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POLICY DIRECTION

Developing fencing policies for dryland ecosystems

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Summary

1. In dryland ecosystems, mobility is essential for both wildlife and people to access unpredictable and spatially heterogeneous resources, particularly in the face of climate change. Fences can prevent connectivity vital for this mobility.

2. There are recent calls for large-scale barrier fencing interventions to address human–wildlife conflict and illegal resource extraction. Fencing has costs and benefits to people and wildlife. However, the evidence available for facilitating sound decision-making for fencing initiatives is limited, particularly for drylands.

3. We identify six research areas that are key to informing evaluations of fencing initiatives: economics, edge permeability, reserve design, connectivity, ecosystem services and communities.

4. *Policy implications*. Implementing this research agenda to evaluate fencing interventions in dryland ecosystems will enable better management and policy decisions. The United Nations Conventions on Migratory Species (CMS) and to Combat Desertification (UNCCD) are appropriate international agreements for moving this agenda forward and leading the development of policies and guidelines on fencing in drylands.

Key-words: barriers, biodiversity conservation, conservation policy, deserts, ecosystem function, management interventions, migration, nomadic pastoralism, rangelands, transhumance

A resurgence in calls for large-scale fencing interventions in Africa

Fencing has been used world-wide for a variety of purposes, including protecting remnant wildlife populations from overhunting, poaching or invasive species and reducing human–wildlife conflict and human encroachment (Somers & Hayward 2012). In Africa, after a proliferation of fencing initiatives in the 1960s and 1970s, there has been a recent resurgence in calls for large-scale fencing to protect biodiversity and to separate wildlife from people, livestock and crops. For example, Uganda intends to fence all of its national parks in a bid to stem human–wildlife conflict (Government of Uganda 2012). The Rwandan authorities recently erected a 120-km fence around the Akagera National Park at a capital cost of \$2·5 million in a bid to eliminate human–wildlife conflict (Hall 2013). Meanwhile, the government of Malawi has stated a wish to protect all parks in the country with electric fences (Kafemveka 2013).

In stark contrast, elsewhere in Africa, authorities are removing fences to restore wildlife populations and migratory movements and to promote wildlife-based economies for conservancies and local communities. The Southern African Development Community (SADC) in the *Phakalane Declaration* has recently recommended strategic realignment of veterinary cordon fences (erected for wildlife disease control) to counteract the harmful impacts of fences on wildlife populations (SADC 2012). In addition, the non-governmental organization (NGO)-led Transfrontier Conservation Area and privately led conservancy movements across Africa are encouraging the widespread removal of fencing to re-establish large-scale animal movements (Van Aarde & Jackson 2007; WCS 2008; Lindsey, Romañach & Davies-Mostert 2009). Their aim is to support or restore wide-ranging species whose populations are no longer viable in small reserves.

Scientific opinion on the topic of fencing appears similarly divided. A recent analysis of African lion *Panthera leo* densities and growth rates from fenced and unfenced populations concluded that fencing was a cost–effective conservation strategy for this species and recommended fencing as a primary conservation tool for lions (Packer *et al.* 2013). However, Creel *et al.* (2013) demonstrated that the studied populations differed in key aspects other than fencing, with fenced populations having markedly higher budgets for substantially smaller areas, which often held intensively managed lion populations well above carrying capacity. In concert, these factors confounded the original analyses and prompted a reanalysis to test for correlates of population size, rather than the proximity of a population to its carrying capacity (Creel *et al.* 2013). This reanalysis found the opposite result that many more lions are conserved per dollar invested in unfenced than in fenced reserves, while also avoiding the ecological and economic costs of fencing (Creel *et al.* 2013). While the proximity of a population to its carrying capacity (Packer *et al.* 2013) is a useful measure of conservation success, population size is generally of greater importance for decisions about conservation priorities (Creel *et al.* 2013), because many populations near carrying capacity are also very small. This debate prompted a subsequent article in *Science* that highlighted the problems associated with large-scale fencing and concluded that, as climate change increases the importance of wildlife mobility and landscape connectivity, fencing of wildlife should become an action of last resort (Woodroffe, Hedges & Durant 2014).

