Best Practice Guidelines for Sustainability and Rehabilitation in the Nama Karoo, South Africa

A RESOURCE FOR MULTIPLE USERS

PART I

Produced by
Claire Relton, Bonnie Schumann and Cobus Theron

With Additional Insights from
Dr Sue Milton-Dean

This report aims to investigate and review various sustainable land management (SLM) practices and techniques utilised in drylands around the world, with specific emphasis on rehabilitation methods. In this report we consider drylands under the context of conserving biodiversity and natural resources; protecting and improving ecosystem goods and services; as well as sustaining the human livelihoods and industries that depend on these systems. This document is the first of a series of three freely-available resources intended for use across multiple sectors and stakeholders, including but not limited to Karoo landowners and practitioners, conservation organisations, government officials, scientists, consultants and local industry & business representatives.

Contents

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Special Acknowledgement to our partner in conservation

The Rand Merchant Bank has supported the Endangered Wildlife Trust's riparian habitat rehabilitation project for several years. This support has enabled us to undertake extensive rehabilitation and monitoring activities on nine sites in the Nama Karoo. The knowledge gained has been invaluable and has ultimately culminated in the production of this document.

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1. General Introduction

1.1. Drylands

The IUCN defines drylands as "areas with low annual precipitation, prolonged periods of heat, low relative humidity and high rates of evaporation" (UNEP 1997). This includes zones classified as hyper-arid, arid, semi-arid and dry sub-humid, which are defined using an aridity index, calculated by the ratio of precipitation to potential evapotranspiration (UNEP 1997). More specifically, any temperate or tropical region with an aridity index less than 0.65 is considered a dryland (UNEP 1997). Although drylands cover at least 41% of the world's terrestrial surface and are home to a third of humanity, these regions are commonly overlooked in environmental sustainability and conservation initiatives (Mortimore 2009). Aronson et al. (2010) found that of 1,582 peer-reviewed papers on ecological restoration from 13 leading scientific journals, arid and semi-arid areas accounted for only 5% of the focus areas, while between 45 and 60% focus on forest and aquatic ecosystems combined. Drylands occur on every continent, but are most extensive across Africa. In Africa, 67% of land is believed to be affected by land degradation (Liniger et al. 2011), and millions of people face considerable rural poverty. Furthermore, people living in drylands currently experience the highest level of poverty, compared to all other zones, and this is likely to continue and become exacerbated in the near future, as these regions are considerably vulnerable to the effects of global climate change (Mortimore 2009) and the rate of population increase.

As drylands extend across broad geographical areas, land-use type in drylands has a substantial impact on atmospheric circulation (Mortimore 2009). Thus, due to their expansive range and the degree of environmental degradation faced by dryland environments, these regions should be considered priority areas for ecological rehabilitation and restoration (Geist & Lambin 2004). Land degradation includes physical processes, such as soil erosion, chemical processes, such as a soil contamination or a decline in soil fertility, and biological processes, such as a loss of biodiversity and biomass. These processes have complex interactions and feedbacks, for example a loss of plant biodiversity can result in a loss of soil stability and accelerated soil erosion.

1.2. Sustainable Land Management

Sustainable Land Management (SLM) is defined as a comprehensive, knowledge-based approach to ensuring long-term, positive change to the environment in order to meet human needs, while ensuring ecosystem services, biodiversity and livelihoods are maintained or improved (Liniger et al. 2011). SLM may include prevention, mitigation and/ or rehabilitation methods for curbing land degradation (Liniger et al. 2008). Prevention aims to maintain ecosystem services, biodiversity and resources that may be susceptible to degradation (Liniger et al. 2008). Mitigation is the implementation of interventions aimed at reducing current degradation, in order to halt further degradation, and improve resources and ecosystem services (Liniger et al. 2008). Rehabilitation is necessary when the environment has been degraded to such an extent that its original functionality and service or resource provision is no longer in place. Often long-term and more costly methods are required for rehabilitation projects, compared to mitigation or prevention (Liniger et al. 2008).

There is some controversy over the use of the terms "restoration" and "rehabilitation", as they are often incorrectly used interchangeably. Restoration is defined as the process of recovering an ecosystem that has been degraded or damaged in an effort to return it to its original, natural condition. Rehabilitation, on the other hand, is the reparation and improvement of an ecosystem's processes, services and productivity in an attempt to re-create a sustainable ecological system, but does not attempt to restore the system to its pre-existing levels of biodiversity and productivity. It is extremely difficult (if not impossible) to define the original state and productivity of the Nama Karoo landscape before it was significantly transformed by humans during the 1850s. Without doubt the landscape was dominated by large herds of wild ungulates (Boshoff et al. 2016). As we acknowledge that absolute restoration is impossible in this context, the aim should be to limit further degradation, increase vegetation cover and diversity in those parts of the landscape that appear to be degraded by ploughing, trampling and grazing and where soil erosion and salinization are preventing passive vegetation recovery. Throughout this document, we retain the use of the term "restoration" only when that term has been used in the source being referenced.

1.3. Benefits of rehabilitation

Ecological restoration is considered a priority for long-term global sustainability, and is vital in degraded landscapes to repair damage, increase productivity of agricultural and rangeland areas (Geerken & Ilaiwi 2004), reduce soil erosion, and prevent economic losses and socioeconomic disruptions (Aronson et al. 2010). Blignaut (2012) maintains that the restoration of natural capital has the unparalleled benefit to, on a continuous basis from the day of engaging in the restoration exercise, contribute meaningfully to climate change adaptation and human welfare through i) ensuring or augmenting the continued delivery of ecosystem goods and services, ii) combatting ecosystem fragmentation and thereby any potential future loss of ecosystem goods and services, and iii) buffering against the impacts of adverse and severe climatological events such as droughts and floods. Blignaut (2012) further highlights that restoration has the unique feature that it can augment the world's rapidly dwindling supply of ecosystems and hence ecosystem goods and services and, in the process, develop resilient and healthy ecosystems, which, in-turn, reduces peoples vulnerabilities through an enhancement of the supply of these services. In Argentina and Ecuador, flood control projects utilize the natural storage and recharge properties of critical forests and wetlands by integrating them into "living with floods" strategies that incorporate forest protected areas and riparian corridors. These simple and effective solutions protect both communities and natural capital. the restoration of degraded natural capital is the only augmentation option to the world's declining stock of natural capital and hence, ecosystem goods and services. It has also been shown that restoration offers excellent returns on investment (Blignaut 2012).

1.4. Costs of rehabilitation

Much research suggests that rehabilitation in drylands is often time-consuming or largely unsuccessful due to biotic and abiotic constraints. Passive rehabilitation involves no direct action to improve the land, other than the removal of primary stressors, such as grazing pressure or cultivation. Primary constraints to passive rehabilitation include dispersal limitation (Bullock et al. 2002), low water availability, soil compaction, low nutrient availability, extreme temperatures (Rey Benayas 1998; López-Barrera et al. 2006) and grazing pressure (Rey Benayas et al. 2005). Land degradation impacts a multi-faceted range of interacting ecosystem services and human livelihoods that depend upon dryland ecosystems (Reed et al. 2015). Globally, billions of dollars are spent on environmental restoration and rehabilitation schemes, and many of these prove unsuccessful (Goldstein et al. 2008). As a result, cost-benefit analyses and adaptive management schemes are vitally necessary to ensure that both environmental conservation, as well as human livelihoods, benefit from such rehabilitation and restoration projects. Costs and benefits associated with ecosystem services and natural capital are highly specific to environmental, social and land-use characteristics (Birch et al. 2010). In order to determine whether investments in SLM practices are worthwhile, one should compare the costs of ecosystem services with those of technically-supplied services, (for example water purification of a wetland compared to anthropogenic chemical water purification) (Aronson & Blignaut 2009). Importantly, however, the complexity of accurately capturing all inter-related cost-benefit values should be considered, as these analyses often miss important dimensions of the values associated with SLM practices, such as cultural and plural values. Ultimately, successful and sustainable land management requires an integration of methods based upon both biophysical and socioeconomic components.

1.5. Climate Change

Within the arid regions of sub-Saharan Africa, climate change is predicted to result in increased rainfall variability and enhanced thermal stress (Davis-Reddy & Vincent 2017). These effects and the compounding influences of land degradation threaten the resilience of dryland regions, as well as the associated human livelihoods and wildlife. In light of these impending circumstances, the use of sustainable land management and restoration practices, and the development of climate-resilient livelihoods and activities that aid in climate change mitigation, are essential (Davis-Reddy & Vincent 2017). The accelerated increase of greenhouse gases, such as CO_2 and methane, in the atmosphere, resulting from the burning of fossil fuels and land-use change, necessitates the identification of techniques to mitigate the effects of climate change (Davis-Reddy & Vincent 2017). The global loss of soil organic carbon through land-use change, injudicious grazing practices, land degradation and soil mismanagement has contributed significant quantities of carbon to the atmosphere (Lal 2004). The adoption of sustainable land and restoration practices on agricultural soils can assist in soil carbon retention and a decreased rate of atmospheric CO_2 enrichment, while positively influencing food security, agricultural industries, water quality and the environment (Lal 2004)

2. The Nama Karoo

This report focuses specifically on the practices that are currently being employed or could be useful in the Nama Karoo Biome of South Africa. The Nama Karoo is situated within the dryland region of southern Africa.

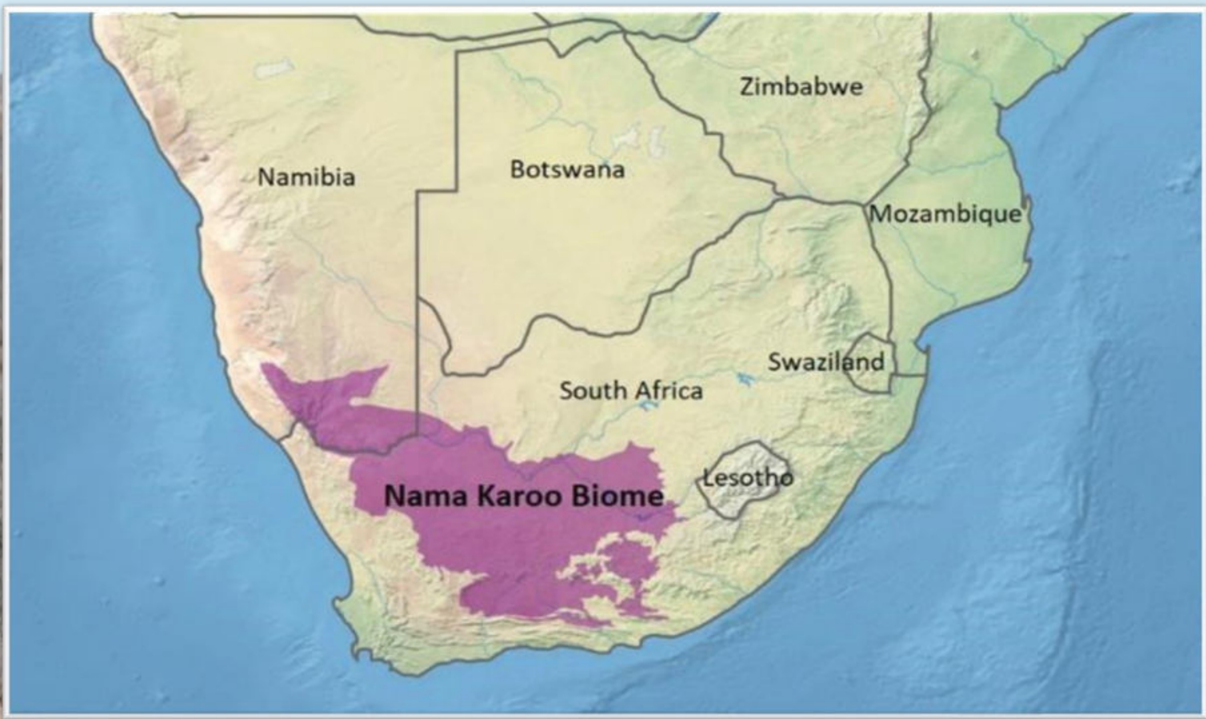

Figure 1. Map depicting the geographic range of the Nama Karoo Biome across southern Africa.

