

# **Restoration after bush control and impact on ecosystem services in the Lephalale municipality, Limpopo Province**

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**“When many work together for a goal, great things may be accomplished”. Ant  
philosophy**

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*Trust in the Lord with all your heart  
and lean not on your own understanding;  
in all your ways submit to him,  
and he will make your paths straight.  
**Proverbs 3:5-6***

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*For my precious daughter Mutsa Boikanyo*

*and*

*my dearest husband Robert*

## Abstract

About 66% of rangelands in South Africa are moderately to severely degraded as a result of bush encroachment or bush thickening. Bush encroachment has nearly doubled over the past decade in many commercial, communal and conservation areas, Limpopo being no exception. Bush encroachment (increase in density of woody species) results in a temporary or permanent loss of ecosystem functions and processes and can have significant socio-ecological implications for land users since it can cause a decrease in the economic value of the land and reduces ecosystem services. To control bush encroachment and to compensate for economic losses, active and/or passive restoration methods are applied. Studies have shown that success with the restoration of bush-encroached rangelands is not only restricted to the environmental (biophysical) conditions of the rangeland but also dependent on active intervention as far as social and economic conditions are concerned. The research presented in this thesis aimed to evaluate the impacts of bush clearing and the use of brush packing restoration technique at two study sites representing two different land-use types: communal and conservation. In essence, brush packing involves covering bare degraded soil surfaces with woody branches from bushes that have been cleared in the surrounding area. Since the success of restoration projects depends on community involvement, the socio-economic benefits for local communities were also investigated. Specific objectives were, therefore, to test the effect and cost-effectiveness of brush packing as a restoration technique (1) to improve grass diversity in bush-cleared areas and (2) to improve aboveground biomass in these areas. In addition, the study set out (3) to determine whether bush clearing and restoration activities address any ecosystem services (especially those of a socio-economic nature). To test the objectives, six different non-brush packing ((1) un-cleared (control plot) (UC); (2) clearing only (CO); (3) clearing and re-seeding (CRS)) and brush packing ((4) clearing and brush packing (C-BP); (5) clearing, re-seeding and brush packing (CRS-BP); and (6) clearing, soil disturbance, re-seeding and brush packing (CSRS-BP)) treatments were compared. The treatments were replicated three times on 18 randomly distributed plots within 3 blocks and the effects compared. The results obtained from this study showed that the brush packing restoration treatments had a positive effect on improving grass species diversity particularly in the continuously grazed communal area. Grass species richness and abundance were highest for the brush packing and re-seeded treatments in the year 2019. The grass composition between the two sites were dissimilar, with the conservation site having a higher heterogeneity than at the communal site. On the other hand, a higher number of decreaser and perennial grass species were identified in the brush packing

treatments particularly in the communal area. Aboveground biomass was significantly higher on the brush packing treatments than on non-brush packing treatments over the two years (2018 and 2019) at both sites. Although the total establishment costs were highest for the brush-packing treatments, this was outweighed by other positive impacts such as higher biomass production, improved grass diversity and contributions to the local community's well-being in the form of socio-economic benefits. Brush packing undoubtedly creates a micro-environment that is favourable for the growth and recruitment of grass species. Additionally, brush packing serves as an effective protection to shield grass seedlings from grazing by livestock and/or game, thus affording grasses an opportunity for re-growth. Essentially, brush packing improves biodiversity, thereby contributing to the ecosystem services of rangeland ecosystems. It is recommended that all bush clearing and restoration projects should not concentrate on the biophysical aspects only, but take regard of the human factor as well. Furthermore, long-term studies on the permanent plots in the communal area and in the conservation area are required to investigate vegetation and diversity changes and to evaluate the effectiveness and restoration success of, particularly, bush clearing, brush packing and re-seeding restoration techniques.

**Keywords:** *aboveground biomass, bush encroachment, bush clearing, brush packing, communal area, conservation area, ecosystem services, grass diversity, restoration*

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# CHAPTER 1

## INTRODUCTION

### 1.1 Background

Land degradation has a broad range of definitions, all of which describe circumstances pertaining to reduced biological productivity of the land (Ma & Zhao, 1994; Hoffmann *et al.*, 2014; Blaikie & Brookfield, 2015; Stavi & Lal, 2015). Broadly speaking, a degraded area is land that experiences a long-term loss of ecosystem function caused by human and natural disturbances and, if past a certain threshold, cannot recover unaided (Hoffman & Ashwell, 2001; Mekuria *et al.*, 2007; Hoffmann *et al.*, 2014). Such land can exhibit a substantial loss of topsoil nutrients and plant species (vegetation cover) which may never be rehabilitated (Tongway & Ludwig, 1996; Alipur *et al.*, 2016; Yirdaw *et al.*, 2017). Some of the factors that can contribute to land degradation include loss of vegetation cover, an increase in woody species density in savanna areas, a decrease in grass/herbaceous production, land mismanagement that can be worsened by below-average precipitation (Meadows & Hoffman, 2002; Hoffmann *et al.*, 2014; Temesgen *et al.*, 2014).

Southern Africa is one of the regions in the world that is most severely affected by land degradation, accounting for roughly 13% of the globe's degraded areas (Table 1.1) (Bai *et al.*, 2008; Bai *et al.*, 2011). Comparatively, Indo-China accounts for 6%, whereas North America accounts for less than 3% (Bai *et al.*, 2011).

Purely based on a headcount, Bai *et al.* (2011) found that most people affected by land degradation in the Southern African Development Community (SADC) reside in the Democratic Republic of the Congo (DRC) ( $\pm 32$  million) followed by South Africa (ZA) ( $\pm 17$  million). This translates to 53.49% and 38.14% of the total population of the two countries,

respectively. Of note, though, is that percentage-wise, Angola tops the scale with 60.74% of the population being affected by land degradation (Table 1.1).

**Table 1.1** Statistics regarding degraded areas (excluding inland water bodies) and affected populations in the Southern African Development Community (SADC) as reported by Bai *et al.*, 2011.

<b>Country</b>	<b>Degrading area (km<sup>2</sup>)</b>	<b>% global degrading area</b>	<b>% total population</b>	<b>Affected people</b>
Angola	828029	2.370	60.74	9263348
Botswana	97831	0.284	30.74	476893
Comoros	181	0.001	21.50	135144
Democratic Republic Congo	1346914	3.760	53.49	32081359
Lesotho	10344	0.033	44.49	941131
Madagascar	163843	0.492	21.56	3901784
Malawi	30869	0.089	19.89	2486085
Mauritania	6301	0.019	2.18	67349
Mozambique	226567	0.651	26.36	5155480
Namibia	288945	0.875	35.87	670983
South Africa	351555	1.124	38.14	17041101
Zambia	454630	1.312	50.07	5789865
Zimbabwe	180125	0.531	39.51	5424488

Undeniably, land degradation is a global problem, with a marked increase in the number of poor people in rural areas of developing countries who are trying to make a living off already degraded land (Gerber *et al.*, 2014; Barbier & Hochard, 2018). The need to stem further environmental degradation and the resultant socio-economic disasters have become all the more pressing (Blaikie & Brookfield, 2015). However, as Barbier and Hochard (2016; 2018) pointed out, even though land degradation evidently threatens the livelihoods of the poor, the interaction between land degradation and poverty is complex and restricted by key economic, social and environmental factors.

Changes in land use can mainly be ascribed to individual management decisions made at local level (Pagella & Sinclair, 2014; Nkonya *et al.*, 2016; Crossland *et al.*, 2018). Land use has a strong impact on soil condition and vegetation cover (Johnson & Lewis, 2007; Blaikie &

Brookfield, 2015), and degradation can stem from various kinds of land mismanagement such as over-utilisation of an area by livestock causing a decrease in vegetation cover and production (Mekuria *et al.*, 2007; Cao *et al.*, 2013). In Southern African, approximately 46% of rangelands are largely represented by savanna and grassland ecosystems (Lesoli *et al.*, 2013). However, given that domestic livestock, particularly species of *Bos* (cattle), *Capra* (goats) and *Ovis* (sheep), have grazed these areas for many years added with land mismanagement a change in plant composition that differs from the original ecosystems (Lesoli *et al.*, 2013) is inevitable. Overgrazing not only results in a reduction in biodiversity and loss of native species but can also be detrimental to soil physical properties (Mekuria *et al.*, 2007; Wang & Batkhishig, 2014; Mureva & Ward 2016). In particular, the soil erosion rate increases thus affecting the water infiltration rate since the top soil becomes denser and more compact as a result of the pressure exerted by animals (Dregne, 2002; Gabriels & Cornelis, 2009; Wang & Batkhishig, 2014; Marquart *et al.*, 2020).

Overgrazing, however, is not the sole cause of land degradation. Land degradation can also be ascribed to population pressure and the poverty of the communities using the land (Lal, 2012; Mace *et al.*, 2012). Likewise, the probability that an area will be classified as degraded increases exponentially in instances where population growth exceeds a region's ability to supply ecosystem services (Mortimore, 1993; Grepperud, 1996; Taddese, 2001; Blaikie & Brookfield, 2015). Ecosystem services (ES) are benefits humans derive from ecosystems and include the provision of goods (food), resources and energy cycles (water and nutrient provision); regulatory services (water quality and soil retention); and cultural services (non-material benefits) (Reyers *et al.*, 2009; Vilà *et al.*, 2011; Rao *et al.*, 2018). According to Gabriels & Cornelis (2009), when the population-to-land ratio increases, intensification (e.g. increase in the pressure on the environment due to an increase in land use) is bound to follow. In other words, as the population increases, the demand for resources (i.e. the demand for fuel,

building materials and land for livestock) also increases (Gabriels & Cornelis, 2009). As a result, people are forced to settle on land that is unexploited, causing the removal of the original vegetative cover of that land (Taddese, 2001; Gabriels & Cornelis, 2009).

The conversion of habitats and unsustainable land management by humans lead to degradation and desertification (Wolff *et al.*, 2018). Establishing protected areas can be one way to address land degradation caused by human activities and buffer the plant and animal communities at risk (Naughton-Treves *et al.*, 2005; Wolff *et al.*, 2018). Even though protected areas are primarily designed for the purpose of biodiversity conservation, they can provide a range of ecosystem goods and services important to global environmental and human welfare (Gjertsen, 2005; Fisher *et al.*, 2011). Furthermore, protected areas can help to diminish land degradation by ensuring that land use is zoned appropriately to avoid uncontrolled grazing practices (Fisher *et al.*, 2011). Thus managing and maintaining healthy ecosystems that will protect water sources and slow the spread of invasive plant species (Fisher *et al.*, 2011).

The conservation of biodiversity and ecosystem stability will retain the ecological value within rangelands. Consequently, restoring rangeland ecosystem health and resilience is an essential social imperative. This will ensure the future supply of ecosystem services, which are vital to the well-being of human societies (Lesoli *et al.*, 2013). These services comprise the provision of productive soils and a steady and clean water supply; the natural occurrence of plants; and the improvement of the livelihoods of people living in and around rangelands (Grice & Hodgkinson, 2002; Lesoli *et al.*, 2013).

#### 1.1.1 Bush encroachment

Approximately 66% of rangelands in South Africa are moderately to severely degraded as due to bush encroachment or bush thickening (Hoffman & Ashwell, 2001; Snyman, 2005; Hoffmann *et al.*, 2014). Bush encroachment and bush thickening are closely related since both refer to an increase in the density of woody species (trees and shrubs) resulting in the latter

competing for soil moisture and nutrients with herbaceous plants, which leads to a reduction in rangelands' forage production (Smit & Rethman, 1999; Smit, 2004; Wigley *et al.*, 2009; Vilà *et al.*, 2010; Kgosikoma & Mogotsi, 2013; Harmse *et al.*, 2016; Dreber *et al.*, 2018). In particular, bush encroachment involves the spread of native (indigenous) woody species introduced from other ecosystems into semi-arid savannas and grasslands resulting in a temporary or permanent loss of ecosystem functions and processes (Ward, 2005; Vilà *et al.*, 2011; Dreber *et al.*, 2018; Belayneh & Tessema, 2017). To date, 40 species have been listed as being part of the bush encroachment problem in South Africa (Turpie *et al.*, 2019). However, it ought to be noted that bush encroachment is not caused by a particular species; rather, it involves a change in the balance between the types of woody plants occurring in an ecosystem, although some species are more suited to encroachment since they are fast and opportunistic growers (Turpie *et al.*, 2019). As a form of disturbance, this phenomenon can have significant socio-ecological implications for land users since it can cause a decrease in the economic value of the land, reduce ecosystem services and lead to a loss in biodiversity (Smit, 2004; Ward, 2005; Joubert *et al.*, 2014; O'Connor *et al.*, 2014; Harmse *et al.*, 2016; Tokozwayo, 2016). Important to note is that ecosystem services extend well beyond catering for livestock production. These services also regulate and maintain the natural ecosystem process and energy cycles and have a bearing on several non-material cultural benefits (Ward, 2005; Hulme, 2006; Vilà *et al.*, 2011).

Several studies have also alluded to the link between climate change and bush encroachment (Ward, 2010; Cao *et al.*, 2013; Mureva & Ward, 2016) with long-term changes to the local climate in combination with grazing effects and fire suppression, being recognised as possible causes of bush encroachment (Ward, 2005; Lesoli *et al.*, 2013; Mureva & Ward, 2016). Trees and grasses respond differently to changes in atmospheric CO<sub>2</sub> because their photosynthetic pathways differ (Scholes & Archer, 1997; Lenihan *et al.*, 2008; Bond & Midgley, 2012).

Consequently, elevated atmospheric CO<sub>2</sub> concentrations will enhance the competitive ability of trees when compared to certain grasses.

#### 1.1.2 Alien invasive plants (IAPs)

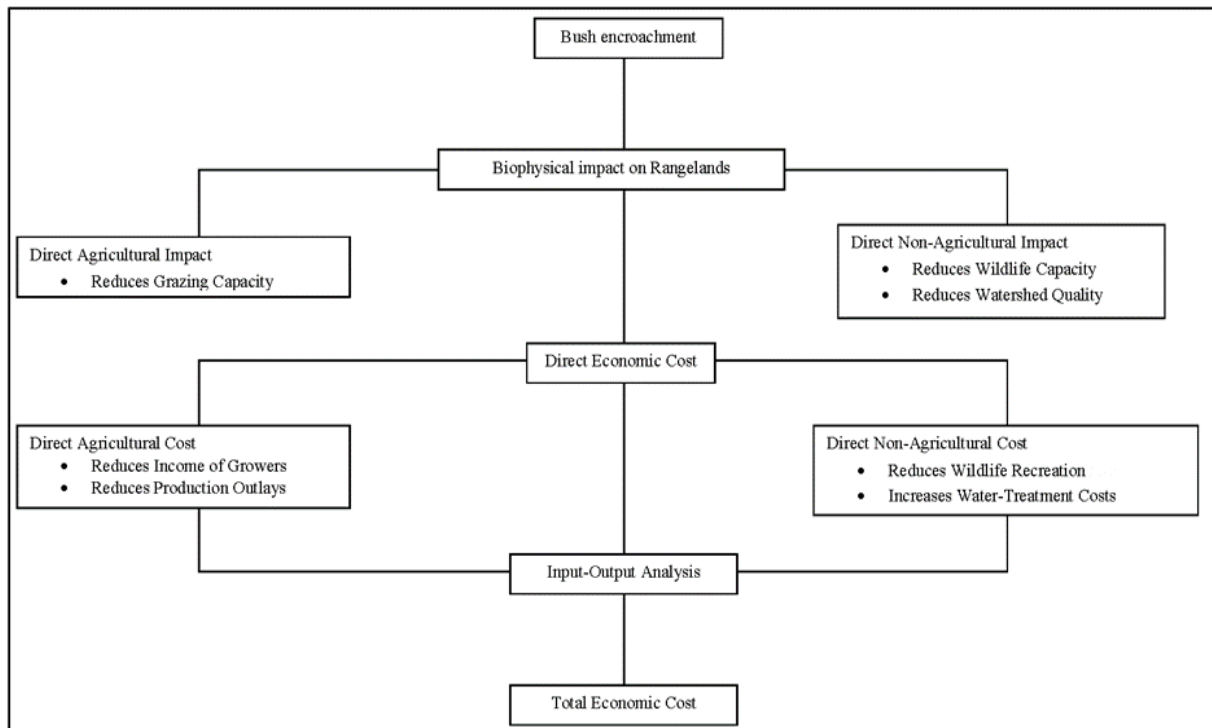
In South Africa, rangelands cover more than 70% of the land surface (O'Connor & Van Wilgen, 2020) and support domestic livestock and human livelihoods (Cousins, 1999; Kariuki *et al.*, 2018; Godde *et al.*, 2020; O'Connor & Van Wilgen, 2020). However, hundreds of alien plant species (non-native plant species) have invaded these rangelands and are multiplying mostly because of land mismanagement (Rahlao *et al.*, 2009; Milton & Dean, 2010; Wigley *et al.*, 2010; Hui & Richardson, 2017). On a national scale, invasive alien plants have reduced the value of soil production and compromised the delivery of ecosystem services and will continue to do so if left unchecked (Van Wilgen *et al.*, 2001; Turpie, 2004; Holmes *et al.*, 2005; Gaertner *et al.*, 2011; Vilà *et al.*, 2011). Given that roughly 10 million hectares have been invaded (Le Maitre *et al.*, 2000; Hui & Richardson, 2017), those charged with managing invasive alien plants in South Africa are facing an enormous challenge. The threat of invasion by IAPs is recognised as the second-largest global threat to biodiversity (Hui & Richardson, 2017). The one peculiar characteristic of invasive alien plants is that if any of them are indigenous to their country of origin, their ability to grow aggressively and generate exorbitant quantities of seed becomes an advantage (Van Wilgen *et al.*, 2004; Ward, 2005). The threat posed by exotic invaders (i.e. species transported to another continent) should, however, not be discounted since newly introduced species tend to spread rapidly and to out-compete native (indigenous) species (Van Wilgen *et al.*, 2004).

#### 1.1.3 Economic and social impact of bush encroachment on rangelands

Rangelands contribute to the economy of southern Africa in many ways. They provide agricultural commodities as well as benefits that are not directly related to the agricultural

sector (e.g. the wildlife industry). Whatever the case may be, land-use activities on rangelands have a direct impact on a country's economy and long term sustainability (Julia *et al.*, 2007; Lesoli *et al.*, 2013).

Worldwide, increases in the density of woody plants pose a major threat to the economy, especially with regards to livestock production, game keeping (Dalle *et al.*, 2006) and biodiversity (Ward, 2005; O'Connor *et al.*, 2014). Invasive species pose problems for managers of rangelands because these plants reduce the land's usefulness for grazing activities (Figure 1.1). Furthermore, bush encroachment has a negative impact on browsers in the wildlife tourism sector (Arbieu *et al.*, 2017) since the high density of woody plant roots depletes the soil moisture and causes trees to drop their leaves earlier in winter. Since browsers feed on leaves, soft shoots or the fruits of high-growing woody plants such as shrubs, this means that browsers will have a limited supply of browsing material during the dry winter months. Bush encroachment has an impact on rangelands, this potentially resulting in the total economic loss (Julia *et al.*, 2007). Figure 1.1 illustrates the economic impacts of bush encroachment in relation to a decline in land carrying capacity (biophysical impacts on rangelands) for wildlife and livestock and the negative impacts on watershed quality (Julia *et al.*, 2007; Lesoli *et al.*, 2013). By way of explanation, non-agricultural economic impacts associated with wildlife relate to reductions in recreation expenditure (tourism) and increases in expenditures to mitigate damages caused by bush encroachment. Direct agricultural impacts relate to a reduction in grazing capacity and a reduction in farmers' income and production outputs. Indirect losses are linked to socio-economical changes in household expenditure patterns as a result of changes in employment caused by bush encroachment.



**Figure 1.1** General hypothetical economic impact of bush encroachment in rangelands (Lesoli et al., 2013).

#### 1.1.4 Restoration of bush-encroached rangelands

Given the extent of bush encroachment in rangelands, and the resultant associated ecological and economic losses (Figure 1.1), instituting appropriate bush clearing and restoration activities is imperative (Hoffman, 2014; Zerga *et al.*, 2018; Naudé, 2019). Depending on the species and the extent of encroachment in semi-arid and arid savannas, several methods are currently being deployed to address this problem (Mndela *et al.*, 2020; [www.environment.gov.za](http://www.environment.gov.za)). One such method is bush clearing, a method that aims to shift dominance of woody species in original rangeland back to herbaceous vegetation to create suitable habitats for grazers and browsers. In essence, bush clearing reduces tree-grass competition and changes and alters habitat conditions by increasing the availability of sunlight, soil surface moisture and soil nutrients particularly in semi-arid and arid savannas (Mndela *et al.*, 2020), thereby increasing the abundance, richness and production of herbaceous species (Abate & Angassa, 2016).

Even though the removal of encroaching woody species is well supported, it is critical to understand that clearing methods are management systems (Barac *et al.*, 2001; Lukomska *et al.*, 2014), each with differing policy implications (Angassa *et al.*, 2012). Therefore, if the intention is to promote the growth of herbaceous species and to increase their composition, cover and density, the potential role of varying bush clearing (restoration) methods should first be examined with due consideration for the objectives of land users and policymakers (Angassa *et al.*, 2012). This is because not all land users might agree about the priorities set for restoration projects and might even disagree about where and how degradation ought to be addressed (Crossland *et al.*, 2018). In short, the impacts of restoration activities are likely to be socially differentiated and for this reason, it is important to understand the interaction between varying restoration interventions and livelihoods and to ensure that restoration activities do not disadvantage the most vulnerable people and ecosystem (Crossland *et al.*, 2018; Mangani *et al.*, 2020).

#### 1.1.4.1 Control methods

The South African government has gone to considerable lengths to address the negative impacts bush encroachment (invading woody species) has on the country's natural resources (Richardson & Van Wilgen, 2004; Grossman & Holden, 2007). Chemical, mechanical and manual or biological technologies (or a combination of all three) are deployed in South Africa to affect de-bushing and to control bush encroachment (Smit & Rethman, 1999; Barac, 2003; Barac *et al.*, 2004; Grossman & Holden, 2007; Wigley *et al.*, 2009; Mandela *et al.*, 2020). If bush encroachment is to be managed effectively, it is important to first gather sound ecological data regarding the affected area and to take heed of land users' requirements (where and when to do bush clearing so as not to disrupt socio-economic benefits and natural ecosystem functioning). Furthermore, it is necessary to assess the long-term benefit (sustainability) of restoration over time (Reed *et al.*, 2015) and to determine the advantages of one bush clearing

method compared to another, which also involves ensuring that the necessary financial and human resources will be available over the long term.

### Chemical control

This method involves using selective herbicides aimed at reducing the competitive ability of invasive woody species by reducing their growth and photosynthetic rate. In this process, species that are not affected by the herbicide gain an advantage over soil nutrients and soil moisture (Barac *et al.*, 2001; Smit, 2004; Lesoli *et al.*, 2013). The use of herbicides is very specific and their primary nature is suited to only control certain woody species at high density where trees are above the browse line and where the bush is unacceptable to animals (Smit & Rethman, 1999; Smit, 2004; Lesoli *et al.*, 2013). For this reason, it is important to ensure that the correct herbicide is used to control (clear) certain woody species only since the chemical properties of herbicides vary which means that they will react differently under diverse climatic and soil conditions. In addition, the method of application (dosage) and the effect of the herbicide on the ecosystems (environment impact) also vary (Lesoli *et al.*, 2013).

Chemical control methods are usually costly to apply (and require long-term follow-up operations) and should be considered under specific circumstances only. Herbicides can sometimes also be used in follow-up procedures such as after bush clearing where the intention is to kill re-emerging seedlings of a targeted plant or re-sprouting shrubs. Even though herbicides are mainly used for weed control in rangeland systems, resistant weed populations might be problematic (Clout & Williams, 2009) while the impact on the environment could also be detrimental since some plants and animals might be vulnerable to the chemicals used (DiTomaso, 2000).

### Mechanical and manual control

Manual and mechanical techniques are used to control bush encroachment particularly if the population is relatively small. These techniques are extremely specific and thus minimise

damage to desired plants (Lesoli *et al.*, 2013). In South Africa, and particularly in this study, most methods used to control bush encroachment (also called 'de-bushing') involve a combination of mechanical and manual methods (Barac *et al.*, 2001; Barac, 2003; Smit, 2004; De Klerk, 2004; Wigley *et al.*, 2010). Machines such as chainsaws are used for mechanical clearing however need trained personnel. Tools such as handsaws, pruning loppers and bush axes are used for manual clearing. Manual bush clearing is also more environmentally friendly since it is less destructive to the soil and does not cause a great deal of pollution (Grossman & Holden, 2007), while the need to involve manual labour contributes to the employment of members of rural communities, thereby improving their livelihoods (Mangani *et al.*, 2020). Even though these techniques have several positive effects, due to the physical labour (manpower) involved, it can be very costly when practised on a large scale (Kellner, 2008; Kimball *et al.*, 2015) and is, therefore, more suitable for smaller scale projects.

### Biological control

Biological control (biocontrol) is defined as the use of living organisms to reduce the activity and reproductive capacity or effects of weeds (DiTomaso, 2000; Hulme, 2006). This method is effective to control alien invasive species since the target is to reduce the effects of ecological release and to return plants to the status of a non-invasive, plants (Van Wilgen *et al.*, 2004).

This control method can be met with some negative aspects. Firstly, it is a long-term solution and therefore effects are only seen within a few years after application; secondly, the released biocontrol agents could attach other indigenous species; and thirdly the bio-agents are easily washed away during rainstorms and then the process has to start all over again (Evans, 2002; Schwarzländer *et al.*, 2018). In the long run, biological control can be regarded as a sustainable, cost-effective and environmentally friendly mechanism, if managed correctly, to prevent the spread of invasive alien species (Morris *et al.*, 1999; Evans, 2002; Schwarzländer *et al.*, 2018).

Even though it is unclear when exactly biocontrol was established in South Africa, the use thereof is allowed nowadays (Van Wilgen *et al.*, 2004; Lesoli *et al.*, 2013).

#### Use of fire and other control methods

Fire is a natural ecological factor that has been in nature for many years (Van Langevelde *et al.*, 2003). The use of fire to control invasive woody plants is warranted due to the fact that when woody plants are burned, they take longer to recover or do not recover at all, thereby allowing herbaceous species to grow with minimal or no competition (Van Langevelde *et al.*, 2003; Sawadogo *et al.*, 2005; Rahlao *et al.*, 2009). Where plants are above browse line, fire can be used to reduce plant height where the fuel load is sufficient. However, if the fuel load is not sufficient, chemical or mechanical control should be used and, in both cases, goats can be used as follow-up control (Lesoli *et al.*, 2013). In many instances, the effectiveness of burning can be enhanced through integration with a vegetation management programme (Lesoli *et al.*, 2013). Although using fire as a control method has proven to be successful, the long-term effect thereof needs to be evaluated. The use of fire on the composition of plant communities and the impact on endangered plant species, wildlife and insect populations as well as the alterations to soil biology and hydrology need further evaluation, especially if incorrectly applied (DiTomaso *et al.*, 2006; Rahlao *et al.*, 2009).

