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Veld restoration strategies in South African semi-arid rangelands. Are there any successes?—A review

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Rangeland deterioration is a major challenge faced especially by communal farmers in most of the developing countries including South Africa. The high population of people and livestock exert pressure on the rangeland leading to deterioration which results to economic loss, due to a reduction in agricultural activities such as livestock production. The rehabilitation of degraded lands has substantial returns from an environmental, economic and social perspective. Except for the powerful economic justification, initiation of restoration and rehabilitation of lands is still required to address the continuing land degradation across the world. To gain an insight on the impact of rangeland degradation, the basic restoration strategies need to be assessed and implemented. In this review, we have highlighted an overview of rangeland degradation in South Africa; Livestock dependency in rangelands; causes and consequences of rangeland degradation which include the economic impact of rangeland degradation; and rehabilitation strategies. Soil, climate, grazing management are some of the major factors to consider when adopting the veld restoration strategies. In South Africa, all restoration methods can be practiced depending on the area and the nature of degradation. Moreover, past land use system records and rehabilitation resources such as material and skilled labour can be required to have a successful rangeland rehabilitation.

KEYWORDS
rangeland rehabilitation, rangeland deterioration, ecosystem, livestock, economy

1 Introduction

Generally, rangelands are commonly denoted as pristine or natural ecosystems primarily inhabited by a diversity of vegetation that includes forbs, natural grasslands, and shrubs or trees, which are suitable for livestock grazing and wildlife (Allen et al., 2011; Zerga, 2015). About 25% of the total land surface worldwide is natural arid and semi-arid rangelands (Liebig et al., 2006; Alkemade et al., 2013). Rangelands have the most land re-sources in Africa, accounting for approximately 65% of the total land surface, as demonstrated by Nalule (2010), and provide a variety of ecologically, culturally, biologically and socioeconomically beneficial goods and services (Asner et al., 2004; Liebig et al., 2006; Mussa et al., 2016).

Typically, rangelands play a critical role as a primary source of feed for both livestock and wildlife (Moyo and Swanepoel, 2010). Nonetheless, rangelands provide other secondary resources such as medical plants, firewood, wild foods and support livelihoods through the provision of essential foods such as milk and meat as sources of nutrients (Mannetje, 2002; Zerga, 2015). The provision of animal products helps smallholder farmers to generate income and also improve household nutrition through sales and consumption of those animal products (Asner et al., 2004). According to Abusuwar and Ahmed (2010), herbivore productivity is generally considered poor in communal grazing systems due to rangeland degradation caused by the heavy grazing, availability of the low-quality pioneer species, invasiveness of unwanted species, climate change and sub-optimal resource use activities.

The impact of land degradation is found to be the major challenge in rangelands world-wide (Palmer et al., 1997). As documented by United Nations Environment Program, 1992, approximately 7–14 million square kilometers of global land is affected by land degradation and an estimation of about 75% of the world`s grazing land has already deteriorated to the point where it has lost a minimum of 25% of its animal carrying capacity (Harrison & Pearce, 2000; Moyo et al., 2013). According to Reynolds et al. (2007) and Myburgh (2013), it has been estimated that about 15%–25% of semi-arid areas have been significantly degraded, which means that soils have been exposed to severe climatic conditions and significant erosion has occurred, allowing nutrients to run off the land surface. Every year, approximately 25,000 ha of agricultural land surface become too degraded for crop production (UNEP, 1992). According to Donald and Jay (2012), reduced food security, famine, and hunger are some of the effects of increased land degradation and drought. The influence of land degradation is greatest in the world's arid and semi-arid areas (Snyman and Du Preez, 2005). All over the world, the problem of rangeland degradation is well documented and proven that these rangelands are more susceptible to degradation over time (Palmer et al., 1997; Hoffman and Todd, 2000; Mekuria and Aynekulu, 2013). Due to the increasing of human population (3.2 billion) around the world, the loss of biodiversity and ecosystems can normally lead to a delay in the development of sustainable goals (Scholes et al., 2018; Mani et al., 2021). Gibbs et al. (2015) indicated that almost one to six billion hectares of world land are highly degraded.

An estimated 25% of South Africa's natural arid and semi-arid rangelands are already degraded (Kellner and de Wet., 2021). Hoffman and Ashwell (2001) stated that poor grazing practices, the inappropriate use of fire, and poor soil conditions such as erosion and salinization cause land degradation. Furthermore, urbanization, mining and deforestation by clearance of woody plants, and other land use types lead to land degradation in these areas (Tizora et al., 2016). Overgrazing of sub-Saharan grasslands can be considered a form of natural resource disturbance, and is partly blamed for desertification (IFPRI, 2003).

For improved and sustainable livestock production and continued provision of other eco-system services, restoration technologies must be applied to combat deterioration in rangelands, particularly those that cannot recover easily. The fact that preserving existing habitats is insufficient to ensure the survival of the biotic community and that damaged systems often do not return to their form by natural successional processes in a reasonable amount of time in arid and semi-arid environments has made restoration an utter necessity (Van den Berg, 2002). According to Ravera (1989), reclamation of an ecosystem is usually complicated and very expensive to acquire, and a complete recuperation is unlikely be-cause certain ecosystem components may have been damaged during the degradation process. For sustainable livestock productivity, soil conservation and biodiversity in conventional agricultural systems, Kavana et al. (2005) proposed that modern scientific knowledge and traditional resource management should be complementary. Restoration objectives derived from geomorphological and ecological imperatives can be a scientific perspective (Kondolf, 1998). McDonald et al. (2004) reported that restoration is more of a method of altering the biophysical environment than a concept, and it captures the relationship between scientific definitions and social objectives. Landowners, administrators, and scientists have used a wide range of restoration methods in conservation and agriculturally managed areas all over the world. Bush clearing, reseeding, prevent erosion, grazing management practices, and some of the methods applied when restoring the rangelands (Liniger et al., 2011). The actual aim of rehabilitation is to restore an ecosystem to its natural state. Saco et al. (2006) indicated that the usual common aim in the rangelands is to promote palatable productive perennials grass species as they are beneficial to animal and other positive environmental output. One of the major obstacles to reduce land degradation and improve rangeland productivity, as well as promote the adoption of sustainable land management among agro-pastoral and pastoral communities, is a lack of rangeland management awareness and skilled rangeland management practitioners (Liniger et al., 2011). Even though the information on causes and consequences of rangeland degradation in the world and South Africa is available in literature, the best methods to rehabilitate the land can depend on the type of land degradation and management technique and or approached used. As a result, this review, describes the major causes of rangeland degradation and their effects; success and challenges of site-specific rehabilitation methods in degraded rangelands of South Africa are evaluated.

2 Livestock dependency in rangelands

The small-scale farmers' farming system has developed over time and is now managed by a complex cultural and social organization whose methods and needs are poorly understood by outsiders of the system (Abate, 2006). In arid and semi-arid areas, livestock production is the mainstay of the farming systems in both rural areas and ruminants are reared for a variety of reasons, such as meat, milk, manure, hides, cultural practices, and security purposes (Quirk, 2000). According to FAO (2009), ruminants are the most common users of rangelands, putting a strain on the biodiversity and natural resources. Over some years, the use of extensive grazing animal systems has shown that the animals tend to use a diverse range of grasses as their primary source of feed and impose variable pressure on the ecosystems (Bati, 2013). Rust and Rust (2013) argued that the majority of ruminant livestock populations around communal grazing lands in Southern Africa are dependent mainly on natural vegetation as a primary source of forage to meet their nutrient needs. In general, natural vegetation such as forbs, grasslands and browse species provide nutrients that are essential for ruminants feeding on extensive production systems (Bati, 2013). Rangelands as a whole can be considered the cheapest source of feed (Ismail et al., 2014), due to their capacity to feed a large number of livestock and their ability to meet the animal nutrients requirements. According to Mary-Howell and Martens (2008), there is spatial variation in the quantity and quality of forage and nutrients provided by rangelands. Assessment of nutritive value and estimating the carrying capacity of communal rangelands in arid and semi-arid areas is critical for designing effective livestock development interventions. This will encourage competitive livestock production while maximizing the use of local rangelands.

However, livestock production in many communal grazing areas of South Africa has been negatively affected by rangeland deterioration caused by overgrazing that leads to a loss of palatable grass species, and bush encroachment. These results in reduced herbaceous biomass which is dominated by low grazing value grasses that limit livestock productivity (Ward, 2005). Due to a limited information about livestock and grazing management, small-scale rural farmers are facing severe profitability constraints from livestock development on communal rangeland. Rangeland practitioners have a pressing need to improve the nutritional status of pastures in order to boost animal production, especially in areas where animal products are in high demand and where people's livelihoods are at risk, such as in developing countries (Boval and Dixon, 2012).

3 Rangeland degradation in South Africa

There are several definitions of rangeland degradation. Conacher and Conacher. (1995) defined land degradation as a process whereby biophysical environmental values are negatively affected by the contribution of human-induced processes on the land. Han et al. (2008) describe rangeland degradation as a decrease in plant height, forage production, vegetative protection, and grass diversity. Ndandani (2014) emphasizes that there is no single distinguishable description of land degradation, but all the meanings explain how various land resources (water, air, soil, and vegetation) have deteriorated from satisfactory to unsatisfactory conditions in the supply of ecosystem services. For example, rangeland degradation resulted in the transition from a favorable palatable perennial grass-dominated regime to an encroachment of unpalatable woody plants, shrubs and/or grasses (Snyman, 2004; Hare et al., 2020).

Rangeland degradation is still a major concern across Sub-Saharan Africa as it results in a drop in environmental quality and productivity, such as loss of cover, change in species composition, alien plant invasions, bush encroachment, and deforestation (Hoffman and Todd, 2000; Palmer and Ainslie, 2006; Jama and Zeila, 2005). Increases in woody cover are thought to affect 10%–25% of rangelands worldwide (Reynolds et al., 2007). Densification is expected to grow at a rate of 0.5%–2% per year globally (Cho and Ramoelo, 2019). The studies by O'connor et al. (2014) highlight that the state of woody species changes has moved from 0.13% to 1.28% per year. The arid and semi-arid rangelands of Sub-Saharan Africa, which are vital for livestock production, have been steadily transforming for the past few years and are now under pressure due to mismanagement of the rangelands (United Nations Environment Program, 1992). Increased hunger or starvation, food shortages, and decreased livestock production are other consequences of rangeland degradation (Al-bukhari et al., 2018). Rangeland ecosystem degradation poses a serious challenge to the African population, threatening communal societies and economies, as well as sustainable animal production (Darkoh, 2003; Wassie et al., 2020).

Even though rangeland deterioration is a global problem, it is particularly acute in Southern Africa's communal grazing lands (Hoffman and Todd, 2000; Moyo et al., 2013). With an estimation of 60% of South African land being degraded (Bai and Dent, 2007), 91% of this land degradation is due to desertification (Hoffman and Ashwell, 2001), as a result of overgrazing (Snyman and Du Preez, 2005). Le Roux et al. (2007) indicated that 70% of the South African land surface is affected by erosion, which causes a severe consequence on soil fertility and will result in lower soil productivity due to the different intensity of soil erosion. Belayneh and Tessema (2017) also pointed to bush encroachment as one of the factors behind rangeland degradation. In South Africa, rangeland management is

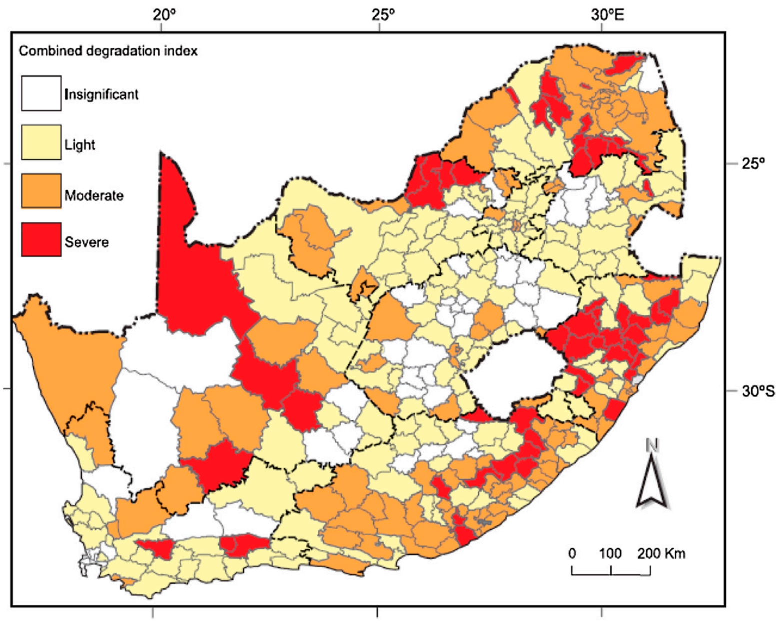

FIGURE 1
Combined degradation index of South African rangeland degradation, darker shading indicates areas with severe degradation. Adopted from Hoffman et al. (1999), Meadows and Hoffman (2002).

