight-Jones, T.J.D., & Rushton, J. (2013). The economic impacts of foot and mouth disease – what are they, how big are they and where do they occur? *Preventive Veterinary Medicine*, 112, 161-173. http://doi.org/10.1016/j.prevetmed.2013.07.013

Letshwenyo, M., Mapitse, N., & Hyera, J.M.K. (2006). Foot-and-mouth disease in a kudu (*Tragelaphus strepsiceros*) in Botswana. *Veterinary Record*, 159, 252-253. http://doi.org/10.1136/vr.159.8.252

Lignereux, L., Chaber, A.-L., Saegerman, C., Heath, L., Knowles, N.J., Wadsworth, J., Mioulet, V., & King, D.P. (2020). Foot-and-mouth disease in captive scimitar-horned oryx (*Oryx dammah*). *Transboundary and Emerging Diseases*, 67, 1716-1724. http://doi.org/10.1111/tbed.13502

Maree, F.F., Kasanga, C.J., Scott, K.A., Opperman, P.A., Chitray, M., Sangula, A.K., Sallu, R., Sinkala, Y., Wambura, P.N., King, D.P., Paton, D.J., & Rweyemamu, M.M. (2014). Challenges and prospects for the control of foot-and-mouth disease: An African perspective. *Veterinary Medicine: Research and Reports*, 5, 119-138. http://doi.org/10.2147/VMRR.562607

Mbaiwa, J.E., & Mbaiwa, O.I. (2006). The effects of veterinary fences on wildlife populations in the Okavango Delta, Botswana. *International Journal of Wilderness*, 12, 17-24.

Meat Board of Namibia. (2014). Development of marketing opportunities for beef products from the Zambezi Region. Report prepared for Millennium Challenge Account Namibia.

Meyer, M., & Börner, J. (2022). Rural livelihoods, community-based conservation, and human-wildlife conflict: Scope for synergies. *Biological Conservation*, 272, 109666. http://doi.org/10.1016/j.biocon.2022.109666

Miguel, E., Grosbois, V., Caron, A., Boulnier, T., Fritz, H., Cornélis, D., Foggin, C., Makaya, P.V., Tshabalala, P.T., & de Garine-Witchatitsky, M. (2013). Contacts and foot and mouth disease transmission from wild to domestic bovines in Africa. 2013. *Ecosphere*, 4(4), 51. http://doi.org/10.1890/ES12-00239.1

Mkonyi, F.J., Estes, A.B., Msuha, M.J. Lichtenfeld, L.L., & Durant, S.M. (2017). Fortified bomas and vigilant herding are perceived to reduce livestock depredation by large carnivores in the Tarangire-Simanjiro ecosystem, Tanzania. *Human Ecology*, 45, 513–523. https://doi.org/10.1007/s10745-017-9923-4

Mogotsi, K., Kgosikoma, O.E, & Lubinda, K.F. (2016). Wildlife-livestock interface, veterinary cordon fence damage, lack of protection zones, livestock and owner apathy: Complex socio-ecological dynamics in foot and mouth disease control in southern Africa. *Pastoralism: Research. Policy and Practice*, 6, 21. http://doi.org/10.1186/s13570-016-0068-7

Mudzengi, B.K., Gandiwa, E., Muboko, N., & Mutanga, C.N. (2021). Towards sustainable community conservation in tropical savanna ecosystems: A management framework for ecotourism ventures in a changing environment. *Environment, Development and Sustainability*, 23, 3028-3047. http://doi.org/10.1007/s10668-020-00772-4

Murombedzi, J. (2001). Committees, rights, costs and benefits: Natural resource stewardship & community benefits in Zimbabwe's CAMPFIRE. In D. Hulme & M.W. Murphree (Eds.), *African Wildlife and African Livelihoods: The Promise and Performance of Community Conservation* (pp. 244-255). James Currey Ltd.