Using the combination of the control methods referred to above can have remarkable results since no single method is likely to prevent either the distribution or encroachment of woody species. Goats and browsers can also be used as a follow-up control after the application of chemical or mechanical/manual control methods (Lesoli *et al.*, 2013). According to García *et al.* (2012), goats and browsers can be used as management technique in bush encroached lands. Through their browsing mechanism the repeated re-sprout of trees, provided that their canopies are below the browse line, can be reduced (García *et al.*, 2012). In this regard, goats are able to reduce bush cover more efficiently than sheep or cattle (communal livestock) and are, thus,

useful for conservation if managed properly (Teague, 1989; Breebaart *et al.*, 2002; García *et al.*, 2012).

#### 1.1.4.2 Re-seeding in restoration

Since a reduction in grass cover is usually the first sign of rangeland degradation (Brits & Kellner, 2009), sowing of grasses is viewed as an effective mitigation action to counter soil erosion and to improve soil physical properties. Grasses have the ability to increase surface roughness, which reduces water runoff and, consequently, a reduction in soil erosion. However, veld grasses are typically slow growing, and failure to establish is higher on bare patches (Brits & Kellner, 2009; Donzelli *et al.*, 2013) since grasses do not establish where topsoil has been removed due to a lack of nutrients and surface moisture, the compaction of the soil surface and extreme exposure to radiation and temperatures (Harmse *et al.*, 2016). For this reason, the microclimate near the ground surface is of prime importance for the establishment of grasses, particularly on bare soils (Modungwa, 2017).

Re-seeding should be reserved for areas where there is a good chance of success and where increased forage will lead to better usage of the land and an increase in livestock production. Typically, native species are used for re-seeding; however, if restoration (i.e. good establishment of grass species) is to succeed, it is of utmost importance to know which grasses to seed in order to avoid weed competition (GeFellers *et al.*, 2020). Since grasses are adapted to certain environmental factors, especially soil and climatic conditions, the time of seeding must be considered (Brits & Kellner, 2009), and only the seeds of native grasses adapted to these conditions should be used. The availability of high volumes of native grass seeds that are required may be problematic since most suppliers usually do not stock these types of grass seeds in high volumes. Seeds are also expensive, which is all the more reason why careful attention should be paid to the selection of sites and the timing of re-seeding.

#### 1.1.4.3 Brush packing as a restoration method

Bush control alone is not enough to facilitate and restore the ecosystem functions and processes of a land to their original or desirable state. Even when sites are re-seeded, a favourable microenvironment is needed to ensure good establishment. In this study, a technique called ‘brush packing’ has been used to restore bush-cleared land by packing branches from the shrubs and trees that have been cut on degraded areas and areas that have been cleared of woody material. In essence, brush packing involves using woody branches, leaves and other organic materials/litter as mulch on bare surfaces to protect grass seedlings from herbivores. Since natural materials are used to create micro-environments that facilitate re-vegetation, brush packing as restoration method is highly cost effective (Kellner, 2008; Harmse, 2013; Modungwa, 2017) and has the added benefit that as the vegetative material used as mulch decompose over time, the nutrient and carbon content of degraded soils is replenished (León & Osorio, 2014; Rai *et al.*, 2016). Following on the studies conducted by Tongway and Ludwig (1996), Barac *et al.* (2001), Tongway and Ludwig (2011), Visser *et al.* (2007), Kellner (2008), Kimiti *et al.* (2017), Modungwa (2017) and Naudé (2019), this study used brush packing to create micro-sites that favour plant establishment to create new vegetated cover and to reduce bare-ground patches.

## **1.2 Problem statement and substantiation**

Bush encroachment is of major concern in rangelands since it poses a threat to natural ecosystems and human livelihoods and, thus, needs to be managed ([www.environment.co.za](http://www.environment.co.za)). However, attaining the desired results by means of restoration is not an easy and straightforward process. Rather, proper planning and maintenance over the long term are essential (Kellner, 2008) especially since restoration of degraded rangelands is not only restricted to environmental conditions but also encompasses active intervention in as far as the social and economic conditions of affected communities are concerned (Aronson & Van Andel,

2006). Given that the savannas of the Limpopo Province rank under those areas most affected by bush encroachment in South Africa (Jordaan *et al.*, 2004; Gibson, 2006; MacLeod *et al.*, 2008; Jordaan, 2010; Scheiter *et al.*, 2018), this study set out to investigate how brush packing as restoration method after bush clearing can improve the biophysical properties of rangelands and the livelihoods of the communities affected by this phenomenon in the Limpopo Province. The following knowledge gaps were identified:

1. What effect bush clearing and restoration techniques have on the ecosystem (biophysical),
2. Whether rural, underprivileged people benefit socially and economically from bush clearing and restoration activities,
3. Whether bush encroachment, albeit an environmental problem affecting most rangelands, is more prevalent in communally managed lands or in conservation areas.

In an attempt to bridge this gap, this study, therefore, set out to investigate the impact of restoration techniques during the years 2017, 2018 and 2019, after bush clearing in relation to two different land-use types, i.e. communally managed land and a conservation area.

#### Alignment with national strategies

This research project was conducted under the auspices of the Natural Resource Management programme which resorts under the South African Department of Environment, Forestry and Fisheries. The programme's objective is to restore the integrity of degraded and bush-encroached rangelands by addressing the loss in biodiversity, ecosystem functions and processes and ecosystem services.

Against this background, this study set out to address target 15.3 as defined in the United Nations' Strategic Development Goals which reads as follows: "By 2030, combat desertification, restore degraded land and soil, including land affected by desertification,

drought and floods, and strive to achieve a land degradation-neutral world” (Ceci *et al.*, 2018; Wunder *et al.*, 2018; Von Maltitz *et al.*, 2019; Lucatello & Huber-Sannwald, 2020).

More importantly, though, this study also addresses the objective to attain land degradation neutrality (LDN) as recently espoused by the United Nations Convention to Combat Desertification (UNCCD) (Wunder *et al.*, 2018; Von Maltitz *et al.*, 2019; ). In essence, LDN aims to maintain or improve the condition of land resources through the sustainable management of soil, water and biodiversity in order to fully realise these resources’ economic, social and environmental benefits, encompassing the restoration of degraded natural ecosystems that provide vital services to people and working landscapes.

### **1.3 Research aims and objectives**

The aim of this study was to evaluate the impacts bush clearing and restoration technologies (brush packing) have on improving the ecosystem processes and functions and socio-economic benefits of two land-use types (a communal and conservation area).

To begin with, before the restoration application, the state of bush encroachment (woody composition) at the two land-use sites was evaluated. Thereafter, the objectives were to:

- Assess the efficacy of brush packing as a restoration technology to improve ecosystem functions, structures and processes paying particular attention to:
  - a) grass species diversity response to brush packing under two different land-use types in semi-arid rangelands; and
  - b) the cost-effectiveness of using brush packing as restoration method to improve grass aboveground biomass after bush clearing in semi-arid areas.
- Determine if any socio-economic benefits stemmed from the bush clearing and restoration projects conducted at the D’Nyala Nature Reserve and in the Shongoane village.

## **1.4 Hypothesis**

The hypothesis of the study was that the control of bush encroachment (bush clearing) and restoration (via brush packing) would improve the ecosystem functions and processes to a desirable state. Furthermore, the hypothesis was that brush packing will improve aboveground biomass and increase the biodiversity of the rangelands, thus enhancing the ecosystem services available to the local community which, in turn, would contribute to their socio-economic well-being.

1. The brush packing treatments (also referred to as technique in the thesis) will increase grass species richness and diversity, thereby improving the ecosystem structure, function and processes.
  - Through the microenvironment created by brush packing, depleted grass species will now be recruited.
2. The brush packing treatments will result in increased aboveground biomass compared to the non-brush-packed treatments.
  - In addition, re-seeding combined with brush packing will yield even higher aboveground biomass.
3. The cost of using brush packing, as a restoration method, will be more effective over the long term compared to when there is no brush packing.
4. The bush clearing and restoration activities will benefit the society (community members) economically and environmentally, thereby improving their livelihoods.

## **1.5 Thesis outline**

This thesis is comprised of nine chapters. Every attempt has been made to ensure that it conforms to the guidelines stipulated in the North-West University's Manual for Higher Degrees Studies

[http://studies.nwu.ac.za/sites/studies.nwu.ac.za/files/files/postgrad/Higher%20Degrees%20Manual\\_Senate\\_1Sept2020.pdf](http://studies.nwu.ac.za/sites/studies.nwu.ac.za/files/files/postgrad/Higher%20Degrees%20Manual_Senate_1Sept2020.pdf)).

By way of clarification, though, it ought to be noted that some of the chapters to follow will be presented in article format. One of these (Chapter 7) has already been published, while two more (Chapters 5 & 6) have been submitted for peer review. Every effort has been made to ensure that all contributors to the above chapters have been credited appropriately. Do also note that there may be some overlap when stating the study area and reporting on methods, materials and results due to the article format followed in chapters 5, 6 and 7.

### Chapter 1: Introduction

In addition to defining the concept 'land degradation', this chapter sketches the extent and impact of land degradation in Southern Africa and provides a historic overview of bush encroachment in South Africa and Limpopo. Interventions to manage invasive plants on a national scale are elaborated on, leading to the identification of knowledge gaps and the formulation of the research aim and objectives as well as the basic hypothesis. Note, too, that the issue of invasive woody species and active restoration methods elaborated on in this chapter were used to interpret the results reported in Chapter 4, 5, 6 and 7.

### Chapter 2: Study area

This chapter presents a detailed description of the study area and provides information regarding the general environment.

### Chapter 3: Materials and methods

The general methodology regarding the survey methods that were followed to collect data pertaining to tree composition, grass diversity, aboveground biomass and socio-economic benefits is set out in this chapter. Furthermore, the experimental layout and design used at the

two study sites are discussed in this chapter, with particular attention being paid to the variation between the biophysical and socio-economic (qualitative) design.

### **Results and objectives**

The objectives of the study are presented in chapter format, with the exception of Chapter 4, Chapters 5, 6 and 7 have been prepared for publication in different peer reviewed international scientific journals and each of these chapters comprise a detailed introduction, statistical analysis of the results and a discussion and conclusion section.

#### Chapter 4: Baseline study: Woody composition, density and cover prior to clearing

This chapter presents the results of the baseline study regarding woody composition, density and cover at different height classes prior to clearing for the two land-use types. The record of the tree composition and height classes of the woody tree and shrub species at the experimental sites is also presented in this chapter. Great differences between the two land-use types were recorded for woody density as well as for the overall woody species compositions at different height classes. This is indicative of the complexity of the manifestation of bush encroachment in different land uses.

#### Chapter 5: Grass species diversity response to brush packing under two different land-use types in semi-arid rangelands of South Africa

[Submitted and under peer-review in the Journal of Arid Environments].

This chapter, presented in article format, addresses the first research objective by providing results on how grass species diversity (richness, evenness and abundance) responds to the different restoration treatments (brush packing versus non-brush packing). Furthermore, the results for rangeland vegetation with the aid of indicator species and ecological status are presented. Lastly, the differences between grass species community structures in the brush-packed restoration plots versus the non-brush-packed plots in relation to the communal and

conservation area is analysed in this chapter. The findings in this chapter showed that brush packing only led to differentiation of the grass community in the highly grazed rangeland. The results thus support the hypothesis that brush packing promotes grass biodiversity under high grazing pressure compared to natural savanna systems.

Chapter 6: Cost-effectiveness of brush packing as restoration technique to improve grass aboveground biomass after bush clearing in semi-arid rangelands of South Africa

[Submitted and under peer-review in the *Sustainability* journal].

This chapter (presented in article format) addresses the second research objective, namely to assess how effective brush packing as a restoration method is to improve grazing capacity in two land-use types. The results for aboveground biomass and the cost-effectiveness of varying restoration treatments applied to the two land-use types are also presented in this chapter. The results in this chapter showed that in all brush-packing treatments at both study sites, aboveground biomass was higher compared to the non-brush-packed treatments. The results also demonstrated that improved aboveground biomass could be achieved by using a relatively cost-effective restoration method, i.e. brush packing, provided that community volunteerism can be incorporated to counter labour costs.

Chapter 7: Socio-economic benefits stemming from bush clearing and restoration projects conducted in the D’Nyala nature reserve and Shongoane village, Lephalale, South Africa

This chapter has been published as a peer-reviewed article in *Sustainability* (<https://doi.org/10.3390/su12125133>) crediting the following contributing authors: Tshepiso Mangani, Hendri Coetzee, Klaus Kellner and George Chirima. It addresses the third study objective by evaluating the socio-economic benefits stemming from the bush clearing and restoration projects initiated by the Department of Environment, Forestry and Fisheries. The findings in this chapter revealed that the socio-economic benefits derived from restoration

projects, such as bush clearing, far outweigh the negatives and that there is every reason to institute projects of a similar nature elsewhere in the country.

#### Chapter 8: Brush packing restoration guideline

A general procedure of how land users (community members or land owners) and restoration specialists (including the researchers and contract workers employed for this purpose) can implement the brush packing restoration method is outlined in this chapter.

#### Chapter 9: Conclusion and recommendations

By way of integration, all findings in this study are summarised in brief in this chapter. In addition, the limitations of the study and recommendations for future restoration actions of this kind are also presented.

## CHAPTER 2

### STUDY AREA

#### 2.1 Brief overview of Limpopo

Limpopo is the northernmost province of South Africa and constitutes ten percent of the country's land surface area (Limpopo, 2017), including the Waterberg Biosphere – a mountain range that covers approximately 15,000 km<sup>2</sup>. Ranching is a major land-use activity in Limpopo, and it is estimated that approximately 80% of the hunting activities carried out in South Africa take place here in the province (Limpopo Travel Guide, n.d.). Despite the economic support derived from hunting activities, Limpopo is the second poorest province in the country and, according to Limpopo's Provincial Treasury (2019), around 72.4% live in poverty of which most reside in rural areas.

There are five district municipalities in the province representing 25 local municipalities in total. Of these districts, the Waterberg is the largest and includes the Lephalale municipal area where this study was conducted.

#### 2.2 General location

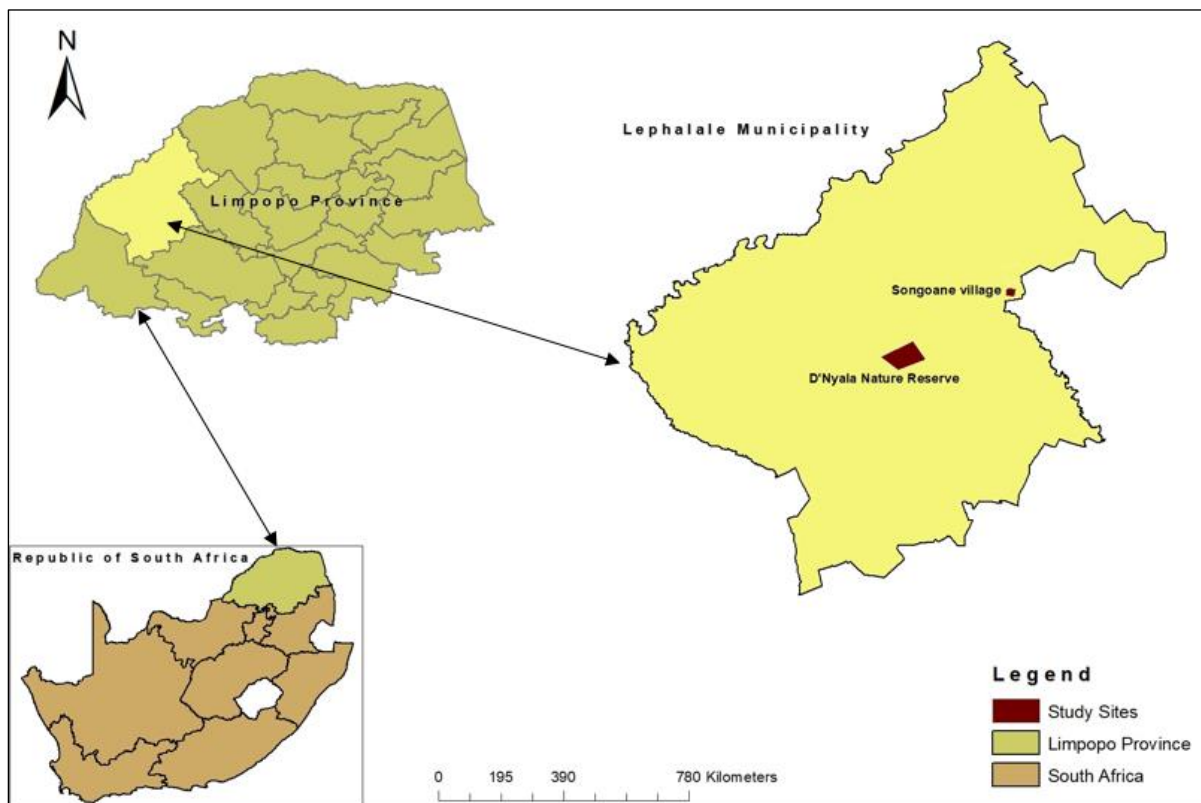
Close to the border with Botswana, Lephalale is located in the western part of Limpopo (Figure 2.1). It lies at 829 m above sea level and is situated between 23°40' South and 27°45' East.

##### 2.2.1 D'Nyala Nature Reserve

Roughly 8 200 ha in size and home to over 60 mammal and some 300 bird species, D'Nyala Nature Reserve lies nearly 15 km southeast of Lephalale in the northern Waterberg range (23°44' South and 27°46' East). The government acquired this reserve in 1986 to allow for the construction of the Vaalwater Lephalale road (R33). The reserve has large tree specimens

(including large *Adansonia* (baobab) trees) that dot its bushveld plains and broad floodplain areas while a huge variety of herbaceous species, grasses, herbs, succulents and forbs are present.

Considered a protected area in South Africa, D’Nyala has been earmarked by the Department of Environment, Forestry and Fisheries (DEFF) as an area where the threat posed by invading alien and indigenous woody species should be countered as a matter of priority to protect its biodiversity and to ensure the long term sustainability of the reserve.



**Figure 2.1** Location map of the study areas (D’Nyala Nature Reserve and Shongoane village) in the Lephalale municipality within Limpopo, a province of South Africa.

### 2.2.2 Shongoane village

This village lies about 45 km from the town Lephalale in the north-eastern rural area of this municipal area ( $23^{\circ}30'$  South and  $28^{\circ}7'$  East) and is estimated to cover an area in excess of 1 823 ha. Since this is communally managed land, it is not possible to determine stocking rates

but it was found that community members mostly keep cattle, donkeys, goats and sheep. The area is administered by traditional leaders and chiefs who mostly belong to the Bapedi and Batswana tribes.

### **2.3 Politics and Local Development Plan**

Politics and integrated development plans (IDPs) mostly lie at the heart of municipal affairs, especially in as far as socio-economic aspects are concerned. Although D’Nyala is a state-owned nature reserve where the national government has a say in most of the policies, the political influence of traditional leaders and chiefs, especially in rural areas, should by no means be discounted. In terms of the Limpopo Houses of Traditional Leaders Act (Act 5 of 2005) (Limpopo (South Africa) 2017)), their main function is to advise government and the legislature on matters pertinent to customs, tradition and culture and to drive developmental initiatives that will have an impact on rural communities.

The total population of Lephalale is estimated at around 140,240 totalling 43,002 households of which 33.2% reside in rural areas. The unemployment rate in Lephalale stands at 22.9% which is below the provincial average. This fact can mostly be attributed to developments relating to the construction of the Medupi power station and the concomitant expansion of coal mines ([www.lephalale.gov.za/docs](http://www.lephalale.gov.za/docs)).

#### **2.3.1 Implementation of the Extended Public Works Programme (EPWP)**

The intention with the EPWP is to create temporary employment opportunities for the unemployed rural poor ([www.epwp.gov.za](http://www.epwp.gov.za)), and for many years, Lephalale has been deploying projects aligned with this programme, notably labour-intensive bush clearing.

## 2.4 Biophysical features

### 2.4.1 Geology and soils

Lephalale is found in the Ellisras basin of the Karoo Supergroup (Erikssen *et al.*, 2006). Most of the soils stem from the Waterberg Group, Sandriviersberg and Mogalakwena Formations and include shale, sandstone, siltstone, mudstone and conglomerates (Erikssen *et al.*, 2006; Bamford, 2014). Very little of the soils in the municipal area are susceptible to water-erosion, but wind erosion can be a serious problem if the topsoil becomes exposed. The predominant soils at Lephalale are Plinthic soils (Soil classification working group, 1991). As per their scoping report dated 2005, Bohlweki Environmental (Pty) Ltd found that some of these soils have a sandy texture and are comprised of quartzite sandstone (shallow sandy soils) and some soils have little or no structure and a very high clay content derived from shale and gneisses. Sandy soils have a reduced capacity to store water, whereas soils with a high clay content have a higher water holding capacity; nevertheless, both of these soils types can have a diverse impact on water flow ([www.lephalale.gov.za/docs](http://www.lephalale.gov.za/docs)).

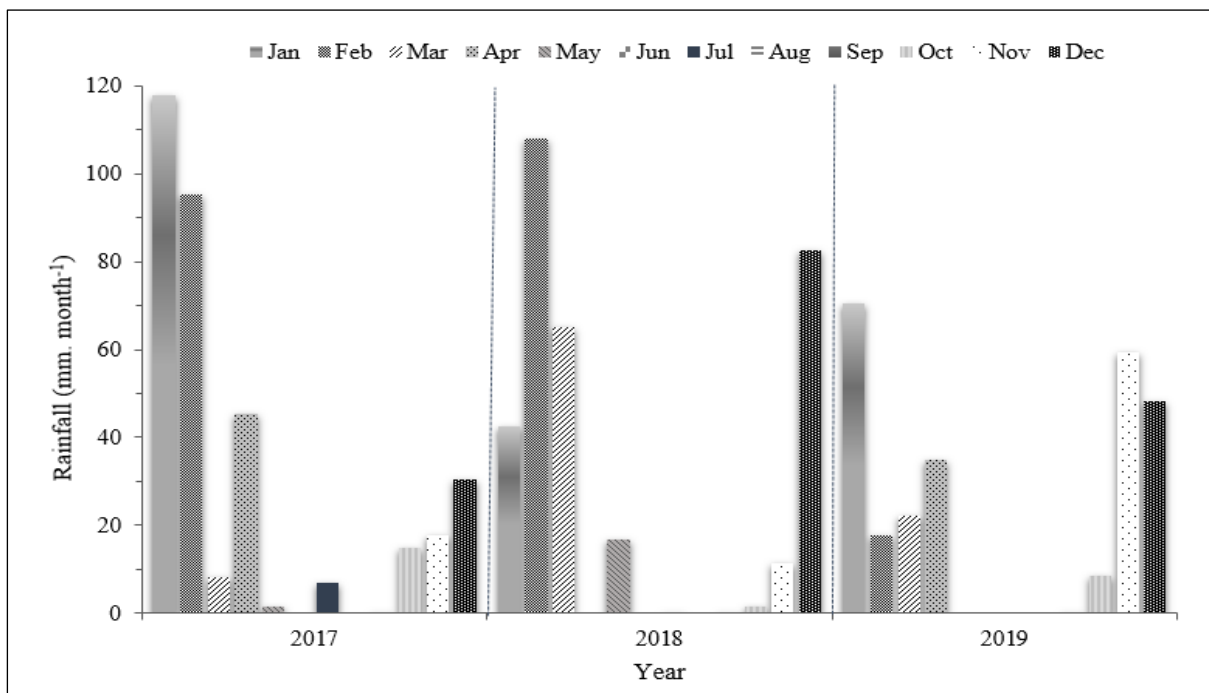
### 2.4.2 Climate

Lephalale lies at 829 m above sea level and, according to the Köppen-Geiger climate classification (Peel *et al.*, 2007; Roffe, 2019), is regarded as semi-arid and, therefore, subject to the so-called ‘steppe climate’ (BSh).

#### 2.4.2.1 Rainfall

Climate, especially low rainfall, is a major limiting factor. Lephalale experiences a fluctuating rainfall. In other words, dryer days are more frequent than wet ones. For this reason, huge investments in infrastructure for water storage have been necessary in an attempt to sustain the viability of agricultural practices since most cultivated lands need to be irrigated and given that there has been a marked decrease in dry-land farming (crops).

Measured over the long term, Lephale's annual rainfall is estimated at around 400-450 mm/y, with the average summer rainfall standing at around 350-450 mm/y (Engelbrecht & Engelbrecht, 2016; Roffe, 2019). Given that summer rainfalls are usually received from October to April, the highest rainfall during the three-year study period (2017-2019) was recorded in the months of January and February (Figure 2.2). The average rainfall in the year 2017 was higher compared to 2018 and 2019 years with very little rainfall recorded in May and no rainfall in the months June, July, August and September.

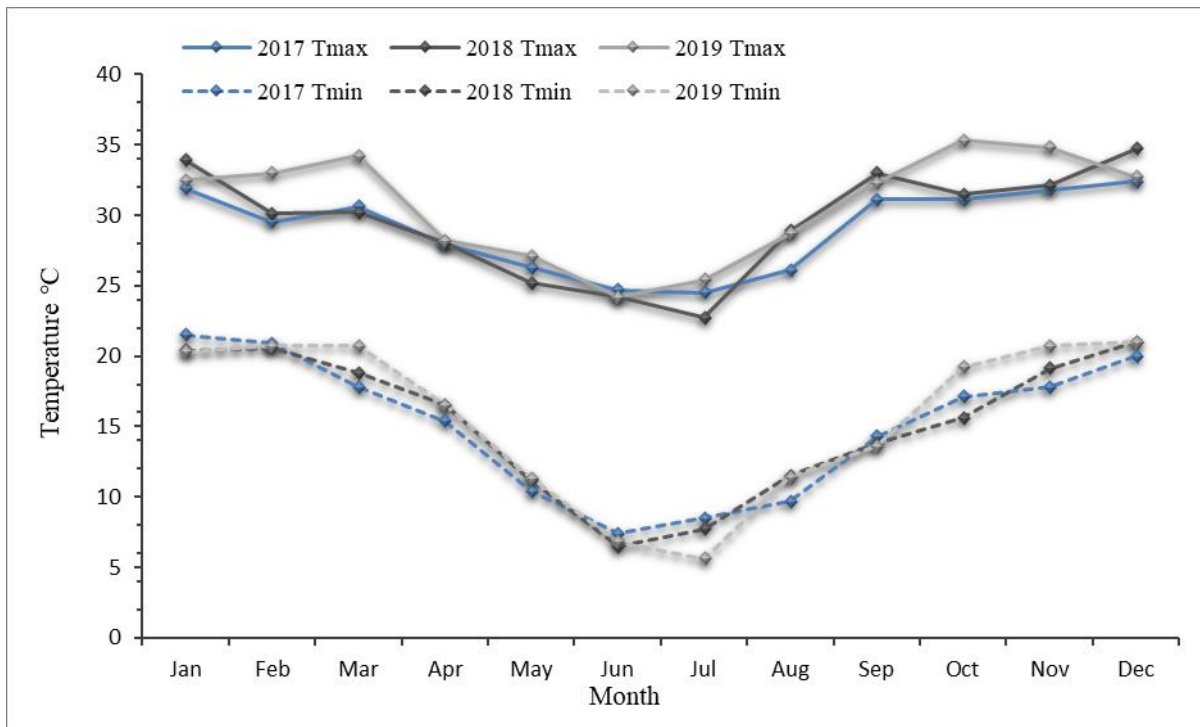


**Figure 2.2** Mean monthly rainfall during the study period (years 2017, 2018 and 2019) at Lephale.

#### 2.4.1.2 Temperature

At Lephale, average daily temperatures vary between 17 and 32°C in summer and between 4°C and 20°C in winter, while the mean minimum and maximum temperatures range between 2.1°C and 39.2°C for June and December, respectively (Engelbrecht & Engelbrecht, 2016).