2.1. Climate

The Nama Karoo experiences infrequent, but violent summer thunderstorms that are characteristically unpredictable. As the Nama Karoo is an arid region, rainfall is considered the most important limiting factor. Rainfall has a significant impact on the success of restoration and rehabilitation projects (Milne 2010). Most rivers are non-perennial and the mean annual precipitation varies from about 70 mm in the regions bordering the Desert Biome in the northwest to about 500 mm in the southeastern parts (Mucina et al. 2006). Rain typically falls during the late summer months (December – April). Frost is common in the Nama Karoo, which is the primary reason that the Nama Karoo does not generally support large trees, other than frost-resistant aliens. The predictions of how climate change might influence the Nama Karoo Biome are discussed on page 10.

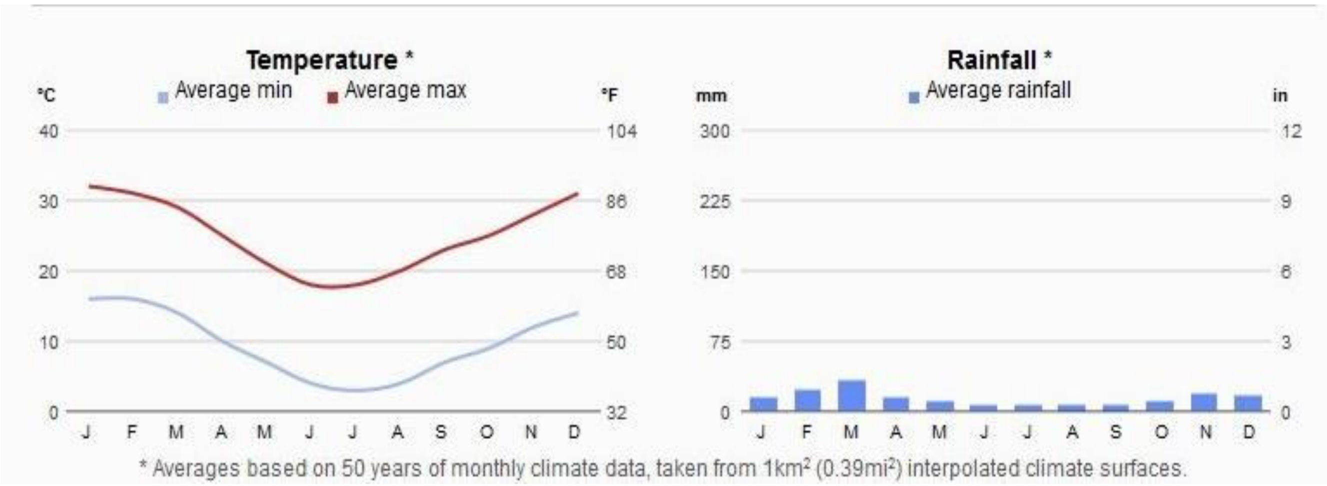

Figure 2. Mean monthly temperature and rainfall values for the Karoo National Park (781 - 1,899 m).
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https://www.safaribookings.com/karoo/climate

2.2. Geology and Soils

The Nama Karoo is characterized by a generally flat landscape or gently undulating sandy or rocky plains, interspersed by igneous boulder outcrops and mesas (flat topped areas of elevated land) that have been molded by wind and water erosion (Mucina et al. 2006). The underlying geology of the Nama Karoo is composed on a 3,000 m deep layer of sedimentary rock with pans, igneous intrusions and lime-rich evaporite (Mucina et al. 2006). The Nama Karoo soils developed from this parent material, under arid conditions, and are generally base-rich, weakly-structured and skeletal (contain rock, cobble or gravel fragments ≥ 2 mm in diameter). The Great Escarpment, located between 100 and 200 km from the coastline, rises about 1,000 m over the surrounding countryside and separates the upper and lower Nama Karoo regions (Mucina et al. 2006). Altitude across the biome ranges from 600 to 2,000 m above sea level (Mucina et al. 2006).

2.3. Vegetation

The Nama Karoo is dominated by dwarf shrubs with a co-dominance of deciduous grasses, as well as some succulents, geophytes and annual forbs (Mucina et al. 2006). Trees occur infrequently along watercourses, on rocky outcrops (Mucina et al. 2006) and in the wetter areas (Todd 2006). The high diversity of plant life is likely attributed to the climatically unstable nature of the biome (Cowling et al. 1994).

2.4. Rivers

The life-giving non-perennial rivers of the Nama Karoo are highly inter- and intra-annually variable, and surface waters are often stressed to meet the demand for all users (Scholes et al. 2016). The rivers transport millions of tons of fertile silt onto their floodplains, making the floodplain zone popular for cultivation. In the northwestern Karoo, the farming method, termed the *Saaidam* (sowing dam) system, has been utilised for at least 135 years (Moseley 2007), whereby low embankments have been constructed along the floodplain zone in order to delay the flow of water and promote infiltration (Moseley 2007). However, successful yields using the *Saaidam* method rely heavily on favorable rainfall and flood waters, and due to the erratic and unpredictable nature of rainfall in the Karoo, as well as threats of intense heat, locusts, crickets, frost and greenfly, cultivation has never been consistently successful in the region (Moseley 2007).

2.5. Land-use

The primary land-use in the Nama Karoo is extensive grazing of small stock, including sheep for wool and mutton, and goats for mohair (Todd 2006). Cattle ranching in the north and east, and game ranching with indigenous antelope are also common (Mucina et al. 2006). Land ownership is mostly private or communal, and although ranches are fenced, they are typically quite large (4,000-15,000 ha). Due to the low productivity of the region and arid conditions, large areas are required to support livestock and wildlife (Mucina et al. 2006). Most livestock enclosures are supplied with watering points and are usually grazed on a rotational system with rest periods of several months to more than a year (Hoffman 1988).

2.6. Stakeholders

Successful restoration and rehabilitation of the environment requires collaboration and participation across multiple stakeholders. The establishment and maintenance of positive and beneficial relationships across stakeholder groups, that co-operate with governmental legislation is essential if long-term rehabilitation schemes are to be initiated. Below is a diagram identifying stakeholders in the Nama Karoo that might directly or indirectly influence, implement and promote sustainable management and rehabilitation practices across the region, as well as their associated mandates:

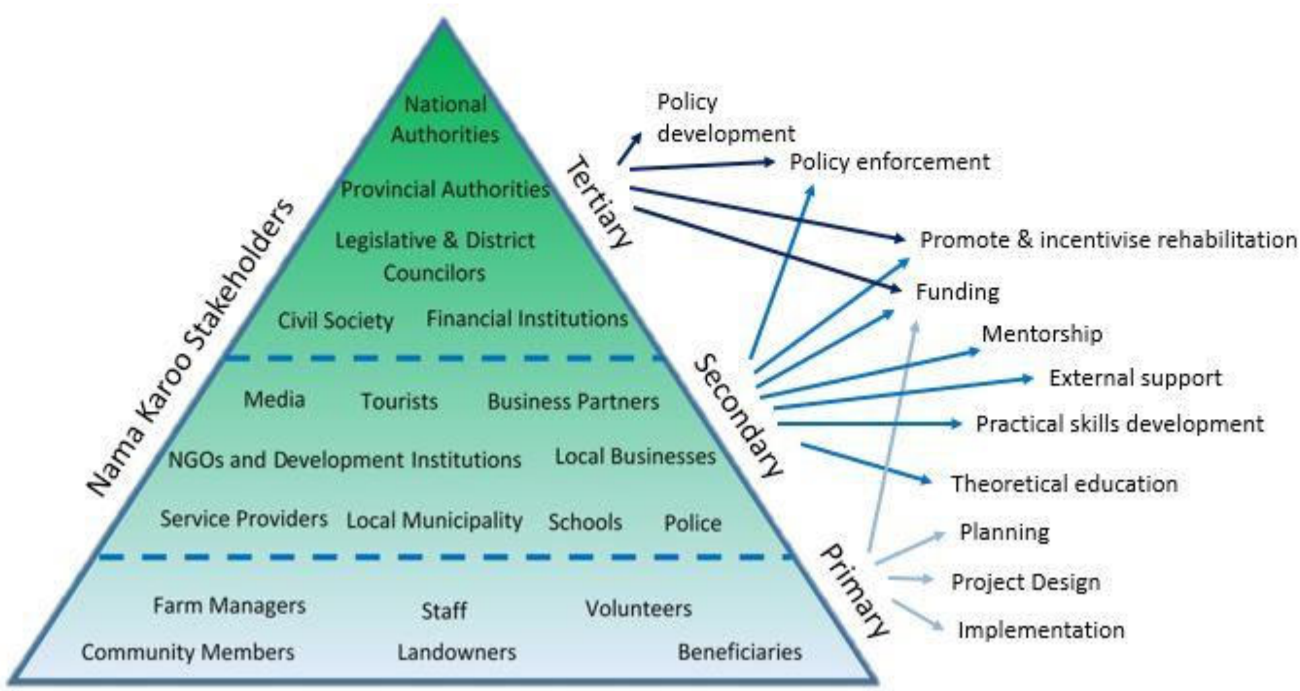


Figure 4. Categorized diagram of land rehabilitation stakeholders in the Nama Karoo and their associated mandates (Diagram compiled by Claire Relton, EWT).

3. Threats

The major threats affecting the ecosystems, industries and local communities of the Nama Karoo are displayed in Figure 3 below. Some of the most important of these are discussed individually in the section to follow. The interactions and relationships between such threats should be viewed holistically when attempting to understand the resilience of the Nama Karoo Biome, and its plant, wildlife and human communities. For example, the dynamic nature of the Nama Karoo system, due largely to the highly seasonal and unpredictable rainfall, means that changes in plant productivity affect grazing opportunities for livestock and the profitability of livestock farming, which resultantly impacts the economy of the region and the community members' livelihoods.