Naidoo, R., Beytell P., Brennan, A., Kilian, W., McCulloch, G., Stronza A., Taylor, T., Tsholofelo, C., & Songhurst, A. (2022). Challenges to elephant connectivity from border fences in the world's largest transfrontier conservation area. *Frontiers in Conservation Science*, 3, 788133. https://doi.org/10.3389/fcosc.2022.788133

Naidoo, R., Chase, M.J., Beytell, P., Du Preez, P., Landen, K., Stuart-Hill, G., & Taylor, R. (2016a). A newly discovered wildlife migration in Namibia and Botswana is the longest in Africa. *Oryx*, 50(1), 138-146. http://doi.org/10.1017/S0030605314000222

Naidoo, R., Kilian, J.W., Du Preez, P., Beytell, P., Aschenborn, O., Taylor, R.D., & Stuart-Hill, G. (2018). Evaluating the effectiveness of local- and regional-scale wildlife corridors using quantitative metrics of functional connectivity. *Biological Conservation*, 217, 96-103. http://doi.org/10.1016/j.biocon.2017.10.037

Naidoo, R., Weaver, L.C., Diggle, R.W., Matongo, G., Stuart-Hill, G., & Thouless, C. (2016b). Complementary benefits of tourism and hunting to communal conservancies in Namibia. *Conservation Biology*, 30(3), 628-638. http://doi.org/10.1111/cobi.12643

Omondi, G.P., Gakuya, F., Arzt, J., Sangula, A., Hartwig, E., Pauszek. S., Smoliga, G., Brito, B., Perez, A., Obanda, V., & VanderWaal, K. (2020). The role of African buffalo in the epidemiology of foot-and-mouth disease in sympatric cattle and buffalo populations in Kenya. *Transboundary and Emerging Diseases*, 67, 2206-2221. http://doi.org/10.1111/tbed.13573

Osofsky, S.A., Cleaveland, S., Karesh, W.B., Kock, M.D., Nyhus, P.J., Starr, L., & Yang, A. (2005). *Conservation and Development Interventions at the Wildlife/Livestock Interface: Implications for Wildlife, Livestock and Human Health*. International Union for Conservation of Nature (IUCN). https://wcs-ahead.org/wpc_launch.html

Osofsky, S.A. (2019). The global burden of (how we manage) animal disease: Learning lessons from southern Africa. *Journal of Wildlife Diseases*, 55(4), 755-757. https://doi.org/10.7589/2019-01-024.

Osofsky, S.A., & Taylor, R.D. (2021). Piecing together an African peace park. *Science*, 373(6557), 864. https://doi.org/10.1126/science.abl7447

Paton, D.J., Sinclair, M., & Rodríguez, R. (2010). Qualitative risk assessment of the commodity risk for spread of foot-and-mouth disease associated with international trade in deboned beef. *Transboundary and Emerging Diseases*, 57, 115-134. http://doi.org/10.1111/j.1865-1682.2010.01137.x

Perkins, J. (2010). Fences and landscape scale degradation. In K. Ferguson & J. Hanks (Eds.), *Fencing impacts: A review of the social, economic and environmental impacts of game and veterinary fencing in Africa with particular reference to the Great Limpopo and Kavango-Zambezi Transfrontier Conservation Areas* (pp. 83-95). Mammal Research Institute; University of Pretoria.