During the study period (years 2017, 2018 and 2019), temperatures rose above 34°C during March of 2019 (Figure 2.3) and dropped below 5°C during July of the same year. In general, temperatures began to drop from April onwards and began to rise again in September.



**Figure 2.3** Mean monthly maximum and minimum temperatures (°C) during the study period (years 2017, 2018 and 2019) at Lephale.

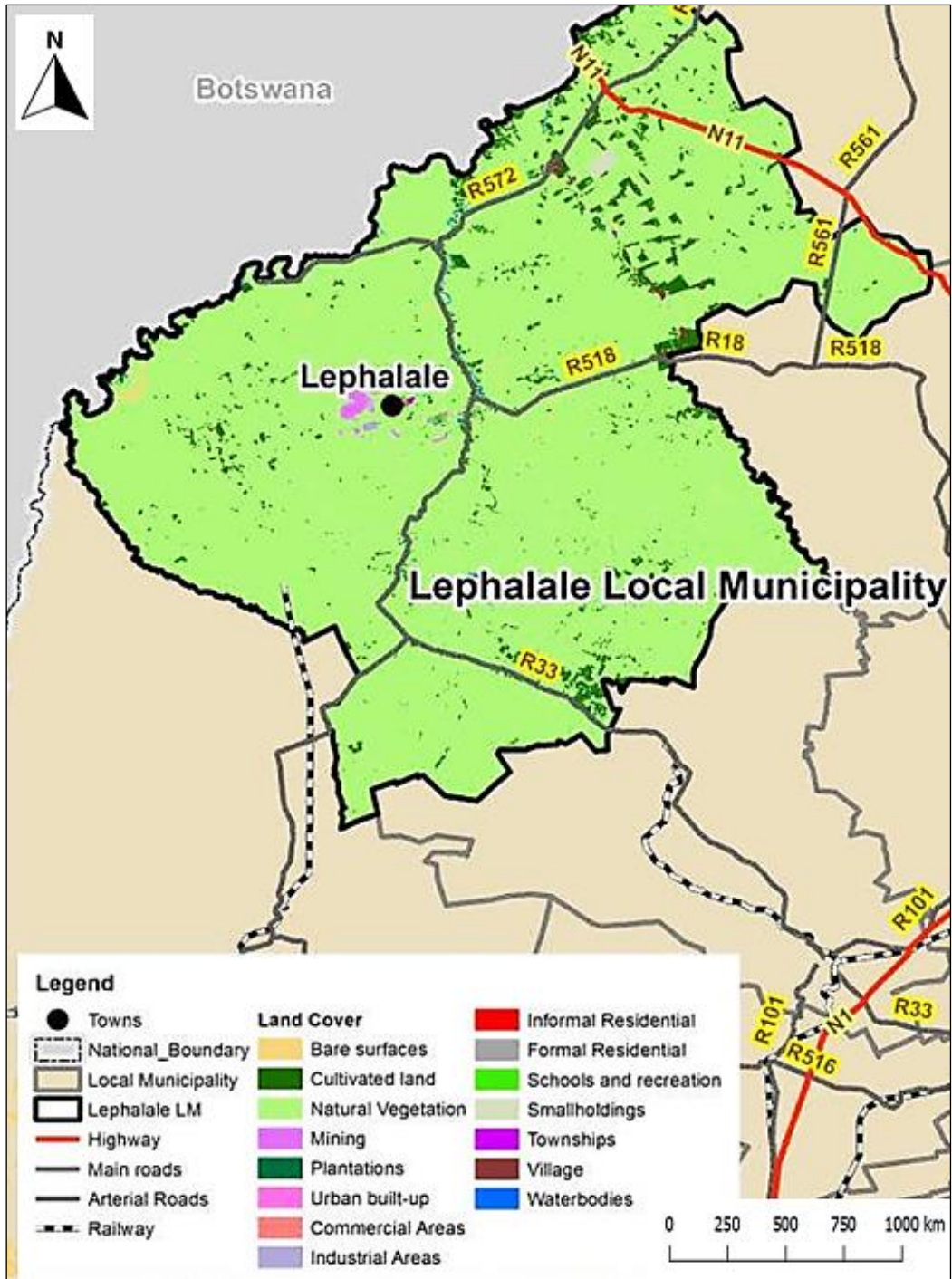
## 2.5 Land use and land cover

Geographically speaking, Lephale’s municipal area measures around 1,378,429.178 hectares and reflects a varied topography (steeper in the Waterberg area in the south-east and generally flattening out towards the north). Developments closely associated with physical and historical factors mostly account for land uses with mining activities being dominant in the municipal area. Even though rural areas, mostly settlements, dominate the eastern part of Lephale, the land in this area is still compatible with most land-use activities (Lephale, 2017; [www.lephale.gov.za/docs](http://www.lephale.gov.za/docs)).

The municipality has large tracts of cultivated commercial dry lands covering an area of 39,624.387 hectares of which 8,488.227 hectares are irrigated by water coming from three rivers, namely the Mokolo, Phalala and Limpopo River. Rural villages, on the other hand, are mainly characterised by cultivated subsistence dry land farming and cover around 17,244.714 hectares (Lephalale, 2017; [www.lephalale.gov.za/docs](http://www.lephalale.gov.za/docs)).

The larger portion of the municipal area, though, is characterised by degraded forests, woodlands, bush clumps and thickets (Figure 2.4), covering 1,303,004.24 hectares. This is another major concern for the municipality as bush encroachment has caused a decline in the land productivity thus affecting ecosystem services ([www.lephalale.gov.za/docs](http://www.lephalale.gov.za/docs)). Furthermore, roughly 828.712 hectares encompass wetlands with the three main tributaries being Lephalala, Mokolo and Matlabas. Combined, rivers, their tributaries and other minor streams cover approximately 1,532.23 hectares and serve as a major catchment area for the lower-Limpopo basin.

Mining is also a dominant land feature in the municipal area with mines and quarries covering 3609.286 hectares of the geographical space.



**Figure 2.4** Land cover and major topographical features of the Lephale municipal area ([http://thehda.co.za/pdf/uploads/multimedia/Lephale\\_Limpopo.pdf](http://thehda.co.za/pdf/uploads/multimedia/Lephale_Limpopo.pdf)).

The reality is that given increased costs (infrastructure, labour) and the environmental challenges (fluctuating rainfall, soil degradation, bush encroachment), viable land-production options are declining rapidly in the Lephale municipal area.

## CHAPTER 3

### MATERIALS AND METHODS

#### 3.1 Overview

Responsibility for research on and the restoration of degraded lands is a one of the priorities within the Natural Resource Management (NRM) programme which resorts under the Department of Environment, Forestry and Fisheries (DEFF). The programme also addresses some of the country's socio-economic challenges, arguably the most challenging being unemployment in rural communities. For this reason, to counter bush encroachment, the NRM programme makes extensive use of the Expanded Public Works Programme (EPWP) by way of several 'working for' projects: Working for Water (WfW) aims to manage invasive species known to have negative impacts on an environment, Working for Ecosystems (WfEco) aims to implement sustainable land management (SLM) practices, and Working on Land (WfL) aims to address degraded ecosystems and ecosystem services for the rural poor ([www.environment.gov.za](http://www.environment.gov.za)). In short, through the EPWP, the NRM makes a considerable contribution to job creation in rural communities to, in this way, improve the socio-economic livelihoods and to promote the well-being of the people in the rural areas of South Africa.

This study was performed in collaboration with the NRM, the aim being to ensure sustainable management of rangelands. In this chapter, the survey methods used to gather data on the woody composition, grass diversity and aboveground biomass of the two study sites in question will be discussed as well as the methods employed to collect data on the socio-economic benefits members of the community derive from the relevant ecosystem services.

The experimental layout and design of the study (biophysical sampling as per Chapters 4, 5 and 6) will be described first. Note, though, that the statistical analysis and results obtained from surveys are presented in the respective chapters (4, 5, 6 and 7) and not in this chapter.

Also note that the design and approach followed in Chapter 7 differ from the rest of the study since the intention here was to conduct a qualitative study hinging on human participation and involved conducting interviews and/or collecting non-numerical data.

### **3.2 Experimental layout and design**

Experimental plots (also known as restoration islands) were identified and permanently marked at both the D’Nyala (conservation area) and Shongoane (communal area) site in February 2017. The plots were laid out in three parallel blocks based on the homogeneity and distributional pattern of the species cover at both study sites. Thereafter, six experimental plots (also called restoration islands) were constructed and replicated three times (18 plots) within the three parallel blocks at both study sites in November 2017 (Figure 3.1). Six different restoration treatments were randomly applied to the 18 plots within the three blocks using a randomised complete block design (six treatments replicated three times) (Figure 3.2). Each plot measured 400 m<sup>2</sup> (20 m x 20 m), with 2.5 m interspacing between each plot and approximately 7 m parallel spacing between the blocks within a 7 500 m<sup>2</sup> area. The same design was used at both study sites, i.e. D’Nyala and Shongoane. The six different restoration treatments that were investigated included:

1. No clearing (control plot) (**UC**)
2. Clearing only (**CO**)
3. Clearing and re-seeding (**CRS**)
4. Clearing and brush packing (**C-BP**)
5. Clearing and brush packing and re-seeding (**CRS-BP**)
6. Clearing and soil disturbance and brush packing and re-seeding (**CSRS-BP**)

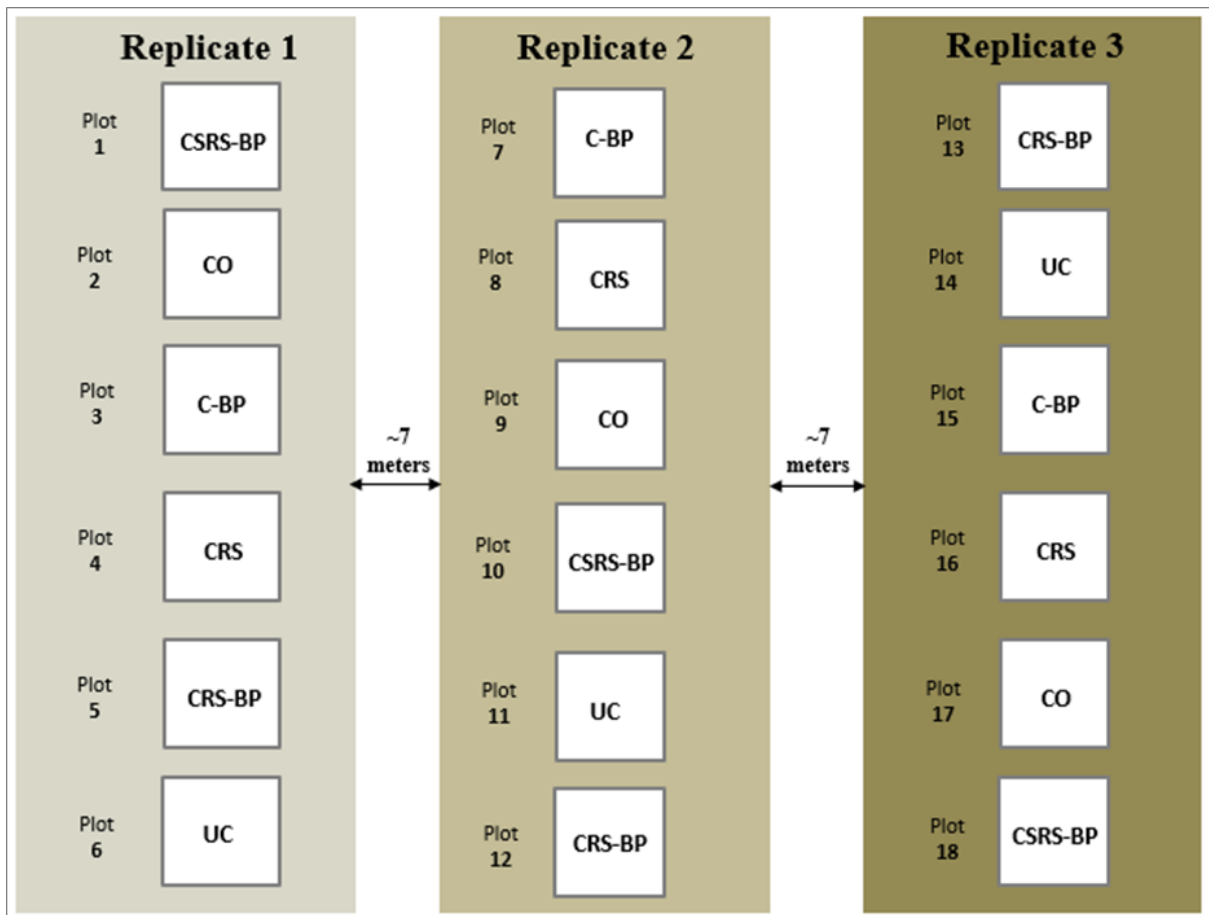
Where re-seeding formed part of the restoration technique (i.e. CSRS-BP, CRS and CRS-BP). This included a mixture of coated grass seeds (*Eragrostis curvula*, *Chloris gayana*, *Digitaria eriantha*, *Cynodon dactylon* and *Cenchrus ciliaris*) was sown at a rate of 200 g.400 m<sup>-2</sup> (1 0.5g. m<sup>-2</sup>) just before the plots were covered with brush (woody twigs, branches and leaves) by making use of the hand-broadcast method. The seed mixture used in this study included palatable grasses that occur naturally at the sites and is a standard veld mixture generally used for re-seeding to restore and rehabilitate degraded and disturbed areas (Van Oudtshoorn, 1999). Note, too, that these seeds are agricoted, implying better seed-to-soil contact and improved germination and establishment (<https://www.agtcovercrops.co.za/agricote>).

Irrespective of the restoration treatment applied, no fertiliser was added to the soil and no irrigation applied during the trial period. All treatment combinations were equally represented within the blocks (based on the landscape) at all sites.



**Figure 3.1** Aerial view of the six restoration plots (islands) covering 400 m<sup>2</sup> (20 m x 20 m each) at D’Nyala.

\*Numbers 1-6 indicate plots and not necessarily treatment order. Numbers 1, 3 and 4 are plots where brush packing as treatment has been applied.



**Figure 3.2** Experimental layout of randomly distributed restoration treatments covering 18 plots at the experimental sites.

\*See above text for abbreviations of restoration treatments at each replicate.

### 3.3 Soil sampling

Soil tests are necessary to determine current fertility and health, to help diagnose plant growth problems and to try to improve plant growing conditions at experimental sites (Khan, 2018). For this purpose, soil data was collected during the baseline survey at both D’Nyala and Shongoane in February of 2017. In each of the 18 plots at each site, five soil samples at a 30cm depth were taken, using a soil auger, where after these samples were mixed to make a composite sample. All soil analytical tests were conducted by Eco-Analytica<sup>1</sup>, a laboratory resorting under

<sup>1</sup> Eco Analitica laboratory, North-West University, Potchefstroom 2531, +27 (18) 285 2732.

the North-West University that fully subscribes to the quality control measures espoused by the International Soil-Analytical Exchange (ISE).

Full details regarding soil sampling and analysis are to be published in an MSc dissertation titled “Evaluation of brush packing methods on different semi-arid savanna soil types and properties” 2021, by Nadine Meyer.

However, the soils at D’Nyala were characterised by high sandy (90%) and very low clay textures (3%). In contrast, the soil structure at Shongoane was comprised mostly of sand (50%) and clay (22%) and had a high calcium carbonate ( $\text{CaCO}_3$ ) content (Kellner *et al.*, 2020). The laboratory soil analysis of the experimental sites indicated that the soils at D’Nyala have a lower pH value (5,79  $\text{H}_2\text{O}$ , 4,91 KCl), while the soils at Shongoane have a higher pH value (7,94  $\text{H}_2\text{O}$ , 6,56 KCl). The phosphorus (P) and potassium (K) concentrations were 6,03 and 81,42  $\text{cmol}^{(+)}.\text{kg}^{-1}$ , respectively for D’Nyala, while the P and K concentrations for Shongoane were 6,95 and 169,08  $\text{cmol}^{(+)}.\text{kg}^{-1}$ , respectively. Percentage-wise, the soils at D’Nyala also have a lower organic matter content (0.55) than the soils at Shongoane (1.16).

### **3.4 Vegetation sampling**

#### **3.4.1 Baseline study of vegetation composition before bush clearing**

The baseline study was carried out in February 2017 prior to the clearing of the woody species and the restoration application at D’Nyala and Shongoane and encompassed sampling of woody and herbaceous (grasses only) species that occurred in the marked plots. To avoid errors in the sampling process, the edges of all plots were demarcated with the aid of droppers.

With reference to woody species, the belt transect sampling technique was used to determine the density and structure within each plot (Van Rooyen *et al.*, 2015; Dreber *et al.*, 2019). Within a 4 m buffer zone (five measurements per plot), height classes were recorded using a measuring

stick with a 5 m height, graduated with 50 cm markings. Woody plants with a height > 2.5 m were defined as mature trees, 1.5- 2.5 m as saplings and those < 1.5 m as shrubs (Table 3.1).

**Table 3.1** Different height classes of tree and shrub species identified during the baseline study.

Height class	Range (m)
1	≤ 1
2	1-1.5
3	1.5-2
4	2-2.5
5	> 2.5

Baseline vegetation surveys also encompassed sampling of the herbaceous component (grasses only). The grass composition was sampled using the point technique along a line transect where the nearest plant within a radius of 30 cm to the point was noted (Kent, 2011). Five transects (temporarily marked), each 20 m in length, were carried out per plot.

#### 3.4.2 Brush packing and vegetation sampling

##### **Brush packing application**

The experiment was executed and established in November 2017 at the two study sites after bush clearing (at the experimental sites) and involved laying out all six treatments (see section 3.2) in the marked plots. As mentioned above, some of the treatments included brush packing application.

In preparation for brush packing, woody plants with a height less than 2.5 metres and a stem thickness of less than 15 cm were cleared manually and mechanically using handsaws, loppers and chain saws. After clearing, chemical control (i.e. the arboricide Kaput gel) was applied to stumps using a hand-spray technique ([www.environment.gov.za](http://www.environment.gov.za)). Maintenance was also carried out by spraying re-sprouts with the same arboricide.

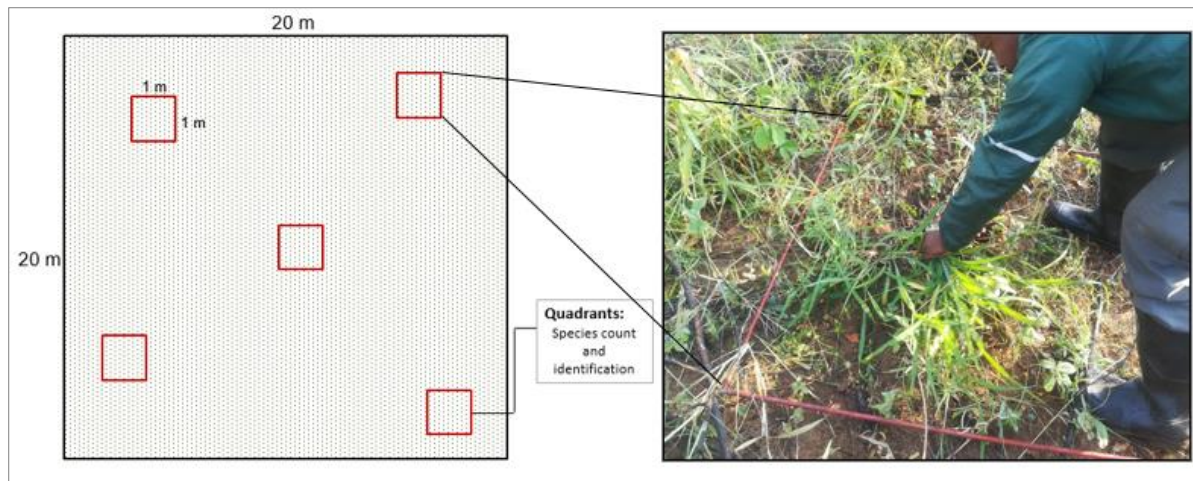
To implement brush packing, branches and twigs (dry without seeds) of the woody species that were cleared on the site were used to cover only those plots prescribed for the brush packing

treatments (C-BP, CRS-BP and CSRS-BP). The brush cover was evenly distributed within the plot to a height of approximately 1.5 m, and all cleared woody species were used for this purpose and not a specific type only, even though thorny branches are preferable.

### **Grass diversity and aboveground biomass sampling**

The baseline surveys conducted in February 2017 did not include aboveground sampling. Instead, aboveground biomass sampling took place during two seasons, namely during March of 2018 and 2019, and involved measuring the different grasses (annuals and perennials) using a 1 m<sup>2</sup> quadrant in five randomly delineated spots (subplots) within each of the 20 m x 20 m experimental plots (Kellner *et al.*, 2020). For this purpose, grass biomass was cut at 5 cm above ground (Nordh & Verwijst, 2004; Kellner *et al.*, 2020) from the quadrants and put in separate bags (marked with treatment identity). A conventional method following studies conducted by Ramoelo *et al.* (2012), Modungwa (2017), Naudé (2019) and Kellner *et al.* (2020) was used to dry all the collected grass samples in an oven at 67°C for 72 hours, after which the dry weight of the biomass was recorded.

To establish grass diversity, sampling was conducted in five 1 m<sup>2</sup> subplots (quadrants) within each of the 20 m x 20 m experimental plots. Individuals of each grass species were identified and counted to determine species richness and abundance (Figure 3.3) in accordance with the prescripts by Germishuizen and Meyer (2003) and Van Oudtshoorn (1999).



**Figure 3.3** Grass species count and identification in randomly placed 1 m<sup>2</sup> quadrants.

### 3.4.3 Costing restoration applications

The cost of setting up the restoration islands (plots) was calculated as a function of time persons spent at each plot (person-hours) following an example by Kimiti *et al.* (2017). The time needed for each plot was different since this depended on the work needed to be done. For example, no work was needed on the control plot (UC) thus the cost amounts to zero Rands. In some plots, more work was required, for example, the Clearing and soil disturbance and brush packing and re-seeding (CSRS-BP) thus resulting in more man hours and amounting to more money. After the above was taken into account, we firstly, recorded the time (hours) needed to clear the experimental plots by using manual techniques. For the restoration treatments that required brush packing Clearing and brush packing (C-BP), Clearing and brush packing and re-seeding (CRS-BP) and Clearing and soil disturbance and brush packing and re-seeding (CSRS-BP), the time needed for two people to gather branches and to set up the brush packing restoration treatments was recorded. The time taken at the three replicates for each treatment was then averaged and multiplied by two to derive an estimate of person-hours per treatment. The cost of labour was then estimated at the daily national minimum wage, i.e. ZAR160 (ZAR20 per hour for eight ordinary hours worked per day).

**Table 3.2** Cost of grass mixture used in a 400 m<sup>2</sup> plot for the re-seeded treatments.

<b>Grass species name</b>	<b>Quantity (kg)</b>	<b>Cost (R)</b>	<b>Cost per 200 g (R)</b>
<i>Eragrostis curvula</i>	25	3000,00	24,00
<i>Chloris gayana</i>	25	1450,00	11,60
<i>Digitaria eriantha</i>	25	1450,00	11,60
<i>Cynodon dactylon</i>	25	2500,00	20,00
<i>Cenchrus ciliaris</i>	20	1500,00	15,00
<b>Total cost of grass mixture per re-seeded treatments</b>			<b>82,20</b>

\*All prices are expressed in South African Rand (ZAR) as at May 2020

Seeing that using a chain saw to cut trees and shrubs is much faster, this method was used to clear the woody species at the D’Nyala study site. This cost was calculated separately and not included as a cost implication since this was a once-off expense and not necessarily for the construction of the plots. The plots were permanently marked using iron droppers, which was added as material cost rather than labour. Although the seeds were provided free of charge for this particular study, the cost of the seeds was calculated as per AGT Foods Africa’s pricing<sup>2</sup> as May 2020 (Table 3.2). Cost implications for the 25 kg seed for all replicates were calculated as the ratio of cost to the average area (m<sup>2</sup>) of each treatment (plot = 400 m<sup>2</sup>).

### **3.5 Evaluating and quantifying socio-economic benefits**

#### **3.5.1 Approach and strategy**

The objective of this chapter was to evaluate and quantify the socio-economic benefits community members derived as a result of their participation in the bush clearing and restoration activities described above. A qualitative, thematic content-analysis approach was used for this purpose.

Given that qualitative research is defined by the nature of the questions asked (Moon *et al.*, 2016; Petty *et al.*, 2012), the concept and methodologies were adapted during the design of this

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<sup>2</sup> Jacobs Street, Chamdor, Krugersdorp 1754, tel. +27 11 762 5261

study, and analysis and interpretation were associated with assumptions (inductive approach) made when collecting the data (Khagram *et al.*, 2010). This approach was followed because the study sought to arrive at an understanding of the benefits derived from bush clearing and restoration projects from the perspective of those who actually benefitted and, as pointed out by Hammersley (2007), because qualitative research provides a more comprehensive and better understanding of the relationships between people and the environment.

### 3.5.2 Participants

Although around 400 people from villages in Lephalale partook in the bush clearing and restoration activities, only 25 of those were directly involved at both the D’Nyala and Shongoane sites. Some of the participants were employed at D’Nyala, with some being part of the management and others were residents from Shongoane. Out of these, a sample of eight workers involved in bush clearing at Shongoane and six involved in bush clearing and management at D’Nyala were purposively selected to partake in the study.