To reconcile such widely divergent opinions and contradictory policies, we review and identify key information needs for conservation policymakers and practitioners for better assessment of costs and benefits of proposed fencing interventions. Critical evaluation of fencing initiatives is most urgent in the world's dryland ecosystems where mobility is essential for both wildlife and people to access temporally variable and spatially heterogeneous resources (Notenbaert *et al.* 2012). In such landscapes, the erection of large-scale impermeable barriers may reduce connectivity and lead to significant ecological and economic impacts (Okin *et al.* 2009).

We define drylands as those areas with an aridity index value of <0·65, in accordance with the Millennium Ecosystem Assessment (Safriel *et al.* 2005; Fig. 1), the United Nations Environmental Programme (UNEP), the International Union for the Conservation of Nature (IUCN) and the Convention on Biological Diversity (CBD) (Davies *et al.* 2012). These areas cover 41% of the land's surface and are home to an estimated 64% of all bird, 55% of mammal and 25% of amphibian species (Davies *et al.* 2012). They support some of the world's largest populations of terrestrial megafauna and significant wildlife migratory systems (Harris *et al.* 2009; Milner-Gulland, Fryxell & Sinclair 2011). Moreover, two billion people live in drylands, including some of the most vulnerable and marginalized communities in the world (Middleton *et al.* 2011). Survival of wildlife and people in these arid lands has depended on adapting to a harsh and highly variable environment, characterized by short growing seasons and low, unpredictable rainfall that are not conducive to agriculture. Historically, people living in drylands depended on nomadic or semi-nomadic pastoralism, a strategy that allows the most efficient use of highly variable and localized rainfall (McCabe 2004; Homewood 2009). Thus, in unpredictable dryland environments, mobility is critical to access transient forage and water resources for both wildlife and people (Notenbaert *et al.* 2012).

Costs and benefits of fencing in dryland ecosystems

Fences are free-standing structures aimed at restricting or preventing movement across boundaries (Hayward & Kerley 2009). Fences are usually erected to reduce threats to wildlife from direct human activities (such as ecosystem degradation, harvesting, persecution and disturbance); reduce conflict between people and wildlife (Lindsey *et al.* 2012); and reduce disease transmission between wildlife and domestic animals, most notably the extensive veterinary barrier fences stretching across southern Africa (Gadd 2012). Fencing is widely used in Australian drylands to exclude invasive non-native species from wildlife areas, though the maintenance and construction costs incurred in building fences able to exclude small invasive predators generally keep such fenced areas relatively small (Dickman 2012).

While we can relatively easily identify the potential benefits, the negative consequences of large-scale fencing interventions may be less obvious. Large-scale fencing can disrupt migration pathways and reduce access to key areas within drylands, such as seasonal foraging areas (Harris *et al.* 2009) and wetland refuges (Davies *et al.* 2012). This can lead to severe reductions in migratory or nomadic ungulate populations and may prompt wider impacts on non-migratory species (Harris *et al.* 2009; Gadd 2012). Some impacts may occur over a long time, which makes them particularly difficult to detect (Norrdahl *et al.* 2002). Fencing also restricts ranging of keystone species, such as African elephants *Loxodonta Africana*, which significantly influence ecosystem structure and function (Shrader, Pimm & Van Aarde 2010; Asner & Levick 2012). The potentially damaging habitat impacts arising from 'compressing' elephants within protected areas have been well documented (Western & Gichohi 1993; Douglas-Hamilton, Krink & Vollrath 2005; Loarie, Van Aarde & Pimm 2009). Similarly, fencing may also cause disruption at high trophic levels, such as altering the population dynamics or restricting movement of top predators, which is likely to lead to cascading impacts, loss of ecosystem function and impoverished biodiversity (Estes *et al.* 2011). Implementing intensive and expensive management to mitigate against such effects, such as translocation or anthropogenic control of population size (e.g. see discussion of lions in Packer *et al.* 2013; Creel *et al.* 2013), may not be feasible or cost effective, particularly for multiple species, and is unlikely to provide an adequate replacement for naturally regulated and connected ecosystems.