different in commercial livestock farms, wildlife (game) farmlands and communal areas, which are mainly found in the former "homelands" communal areas. Tokozwayo (2016) argued that communal production systems tend to be known for their composite nature since many individuals share the resources. Nevertheless, Moyo et al. (2013) stressed that in semi-arid of South Africa mismanagement of the rangelands has drastically reduced the capacity of the communal rangelands to produce sufficient livestock food. Also, a research study conducted by Ravhuhali et al. (2021) support that most of the communal grazing areas of South African rangelands, such as North-West province, are not well managed. Furthermore, Tefera et al. (2010) argued that poor grazing management has a negative impact on grazing rangelands, with the most desirable and high-grazing-value species being largely replaced by low-grazing-value and less desirable species. While, the study conducted by Meadows and Hoffman (2003) highlights that it is not only mismanagement that negatively affects South African rangelands, there are other environmental attributes that contribute to negatively impacting areas of the country that are already severely degraded, such as future precipitation changes coupled with other changes in climatic variables. The South African National Report on Land Degradation (NRLD, Wessels et al., 2007) indicates that the severity of rangeland degradation is predominantly confined largely to communal lands and small patches of commercial lands, although not all parts of the communal lands are degraded. Again, Wessels et al. (2007) stated that communal areas are characterized by increased human and animal populations, bush encroachment, overgrazing, climatic change, soil erosion, excessive wood removal, loss of more palatable grazing species, and drought are among the well-known and are thus significantly regarded as degraded. However, mapping and quantification of the extent of the problem are hampered by a weak database. Erosion is considered a pernicious threat to the productivity of the land and to water resources (Critchley and Netshikovhela, 1998). Below, Figure 1 represents South African land degradation with a combined degradation index.

3.1 Causes of rangeland degradation

3.1.1 Bush encroachment and alien plant invasion (Woody densification)

In South Africa, bush encroachment occurs when there is a rise in the abundance of woody plants in previous grassland regions especially in semi-arid areas (Magandana, 2016), which is accompanied by changes in the herbaceous cover and composition of the natural vegetation (Safriel, 2009). The rapid spread of woody densification and invasion of woody plant species in arid and semi-arid rangelands of South Africa has been well established as a frequent form of rangeland degradation (Mussa et al., 2016). Msiza and Ravhuhali (2019) argued that rangeland vegetation alters from herbage to woody plants as the bush encroaches, resulting in the rise of bare patches

FIGURE 2
Bush encroachment, spread of acacia species around North West province of South Africa. Photo taken by H. S. and K. E.

in the area and a decrease in herbage cover. In the North West province of South Africa, the spread of acacia species has been noted to be the one encroaching the land in semi-arid zones (Figure 2) (Msiza and Ravhuhali, 2019). Woody vegetation expansion decreases the relative amount of forage grasses, and rangeland carrying capacity with adverse effects on animal productivity (Al-bukhari et al., 2018). Reduction of forage and grasses decrease grazing capacity and livestock carrying capacity, as demonstrated by Long et al. (2010). The grazer carrying capacity can be reduced by up to 89% in severe cases (de Klerk, 2004).

Several authors have reported the worldwide challenges of densification such as threatening the herbaceous layer, and weakening the ecosystems services (Asner and Heidebrecht, 2003; Wigley et al., 2010; Reich et al., 2019). Despite the fact that woody densification does not reduce primary production, it meets the IPBES definition of degradation by reducing certain ecosystem services and biodiversity over time (Díaz et al., 2019). The effects of woody densification on carbon stocks are mixed, and the findings are inconclusive. According to Berthrong et al. (2012), most sites lose soil organic carbon, but this is compensated for by aboveground carbon gains. Gebeyehu et al. (2019) found a decrease in carbon stocks in heavily disturbed areas when compared to the less disturbed sites, and this might have been due to the fact that woody encroachment normally increases the amount of carbon stored in the ecosystem as influenced by the amount of above-ground biomass.

The causes of woody densification is unknown, but it is thought to be heavy grazing, which causes grass loss thereby decreasing the potential of rangeland fires, which reduces competition between grasses and woody plants. At the end woody plants will outcompete the grasses. Furthermore, there is also mounting evidence that increased atmospheric CO_2 fertilization effects, which favour C3 tree growth more than C4 grasses thus aiding densification of woody species (Kgope et al., 2010; Higgins and Scheiter, 2012). In areas such as natural dense sites, there is an increased CO_2 which normally contributes to the increase of woody species as this is due to better climatic conditions associated with greenhouse gas concentration and nitrate availability in the soil (Huang et al., 2007).

Invasive alien species have increased by 71% between 2006 and 2016 (O'Connor and van Wilgen 2020), are known for their negative impact on biodiversity and rangeland production (Ntalo et al., 2022) and as a result of that, they contribute to economic or financial loss around the world as they are the drivers of environmental changes (Richardson et al., 2014; Shackleton et al., 2014; Stanford et al., 2017). Though the beneficial effects of some of these alien species are observed, Shackleton et al. (2017) indicated that these species can have harmful effects on social ecological systems. The spread of alien species threatens livestock productivity due to their negative impact to the environment (Ntalo et al., 2022), and also affects the water supply (Ravhuhali et al., 2021). O'Connor and van Wilgen (2020) highlighted that the densification of woody species such as *Prosopis* spp., *Acacia mearnsii,* and *Pinus* spp., can reduce the herbaceous layer (reduce carrying capacity), leading to lower animal productivity.

3.1.2 Overgrazing

Rangelands in large parts of grazing areas in developing countries are not properly managed (Ravhuhali, 2018). Jeddi and Chaieb (2010) indicated that the grazing systems practised in

FIGURE 3
Aristida species, less palatable grass species. Photo taken by H. S. and K. E.

communal areas such as continuous grazing are the most common causes of communal rangeland degradation. Excessive heavy grazing has frequently been blamed for the resultant decline in biodiversity in arid and semi-arid regions. Overgrazing is a huge threat in most parts of South Africa's rangelands, and according to Smit (2003), is one of the major causes of woody densification (bush encroachment). It is believed that the increased bush encroachment in the savannahs of Africa has been caused by the removal of wildlife animals and replacement by domestic livestock which mainly graze than browse. Furthermore, communal areas have high stocking densities (Owen-Smith, 1989), which lead to poor grazing management (Smit, 2003). Barac (2003) and Van den Berg (2007) argued that excessive overgrazing leads to soil cover (top soils) exposure to runoff, compaction of soils, soil erosion, decrease in carrying capacity, and changes in species composition as well as bush encroachment. Ravhuhali (2018) stressed that overgrazing pressure leads to subsequent changes in botanical composition, species diversity and soil moisture properties. Overgrazing pressure, which occurs in tandem with an increase in livestock and human population, has been reported to result in an increase in less palatable grass species, and woody plant species in communal rangelands (Chipika and Kowero, 2000; Kraaij and Ward, 2006). Figure 3 below presented semi-arid area located in North West province South Africa which is infested with less palatable grass species such as *Aristida* spp.

In addition, domestic livestock grazing on local communal grazing areas has a negative effect on soil, hydrology, and local vegetation (Ibanez et al., 2007). According to Saini et al. (2007), negative impacts of poor livestock grazing systems result in a loss of plant cover, diversity, and productivity, topsoil disruption, and soil compaction because of animal trampling, resulting in decreased water penetration and increased erosion (Figure 4), aggravating the effects of drought (Taube et al., 2013; Tesfahunegn, 2018). According to Sullivan and Rohde (2002), animals selectively graze plants according to their dietary preferences (palatable herbaceous plants), resulting in an increase in unpalatable herbaceous plant species (pioneers, annual plants, and bushes), and leading to a reduction in species richness (Figure 3). Grazing pressure has resulted in a decline in rangeland condition around the world, as well as a decrease in forage quality and quantity (Kirkman and de Faccio Carvalho, 2003).

3.1.3 Climate change

The challenges of biodiversity and climate change are global problems with complex causes that vary in different parts of the world (Lüscher et al., 2014). Climate change is the primary driver of rangeland dynamics in both arid and semi-arid regions, particularly in Africa (Bloor et al., 2010; UNCCD, 2015). Changes in vegetation diversity, soil profiles, hydrological cycles, and rangeland water patterns all lead to land degradation, and all of these are the results of climate change (Hopkins and Del Prado, 2007). As the rangelands are affected by climate change, farming and grazing systems are also altered as a response to the increased precipitation variability and intensity of floods and droughts, particularly in semi-arid and arid regions (Nicholson, 2000; Mussa et al., 2016). According to Zerga (2015) and Fereja (2017), climate change had vast negative impacts on the rangelands, which include a decrease in plant diversity, topsoil, water scarcity and enhanced rangeland deterioration. In recent years, South Africa, has experienced increased drought frequency and severity that lead to approximately 10% of soil moisture decline across most semi-arid regions (Hermans and

FIGURE 4
Photo displaying soil erosion and bare patches in some grazing area around semi-arid area in North West province of South Africa. Photo taken by H. S. and K. E.

McLeman, 2021) and with the high temperatures drawing salt to the soil surface (Ramamurthy and Pardyjak, 2011). Because of frequent droughts in Africa, notably in South Africa most woody cover has been enhanced due to its high ability to survive extreme temperature, which is more unfavourable to grasses and other herbaceous species (Teague and Smit, 1992). Ward et al. (2014) stressed that the growth of woody plant trees in South Africa is favoured by the increased levels of atmospheric (CO_2) accumulated in the area. The high growth of C3 plants (trees) versus the C4 (grasses) serves as evidence that the increased levels of atmospheric CO_2 in semi-arid environment plays a huge role in bush encroachment (Ward, 2010). According to Wigley et al. (2010) the increased concentration levels of atmospheric CO_2 in a given environment tend to lead to high biomass of the roots which normally causes the rapid re-growth of C3 (woody trees) plants after the above-ground biomass has been disturbed by various factors such grazing, fire as well as other anthropogenic factors.

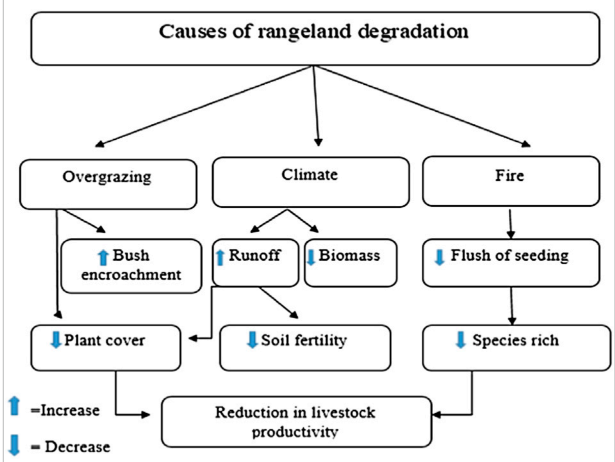

FIGURE 5
The schematic presentation of the process of degradation. Adopted from Ravhuhali (2018).

4 Impacts of rangeland degradation

The impacts of rangeland degradation are presented in Figure 5. Rangeland degradation has a significant impact on the livelihoods of inhabitants of communal areas and the economy of South Africa due to its deleterious impact on rangeland condition (Rouget et al., 2006), soil profile (Mekuria et al., 2007), and livestock productivity (Kwon et al., 2015). These communal area inhabitants tend to lose their livestock assets and become destitute. As a result, the local population normally experiences food insecurity, and the government has to provide assistance to maintain food security and sustain livelihoods through alternative sources of revenue diversification and other sources of money (Teshome and Ayana, 2016). Solomon et al. (2007) indicated that in other countries such as Ethiopia, this leads to poverty and tribal disputes over grazing land and water supplies in the long term. In addition, bush encroachment has been shown to affect 10–20 million hectares of agricultural productivity and biodiversity (Ward, 2005) and has emerged as one of the top perceived rangeland problems in about 25% of South Africa's districts (Hoffman et al., 1999).