Comprised of both males and females ranging between 22 and 55 years in age, most of the participants had at least six months’ experience of bush clearing and restoration projects and were previously unemployed or recently retrenched. In sum, the group consisted of six (6) general workers, two (2) group supervisors, two (2) nature conservationists, three (3) tax and revenue collectors and one (1) project coordinator. Thus, this group represented the entire skill-set and functionality within the project.

Purposive sampling was used because this part of the study aimed to target only those who were directly involved and who could provide a first-hand/informed account of how they benefited from the bush clearing and/or restoration projects (Johnson & Waterfield, 2004).

### 3.5.3 Procedure and ethical considerations

The North-West University's Research Ethics Regulatory Committee (NWU-00120-18-A1) granted permission for this part of the study. The principles and the regulations issued by the university's registered ethics committee regarding research where human subjects are involved were taken into consideration during all of the phases. Participation was voluntary and, having been assured that their identities would remain confidential, participants consented to partaking individually. Interviews lasting approximately 20 to 35 minutes were conducted at participants' place of work, in the field at the village or at the offices of the nature reserve. In all instances, participants could choose a venue and time that suited them best.

### 3.5.4 Data gathering

Data was gathered by means of semi-structured interviews after bush clearing and restoration projects had been completed. The questions asked during the interviews focused on participants' first-hand experiences as direct beneficiaries of these projects from the time of the inception of the project right up until completion. The three questions asked were similar in nature, with the exception that question 3 was adopted for the sake of site relevance (Table 3.3). Following the example by Oltmann (2016), interviews were conducted face-to-face, and participant's response to question 3 led to follow-up questions being asked where necessary in an attempt to gain a better understanding.

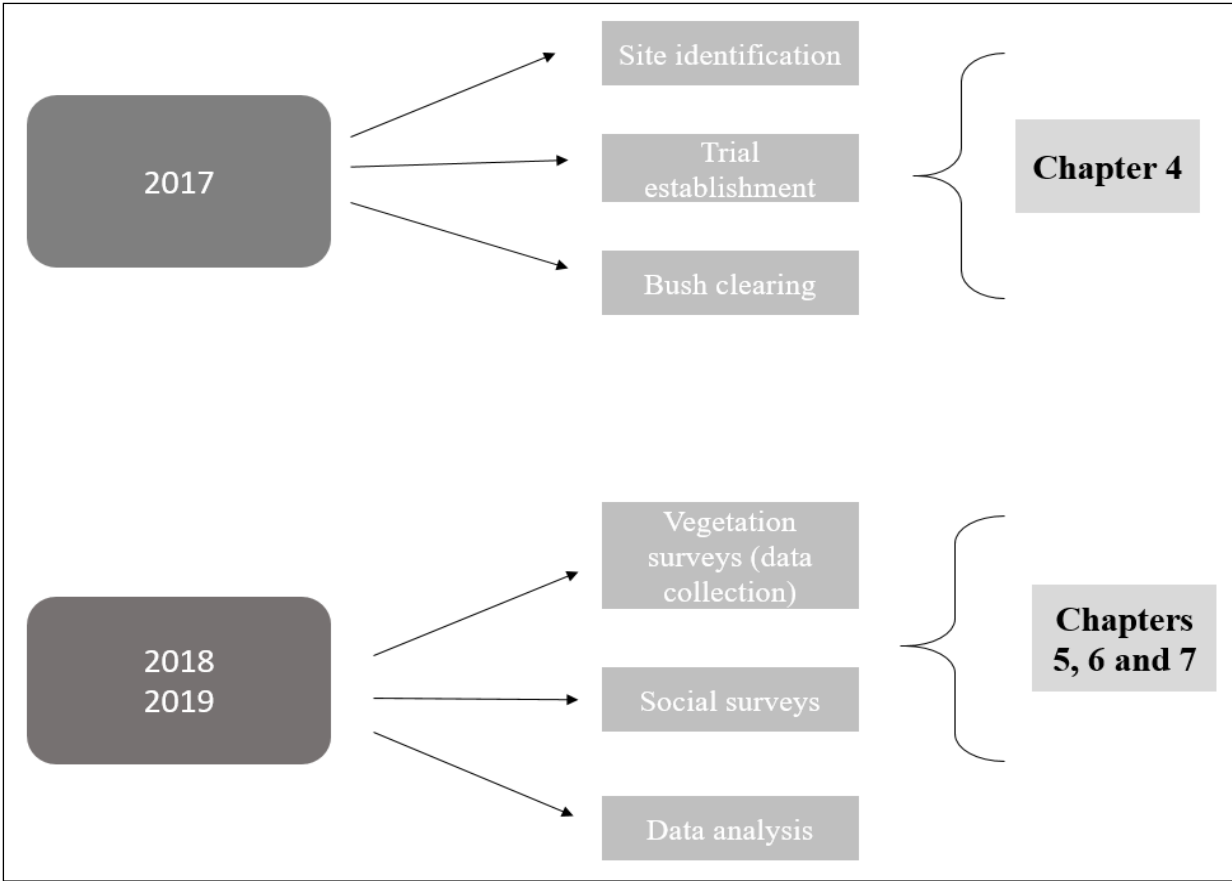
At D'Nyala, all participants were interviewed. However, at Shongoane only nine workers were interviewed because at that point, saturation had been reached. In other words, it was clear at this point that no new information will be discovered and that conducting further interviews would lead to redundancy in the data collected. In total, data was collected from 14 participants from the two sites. All interviews were recorded digitally.

**Table 3.3** Interview schedule for Shongoane village and D’Nyala Nature Reserve.

Topics	Questions
1. Bush clearing programme’s main benefit	Can you please describe what the main benefit that you received was and how you used the provision from participating in the bush clearing project? What was your involvement directly or indirectly in the bush clearing and restoration project?
2. Programme influences and the outcome	Can you describe how you experienced the programme: Did it help in any way, or not at all?
3. Possible lasting/sustainable impact of the bush clearing programme	(a) <u>Shongoane participants</u> : What changes, if any, have you seen in your well-being (included here are money for school fees, food and basic needs, etc.) as a result of participating in the bush clearing and restoration project? Is there anything that you gained from the project that will help you in future? Please describe if there are any.  (b) <u>D’Nyala participants</u> : What changes, if any, have you seen in the nature reserve (included here are generating money, enhancing game/nature viewing, etc.) as a result of participating in the bush clearing and restoration project?

### 3.6 Summary

A diagram summarising the various elements of this study from trial establishment in 2017 through to completion in 2019 is presented below as Figure 3.4.



**Figure 3.4** Diagram summarising the various elements of the study from 2017 to 2019.

## CHAPTER 4

### BASELINE STUDY: EVALUATION OF THE STATE OF BUSH ENCROACHMENT PRIOR TO BUSH CLEARING AT THE TWO STUDY SITES – COMMUNAL AREA AND NATURE RESERVE

#### 4.1 Introduction

Rangelands contribute around 30 billion ZAR to South Africa's economy annually (O'Connor & Van Wilgen, 2020), and the decline in vegetation cover and increase in bush encroachment pose a serious threat to these rangelands (Ward, 2005; O'Connor *et al.*, 2014). It is estimated that bush encroachment affects 25% of the country's rangelands (Hoffman & O'Connor, 1999; O'Connor *et al.*, 2014), resulting in a decline in biological diversity and a reduction in grazing capacity for domestic and wild herbivores (Ward, 2005; Belayneh & Tessema, 2017), hence the need for control methods.<sup>3</sup>

Bush encroachment in rangelands can occur as result of either mismanagement through anthropogenic influences or can be natural due to climate change (Hess *et al.*, 2015). Even though several studies have shown that bush encroachment is an environmental problem that predominantly affects savanna ecosystems (Hoffman & Ashwell, 2001; Ward, 2005; Angassa *et al.*, 2012; Kgosikoma *et al.*, 2012; O'Connor *et al.*, 2014; Dougill *et al.*, 2016; Mureva & Ward, 2016; Belayneh & Tessema, 2017), it is not yet clear whether this phenomenon is more prevalent in communal areas (unrestricted open grazing) or conservation areas (restricted closed grazing).

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<sup>3</sup> For a detailed description of the phenomenon bush encroachment, the impact it has on ecosystem services and control methods see Chapter 1.

The composition of woody species has an impact on biodiversity patterns, irrespective of land-use type and, for this reason, conducting land assessments is warranted in an attempt to understand which restorations activities would be most appropriate to restore degraded rangelands. For this reason, a baseline study was carried out to evaluate the status of bush encroachment (woody density and composition) before bush clearing and brush packing application at the two sites, i.e. D’Nyala Nature Reserve and Shongoane village.

## **4.2. Materials and methods**

### **4.2.1 Woody composition**

Data on woody plant species was collected in February 2017 only, in other words before bush clearing commenced at the D’Nyala and Shongoane study sites (see study area map in Chapter 2). By applying the belt transect sampling technique, baseline sampling was conducted in marked plots that were demarcated prior to the start of the experiment. (See Chapter 3 sections 3.4.1 for a detailed description of the sampling technique that was used to obtain the results reported in section 4.3.).

Microsoft Excel version 2016 was used to analyse the data.

## **4.3 Results**

### **4.3.1 Woody species density and growth forms at the two study sites**

As stated earlier, the two study sites represent different land-use types: Unrestricted open grazing (i.e. Shongoane,communal area) and restricted closed grazing (i.e. D’Nyala, a nature reserve). The density of woody species (including trees and shrubs) at D’Nyala was 2,045/7 500 m<sup>2</sup>. Out of the 2,045 woody species, 12 individuals were identified (Table 4.2). In contrast, the density of woody species at Shongoane was 1,188/7 500 m<sup>2</sup> and ten (10) different woody species were identified (Table 4.3). Thus, the density of woody species was higher at the

D’Nyala site than at the Shongoane site. These observations showed that the D’Nyala study site was more bush encroached than Shongoane.

**Table 4.1** Woody species identity and density (individuals/7 500 m<sup>2</sup>) per height class at D’Nyala at the time of the baseline survey.

Name of woody species	*Height class					Total
	1	2	3	4	5	
<i>Asparagus laricinus</i>	1	5	0	1	0	7
<i>Combretum imberbe</i>	12	18	32	25	32	119
<i>Combretum zeyheri</i>	42	60	61	35	86	284
<i>Dichrostachys cinerea</i>	62	51	84	120	221	538
<i>Dombeya rotundifolia</i>	6	11	13	27	22	79
<i>Grewia bicolor</i>	0	3	8	10	4	25
<i>Grewia flava</i>	6	34	87	157	111	395
<i>Grewia flavescens</i>	10	40	74	90	40	254
<i>Sclerocarya birrea</i>	7	8	9	18	12	54
<i>Senegalia mellifera</i>	0	3	8	10	9	30
<i>Tarchonanthus camphoratus</i>	3	12	28	13	17	73
<i>Vachellia tortilis</i>	22	19	35	31	80	187
<b>Total density</b>						<b>2045</b>

\*Height classes: **1** = ≤ 1 m, **2** ≥ 1-1.5 m; **3** ≥ 1.5-2 m; **4** ≥ 2-2.5 m; **5** = > 2.5 m

**Table 4.2** Woody species identified and density (individuals/7 500 m<sup>2</sup>) per height class at Shongoane at the time of the baseline survey.

Name of woody species	*Height class					Total
	1	2	3	4	5	
<i>Asparagus laricinus</i>	38	9	6	4	0	57
<i>Combretum imberbe</i>	0	1	2	5	16	24
<i>Dichrostachys cinerea</i>	1	5	17	13	5	41
<i>Dombeya rotundifolia</i>	0	0	3	0	0	3
<i>Grewia flava</i>	8	27	86	84	24	229
<i>Lantana camara</i>	3	10	10	4	2	29
<i>Senegalia mellifera</i>	110	113	139	60	115	537
<i>Tarchonanthus camphoratus</i>	0	0	3	3	0	6
<i>Vachellia tortilis</i>	44	58	87	46	11	246
<i>Ziziphus mucronata</i>	7	3	2	2	2	16
<b>Total density</b>						<b>1188</b>

\*Height classes: **1** = ≤ 1 m, **2** ≥ 1-1.5 m; **3** ≥ 1.5-2 m; **4** ≥ 2-2.5 m; **5** = > 2.5 m

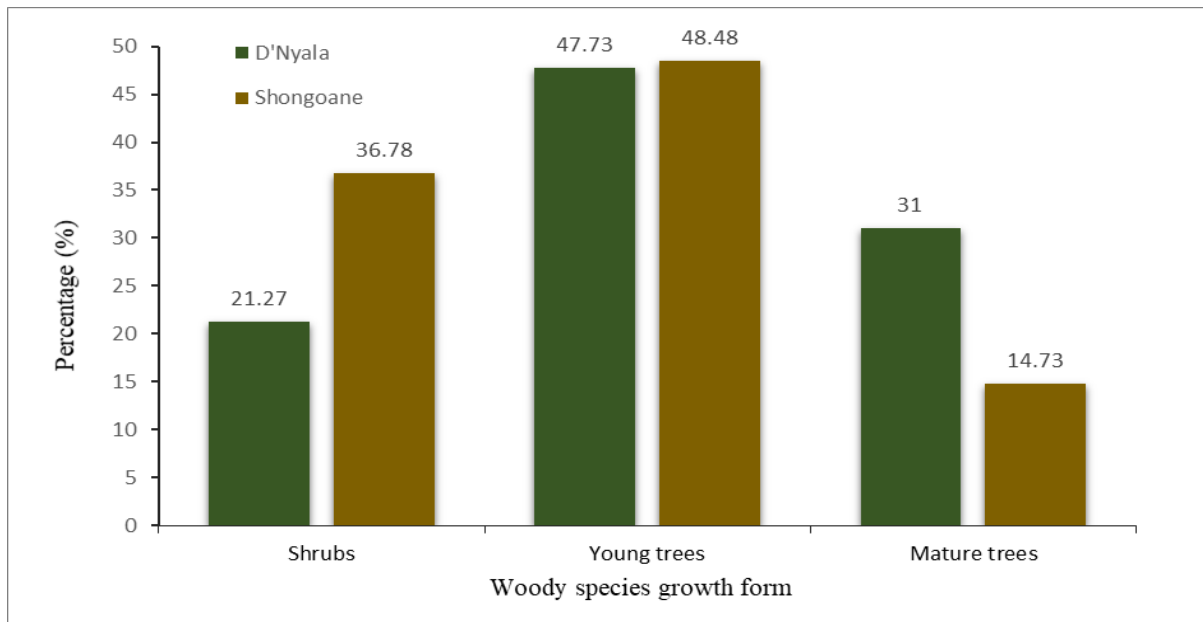
Some woody species individuals, as listed below, were common (occurred) to both sites:

1. *Asparagus larycinus*
2. *Combretum imberbe*
3. *Dichrostachys cinerea*
4. *Dombeya rotundifolia*
5. *Grewia flava*
6. *Senegalia mellifera*
7. *Tarchonanthus camphoratus*
8. *Ziziphus mucronata*

Even though the sites had eight woody species in common, not all were dominating encroachers at either site. *Grewia flava* and *Vachellia tortilis* were the only two woody species that were amongst the dominant encroachers at both sites during the baseline survey. This suggests a low level of similarity between the two sites.

Some woody species contributed less to woody cover per area (7 500 m<sup>2</sup>) at the two sites. Woody species with a count below 20 per experimental area (7 500 m<sup>2</sup>), irrespective of the height class, were regarded as least/minor occurring encroachers at the sites. *Asparagus larycinus* (seven individuals) was the only encroacher having less than 20 counts at the D’Nyala site, while *Tarchonanthus camphoratus* (six individuals), *Dombeya rotundifolia* (three individuals) and *Ziziphus mucronata* (16 individuals) were the least occurring encroachers at Shongoane.

The growth form of woody species at D’Nyala stood at 31% for height class 5 (mature trees), at roughly 48% for height class 3 and 4(saplings) and at roughly 21% for height class 1 and 2 (shrubs). At Shongoane, these percentages stood at roughly 15% for mature trees, roughly 48% for saplings and roughly 37% for shrubs (Figure 4.1). Furthermore, there was a high percentage of saplings recorded at both the D’Nyala and Shongoane sites (47.73% and 48.48%. respectively).

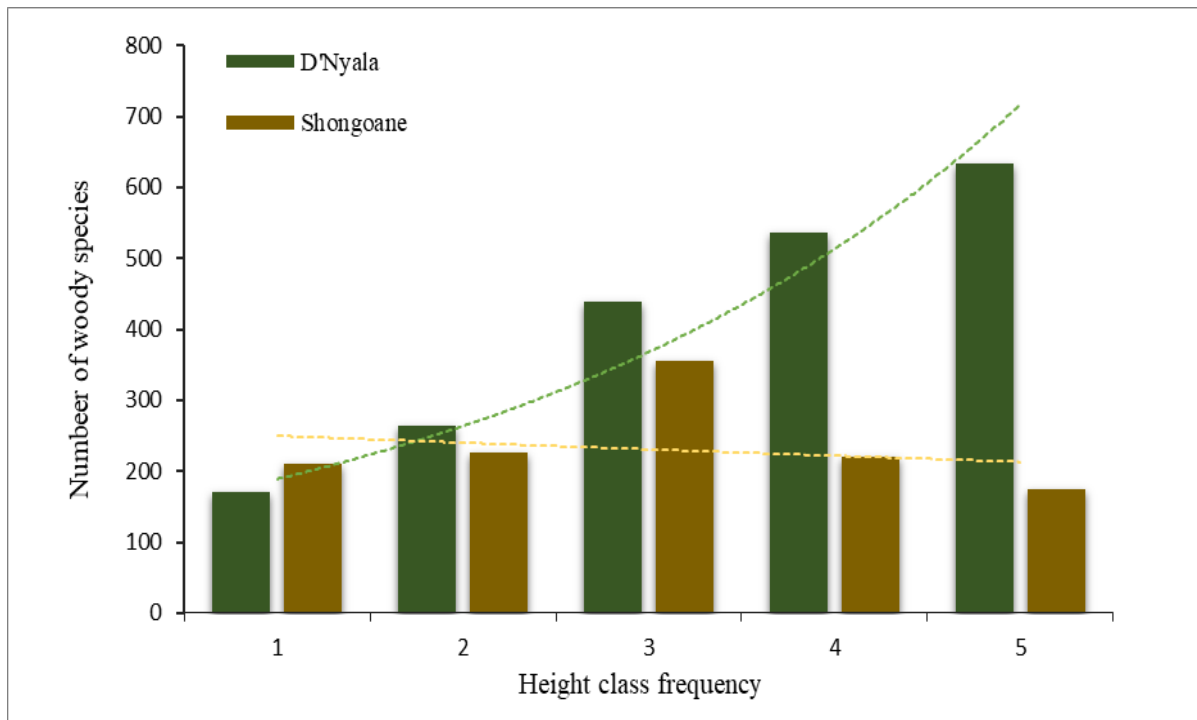


**Figure 4.1** Growth forms of woody species (i.e. mature trees, shrubs and sapling) at D’Nyala and Shongoane expressed as percentages.

\*Woody plants with a height of 2.5 m were classed as mature trees, those between 1.5 and 2.5 m as saplings and those with a height below 1.5 m as shrubs

#### 4.3.2 Density of woody species at different height classes at the two study sites

Woody density at different height-class frequencies at D’Nyala and Shongoane is illustrated in Figure 4.2. More shrubs (211 individuals/7 500 m<sup>2</sup>) below the height of 1 m occurred at Shongoane, while D’Nyala had more mature trees (634 individuals/7 500 m<sup>2</sup>) compared to Shongoane where only 175 individuals/7 500 m<sup>2</sup> were recorded. In addition, D’Nyala had more woody species resorting under height class 5 (> 2.5 m), while Shongoane had more woody species resorting under height class 3 (1.5-2 m).



**Figure 4.2** Woody species density at different height classes at D’Nyala and Shongoane.

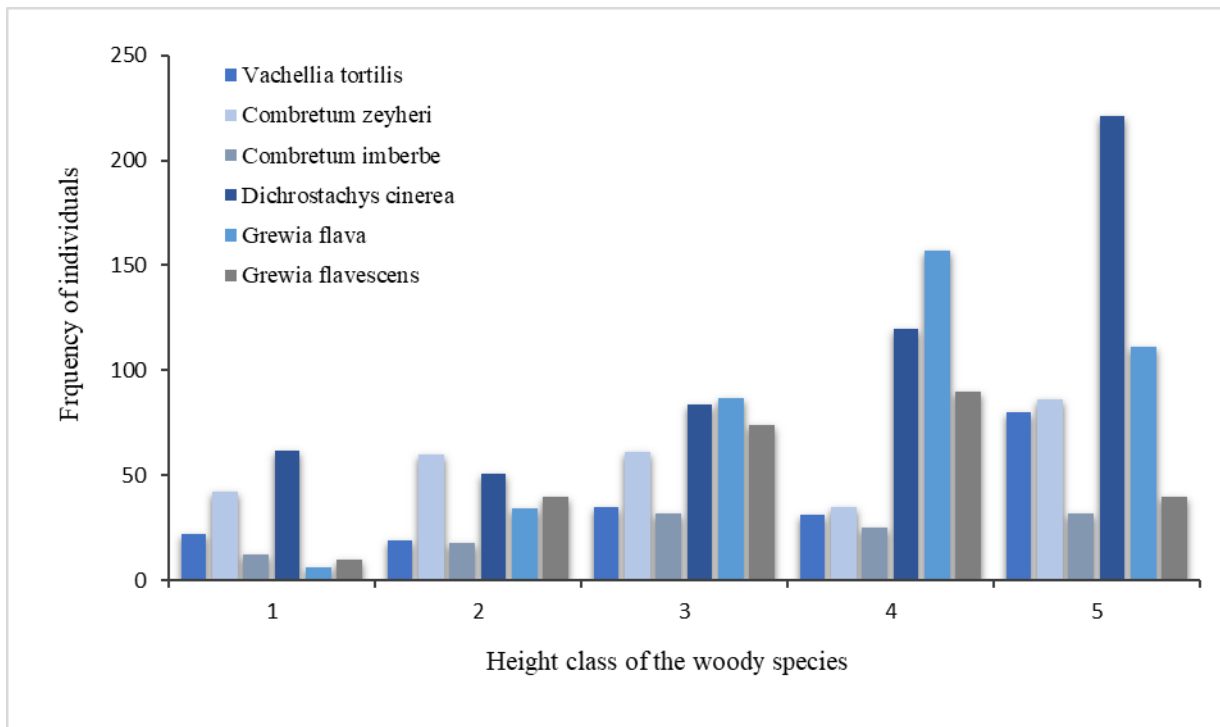
\*Height classes: **1** = ≤ 1 m, **2** = 1-1.5 m; **3** = 1.5-2 m; **4** = 2-2.5 m; **5** = > 2.5 m

#### 4.3.2.1 Density of dominant woody species in different height classes at D’Nyala and Shongoane

Major woody species that occurred at the sites were defined based on the total count of the woody species occurrence per area (7 500 m<sup>2</sup>).

In ascending order, the D’Nyala study site was dominated by *Combretum imberbe* (119 individuals/7 500 m<sup>2</sup>), *Vachellia tortilis* (187 individuals/7 500 m<sup>2</sup>), *Combretum zeyheri* (284 individuals/7 500 m<sup>2</sup>), *Grewia flava* (395 individuals/7 500 m<sup>2</sup>), *Grewia flavescens* (254 individuals/7 500 m<sup>2</sup>) and *Dichrostachys cinerea* (538 individuals/7 500 m<sup>2</sup>) (Figure 4.3).

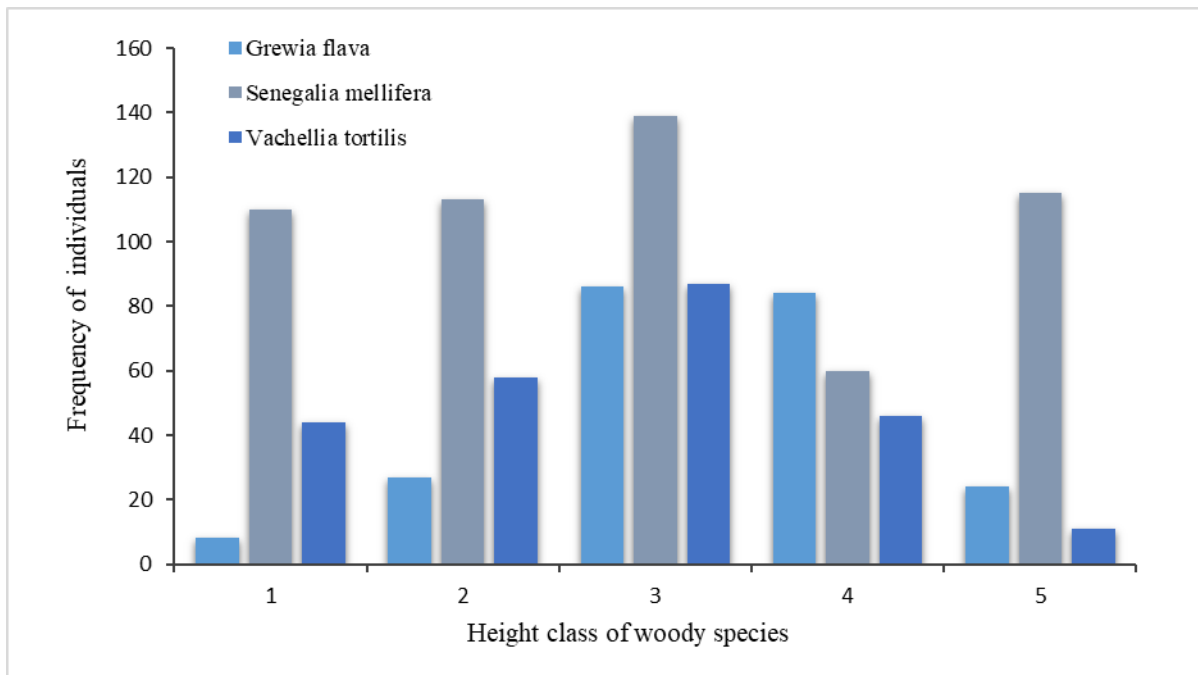
These woody species accounted for 86.89% of the total woody density (1,777 individuals/7 500 m<sup>2</sup>) in the experimental area. *Dichrostachys cinerea* contributed the most density compared to all other species, with the highest density recorded in height class 5 (> 2.5 m) (Figure 4.3). Comparatively, the density of *Combretum imberbe* was evenly distributed across all five-height classes (Figure 4.3).