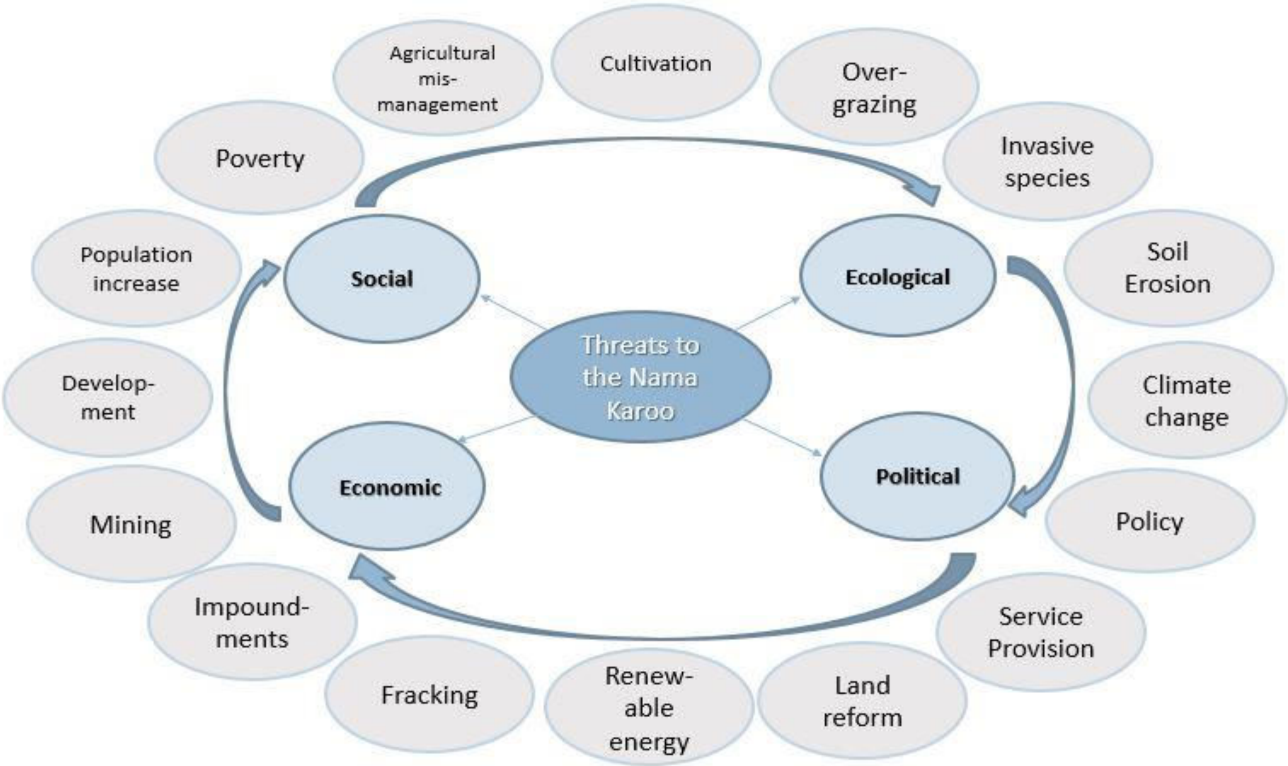


Figure 3. Diagrammatic representation of direct and indirect threats to the Nama Karoo.

Rainfall cycles and annual temperatures naturally fluctuate in the arid zones of southern Africa due to large-scale weather patterns (Esler et al. 2002). Prolonged or recurrent drought may result in mortality of perennial plant species, which may lead to the development of bare patches, and alter the vegetation composition of the Nama Karoo in favour of short-lived species. Under the effects of anthropogenic climate change, rainfall is predicted to increase slightly between December and March, but is expected to become increasingly variable (Altwegg & Anderson 2009). Rutherford et al. (1999) evaluated the critical thresholds of plant growth days and minimum temperature under a predicted climate change scenario. Their results predicted that more than one third of plant species in the Augrabies Falls National Park may become locally extinct under scenario effects of climate change (Rutherford et al. 1999). However, under the same scenario, the Karoo National Park appeared to be substantially less vulnerable to the effects of climate change (Rutherford et al. 1999). The complex systems and interactions between climatic, environmental and biotic factors make predicting the response of ecosystems to climate change extremely complicated.

In light of this, the principal method to improve the resilience of the Nama Karoo and mitigate against the threat of climate change is to conserve natural biodiversity (Esler et al. 2002), promote the growth of indigenous vegetation, reverse degradation and promote sustainable land management.

3.1. Overgrazing

Inappropriate grazing management is considered one of the leading causes of land degradation in South Africa, and is especially important in the Nama Karoo when in combination with periodic drought, low vegetation cover and heavy thundershowers, which promote high runoff and low infiltration (Saayman & Botha 2010). Extensive farming of sheep and goats, overgrazing, or, in some cases, injudicious practices, usually results in a change from palatable to unpalatable plant species, a replacement of grasses by shrubs and a loss in biodiversity. In grassy, summer-rainfall areas, bush thickening occurs where the grasses are over-utilised. This affects the availability of food resources for livestock and ultimately threatens the human livelihoods dependent on these small-stock industries. In addition to a delay in vegetation recovery and loss of plant diversity, Hoffman & Zeller (2005) found that overgrazing leads to a decline in species richness, abundance, diversity and settlement of small mammals in the Nama Karoo. The loss of grass cover, in association with bush encroachment, led to a decline in arthropod abundance (food availability), dew retention (water availability) and shelter, as well as an increase in predation risk for small mammals (Hoffmann & Zeller 2005). Degradation is common along the highly productive areas adjacent to seasonal river courses, as the soils are highly vulnerable to trampling. The effects of trampling are most severe in wet, fine-textured soils, and the regular movement of livestock along fences, to and from water points or feeding troughs leads to soil compaction and loss of vegetation cover (Esler et al. 2006).

3.2. Cultivation

Deep alluvial soils in riparian zones are ideal for cultivation, thus are commonly ploughed, leading to a major loss of natural habitat and biodiversity. In the Nama Karoo a loss of at least 60% of natural biodiversity has taken place, specifically from Calvinia to Williston, along the lower Sak, Renoster and Fish Rivers. Cultivation practices result in the expansion of bare patches, which promotes salinization though accelerated evaporation. Additionally, soil nutrient levels decline (Mortimore 2009) and erosion by wind and water is common. Natural restoration is extremely slow, and in most cases unlikely, as very little is able to germinate in these degraded soils. Flood irrigation practices, such as the *Saaidam* system (Page 8) are still conducted in the Nama Karoo, particularly when farming for Lucerne. Flood irrigation is certainly not as efficient or cost-effective as many other irrigation schemes, as about half of the water applied is lost to runoff, evaporation, transpiration through weeds and infiltration into uncultivated areas. Although there are plans to expand cultivation practices in the Nama Karoo region, the climatic conditions (irregular rainfall and intense thunderstorms) suggest that this may not be a viable option.

3.3. Invasive and/or alien vegetation

Ground water availability in the Nama Karoo is largely affected by alien invasive species, such as *Eucalyptus* spp, *Prosopis* and *Populus* spp. (Milton-Dean 2010). Some of which were intentionally introduced to combat drought, but lead to unexpected establishment of unwanted species. A range of *Prosopis* species from North and South America (*Prosopis glandulosa*, *P. juliflora*, *P. velutina*) were widely introduced to areas of the Karoo for shade, firewood and as a forage supplement for livestock. These *Prosopis* species have hybridised in South Africa, and the deep-rooted hybrid species have become extensive and harmful invaders in the Karoo ecosystem (Poynton 1990; Milton-Dean 2010). *Prosopis* invasions along river courses, within drainage basins and associated rangelands are common, and lead to a loss of water and native palatable grazing material (Harding & Bate 1991; Ntshidi 2015). Dzikiti et al. (2013) found that clearing *Prosopis* could result in groundwater savings of up to 70 m^3/ month, and prevent a loss of 345 m^3/ha of groundwater per year. It is predicted that climate change could significantly exacerbate the spread of invasive species (Richardson & van Wilgen 2004). Importantly, the predicted increases in atmospheric CO_2 are suggested to favour C3 plants, such as woody invasive species over C4 grasses (Midgley et al. 1999; Bond 2008). Some farmers prefer to remove invasive trees before they take over riverbanks, as they reduce the grazing potential of the surrounding landscape, however others feel that the protein-rich pods of *Prosopis* species can be valuable in times of drought, and removing the trees may only increase the risk of erosion (Moseley 2007).

3.4. Erosion

Erosion by wind and rain, specifically in riparian zones, results in a dramatic loss of topsoil and resultantly, vegetation cover in the Nama Karoo. Although erosion is a natural process, mismanagement of the landscape causes accelerated soil erosion, at a rate that is harmful to biodiversity and ecosystem functionality. Nama Karoo soils are highly prone to rapid erosion, as they are lime-rich and weakly-developed (Moseley 2007). The development of badlands and rill & gulley systems and the degradation of river channels, often leads to a major loss of biodiversity, resulting from the replacement of grasslands with unpalatable shrub-lands. Intense, convective rainfall in association with low vegetation cover (caused by aridity and overgrazing) promotes extensive soil erosion and the loss of valuable soil nutrients. Within semi-arid soils, nutrients are generally located in the upper layers, thus the loss of topsoil by processes such as sheet erosion, results in a feedback of low plant productivity. Natural restoration is often impossibly slow, thus without intervention, erosion is likely to continue. Areas of high productivity are generally associated with non-perennial rivers, which are the dominant river systems in the Nama Karoo. As a result, soil erosion is often associated with the riverine and floodplain areas linked to these seasonal rivers, as these regions are most vulnerable to overgrazing, trampling, flooding and unsustainable cultivation.

3.5. Mining & Energy

The Nama Karoo is vulnerable to the imminent threats associated with expanding Uranium mines, the construction of renewable energy plants, fracking and the extensive overhead development and infrastructure associated with these practices (e.g. the construction of transport routes, pipelines associated with gas etc.). Impacts associated with mining include habitat loss, pollution and over-extraction of water resources and soil compaction, in addition to the associated risks to human health. Post-mining rehabilitation is largely ineffective and restoration of natural ecosystem services following the closure of mined areas is extremely unlikely. Additionally, possible future development in the Karoo Basin includes geothermal energy production (Campbell et al. 2016).

The construction of dams leads to irreversible habitat transformation, fragmentation and alteration the natural water flow regime. Development of dams such as the Houwater, Kalkfontein and Smart Syndicate Dams in the Northern Upper Karoo may promote the increase of human settlement around those areas, leading to further habitat loss and conversion (Mucina et al. 2006). In the Eastern Upper Karoo, most transformation has resulted from the construction of the Gariep, Grassridge, Killowen, Kommandodrift, Kriegerspoort, Lake Authur, Modderpoort, Schuil Hoek, Vanderkloof, Victoria West, Wonderboom and Zoetvlei Dams (Mucina et al. 2006).