Most farmers normally prioritise livestock more than the resources available to sustain the livestock. Due to the unregularly usage of rangelands, high stocking rates can result in plant cover and species diversity reduction, leading to rangeland degradation which will negatively affect animal production (Ravhuhali, 2018). Rangeland degradation can result in a depletion in soil quality (Nutrients loss, poor soil structure, soil compaction, unbalancing of elements, high salination and acidity) due to human and climate change (Eswaran et al., 2001; Mekuria et al., 2007). Eswaran et al. (2001) highlighted that there is a severe economic impact in most parts of semi-arid zones through nutrient depletion as a form of rangeland degradation. These nutrients leaching from the land can affect plant growth and yield.

Rangeland degradation can alter the species composition of the herbaceous layer. Through overgrazing, the grass species diversity declined, followed by infestation of unpalatable pioneer species and some invasive non-native species in a space of perennial and high grazing value grass species (Huxman et al., 2005; Wheeler, 2010), and this can affect the sustainability of ruminant animal farming (Nenzhelele, 2017).

Due to the increasing population globally, the demand for animal products tends to increase. The biggest threat of rangeland degradation lies in the sustainability of livestock. The reduction of animal production normally happens as a result of land degradation (lack of palatable and more nutritious grass species). The number of livestock, animal gains, low reproductive rate, and more mortality are some of the rangeland degradation highlights (Tesfa and Mekuriaw, 2014).

5 Rehabilitation of the degraded rangelands in South Africa

Understanding the conservation of existing ecosystems is insufficient to secure the future of the world population (Yirdaw et al., 2017). Degraded ecosystems in semi-arid areas often do not improve under the natural process of succession within short periods of time to a potential that can be utilized for livestock production (Van den Berg, 2002). Kellner (2000) and Tuffa et al. (2017) stressed that restoration is a possible intervention once vegetation transitions and rangeland conditional states tend to cross the threshold limitations for natural recovery. Several authors have described rangeland improvement efforts using various terminology, such as reinforcement, rehabilitation, reclamation, re-vegetation, and restoration (Le Houerou, 2000; Bainbridge, 2003). Most of these terms are used to characterize restoration ecology in the context of the current review.

The ecological restoration is known as the process of maintaining, conserving and repairing the world's ecosystems (Schlesinger et al., 1999) after they have been degraded, damaged, or destroyed (Bainbridge, 2007). Harris et al. (1996) stressed that ecological restoration is the process of restoring the diversity and dynamics of indigenous ecosystems to their original condition before any decline. Ecological restoration may require considerable investments in decision support tools and associated outlines or frameworks that can help to ensure and guarantee that the technique is successful and that the restoration goals are accomplished. Restoration techniques are required worldwide, notably in Africa's communities in order to restore the communal rangelands' structure and functions. These restoration techniques can help with social, economic and environmental problems not only in South Africa, but also around the world. Rangeland restoration may help local communities adapt to land degradation, desertification problems and climate change by providing alternative food security in Sub-Saharan regions (Mureithi et al., 2016).

To ensure proper rehabilitation of degraded rangelands, we need to understand how they functioned before they were degraded, and then use this knowledge to reinstate essential processes that are highly needed (Fayiah et al., 2020). Generally, there are two types of restoration depending on the degree of damage, which include passive and active restoration. According to Kauffman et al. (1997), active restoration means manipulation of biota through reintroducing animal or plant species that have extirpated from an area, while passive restoration means the restoration of degraded ecosystems by removing anthropogenic perturbations that are causing degradation. For effective rehabilitation of the rangeland, we can use numerous active restoration practices such as direct seeding, reseeding, or passively by allowing the progression of natural regeneration. In addition, water and soil conservation measures, water harvesting, surface scarification, grazing/livestock management, control of bush encroachment and the use of controlled fires (Figure 6) (Li et al., 2011) are other active restoration activities. The following are some of the most frequently utilized approaches for rehabilitation of degraded rangelands.

5.1 Management of bush encroachment (the removal of encroached trees and invasive species)

Bush encroachment has received increased attention recently, notably in South Africa, and it is now one of the

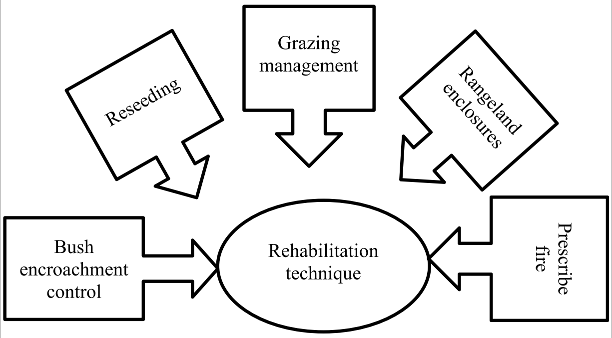

FIGURE 6
A diagram showing some of the techniques when rehabilitating the rangeland. Adopted from Li et al. (2011).

most prevalent forms of rangeland degradation all over the world (O'connor et al., 2014). Because it is one of the most prominent factors of degradation in rangelands, it is important to control bush encroachment and rehabilitate the rangeland to its normal form. According to Angassa and Oba (2008) and Mussa et al. (2016), bush encroachment control is described as a method of reducing and suppressing the excessive spread of invasive woody plant community structures and shifting the rangeland vegetation from woody tree domination to herbaceous vegetation in order to create a suitable habitat for grazers. To accomplish this, we can employ a variety of ways of controlling bush encroachment that are well known, viz, mechanical, chemical, and biological technique. Nevertheless, for a better degraded rangeland rehabilitation, integrated approaches are recommended (Belachew and Tesema, 2015).

One of the studies conducted in South Africa, it shows that with the appropriate management and control of woody encroachment and alien plant invasions, the ecosystems can be rehabilitated to its normal form (Stafford et al., 2017). The same authors stressed that the removal of woody plants community will likely decrease the amount of atmospheric CO_2 in an ecosystem since the woody plants are a significant carbon sink. Several authors in South Africa have investigated various techniques to restore heavily encroached rangelands and those invaded by alien plants, and they include the use of fire (Trollope, 1974; Kraaij and Ward, 2006), chemicals (Wigley et al., 2010), and competent grazing management (Lesoli et al., 2013). The study by Smit et al. (2016) revealed that the application of high intensity fire treatments reduced the tree species by up-to 70% in Kruger National Park. Gordijn (2010) recommended one burn every 2–4 years for the best output through the use of fire on the encroached areas. Debushing through mechanical is one the most affordable bush encroachment control done by farmers around semi-arid areas of South Africa. Most of the famers around North West province are applying this particular methods in controlling bush encroachment (Figure 7). Kellner and de Wet. (2021) also found that introducing different restoration treatments (which include clearing, soil disturbance, brush packing and reseeding (CSRSBP); clearing and brush packing (CBP); and clearing, brush packing and reseeding (CRSBP) increased the carrying capacity of some selected rangelands in South Africa. However, there are some significant risks in terms of attaining the ecosystem service benefits from rangeland restoration techniques. Although there are numerous risks, the benefits from restoring rangeland affected by bush encroachment and alien plant invasions depends on the subsequent land use and land use practices (Lesoli et al., 2013; Stafford et al., 2017). Ultimately, proper management of bush encroachment and invasive alien plant species can deliver significant ecosystem services benefits that surpass costs of restoration.

In addition, to be successful in rangeland restoration initiatives, indigenous traditional knowledge of the local community should be included, as well as the promotion of awareness and an integrated strategy by rangeland practitioners (Patel, 2011; Tessema et al., 2011). Alien invasion and bush encroachment problem has become a major concern in African rangelands, as well as in South Africa, notably in the Savannah biome rangelands, it transforms grasslands into shrublands by competing with herbaceous fodder and reducing the stocking rate (Abule et al., 2007; Angassa and Oba, 2008). Controlling the bush encroachment can assist in establishing a grazing area with palatable herbaceous species for the livestock, and if done consistently, it can help stabilize rangelands and reduce the negative consequences of future feed and food shortages. The combined actions of regulating fire, controlling grazing and cutting can prevent woody species succession (Sawadogo et al., 2002; Milton, 2004). Mussa et al. (2016) stressed that herbaceous vegetation generates more feed as the number of woody species declines.

5.2 The use of invasive species such as prickly pear to arrest the top soil loss

Species such prickly pear is one of the invasive species that normally disturb the vegetation due to its contribution to the reduction of carrying capacity and, most importantly, causing injuries to people and some livestock (Walters et al., 2011). They are also known for hampering livestock movement due to their thicket form. The invasiveness of this species can result in social and ecological costs (Shackelton et al., 2017; Pyšek et al., 2020; Seebens et al., 2021). In semi-arid regions, prickly pear especially its spines can be regarded as an excellent rangeland restoration, rehabilitation plant and can be used in the recovery of degraded and dry lands (Neffar et al., 2013). In South Africa, the role of prickly pear as a biological resource for adaptation in poor environmental conditions because of its resistance to dry lands has been reported (Habibi et al., 2009; Neffar et al.,

FIGURE 7
Mechanical method of controlling bush encroachment in communal grazing areas around North West province of South Africa. Photo taken by H. S. and K. E.

2013). This phenomenon is supported by findings of Singh (2004) that these invasive species have an ability to strengthen poor soils subjected to erosion and erratic rainfalls of arid zones. Apart from being an alien species, prickly pear has become a dominant plant in most countries, it spreads aggressively by anchoring top soils from degrading due to adverse climatic conditions (Milton and Dean, 2010; Sipango et al., 2022). In most semi-arid and arid regions, the use of prickly pear plants, which are salt tolerant and adapt to different soils makes them an ideal plant for sustainable agriculture production (Singh et al., 2014). Prickly pear adapt in poor degraded soils and facilitate the reduction of soil erosion (Sipango et al., 2022). This invasive plant species uses its extensive deep root stem to survive in severely degraded soils with a limited or no nutrient supply (Snyman, 2006; Sipango et al., 2022). Cactus species is well known as an invasive species which are defined as one of the non-native aliens that are harmful to the ecosystem [Convention on Biological Diversity (CBD), 2008; Pejchar and Mooney, 2009]. In South Africa, studies reported that cactus availability play an important part in the control of top soil erosion and degradation (Van Wilgen and Scott, 2001; Pejchar and Mooney, 2009).

5.3 Rangeland re-vegetation and reseeding

Introducing seed techniques in rangelands is extremely useful (Tessema et al., 2011), and very important for areas that have experienced prolonged veld degradation to fill up the bare patches. Degraded rangelands have been successfully rehabilitated in a short period of time by introducing native grasses that are well-adapted to the harsh environment of that area (Snyman et al., 2013), and this has also enhanced the necessary habitat for many local animals, which tends to improve animal production (Palmer and Ainslie, 2005; Opiyo et al., 2011). Several authors advocated for the use of grass reseeding as a cost-effective and successful rehabilitation technique for degraded rangelands, particularly in Africa, because most African countries are still underdeveloped, and the lower the cost, the higher the chances of its widespread use (Van Den Berg and Kellner, 2005; Mganga, 2009; Tilahum et al., 2017). Successful reseeding/re-vegetation, on the other hand, has been shown to be dependent on factors such as weed control, seedbed preparation, seed pre-treatment for improving germination and climatic conditions (rainfall, temperature and humidity) (Mganga, 2009). Snyman (2003) stressed that semi-arid rangelands, which have retrogressed beyond a certain threshold and cannot be rest-covered, can only be repaired by mechanical inputs in order to assist the re-establishment of rangeland vegetation. This is because most of these areas have already been severely damaged, and natural succession processes will make recovery difficult or practically impossible.

However, there are some studies conducted in South Africa where degraded rangelands have successfully recovered by the use of proper re-vegetation and rotational grazing, and high forage production and wood density reduction were observed (Bolo et al., 2019). Furthermore, due to their establishment rate and frequency over three seasons, Kellner and de Wet (2021) recommend restoration of degraded semi-arid rangelands by over sowing forage species such as *C. ciliaris* and *A. pubescens* in a sandy soils (8%–42%, respectively), and *D. eriantha*, and *C. gayana* (30%–64%, respectively) when the soils have more silt and clay. These species were also supported by Msiza et al. (2021). Knowing the soil type of the certain area assists in choosing the grass species that are well adapted to the environment and significantly reduce the over-sowing expenses, making this rehabilitation approach more accessible to land managers.