**Figure 4.3** Density of dominant woody species according to different height classes at D’Nyala.

\*Height classes: **1** =  $\leq 1$  m, **2** = 1-1.5 m; **3** = 1.5-2 m; **4** = 2-2.5 m; **5** =  $>2.5$  m

The Shongoane study site was dominated by *Grewia flava* (229 individuals/7 500 m<sup>2</sup>), *Vachellia tortilis* (246 individuals/7 500 m<sup>2</sup>) and *Senegalia mellifera* (537 individuals/7 500 m<sup>2</sup>) which accounted for 85.19% of the total woody density (1,012 individuals/7 500 m<sup>2</sup>) (Figure 4.4). *Senegalia mellifera* contributed the most density, with the woody species having an even distribution across most height classes (i.e. 1, 2, 3 and 5). The lowest density was recorded in height class 4, with 60 species counted (see Table 4.2). Of the three dominant woody species, *Vachellia tortilis* had the lowest density in height class 5.



**Figure 4.4** Density of dominant woody species according to different height classes at Shongoane.

\*Height classes: **1** =  $\leq 1$  m; **2** = 1-1.5 m; **3** = 1.5-2 m; **4** = 2-2.5 m; **5** =  $>2.5$  m

#### 4.4. Discussion and conclusion

As found by Kgosikoma *et al.* (2012) and Lesoli *et al.* (2013), this study, too, revealed that even though land use does have an effect on the woody composition of rangelands, determining the manner and occurrence of bush encroachment in any given study area is not all that simple. In this study, huge differences were recorded in woody density between the different height classes and the overall diversity of woody species at both study sites before bush clearing.

Nevertheless, more woody species were recorded at D’Nyala (restricted closed grazing) than Shongoane (open unrestricted grazing). Furthermore, the difference between common and dominating woody species occurring at the two sites suggests that the level of similarity between the communal area and the nature reserve is low (Nacoulma *et al.*, 2011). A higher woody density at height class 5 ( $> 2.5$  m) was recorded at D’Nyala, with a much lower woody density recorded at Shongoane for the same height class. The curve reflected in Figure 4.2

suggests either poor reproduction or recruitment of woody species at Shongoane. According to Atsbha *et al.* (2019), a decrease in woody density in higher height classes for this land-use type (i.e. open unrestricted grazing) could also be ascribed to the surrounding community's preference to cut/select woody species that are taller for own consumption as fuel or for use as material to construct kraals. The latter hypothesis is supported by Tabuti *et al.* (2003), Mengistu *et al.* (2005) and Russell and Ward (2016) who found that community members tend to harvest woody species with a height in excess of 2.5 m (or > 30 cm stem diameter) for use as firewood.

In contrast, woody species recorded at D'Nyala showed an exponential increase at higher height classes (Figure 4.2) which can likely be attributed to the conservation status of this site (i.e. a nature reserve). This hypothesis is supported by Atsbha *et al.* (2019) who hold that nature reserves play a role in protecting biodiversity since these reserves protect species that would otherwise be frequently used in communal areas.

Even though the D'Nyala study site was more encroached (higher density with more individuals), the status of the area can be considered 'good' since the density of mature trees (2.5 m) was higher than the density of saplings (1.5-2.5 m) and shrubs (1.5 m). Unless the shift is a natural successional shift or due to climate change, proper planning and management over the long term will still be required to prevent a shift from natural vegetation to undesirable forestland, resulting in excessive land degradation.

The findings revealed that land use type has an impact on biodiversity and vegetation structure patterns. Thus, at each site the relevant management appropriate for the land use, should be considered.

## CHAPTER 5

### GRASS SPECIES DIVERSITY RESPONSE TO BRUSH PACKING UNDER DIFFERENT LAND-USE TYPES IN SEMI-ARID RANGELANDS OF SOUTH AFRICA

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## **Abstract**

Most semi-arid savannas in South Africa are degraded indicated by bush encroachment thus, causing a decline in biological diversity and grazing capacity for both wild, and domestic herbivores. We tested the effect of six different restoration treatments consisting of combinations of bush clearing, brush packing, soil disturbance, and re-seeding. Grass diversity was measured in two land use types (communal and conservation area) over three years (2017, 2018 and 2019) on 18 randomly distributed plots within 3 blocks. We further assessed the effect of brush packing versus non-brush packing on rangeland vegetation by analysing indicator species and listing their ecological status to evaluate the level of degradation between these restoration treatments. Lastly, we analysed the differences in the structure of grass species communities in the brush-packed restoration plots versus the non-brush packed plots. The diversity indices showed that grass diversity was lowest in the un-cleared treatment compared to those which were bush cleared and brush packed at both sites. Grass richness only improved at the communal site, while the treatments barely changed evenness. Although the species abundance results were variable, improvement was noticeable in 2018 and 2019 at both sites. A higher number of decreaser and perennial grass species were identified in the brush packing treatments particularly in the communal area. The results also showed that the grass composition between the two sites was dissimilar. The results suggest that brush packing promotes grass diversity under high grazing pressure, in communal areas compared to conservation areas.

**Keywords:** Bush encroachment, grass biodiversity, land-use, overgrazing, restoration

## 5.1 Introduction

A degraded land is an area that has reduced biological productivity and experiences a long-term loss of ecosystem functions (Ma & Zhao, 1994; Hoffman & Ashwell, 2001; Mekuria *et al.*, 2007; Hoffmann *et al.*, 2014; Blaikie & Brookfield, 2015). Several studies conducted in the course of the past two decades have revealed that the world's terrestrial areas are showing signs of degradation and that this state of affairs is exacerbated as a result of the heightened pressure exerted by human settlements (Adepoju, 2003; Bai *et al.*, 2008; Vlek *et al.*, 2010; Bai *et al.*, 2011; Nkonya *et al.*, 2011; Le *et al.*, 2016). Land degradation has become a global issue as it poses a serious threat to the livelihoods of 1.5 billion people worldwide, especially those who depend on livestock and wildlife (Kimiti *et al.*, 2017; Yirdaw *et al.*, 2017).

Approximately 20% of arid and semi-arid rangelands globally have been classified as degraded, with 70% of land degradation occurring in sub-Saharan Africa (Kimiti *et al.*, 2017). In the rule, degradation of drylands is described as a loss of perennial grass cover that results in bare ground patches (Dregne, 2002; McCluney *et al.*, 2012). Given their unique biodiversity and the fact that drylands support the livelihoods of approximately a third of the world's population by providing essential ecosystem services such as forage for livestock and wildlife (MEA, 2005; Safriel *et al.*, 2005), degradation of drylands poses a serious threat to ecosystems' biodiversity and human well-being, particularly in developing countries (Kimiti *et al.*, 2017; Turpie *et al.*, 2017).

With an average rainfall ranging between 400-500 mm annually, South Africa ranks amongst the top-40 driest countries in the world (Meissner *et al.*, 2018) and, given that rangelands cover more than 70% of South Africa's land surface. The combination of land degradation and water scarcity is of major concern (O'Connor *et al.*, 2014; O'Connor & Van Wilgen, 2020). Most semi-arid savannas in South Africa have degraded due to bush encroachment (O'Connor & Van Wilgen, 2020), a phenomenon defined by Ward (2005) as "the suppression of palatable

grasses and herbs by encroaching woody species often unpalatable to domestic livestock”. Variations in rainfall and overgrazing, or a combination of the two, impact the degree of bush encroachment in semi-arid areas (Mucina & Rutherford, 2006; Turpie *et al.*, 2017), with fire suppression and a reduction in soil moisture and nutrients acting as exacerbating factors (Van Langevelde *et al.*, 2003; Ward, 2005; Van Auken, 2009; Belayneh & Tessema, 2017).

Overgrazing occurs when livestock and other grazers (e.g. wildlife) consume vegetative biomass at a rate that exceeds the vegetation's ability to recover, thereby reducing the land's productive capacity mostly as a result of exposed soil (Angerer *et al.*, 2016) since continuous high grazing pressure halts the growth of the grass layer (Angassa, 2005). This practice leads to land degradation because biodiversity is reduced, resulting in altered biological communities and ecosystem functions and structures that promote encroachment by woody species (Rosales & Livinets, 2005; Eldridge *et al.*, 2011; Eldridge & Soliveres, 2015; Reid *et al.*, 2018; Wilson *et al.*, 2020).

The impact large herbivores has on the soil is a complex matter since grazing not only alters the soil physically but also impacts its chemical and biological properties, all of which can intensify bush encroachment (Dombos, 2001). Although difficult to distinguish, most researchers are of the opinion that three mechanisms underpin grazing: defoliation, fertilisation and trampling (Dombos, 2001; Sørensen *et al.*, 2009; Lezama & Paruelo, 2016). Defoliation, i.e. the removal of plant tissue, affects the quantity of carbon that enters the soil, thus causing a reduction in the quality of soil organic matter and a depletion in the amount of carbon supplied to the soil (Sankaran & Augustine, 2004; Sørensen *et al.*, 2009). Fertilisation occurs through the nutrients in urine and dung which stimulate soil microbial activity, but this mechanism only affects a small portion of the grazed area (Augustine & Frank, 2001). Of the three mechanisms, trampling is regarded as the major cause of alterations in the soil's physical properties (Gamoun *et al.*, 2010; Dunne *et al.*, 2011; McManus *et al.*, 2018) since it results in the destruction of

vegetation and soil crusts, increases soil compaction and soil surface temperatures, and decreases the infiltration and retention of moisture and nutrients as a result of reduced soil pores (McManus *et al.*, 2018). In combination, all three mechanisms can have a heavy impact on ecosystems' vegetation structure, especially grass communities (Gamoun *et al.*, 2010).

Globally, diminishing land use as a result of overgrazing in most arid and semi-arid rangelands is of great concern and calls for mitigating practices (Van der Merwe & Kellner, 1999). The underlying principle of dryland restoration is based on improving the soil structure, increasing water infiltration, shifting the competition between undesired woody species and grasses and, eventually, restoring the affected area's biodiversity and ecosystem functioning (Tongway & Ludwig, 1996; Scholes & Archer, 1997; Smit & Rethman, 1999; Clout & Williams, 2009; Donzelli *et al.*, 2013). As an alternative, enforcing grazing exclusion could be considered, but such an approach to land management would be extremely difficult to enforce in communal areas (García *et al.*, 2013; Lesoli *et al.*, 2013; Listopad *et al.*, 2018).

Research has shown that bush-control methods (e.g. clearing of woody plants) can improve the condition of the land and help to re-establish the grass layer. (Kellner, 2008; Modungwa, 2017; Mokgotsi, 2018; Naudé, 2019). However, to discourage livestock and/or wildlife from grazing on newly established grass seedlings, brush packing (thorny branches) in extremely degraded bare patched areas are recommended (Barac *et al.*, 2001; Harmse, 2013; Kimiti *et al.*, 2017; Modungwa, 2017; Naudé, 2019). Brush packing is mainly used as an above-ground obstruction and involves covering bare patches of land to allow grass seedlings to establish without the threat of being grazed by livestock or wildlife (Kellner, 2008; Kellner, 2013; Modungwa, 2017; Kellner *et al.*, 2020). A study conducted by Tongway and Ludwig (2011) in Australian rangelands found that simple brush packing promoted the establishment and growth of perennial grasses and increased the productive potential of soils considerably.

The ability to manage and preserve ecosystems and to improve biodiversity is closely related to using low-intensity, low-input management techniques (Kimiti *et al.*, 2017; Stafford *et al.*, 2017) such as brush packing. As much as brush packing has widely been accepted as a technique that can help to create suitable microenvironments that can facilitate the re-establishment of the grass layer, it is not yet clear how this restoration technique affects grass diversity, particularly in ecosystems that are highly grazed and where high structural diversity is evident.

This study set out to test the effectiveness of six different restoration techniques (ranging from brush packing, soil disturbed and re-seeded treatments to treatments without bush control) on grass diversity in a bush-cleared, overgrazed communal area and wildlife conservation area. In evaluating the effectiveness of these different techniques, the following objectives were tested (1) will grass species diversity differ between the communal and conservation area before bush clearing (2017) and to test the effect of treatments after bush clearing on grass species diversity (2018 and 2019); (2) to assess the effect of brush packing versus non-brush packing on rangeland vegetation by looking at indicator species and listing their ecological status in order to evaluate the level of degradation between these restoration techniques and land use types and; (3) to analyse the differences in the structure of grass species communities in the brush-packed restoration plots versus the non-brush packed plots in both the communal and conservation area.

## **5.2 Materials and methods**

### **5.2.1 Surveys conducted to establish grass species diversity**

Initial data collection (baseline vegetation surveys) was conducted in February 2017 prior to the clearing of woody species. In the years 2018 and 2019, following on the application of restoration techniques (treatments), vegetation surveys were conducted to assess the effect of

the restoration techniques, focusing in particular on the effect brush packing versus non-brush packing had on grass biodiversity. Please refer to Chapter 3 (Materials and Methods, section 3.4.1 and 3.4.2) for a detailed description of the sampling method performed to obtain the results reported in section 5.5.

### 5.3 Diversity measures

Species diversity refers to the number of different species that make up a given community. Each plot was characterised according to varying measures of diversity (i.e. species richness and abundance), Shannon's and Simpson's diversity index (2003) and Pielou's evenness. Species richness (*S*) is the number of different grass species and abundance (*A*) is the total count of grass species as found in the five subplots, each measuring one square metre (Ricotta & Avena, 2003). This however, denotes the local alpha diversity (an estimate of grasses in each plot within the five quadrants) and does not represent the diversity of the whole area in totality. Species evenness refers to how close in greater or less variable each grass species in an environment is. This is independent of species richness and sensitive to both rare and common species and species abundance (number of grass individuals).

Shannon diversity index was calculated as:

$$H' = - \sum_{i=1}^S p_i \ln p_i$$

Where *H* = Shannon diversity index. *pi* is the proportion of individuals found in species (*i*). We can estimate this proportion as *pi* = *ni*/*n*, where *ni* is the number of individuals in species *i* and *n* is the total number of individuals in the community for a well-sampled community.

Evenness was calculated as:

$$J = \frac{H}{\log(S)}$$

where *H* is the Shannon diversity index and *S* is species richness.

Simpson's diversity index was calculated as follows:

$$D = 1 - \sum_{i=1}^S \frac{n_i(n_i - 1)}{n(n - 1)}$$

where  $n_i$  represents the number of grass individuals of a species ( $i$ ), and  $n$  represents the total number of individuals.  $D$  is 0, if all individuals belong to the same species, implying that there is no diversity at all. The greater the diversity, the more  $D$  approaches 1. Hence, this index equals the probability that two grass individuals taken at random from a sample represent the same species (Ricotta & Avena, 2003).

## 5.4 Statistical analysis

### 5.4.1 Grass species' richness, evenness and abundance

The effects of the treatments on all response variables except for abundance, were tested using linear mixed-models with restricted maximum likelihood (REML). P-values were derived using Kenward-Roger approximations for degrees of freedom (Chawla *et al.*, 2014). For grass species abundance, generalized linear mixed-models with a poisson distribution were fitted. Maximal models included treatment, year and the interaction of both factors as fixed factors. Individual plots were included in the models as random factors to correct for repeatedly sampling the same plots every different year. Final models were derived via stepwise backwards model selection excluding only fixed effect based on the models' AIC (Akaike information criterion) values. Each study site was tested separately. For significant effects, pair-wise differences between group means were calculated using Tukey-HSD *post-hoc* tests to compare the differences between treatments and years and treatments within each year in case of significant interactions.

#### 5.4.2 Indicator species and ecological status

To determine which species can be used as indicators, the study sites were compared in 2017 with the added effect of brush packing versus non-brush packing in the years 2018 and 2019. The indicator value (IndVal) index was used to measure the association between a species and a site group. Following the method proposed by Dufrière and Legendre (1997), the indicator value between species and each site group was first calculated where after the group corresponding to the highest association value was identified. The statistical significance of this relationship was then tested by using a permutation test.

The ecological status of the grass species was listed as per occurrence within the 18 plots per study site. According to Foran *et al.* (1978) and Trollope (1990), plants species can be classified as either increasers or decreasers based on changes in their relative abundance in the presence or absence of grazing, and this classification is indicative of the condition of rangelands. Increaser species broadly resort under three types: increaser I, increaser II and increaser III (Trollope, 1990). Increaser I species dominate in poor veld and increase in abundance with under-utilisation (e.g. conserved areas) and understocking, increaser II species increase in abundance when the rangeland is overgrazed, and increaser III species dominate rangelands that are selectively grazed (Trollope, 1990; Van Oudtshoorn, 1999). On the other hand, decreaser species dominate in good veld but decrease when the veld is mismanaged (Trollope, 1990). The palatability of grasses were identified in accordance to Guide to grasses of South Africa (Van Oudtshoorn, 1999).

#### 5.4.3 Grass species' community structure

We computed the Bray–Curtis measure of dissimilarity to assess grass composition difference amongst brush packing restoration plots versus non-brush packing plots (2018 and 2019 seasons) in relation to the communal and conservation areas using Bray–Curtis-based nonmetric multidimensional scaling (NMDS). Bray-Curtis distances vary between zero (=

similar grass species composition present at two plots) and 1 (= no similar grass species occurring at two plots). The analysis was executed with 9999 permutations with a stress of 0.2199332. Nonmetric Multidimensional Scaling (NMDS) scores for each plot were plotted in ordination space, and 95% confidence ellipses associated with the scores were calculated. NMDS ordinations are based on grass species and environmental space (land-use type and brush packing). Similar species are clustered closer together and dissimilar species further apart on the ordination plot (Kent, 2011).

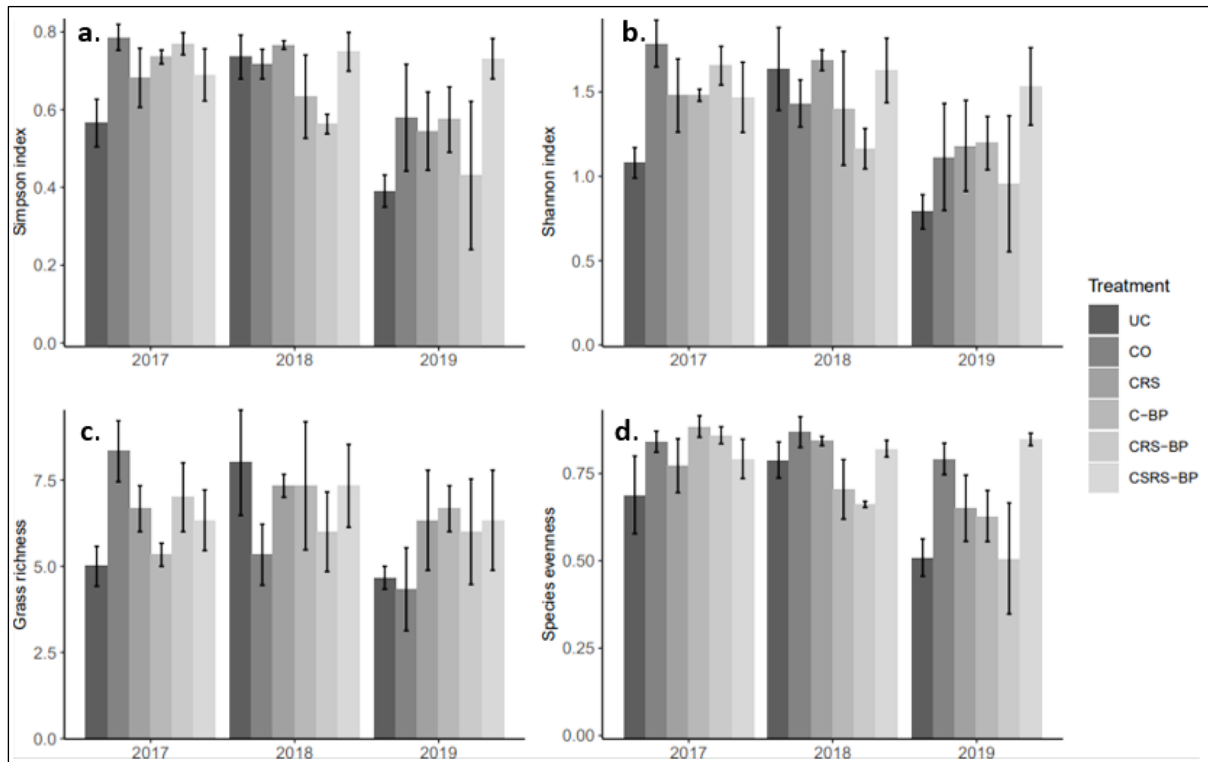
All analyses were performed with the aid of R Version 4.0.0 (R Core Team, 2020) and made use of the “vegan” package for diversity analysis and community ordination (Oksanen *et al.*, 2019) and the “indicspecies” package for indicator species analysis (De Cáceres & Legendre, 2009). The assumptions (homoscedasticity, normality, etc.) for linear mixed models were tested visually. The significance level of all test statistics was  $p < 0.05$ .

## 5.5 Results

### 5.5.1 Grass species diversity (richness, evenness and abundance) at the different land-use types

The grass diversity, represented by the Simpson and Shannon index, at the D’Nyala study site (Figure 5.1 a. and b.) showed a significant difference ( $F_{[2,34]} = 4.09$ ,  $p < 0.05$  and  $F_{[2,34]} = 5.62$ ,  $p < 0.01$ , respectively for the Simpson and Shannon indices) between the years. The 2019 diversity was lower compared to the years 2017 and 2018. Diversity appeared lowest in the UC treatment in the years 2017 and 2019. The indices seemed not to be affected by the restoration treatments ( $p > 0.05$ ). Grass species richness was also not significantly affected by the restoration treatments or year and the interaction of both treatments and year ( $p > 0.05$ ) (Figure 5.1 c.). However, by observation from the graph, grass richness decreased in 2019 compared to the 2017 season. Grass species evenness was only affected by year ( $F_{[2,34]} = 6.79$ ,  $p = 0.03$ )

(Figure 5.1 d.). The decline in evenness between 2017 and 2019 pair was higher ( $t = 3.44$ ,  $p = 0.004$ ) than between 2018 and 2019 pair ( $t = 2.87$ ,  $p = 0.01$ ). Overall, species evenness was highest in the CSRS-BP treatment in 2019 compared to the other treatments.



**Figure 5.1** Treatments' effect according to Simpson index (a), Shannon index (b), grass species richness (c) and evenness (d) over the years (2017 pre-bush clearing, 2018 and 2019 post-clearing and restoration application) at the D'Nyala Nature Reserve.

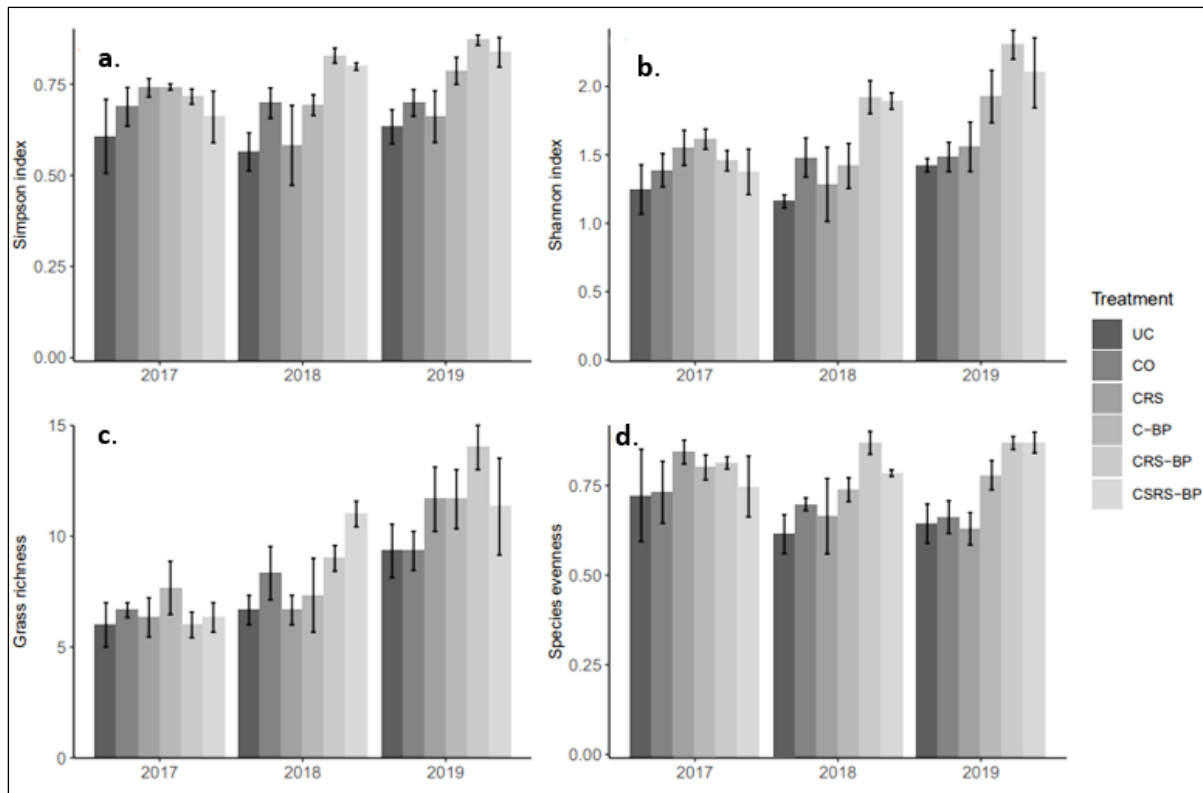
Treatment description: No clearing (control plot) (UC), clearing only (CO), clearing and re-seeding (CRS), clearing and brush packing (C-BP), clearing and brush packing and re-seeding (CRS-BP), and clearing and soil disturbance and brush packing and re-seeding (CSRS-BP)

Error bars represent  $\pm$  standard error of mean

Figure 5.2 illustrates the results for the Shongoane study site. Here, grass diversity represented by the Simpson and Shannon indices (Figure 5.2 a. and b.) showed a significant difference for treatment ( $F_{[5,12]} = 7.22$ ,  $p < 0.01$ ,  $F_{[5,12]} = 5.60$ ,  $p < 0.01$ ) and year ( $F_{[2,24]} = 9.58$ ,  $p < 0.001$ ,  $F_{[2,24]} = 11.08$ ,  $p < 0.001$ ) and the interaction of treatment and year ( $F_{[10,24]} = 3.52$ ,  $p < , F_{[10,24]} = 2.27$ ,  $p < 0.05$ ). The Simpson and Shannon index showed that grass diversity was higher in the treatments with brush packing versus those without (for example, the comparison

between CRS-BP and UC was highly significant ( $p < 0.001$ ) in 2019). Grass species richness was only affected by the year ( $F_{[2,34]} = 28.72$ ,  $p < 0.001$ ). Grass species richness was highest in the year 2019 (11.22 species) compared to the other years (6.50 and 8.17 species for 2017 and 2018, respectively). Comparatively, richness was lowest in 2017 before restoration treatments were applied (Figure 5.2 c.). Although not significant, species richness showed the same trend as the diversity indices, i.e. higher mean values in brush packed treatments compared to non-brush packed treatments. Grass species evenness was not affected by the restoration treatments or year and the interaction of both treatments and year ( $p > 0.05$ ) (Figure 5.2 d.). However, a tendency that evenness increases over the years when brush packing was applied was revealed by a barely non-significant interaction term ( $F_{[5,12]} = 2.99$ ,  $p > 0.055$ ).