3.6. Social & Policy

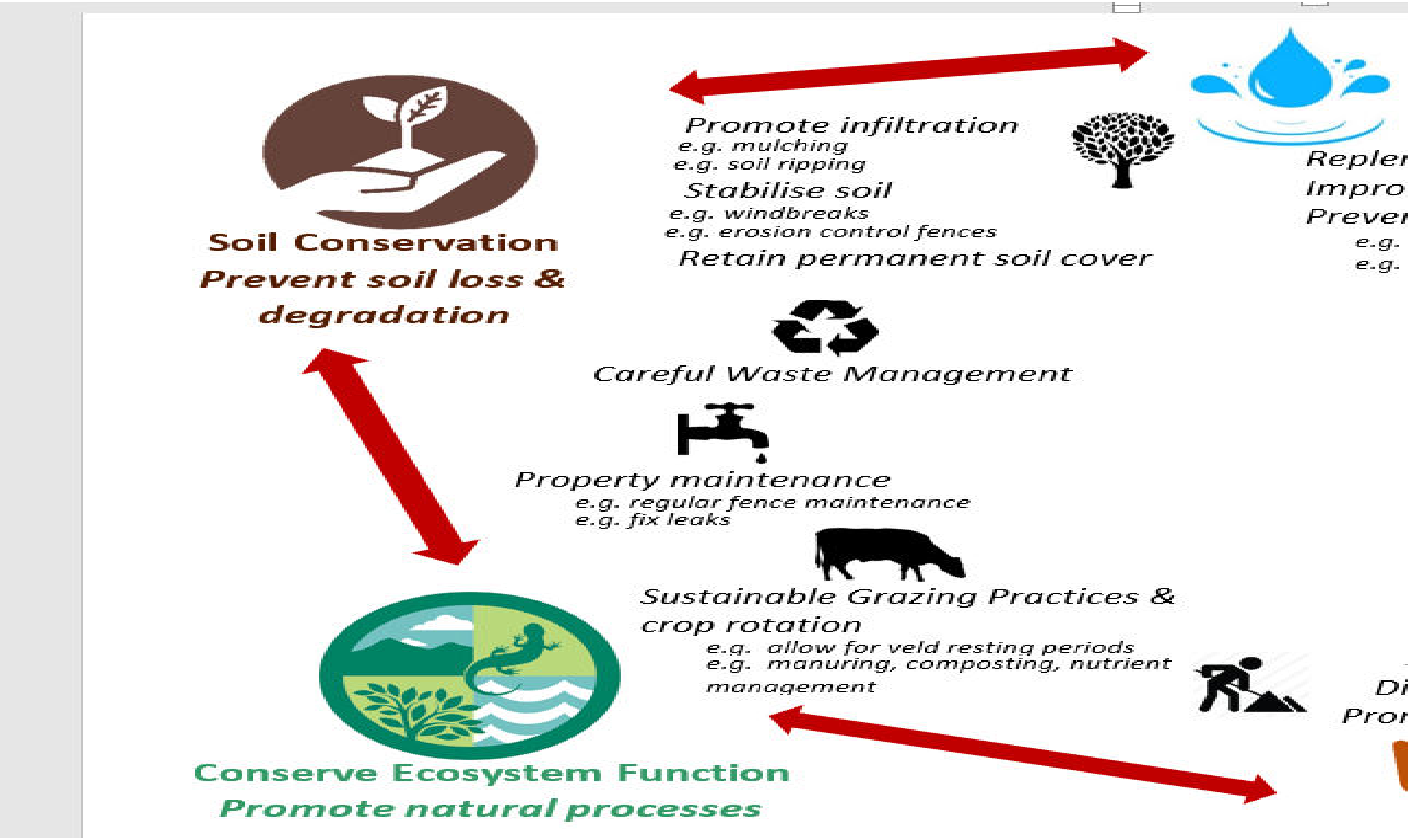
Although the Nama Karoo is sparsely populated compared to other South African biomes, the net influx of people into certain areas, as well as natural population growth has resulted in a lack of services and resources. This trend is likely to continue, for example, in the Central Karoo District (Western Cape) population in 2017 is estimated at 75,022 and is predicted to increase to 79,014 by 2023 (Provincial Treasury 2016). This has led to an escalation of poaching and the unsustainable utilisation of trees, shrubs and grasses for wood and livestock grazing, increased water and terrestrial pollution, and a gradual decline in ecosystem services. The resettlement of lands aims to empower indigenous South Africans economically, while improving food productivity. However, the purchase of farms for land reform also poses challenges, as often the units supplied are not economically viable and stocking rates are too high. This results in increased overgrazing, which is associated with biodiversity loss and soil erosion. Furthermore, rapid land reform programmes can result in accelerated environmental degradation through a lack of governance, consultation and participation, and insufficient agricultural skills training, knowledge development and resources, resulting in bad farming practices and an overexploitation of natural resources (Zembe et al. 2014).

4. Final introductory remarks

The processes and threats associated with land degradation in the Nama Karoo are interactive and multifaceted, thus understanding the system from a holistic perspective is essential. This includes ecological, social, economic and political aspects. If threats in the Karoo are not addressed through rehabilitation, degradation will passively continue. Rehabilitation has proven to be largely unsuccessful in drylands, due to the arid conditions and slow recruitment rate of palatable species. The influx of emerging farmers into the Nama Karoo creates financial, cultural and social opportunities for local families and communities, and aims to promote economic growth and equality in South Africa. However, knowledge, resources, and financial and practical assistance should be accessible to all emerging farmers to ensure the land is managed sustainability and effective farming practices are sustained.

The short-term costs of effective rehabilitation are often higher than the per hectare market value of the land and many landowners do not consider rehabilitation to be economically viable, due to the relatively low carrying capacity of the area and time-consuming processes. However, the long-term benefits of rehabilitation, such as the provision and protection of natural resources and ecosystem services, job creation, increases in productivity, availability of natural land for wildlife, flood protection in riparian areas, tourism, poverty alleviation, improved food security, mitigation of the threats of climate change and contributions to a green economy should be considered in financial planning. As degradation is primarily concentrated around riverine and floodplain areas of the Nama Karoo, the rehabilitation of these areas would significantly improve habitat availability and connectivity for the Critically Endangered Riverine Rabbit, *Bunolagus monticularis,* which is a flagship species of the Karoo, severely threatened by habitat loss and fragmentation. Land rehabilitation in the Karoo can double the carrying capacity for wildlife or livestock, reduce erosion (Coetzee 1992), and lead to substantial economic improvements of local industries, which rely heavily on the availability of water and indigenous species. Various rehabilitation techniques, case studies and approaches for tackling land degradation are discussed below.

5. Sustainable Land Management in the Nama Karoo



6. Rehabilitation & Mitigation Techniques

	Technique	Description	Purpose	Advantages	Disadvantages	Recommendations	Costs
	Soil Ripping *During wet conditions, heavy machinery should be avoided, as compaction can occur, which breaks down the soil structure.*	A modified plough is dragged behind a tractor or cattle in order to break the soil surface (usually compacted soils). Used in cultivation as well as on restoration sites where a single tine may also be used to penetrate soil up to 1,5 m.	Loosens the soil to allow increased infiltration, reduced runoff and the penetration of plant roots.	• Increased crop yield. • Reduced soil loss • Improved soil cover. • Reduced river pollution (chemical contamination). • In contrast to conventional tillage, the soil is not inverted. *[1] • If mechanised, technique can be applied over a large area in a relatively short period of time.	• Heavy equipment (or animals) required • Water logging can occur. • More prone to weeds. • High equipment / animal maintenance costs. • In fine clay soil the ripper line caps before much infiltration can occur. • Use of a heavy vehicle can lead to further compaction & localised damage of fauna & flora • May add pollutants (such as oil) to the environment.	• Livestock and game should be excluded. • Fertiliser can be used in combination with soil ripping to increase yield. • Furrows to a depth of 100 mm using a three-tine ripper drawn tractor was used by de Abreu (2011), however the author states that this may have been too shallow.*[2] • Rip lines should be cut along contours.	R 0.13 / m^2 (de Abreu 2011).

	Technique	Description	Purpose	Advantages	Disadvantages	Recommendations	Costs
	Micro-catchments	Hollows or pits dug into the soil, which form fertile microclimates trapping seeds and organic materials. Can be hand-dug or created with the use of a pitter plough or "happloeg".	Hollows hold water aiding rehydration of the soil by facilitating increased infiltration. Hollows trap windblown seeds and leaf litter. Common shapes include planting pits, half-moons*3 or semi-circles (Coetzee & Stroebel 2015).	• Slows runoff • Cheap and easy to produce by hand. • Can aid in local job creation and skills development. • Reduces unpalatable plant neighbour competition when favourable species are planted.	• Not suitable for use on slopes. • Labour intensive. • Not appropriate on seasonal riverbeds that experience occasional flash floods. • Problematic where soils are fine and have a high clay content as waterlogging results in plants drowning.	• Livestock & game must be excluded. • Best be used in combination with other techniques such as mulching, seeding or planting plugs to speed up recovery rate. • Each hollow should trap ~50 litres of water. • Orientate to face upslope in order to trap rainwater more effectively.	R 1.54 / m² (de Abreu 2011).
	Erosion Control Fences	Construction of permanent (check dams) or semi-permanent structures along erosion gullies to slow down destructive water flow.	Allow for soil to accumulate behind the "fence" and for water to infiltrate the soil to feed plants and replenish the ground water table. Stabilises small dongas and gulleys.	• Can be simple and cost effective or more complex if necessary. • Can be used on flat and sloping terrain (to treat small rills) • Fences in series will prevent large runoff flows.	• Labour intensive. • Resource intensive (expensive). • In arid areas the regeneration of vegetation may not be fast enough before the materials biodegrade.	• Livestock & game must be excluded. • Start on the small paths and rills that feed the larger gullies. Never start erosion control in large gullies • Erosion fences should be built near existing vegetation. • Use in combination with mulching to control water. • Old low grade fencing netting can be used with jute geotextile.	

	Technique	Description	Purpose	Advantages	Disadvantages	Recommendations	Costs
	Windbreaks	Can be planted or constructed using shade cloth. Usually perpendicular to the prevailing wind. Also in the shape of an X to trap seed from all directions.	Provide favourable microclimates by protecting against damaging wind at ground level and ultimately reducing wind erosion and water loss from the soil surface.	• Proven success in semi-arid environments by providing sheltered microhabitat for seeds to germinate. • Also traps seed, fog and light organic matter.	• Trees & shrubs planted as windbreaks can deplete groundwater. • Timber is susceptible to pests. • Expensive. • Labour intensive.	• Should be removed once vegetation cover is high enough to prevent wind erosion. • 40 % density shade cloth can be used. • Placing wind barriers in the shape of an X can protect plants from all wind directions.	
	Brush Packing Warning – When using brush from cleared alien vegetation, ensure brush is not carrying seed.	Brush packs of fine branches, reeds or thatch are laid on the soil surface to aid the development of fertile, well-vegetated patches beneath them.	Act as traps for water, seeds and organic matter, modify soil surface temperature, and prolongs moisture retention to improve the natural recruitment of herbaceous species and the establishment of seedlings.	• Resources naturally available. • Brush packing can lead to natural recruitment of vegetation. • Protect small seedlings from grazing herbivores. • Technique can be improved upon if brush packs are pinned in place. • Protect soil from erosion and solar radiation.	• Not appropriate on seasonal riverbeds that experience occasional flash floods. • Cost depends on the availability of brush materials and distance from the site.	• Along gulley's, packs should be > 1m from the edge to prevent continued erosion. • Packed loosely enough to allow sunlight to penetrate the soil surface. • Should be pegged to the ground, especially in windy terrain to prevent them from blowing away.	

	Technique	Description	Purpose	• Advantages	Disadvantages	Recommendations	Costs
 Working for Wetlands	Stone Packing Warning – removal of stones from the soil surface can initiate soil erosion.	Stone packs in roads should be placed on reeds, straw, branches or geotextiles to reduce the rate but not restrict water flow while trapping silt.	Trap mulch, slow down water movement and reduce the impact of raindrops on bare soil.	• Low material costs if locally available. • Cheap and easy to produce by hand. • Can aid in local job creation and skills development.	• Labour intensive. • Expensive material costs if not locally available. • Soil surface can be compromised where stones are sourced.	• If stones / rocks are collected locally, avoid starting additional erosion problems when removing rocks. • Shade cloth or geotextiles can be incorporated to aid the build-up of silt and soil.	
 Coetzee & Stroebel 2011	Mulching	A mulch of chipped wood is laid on the soil surface to aid the development of fertile, well-vegetated patches beneath them.	Increased water absorption, reduced runoff, development of a fertile microhabitat to aid seed germination.	• Can aid in local job creation and skills development. • Cheap and easily done by hand.	• Can create a barrier for seed germination. • Mulch can be washed/ blown away. • In arid areas mulch is often not available.	• Must be packed lightly to prevent restricted growth of seedlings.*[4] • Where aliens are chipped, ensure they are not seeding at the time of chipping, to prevent accidental spread of unwanted species.	R 2.47 / m^2 (de Abreu 2011).
 South Coast Herald 2016	Tilling	Mechanically breaking or disturbing the soil surface using handheld implements, such as hoes.	The aim is to reduce soil compaction and water runoff, and increase infiltration.	• Low input costs. • Improves soil aeration. • Proven to be useful for maintaining and increasing soil organic matter.	• Soil disturbance can increase seeding germination of unfavourable species. • Tillage implements are required.	• Tilling should be very shallow to prevent large-scale soil disturbance. • Where possible, care should be taken not to mix soil layers.	• Cost dependent on labour costs.