5.4 Grazing management (resting of the overgrazed areas)

Rangeland grazing management techniques are mostly focused on balancing livestock numbers with forage availability, equal distribution of animals in the veld, sustaining vegetation by alternating grazing periods and rest times, and utilizing the most suitable livestock (Mussa et al., 2016). In semi-arid areas, veld degradation is linked to poor livestock management, so it is critical to improve grazing management strategies in relation to the amount and kind of livestock, as well as the type of vegetation, in order to maintain productive and healthy rangelands (Mitchell et al., 2009; Ash et al., 2011). According to previous studies documented in South African degraded rangelands, the reduction of livestock numbers and controlled grazing activities optimize the grazing pressure in the veld and improve the chances of rangeland restoration. Woodfine (2009) corroborates the findings of that proper grazing management in degraded rangeland has great potential to restore and protect the biodiversity of the degraded area, as well as enhancing the processes and functions of the ecosystem. On the effect of precipitation and grazing-induced degradation on vegetation productivity, the same authors found that the normalized difference vegetation index of degraded areas were between 1.4% and 20% lower than non-degraded areas. Furthermore, Harmse et al. (2020) stressed that rotational grazing is one of the techniques successfully used to restore the degraded rangelands of South Africa.

Sankaran et al. (2005) stressed that a proper understanding of the effects of grazing management systems on vegetation ecosystem dynamics is required to maintain optimum carrying capacity and species diversity, since changes in species composition has a substantial impact on animal production sustainability. Grazing management is the best strategy for rehabilitating degraded rangelands in areas with poor vegetation cover, overgrazed, and have degraded soils, and this is considered the most promising initiative for restoring degraded rangeland (Woodfine, 2009), since it enhances the vitality of mature perennial grasses. Neely et al. (2010) argued that knowing the grazing history and ecological variation can assist when practicing timely grazing management and can enhance a positive impact on rangeland condition, as well as the functioning of dry-land hydrological systems and the restoration of biodiversity in the ecosystem.

5.5 Manipulation of the rangeland to improve livestock distribution

South Africa is a semi-arid nation and characterized by prolonged drought periods (Rountree et al., 2000) that have a negative impact on rangeland vegetation and soils. Interventions which involve manipulation of the distribution of watering points, shaded and rested areas, forage and mineral salts can be initiated to improve veld condition (Vaniman et al., 2004; Kapu, 2012). Animals are obviously attracted to water in arid areas, however the supplementation of salt and mineral was reported to have mixed results (Ganskopp, 2001; Vaniman et al., 2004). Even though veld recovery might become extremely difficult if soil quality deteriorates, the distribution of mineral salt and watering developments and fencing has been used successfully to improve veld conditions in arid regions. Mineral salt and major watering points such as water holes, troughs and dams can be strategic initiatives needed to limit and reduce grazing pressure in certain areas of the rangeland in arid regions (Porath et al., 2002). Mapiye et al. (2008) added that rangeland managers can manipulate South African rangelands and livestock productivity by using an appropriate planned fire type, season and burning frequency. However, prescribed burning must be integrated with other grazing management techniques in order to improve livestock distribution.

5.6 Rangeland enclosures

Rangeland enclosures halt grazing for a certain period, and is a common strategy that has been successfully examined in the rehabilitation of damaged rangelands (Mohammed et al., 2016). Based on their experience in various locations in Ethiopia, Mussa et al. (2016) found that rangeland enclosures are a good structure for rangeland restoration, as long as they completely specify their users, resource restrictions, and realistic norms originating locally. In South Africa, Bolo et al. (2019) and Treydte et al. (2021) highlighted that this can be an ideal method for improving vegetation regeneration and promoting land restoration for degraded lands than open grazing of rangelands. Milton et al. (1998) and Verdoodt et al. (2009) added that this can transform degraded rangeland to its productive stage, with an increased seedling proportions and the stimulation of high palatable forage density with the great chances of enhancing livestock production in South Africa. Gidey and Van der Veen, (2014) in Ethiopia and Nyberg et al. (2015) in Kenya reported similar results. However, if scientific and indigenous knowledge are not integrated, bush encroachment will become a major threat in these enclosures over time, as compared to more regular grazing rangelands (Ayana, 2005; Angassa, 2007).

5.7 Prescribed fire

Fire is a phenomenal force that influences the ecological process in woodland and grassland systems throughout the world, notably in African savannah biomes (Higgins et al., 2000; Hamman et al., 2011). Prescribed fires have a history of maintaining the diversity of grassland ecosystems in semi-arid regions by creating the vegetative composition of rangelands (Williams, 2003; McGranahan & Kirkman, 2013). Tefera et al. (2010) stressed that the main role of prescribed fires on rangeland is to suppress undesirable grasses, woody species, clearing, and controlling pests and wildfires to enhance desirable grasses' ability to regenerate, because through fire, unwanted seeds and trees can be destroyed when exposed to lethal temperatures. Fire is also known to remove dead plant materials on the rangeland and, because of this, can produce several benefits, such as an increase in grass nutritional quality, palatability and availability, as well as improving new grass growth (Croft et al., 2015).

In the South African rangeland, Mapiye et al. (2008) reported that controlled fires play a beneficial role in enhancement of proliferation of high quality forages through preventing the spread of undesirable C3 (woody plants) plants. However, fires can also remove desirable and palatable plant species if not carefully planned in advance and prepared appropriately according to seasons (summer and late autumn). This malpractice leaves behind the non-palatable big stemmed woody plant species, which tend to lead to rangeland degradation. Similarly, in the South African rangelands, early winter burns has been found to leave soil cover exposed to erosion and insolation throughout the winter season (Trollope et al., 1989), which lead to severe erosion and compaction with the first coming rainfall. Although, there is a lot of information regarding the positive effects in the use of fire as a management tool in South African savannah rangelands, the information needed to carry out specific prescribed burns is often disjointed (Mapiye et al., 2006). Van Langevelde et al. (2003) stressed that throughout the post-fire growth season, post-burned grassland vegetation had a higher aboveground nutrient content than unburned vegetation. Again, Coppock et al. (2007) and Gebru et al. (2007) reported similar results, on investigations conducted in Southern Ethiopia rangeland using fire to burn the land, and the vegetation cover of highly valuable grass (*Themeda triandra*) had increased from 18% to 40% of basal cover and the quantity of bare ground was drastically reduced after burning. The burning strategy, when combined with other suitable rangeland management strategies, can successfully minimize bush encroachment and increase forage production and quality for grazing animals. Government guidelines in South Africa recommend burning immediately after the first springs to improve the removal of amassed moribund and unwanted materials. Generally, without fire, organic waste and litter would accumulate, thus increasing tree density and eventually leading to woodland biomes.

6 Economic cost of rehabilitation techniques

Historically, economic development in most countries is based on the exportation of natural resources, particularly land resources (Worlanyo and Jiangfeng, 2021). Globally, land degradation has been the greatest threat, posing a major economic challenge for farmers (Zhao et al., 1991; Utuk and Daniel, 2015; Megerssa and Bekere, 2019). Degradation is hampering the developing world economically, and this is because of high human population pressure on land. Restoration of degraded lands is a positive return action from both an environmental and an economic and social standpoint (Arneth et al., 2001). The case study of Nkonya et al. (2016) reported that the money invested in land restoration yields high economic returns over the years. Except for the powerful economic justification, initiation of restoration and rehabilitation of lands is still required to address the continuing land degradation across the world (Mirzabaev et al., 2019; Hermans and McLeman, 2021).

Some of the main specific barriers to the restoration of degraded lands are a lack of financial benefit, prohibitive adoption costs, and a lack of knowledge (Mirzabaev et al., 2019). When compared to other approaches with no system baseline, spatial prioritization of restoration efforts could deliver benefits in biodiversity conservation and carbon storage at significantly lower costs (Strassburg et al., 2019). When land is restored, farmers breed animals at a high rate for economic considerations (Hermans and McLeman, 2021). It was reported that small camp erection by farmers has key implications caused by the cost of fencing (Hobbs and Harris, 2001). In the near future, the economic implications should be weighed against the future of rich biodiversity and the introduction of ideas that government subsidies to farmers should be reconsidered to lower the cost of these rehabilitation techniques on degraded lands (Cupido, 2005). It was discussed that economic and technical factors have an impact by hindering the effective restoration of degraded areas (Milton et al., 2003). Aside from financial suggestions, veld restoration may be hampered by a scarcity and lack of palatable grass seeds (Aronson et al., 2010).

The availability of funds for the seed companies to produce indigenous seeds rely on governments land care entities and these entities can fund research based on restoration techniques. The study highlighted that if the financial investments in rehabilitation techniques are not justified; veld restoration could be funded by ecosystem services (Mugido, 2011). Restoration of degraded lands is not only ecological, hydrological, and the focus of research; sound investigation rules and information are required to improve the success of restoration economically and practically (Hobbs and Harris, 2001). Furthermore, the rehabilitation cost depends on the density of space in that particular area, and rehabilitation costs are complex processes that involve economic implications (Spurgeon, 1999). Therefore, projects such as Land Redistribution (LRAD), Comprehensive Agricultural Support Package (CASP), Succulent Karoo ecosystem planning and local governments (SKEP) should be used as vehicles to reduce these challenges facing degraded veld by way of creating jobs in these regions through establishing indigenous seed farms (Esler and Kellner, 2001).

It was discussed that since degraded lands cannot contribute effectively to sustained economic development, land restoration is the best option to increase the chance of attaining sustainability and improve economic returns for farmers (Brown and Lugo, 1994). In this context, establishing a financial mechanism for compensating land users and improving ecosystem delivery could increase investment in land restoration and rehabilitation, and redirecting misdirected subsidies is a serious approach that must be taken (Wilson and Lovell, 2016). The cultivation of sustainable lignocellulosic energy plants provides economic returns while playing a part in the rehabilitation and restoration of degraded lands (Mentis, 2020). Even though the economic benefit of restoration, is higher than the cost of restoration land restoration could provide an economic return (WRI, 2017), more investments at the global level stage (Bakshi et al., 2014).

7 Summary

The best method for rangeland restoration is based on several factors, such as soil, climate and grazing management. Understanding rehabilitation strategies on degraded rangelands is critical for existing ecosystems in order to ensure the survival of living organisms. In South Africa, all restoration methods can be practiced depending on the area and the nature of degradation. Ecological restoration may need considerable capital injection, skilled labour, in decision support tools and the integration of other stakeholders that can help to ensure and guarantee that the technique is successful and that the restoration goals are accomplished. In order to have better rangeland rehabilitation programs, there should be records of the past land use system, and these records are needed to reinstate essential processes for successful rangeland restoration.

Author contributions

Conceptualization, HSM, NHM, NS, KER, HKM, and BM; Validation, HSM, NHM, NS, KER, HKM, and BM; Data curation, HSM, NHM, NS, KER, HKM, and BM; Writing—original draft preparation, HSM, NHM, NS, and KER; Writing—review and editing, HSM, NHM, NS, KER, HKM, and BM; Visualization, HSM, KER, and NS; Supervision, KER, HKM, and BM. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

Abate, A. L. (2006). *Livestock production challenges in the rangelands ecosystem of South Sudan paper presented at the workshop on environmental management plan for post-conflict Sudan, rah hotel*. Juba, South Sudan.

Abule, E., Snyman, H. A., and Smit, G. N. (2007). Rangeland evaluation in the middle awash valley of Ethiopia: II. Woody vegetation. *J. Arid. Environ.* 70, 272–292. doi:10.1016/j.jaridenv.2007.01.007

Abusuwar, A. O., and Ahmed, E. O. (2010). Seasonal variability in nutritive value of ruminant diets under open grazing system in the semi-arid rangeland of Sudan (South Darfur State). *Agric. Biol. J. N. Am.* 1 (3), 243–249. doi:10.5251/abjna.2010.1.3.243.249

Al-Bukhari, A., Hallett, S., and Brewer, T. (2018). A review of potential methods for monitoring rangeland degradation in Libya. *Pastoralism* 8 (13), 13–14. doi:10.1186/s13570-018-0118-4

Alkemade, R., Reid, R. S., van den Berg, M., de Leeuw, J., and Jeuken, M. (2013). Assessing the impacts of livestock production on biodiversity in rangeland ecosystems. *Proc. Natl. Acad. Sci. U. S. A.* 110 (52), 20900–20905. doi:10.1073/pnas.1011013108

Allen, V. G., Batello, C., Berretta, E. J., Hodgson, J., Kothmann, M., Li, X., et al. (2011). An international terminology for grazing lands and grazing animals. *Grass Forage Sci.* 66, 2–28. doi:10.1111/j.1365-2494.2010.00780.x

Angassa, A., and Oba, G. (2008). Herder perceptions on impacts of range enclosures, crop farming, fire ban and bush encroachment on the rangelands of Borana, southern Ethiopia. *Hum. Ecol.* 36, 201–215. doi:10.1007/s10745-007-9156-z

Angassa, A. (2007). "The dynamics of savanna ecosystems and management in Bora, Southern Ethiopia," (Norway: Norwegian University of Life Sciences). PhD thesis.