Treatments effect on grass species abundance over the years at the different land-use types is illustrated in Figure 5.3 (a. D’Nyala and b. Shongoane). In D’Nyala an interaction between brush-packing treatments and year increased grass abundance ( $\text{Chi}^2_{[10, N = 15]} = 130.29$ ,  $p < 0.05$ ). The same trend was observed at the Shongoane site, with interaction between brush-packing treatments and year having an effect on grass abundance ( $\text{Chi}^2_{[10, N = 15]} = 212.36$ ,  $p < 0.05$ ).

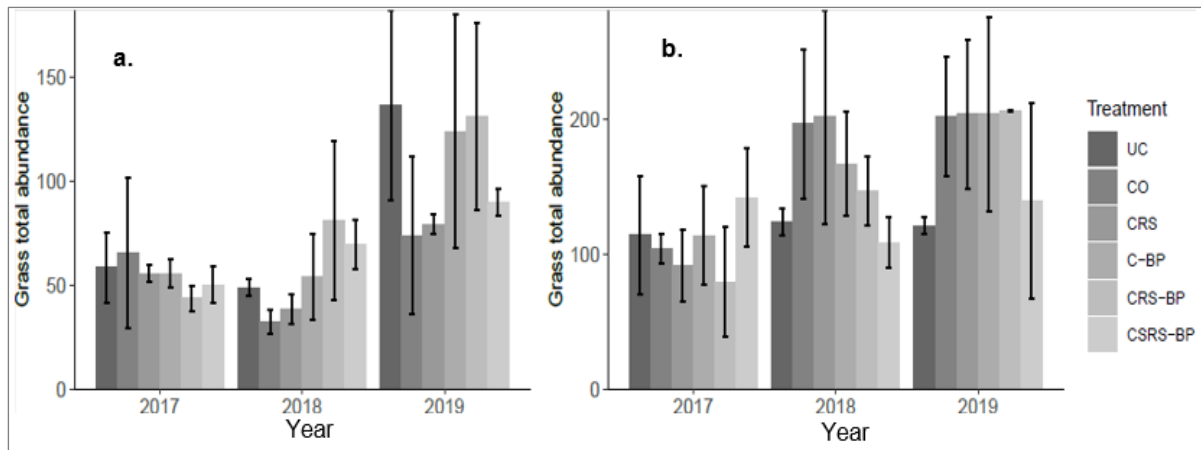


**Figure 5.2** Treatments' effect according to Simpson index (a), Shannon index (b), grass species richness (c) and evenness (d) over the years (2017 pre-bush clearing, 2018 and 2019 post-clearing and restoration application) at the Shongoane site.

Treatment description: No clearing (control plot) (UC), clearing only (CO), clearing and re-seeding (CRS), clearing and brush packing (C-BP), clearing and brush packing and re-seeding (CRS-BP), and clearing and soil disturbance and brush packing and re-seeding (CSRS-BP)

Error bars represent  $\pm$  standard error of mean

The results showed, that there was much variance of grass abundance between the three years at both sites, however it seems that grass abundance improved after the restoration application in 2018 and 2019 compared to 2017. Unexpectedly, the UC (control) treatment had the highest abundance than all other treatments at D'Nyala in 2019. At Shongoane, grass abundance was lowest (roughly 60 % lower) in the UC treatment compared to other treatments during 2018 and 2019. Changes in grass abundance were more pronounced post clearing (2018 and 2019).



**Figure 5.3** Grass species' total abundance, over the years, where 2017 is the pre-bush-clearing year and 2018-2019 the post-bush-clearing and restoration years for D'Nyala (a) and Shongoane (b).

Treatment description: No clearing (control plot) (UC), clearing only (CO), clearing and re-seeding (CRS), clearing and brush packing (C-BP), clearing and brush packing and re-seeding (CRS-BP), and clearing and soil disturbance and brush packing and re-seeding (CSRS-BP)

Error bars represent  $\pm$  standard error of mean

### 5.5.2 Ecological status and indicator species response to treatments at the different land-use types

Table 5.1 and 5.2 represent the grass species' ecological status, life form and indicator species during the three years of the study at the D'Nyala and Shongoane sites, respectively.

Out of a total of 30 grass species recorded over the three years at D'Nyala, 26 were classified as increaser II with only four species classified as decrease: *Chloris gayana*, *Digitaria eriantha*, *Panicum deustum*, *P. maximum* and *Schmidtia pappophoroides*. Similarly at Shongoane, 26 out of the 30 grass species were classified as increaser II with the remainder (*Cenchrus ciliaris*, *Centropodia glauca*, *Chloris gayana* and *Digitaria eriantha*) being decrease. In 2018 and 2019, the majority of the decrease grasses at both sites were re-seeded grasses (i.e. *Cenchrus ciliaris*, *Chloris gayana*, *Digitaria eriantha*).

By making use of indicator species, different levels of degradation were identified in 2017 before bush clearing and again in 2018 and 2019 after clearing and restoration application. In 2017, D'Nyala had three indicator species of which two were increaser II and one a decrease.

Shongoane, on the other hand, had five indicator species: four were increaser II and one a decreaser. In 2018 and 2019, only one grass species (*P. maximum*-decreaser species) was identified in the brush packing treatments at D’Nyala, with six species identified in the brush packing treatments at Shongoane. A higher number of decreaser and perennial grass species were identified (*Cenchrus ciliaris*, *Chloris gayana*, *C. virgate*, *Cynodon dactylon*, *Digitaria eriantha*, and *Enneapogon cenchroides* at  $p < 0.001$ ) in the brush packing treatments particularly at Shongoane.

**Table 5.1** Grass species ecological status, life form and indicator species at D’Nyala (nature reserve and controlled grazing).

2017			2018			2019		
Name of grass species	ES	LF†	Name of grass species	ES	LF †	Name of grass species	ES	LF†
<i>Aristida adscensionis</i>	2	A	<i>Aristida canescens</i>	2	P	<i>Aristida bipartita</i>	2	P
<i>A. bipartita</i>	2	P	<i>A. congesta</i>	2	WP	<i>A. canescens</i>	2	P
<i>A. canescens</i>	2	P	<i>A. rhinochloa</i>	2	A	<i>A. congesta</i>	2	WP
<i>A. congesta</i>	2	WP	<i>A. stipitata</i>	2	P	<i>A. rhinochloa</i>	2	A
<i>A. diffusa</i>	2	A	<i>Bothriochloa radicans</i>	2	P	<i>A. stipitata</i>	2	P
<i>A. rhinochloa</i>	2	A	<i>Bracharia deflexa</i>	2	P/A	<i>Bothriochloa radicans</i>	2	P
<i>A. stipitata</i>	2	P	<i>Chloris gayana</i>	D	WP	<i>Bracharia deflexa</i>	2	P/A
<b><i>Bracharia deflexa</i>**</b>	2	P/A	<i>C. virgata</i>	2	A	<i>Digitaria eriantha</i>	D	P
<b><i>Eragrostis curvula</i>**</b>	2	P	<i>Enneapogon cenchroides</i>	2	P/A	<i>Enneapogon desvauxii</i>	2	P
<i>E. tef</i>	2	P	<i>Eragrostis curvula</i>	2	P	<i>Eragrostis curvula</i>	2	P
<i>Melinis repens</i>	2	WP	<i>E. lehmaniana</i>	2	P	<i>E. lehmaniana</i>	2	P
<i>Panicum deustum</i>	D	P/A	<i>E. rigidior</i>	2	P	<i>E. rigidior</i>	2	P
<i>P. maximum*</i>	D	P/A	<i>E. tef</i>	2	P	<i>E. pallens</i>	2	P
<i>Perotis patens</i>	2	A	<i>E. trichophora</i>	2	P	<i>E. trichophora</i>	2	P
<i>Pognarthria squarrosa</i>	2	P	<i>Melinis repens</i>	2	WP	<i>Melinis repens</i>	2	WP
<i>Schmidtia pappophoroides</i>	D	P	<b><i>Panicum maximum</i>**a</b>	D	P/A	<i>Panicum deustum</i>	D	P/A
<i>Tragus berteronianus</i>	2	P	<i>Perotis patens</i>	2	A	<b><i>P. maximum</i>**a</b>	D	P/A
<i>Urochloa mosambicensis</i>	2	A	<i>Pognarthria squarrosa</i>	2	P	<i>Perotis patens</i>	2	A
<i>Urochloa panicoides</i>	2	A	<i>Schmidtia pappophoroides</i>	D	P	<i>Pognarthria squarrosa</i>	2	P
-	-	-	<i>Tragus berteronianus</i>	2	P	<i>Schmidtia pappophoroides</i>	D	P
-	-	-	-	-	-	<i>Tragus berteronianus</i>	2	P
-	-	-	-	-	-	<i>Urochloa mosambicensis</i>	2	A
-	-	-	-	-	-	<i>Urochloa panicoides</i>	2	A

-Absence of grasses during the data collection year

Ecological status (ES): D = decreaser, 2 = increaser II

†Life form (LF): WP = weak perennial, A = annual, and P – perennial

Indicator species in bold with significance levels: \*\*\* 0.001, \*\* 0.01 and \* 0.05

**a** = brush packing treatments **b** = non-brush packing treatments

**Table 5.2** Grass species ecological status, life form and indicator species at Shongoane (communal area, continuous grazing).

2017			2018			2019		
Name of grass species	ES	LF†	Name of grass species	ES	LF†	Name of grass species	ES	LF†
<i>Aristida adscensionis</i> **	2	A	<i>Aristida bipartita</i> ***b	2	P	<i>Andropogon schirensis</i>	D	P
<i>A. bipartita</i>	2	P	<i>A. canescens</i>	2	P	<i>Aristida bipartita</i> ***b	2	P
<i>A. diffusa</i>	2	A	<i>A. congesta</i>	2	WP	<i>A. canescens</i>	2	P
<i>A. stipitata</i>	2	P	<i>A. rhinochloa</i>	2	A	<i>A. congesta</i>	2	WP
<i>A. rhinochloa</i>	2	A	<i>A. stipitata</i>	2	P	<i>A. rhinochloa</i>	2	P
<i>Brachiaria deflexa</i>	2	P/A	<i>Brachiaria deflexa</i>	2	P/A	<i>Aristida stipitata</i>	2	P
<i>Cenchrus ciliaris</i> **	D	P	<i>B. distachya</i>	2	A	<i>Brachiaria deflexa</i>	2	P/A
<i>Centropodia glauca</i>	D	P	<i>Cenchrus ciliaris</i> ***a	D	P	<i>Brachiaria distachya</i>	2	A
<i>Chloris gayana</i>	D	WP	<i>Chloris gayana</i> ***a	D	WP	<i>Cenchrus ciliaris</i> ***a	D	P
<i>C. virgata</i>	2	A	<i>C. virgata</i> ***a	2	A	<i>Chloris gayana</i> ***a	D	WP
<i>Cynadon dactylon</i> *	2	P	<i>Digitaria eriantha</i> ***a	D	P	<i>C. virgata</i> ***a	2	A
<i>C. nlemfuensis</i>	2	P	<i>Enneapogon cenchroides</i> ***a	2	P	<i>Cynodon dactylon</i> ***a	2	P
<i>Digitaria longiflora</i>	2	P	<i>E. desvauxii</i> **b	2	P	<i>Digitaria eriantha</i> ***a	D	P
<i>D. ternata</i>	2	P	<i>Eragrostis curvula</i>	2	P	<i>Enneapogon cenchroides</i> ***a	2	P
<i>Enneapogon cenchroides</i> *	2	P	<i>Melinis repens</i>	2	WP	<i>E. desvauxii</i> **b	2	P
<i>Eragrostis curvula</i>	2	P	<i>Panicum maximum</i>	D	P/A	<i>Eragrostis curvula</i>	2	P
<i>Melinis repens</i>	2	WP	<i>Tragus berteronianus</i> ***b	2	P	<i>Melinis repens</i>	2	WP
<i>Panicum maximum</i>	D	P/A	<i>Urochloa panicoides</i>	2	P	<i>Panicum maximum</i>	D	P/A
<i>Perotis patens</i>	2	A	-	-	-	<i>Tragus berteronianus</i> ***b	2	P
<i>Pognarthria squarrosa</i>	2	P	-	-	-	<i>Urochloa panicoides</i>	2	A
<i>Tragus berteronianus</i>	2	P	-	-	-	-	-	-
<i>Urochloa mosambicensis</i>	2	A	-	-	-	-	-	-
<i>Urochloa panicoides</i> **	2	A	-	-	-	-	-	-

-Absence of grasses during the data collection year

Ecological status (ES): D = decreaser, 2 = increaser II

†Life form (LF): WP = weak perennial, A = annual, and P – perennial

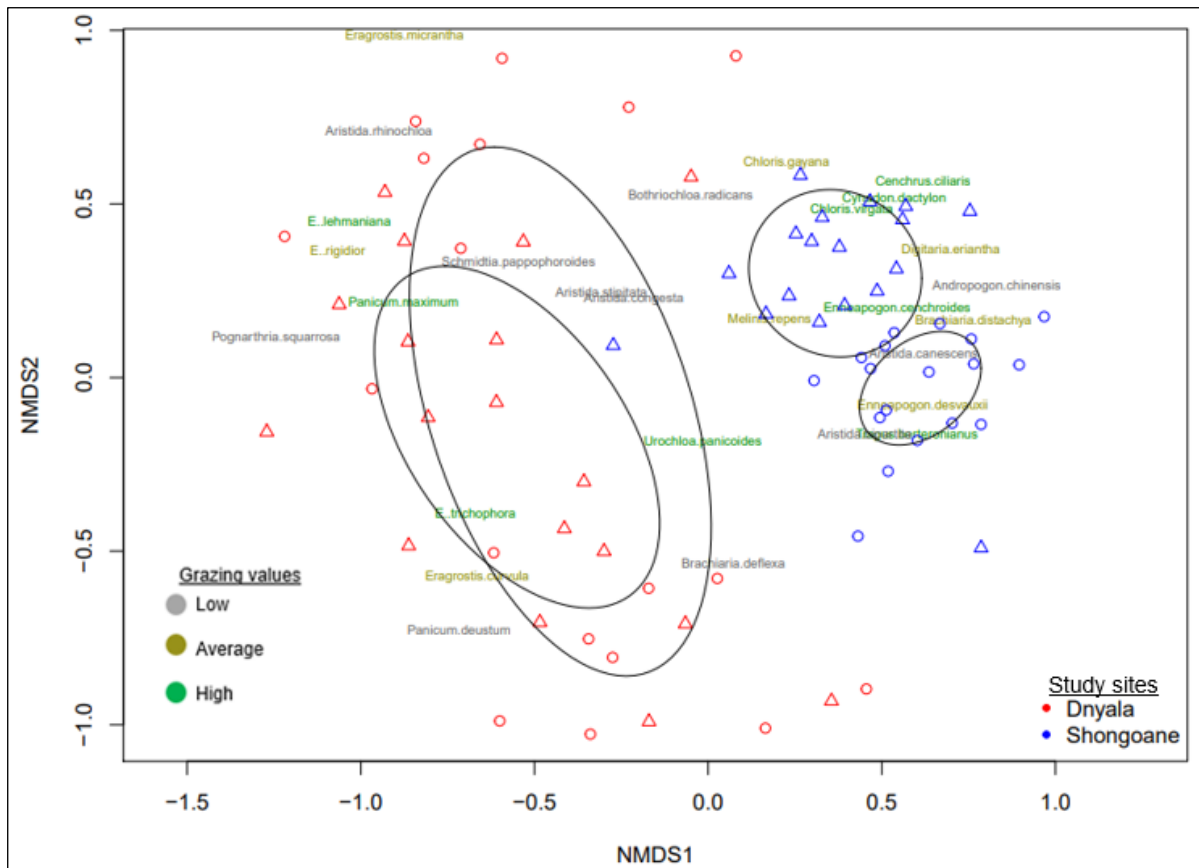
Indicator species in bold with significance levels: \*\*\* 0.001, \*\* 0.01 and \* 0.05

**a** = brush packing treatments **b** = non-brush packing treatments

### 5.5.3 Community structure in brush-packing restoration treatments versus non-brush-packing treatments in relation to communal and conservation areas

Grass species distance similarity between plots (brush packing and non-brush packing) is illustrated in Figure 5.4 (D’Nyala Nature reserve in red and Shongoane in blue). Non-metric multi-dimensional scaling (NMDS) showed that grass species composition were mostly dissimilar within the plots at the two sites. The grass communities on the plot scale at the D’Nyala nature reserve showed a higher heterogeneity than at Shongoane, which is indicated by a relatively wide-spread cluster. On the other hand, the Shongoane site had a clear separation between the brush packed and non-brush packed plots ( $p < 0.001$ ). Most grasses that clustered in the brush packing treatments were of the high and moderate grazing value. Brush packing seemingly did not affect species composition at D’Nyala ( $p > 0.05$ ) as there was an overlap between the brush packing treatments and the non-brush packing treatments and no clear clustering in the NMDS ordination was found.

Comparatively, very few brush-packed plots resulted in similar grass composition between the two sites. However, the NMDS ordination plot showed that brush packing promotes biodiversity under frequent grazing pressure; hence, clusters are apparent at the Shongoane (communal) study site.



**Figure 5.4** Non-metric multi-dimensional scaling (NMDS) ordination scatter plot illustrating grass species' dissimilarities in the brush-packed restoration plots versus non-brush-packed plots based on pair-wise Bray-Curtis distances in relation to the communal and conservation area, respectively. Ellipses indicate the standard error of the mean.

△ = treatments that included brush packing, ○ = treatments not including brush packing

## 5.6 Discussion

To the best of the research team's knowledge, this is the first study that evaluated grass biodiversity where brush packing as restoration technique has been used at different land-use types in semi-arid rangelands of South Africa. The study confirms that brush packing as a restoration technique can, indeed, improve grass diversity under conditions of continuous heavy grazing by creating a micro-environment that is favourable for the growth and recruitment of grass species and by serving as an effective shield that protects grass seedlings against grazing by livestock or game. Brush packing succeeded in increasing species richness in continuously grazed communal areas. Although species abundance was not affected by brush

packing, the aboveground biomass results indicated by Mangani et al. (2020 in review) also presented in Chapter 6, showed that brush packing can produce more (approximately > 50%) aboveground biomass when compared to the non-brush-packed treatments. In essence, this method affords especially highly palatable grasses the opportunity to reach reproductive status. In degraded ecosystems, the outcome might not only lead to beneficial re-growth within brush-packed patches but can also improve the re-establishment of palatable grasses in degraded bare-soil interspaces. Essentially, brush packing improves biodiversity and in this way contributes to the ecosystem services of the rangelands.

The brush packing restoration techniques was used as an enclosure to counter interference by humans and large herbivores with the goal of promoting the natural regeneration of grasses and reducing land degradation (Mebrat, 2015; Atsbha *et al.*, 2019). The results showed that brush packing works best particularly in highly degraded areas where ongoing heavy grazing has caused a reduction in plant species richness and diversity over time, compared to the encroached but moderately grazed conservational area (D'Nyala). The brush packing technique led to an increase in grass diversity as measured by the two diversity indices (Simpson and Shannon) particularly at Shongoane (communal area).

Although, the effect on grass evenness was less pronounced than on the diversity indices, the findings showed that restoration treatments increased evenness of grass communities on the brush-packed treatments in comparison to the no-brush packed treatments. This could be attributed to *Tragus berteronianus* dominating the non-brush-packed plots and *Enneapogon desvauxii* dominating only the brush-packed plots at Shongoane. Grass species evenness at D'Nyala was lower in 2019 and might be ascribed to the fact that *Brachiaria deflexa* mainly occurred in high numbers in the brush-packing plots, thus possibly affecting evenness in the conservation area. The relationship between plant characteristics and varying disturbances should not be discounted since research has shown that species with different traits often

respond differently to land-use type and grazing patterns (Kleijn *et al.*, 2009). Nevertheless, the ecological status, as per classification by Foran *et al.* (1978) and Trollope (1990), showed that the ratio of grass ecological types within grass communities indicated the poor land conditions as a result of bush encroachment and overgrazing. Some of the decreasers that occurred at the sites were amongst the re-seeded grasses, with most of the sown grasses occurring and surviving in the brush-packed treatments during the 2019 season. At Shongoane in particular, the brush-packed and re-seeded treatments were characterised by a higher number of decreaser species (*Chloris gayana* and *Cenchrus ciliaris*, which were also indicator species), confirming that brush packing can counteract degradation.

Even though the ecological status of the grass species was similar, this does not indicate similarity regarding the life form of the grasses at the two sites. Findings in this study suggest that the use of brush packing as restoration technique might be an option to prevent major shifts from perennial to annual grasses in overgrazed areas. Even though experiments carried out in the course of the study only cover a short period during which brush packing was applied, it is anticipated that with continued use of brush packing coupled with the correct grazing strategies, perennials could persist in a rangeland and avoid a shift to annual grasses.

Although ecological status can be used to evaluate the level of degradation, indicator species can provide additional information too (Mansour *et al.*, 2012). This is because most grass species are well adapted to certain growth conditions, and their quality and quantity decrease or increase depending on growth conditions which, in turn, are affected by, for example, the use of brush packing. The findings in this study indicated that brush packing had an effect on changes in environmental conditions, with more indicator species being identified in brush-packed plots being indicative of good conditions. This effect of brush packing on the grass community was more pronounced at the communal rangeland where grazing pressure was higher but, apparently, also occurred at the conservational area (as indicated by the decreaser

grass *Panicum maximum*). The results showed that brush packing plots led to lower grazing pressure in highly utilised rangelands where grazing pressure is high. Different grazers and browsers have different effects on rangeland vegetation due to their specific nutritional demands, jaw anatomy and grazing behaviour (Rook *et al.*, 2004; Schmitz & Isselstein, 2020). Grazing pressure is another important predictor for species turnover in rangelands (Kikoti & Mligo, 2015), and constant livestock grazing of especially grass seedlings at the beginning of the rainy season will weaken palatable perennial grasses (Nacoulma *et al.*, 2011). In this study, there was a good balance between unpalatable and palatable grasses at the two sites. Some of the unpalatable grass species found at D’Nyala included *Aristida diffusa*, *E. pallens* and *Pognarthria squarrosa*, but these were completely absent in the plots at the Shongoane site. As per findings by Kellner *et al.* (2020) the differences in grass palatability, could be ascribed to the effect of the different soil types and not necessarily to the type of treatment. Nevertheless, between the two sites, very few brush-packing plots showed similarity in grass species composition.

Interestingly, we could not observe any impacts of the restoration treatments on total grass abundance neither at the continuously highly grazed communal land nor at the conservation area. However, unexpectedly the control treatment (uncleared plot) at D’Nyala had the highest abundance amongst all treatments. This could have been driven by *Panicum maximum* (understorey species) which thrives well under shaded, tree canopies of the uncut woody species. More analysis of responses of the various grass species’ to clearing and brush packing could potentially give better results to determine abundance. Generally abundance did not give a good indicator of the effect of brush packing restoration, rather, as per the findings presented in the article by Mangani *et al.* (2020 under review), aboveground grass biomass could be a better indicator of restoration success than grass abundance. Even though results obtained in 2018 and 2019 were highly variable, the findings concur with Schmitz and Isselstein (2020)

who hold that grazing method (e.g. domestic livestock versus game) affects species richness. Given the difference in grazing methods practised at the two sites (limited and discontinuous grazing by game at D’Nyala and continuous grazing by communal livestock at Shongoane), higher species richness was recorded at Shongoane than at D’Nyala.

This study also concurs with the findings of the study conducted by Kleijn *et al.* in 2009, that land-use type should be taken into consideration when addressing conservation issues. This study revealed that brush packing primarily functions as a means to facilitate grazing enclosure and, compared to conventional enclosures such as fencing, this restoration method could potentially also help to improve other aspects of ecosystem functioning. The brush layer can reduce soil erosion and intercept precipitation, thereby reducing soil compaction. Furthermore, in the long run, the decomposition of the layer’s woody biomass can improve soil microbial activity and, thus, its nutrient and carbon-storage. In addition, as a result of lower solar radiation and reduced surface temperatures created by the brush layer (Modungwa, 2017) favourable habitats for small mammals and invertebrates can be created (Sikwane *et al.*, unpublished data). Thus, even though this study did not find that brush packing had a direct beneficial impact on grass diversity in conservational areas, this restoration method could lead to several positive effects on ecosystems’ heterogeneity in these areas too and should, therefore, not be limited to overgrazed communal areas.

## **5.7 Conclusion**

Currently, the encroachment and thickening of woody species is the major cause of land degradation in the Limpopo Province. This study contributes to the regional literature describing the decline of arid and semi-arid rangelands in South Africa, and demonstrates a simple and affordable method for potentially restoration. Even though bush clearing can help to improve ecosystem structures and their functioning, better results can be obtained if this

restoration technique is combined with brush packing since this technique seemingly has an influence on the promotion of grass species diversity with due consideration for variations in land-use and soil types. The results support that brush packing promotes biodiversity where there is frequent and high grazing pressure, in communal areas compared to conservation area.

## CHAPTER 6

### **COST-EFFECTIVENESS OF BRUSH PACKING AS RESTORATION TECHNIQUE TO IMPROVE GRASS ABOVEGROUND BIOMASS AFTER BUSH CLEARING IN THE SEMI-ARID RANGELANDS OF SOUTH AFRICA**

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## **Abstract**

Land degradation as a result of bush encroachment/thickening is a major challenge in South Africa. In order to curb this problem, the government initiated bush clearing projects in different parts of the country. This led to a need to devise cost-effective restoration methods, particularly methods that would suit the conditions prevalent in the country's rural rangelands. This study set out to assess the aboveground biomass yield and cost-effectiveness of five restoration treatments – (1) clearing, soil disturbance, re-seeding and brush packing; (2) clearing only; (3) clearing and brush packing; (4) clearing and re-seeding; (5) clearing, re-seeding and brush packing and the control – applied to two sites. Aboveground biomass ( $\text{g}\cdot\text{m}^{-2}$ ) collected from treatment plots in two seasons (i.e. 2018 and 2019) revealed that the brush-packed treatments had significantly higher aboveground biomass ( $p < 0.05$ ) than the non-brush-packed treatments. Clearing with brush packing as a treatment method produced the highest aboveground biomass ( $212.2 \text{ g}\cdot\text{m}^{-2}$  and  $401.9 \text{ g}\cdot\text{m}^{-2}$  for 2018, and  $272 \text{ g}\cdot\text{m}^{-2}$  and  $559.1 \text{ g}\cdot\text{m}^{-2}$  for 2019) at the two sites – D'Nyala Nature Reserve and Shongoane village, respectively. Likewise, the aboveground biomass deviation amongst the brush packing treatments with reference to the control plots was greater than 100% in both seasons at both sites. However, in as much as aboveground biomass was highest for the brush-packing treatments, the total person-time and set-up costs were also the highest, with each plot taking more than an hour and a half and costing more than ZAR100.00/plot. In all brush-packing treatments at both study sites, the aboveground biomass was higher compared to the non-brush-packed treatments. This study also demonstrated that improved aboveground biomass could be achieved by using a relatively cost-effective restoration method, i.e. brush packing, if community volunteerism can be incorporated to counter labour costs.