	Stone Gabions Warning – removal of stones from the soil surface can initiate soil erosion.	Functional filters constructed from stones or other material, useful in the restoration of donga systems and degraded river channels.	Used in donga restoration to trap silt and organic matter, but allow for the percolation of water.	• Can aid in local job creation and skills development. • Low material costs if organic material (rocks / stones) are locally available.	• Cost of failure is high, thus gabion shape, formation and height is critical. • Labour intensive. • High material costs if rocks / stones are not locally available. • Soil surface disturbance can lead to further erosion. • Scattered stones slow down water flow and provide cool, warm, sheltered or moist sites for plants and small animals.	• Wire netting can be used to keep the structure together, and a geotextile can be used to trap silt and organic matter. • Ratio of depth of gabion walls to surface height and downstream aprons are correct to prevent wash-aways. • Should not prevent the flow of water, as this might lead to additional erosion.	
	Technique	Description	Purpose	Advantages	Disadvantages	Recommendations	Costs
	Retaining Berms Beware initiating erosion by removal of large rocks from soil surfaces elsewhere.	Earth, sand or rock-pack barrier for flood control or to restrict, divert or dissipate water flow.	Decreases soil loss and rate of run off, diverts intense water flow away from particular features, promotes infiltration, or controls contaminated runoff and construction water.	• Don't necessarily require any digging. • Can aid in local job creation and skills development. • Low material costs if rocks / stones are locally available.	• May be detrimental to freshwater ecosystems. • Labour intensive.	• Should not be placed in or close to priority wetlands, their riparian areas or their buffers. • Berms should be raised above the natural soil level. • Mulch could be placed within the berm basin. • Wire mesh could be placed around the berms to improve stability.	

	Physical removal of alien, unpalatable[*5] or invasive species *Widespread, simultaneous clearing is not recommended in drylands, particularly in the absence of active rehabilitation.*	The direct removal (by felling, cutting, uprooting) of unfavourable plant species to ensure a sustainable water supply and promote growth of more favourable species.	Clearing of unpalatable trees and bushes can be done by hand or with a tractor-drawn cultivator. Increases the availability of water for preferable seedlings and improves the survival of grass and forage plant seedlings.	• Uprooted bushes can be left scattered in the veld or used for bush packing to protect new seedlings from desiccation, browsing and trampling. • Can aid in job creation and skills development.	• Expensive • If surrounding landowners don't put in equal effort, reinvasion will occur. • Labour intensive. • Consistent follow-ups are essential to prevent mass-seeding recruitment, which can dramatically increase the problem. • Destruction of refuges for plants, microbes and animals.	• Consider soil exposure to wind and water erosion[*6]. • Competitive indigenous vegetation should be planted in cleared areas. • Uprooted bushes should be scattered in the veld to protect new seedlings. • Clearing should be limited to 20-30m strips or patches and not applied to large blocks of veld. • Material should be removed to prevent it being washed downstream in a flood.	US$ 10 – $500 per ha.[*6]
	Technique	Description	Purpose	Advantages	Disadvantages	Recommendations	Costs
	Brush-cutting *A study in the Succulent Karoo found brush-cutting of Pteronia paniculata to be more costly but not significantly better than long-term resting in improving veld condition and productivity (Saayman et al. 2009).*	Brush cutting does not kill plant species but can substantially reduce their root volume.	Reduce poisonous plant density and improve veld species diversity.	• Time saving. • Can be simple and cost effective if tools are readily available.	• Reinvasion is probable, specifically if surrounding landowners don't put in equal effort. • Labour intensive. • Not considered economically viable.	• A cautious approach should be taken[*7]. • When the plant is in flower, but not in seed is the most effective time for brush-cutting, as it destroys their entire seed crop.	R 230/ha (2004) resulted in an increased gross margin of R6-R13/ha after 4-9 years (Saayman et al. 2009).

	Seeding or reseeding	Actively planting indigenous, favourable and functional species that positively influence their surrounding environment, on suitable surface of sand and tailings (Milne 2010) or topsoil (Burke 2008).	A mixture of seeds should be planted. Timing of sowing is important – just before a rainstorm is ideal. Mostly germinate in Autumn so plant can establish in spring. Reseeded areas should be protected for 3 years to allow establishment.	• Costs can be reduced if seeds are collected by hand or with a modified vacuum cleaner / leaf blower. Seeds should be packed into hessian bags (breathable).	• Time consuming. • Can be expensive, thus it is important to select locally indigenous and most suitable species for the soil type, slope, habitat and climate. • Establishment of seedlings is dependent on unreliable rainfall.	• Seeds should be sown in a hand dug depression to which litter and water are added. • Seeds should be on a roughly raked soil surface, not deep. • Seeds should be dry or they will rot. • Seeding must be used in conjunction with other techniques, germination depends on the microsite where the seed is deposited.	R 0.37 / m² (de Abreu 2011)
	Technique	**Description**	**Purpose**	**Advantages**	**Disadvantages**	**Recommendations**	**Costs**
	Plug Planting	Indigenous nursery grown, functional & favourable plant species are actively planted.	Aids in the reestablishment of favourable indigenous species.	• Survival is generally better compared to seeding. • Can aid in job creation and skills development. • Short-term success has been demonstrated.	• Time consuming. • Labour intensive. • Can be expensive. • Establishment of seedlings is strongly dependent on unreliable precipitation. (Matthee 2015).	• Mulching should be incorporated to improve infiltration. • Seedlings planted underneath canopies of naturally established indigenous species may show higher survival rates (Hanke & Schmiedel 2010).	
	Herbicides *Many chemicals used in herbicides are highly persistent*	Toxic substances that are sprayed onto unwanted vegetation, either by hand or with the use of machinery or light aircraft.	Used for control against invasive alien species, usually with the aim of leaving the desired species relatively unharmed.	• Timely weed control. • Higher water use by agricultural crops. • Decline in agricultural crop failure.	• Herbicides kill plants unselectively (palatable & unpalatable species will perish).	• Herbicides should be avoided or used with extreme caution. • In areas that still contain a reasonable abundance of non-target species,	

	in the soil, especially in dry regions.		Alternatively, unselective herbicides aim to clear all vegetation.		• Can contaminate water sources.	herbicide use is discouraged.	
	Fertilizers Warning may promote annual weeds and lower resilience to drought.	A natural or synthetic chemical substance added to soil to supply plant nutrients essential to plant growth.	Aim is to increase fertility and productivity and restore soil organic matter and soil structure.	• Increase the productivity and growth quality of plants. • Some Studies propose that fertilisers assist in the revegetation process.	• Can be expensive. • Bulky and expensive to transport. • Studies suggest that fertilisers promote weeds and annuals and do not improve establishment of perennials (Matthee 2015).	• The local availability of fertilisers is a key factor determining suitability. • Use in conjunction with seeding or planting to enhance early establishment.	
	Technique	Description	Purpose	Advantages	Disadvantages	Recommendations	Costs
	Burning *Slow veld regeneration results in increased erosion, and grazing too soon after fire can cause significant veld damage.*	Controlled and contained fires.	To clear invasive species and restore natural diversity.	• Rejuvenate plant growth. • Promote long-term survival of native species. • Cost-effective if managed correctly.	• Recent burning, followed by heavy rainfall results in extensive soil erosion. • Uncontrolled fires can cause damage to infrastructure. • Labour intensive.	• Due to low biomass and slow rate of regeneration, burning is not considered a suitable technique in the Nama Karoo.	

	Topsoil Application Refers to topsoil saved on site during construction projects.	Topsoil is spread on rehabilitated areas prior to seeding/plug planting.	Aids in plant recolonization where topsoil has been stripped or eroded away.	• Stimulates plant growth during transplanting/ seeding events.	• Topsoil layer in most of the Karoo is very thin. • Precipitation is still the key determinant of success (Milne 2010).	• Topsoil should be spread at about 10 cm thick (Burke 2008). • Type of topsoil used should be site-specific.	

*1 If soil is not inverted, crop residues are left on the soil surface, thus the soil is less exposed and not as vulnerable to the loss of water by evapotranspiration, sheet and splash erosion and runoff.
*2 Soil ripping treatments described in de Abreu (2011) were not found to be beneficial for rangeland rehabilitation in the short-term, and ripping techniques (100 mm depth) may have been too shallow, especially where soils consist of a high percentage of sand.
*3 Example of *Demi-lune* micro-catchments in an arid zone, Niger (Liniger et al. 2011):

- *4 Mulching can physically damage small seedlings of less palatable, which may benefit seedlings of large-seeded palatable species in the long term, but would decrease food availability in the short-term.
- *5 Unpalatable bossies include biltongbos, scholtzbos, geel melkbos etc.
- *6 Alien clearing should be done cautiously in the Nama Karoo, especially in areas prone to flooding, as shrubs and Karoo bossies take decades to grow in arid climates, and regardless of their species, will provide shade and shelter for other plants and small animals, and roots assist in water infiltration and hold soil. Total clearing may cause soil erosion, increase soil compaction and prevent the successful establishment of more favourable plant species.
- *7 Range varied based on invasion densities and objectives for control (Shackleton et al. 2015).

7. Local Case Studies

7.1. Clearing *Prosopis*

Introduction to the problem: Described in Blignaut (2010), a restoration study of the veld and hydrogeology was conducted on two adjacent farms located 30 km north of Beaufort West within the Nama Karoo. The site was heavily grazed and degraded; and additionally alien plants had invaded the region, with the most harmful of these being the mesquite (*Prosopis* sp.). Occurring predominantly around water points, these species had led to a decline in the availability of groundwater in the upper soil levels, as their roots penetrate deep into the soil. The protection of groundwater at this site is vitally important as it contributes to the water supply of the town of Beaufort West. Erosion and mesquite infestations threaten the sustainability of the meat and wool industries of the area, as the natural palatable vegetation continues to decline. *Methodology:* A Working for Water team was employed to clear *Prosopis* sp. in the hopes that this would raise the level of the water table, and lead to an economic improvement of the local industries. However, in the short-term, clearing *Prosopis* sp. has not shown any significant improvement in the grazing value of the vegetation, as palatable plant species have not recolonized the area. *Conclusion:* The study recommends that the area is reseeded with native palatable plants species, following the clearing of alien invasive species. Additionally, livestock and game should be excluded from the area to allow for native species to establish without the pressures of trampling and grazing.

7.2. Control of invasive *Prosopis* in the Calvinia area.

Introduction to the problem: Following on from the previous case study, Milton-Dean (2010) describes the effects of *Prosopis* clearing on ecosystem goods and services along the Hantamsrivier and its tributaries within the Calvinia Working for Water project area. *Prosopis* invasions are common along riverbeds and in alluvial soils, as well as in overgrazed areas and abandoned pastures. *Methodology:* Clearing invasive species and leaving the land bare can increase the threat of soil erosion and facilitate rapid reinvasion in the disturbed soil. *Prosopis* can reinvade areas by re-sprouting from treated trees that have surviving roots, or by reintroduction by water, livestock, wildlife or will propagate from seeds that have survived in the soil. *Conclusion:* Natural re-colonization by native species is limited by seed dispersal, competition and the availability of appropriate species. To prevent further disturbance of the landscape and reinvasion of alien species, the appropriate indigenous vegetation should be actively established as soon as possible following the event of clearing. If soil has been previously overgrazed or is compacted, techniques to improve soil permeability and trap water, seed and soil should be conducted. Additionally, herbivores should be restricted from the area to allow for successful establishment of newly planted species. These interventions reduce the likelihood of reinvasion of alien species, thus reducing future costs of clearing. Additionally, these interventions should lead to the improvement of grazing value and veld condition, reduction in the loss of soil and water from cleared landscapes, sequestration of carbon, job creation and skills development in activities of seed collection, plant propagation and soil management. Importantly, this study identified that soils in differing topographic conditions require differing rehabilitation interventions.