Arneth, A., Olsson, L., Cowie, A., Erb, K. H., Hurlbert, M., Kurz, W. A., et al. (2021). Restoring degraded lands. *Annu. Rev. Environ. Resour.* 46, 569–599. doi:10.1146/annurev-environ-012320-054809

Aronson, J., Blignaut, J. N., Milton, S. J., Le Maitre, D., Esler, K. J., Limouzin, A., et al. (2010). Are socioeconomic benefits of restoration adequately quantified? A meta-analysis of recent papers (2000–2008) in restoration ecology and 12 other scientific journals. *Restor. Ecol.* 18 (2), 143–154. doi:10.1111/j.1526-100x.2009.00638.x

Ash, A. J., Corfield, J. P., McIvor, J. G., and Ksiksi, T. S. (2011). Grazing management in tropical savannas: Utilization and rest strategies to manipulate rangeland condition. *Rangel. Ecol. Manag.* 64, 223–239. doi:10.2111/rem-d-09-00111.1

Asner, G. P., Elmore, A. J., Olander, L. P., Martin, R. E., and Harris, A. T. (2004). Grazing systems, ecosystem response, and global change. *Ann. Rev. Environ. Resour.* 29, 261–299. doi:10.1146/annurev.energy.29.062403.102142

Asner, G. P., and Heidebrecht, K. B. (2003). Imaging spectroscopy for desertification studies: Comparing AVIRIS and EO-1 Hyperion in Argentina drylands. *IEEE Trans. Geosci. Remote Sens.* 41 (6), 1283–1296. doi:10.1109/tgrs.2003.812903

Ayana, A. (2005). The ecological impact of bush encroachment on the yield of grasses in borana rangeland ecosystem. *Afr. J. Ecol.* 43 (1), 14–20. doi:10.1111/j.1365-2028.2005.00429.x

Bai, Z. G., and Dent, D. L. (2007). *Land degradation and improvement in South Africa. 1: Identification by remote sensing*. Wageningen, Netherlands: ISRIC-World Soil Information.

Bainbridge, D. A. (2007). *A guide for desert and dryland restoration: New hope for arid lands*. Washington. USA: Island Press.

Bainbridge, D. A. (2003). New hope for arid lands - restoration can succeed. 2003 southwest lands habitat restoration conference. Palm springs. In Proceedings. Website Available at: http://www.dmg.gov.sessions.html.

Bakshi, M., Singh, H. B., and Abhilash, P. C. (2014). Unseen impact of nanoparticles: More or less? *Cur. Sci.* 106, 350–352.

Barac, A. S. (2003). "EcoRestore: A decision support system for the restoration of degraded rangelands in southern Africa," (South Africa: North-West University). Doctoral dissertation.

Bati, B. M. (2013). "Climate change, cattle herd vulnerability and food insecurity: Adaptation through livestock diversification in the Borana pastoral system of Ethiopia," (Hohenheim: University of Hohenheim). Ph.D. thesis.

Belachew, K., and Tessema, T. (2015). Assessment of weed flora composition in Parthenium (Parthenium hysterophorus L.) infested area of East Shewa zone, Ethiopia. *Malays. J. Med. Biol. Res.* 2, 105–112. doi:10.18034/mjmbr.v2i2.397

Belayneh, A., and Tessema, Z. K. (2017). Mechanisms of bush encroachment and its inter-connection with rangeland degradation in semi-arid african ecosystems: A review. *J. Arid. Land* 9, 299–312. doi:10.1007/s40333-016-0023-x

Berthrong, S. T., Pineiro, G. E. R. V. A. S. I. O., Jobbágy, E. G., and Jackson, R. B. (2012). Soil C and N changes with afforestation of grasslands across gradients of precipitation and plantation age. *Ecol. Appl.* 22 (1), 76–86. doi:10.1890/10-2210.1

Bloor, J. M., Pichon, P., Falcimagne, R., Leadley, P., and Soussana, J. F. (2010). Effects of warming, summer drought, and CO2 enrichment on aboveground biomass production, flowering phenology, and community structure in an upland grassland ecosystem. *Ecosystems* 13 (6), 888–900. doi:10.1007/s10021-010-9363-0

Bolo, P. O., Sommer, R., Kihara, J., Kinyua, M., Nyawira, S., and Notenbaert, A. M. O. (2019). *Rangeland degradation: Causes, consequences, monitoring techniques and remedies*. Palmira, Colombia: CIAT Publication.

Boval, M., and Dixon, R. M. (2012). The importance of grasslands for animal production and other functions: A review on management and methodological progress in the tropics. *Animal* 6, 748–762. doi:10.1017/s1751731112000304

Brown, S., and Lugo, A. E. (1994). Rehabilitation of tropical lands: A key to sustaining development. *Restor. Ecol.* 2 (2), 97–111. doi:10.1111/j.1526-100x.1994.tb00047.x

Chipika, J. T., and Kowero, G. (2000). Deforestation of woodlands in communal areas in Zimbabwe: Is it due to agricultural policies? *Agric. Ecosyst. Environ.* 79, 175–185. doi:10.1016/s0167-8809(99)00156-5

Cho, M. A., and Ramoelo, A. (2019). Optimal dates for assessing long-term changes in tree-cover in the semi-arid biomes of South Africa using MODIS NDVI time series (2001–2018). *Int. J. Appl. Earth Obs. Geoinf.* 81, 27–36. doi:10.1016/j.jag.2019.05.014

Conacher, A., and Conacher, J. (1995). *Rural land degradation in Australia*. South Melbourne, Victoria: Oxford University Press Australia, 2.

Convention on Biological Diversity (Cbd) (2008). *Alien species that threaten ecosystems*. Article8: Habitats or Species. (h).

Coppock, D. L., Gebru, D. L., Desta, S., Gizachew, L., Amosha, D., and Taffa, F. (2007). *Stakeholder alliance facilitates re-introduction of prescribed fire on the Borana Plateau of Southern Ethiopia*. University of California, Davis, United States: Environment and Society Faculty Publications.

Critchley, W. R., and Netshikovhela, E. M. (1998). Land degradation In South Africa: Conventional views, changing paradigms and a tradition of soil conservation. *Dev. South. Afr.* 15 (3), 449–469. doi:10.1080/03768359808440024

Croft, P. J., Hunter, J. T., and Reid, N. (2015). Forgotten fauna: Habitat attributes of long-unburnt open forests and woodlands dictate a rethink of fire management theory and practice. *For. Ecol. Manage.* 366, 166–174. doi:10.1016/j.foreco.2016.02.015

Cupido, C. F. (2005). Assessment of veld utilisation practices and veld condition in the Little Karoo. Doctoral dissertation. Stellenbosch, South Africa: University of Stellenbosch.

Darkoh, M. B. K. (2003). Regional perspectives on agriculture and biodiversity in the drylands of Africa. *J. Arid. Environ.* 54 (2), 261–279. doi:10.1006/jare.2002.1089

de Klerk, J. N. (2004). *Bush encroachment in Namibia: Report on phase 1 of the bush encroachment research, monitoring and management project*. Windhoek: John Meinert-Printing.

Díaz, S. M., Settele, J., Brondízio, E., Ngo, H., Guèze, M., Agard, J., et al. (2019). *The global assessment report on biodiversity and ecosystem services: Summary for policy makers*. Bonn, Germany: IPBES secretariat, 56. doi:10.5281/zenodo.3553579

Donald, J. B., and Jay, P. A. (2012). Rangeland degradation, poverty, and conflict: How can rangeland scientists contribute to effective responses and solutions? *Rangel. Ecol. Manag.* 65 (6), 606–612. doi:10.2111/rem-d-11-00155.1

Esler, K. J., and Kellner, K. (2001). *Resurrecting degraded Karoo veld [South Africa]. Farmer's Weekly (South Africa)*, 24–26. March9.

Eswaran, H., Lal, R., and Reich, P. F. (2001). *Land degradation. An overview conference on land degradation and desertification*. ThailandNew Dehli, India: Khon kaenOxford Press.

FAO (2009). *The state of food and agriculture: Livestock in the balance*. Rome, Italy. doi:10.1017/S2078633610001128

Fayiah, M., Dong, S. K., Khomera, S. W., Rehman, S. A. U., Yang, M., and Xiao, J. (2020). Status and challenges of Qinghai-Tibet Plateau's grasslands: An analysis of causes, mitigation measures, and way forward. *Sustainability* 12, 1099. doi:10.3390/su12031099

Fereja, G. B. (2017). The effect of climate change on rangeland and biodiversity. *Int. J. Res. Granthaalayah.* 5, 172–182. doi:10.29121/granthaalayah.v5.i1.2017.1732

Ganskopp, D. (2001). Manipulating cattle distribution with salt and water in large arid-land pastures: A GPS/GIS assessment. *Appl. Anim. Behav. Sci.* 73 (4), 251–262. doi:10.1016/s0168-1591(01)00148-4

Gebeyehu, G., Soromessa, T., Bekele, T., and Teketay, D. (2019). Carbon stocks and factors affecting their storage in dry Afromontane forests of Awi Zone, northwestern Ethiopia. *J. Ecol. Environ.* 43 (1), 7–18. doi:10.1186/s41610-019-0105-8

Gebru, G., Desta, S., Coppock, D. L., Gizachew, L., Amosha, D., and Taffa, F. (2007). *Stakeholder alliance facilitates Re-introduction of prescribed fire on the borana plateau of southern Ethiopia*. University of California, Davis, United States: Environment and Society Faculty Publications.

Gibbs, H. K., Salmon, J. M., Kellner, K., Mangani, R. T., Sebitloane, T. J., Chirima, J. G., et al. (2015). Mapping the world's degraded landsRestoration after bush control in selected range-land areas of semi-arid savannas in South Africa. *BothaliaABC.Afr. Biodivers. Conserv.* 5751 (1), 121–2113. doi:10.38201/btha.abc.v51.i1.7

Gidey, T. G., and van der Veen, A. (2014). The effect of enclosures in rehabilitating degraded vegetation: A case of enderta district, northern Ethiopia. *For. Res.* 3 (4).

Gordijn, P. J. (2010). *The role of fire in bush encroachment in ithala game reserve (master of science dissertation*. South Africa: University of Kwazulu Natal Kwazulu Natal Province South Africa.

Habibi, Y., Mahrouz, M., and Vignon, M. R. (2009). Microfibrillated cellulose from the peel of prickly pear fruits. *Food Chem. x.* 115 (2), 423–429. doi:10.1016/j.foodchem.2008.12.034

Hamman, S. T., Dunwiddie, P. W., Nuckols, J. L., and McKinley, M. (2011). Fire as a restoration tool in pacific northwest prairies and oak woodlands: Challenges, successes, and future directions. *Northwest Sci.* 85 (2), 317–328. doi:10.3955/046.085.0218

Han, J. G., Zhang, Y. J., Wang, C. J., Bai, W. M., Wang, Y. R., Han, G. D., et al. (2008). Rangeland degradation and restoration management in China. *Rangel. J.* 30, 233–239. doi:10.1071/rj08009

Hare, M. L., Xu, X., Wang, Y., and Gedda, A. I. (2020). The effects of bush control methods on encroaching woody plants in terms of die-off and survival in Borana rangelands, southern Ethiopia. *Pastoralism* 10 (1), 16–14. doi:10.1186/s13570-020-00171-4

Harmse, C. J., Dreber, N., Kellner, K., and Kong, T. M. (2020). *Linking farmer knowledge and biophysical data to evaluate actions for land degradation mitigation in savanna rangelands of the Molopo*. South Africa.

Harris, J. A., Birch, P., and Palmer, J. (1996). *Landscape restoration and reclamation: Principles and practice*. Essex: Longman.

Harrison, P., and Pearce, F. (2000). *Aaas - atlas of population and environment*. American Association of the Advancement of Science and the University of California Press.

Hermans, K., and McLeman, R. (2021). Climate change, drought, land degradation and migration: Exploring the linkages. *Curr. Opin. Environ. Sustain.* 50, 236–244. doi:10.1016/j.cosust.2021.04.013

Higgins, S. I., Bond, W. J., and Trollope, W. S. W. (2000). Fire, re-sprouting and variability: A recipe for grass–tree coexistence in savanna. *J. Ecol.* 88, 213–229. doi:10.1046/j.1365-2745.2000.00435.x

Higgins, S. I., and Scheiter, S. (2012). Atmospheric CO2 forces abrupt vegetation shifts locally, but not globally. *Nature* 488 (7410), 209–212. doi:10.1038/nature11238

Hobbs, R. J., and Harris, J. A. (2001). Restoration ecology: Repairing the earth's ecosystems in the new millennium. *Restor. Ecol.* 9 (2), 239–246. doi:10.1046/j.1526-100x.2001.009002239.x

Hoffman, M. T., Todd, S. W., Ntshona, Z. M., and Turner, S. D. (1999). *Land degradation in South Africa*. South Africa: Report prepared for the Department of Environmental Affairs and Tourism.