Perkins, J.S. (2019). 'Only connect': Restoring resilience in the Kalahari ecosystem. *Journal of Environmental Management*, 249, 109420. http://doi.org/10.1016/j.jenvman.2019.109420

Picado, A., Speybroeck, N., Kivaria, F., Mosha, R.M., Sumaye, R.D., Casal, J., & Berkvens, D. (2011). Foot-and-mouth disease in Tanzania from 2001 to 2006. *Transboundary and Emerging Diseases*, 58, 44-52. http://doi.org/10.1111/j.1865-1682.2010.01180.x

Pietersen, D. (2022). Body size, defensive behaviour and season influence mortality probability in wildlife interactions with electrified fences. *African Journal of Wildlife Research*, 52, 172-184. https://doi.org/10.3957/056.052.0172

Roeder, P.L. (2011). Rinderpest: The end of cattle plague. *Preventive Veterinary Medicine*, 102, 98-106. http://doi.org/10.1016/j.prevetmed.2011.04.004

Roeder, P.L., Abraham, G., Mebratu, G.Y., & Kitching, R.P. (1994). Foot-and-mouth disease in Ethiopia from 1988 to 1991. *Tropical Animal Health and Production*, 26, 163-167.

Rosen, L.E., Amuthenu, N.S., Atkinson, S.J., Babayani, N.D., Elago, S.A.T., Hikufe, E., Mafonko, B.R., Mbeha, B., Mokopasetso, M., Motshegwa, K., Nkgowe, C., Penrith M-L., Ramokwena, E.M., Ramsden, N., Segale, K., Sharpe, J., Shilongo, A., Shoombe, K.K., Shuro, T., Thololwane, O.I., van Rooyen, J., & Osofsky, S.A. (2024). Veterinary fences in the KAZA TFCA: Assessment of livestock disease risks of potential removal of specific fence sections, with an emphasis on the Botswana-Namibia border. AHEAD Programme, Cornell University on behalf of the KAZA Animal Health Sub Working Group. 300 pp. https://www.wcs-ahead.org/documents/livestock-dz-risk-assess_lo_res_final_20240917.pdf

SADC. (2012). *The Phakalane declaration on adoption of non-geographic approaches for management of foot and mouth disease.* Southern African Development Community. https://www.wcs-ahead.org/phakalane_declaration.html

SADC & AHEAD. (2012). Proceedings of SADC TADS project scientific symposium on "Foot and mouth disease in SADC" and joint SADC-AHEAD workshop on "Reconciling livestock health and wildlife conservation goals in southern Africa: Strategies for sustainable economic development", Gaborone, Botswana. http://www.wcs-ahead.org/phakalane_workshop_2012/sadc_ahead_workshop_proceedings.pdf

SADC & AHEAD. (2021). Guidelines on commodity-based trade approaches for managing foot and mouth disease risk in beef in the SADC Region. (4th ed.). Southern African Development Community & Animal & Human Health for the Environment And Development. https://www.sadc.int/sites/default/files/2022-07/Guidelines_for_implementing_CBT_2022_SADC_ENG_final_0.pdf

Sangare, O., Bastos, A.D.S., Marquardt, O., Venter, E.H., Vosloo, W., & Thomson, G.R. (2001). Molecular epidemiology of serotype O foot-and-mouth disease virus with emphasis on West and South Africa. *Virus Genes*, 22(3), 345-351.

Schlossberg, S., Chase, M.J., & Griffin, C.R. (2018). Poaching and human encroachment reverse recovery of African savannah elephants in south-east Angola despite 14 years of peace. *PLoS ONE*, 13(3), e0193469. http://doi.org/10.1371/journal.pone.0193469

Schlossberg, S., Chase, M.J., & Sutcliffe, R. (2019). Evidence of a growing elephant poaching problem in Botswana. *Current Biology*, 29, 2222-2228. http://doi.org/10.1016/j.cub.2019.05.061

Schlossberg, S., Gobush, K.S., Chase, M.J., Elkan, P.W., Grossmann, F., & Kohi, E.M. (2020). Understanding the drivers of mortality in African savannah elephants. *Ecological Applications*, 30(6), e02131. http://doi.org/10.1002/eap.2131

Scoones, I., Bishi, A., Mapitse, N., Moerane, R., Penrith, M.L., Sibanda, R., Thomson, G., & Wolmer, W. (2010). Foot-and-mouth disease and market access: Challenges for the beef industry in southern Africa. *Pastoralism*, 1(2). https://repository.up.ac.za/bitstream/handle/2263/16879/Scoones_Foot(2010).pdf?sequence=1&isAllowed=y