**Keywords:** Aboveground biomass, Cost-effective restoration, Land degradation, Semi-arid rangelands

## 6.1 Introduction

One of the major global challenges that threatens environmental conservation and sustainable development in the twenty-first century is land degradation (Temesgen *et al.*, 2014; Terefe *et al.*, 2020; Gebretsadik, 2013; Gashaw, 2015). Land degradation generally restrains environmental sustainability and compromises the progress of agricultural productivity in many countries (Hoffman & Ashwell, 2001; Brooks *et al.*, 2006; Berhanu *et al.*, 2016). According to Gashaw (2015) and Terefe *et al.* (2020), about 43% of the Earth's vegetated terrestrial surface has been degraded through soil erosion associated with dryland vegetation deterioration. Vegetation degradation is mainly attributed to invasive plant species that alter and modify biotic interactions, eventually resulting in a substantial loss in native biodiversity (Mitchell *et al.*, 2006; Powell *et al.*, 2017).

South Africa faces increasing levels of loss of productive land due to land degradation, particularly soil erosion and mostly in rangelands (DEA, 2013). Rangelands are mainly used for grazing and occupy over 70% of the land surface of the country, making this the single largest form of land use (Snyman, 2003). About 66% of rangelands in South Africa are moderately to severely degraded and due to the high degree of degradation, the cover, density and production of aboveground biomass for grazing animals is reduced (Hoffman & Ashwell, 2001; Snyman, 2005). Thus, drastic restoration measures must be applied to assist the re-establishment of vegetation in such cases.

Because of severe financial limitations and constraints, experimental interventions that aim to mitigate degradation in African rangelands are not common (Milton *et al.*, 2003; Kimiti *et al.*, 2017). In addition, the complex socioeconomic conditions, particularly in communal rural areas, pose a challenge to the successful implementation of restoration projects (Mangani *et al.*, 2020), which heightens the need to investigate restoration methods suited to rural rangelands that can be implemented cost effectively.

Furthermore, Milton *et al.* (2003) caution that since some economic gain can be derived from land impacted by bush encroachment, economics are bound to compromise effective ecological restoration, especially in developing countries. In order to create an understanding of the economics of land impacted by bush encroachment and alien plant invasions requires that a number of ecosystem services stemming from landscape restoration be assessed based on their value (Birch *et al.*, 2010; Bullock *et al.*, 2011; Newton *et al.*, 2012; Turner *et al.*, 2016; Stafford *et al.*, 2017).

As soil cover is an important factor determining the vulnerability of an ecosystem, restoration should aim towards creating a better microclimate and sustainable water balance for plant cover and density (O'Connor *et al.*, 2001; Snyman, 2000). The commonly applied management tool to reduce invasive woody plant densities in heavily encroached rangelands for the restoration of grass cover and aboveground biomass is bush clearing (Archer & Predick, 2014; Harmse *et al.*, 2016; O'Connor *et al.*, 2014; Lukomska *et al.*, 2014). Bush clearing creates habitat conditions that can be environmentally efficient in the altered cleared area (Dodson *et al.*, 2008) and also plays a role in ecosystem resistance and resilience. The abundance, richness and production of herbaceous species (including grasses) may be increased through bush clearing since this reduces tree-grass competition (Scholes & Archer, 1997; Tedder *et al.*, 2014; Smit & Rethman, 1999; Harmse *et al.*, 2016; Donzelli *et al.*, 2013; Smit, 2004; Smit, 2005). However, the effects of bush clearing are dependent on the method used, as some methods can intensely disturb or pollute the soil (Mndela *et al.*, 2020; Faist *et al.*, 2015; O'Connor *et al.*, 2014; Haussmann *et al.*, 2016; Okore *et al.*, 2007; Dalle *et al.*, 2006). According to Frank *et al.* (2018), the use of manual bush cutters and chemical stump-treatment methods seem to be less destructive.

In South Africa, too, the commonly used method of bush clearing in rangelands is manual, as determined by a national programme called Working for Water (WfW), launched in 1995 by

the Department of Environmental Affairs (nowadays known as the Department of Environment, Forestry and Fisheries (DEFF) under the Natural Resource Management (NRM) and Expanded Public Works Programmes (EPWP) (Grossman & Holden, 2007; [www.environment.gov.za](http://www.environment.gov.za)).

The biomass from cleared woody species is of great use for brush packing (BP) since it mainly involves creating an aboveground obstruction by packing branches on bare patches of land to allow seedlings to establish without the threat of herbivores (Visser *et al.*, 2007). Brush packing can be used as a cost-effective method to restore degraded land after bush clearing (Barac *et al.*, 2001; Barac, 2003; Botha *et al.*, 2008). It creates a micro-environment that is favourable for the growth and recruitment of grass species and also serves as an effective barrier to shield new grass seedlings (Visser *et al.*, 2007; Harmse *et al.*, 2016; Yirdaw *et al.*, 2017). Furthermore, as the branches from the brush packing decompose over time, they will also increase the nutrient and carbon content of the degraded soils (Tongway & Ludwig, 1996; Lal, 2015). Several studies have reported that mulch materials (brush packing) improve soil physicochemical properties, suppress soil surface temperature, reduce evaporation and increase the soil moisture content of the upper soil layer as a result of the shade effect, thereby creating an environment that is conducive to plant growth. Brush packing helps in manipulating plant-growing conditions to increase aboveground biomass or plant cover. It also improves production quality by reducing weed growth, improving soil structure and enhancing organic matter content (Visser *et al.*, 2007).

According to the Society for Ecological Restoration (SER) report, ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed (Davis & Slobodkin, 2004). However, Hobbs (2016) cautions that even though the term “restoration” presupposes an apparently straightforward aim, this process does not provide an instant solution.

Often, measuring restoration success is based on the very early stages of management, and few studies examine whether restoration can be maintained over the long term because continued monitoring and management require time and a considerable financial commitment (Powell *et al.*, 2017; Duke *et al.*, 2013). Nevertheless, to improve the viability of restoration over the long term, information regarding the costing of restoration is important. Long-term restoration will also help contribute to skills development and serve as a means to keep land users and policy makers abreast of cost-effective, sustainable restoration methods (Goldstein *et al.*, 2008). The challenge in South Africa is that post-clearing monitoring is hardly ever conducted, as it is assumed that plants will re-establish and regenerate naturally once the competition factor caused by the increase in woody density has been removed (Mndela *et al.*, 2020). This highlights a need to assess the actual aboveground biomass achieved at such sites.

Clearly, finding sustainable and economic ways to improve land productivity, particularly in semi-arid rural rangelands is essential. In Limpopo, for example, restoration projects have been necessitated due to the magnitude of the infestation of alien invasive woody plants (Gibson, 2006). At the two sites included in this study, a possible combination of invasive woody plants and poor land management has caused severe land degradation leading to bush encroachment in some portions of the area. Given the state of the land, investigating the improvement of biophysical properties once bush clearing has been completed and restoration implemented became imperative. The use of brush packing after bush clearing to improve aboveground biomass has not been quantified scientifically in the conservation of communal semi-arid rangelands in Limpopo. Furthermore, the cost effectiveness of using brush packing as a restoration method has not been reported in the country. Thus, the objective of this study was to assess and compare the effect of brush-packed treatments versus non-brush-packed treatments in improving aboveground biomass, and to evaluate the cost implications of using such a restoration method in two different land management areas.

To this end, the research team set out answer the following questions: (1) Does the brush packing restoration method produce significant aboveground biomass over time when looking at two different land management types and (2) is the cost of using the brush packing method sustainable for future restoration in rural parts of South Africa?

## 6.2 Materials and methods

### 6.2.1 Surveys conducted on aboveground biomass of grasses

Aboveground biomass collected in 2018 and 2019 was used to address the aim and objectives of this chapter. Please refer to Chapter 3 (Materials and Methods, section 3.4.2) for a detailed description of the sampling performed to obtain the results reported in section 6.4.1.

### 6.2.2 Cost implications of the restoration

The cost of setting up the restoration islands (plots) was calculated as a function of time persons spent at each plot (person-hours) (Kimiti *et al.*, 2017) during the establishment period in 2017. Please refer to Chapter 3 (Materials and Methods, section 3.4.3) for a full description of how the calculations were done to obtain the results reflected in section 6.4.2.

## 6.3 Statistical analysis

The statistical analysis were computed using Microsoft Excel version 2016 and, Genstat 19 (<https://genstat.kb.vsnr.co.uk/knowledge-base/new-features-genstat-19th-edition>) was used.

Percentage deviation was computed using the formula:

$$\frac{\textit{Treatment } x - \textit{Control}}{\textit{Control}} \times 100$$

Where x is the either treatment; Clearing, soil disturbance, re-seeding and brush packing (CSRS-BP); clearing only (CO); clearing and brush packing (C-BP); clearing and re-seeding (CRS); or clearing, re-seeding and brush packing(CRS-BP) and Control is no clearing (UC).

A one-way analysis of variance (ANOVA) was conducted to evaluate the effect of the different restoration treatments on aboveground biomass. Least significant differences (LSD) and Tukey's Studentized (HSD) range at  $P \leq 0.05$  were used to separate treatment means when there was a significant treatment effect. Each site (Shongoane and D'Nyala) was analysed separately, while the data from the two seasons was also analysed separately because of significant ( $p < 0.05$ ) season-year interactions.

## 6.4 Results

### 6.4.1 Restoration treatments' effect on the aboveground biomass of grasses

The most important habitat component of rangeland areas is ground cover (Alemu *et al.*, 2017). Of particular importance for this study were the grass species that constituted ground cover and for this reason, grass species present at the sites were identified (Table 6.1 and 6.2) to represent the aboveground biomass.

The mean aboveground biomass ( $\text{g}\cdot\text{m}^{-2}$ ) during 2018 and 2019 at the two sites is illustrated in Figure 6.1 and 6.3 for D'Nyala and Shongoane, respectively. The two-way ANOVA revealed a significant difference ( $p < 0.05$ ) for aboveground biomass between the treatments over the two seasons for both sites. Shongoane, however, had a relatively higher aboveground biomass than D'Nyala, Figures 6.2 and 6.3 are examples of the biomass differences taken at the two sites. Two factors that mainly influenced the grass aboveground biomass were season and treatments, which implies this is a season-treatment interaction effect.

In 2018, the lowest aboveground biomass at D'Nyala was recorded within the non-brush-packed treatments (Figure 6.1), with the CRS treatment being the lowest ( $28.2 \text{ g}\cdot\text{m}^{-2}$ ), followed by the CO treatment ( $42.3 \text{ g}\cdot\text{m}^{-2}$ ) and then the UC treatment with  $64.2 \text{ g}\cdot\text{m}^{-2}$ . Amongst these treatments, the biomass for CRS and CO did not differ significantly from one another ( $p > 0.05$ ) but did, however, differ significantly ( $p < 0.05$ ) from the UC treatment.

A comparison between the brush-packing treatments showed that C-BP ( $212.2 \text{ g.m}^{-2}$ ) had the highest aboveground biomass, followed by the treatments CRS-BP and CSRS-BP with  $128.9$  and  $128.7 \text{ g.m}^{-2}$ , respectively. In 2019, D’Nyala produced the highest aboveground biomass in the C-BP ( $272 \text{ g.m}^{-2}$ ) treatment. This represents an increase of  $59.8 \text{ g.m}^{-2}$  compared to the 2018 season. Likewise, the brush-packing treatments were amongst the ones to produce significantly higher aboveground biomass ( $p > 0.05$ ) when compared to the non-brush-packing treatments in 2019 (example used in Figure 6.2). UC, as the control treatment, produced higher aboveground biomass ( $85.2 \text{ g.m}^{-2}$ ), and the CRS treatment produced the least aboveground biomass ( $31.5 \text{ g.m}^{-2}$ ) amongst the treatments with no brush packing. Although the CRS treatment had the least biomass amongst the non-brush packing treatments, an increase of  $6.6 \text{ g.m}^{-2}$  was recorded between the two sampled seasons.

At the Shongoane study site, there were highly significant differences ( $p > 0.001$ ) between the brush-packing and non-brush-packing treatments in both seasons (Figure 6.3). In 2018, the lowest aboveground biomass, ( $25.2 \text{ g.m}^{-2}$ ) was for the UC treatment. This corresponds with the two other non-brush packed treatments (CO and CRS) which also produced low aboveground biomass (Figure 6.5). The C-BP treatment produced the highest aboveground biomass of  $401.9 \text{ g.m}^{-2}$ , followed by the CRS-BP treatment with  $338.6 \text{ g.m}^{-2}$ . In 2019, the UC treatment produced the least aboveground biomass ( $47.7 \text{ g.m}^{-2}$ ), and the C-BP treatment produced the highest aboveground biomass ( $559.1 \text{ g.m}^{-2}$ ). Figure 6.3 also shows there was no significant difference on biomass ( $p < 0.05$ ) between the brush-packing treatments (CSRS-BP, C-BP and CRSBP).

**Table 6.1** Average grass species life form and richness per the six restoration methods for the 2018 and 2019 seasons at D’Nyala.

Species	LF†	Treatments											
		2018						2019					
		†CSR S-BP	CO	C-BP	CRS	CRS- BP	UC	†CSR S-BP	CO	C-BP	CRS	CRS- BP	UC
<i>Aristida bipartida</i>	P	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	1,7	0,0	0,3	0,7
<i>A. canescens</i>	P	0,0	0,0	3,3	1,7	1,3	3,0	0,0	0,0	0,7	0,0	0,0	2,7
<i>A. congesta</i>	WP	5,7	5,0	2,7	8,0	6,3	0,3	1,3	0,0	2,7	1,0	0,0	3,7
<i>A. rhinochloa</i>	A	6,3	2,3	0,7	0,0	8,3	0,0	8,3	19,3	20,7	4,0	5,3	12,3
<i>A. stipitata</i>	P	3,3	2,3	3,3	9,3	1,7	2,0	0,0	0,0	1,0	12,7	1,3	0,0
<i>Bothriochloa radicans</i>	P	0,0	0,0	3,7	8,3	0,0	0,0	0,0	0,0	0,0	2,7	0,0	0,0
<i>Bracharia deflexa</i>	P/A	9,3	0,0	7,3	0,3	5,3	1,0	28,0	22,3	51,0	103,7	39,7	90,3
‡ <i>Chloris gayana</i>	WP	1,7	0,0	0,7	0,0	0,0	2,7	0,0	0,0	0,0	0,0	0,0	0,0
<i>C. virgata</i>	A	2,7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
‡ <i>Digitaria eriantha</i>	P	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,7	0,0	0,0	0,0	0,0
<i>Enneapogon cenchroides</i>	A	0,0	0,0	0,7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
<i>E. desva</i>	P	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,7	0,0	0,0
<i>Enteropogon micrantha</i>	A	0,0	0,0	0,7	0,0	4,7	0,0	0,0	0,0	0,0	0,0	0,0	0,0
‡ <i>Eragrostis curvula</i>	P	16,0	2,3	2,7	0,0	2,7	30,3	18,7	10,3	26,3	6,3	10,7	3,0
<i>E. lehmaniana</i>	P	2,0	4,0	0,0	2,3	0,3	2,7	3,3	0,0	0,0	0,0	0,0	8,0
<i>E. rigidior</i>	P	0,3	8,0	0,3	2,0	2,0	8,3	4,0	0,0	1,3	0,0	0,7	0,0
<i>E. pallens</i>	P	0,0	0,0	0,0	0,0	0,0	0,0	1,7	0,0	0,0	0,0	0,0	0,0
<i>E. tef</i>	P	0,0	0,0	0,0	0,0	1,3	0,0	0,0	0,0	0,0	0,0	0,0	0,0
<i>E. trichophora</i>	P	0,0	0,0	0,0	1,0	0,0	1,3	0,0	0,0	1,3	0,0	2,0	0,3
<i>Melinis repens</i>	WP	0,7	1,0	0,3	8,3	1,7	0,0	1,0	4,3	1,0	0,0	1,7	5,7
<i>Panicum maximum</i>	P/A	12,0	6,0	24,0	0,7	1,0	26,7	13,0	0,0	0,7	0,0	0,0	1,3
<i>Perotis patens</i>	A	3,3	0,3	0,0	4,0	0,0	1,0	0,0	0,0	0,0	0,0	0,0	0,0

<i>Pogonarthria squarrosa</i>	P	0,0	0,3	0,3	0,7	0,0	1,3	0,0	0,0	0,0	0,0	0,0	0,0
<i>Schmidtia pappophoroides</i>	P	6,0	0,0	1,0	0,3	1,0	0,0	5,0	0,7	0,0	0,0	0,7	0,0
<i>Uroclhoa mosabicanoides</i>	A	0,0	0,0	0,0	0,0	0,0	0,0	2,7	3,3	0,3	1,3	1,0	0,3
<i>Uroclhoa panicoides</i>	A	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	5,3	0,0	0,0	0,0
<i>Tragus berteronianus</i>	A	0,0	0,3	2,0	1,7	0,3	0,0	1,7	12,7	6,7	4,0	4,0	0,0

‡Grasses that were seeded † LF (life form): WP = weak perennial, A = annual and P = perennial

†Clearing, soil disturbance, re-seeding and brush packing (CSRS-BP); clearing only (CO); clearing and brush packing (C-BP); clearing and re-seeding (CRS); clearing, re-seeding and brush packing(CRS-BP); and no clearing (control plot) (UC)

**Table 6.2** Average grass species life form and richness per the six restoration methods for the 2018 and 2019 seasons at Shongoane.

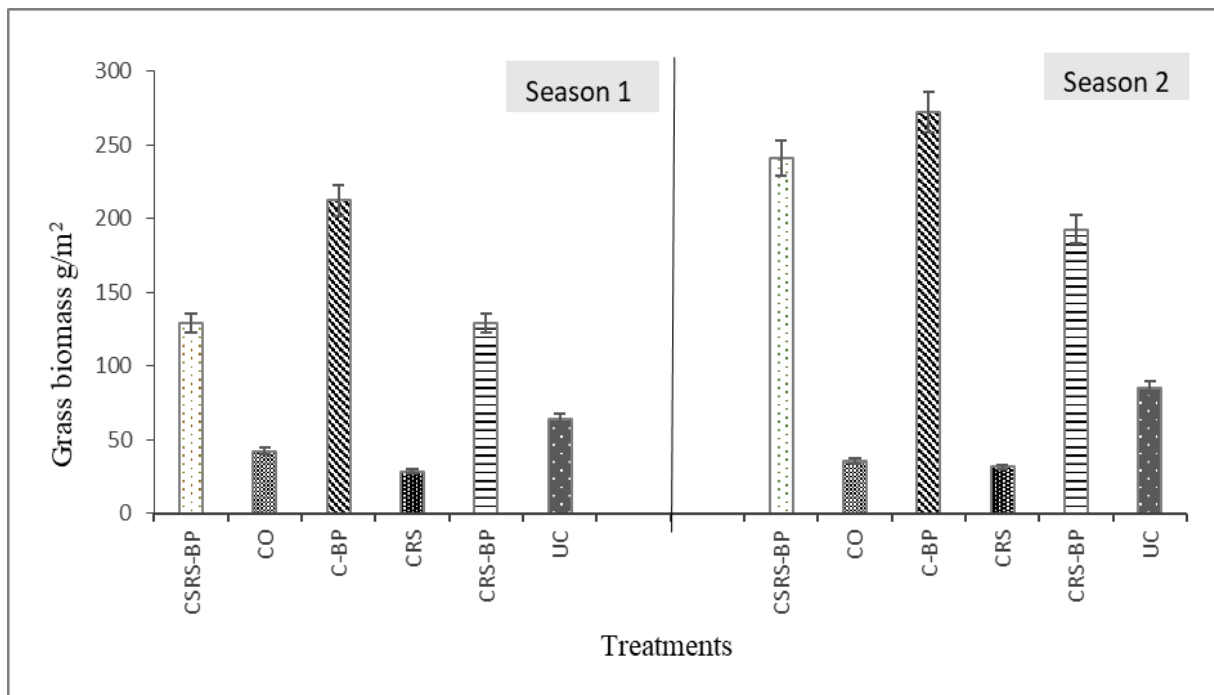
Species	LF†	Treatments											
		2018						2019					
		‡CSR S-BP	CO	C-BP	CRS	CRS- BP	UC	CSRS- BP	CO	C-BP	CRS	CRS- BP	UC
<i>Andropogon chinensis</i>	P	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	1,0	0,7	0,0
<i>Aristida stipitata</i>	P	0,3	0,7	3,3	0,0	6,0	2,3	0,0	0,0	1,3	1,0	5,0	0,0
<i>A. bipartita</i>	P	0,0	2,0	0,0	7,0	4,0	0,0	0,0	3,0	0,0	10,0	3,7	0,3
<i>A. congesta</i>	WP	11,3	9,3	30,7	7,3	0,0	1,0	6,3	10,3	29,3	8,7	3,7	0,7
<i>A. canescens</i>	P	22,0	27,7	20,7	12,7	22,0	38,7	28,5	23,3	18,0	11,7	14,3	31,7
<i>A. rhinochloa</i>	A	1,7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
<i>Brachiaria distachya</i>	A	20,0	44,7	25,0	44,0	20,0	3,7	29,5	47,0	8,3	54,0	19,3	8,3
<i>B. deflexa</i>	P/A	17,7	10,0	54,0	15,3	22,3	12,0	18,3	5,0	60,3	11,3	30,3	9,0
‡ <i>Cenchrus ciliaris</i>	P	2,7	0,3	1,7	0,0	15,3	0,0	8,5	0,0	11,0	0,7	14,7	0,3
‡ <i>Chloris gayana</i>	WP	3,0	0,0	0,7	0,0	1,7	0,0	7,5	0,3	3,3	1,3	7,3	0,0
<i>C. virgata</i>	A	0,7	0,3	0,3	2,0	0,0	0,0	10,0	0,3	1,7	0,3	5,3	0,3
‡ <i>Cynodon dactylon</i>	P	0,0	0,0	0,0	0,0	0,0	0,0	19,5	0,3	10,3	0,7	16,3	2,0
‡ <i>Digitaria eriantha</i>	P	8,7	3,3	1,0	2,0	31,3	0,7	13,3	6,7	2,3	4,3	32,0	0,7
<i>Enneapogon cenchroides</i>	P	11,3	0,7	22,0	1,7	11,7	2,0	14,0	2,0	32,3	2,0	18,7	1,7
<i>Enneapogon desvauxii</i>	P	1,7	35,7	3,3	76,7	0,0	32,3	0,0	32,0	3,3	59,0	0,0	32,3
‡ <i>Eragrostis curvula</i>	P	2,3	0,0	0,0	0,0	0,0	0,0	7,0	0,3	4,3	1,3	8,0	0,0
<i>Melinis repens</i>	WP	2,0	3,3	4,0	2,7	10,7	3,7	5,0	7,0	9,0	4,3	15,3	2,7
<i>Panicum maximum</i>	P/A	0,3	0,0	0,7	0,0	1,3	0,0	6,3	0,0	7,3	0,0	5,0	0,0
<i>Tragus berteronianus</i>	A	1,7	59,0	0,0	30,7	0,7	27,7	1,5	64,3	0,0	32,3	1,0	30,0
<i>Urochloa panicoides</i>	A	1,0	0,0	0,0	0,0	0,0	0,0	1,0	0,3	1,7	0,0	0,3	1,0

‡Grasses that were seeded † LF (life form): WP = weak perennial, A = annual, and P - perennial

‡Clearing, soil disturbance, re-seeding and brush packing (CSRS-BP); clearing only (CO); clearing and brush packing (CBP); clearing and re-seeding (CRS); clearing, re-seeding and brush packing(CRS-BP); and no clearing (control plot) (UC)

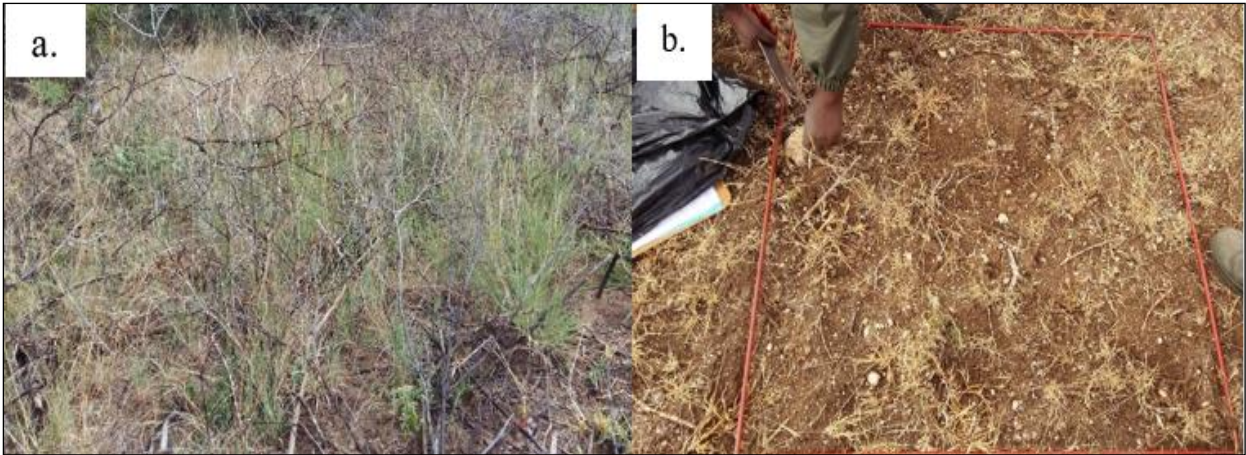
Although the two sites were not compared, Shongoane had the highest aboveground biomass on the brush-packing treatments, for example 559.1 g.m<sup>-2</sup> on the C-BP treatment versus the 272.2 g.m<sup>-2</sup> obtained in the same treatment at D’Nyala.

The aboveground biomass increased in the 2019 season with a more apparent effect in the brush-packing treatments (CSRS-BP, CBP and CRS-BP) (Figure 6.1 and 6.3). However, the treatments that were re-seeded (CSRS-BP, CRS and CRS-BP) did not have much effect in increasing biomass. The latter means that re-seeding did not have the desired effect even when combined with brush packing and this was observed at all sites.