Hoffman, T., and Ashwell, A. (2001). *Nature divided: Land degradation in South Africa*. Cape Town, South Africa: University of Cape Town Press.

Hoffman, T., and Ashwell, A. (2001). *Nature divided. Land degradation in South Africa*. Cape Town: University of Cape Town Press.

Hoffman, T., and Todd, S. (2000). A national review of land degradation In South Africa: The influence of biophysical and socio-economic factors. *J. South. Afr. Stud.* 26, 743–758. doi:10.1080/713683611

Hopkins, A., and Del Prado, A. (2007). Implications of climate change for grassland in europe: Impacts, adaptations and mitigation options: A review. *Grass Forage Sci.* 62 (2), 118–126. doi:10.1111/j.1365-2494.2007.00575.x

Huang, J. G., Bergeron, Y., Denneler, B., Berninger, F., and Tardif, J. (2007). Response of forest trees to increased atmospheric CO_2. *Crit. Rev. Plant Sci.* 26 (5-6), 265–283. doi:10.1080/07352680701626978

Huxman, T., Wilcox, B., Breshears, D., Scott, R., Snyder, K., Small, E., et al. (2005). Ecohydrological implications of woody plant encroachment. *Ecology* 86 (2), 308–319. doi:10.1890/03-0583

Ibanez, J., Martınez, J., and Schnabel, S. (2007). Desertification due to overgrazing in a dynamic commercial livestock–grass–soil system. *Ecol. Modell.* 205, 277–288. doi:10.1016/j.ecolmodel.2007.02.024

International Food Policy Research Institute (IFPRI) (2003). Cropland degradation. Available: http://www.ifpri.org.

Ismail, A. B. O., Fatur, M., Ahmed, F. A., Ahmed, E. O., Elmahdi, M., and Ahmed, E. (2014). Nutritive value and palatability of some range grasses in low rainfall woodland savanna of South Darfur in Sudan. *Range Manag. Agrofor.* 35, 193–197.

Jama, B., and Zeila, A. (2005). *Agroforestry in the drylands of eastern Africa: A call to action. ICRAF working paper – No. 1*. Nairobi: World Agroforestry Centre.

Jeddi, K., and Chaieb, M. (2010). Changes in soil properties and vegetation following livestock grazing exclusion in degraded arid environments of South Tunisia. *Flora - Morphol. Distribution Funct. Ecol. Plants* 205, 184–189. doi:10.1016/j.flora.2009.03.002

Kapu, N. L. (2012). “Assessment of rangeland condition and evaluation of the nutritional value of common grass and browse species at the neudamm experimental farm,” (Namibia. Doctoral dissertation.

Kauffman, J. B., Robert, L. B., Nick, O., and Danna, L. (1997). An ecological perspective of riparian and stream restoration in the western United States. *Fisheries* 22, 12–24. doi:10.1577/1548-8446(1997)022<0012:aepora>2.0.co;2

Kavana, P. Y., Kizima, J. B., and Msanga, Y. N. (2005). Evaluation of grazing pattern and sustainability of feed resources in pastoral areas of eastern zone of Tanzania. *Livest. Res. Rural. Dev.* 17 (1).

Kellner, K., and de Wet, S. (2021). *Evaluation of a number of grass species for restoring degraded semi-arid rangelands in Southern Africa*.

Kellner, K. (2000). “Desert margins program,” in Proceedings of a National Workshop: Appropriate Restoration Technologies in South Africa, South Africa, 13-26 March 1998 (Potchefstroom, South Africa: Potchefstroom University for CHE).

Kgope, B. S., Bond, W. J., and Midgley, G. F. (2010). Growth responses of African savanna trees implicate atmospheric [CO2] as a driver of past and current changes in savanna tree cover. *Austral Ecol.* 35 (4), 451–463. doi:10.1111/j.1442-9993.2009.02046.x

Kirkman, K. P., and de Faccio Carvalho, P. C. (2003). “Management interventions to overcome seasonal quantity and quality deficits of natural rangeland forages,” in Proceedings of the VII International Rangeland Congress, Durban, July 2003.

Kondolf, G. M. (1998). Lessons learned from river restoration projects in California. *Aquat. Conserv.* 8, 39–52. doi:10.1002/(sici)1099-0755(199801/02)8:1<39:aid-aqc250>3.0.co;2-9

Kraaij, T., and Ward, D. (2006). Effects of rain, nitrogen, fire and grazing on tree recruitment and early survival in bush-encroached savanna, South Africa. *Plant Ecol.* 186 (2), 235–246. doi:10.1007/s11258-006-9125-4

Kwon, H. Y., Nkonya, E., Johnson, T., Graw, V., Kato, E., and Kihiu, E. (2015). "Global estimates of the impacts of grassland degradation on livestock productivity from 2001 to 2011," in *Economics of land degradation and improvement-A global assessment for sustainable development*. Springer, Cham. Switzerland, 197–214. doi:10.1007/978-3-319-19168-3_8

Le Houerou, H. N. (2000). Restoration and rehabilitation of arid and semiarid mediterranean ecosystems in North Africa and west asia: A review. *Arid Soil Res. Rehabilitation* 14, 3–14. doi:10.1080/089030600263139

Le Roux, J. J., Newby, T. S., and Sumner, P. D. (2007). Monitoring soil erosion In South Africa at a regional scale: Review and recommendations: SAEON review. *S. Afri. J. Sci.* 103 (7), 329–335.

Lesoli, M. S., Gxasheka, M., and Solomon, T. B. (2013). "Integrated plant invasion and bush encroachment management on southern African rangelands," in *Herbicides-Current research and case studies in use* Editors A. J. Price and J. A. Kelton. London, UK: IntechOpen, 259–313. doi:10.5772/56182

Li, X. L., Gao, J., Brierley, G., Qiao, Y. M., Zhang, J., and Yang, Y. W. (2011). Rangeland degradation on the qinghai-tibet plateau: Implications for rehabilitation. *Land Degrad. Dev.* 22, 72–80. doi:10.1002/ldr.1108

Liebig, M. A., Gross, J. R., Kronberg, S. L., Hanson, J. D., Frank, A. B., and Phillips, R. L. (2006). Soil response to long-term grazing in the northern Great Plains of North America. *Agric. Ecosyst. Environ.* 115, 270–276. doi:10.1016/j.agee.2005.12.015

Liniger, H. P., Studer, R. M., Hauert, C., and Gurtner, M. (2011). *Sustainable land management in practice: Guidelines and best practices for sub-saharan Africa. TerrAfrica, world overview of conservation approaches and technologies (WOCAT) and food and agriculture organization of the united nations*. Québec City, Canada: FAO.

Long, Y. U., Li, Z., Wei, L., and Hua-Kun, Z. (2010). Using remote sensing and GIS technologies to estimate grass yield and livestock carrying capacity of alpine grasslands in Golog Prefecture, China. *Pedosphere* 20 (3), 342–351. doi:10.1016/s1002-0160(10)60023-9

Lüscher, A., Mueller-Harvey, I., Soussana, J. F., Rees, R. M., and Peyraud, J. L. (2014). Potential of legume-based grassland-livestock systems in europe: A review. *Grass Forage Sci.* 69, 206–228. doi:10.1111/gfs.12124

Magandana, T. P. (2016). “Effect of Acacia karoo encroachment on grass production in the semi-arid savannas of the Eastern Cape, South Africa,” (South Africa: University of Fort Hare). MSc dissertation.

Mani, S., Osborne, C. P., and Cleaver, F. (2021). Land degradation in South Africa: Justice and climate change in tension. *People Nat.* 3 (5), 978–989. doi:10.1002/pan3.10260

Mannetje, L. (2002). *Global issues of rangeland management*. Netherlands: Department of plant sciences, Wageningen University.

Mapiye, C., Mugabe, P. H., and Munthali, D. (2006). The potential of burning and grazing intensity management for rangeland improvement. *South. Afr. J. Educ. Sci. Technol.* 1, 103–110. doi:10.4314/sajest.v1i2.50387

Mapiye, C., Mwale, M., Chikumba, N., and Chimonyo, M. (2008). Fire as a rangeland management tool in the savannas of southern Africa: A review. *Trop. Subtropical Agroecosyst.* 8 (2).

Mary-Howell, M., and Martens, K. (2008). “NODPA. Lakeview organic grain,” in *Almost year round grazing in the northeast* (New York: Penn Yan).

McDonald, A., Lane, S. N., Haycock, N. E., and Chalk, E. A. (2004). Rivers of dreams: On the gulf between theoretical and practical aspects of an upland river restoration. *Trans. Inst. Br. Geog.* 29, 257–281. doi:10.1111/j.0020-2754.2004.00314.x

McGranahan, D. A., and Kirkman, K. P. (2013). Multifunctional rangeland in Southern Africa: Managing for production, conservation, and resilience with fire and grazing. *Land* 2 (2), 176–193. doi:10.3390/land2020176

Meadows, M. E., and Hoffman, M. T. (2002). The nature, extent and causes of land degradation in South Africa: legacy of the past, lessons for the future?. *Area* 34 (4), 428–437.

Meadows, M. E., and Hoffman, T. M. (2003). Land degradation and climate change in South Africa. *Geogr. J.* 169 (2), 168–177. doi:10.1111/1475-4959.04982

Megerssa, G. R., and Bekere, Y. B. (2019). Causes, consequences and coping strategies of land degradation: Evidence from Ethiopia. *J. Degr. Min. Land. Manage.* 7 (1), 1953–1957. doi:10.15243/jdmlm.2019.071.1953

Mekuria, W., Veldkamp, E., Haile, M., Nyssen, J., Muysd, B., and Gebrehiwot, K. (2007). Effectiveness of exclosures to restore degraded soils as a result of overgrazing in Tigray, Ethiopia. *J. Arid. Environ.* 69, 270–284. doi:10.1016/j.jaridenv.2006.10.009

Mekuria, W., and Aynekulu, E. (2013). Exclosure land management for restoration of the soils in degraded communal grazing lands in northern Ethiopia. *Land Degrad. Dev.* 24 (6), 528–538. doi:10.1002/ldr.1146

Mentis, M. (2020). Environmental rehabilitation of damaged land. *For. Ecosyst.* 7 (1), 19–16. doi:10.1186/s40663-020-00233-4

Mganga, K. Z. (2009). “Impact of grass reseeding technology on rehabilitation of the degraded rangelands: A case study of kibwei district, Kenya,”. Doctoral dissertation.

Milton, S. J. (2004). Grasses as invasive alien plants In South Africa: Working for water. *S. Afr. J. Sci.* 100 (1), 69–75.

Milton, S. J., Dean, W. R. J., and Ellis, R. P. (1998). Rangeland health assessment: A practical guide for ranchers in arid karoo shrublands. *J. Arid. Environ.* 39 (2), 253–265. doi:10.1006/jare.1998.0395

Milton, S. J., and Dean, W. R. J. (2010). Plant invasions in arid areas: Special problems and solutions: A South African perspective. *Biol. Invasions* 12 (12), 3935–3948. doi:10.1007/s10530-010-9820-x

Milton, S. J., Dean, W. R. J., and Richardson, D. M. (2003). Economic incentives for restoring natural capital in southern African rangelands. *Front. Ecol. Environ.* 1 (5), 247–254. doi:10.1890/1540-9295(2003)001[0247:eifrnc]2.0.co;2

Mirzabaev, A., Wu, J., Evans, J., García-Oliva, F., Hussein, I. A., Iqbal, M. H., et al. (Editors) (2019). *IPCC, 2019: Climate Change and Land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*. Geneva, Switzerland, 3, 249–343.

Mitchell, S. R., Harmon, M. E., and O'Connell, K. E. B. (2009). Forest fuel reduction alters fire severity and long-term carbon storage in three Pacific Northwest ecosystems. *Ecol. Appl.* 19, 643–655. doi:10.1890/08-0501.1

Mohammed, M., Abule, E., and Lissahanwork, N. (2017). Soil organic carbon and total nitrogen stock response to traditional enclosure management in eastern Ethiopia. *J. Soil Sci. Environ.* 8 (2), 37–43.

Moyo, B., Dube, S., Lesoli, M., and Masika, P. (2013). Seasonal habitat use and movement patterns of cattle grazing different rangeland types in the communal areas of the Eastern Cape, South Africa. *Afr. J. Agricul. Res.* 8 (1), 36–45.