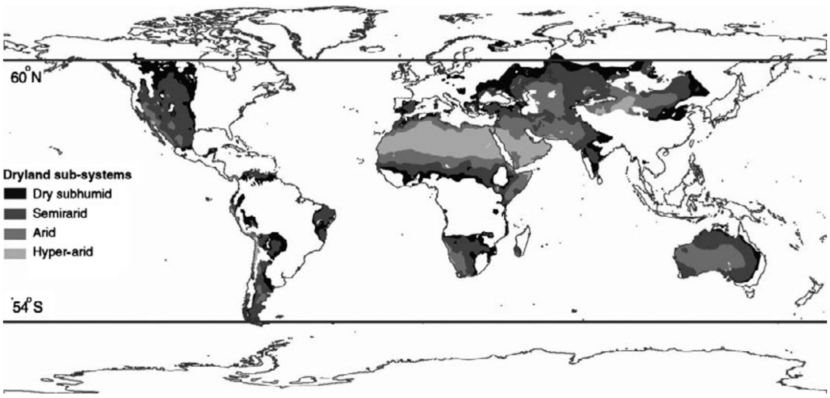

Fig. 1. The world's dryland zones based on an aridity index <0·65 (Safriel *et al.* 2005).

Keeping wildlife in or people out?

A well-constructed, well-maintained fence can be wildlife proof, but can never be human proof. Even the most heavily fortified fences have not prevented the illegal killing of white rhinoceros *Ceratotherium simum* and black rhinoceros *Diceros bicornis* in South Africa over recent years (Woodroffe, Hedges & Durant 2014). People are likely to be able to circumvent any fence, but they may also destroy fences in order to gain access to useful resources on the other side of the barrier, such as bushmeat, ivory, honey, medicinal plants and grazing. In doing so, they may make the fence permeable to wildlife, and sometimes wildlife may not be able to find their way back through the fence. The fence itself may also serve as a readily available source of snare wire, rendering a fence erected to protect wildlife from bushmeat extraction counterproductive (Lindsey *et al.* 2011, 2013; Becker *et al.* 2013). Alternative fencing materials, such as kinked mesh wire, can reduce this risk, but they are not well known to local management agencies, difficult to source and more expensive. Thus, they are less likely to be adopted, particularly in government fencing programmes that may be focused more on protecting people than wildlife.

A fence can reduce human–wildlife conflict, but may also prevent people from accessing benefits from nature and adversely impact the development of community-based incentives for wildlife conservation (East *et al.* 2012; Gadd 2012). Moreover, a fence may also contribute to the loss of coping strategies that have enabled communities to coexist with wildlife. Thus, if a fence, after erection, is lost or breached, human–wildlife conflict may reach levels much higher than those that existed prior to the establishment of the fence (Gadd 2012). Hence, it is critical that, once erected, a fence is maintained as an impermeable barrier. Wildlife often inflicts small breaches in a fence, necessitating frequent and costly ongoing maintenance to sustain its effectiveness as a barrier (Lindsey, Romañach & Davies-Mostert 2009; Kesch, Bauer & Loveridge 2013). Thus, the initial capital construction costs are only a small part of the investment required.

Developing an evidence base to evaluate dryland fencing interventions

Scientific understanding of the costs and benefits of fences is still in its infancy (Somers & Hayward 2012) and is currently inadequate to support sound policymaking. Here, we identify six research areas where incomplete or poor information hinders the wise use of fencing (Table 1). For the purposes of this discussion, we consider perimeter fencing of reserves, but our analysis is relevant for other large-scale fencing interventions, such as the increasing use of fencing to safeguard oil or gas pipelines and transport networks.