7.3. Seeding, Brush-packing & Tilling

Introduction to the problem: Described in Saayman & Botha (2010), a study commencing in November 1999 in the bossieveld of Gamka Karoo in the District of Beaufort West used 6 treatment techniques to test their success in the restoration of vegetation on sandy soils. *Methodology:* The treatments included Seeding, Seeding & Brush packing, Tilling, Tilling & Seeding, Tilling, Seeding & Brush packing, as well as a control treatment. *Acacia karroo* trees were cut and used for brush packing. *Conclusion:* Ten years later, the results indicated that the seeding in combination with brush packing technique; and the tilling, seeding and brush packing technique were the most successful. Brush packing is considered highly important, as it offers shade, which decreases soil surface temperature on bare areas. Additionally, this technique traps plant material, soil and seed, thus reduces runoff and both wind and water erosion. The seeding and brush packing technique resulted in the highest vegetation density and species richness. Additionally, when techniques were viewed individually, the results indicated that over the long term, brush packing is more effective than tilling.

7.4. Micro-catchments & Transplanting

Introduction to the problem: Described in Jackson (2016), a study conducted near Loxton, Northern Cape in the Nama Karoo Biome, the study assessed the effectiveness of the water harvesting and soil disturbance techniques of microcatchments in riparian areas of the Nama-Karoo. In addition, the survival rates and performance of nursery-grown plants (bossies) was assessed in relation to microcatchments. The site had a history of erosion and overgrazing, with erosion and compacting of the alluvial soil resulting in degraded bare patches within a mosaic of remnant vegetation. *Methodology:* The species used in this study were *Tripteris spinescens* (Rivierdraaibos) and *Salsola aphylla* (Riviergannabos). Species with different functional characteristics were chosen in order to observe how different plant functional types responded to the treatments. Two age classes (>6 months & <6 months) were used to test for differences in survival and growth when planted in relation to microcatchments, both inside and on the toe of each catchment. Conclusion: The results of this study indicated that micro-catchments are a useful means of creating microsites that were valuable for the survival and growth of transplanted native species. Survival rates for *Salsola aphylla* were greater than those of *Tripteris spinescens,* while plants which were older (>6 months) at the time of translocation experienced higher rates of survival compared to younger plants (<6 months). Survival rates for both species were greater for plants planted in the "toe" of the microcatchment, just on the high-water line, than those planted inside the microcatchment. Drowning as a result of inundation was caused by the poor infiltration rates of the fine clay-based soils, where water was observed in some of the microcatchments up to several days following rainfall events.

Left: Satellite image of degraded riparian area. Blue circled areas indicate treatment patches.

Middle: Monitoring along a transect line through the centre of the microcatchment.

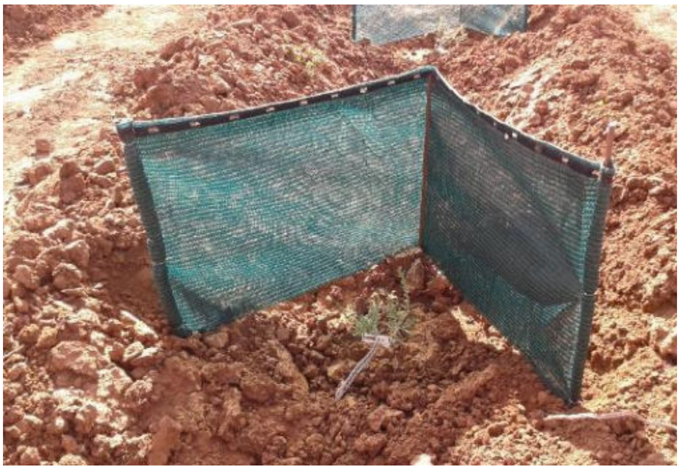
Right: Microcatchments showing recruitment along edges of the microcatchment.

7.5. Shade-cloth protection & Transplanting

Introduction to the problem: The trial is ongoing and results are unpublished. Described by Schumann (pers comm) the study is being conducted near Victoria West on a degraded section of riparian habitat with typical bare patches. Degradation exacerbated by a severe hail storm in addition to erosion by wind erosion and water. *Methodology*: Treatments included ploughing furrows and planting several species of riparian specific nursery-grown bossies. Plants were planted in association with a shade cloth structure (35cm high, 40+40cm wide) orientated to protect from direct sun as well as the prevailing NW wind. Two treatments were applied, allowing for comparison of survival rates under 50% and 80% shade cloth respectively. *Conclusion*: Results show the following survival rates under different treatments: protected by 80% shadecloth; protected by 50% shadecloth; and controls (no protection). The overall survival rate of all species planted in April 2015 was 65% in May 2017.

Control plants (no protection) showed a survival rate of 55%, while those under 80% shadecloth showed a survival rate of 61%, compared to the plants under 50% shadecloth, which recorded the best survival rate at 69%. At an individual species level, Gannabos (*Salsola aphyla*) demonstrated the best overall survival rate at 84%, while Draaibos (*Tripteris spinescens*) demonstrated the lowest survival rate at 41%. Survival rates for the other species planted were: vaalbrak (*Atriplex vestita*) and kriedoring (*Lycium pumilum*) at 72% respectively; bierbos (*Pteronia erythrochaeta*) and skaapbos (*Pentzia incana & P. globose*) at 67% respectively; klappiesbrak (*Tetragonia fruticosa*) at 51%. Bi-annual monitoring continues to determine long-term survival rates.

While the plough lines trapped water initially, they were mostly levelled off during a severe rainfall event. Deeper plough lines or ongoing maintenance are needed to maintain their water-conservation effect.



8. General Case Studies

8.1. Seeding, Mulching, Ripping & Micro-catchments

Introduction to the problem: Described in de Abreu (2011), a study investigating whether four commonly-used rehabilitation methods would generate short-term improvements to grazing capacity on a time-scale that is valuable to the landowner was conducted on a seriously degraded ostrich farm in the Succulent Karoo. Ostriches are kept at high densities in this region, thus trampling and overgrazing have led to a decline in the density and biodiversity of native vegetation, which has exposed the top soil to wind and water erosion. Natural recovery of vegetation is unlikely, as the soil is compacted, water infiltration is difficult and large dongas have formed. *Methodology:* The four rehabilitation techniques included ripping (a tractor-drawn ripper broke apart the hard, caked soil surface to allow for increased infiltration and the penetration of plant roots), micro-catchments (spaced 1 m, 0.25 m deep and 1 m diameter) sowing seed and mulching. *Conclusion:* Micro-catchments were found to increase species richness and density of palatable plants, while seed treatments increased only species richness and mulching increased only plant density. Although the benefits of rehabilitation included increases in rainfall infiltration and the trapping of nutrients, soil and water, increases in soil cover, none of these techniques were considered cost-effective in the short-term. Although ripping was the least cost effective technique, in the short-term, it was also considered the least effective. Mulching, micro-catchments and sowing seed were the most, second- and third- most expensive techniques, respectively, but micro-catchments were considered to be the most effective technique. It was noted that the growth of seedlings was negatively impacted by grazing pressure by springbok (*Antidorcas marsupialis*). Treatments were not found to have a positive effect on vegetation cover and grazing capacity in the short-term. As these rehabilitation techniques were considered costly and labour-intensive, it was concluded that government subsidization for rehabilitation programmes in the Succulent Karoo should be investigated. In order for landowners to reduce costs, they are encouraged to use resources that are readily available. Additionally, long-term studies of the effectiveness of rehabilitation techniques should be conducted.

8.2. Linking sustainable livelihoods with ecosystem services

Introduction to the problem: Reed et al. (2015) describes new ways of achieving sustainable land management with the use of economic mechanisms. The study aims to identify possible economic opportunities linked to ecosystem services arising from sustainable land management. A study conducted in the Kalahari rangelands of southwest Botswana investigated the impacts of bush encroachment (a widespread form of degradation across drylands) and the loss of grass cover, forage availability, and a range of ecosystem services. The region is characterized by game ranches, sheep ranches, communal livestock grazing areas, and the Kgalagadi Transfrontier Park and the Wildlife Management Areas that surround it. *Methodology:* An integrated approach was explored on how to tackle degradation by focusing on both the opportunities and costs of bush encroachment for both biodiversity and ecosystem services. *Conclusion:* It is suggested that *limited* bush presence may enhance the resilience of the landscape by supplying drought forage for livestock in the form of fallen leaves and pods, and by sheltering grass seed sources (Perkins & Thomas 1993; Dougill et al. 1999). Ecological models described in Joubert et al. (2013) suggest that bush encroachment is only reversible in the short-term with the use of mechanical or chemical removal, active reseeding of grass and adequate rainfall. Mechanical and chemical techniques to remove invasive bushes, such as the use of herbicide, cutting and uprooting are considered to be the most effective, yet are rarely cost-effective (Buss & Nuppenau 2003) and require extensive expertise and equipment. Cutting and burning are cheaper, and depend on less experience, but are less effective without being frequently repeated. Browsing was only proven to be effective if used in combination with other methods. Some farmers opted for a shift from cattle to small-stock species, such as goats in order to make use of browse resources. As an alternative approach, certain encroaching bush species (e.g. *Colophospermum mopane* and *Senegalia* (formally *Acacia) mellifera*) have proven useful for the production of charcoal, but a lack of a local charcoal markets and sandy soils suggest that the area is not conducive to a charcoal industry (Tabor 1994). In some areas, a complete change of land-use may be a possible adaptation option, for example shifting from livestock to wildlife and tourism, however this approach may not be viable in remote sites, where skills and infrastructure are lacking. Although bush encroachment has a negative impact on ecosystem services (e.g. loss of species diversity, compromised cattle production), there are some benefits, which may offset some of the negative effects (e.g. reduction in erosion, increased forage for goats, provision of materials for fencing, charcoal production, medicinal uses of tree resin, function as a wind break, increased carbon sequestration). In conclusion, it is imperative to review costs, benefits and trade-offs when considering restoration practices, as well as the availability of alternative livelihoods and resources.

8.3. Micro-catchments, Brush packs, Seeding & Plug Planting

Introduction to the problem: Simons & Allsopp (2007) describe how substantial grazing pressure in low-lying areas of Namaqualand has led to a decline in palatable perennial shrubs, and encroachment of the unpalatable shrub, *Galenia africana*. The study aimed to use physical and biological techniques to improve ecosystem functionality and enhance resource capture. *Methodology*: Micro-catchments and brush packs were used to form microhabitats, which aimed to trap seed, water and organic material. Subsequently, seeds and seedlings of palatable species were introduced to these microhabitats. *Conclusion*: After two years, at two of three sites, natural recruitment of herbaceous plant species was improved within microhabitats compared to bare areas. However, this trend was not shown for the recruitment of perennial seedlings. This is likely a result of the rapid growth rate and opportunistic characteristics of ephemeral species. Additionally, seedlings planted under large *G. africana* shrubs revealed higher survival rates compared to seedlings in unmodified areas at two of the three sites. Adult *G. africana* provide suitable conditions for seedling establishment, as they provide protection from climatic conditions and nutrient-rich soils. Factors such as seed size, rainfall, texture of the soil surface and wind speed play an important role in the success of seed germination and establishment. In this study, microhabitats showed decreased survival success of transplanted seedlings compared to unmodified sites. This surprising result may be a consequence of the removal of fertile topsoil in microhabitats during their creation. Although brush packing was found to positively influence natural recruitment, it did not have the same effect on promoting seedling survival. Brush packing is, however, still a beneficial technique for preventing soil loss, providing protection to developing seeds, and protecting the soil surface from scalding. Again, it is noted that the time scale of this study is too short to accurately investigate the successes and failures of the techniques used.