Moyo, S., and Swanepoel, F. J. C. (2010). "Multifuncionality of livestock in developing communities in the role of livestock in developing communities: Enhancing multifunctionality," in *Frans Swanepoel, aldo stroebel and siboniso Moyo* (Cape Town, South Africa: CTA and University of the Free State). Co-published by the Technical Centre for Agricultural and Rural Cooperation. https://hdl.handle.net/10568/3043.

Msiza, N. H., and Ravhuhali, K. E. (2019). Bush encroachment in North West province. Is it a threat? *Grassroots-Newsletter Grassl. Soc. South. Afr.* 19, 9–11.

Msiza, N. H., Ravhuhali, K. E., Mokoboki, H. K., and Mavengahama, S. (2021). *The morphological, crude protein and* in-vitro *dry matter degradability characterisation of nine native grass species for veld restoration in semi-arid environment*.

Mugido, W. (2011). *A financial cost-benefit analysis of the implementation of a small-camp system in ostrich farming to allow veld restoration* (Stellenbosch: University of Stellenbosch). Doctoral dissertation.

Mureithi, S. M., Verdoodt, A., Njoka, J. T., Gachene, C. K. K., and van Ranst, E. (2016). Benefits derived from rehabilitating a degraded semi-arid rangeland in communal enclosures, Kenya. *Land Degrad. Dev.* 27, 1853–1862. doi:10.1002/ldr.2341

Mussa, M., Hashim, H., and Teha, M. (2016). Rangeland degradation: Extent, impacts, and alternative restoration techniques in the rangelands of Ethiopia. *Trop. Subtropical Agroecosyst.* 19 (3).

Myburgh, T. (2013). "Vegetation dynamics and soil characteristics of abandoned cultivated fields," (South Africa: University of the Free State). MSc dissertation.

Nalule, S. (2010). *Social management of rangelands and settlement in Karamoja*. Kampala: FAO.

Ndandani, A. (2014). "Range condition assessment to document the extent of degradation on selected semi-arid rangelands of the Eastern Cape, South Africa," (South Africa: University of Fort Hare). MSc dissertation.

Neely, C., Bunning, S., and Wilkes, A. (2010). *Managing dryland pastoral systems: Implications for mitigation and adaptation to climate change*. Nairobi, Kenya: worldagroforestry.

Neffar, S., Chenchouni, H., Beddiar, A., and Redjel, N. (2013). Rehabilitation of degraded rangeland in drylands by prickly pear (*Opuntia ficus-indica* L.) plantations: Effect on soil and spontaneous vegetation. *Ecol. Balk.* 5 (2).

Nenzhelele, E. (2017). *Conservation Biology*. Town, South Africa: Department of Biological Sciences. University of Cape.Long-term impact of livestock grazing in the succulent karroo: 20 year study of vegetation change under different grazing regimes in namaqualand. MSc thesis.

Nicholson, S. E. (2000). The nature of rainfall variability over Africa on time scales of decades to millenia. *Glob. Planet. change* 26 (1-3), 137–158. doi:10.1016/s0921-8181(00)00040-0

Nkonya, E., Mirzabaev, A., and Braun, J. V. (2016). "Economics of land degradation and improvement: An introduction and overview," in *Economics of land degradation and improvement–a global assessment for sustainable development* (Cham: Springer), 1–14.

Ntalo, M., Ravhuhali, K. E., Moyo, B., Hawu, O., and Msiza, N. H. (2022). Lantana camara: Poisonous species and a potential browse species for goats in southern africa—a review. *Sustainability* 14 (2), 751. doi:10.3390/su14020751

Nyberg, G., Knutsson, P., Ostwald, M., Öborn, I., Wredle, E., Otieno, D. J., et al. (2015). Enclosures in West Pokot, Kenya: Transforming land, livestock and livelihoods in drylands. *Pastoralism* 5 (1), 25. doi:10.1186/s13570-015-0044-7

O'connor, T. G., Puttick, J. R., and Hoffman, M. T. (2014). Bush encroachment in southern Africa: Changes and causes. *Afr. J. Range Forage Sci.* 31 (2), 67–88. doi:10.2989/10220119.2014.939996

O'Connor, T. G., and van Wilgen, B. W. (2020). "The impact of invasive alien plants on rangelands In South Africa," in *Biological invasions in South Africa*. Editors B. van Wilgen, J. Measey, D. Richardson, J. Wilson, and T. Zengeya (Cham: Springer), 14. Invading Nature - Springer Series in Invasion Ecology.

Opiyo, F. E. O., Ekaya, W. N., Nyariki, D. M., and Mureithi, S. M. (2011). Seedbed preparation influence on morphometric characteristics of perennial grasses of a semi-arid rangeland in Kenya. *Afr. J. Plant Sci.* 5, 460–468.

Owen-Smith, N. (1989). "Morphological factors and their consequences for resource partitioning among African savanna ungulates: A simulation modelling approach," in *Patterns in the structure of mammalian communities*. Editors D. W. Morris, Z. Abramsky, B. J. Fox, and M. R. Willig. (Texas Tech University Press), 155–165.

Palmer, A. R., and Ainslie, A. M. (2005). Grasslands of South Africa. *Grassl. World* 34, 77.

Palmer, A. R., Tanser, F., and Hintsa, M. D. (1997). *Using satellite imagery to map and inventories vegetation status for Eastern Cape Province*. Grahamstown: Unpublished reportRange and Forage Institute.

Palmer, T., and Ainslie, A. (2006). *Country pasture/forage resource profiles*. South Africa. Food and Agriculture Organization.

Patel, S. (2011). Harmful and beneficial aspects of parthenium hysterophorus: An update. *3 Biotech.* 1, 1–9. doi:10.1007/s13205-011-0007-7

Pejchar, L., and Mooney, H. A. (2009). Invasive species, ecosystem services and human well-being. *Trends Ecol. Evol.* 24 (9), 497–504. doi:10.1016/j.tree.2009.03.016

Porath, M. L., Momont, P. A., DelCurto, T., Rimbey, N. R., Tanaka, J. A., and McInnis, M. (2002). Offstream water and trace mineral salt as management strategies for improved cattle distribution. *J. Animal Sci.* 80 (2), 346–356. doi:10.2527/2002.802346x

Pyšek, P., Hulme, P. E., Simberloff, D., Bacher, S., Blackburn, T. M., Carlton, J. T., et al. (2020). Scientists' warning on invasive alien species. *Biol. Rev.* 95 (6), 1511–1534. doi:10.1111/brv.12627

Quirk, M. (2000). Understanding grazing lands for better management: Are we making any progress? *Trop. Grassl.* 34, 182–191.

Ramamurthy, P., and Pardyjak, E. R. (2011). Toward understanding the behavior of carbon dioxide and surface energy fluxes in the urbanized semi-arid Salt Lake Valley, Utah, USA. *Atmos. Environ. X.* 45 (1), 73–84. doi:10.1016/j.atmosenv.2010.09.049

Ravera, O. (1989). *Ecological assessment of environmental degradation, pollution and recovery*. New York: Elsevier Science Publishers.

Ravhuhali, K. E., Mlambo, V., Beyene, T. S., and Palamuleni, L. G. (2021). Effect of soil type on spatial distribution and nutritive value of grass species growing in selected rangelands of South Africa. *South Afr. J. Plant Soil* 38 (5), 361–371. doi:10.1080/02571862.2021.1933630

Ravhuhali, K. E., Mudau, H. S., Moyo, B., Hawu, O., and Msiza, N. H. (2021). Prosopis species—an invasive species and a potential source of browse for livestock in semi-arid areas of South Africa. *Sustainability* 13 (13), 7369. doi:10.3390/su13137369

Ravhuhali, K. E. (2018). "Spatial variation in density, species composition and nutritive value of vegetation in selected communal areas of the North West province," (South Africa: North-West University). Doctoral dissertation.

Reich, P. F., Numbem, S. T., Almaraz, R. A., and Eswaran, H. (2019). "Land resource stresses and desertification in Africa," in *Response to land degradation* (Florida, United States: CRC Press), 101–116.

Reynolds, J. F., Maestre, F. T., Kemp, P. R., Stafford-Smith, D. M., and Lambin, E. (2007). "Natural and human dimensions of land degradation in drylands: Causes and consequences," in *Terrestrial ecosystems in a changing world* (Berlin, Heidelberg: Springer), 247–257.

Richardson, D. M., Hui, C., Nunez, M. A., and Pauchardm, A. (2014). Tree invasions: Patterns, processes, challenges and opportunities. *Biol. Invasions* 16, 473–481. doi:10.1007/s10530-013-0606-9

Rouget, M., Cowlingw, R. M., Vlokz, J., Thompson, M., and Balmford, A. (2006). Getting the biodiversity intactness index right: The importance of habitat degradation data. *Glob. Chang. Biol.* 12, 2032–2036. doi:10.1111/j.1365-2486.2006.01238.x

Rountree, M. W., Rogers, K. H., and Heritage, G. L. (2000). Landscape state change in the semi-arid Sabie River, Kruger National Park, in response to flood and drought. *South Afr. Geogr. J.* 82 (3), 173–181. doi:10.1080/03736245.2000.9713711

Rust, J. M., and Rust, T. (2013). Climate change and livestock production: A review with emphasis on Africa. *S. Afr. J. Anim. Sci.* 43 (3), 255–267. doi:10.4314/sajas.v43i3.3

Saco, P. M., Willgoose, G. R., and Hancock, G. R. (2006). Eco-geomorphology and vegetation patterns in arid and semi-arid regions. *Hydrol. Earth Syst. Sci. Discuss.* 3, 2559–2593.

Safriel, U. (2009). Deserts and desertification: Challenges but also opportunities. *Land Degrad. Dev.* 20 (4), 353–366. doi:10.1002/ldr.935

Saini, M. L., Jain, P., and Joshi, U. N. (2007). Morphological characteristics and nutritive value of some grass species in an arid ecosystem. *Grass Forage Sci.* 62, 104–108. doi:10.1111/j.1365-2494.2007.00563.x

Sankaran, M., Hanan, N. P., Scholes, R. J., Ratnam, J., Augustine, D. J., Cade, B. S., et al. (2005). Determinants of woody cover in African savannas. *Nature* 438, 846–849. doi:10.1038/nature04070

Sawadogo, L., Nygard, R., and Pallo, F. (2002). Effects of livestock and prescribed fire on coppice growth after selective cutting of Sudanian savannah in Burkina Faso. *Ann. For. Sci.* 59 (2), 185–195. doi:10.1051/forest:2002005

Schlesinger, W. H., Abrahams, A. D., Parsons, A. J., and Wainwright, J. (1999). Nutrient losses in runoff from grassland and shrub land habitats in southern new Mexico: I. Rainfall simulation experiments. *Biogeochemistry* 45, 21–34. doi:10.1007/bf00992871

Scholes, R., Montanarella, L., Brainich, A., Barger, N., ten Brink, B., Cantele, M., et al. (2018). *Summary for policymakers of the assessment report on land degradation and restoration of the intergovernmental science-policy platform on biodiversity and ecosystem services*. Bonn: IPBES Secretariat.

Seebens, H., Blackburn, T. M., Hulme, P. E., van Kleunen, M., Liebhold, A. M., Orlova-Bienkowskaja, M., et al. (2021). Around the world in 500 years: Inter-regional spread of alien species over recent centuries. *Glob. Ecol. Biogeogr.* 30, 1621–1632. doi:10.1111/geb.13325

Shackleton, R. T., Le Maitre, D. C., Pasiecznik, N. M., and Richardson, D. M. (2014). Prosopis: A global assessment of the biogeography, benefits, impacts and management of one of the world's worst woody invasive plant taxa. *AoB Plants* 6, plu027. doi:10.1093/aobpla/plu027

Shackleton, R. T., Witt, A. B., Piroris, F. M., and van Wilgen, B. W. (2017). Distribution and socio-ecological impacts of the invasive alien cactus Opuntia stricta in eastern Africa. *Biol. Invasions* 19, 2427–2441. doi:10.1007/s10530-017-1453-x

Singh, G. (2004). An overview of cactus pear research and development in India. *Acta Hortic.* 728, 43–50. doi:10.17660/actahortic.2006.728.4

Singh, G., Dagar, J. C., Lal, K., and Yadav, R. K. (2014). Performance of edible cactus (*Opuntia ficus-indica*) in saline environments. *Indian J. Agric. Sci.* 84 (4), 73–78.