1. *Economics*. Economic costs form the basis for many conservation policies, but we still know very little about the ability of different conservation interventions, including fencing, to deliver conservation success for a given cost (McCreless *et al.* 2013). This makes it very difficult to assess the relative expenditure to benefit ratio of fencing against other alternative interventions (Possingham *et al.* 2001). Yet, the economic assessment of fencing is fundamental to sound policy decisions since limited conservation resources must be spent wisely to deliver sustainable solutions and maximize conservation impact. The only economic analyses conducted on the efficacy of fencing do not control for the apportioning of the overall budget to other reserve management activities (i.e. Creel *et al.* 2013; Packer *et al.* 2013), and only the most well-financed reserves are able to afford fencing interventions. Thus, it is not possible to disentangle the benefits of fencing from those of other investments such as anti-poaching efforts, community engagement, infrastructure investment and other activities that potentially confound the effect of fences on the effectiveness of a reserve and the density of a focal species. Without such an analysis, it is impossible to ascertain whether a budget increase, which allows fencing interventions and subsequent management, would deliver better outcomes for conservation and communities compared with investing the same funds in other reserve management strategies, such as community engagement and anti-poaching, without any fencing. A proper comparison of alternative strategies using long-term data and metrics of conservation success must include short-term capital costs, which can be considerable for fencing, as well as recurring maintenance costs.

2. *Edge permeability*. Fencing an already existing abrupt transition (i.e. 'hard edge') between a reserve and the surrounding anthropogenically modified landscape can be part of the justification for fencing interventions. Fencing of such habitat edges prevents the movement of wildlife beyond the reserve, where they might forage in crops or kill livestock. A presumed 'hard edge' suggests that negative impacts on wildlife from the fence due to restriction in movement will be minimal since the surrounding modified landscape is often viewed as comprising marginal habitat. Yet, the actual permeability of the edge will be species- and system specific, as well as context specific (Ries & Sisk 2010). Understanding what constitutes a hard edge for different species in the context of overall conservation and management objectives of fencing interventions is necessary to assess whether a 'hard edge' justification is appropriate.

3. *Reserve design*. A landscape perspective on fencing implementation is critical as the impacts of a fence on wildlife, ecosystems and communities depend on its location relative to the broader ecological context (Soulé & Terborgh 1999). Dryland protected areas often have boundaries delineated by key resources that may be shared by wildlife and humans, such as major rivers that

Table 1. Evidence needs and potential data that can be used to evaluate fencing interventions in drylands

Research issue	Question	Evidence needs	Data
Economics	Is fencing a cost–effective and sustainable approach to deliver conservation success?	How do different conservation activities compare with fencing under similar operating budgets, bearing in mind the substantial capital and maintenance costs required for fencing? Is fencing economically more or less sustainable than other options?	Reserve expenditure reports broken down by management activity Data on fence integrity Measures of conservation success
Edge permeability	Does the boundary to be fenced constitute a hard edge?	What is the definition of a hard edge and how does this vary between species and ecosystems?	Remote sensing data Wildlife movement and distribution data on the edge of protected areas
Reserve design	How does the reserve's design impact the costs and benefits of fencing?	What is the impact of reserve shape? If reserve boundaries lie on key landscape features and resources, such as rivers, then how will this mediate the balance between costs and benefits of fencing for wildlife and people?	Protected area database Remote sensing data Geographic information system (GIS) layers Wildlife movement and distribution data in relation to landscape and resources Contribution of resources to local livelihoods
Connectivity	How important is connectivity to the overall goals of the reserve and ecosystem function?	How important are wildlife movements into and out of reserves to their population viability? How does a fence affect wildlife movements and does it prevent wildlife from accessing key resources? Which species are most vulnerable to reserve isolation? What constitutes connectivity for these species? What are the impacts from the restriction of wildlife movement due to fencing on ecosystem function?	Remote sensing data GIS layers Wildlife movement data in fenced and unfenced areas Wildlife habitat and resource use data inside and outside the reserve Map of potential barriers to movement Map of potential areas of connectivity Measures of immigration and emigration for wide-ranging wildlife Life-history and survivorship data for wide-ranging and dispersing species
Ecosystem services	How does the establishment of a fence impact delivery of ecosystem services?	What is the relationship between habitat subdivision and carrying capacity? How does fencing affect delivery of ecosystem services? If the fence is to entirely enclose a reserve – how will this affect the viability of low density and wide-ranging species within the reserve? (If such species require intensive management, then this should be included in the economic costing of the fencing intervention) How does fencing affect the interactions between ecosystem service delivery and rainfall and productivity? How is climate change likely to affect ecosystem resilience and how is this likely to be impacted by fencing?	Remote sensing data GIS layers Protected area database Wildlife surveys Demographic data and population viability modelling Climate data and climate change predictions
Communities	What are the benefits and costs to local communities of fencing and how are these distributed between individuals?	What legal and illegal benefits do the communities derive from the presence of the reserve? How are these benefits distributed within the community? What are the costs to communities from the presence of the reserve? How are these costs distributed within the community? How will fencing affect these costs and benefits? Who is likely to benefit from fencing and by how much, and who is likely to pay the costs and by how much?	Game scout and ranger patrol reports Resource extraction data Socio-economic data from households within local communities around fenced and unfenced reserves including: Wealth and livelihoods Distribution of resources Costs and benefits from wildlife