8.4. Surface runoff and seed trapping efficiency of shrubs

Introduction to the problem: Aerts et al. (2006) focuses on the seed trapping efficiency of shrubs in an area characterized by poverty, high population density, deforestation, site degradation and soil erosion.

In order to combat environmental degradation and deforestation, revegetation efforts involve the establishment of protected areas where free grazing and cutting is prohibited. The purpose of these protected areas is to allow for natural regeneration of forest tree species, i.e. this is a passive approach to restoration. This approach relies on natural seed dispersal by wind, water, mammals and birds from nearby forest patches. *Methodology*: This study investigated secondary dispersal in protected areas to determine whether seeds deposited under the protective crowns of shrubs were less likely to be lost by surface wash than seeds in bare patches. *Conclusion*: Surprisingly, the seed trapping efficiency of multi-stemmed shrubs was not superior to that of shrubs with few stems. Additionally, micro-topographic structures under the shrubs caused water runoff to be diverted away from the shrub into adjacent rills. Seeds deposited under the protective crowns of shrubs were trapped and protected from surface water runoff, even under extreme rainfall conditions. Seeds were successfully established under protective shrubs, but not in bare patches. Seeds in bare patches are likely to be lost to seed or seedling predation, mortality and unsuccessful germination.

8.5. Seeding, Transplanting & Landscaping

Introduction & Methodology: Carrick and Krüger (2007) evaluated the interactions between climatic conditions, mining, soil structure and composition, seeding, transplantation, seedbanks and landscaping in mined areas along the Namaqualand coastline. The region faces degradation due to three major land-use activities: livestock grazing, cereal cropping and, more recently, diamond mining. Namaqualand hosts unique vegetation, thus determining appropriate interventions is critical to preventing major loss in unique biodiversity. Generally, it was noted that autogenic recovery of perennial plant species does not occur, due to naturally low annual rainfall, low representation of perennial species in the seedbank, and strong wind speeds. On the other hand, climatic conditions such as predictable rainfall and strong seasonality together with ecological resilience of plant species allows for promising restoration opportunities. *Conclusion*: It is predicted that the upper 5 cm of the soil contains the majority of the seed bank, however, preservation of the topsoil and re-applying the topsoil to the restoration site is not enough to reestablish the same degree of species richness and diversity as that of un-degraded sites. One reason for this is that not all Namaqualand plants produce seeds that are able to remain dormant for an extended period until conditions are favourable in which to germinate. The majority of dormant seeds retained in the seedbank are annual species, while perennial seeds are often lost, thus post-mining recruitment from the seedbank is biased in favour of short-lived annuals, which does not allow for long-term recovery of vegetation. However, many succulent species respond successfully to transplantation, and thus the activity of relocating plants from pre-mined areas to post-mined rehabilitation sites could aid in the avoidance of an unnecessary loss of species richness. Additionally, large established transplanted species assist in soil stability, contribute to the seed bank at the rehabilitation site, and provide microhabitats for seedlings and small animals. Transplantation does however, necessitate moderately intensive labour and time commitments, and thus increases the cost of restoration. Seeding, although cheaper and less intense in labour does not provide the benefits associated with larger transplanted plants. The study highlighted the importance of ongoing proactive restoration, involving a number of adaptive methods in order to reestablish a high proportion of the natural species richness and ecosystem services.

8.6. Livestock exclusion, brushpacking, dung mulching, stone applications, microcatchments and transplanting functional plants

Introduction to the problem: Hanke and Smiedel (2010) collated the findings of four different restoration experiments aimed at identifying resource manipulations that can restore functionality of the ecosystem and vegetation cover. Degradation was caused by overgrazing in three cases, and the installation of a pipeline in the fourth case. Not all the parameters measured are dealt with in this summary, only the parameters relating to soil moisture, plant cover and growth form are captured here. Historical changes in rangeland management included a shift from transhumance strategies to pastoralists settling in communally managed areas. Over time these landscapes have been transformed and experienced a decline in rangeland quality primarily due to inappropriate management strategies and overstocking. Degradation caused by trampling, disturbances in the soil crust and erosion is evident. Without active interventions, the degraded areas will take decades to recover. *Methodology:* The treatments included livestock exclusion, brushpacking, dung mulching, stone applications, microcatchments and transplanting functional plants (*Brownanthus pseudoschlichtianus* and *Cephalophyllum spissum*). Experiments were carried out in the Richtersveld, Coastal Plains, Knersvlakte and Namaqualand Klipkoppe regions. *Conclusion: Livestock exclusion* was achieved with exclusion plots at two of experiments. Soil moisture differences were not detected but this was possibly due to the short time frame following establishment. Plant cover responded immediately to the release from grazing pressure in both experiments, with the benefit that annual plant cover receives following of a year's rest being evident. There was a difference in annual cover on exclusion plots and adjacent grazed areas, as one area experienced high intensity grazing and the other moderate intensity grazing. While the cover of perennials remained the same at one treatment, species richness of annuals and perennials increased significantly inside the exclosures (rest from heavy grazing). In contrast, a decline in perennial cover as well as species richness was recorded inside the exclosures at the second treatment (rest from moderate grazing).

Brushpacking resulted in increased soil moisture retention, and an increase in the establishment of ephemeral plants on all except one site (no effect). However, the establishment of perennial plants was not influenced positively at any site, and in one case actually caused a decrease in the abundance and species richness of perennial plants (possibly due to damage caused to existing plants while packing the brush). *Dung mulching* had pronounced effects on soil water status and vegetation cover. Dung absorbed and retained water during low rainfall events, preventing it percolating to the soil, but where precipitation exceeded 5.2mm of rain, the dung was saturated and moisture percolated through to the soil. The shading effect of dung was evident, resulting in moisture being stored for longer periods on treatment plots than in control plots. The cover of annuals increased in some cases, but species richness of annuals and perennials was negatively affected in some cases.

Stone treatments were applied at two of the sites. The soil and vegetation variables examined showed positive effects on one site, with plant individuals increasing significantly compared to the control plots. This was only evident four years later, but the significant effect was no longer evident some seven years after the introduction of stones. No differences were observed between the second site and the control. *Microcatchments* did not improve either recruitment or the establishment of perennial seedlings. This was possibly due to the removal of fertile topsoil when digging the pits, and may also have accounted for the fact that cover of geophytes was also negative by uprooting. A minor improvement in cover of ephemerals was only recorded at one site. Soil water content and storage was not significantly different to controls, possibly due to the insufficient rainfall to generate runoff. Transplanting *functional plants.* Key species were planted at two of the sites, of which *Brownanthus pseudoschlichtianus* transplants showed a survival rate of 71% and the *Cephalophyllum spissum* transplants showed a survival rate of

55%. A positive impact on soil water content and storage was recorded. The result of increased numbers of individuals remained despite plant mortality recorded after the first year and subsequently; the abundances of other plant species also increased significantly on the *C. spissum* transplant plots.

9. Summary of Case Studies

Case Study	Region	Problems	Techniques Used	Major project outcomes & recommendations
1	Nama Karoo	Heavily grazed and degraded Invasive alien species	Clearing of *Prosopis* sp.	No significant short-term improvement in the grazing value of vegetation. Recommend reseeding with native palatable plant species. Recommend the exclusion of livestock & game.
2	Nama Karoo	Invasive alien species	Clearing of *Prosopis* sp.	After clearing, indigenous vegetation should be actively established. If soil has been previously overgrazed/degraded use soil rehabilitation techniques. Techniques should improve permeability & trap soil, seed & water. Recommend the exclusion of livestock & game. Soils in different topographic conditions require different techniques.
3	Nama Karoo	Poor grazing management Large areas denuded of vegetation	Seeding Brush packing Tilling (and combinations)	Seeding + Brush packing AND Tilling + Seeding + Brush packing are most successful. Brush packing is important as it offers shade, and decreases soil temperature in bare areas. Over long-term brush packing is more effective than tilling
4	Nama Karoo	Erosion Overgrazing	Micro-catchment Plant translocation	Micro-catchments are useful when used in combination with plant translocation. Species adapted to saline & inundated conditions were most successful. Older transplanted plants experienced higher survival rates. Mortality decreased when plants were planted adjacent to micro-catchments (in the "toe" of the catchment).
5	Succulent Karoo	Intensively stocked with Ostrich; Bare patches of compacted soil Loss of palatable plants	Ripping Micro-catchments Sowing Seed Mulching	Micro-catchments increased species richness and palatable plant density. Seeding increased only species richness. Mulching increased only plant density. None of these techniques are considered cost-effective in the short-term. Ripping was least cost-effective in the short-term and least effective. Seedling growth was decreased by grazing pressure. Government subsidisation for restoration and rehabilitation programmes should be investigated. Resources which are locally and readily available should be utilised to reduce costs.
6	Dry Savanna	Bush encroachment	Identify costs & benefits Cutting & uprooting Cutting & burning Browsing Reseeding	Costs: • Loss of grass cover and forage • Loss of biodiversity • Compromised cattle production Benefits:

			Shift in land-use	• Availability of drought forage for livestock • Sheltering for seeds • Provision of materials for charcoal, fuel, fence posts, resin • Provision of services, such as wind breaks, reduction in erosion • Increased forage for goats Cutting and uprooting are most effective, yet rarely cost-effective. Cutting and burning are cheaper but less effective. Browsing is only effective when used in combination with other measures. Shift from cattle to small-stock species (goats) results in a loss of income and cultural status. Shift from livestock to wildlife may not be viable where skills and infrastructure is lacking. Costs, benefits and trade-offs should be considered when considering SLM.
7	Succulent Karoo	Over-grazing Invasive encroachment	Micro-catchments Brush packing Seeding Planting plugs	Natural recruitment of herbaceous plant species improved within microhabitats compared to bare areas BUT this was not shown for perennial species. Adult *Galenia africana* provide suitable conditions for seedling establishment. Removal of topsoil from micro-habitat sites may have led to decreased seedling survival.
8	Semiarid Woodland	Deforestation Soil erosion	Passive Restoration	Shrubs trap and prevent the loss of seeds by water runoff. Seeds were successfully established under the crowns of protective shrubs. Seeds deposited in bare patches are likely to be lost to predation and mortality.
9	Succulent Karoo	Diamond mining	Seeding Transplantation Landscaping	Landscape the area to restore natural topography and ensure long-term soil stability. Landscaping also reduces the impact of wind and protects against soil erosion. The provision of topsoil is considered the most important factor in successful restoration. The upper 5 cm of soil contains the majority of the seed bank. Transplantation of perennial species assists in soil stability and seedbank provision. Large transplanted plants provide microhabitats for establishing seedlings & animals. Seeding is less costly and time consuming, but less effective than transplanting.
10	Succulent Karoo	Overgrazing Pipeline installation	Livestock exclusion Brushpacking Dung addition Stone applications Micro-catchments Transplanting functional plants	Species richness was increased by rest from heavy grazing, but decreased in response to rest from moderate grazing. Annuals responded more strongly to the treatments than perennials. Only two of the restoration treatments had an unambiguously positive influence on the perennial vegetation cover: the scattering of quartz stones on disturbed quartz fields; and planting, where perennial cover was directly improved through the transplants. However, the cover of annual species was promoted by four treatments: livestock

				exclusion, dung mulching, scattering of quartz stones, and to a certain degree also by brushpacking. Dung addition led to increased cover in wet years, but diversity decreased and non-indigenous annuals (opslag) dominated cover. Among the active treatments, dung appeared to have the greatest impact on competitive interactions between growth forms. Removal of topsoil from micro-habitat sites may have led to decreased seedling survival.