Sipango, N., Ravhuhali, K. E., Sebola, N. A., Hawu, O., Mabelebele, M., Mokoboki, H. K., et al. (2022). Prickly pear (*opuntia* spp.) as an invasive species and a potential fodder resource for ruminant animals. *Sustainability* 14 (7), 3719. doi:10.3390/su14073719

Smit, G. N. (2003). "The importance of ecosystem dynamics in managing the bush encroachment problem in southern Africa. Bloemfontein: University of the free state," in Proceedings of the Seventh International Rangelands Congress, Durban, South Africa, 26 July–1 August 2003.14–22.

Smit, I. P., Asner, G. P., Govender, N., Vaughn, N. R., and van Wilgen, B. W. (2016). An examination of the potential efficacy of high-intensity fires for reversing woody encroachment in savannas. *J. Appl. Ecol.* 53 (5), 1623–1633. doi:10.1111/1365-2664.12738

Snyman, H. A., Ingram, L. J., and Kirkman, K. P. (2013). *Themeda triandra*: A keystone grass species. *Afr. J. Range Forage Sci.* 30 (3), 99–125. doi:10.2989/10220119.2013.831375

Snyman, H. A. (2003). Revegetation of bare patches in a semi-arid rangeland of South Africa: An evaluation of various techniques. *J. Arid. Environ.* 55, 417–432. doi:10.1016/s0140-1963(02)00286-0

Snyman, H. A. (2006). Root distribution with changes in distance and depth of two-year-old cactus pears *Opuntia ficus-indica* and *O. robusta* plants. *South Afr. J. Bot.* 72 (3), 434–441. doi:10.1016/j.sajb.2005.12.008

Snyman, H. A. (2004). Soil seed bank evaluation and seedling establishment along a degradation gradient in a semi-arid rangeland. *Afr. J. Range Forage Sci.* 21, 37–47. doi:10.2989/10220110409485832

Snyman, H. D., and Du Preez, C. C. (2005). Rangeland degradation in a semi-arid South Africa—ii: Influence on soil quality. *J. Arid. Environ.* 60 (3), 483–507. doi:10.1016/j.jaridenv.2004.06.005

Solomon, T., Snyman, H. A., and Smit, G. N. (2007). Rangeland dynamics in southern Ethiopia: (1) botanical composition of grasses and soil characteristics in relation to land-use and distance from water in semi-arid borana rangelands. *J. Environ. Manage.* 85 (2), 429–442. doi:10.1016/j.jenvman.2006.10.007

Spurgeon, J. (1999). The socio-economic costs and benefits of coastal habitat rehabilitation and creation. *Mar. Pollut. Bull.* 37 (8-12), 373–382. doi:10.1016/s0025-326x(99)00074-0

Stafford, W., Birch, C., Etter, H., Blanchard, R., Mudavanhu, S., Angelstam, P., et al. (2017). The economics of landscape restoration: Benefits of controlling bush encroachment and invasive plant species in South Africa and Namibia. *Ecosyst. Serv.* 27, 193–202. doi:10.1016/j.ecoser.2016.11.021

Strassburg, B. B., Beyer, H. L., Crouzeilles, R., Iribarrem, A., Barros, F., de Siqueira, M. F., et al. (2019). Strategic approaches to restoring ecosystems can triple conservation gains and halve costs. *Nat. Ecol. Evol.* 3 (1), 62–70. doi:10.1038/s41559-018-0743-8

Sullivan, S., and Rohde, R. (2002). Guest editorial: On non-equilibrium in arid and semi-arid grazing systems. *J. Biogeogr.* 29 (12), 1595–1618. doi:10.1046/j.1365-2699.2002.00799.x

Taube, F., Gierus, M., Hermann, A., Loges, R., and SchÖnbach, P. (2013). Grassland and globalization-challenges for north-west European grass and forage research. *Grass Forage Sci.* 69, 2–16. doi:10.1111/gfs.12043

Teague, W. R., and Smit, G. N. (1992). Relations between woody and herbaceous components and the effects of bush-clearing in southern African savannas. *J. Grassl. Soc. South. Afr.* 9 (2), 60–71. doi:10.1080/02566702.1992.9648301

Tefera, B. S., Dlamini, B. J., and Dlamini, A. M. (2010). Changes in soil characteristics and grass layer condition in relation to land management systems in the semi-arid savannas of Swaziland. *J. Arid. Environ.* 74, 675–684. doi:10.1016/j.jaridenv.2009.10.016

Tesfa, A., and Mekuriaw, W. (2014). The effect of land degradation on farm size dynamics and crop-livestock farming system in Ethiopia: A review. *Open J. Soil Sci.* 4, 1–5. doi:10.4236/ojss.2014.41001

Tesfahunegn, G. B. (2018). Farmers' perception on land degradation in northern Ethiopia: Implication for developing sustainable land management. *Soc. Sci. J.* 56, 268–287. doi:10.1016/j.soscij.2018.07.004

Teshome, A., and Ayana, A. (2016). Conversion of savanna rangelands to bush dominated landscape in Borana, Southern Ethiopia. *Ecol. Process.* 5 (6), 1–18.

Tessema, Z. K., de Boer, W. F., Baars, R. M. T., and Prins, H. H. T. (2011). Changes in soil nutrients, vegetation structure and herbaceous biomass in response to grazing in a semi-arid savanna of Ethiopia. *J. Arid. Environ.* 75, 662–670. doi:10.1016/j.jaridenv.2011.02.004

Tilahun, A., Teklu, B., and Hoag, D. (2017). Challenges and contributions of crop production in agro-pastoral systems of Borana Plateau, Ethiopia. *Pastoralism* 7, 2–8. doi:10.1186/s13570-016-0074-9

Tizora, P., Le Roux, A., Mans, G. G., and Cooper, A. K. (2016). "Land use and land cover change in the western cape province: Quantification of changes & understanding of driving factors," in Proceeding of the 7th Planning Africa Conference 2016 – Making Sense of the Future: Disruption and Reinvention, Johannesburg, South Africa, 3-6 July 2016 (Pretoria, Gauteng, South Africa: Sandton Convention Centre, ResearchSpace, CSIR. http://hdl.handle.net/10204/8995).

Tokozwayo, S. (2016). "Evaluating farmer's perceptions and the impact of bush encroachment on herbaceous vegetation and soil nutrients in Sheshegu communal rangelands of the Eastern Cape, South Africa," (South Africa: University of Fort Hare). MSc dissertation.

Treydte, A. C., Baumgartner, S. A., Tuffa, S. K., and Abdeta, A. A. (2021). *Rangeland management in a changing world–active and passive restoration case studies from Ethiopia, Tanzania, and South Africa*.

Trollope, W. S. W., Potgieter, A. L. F., and Zambatis, N. (1989). Assessing veld condition in the Kruger National Park using key grass species. *Koedoe* 32 (1), 67–93. doi:10.4102/koedoe.v32i1.465

Trollope, W. S. W. (1974). Role of fire in preventing bush encroachment in the Eastern Cape. *Proc. Annu. Congr. Grassl. Soc. South. Afr.* 9 (1), 67–72. doi:10.1080/00725560.1974.9648722

Tuffa, S., Hoag, D., and Treydte, A. C. (2017). Clipping and irrigation enhance grass biomass and nutrients: Implications for rangeland management. *Acta oecol. (Montrouge).* 81, 32–39. doi:10.1016/j.actao.2017.05.001

UNCCD (2015). *Climate change and land degradation: Bridging knowledge and stakeholders 9-12 march 2015, outcomes from the UNCCD 3rd scientific conference*. Mexico: Cancún.

United Nations Environment Program (UNEP) (1992). *World atlas of desertification*. London: Edward Arnold.

Utuk, I. O., and Daniel, E. E. (2015). Land degradation: A threat to food security: A global assessment. *J. Environ. Earth Sci.* 5 (8), 13–21.

van den Berg, L., and Kellner, K. (2005). Restoring degraded patches in a semi-arid rangeland of South Africa. *J. Arid. Environ.* 61, 497–511. doi:10.1016/j.jaridenv.2004.09.024

Van den Berg, L. (2007). "The evaluation and promotion of best practices for the restoration of arid-and semi-arid rangelands in southern Africa.," (South Africa: North-West University). Doctoral dissertation.

Van den Berg, L. (2002). "The evaluation of a number of technologies for the restoration of degraded rangelands in selected arid and semi-arid regions In South Africa," (Potchefstroom, South Africa: Potchefstroom University for CHE). MSc thesis.

van Langevelde, F., van de Vijver, C., Kumar, L., van de Koppel, J., de Ridder, N., van Andel, J., et al. (2003). Effects of fire and herbivory on the stability of savanna ecosystems. *Ecology* 84, 337–350. doi:10.1890/0012-9658(2003)084[0337:eofaho]2.0.co;2

Van Wilgen, B. W., and Scott, D. F. (2001). Managing fires on the cape peninsula, South Africa: Dealing with the inevitable. *J. Mediterr. Ecol.* 2, 197–208.

Vaniman, D. T., Bish, D. L., Chipera, S. J., Fialips, C. I., William Carey, J., and Feldman, W. C. (2004). Magnesium sulphate salts and the history of water on Mars. *Nature* 431, 663–665. doi:10.1038/nature02973

Verdoodt, A., Mureithi, S. M., Ye, L., and Van Ranst, E. (2009). Chronosequence analysis of two enclosure management strategies in degraded rangeland of semi-arid Kenya. *Agric. Ecosyst. Environ.* 129 (1-3), 332–339. doi:10.1016/j.agee.2008.10.006

Walters, M., Figueiredo, E., Crouch, N. R., Winter, P. J. D., Smith, G. F., Zimmermann, H. G., et al. (2011). *Naturalised and invasive succulents of southern Africa*. Brussels, Belgium: Abc Taxa Belgium Development Corporation. 11.

Ward, D. (2010). A resource ratio model of the effects of changes in CO2 on woody plant invasion. *Plant Ecol.* 209, 147–152. doi:10.1007/s11258-010-9731-z

Ward, D. (2005). Do we understand the causes of bush encroachment in African savannas? *Afr. J. Range Forage Sci.* 22 (2), 101–105. doi:10.2989/10220110509485867

Ward, D., Hoffman, M. T., and Collocott, S. J. (2014). A century of woody plant encroachment in the dry Kimberley savanna of South Africa. *Afr. J. Range Forage Sci.* 31 (2), 107–121. doi:10.2989/10220119.2014.914974

Wassie, S. B. (2020). Natural resource degradation tendencies in Ethiopia: A review. *Environ. Syst. Res.* 9 (1), 33–29. doi:10.1186/s40068-020-00194-1

Wessels, K. J., Prince, S. D., Malherbe, J., Small, J., Frost, P. E., and VanZyl, D. (2007). Can human-induced land degradation be distinguished from the effects of rainfall variability? A case study In South Africa. *J. Arid. Environ.* 68 (2), 271–297. doi:10.1016/j.jaridenv.2006.05.015

Wheeler, A. D. (2010). "Impacts of degradation on critically endangered Oudtshoorn Gannaveld," (South Africa: University of Western Cape). PhD Thesis.

Wigley, B. J., Bond, W. J., and Hoffman, M. T. (2010). Thicket expansion in a South African savanna under divergent land use: Local vs. global drivers? *Glob. Chang. Biol.* 16 (3), 964–976. doi:10.1111/j.1365-2486.2009.02030.x

Williams, M. (2003). *Deforesting the earth: From prehistory to global crisis*. Chicago, Illinois, USA: University of Chicago Press.

Wilson, M. H., and Lovell, S. T. (2016). Agroforestry—The next step in sustainable and resilient agriculture. *Sustainability* 8 (6), 574. doi:10.3390/su8060574

Woodfine, A. (2009). *Using sustainable land management practices to adapt to and mitigate climate change in sub-saharan Africa. Resource guide version 1.0*. African: TERRAFRICA.

Worlanyo, A. S., and Jiangfeng, L. (2021). Evaluating the environmental and economic impact of mining for post-mined land restoration and land-use: A review. *J. Environ. Manage.* 279, 111623. doi:10.1016/j.jenvman.2020.111623

WRI (2017). Roots of prosperity: The economics and finance of restoring land. Available at: https://www.wri.org/publication/roots-of-prosperity (accessed on 12 May 2022).

Yirdaw, E., Tigabu, M., and Monge, A. (2017). Rehabilitation of degraded dryland ecosystems- review. *Silva Fenn. Hels.* 51, 2–32. doi:10.14214/sf.1673

Zerga, B. (2015). Rangeland degradation and restoration: A global perspective. *Point J. agri. Biotechnol. Res.* 1, 37–54.

Zhao, F., Hitzhusen, F., and Chern, W. S. (1991). Impact and implications of price policy and land degradation on agricultural growth in developing countries. *Agric. Econ.* 5 (4), 311–324. doi:10.1016/0169-5150(91)90025-g