are accessed by both people and wildlife. Fencing interventions to separate people and wildlife may result in a barrier preventing access to the resource for wildlife, preventing access for human communities, or both. Productive agricultural land or key habitats, such as wetlands, may also border reserves (Watson *et al.* 2013) and play key roles for ecosystem function and local communities. The impacts of fencing in relation to the design of reserve boundaries, and how to mitigate these impacts, need to be better understood.

4. *Connectivity*. Connectivity is fundamental to the long-term viability of many wildlife populations, particularly migratory and nomadic species common to dryland systems. Dryland reserves often do not cover the entire extent of an animal's range and may often be placed in either dry or wet season ranges for migratory or nomadic species (Fynn & Bonyongo 2011). In such situations, perimeter fencing of reserves, preventing access to critical seasonal resources, can lead to collapse in the populations of these species (Gadd 2012). Moreover, access to ephemeral resources may also be critical to the long-term survival of some species. For example, foraging or water resources in key areas outside a reserve may be important for the survival of long-lived species, such as elephants, during extreme climatic events (Foley, Pettorelli & Foley 2008). Identification of those species that are most vulnerable to reserve isolation and developing a clear understanding as to what constitutes connectivity for such species is key to evaluating the ecological impacts of fencing interventions.

5. *Ecosystem services*. Beyond the specifics of the reserve site and design, there is also a need to better understand how the delivery of ecosystem services (e.g. soil and watershed protection, timber, plant and animal harvesting) is compromised or enhanced by fencing initiatives. Given the large-scale ecological processes that characterize dryland systems and the dependence of people and wildlife on them, it is unlikely that fencing will have no impact on ecosystem service delivery and access. Indeed, studies show that simply subdividing land in drylands can substantially reduce overall grazing carrying capacity (Boone *et al.* 2005). Soil-based ecosystem services, such as nutrient recycling and water capture, are particularly vulnerable to degradation in drylands (Parr *et al.* 1990), yet there is no information on how these services may be impacted by fencing. An understanding is needed as to how fencing might hinder or help meet a reserve's overall biodiversity conservation goals and the continued delivery of ecosystem services, as well as how this may be modified by climate change.

6. *Human communities*. Many protected areas permit some limited access for local communities, and some of the poorest and most marginalized members of communities may be particularly dependent on natural resources from these areas (Loibooki *et al.* 2002; Brashares *et al.* 2011). Fencing interventions are likely to make legitimate access more difficult, and risk marginalizing these individuals still further. Local communities are heterogeneous; some individuals may suffer the costs of wildlife, in the form of crop and livestock depredation for example, while others may benefit from wildlife through tourism and hunting revenue or associated ecosystem services (Thompson & Homewood 2002), and hence, the costs and benefits of fencing interventions are likely to be unevenly distributed between households. While it is important that conservation interventions maintain the integrity of reserves, they should avoid contributing to or exacerbating existing inequities within communities. A better understanding of the socio-economic impacts of fencing is needed to avoid such unintended consequences on local communities.

The information from these six major research areas is key to a proper evaluation of fencing interventions. Such evaluations need to be carefully undertaken in the context of the aims of the proposed fencing intervention. For example, fences designed to keep wildlife in versus those meant to keep people out are two substantially different objectives, which in turn will likely have variable success and impacts. Any evaluation also needs to be undertaken in the context of the overall management goals for each reserve; rarely, for example, are such goals focused on a single species as per the analyses of Packer *et al.* (2013).