10. Approaches to sustainability & rehabilitation projects

There is a global trend towards the implementation of sustainable land practices and rehabilitation, as land managers usually aim to ensure long-term, high productivity yields, while maintaining integral ecosystem services. However, tackling land degradation in drylands may be as much about incentivising and promoting sustainable land management to stakeholders, as it is about the practices and techniques employed. The implementation and adaptation of these processes on the ground and sourcing the capital required is often a major challenge.

Traditional approaches to land rehabilitation include government subsidies and loans, with a top-down approach of forced implementation of externally-developed practices. These methods may lead to ineffective or short-term results, and discontentment around perceived inequality. With a struggling economy, booming population, political unrest and extreme poverty, reliance on government subsidies and loans for environmental restoration projects may be futile, thus alternative approaches should be investigated.

The type of approach implemented is dependent on the specific social construct, available resources and degree of political involvement and support linked to the degraded environments. Importantly, communities are not homogenous or static, different community members will have varying needs, objectives, attitudes, opportunities and asset resources, which are likely to change with time. Similarly, the community will be comprised of people varying in age, gender, religion, class, ethnicity, wealth, level of education and health. When approaching a community with a restoration project in mind, winning the support of the community is essential, and empowering communities to acknowledge their rights can provide an enabling environment in which to discuss conservation issues and possible solutions. The stability of an environment is linked directly to the social stability of the human communities that live within it. Facilitating the participation of marginalised community members, may promote positive change within societies.

Case studies throughout sub-Saharan Africa have proven that a successful approach to implementing SLM and rehabilitation practices most often requires the following characteristics:

1. A **people-centered** vision, where local stakeholders, landowners and the community are involved at all stages of SLM. This includes the initial stages of identifying the causes of degradation, and the decision-making stages, whereby prevention, mitigation or rehabilitation methods are decided upon, as well as the final stages of implementation, monitoring and adaptation (Liniger et al. 2011). The local community needs to feel a sense of ownership or, at the very least, understand and approve of the project in order to ensure continued stakeholder and community support (Liniger et al. 2011).
2. **Integrated spatial planning and zoning** (including the identification of priority areas and corridors for biodiversity) should be one of the first steps to SLM, before these areas can be transformed by mining and urban development (Milton & Dean 2010).
3. An **adaptive, goal-orientated** approach, whereby short- and long-term progress is monitored carefully and revised or improved over time if necessary to achieve a required level of sustainability, species diversity or improvement of ecosystem services.
4. **Environmental awareness** and a **holistic** approach, focusing on how land degradation might be affecting natural capital, ecosystem services, as well as the livelihoods of local stakeholders, in order to ensure all factors (environmental, social and economic) are considered when conducting SLM programmes (Milton & Dean 2010). Comprehensive and integrated strategies should be implemented, if possible. For example, projects that build on existing collaborations between human health, family planning and environmental programmes are more effective than executing separate schemes that might not complement those already in place.
5. The development of **multi-level and multi-stakeholder partnerships** and **collaborations** to ensure that scientific, technical, practical and historic knowledge is shared (Liniger et al. 2011). This builds trust and understanding between various stakeholders, empowers local community members in terms of knowledge, skills and resources, and encourages continued support and a vested interest in the process (Liniger et al. 2011). Diversity among stakeholders should be recognised in order to generate innovative solutions, and promote and enhance social equity. Similarly, the existing institutions within a community should be recognised, for example societies often have their own ways of communicating issues and making decisions.
6. An **enabling environment** on a socio-cultural, legal and political level. Furthermore, it is vital to acknowledge people's rights, as well as the law, to prevent conflicts over environmental resources.
7. Enough **resources**, including locally-available materials, labor and finances.

Despite the financial costs associated with sustainable land management, land owners are usually willing to adopt such practices if they prove to increase net productivity and decrease risks (Liniger et al. 2011). Cost-efficiency of prevention, mitigation and rehabilitation practices is a primary component for adoption of SLM (Liniger et al. 2011). Financial and technical assistance may be required in the case of small-scale subsistence land users when costs are high and benefits are not immediate (Liniger et al. 2011). Importantly, with careful governance, these schemes should aim to improve the livelihoods of those most at risk to poverty by targeting the poorest in society that have an impact on the targeted ecosystem services (Reed et al. 2015), as well as those adjacent landowners that may be contributing most substantially to land degradation. Approaches should aim to promote self-reliance and resilience to environmental disturbances. A range of SLM approach case studies from sub-Saharan Africa have been investigated in the table below:

Farmer Field Schools (Asiabaka 2002) Group learning approach Builds capacity and knowledge Enables land users to identify land degradation threats, identify solutions, and plan and implement restoration without external support. Land users from similar political, socioeconomic and environmental situations are brought together. Facilitated by trained land users, specialists or technically-trained workers.	**Integrating Environment & Development** (Bass et al. 2009) Utilises perspective of in-country leaders as an entry point. Synthesise local ideas to identify challenges and opportunities. Reflect collective insights back to local leaders to promote progressive change in national and international policy on development and environment	**New Markets** (Reed et al. 2015) Creation or encouragement of markets that can pay for land management activities that supply ecosystem services. This may be improved by linking eco-labels or certified schemes to such products and services, e.g. Badger-friendly honey. These new markets can pay for increasing biodiversity, reducing degradation and improve carbon storage.
Sustainable Livelihoods (Baumann et al. 2004; Allison & Horemans 2006) Connects people and the environment that influences the outcomes of their livelihood strategies. Focuses on the strengths and potential of people, including their skills, access to resources, influence and social networks. Identifies a means of reducing poverty and vulnerability of communities, while preventing increased pressure on over-exploited resources and environments. Inform, develop and manage policies than aim to enhance livelihoods and food security.	**Payment of Ecosystem Services** (Tallis et al. 2008) Once the value of ecosystem services (e.g. clean water / flood control) is established, governments can invest in their conservation. The money can come from charging beneficiaries for the use of ecosystem services, and then using payments to improve enforcement or compensate those whose livelihoods are diminished by conservation efforts. Typically payments are from beneficiaries outside of the local area, thus governments or other agencies are responsible for collecting and distributing funds.	**Tax Incentives** (Reed et al. 2015) Promote sustainable practices by decreasing the cost of agricultural inputs that are considered sustainable, while increasing the cost of those that are not. Land managers are incentivised to conduct activities that reverse degradation and promote sustainable land management. Examples include reducing stock density and clearing invasive species.

11. Recommendations & Conclusion – The Road to Restoring the Nama Karoo

Prevention of degradation, through sustainable land management should be considered the most ideal and cost-effective situation, thus the ability to identify the initial stages of degradation is vital knowledge for landowners, land managers and local farmers utilising communal land. The easiest and most effective method of improving water infiltration and preventing erosion is to conserve a high density of natural vegetation cover (Esler et al. 2006). In order to recognise detrimental environmental change at its earliest stages, continued and effective rangeland monitoring is essential. This will allow farmers to respond immediately to prevent exacerbated and costly degradation. Rangeland management should be flexible and simple in its approach. Firstly, degradation indicators as well as baseline conditions need to be identified (Reed & Dougill 2010). These will depend on the environmental conditions of a particular area. Some examples of indicators include:

1. Degree of grass cover or bare ground.
2. Growth rate of plants after rainfall.

3. Duration livestock spend grazing between drinking.
4. Proportion of invasive alien species compared to indigenous species.

Secondly, farmers should identify what they or others (local community members, scientists, conservationists etc.) know about these degradation indicators, i.e. what causes the degradation. Next, the land manager should evaluate his/her options regarding rehabilitation or restoration practices, then select and initiate the most appropriate technique(s), while continuing to monitor both the short- and long-term changes in the indicators, and adapt their technique(s) when necessary (Reed & Dougill 2010). **Interaction and communication** with neighbours and local authorities is a critical component of sustainable land management and rehabilitation in order to learn and share information (Esler et al. 2002).

When assessing the status of the environment, it is important to recognise that biodiversity and functionality are not linked together, for example, a system's biodiversity could still be intact, while its functionality has declined beyond a critical threshold. Strictly speaking, natural capital can be eroded continuously to a certain extent and still maintain provision of ecosystem services, until a threshold is crossed and ecosystem service provision deteriorates (Reed et al. 2015).

Attempting to tackle large-scale land degradation can seem impossible, futile or unrealistically expensive, thus it is important for practitioners to begin at a level that is achievable with a realistic time frame in mind. Esler et al. (2002) introduced the concept of "**Start small – think big**", whereby small-scale objectives are set, which lead to a larger successful outcome. It may be useful to consider the desired ultimate result (think big), while listing a number of small-scale features (e.g. the loss of vegetation around waterholes or erosion near the riverbank) that make up the degraded landscape (Esler et al. 2002). Then start the restoration project focusing on one degraded feature in one area (start small), making sure to monitor changes and adapt the approach if necessary, while bearing in mind that changes occur gradually in the Karoo, thus patience is essential (Esler et al. 2002). Rehabilitation efforts must include addressing the cause of the erosion, with work starting upstream, focusing on reducing run-off from rangeland, including treating erosion along stock paths and the rills that feed into soil erosion systems.

In order for projects to become **evidence-based and repeatable**, large-scale restoration projects with a socio-economic element are encouraged to monitor and record the project impact in a similar way to the biophysical elements (Ntshotsho et al. 2015). Examples of socio-economic indicators include:

1. Environmental awareness levels.
2. Household income.
3. People living in poverty.
4. Number of jobs created.
5. Unemployment rate.

Carefully-managed SLM projects in dryland areas have the potential to recover ecological services, enhance biodiversity, improve carbon sequestration, and benefit impoverished and threatened livelihoods (Birch et al. 2010). In the last few decades, the **economic evaluation** of ecosystem services, such as water supply and carbon sequestration, and the financial payment for such services are becoming increasingly important in the prevention of biodiversity and productivity loss and the deterioration of ecosystem services. By maintaining biodiversity and encouraging the development and continuation of multiple livelihoods, society can mitigate the threats of climate change, and ensure an enhanced resilience to drought, specifically in drylands and vulnerable ecosystems.

The process of sufficiently valuing natural capital is an essential part of SLM (Reed et al. 2015). Integration of local and scientific knowledge, as well as communication and collaborative efforts between stakeholders, are vital processes of successful prevention, mitigation and rehabilitation. Land degradation often threatens livelihoods by causing a reduction in the provision of these ecosystem services (including provisioning, supporting, regulating and cultural services). These services are interconnected by non-linear relationships. However, focusing solely on cost-effect restoration practices is not enough to protect and conserve the environment from continuing degradation. Identifying the drivers and economic root causes of degradation and recognising the earliest signs of degradation can aid in the preventing the expansion of degradation and future financial losses. Rehabilitation of degraded landscapes rarely leads to the complete restoration of natural biodiversity across all taxonomic levels and the original condition of ecosystem services. The prevention of degradation and proactive implementation of rapid rehabilitation techniques is preferable. Additionally, acknowledging the opportunities among the challenges of land degradation can positively benefit communities, for example areas of bush encroachment can provide fuelwood for local communities, and rehabilitation projects can provide jobs, skills development, promote alternative livelihoods and create new markets.

When it comes to the approach and implementation of SLM practices, there is no perfect solution that will work in all situations. Each site is different and consists of its own set of stakeholders, resources and environmental conditions, and thus needs to be evaluated within its individual context, while drawing on knowledge from previous projects. If we hope to ensure intergenerational equality and conserve ecosystem services and biodiversity, SLM is essential in dryland environments, specifically under the conditions of climate change and an exploding human population. Furthermore, governments, large and local businesses, NGOs, educators, community members and landowners should all acknowledge their role in the conservation of our natural environment and its resources.

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