Shaffer, L.J., Khadka, K.K., Van Den Hoek, J., & Naithani, K.J. (2019). Human-elephant conflict: A review of current management strategies and future directions. *Frontiers in Ecology and Evolution*, 6, 235. http://doi.org/10.3389/fevo.2018.00235

Songhurst, A. (2017). Measuring human-wildlife conflicts: Comparing insights from different monitoring approaches. *Wildlife Society Bulletin*, 41, 351-361.

Songhurst, A., & Coulson, T. (2014). Exploring the effects of spatial autocorrelation when identifying key drivers of wildlife crop-raiding. *Ecology and Evolution*, 4(5), 562-593. http://doi.org/10.1002/ece3.837

Songhurst, A., McCulloch, G., & Coulson, T. (2016). Finding pathways to human-elephant coexistence: A risky business. *Oryx*, 50(4), 713-720. http://doi.org/10.1017/S0030605315000344

Stenfeldt, C., & Arzt, J. (2020). The carrier conundrum: A review of recent advances and persistent gaps regarding the carrier state of foot-and-mouth disease virus. *Pathogens*, 9 (3), 167. https://doi.org/10.3390/pathogens9030167

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. http://doi.org/10.1111/j.1749-6632.2002.tb04377.x

Taylor, R. (2009). Community based natural resource management in Zimbabwe: The experience of CAMPFIRE. *Biodiversity and Conservation*, 18(10), 2563-2583. https://doi.org/10.1007/s10531-009-9612-8

Thomson, G.R. (1995). Overview of foot and mouth disease in southern Africa. *Revue scientifique et technique, Office international des Épizooties*, 14, 503-520.

Thomson, G.R., & Bastos, A.D.S. (2004). Foot-and-mouth disease. In J.A. W Coetzer & R.C Tustin (Eds). *Infectious Diseases of Livestock* (2nd ed.), Vol. 2, (pp. 1324-1365). Oxford University Press.

Thomson, G.R., Leyland, T.J., & Donaldson, A.I. (2009). De-boned beef – an example of a commodity for which specific standards could be developed to ensure and appropriate level of protection for international trade. *Transboundary and Emerging Diseases*, 59, 9-17. http://doi.org/10.1111/j.1865-1682.2008.01054.x

Thomson, G.R., & Penrith, M-L. (2017). Eradication of transboundary animal diseases: Can the rinderpest success story be repeated? *Transboundary and Emerging Diseases*, 64, 459-475. http://doi.org/10.1111/tbed.12385

Thomson, G.R., Penrith, M.-L., Atkinson, M.W., Atkinson, S.J., Cassidy, D., & Osofsky, S.A. (2013a). Balancing livestock production and wildlife conservation in and around southern Africa's transfrontier conservation areas. *Transboundary and Emerging Diseases*, 60, 492-506. http://doi.org/10.1111/tbed.12175

Thomson, G.R., Penrith, M.-L., Atkinson, M.W., Thalwitzer, S., Mancuso, A., Atkinson, S.J., & Osofsky, S.A. (2013b). International standards for commodities and products derived from animals: The need for a system that integrates food safety and animal disease risk management. *Transboundary and Emerging Diseases*, 60, 507-515. http://doi.org/10.1111/tbed.12164

Thomson, G.R., Tambi, E.N., Hargreaves, S.K., Leyland, T.J., Catley, A.P., van t'Klooster, G.G.M., & Penrith, M.-L. (2004). International trade in livestock and livestock products: The need for a commodity-based approach. *Veterinary Record*, 155, 429-433.