While the information required for these evaluations may appear extensive, in reality, many of these research areas can be addressed by collating and analysing existing information, or by implementing targeted monitoring and evaluation of new fencing interventions (Table 1). For example, most protected areas have documented expenditure reports; measures of reserve design are available from the protected area database; and remote sensing data can be used to delineate edge permeability and monitor the delivery of some key ecosystem services (Ayanu *et al.* 2012). There are, however, some areas where additional information is required. For example, while research areas such as ecosystem service delivery may be measured using remote sensing data, there are others, such as wildlife abundance or species diversity, which require direct sampling. There is also a need for improvements in our understanding of movement patterns, and what constitutes barriers to movement, for many wide-ranging wildlife species. Such information could be provided through fitting satellite or GPS collars to target species. Regardless of the availability of ecological data, a clear information gap is the socio-economic impacts of reserves on local human communities, and there is a clear need for detailed socio-economic studies on people living close to fenced and unfenced wildlife areas.

Towards policy guidelines on large-scale fencing interventions for drylands

It is clear that fences erected to protect wildlife or people can be a useful conservation tool, but can also be counterproductive. Guidelines, which take into account species-specific requirements, ecological conditions and human communities would help conservation practitioners better evaluate large-scale fencing interventions. The United Nations Convention on Migratory Species (CMS) is ideally suited to lead such guideline development, given the CMS's focus on wide-ranging species, experience with fencing as a management tool, and recognized expertise in conservation action for arid areas (e.g. CMS 2011).

The United Nations Convention to Combat Desertification (UNCCD), because of its mandate for sustainable management of drylands, is also well placed to engage with the breadth of the proposed research agenda. The UNCCD is one of three treaties developed from the United Nations Earth Summit in 1992 and aims to prevent and reverse land degradation and to mitigate the effects of drought and is particularly relevant to developing countries, where most drylands are located. As well as CMS and UNCCD, the Food and Agriculture Organisation of the United Nations (FAO) has an important role to play in the sustainable management of drylands.

Neither the CMS or UNCCD currently provides general policy guidelines as to the use of large-scale fencing, nor does the FAO. Better understanding of the impacts of fencing interventions would facilitate the development of appropriate policies to help communities and governments to improve sustainable management of drylands. Developing policies and guidelines for assessing when, where and the type of fencing that should, or should not, be used in drylands would help to prevent a repeat of the past harm done by fences to people, wildlife and ecosystems. Preventing further degradation is likely to require solutions within an integrated landscape approach to conservation that acknowledges local communities as part of the ecosystems (IIED 2013).

Many large-scale fencing interventions are likely to impact multiple countries; hence, it may also be useful to make use of regional economic structures, such as the SADC, East African Community (EAC), West African Economic and Monetary Union (UEMOA) and South Asian Association for Regional Cooperation (SAARC), and target bilateral and multilateral donors, to enforce guidelines and to help promote the need for full environmental impact assessments (EIA). These structures could also be used to ensure that all large-scale fencing interventions have a practical and achievable long-term maintenance and financing plan to guarantee the long-term integrity of the barrier once established. We recommend active engagement of these organizations in contributing to the improvement of knowledge of the impacts of fencing in drylands and in the development and implementation of policy guidelines.

Despite the high capital costs, fencing can initially appear to be an easy solution. Yet, unless fencing strategies have local community support and a financing plan to meet the expensive long-term costs of fence maintenance, there is a danger that they may generate more problems than they solve. The research agenda proposed will generate information necessary for better evaluation of fencing interventions that take into account the full range of likely impacts in dryland systems. Ultimately, there is a need for funding agencies to increase support for these areas and their marginalized peoples and develop better management strategies to sustain dryland ecosystems (Mortimore *et al*. 2009). The CMS and UNCCD could help to prevent further degradation of these important systems by leading global efforts to develop an understanding of the impacts of large-scale fencing interventions in drylands and establishing guidelines to regulate their use.

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Data accessibility

Data have not been archived because this article does not contain data.

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