Thomson, G.R., Vosloo, W., & Bastos, A.D.S. (2003). Foot and mouth disease in wildlife. *Virus Research*, 91, 145-161. http://doi.org/10.1016/s0168-1702(02)00263-0

Vosloo, W., Bastos, A.D.S., & Boshoff, C.I. (2006). Retrospective genetic analysis of SAT-1 type foot-and-mouth disease outbreaks in southern Africa. *Archives of Virology*, 151, 285-298. http://doi.org/10.3007/s00705-005-0629-3

Vosloo, W., Bastos, A.D.S., Sangare, O., Hargreaves, S.K., & Thomson, G.R. (2002). Review of the status and control of foot and mouth disease in sub-Saharan Africa. *Revue scientifique et technique, Office international des Épizooties*, 21 (3), 437-449.

Vosloo, W., Boshoff, K., Dwarka, R., & Bastos, A. (2002). The possible role that buffalo played in the recent outbreaks of foot-and-mouth disease in South Africa. *Annals of the New York Academy of Sciences*, 969, 187-190. http://doi.org/10.1111/j.1749-6632.tb04376.x

Vosloo, W., Kirkbride, E., Bengis, R.G., Keet, D.F., & Thomson, G.R. (1995). Genome variation in the SAT types of foot-and-mouth disease viruses prevalent in buffalo (*Syncerus caffer*) in the Kruger National Park and other regions of South Africa, 1986-93. *Epidemiology and Infection*, 114, 203-218.

Vosloo, W., Swanepoel, S.P., Bauman, M., Botha, B., Esterhuysen, J.J., Boshoff, C.I., Keet, D.F., & Dekker, A. (2011). Experimental infection of giraffe (*Giraffa camelopardalis*) with SAT-1 and SAT-2 foot-and-mouth disease viruses. *Transboundary and Emerging Diseases*, 58, 173-178. http://doi.org/10.1111/j.1865-1682.2010.01188.x

Vosloo, W., & Thomson, G.R. (2017). Natural habitats in which foot-and-mouth viruses are maintained. In F. Sobrino, E. Domingo (Eds). *Foot-and-Mouth Disease Virus – Current Research and Emerging Trends* (pp. 179-210). Caister Academic Press.

Vosloo, W., Thompson, P.N., Botha, B., Bengis, R.G., Thomson, G.R. (2009). Longitudinal study to investigate the role of impala (*Aepyceros melampus*) in foot-and-mouth disease maintenance in the Kruger National Park, South Africa. *Transboundary and Emerging Diseases*, 56, 18-30. http://doi.org/10.1111/j.1865-1682.2008.01059.x

Weaver, L.C., & Petersen, T. (2008). Namibia communal area conservancies. *Best Practices in Sustainable Hunting*, 2008, 48-52.

Weaver, G.V., Domenech, J., Thiermann, A.R., & Karesh, W.B. (2013). Foot and mouth disease: A look from the wild side. *Journal of Wildlife Diseases*, 49(4), 769-785. http://doi.org/10.7589/2012-11-276

Wekesa, S.N., Sangula, A.K., Belsham, G.J., Tjørnehoj, K., Muwanika, V.B., Gakuya, F., Mijele, D., & Siegismund, H.R. (2015). Characterisation of recent foot-and-mouth disease viruses from African buffalo (*Syncerus caffer*) and cattle in Kenya is consistent with independent virus populations. *BMC Veterinary Research*, 11, 17. http://doi.org/10.1186/s12917-015-0333-9

Woldemariyam, F.T., Leta, S., Assefa, Z., Tedeka, E., Gebrewold, D.S., & Paeshuyse, J. (2022). Temporal and spatial patterns and a space-time cluster analysis of foot-and-mouth disease outbreaks in Ethiopia from 2010 to 2019. *Viruses*, 14, 1558. http://doi.org/10.3389/v14071558

Woodroffe, R., Hedges, S., & Durant, S.M. (2014). To fence or not to fence. *Science*, 344(6179), 46-48. http://doi.org/10.1126/science.1246251