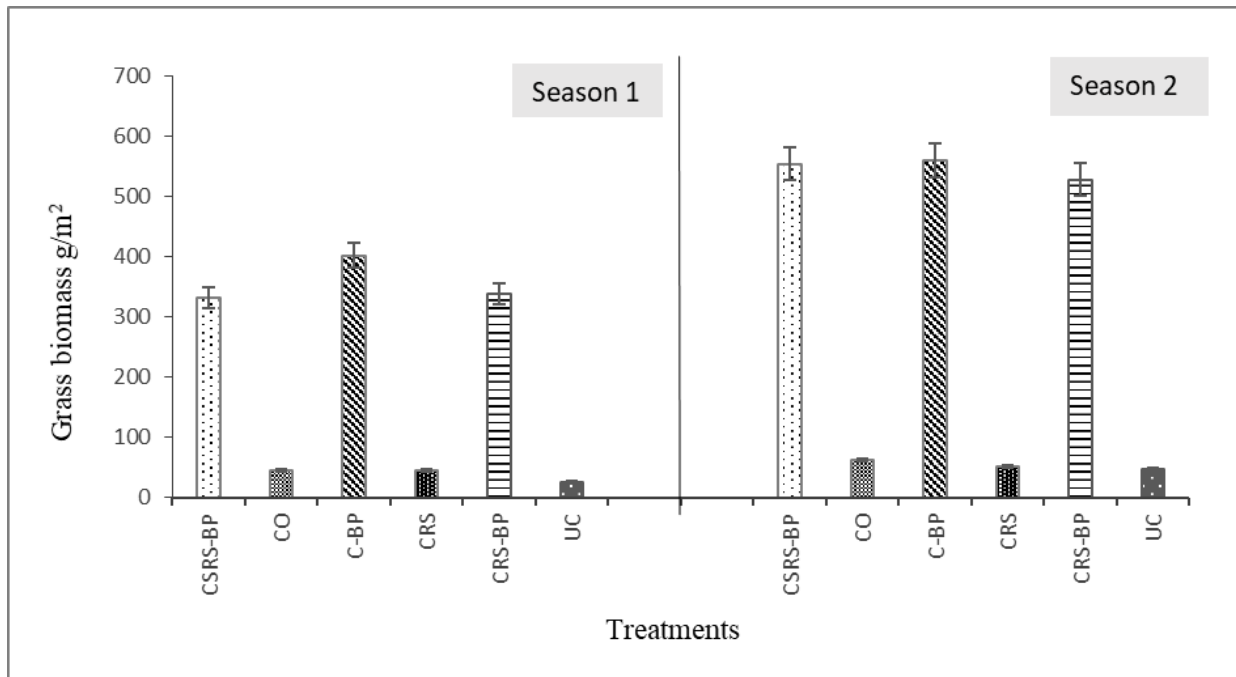


**Figure 6.1** The effect of the restoration treatments on aboveground biomass of grasses (g.m<sup>-2</sup>) for the 2018 and 2019 seasons at the research site D’Nyala. Error bars indicate the 95% confidence interval of each mean value.

\*Clearing, soil disturbance, re-seeding and brush packing (CSRS-BP); clearing only (CO); clearing and brush packing (CBP); clearing and re-seeding (CRS); clearing, re-seeding and brush packing (CRS-BP); and no clearing (control plot) (UC)

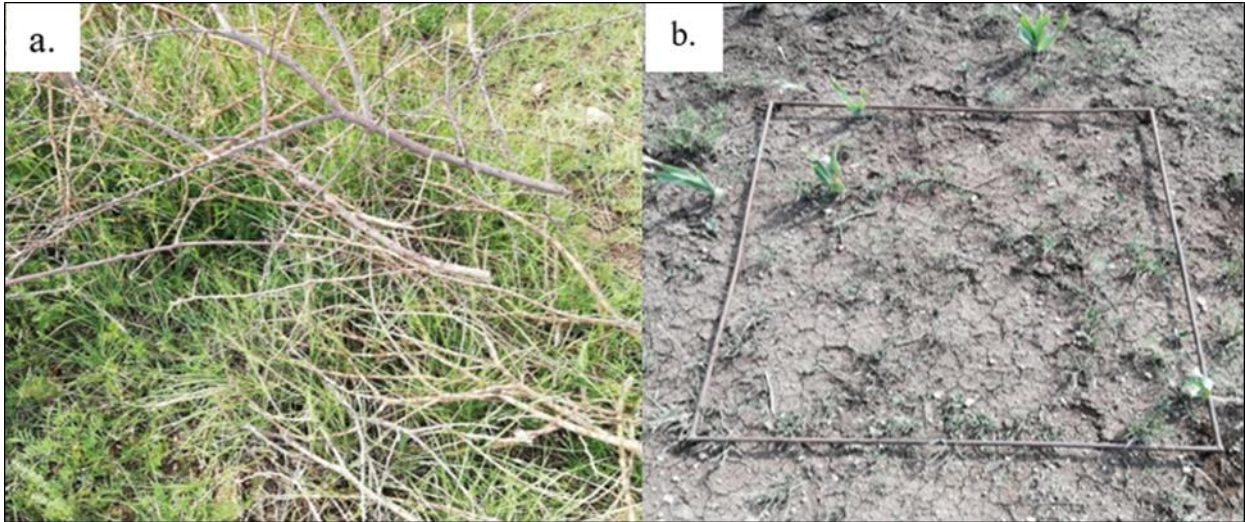


**Figure 6.2** Aboveground biomass production in brush-packed plot (a) versus plot without brush packing (b) at D’Nyala.



**Figure 6.3** The effect of the restoration treatments on aboveground biomass of grasses (g.m<sup>-2</sup>) for the 2018 and 2019 seasons at the research site Shongoane. Error bars indicate the 95% confidence interval of each mean value.

\* Clearing, soil disturbance, re-seeding and brush packing (CSRS-BP); clearing only (CO); clearing and brush packing (CBP); clearing and re-seeding (CRS); clearing, re-seeding and brush packing (CRS-BP); and no clearing (control plot) (UC)



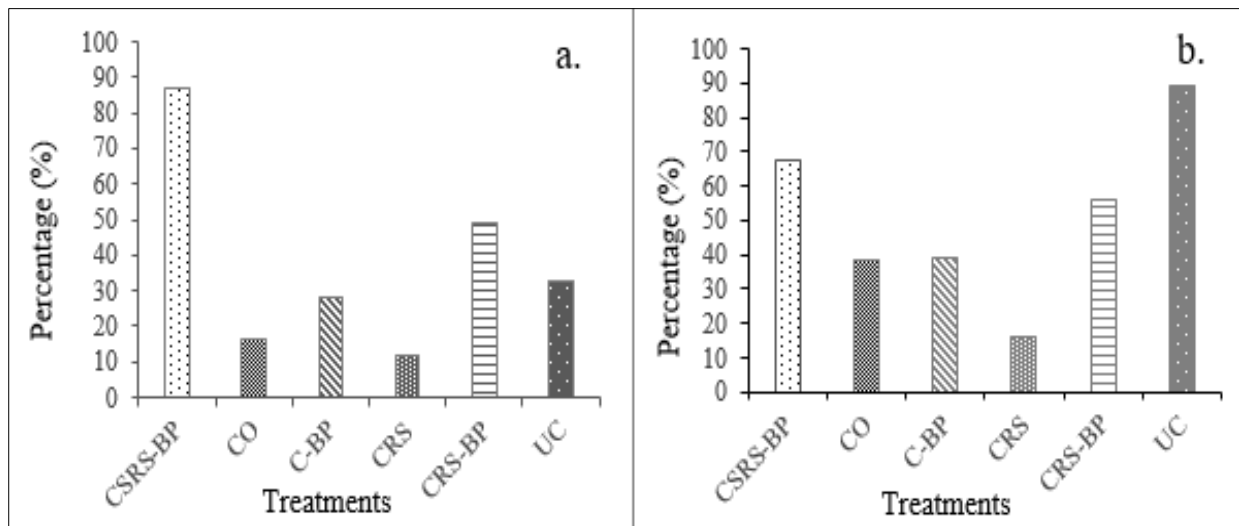
**Figure 6.4** Aboveground biomass production in brush-packed plot (a) versus plot without brush packing (b) at Shongoane.

Figure 6.5 illustrates the percentage increase of aboveground biomass in 2019 compared to the first growing season, i.e. 2018: (a) represents D’Nyala and (c) Shongoane.

At D’Nyala, the percentage aboveground biomass showed similar trends over time in the brush-packed and non-brush-packed treatments. The effects of brush packing were more evident in 2019, with aboveground biomass increasing by 87.1% (128.7 to 240.8 g.m<sup>-2</sup>) in the CSRS-BP treatment, followed by the CRS-BP treatment with 48.95%. A much lower percentage was achieved in the non-brush-packed treatments with 16% for CO and 11.7% for CRS treatments. The UC treatment was an exception, with a 32.7% increase, this being higher than the 28.2% increase in the C-BP treatment. Overall, the brush-packed treatments had an increase of more than 54.8% in aboveground biomass compared to the 20.1% increase in aboveground biomass in the non-brush-packed treatments.

The trends for percentage aboveground biomass increase at Shongoane were somewhat different. The UC treatment had the highest percentage increase in aboveground biomass at 89.3%, followed by the CSRS-BP with 67.2%, CRS-BP at 55.9% and C-BP at 39.1%. The CRS treatment had the lowest increase (16.1%) amongst all six treatments. Although the UC treatment had the highest or more improved aboveground biomass in terms of percentage, the

grams-per-area increase differed by only 22.5 g.m<sup>-2</sup> (25.2 to 47.7 g.m<sup>-2</sup>). The brush-packing treatments had an increase of 54.0% aboveground biomass compared to a 47.9% increase in aboveground biomass in the non-brush-packed treatments.



**Figure 6.5** Percentage (%) increase in aboveground biomass for the 2019 restoration season compared to 2018 season at D’Nyala (a) and Shongoane (b).

\* Clearing, soil disturbance, re-seeding and brush packing (CSRS-BP); clearing only (CO); clearing and brush packing (CBP); clearing and re-seeding (CRS); clearing, re-seeding and brush packing (CRS-BP); and no clearing (control plot) (UC)

The aboveground biomass of the control (UC) at D’Nyala was 64.2 g.m<sup>-2</sup> and 85.2 g.m<sup>-2</sup> in the 2018 and 2019 seasons, respectively (refer to Figure 6.1). The CSRS-BP and CRS-BP treatments had a similar biomass deviation when compared to the UC treatment in 2018. Both brush packing restoration treatments had an aboveground biomass of more than 64.5 g.m<sup>-2</sup> with reference to the control (UC), amounting to a 100% increase. The aboveground biomass of the CO restoration treatment was -21.9 g.m<sup>-2</sup> (34.1%) less (negative deviation) with reference to the control (UC). The C-BP treatment had the highest aboveground biomass deviation, with a total of 148 g.m<sup>-2</sup> (231%) difference when compared to the UC. As illustrated above, the trends indicate that the brush packing restoration treatments (CSRS-BP, C-BP and CRS-BP) significantly improved aboveground biomass.

The aboveground biomass of the control treatment (UC) at Shongoane was 25.2 g.m<sup>-2</sup> in the 2018 and 47.7 g.m<sup>-2</sup> in the 2019 season (refer to Figure 6.3). At this site, all treatments showed a positive deviation in all seasons (2018 and 2019) in terms of aboveground biomass with reference to the control treatment (UC). The CRS treatment deviated the least from the control in both 2018 and 2019 (18.9 and 3.5 g.m<sup>-2</sup>, respectively). Noteworthy is that the aboveground biomass of the CRS treatment only improved by 7% in 2019 with reference to the UC treatment. The CSRS-BP treatment had the highest deviation (306 and 506.2 g.m<sup>-2</sup>) in both seasons. While aboveground biomass improved in the 2019 season with reference to the UC treatment, the percentage deviation was lower compared to the 2018 season. In this instance, too, the results showed that the brush packing treatments (CSRS-BP, C-BP and CRS-BP) significantly improved aboveground biomass, with all treatments being 10-fold (1000%) higher compared to the control treatment.

**Table 6.3** Aboveground biomass deviation (g.m<sup>-2</sup> and %) compared to the control treatment (UC) for D’Nyala.

Season	Treatments	Aboveground biomass deviation (g.m <sup>-2</sup> )	Aboveground biomass deviation (%)
<b>2018</b>	CSRS-BP	64,5	100
	CO	-21,9	-34
	C-BP	148	231
	CRS	-36	-56
	CRS-BP	64,7	101
<b>2019</b>	CSRS-BP	155,6	183
	CO	-49,8	-58
	C-BP	186,8	219
	CRS	-53,7	-63
	CRS-BP	107,1	126

\* Clearing, soil disturbance, re-seeding and brush packing (CSRS-BP); clearing only (CO); clearing and brush packing (CBP); clearing and re-seeding (CRS); clearing, re-seeding and brush packing (CRS-BP); and no clearing (control plot) (UC)

Table 6.3 (D’Nyala) and Table 6.4 (Shongoane) represent the aboveground biomass of the five restoration treatments (CSRS-BP, CO, C-BP, CRS and CRS-BP) in relation to the biomass

obtained from the control treatment (UC) in 2018 and 2019. These results denote what the deviation in aboveground biomass would have been if no restoration methods were implemented compared to the results obtained with the respective restoration treatments.

**Table 6.4** Aboveground biomass deviation (g.m<sup>-2</sup> and %) to the control treatment (UC) for Shongoane.

Season	Treatments	Aboveground biomass deviation (g.m <sup>-2</sup> )	Aboveground biomass deviation (%)
<b>2018</b>	CSRS-BP	306	1214
	CO	19,8	79
	C-BP	376,7	1495
	CRS	18,9	75
	CRS-BP	313,4	1244
<b>2019</b>	CSRS-BP	506,2	1061
	CO	14,5	30
	C-BP	511,4	1072
	CRS	3,5	7
	CRS-BP	480,1	1006

\* Clearing, soil disturbance, re-seeding and brush packing (CSRS-BP); clearing only (CO); clearing and brush packing (CBP); clearing and re-seeding (CRS); clearing, re-seeding and brush packing (CRS-BP); and no clearing (control plot) (UC)

#### 6.4.2 Cost implications of the restoration

The cost ratio for the construction of the six restoration plots (restoration treatments) at D’Nyala and Shongoane is illustrated in Table 6.5. The most complex treatment (CSRS-BP) required 3 hours and 20 minutes per person to complete at D’Nyala and 4 hours and 40 minutes per person at Shongoane. Thus, the cost for employing two persons amounted to, respectively, ZAR133.20 and ZAR186.80. This treatment required more person-time because it involved clearing, soil disturbance, re-seeding and brush packing, which also took longer at Shongoane due to the hard clay texture of the soil. The re-seeded treatments (CSRS-BP, CRS and CRS-BP) incurred additional costs amounting to approximately ZAR82.20 per treatment (refer Table 3.2 in Chapter 3: Materials and methods section 3.4.3). As was to be expected, the UC treatment incurred no costs, except for the cost associated with using iron droppers. Total person-time

and costs were highest for the brush-packed treatments, with each plot (CSRS-BP, C-BP and CRS-BP) taking more than an hour and a half. The total cost ratio for constructing the brush-packed restoration treatments at D’Nyala were as follows: ZAR215.40 for CSRS-BP, ZAR60.00 for C-BP and ZAR148.50 for CRS-BP. At Shongoane the total cost ratio amounted to ZAR284.00 for CSRS-BP, ZAR81.80 for C-BP and ZAR170.40 for CRS-BP, respectively.

**Table 6.5** Average cost ratio for the establishment of six restoration treatments at D’Nyala and Shongoane. (Costs for chain-saw cutting are not included since this was a once-off expense and not necessarily for the treatments).

Site	Treatments	Materials (R)		~Wage per person-time		Total cost (R/400m <sup>2</sup> )
		Iron dropper	Grass mixture	Time (hour)	Cost per two workers	
<b>D’Nyala</b>	CSRS-BP	0.00	82.20	3.33	133.20	215.4
	CO	0.00	0.00	0.58	23.20	23.2
	C-BP	0.00	0.00	1.5	60.00	60.00
	CRS	0.00	82.20	0.75	30.00	112.20
	CRS-BP	0.00	82.20	1.67	66.3	148.5
	UC	0.00	0.00	0.00	0.00	0.00
<b>Shongoane</b>	CSRS-BP	15.00	82.20	4.67	186.80	284.00
	CO	15.00	0.00	0.67	26.80	41.80
	C-BP	15.00	0.00	1.67	66.80	81.80
	CRS	15.00	82.20	0.75	30.00	112.20
	CRS-BP	15.00	82.20	1.83	73.20	170.40
	UC	15.00	0.00	0.00	0.00	15.00

~Wage per person-time calculated at national minimum wage rate of R20/hour.

\* Clearing, soil disturbance, re-seeding and brush packing(CSRS-BP); clearing only (CO); clearing and brush packing (CBP); clearing and re-seeding (CRS); clearing, re-seeding and brush packing(CRS-BP); and no clearing (control plot) (UC)

## 6.5 Discussion

Several studies have shown that creating restoration islands is an effective method to initiate self-generated recovery in degraded semi-arid lands (Barac *et al.*, 2001; Kellner, 2008; Kimiti

*et al.*, 2017). This study sought to assess the effectiveness of six restoration treatments in terms of promoting plant establishment by improving grass aboveground biomass in degraded semi-arid rangelands, with the proviso that the methods used must be relatively cost effective and uncomplicated.

To this end, the restoration treatments were tested at two sites with different land management regimes, i.e. a conservation area and communally managed area. The ultimate goal of the study was to promote grass establishment which would then result in improved aboveground biomass for grazing herbivores at minimal cost. Although all the brush packing treatments successfully increased aboveground biomass, the establishment cost for restoration using these treatments was higher (greater than ZAR100.00) compared to the non-brush packing treatments (less than ZAR45.00) over the two-year experiment.

At both sites, a general trend in the results showed an increase in biomass for the brush-packed treatments – irrespective of whether the treatment involved re-seeding or not – as opposed to the non-brush-packed treatments which showed a lower increase in biomass. This correlates with the results obtained by Kimiti *et al.* (2017) which showed that effective brush packing reduces the amount of top-soil being lost by lowering the intensity of raindrops and excessive temperatures in a system, thereby creating a microenvironment that is conducive to plant establishment and growth. Although the aboveground biomass for the brush packing restoration treatments did not differ statistically ( $P < 0.05$ ) from one another, the CSRS-BP treatment had a somewhat higher aboveground biomass. The high aboveground biomass in this treatment (CSRS-BP) could be due to the inclusion of soil disturbance. This supposition is supported by Kinyua *et al.* (2010) and Kimiti *et al.* (2017) who also found that grasses do establish more effectively when the soil is tilled. According to Visser *et al.* (2007), the higher aboveground biomass in the brush packing treatments compared to non-brush packing treatments can be ascribed to the resultant microenvironment which improved soil structure

and enhanced soil organic matter. Further studies conducted by Agbede *et al.* (2013) confirm that mulching manipulates plant growing conditions by increasing soil moisture. These results confirm the ultimate goal of the brush packing method, namely to prevent soil erosion and enhance vegetation establishment by creating a better microenvironment.

The effects of re-seeding were also tested to establish whether this method would render more aboveground biomass in combination with restoration treatments that either involved brush packing or not. Thus, if grass established well in the re-seeded, brush-packed treatments relative to the non-brush-packed treatments, it can be assumed that the resultant microenvironment was favourable for grass establishment, regardless of whether naturally occurring seeds were present or not. Interestingly, the assumption that the re-seeded restoration treatments would yield more favourable results proved to be false. A comparison between the cleared and re-seeded restoration treatment (CRS) and the clearing only treatment (CO) showed a difference of 5% at D’Nyala and 21.9% at Shongoane, thus indicating that re-seeding over the short-term does not improve biomass. The combination of brush packing with re-seeding also did not yield better than expected aboveground biomass as the aboveground biomass was mostly attributed to the naturally occurring grasses at all the plots at both sites. However, contrary to this study, re-seeding could be more important for more intensely bare-patched areas as highlighted by Kimiti *et al.* (2017).

Although brush packing restoration treatments had significant positive effects regarding the production of aboveground biomass, the results indicated that seasonality was also an overriding determinant for aboveground biomass. The deduction regarding seasonality can be viewed from two perspectives: Firstly, in terms of time taken the grasses to grow in the first season (2018) and, secondly, the difference in rainfall between the 2018 and 2019 seasons. Higher percentage increases in 2019 (%) in aboveground biomass were observed at the Shongoane site. Most of the percentage increase was in the brush packing treatments with the

CSRS-BP having more than an 80% increase in aboveground biomass in 2019 at the two sites (see Figure 6.3).

Aboveground biomass deviation ( $\text{g.m}^{-2}$  and %) with reference to the control plot (UN) was assessed to evaluate, firstly, if bush clearing has a dominant effect on improving aboveground biomass over the short-term and, secondly, to evaluate clearing in terms of the effort it takes against the resultant increase in aboveground biomass. Thus, if there was a deviation when compared to other treatments, it can be assumed that bush clearing is indeed important in assisting plant recruitment (Mndela *et al.*, 2020). All brush packing treatments resulted in a higher deviation in aboveground biomass compared to the control plot. This means that bush clearing and using the resultant brush (branches) did, indeed, increase aboveground biomass. It was interesting to see that the control treatment yielded better aboveground biomass compared to the CO and CRS treatments at the D’Nyala site. This implies that clearing and re-seeding did not add much value to ecological improvement. To the contrary, all restoration treatments showed improved results versus the control treatment at the Shongoane site. This could be as a result of the clay soil that accumulates more moisture over time, which is aided by the effect of the brush packing. D’Nyala, on the other hand, has fine, sandy soil. As observed in the unpublished study by Kellner *et al.* (2020), in conditions such as these, brush packing can curb run-off and help to retain most of the moisture.

For sustainable aboveground biomass over the long term and, ultimately, to achieve better restoration, the durability and effectiveness of brush packing is a key component (Kimiti *et al.*, 2017). If the brush pack cannot survive heavy water flow or the effects of animal trampling and human disturbance, especially in the first few months before plants establish, its contribution to restoration will be minimal. The brush packing treatments at the D’Nyala site were still intact even after the two years of restoration, as this area is a nature reserve where the disturbance factor by animals and humans is very low. The scenario at the Shongoane site

was, however, very different since cattle still utilised the area and community members harvested the brush pack for personal use. There were even instances where community members took up residence in some of the cleared experimental sites. For this reason, even in instances where community members are involved in and rewarded for their contribution towards the establishment of restoration plots, the success of restoration by means of brush packing should, where applicable, be considered against the backdrop of communities where grazing is managed communally and where village expansion is still a necessity.

Despite the widespread call for cost-effective conservation, literature rarely reports costs for ecological restoration (Powell *et al.*, 2017; Duke *et al.*, 2013). In this study, though, a costing ratio for the construction of six restoration treatments at two different land management sites is reported. However, it ought to be noted that the estimated costs are mainly based on the labour and material required to establish a specific experimental site and do not cover the management of such a site.

Despite the fact that the costs associated with person-time and materials were the highest for the brush-packed and re-seeded treatments, these treatments were most effective in producing the highest aboveground biomass. The experimental establishment and preparation mainly took place in the first year at both sites, meaning that if the sites are not disturbed, the restoration islands implemented can have a positive effect over the long term. Re-seeding and brush packing with soil disturbance dominated the costs simply because it took more time, hence requiring more person-hours and effort.

According to Friday *et al.* (2015), ecological restoration projects should consider ways to reduce establishment costs and they recommend that one way to do this is to minimise labour and material costs. Labour costs in this study were minimal since most of the workers were sourced from the Expanded Public Works Programme (EPWP), which is a separate budget for research. If the restoration methods recommended in this study are to be expanded

countrywide, the EPWP workers could be used to construct the plots, thus making it affordable at a larger scale. However, the labour costs could be reduced even more if the project were to use services volunteered by community members (Goldstein *et al.*, 2008).

Due to the high cost of seeds, it seems that re-seeding is not a cost-effective restoration method over the short-term to improve the aboveground biomass of grasses. Note that even though grass seeds were another dominant cost in the cost estimation, the actual cost for these specific experimental sites were reduced to zero since the seeds were donated by a seed company for the research.

Although the results suggest that the costs of restoration are considerable, especially in the aforementioned treatments, it ought to be noted that costs can vary depending on actual site conditions and restoration methods applied. Accordingly, the costs of restoration certainly increased concomitant with the degree of soil crusting at the Shongoane site where the soil had a higher clay content compared to the D’Nyala site which had fine sandy soil. It took more time to do soil disturbance on the crusted soil, resulting in higher labour costs. The experimental site at Shongoane also has unrestricted livestock grazing, which would require more intense and frequent management, versus the site in the protected D’Nyala.

The cost analysis in this study focused on the specific experimental sites and does not estimate costs for every restoration project precisely. What stands out, though, is that this study included the initial costs of restoration, which is a first for South Africa.

## **6.6 Conclusion**

It is becoming increasingly important to examine whether the restoration methods used in projects are cost effective or not, especially in degraded African rangelands where finance is a major challenge. This study demonstrated that an improved aboveground biomass could be achieved by using a relatively cost-effective restoration technique: brush packing. In all the

brush-packed restoration treatments at D’Nyala and Shongoane, the aboveground biomass was higher compared to the non-brush-packed treatments. If grass biomass production is increased, it will improve grazing capacity, reduce erosion, increase biodiversity and contribute to sustainable land management practices. Therefore, if the implementation of brush packing technologies is well managed, it can help to restore many hectares of degraded land, expand production yields and contribute to the conservation of biodiversity in vulnerable ecosystems. It was further noted that bush clearing of invasive trees did, indeed, increase the ecological potential of the land, but even more so when it was used in combination with brush packing.

Of particular interest in this study is that re-seeding did not yield higher aboveground biomass, even when used in combination with brush packing. This suggests that adding re-seeding to restoration projects should be weighed carefully as this can add an unnecessary expense. Although the establishment costs, particularly the brush packing, soil disturbance and re-seeding were more costly, other effective ways such as using community volunteer programmes could be used in future. For this reason, it is recommended that land users and policy makers should consider including effective brush packing technologies in future drives to restore degraded rangelands.

## CHAPTER 7

### **SOCIO-ECONOMIC BENEFITS STEMMING FROM BUSH CLEARING AND RESTORATION PROJECTS CONDUCTED IN THE D'NYALA NATURE RESERVE AND SHONGOANE VILLAGE, LEPHALALE, SOUTH AFRICA**

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## **Abstract**

This study aimed to investigate the socio-economic benefits stemming from bush clearing and restoration projects conducted in the Lephalale municipality, within the Limpopo Province of South Africa. The study was conducted at two sites: the D’Nyala Nature Reserve and a nearby local village, Shongoane. A qualitative thematic content analysis approach and semi-structured interviews were used to gather data from 14 purposively selected participants between the ages of 22 and 55 (male = 9 and female = 5). The results indicated that the nature reserve benefited from the project via the improved visibility of the landscape features and game viewing, which made the reserve more attractive for tourists and resulted in increased revenue. The costs of buying feed for game could also be curbed since the grazing capacity increased. Since the nature reserve sourced temporary labour from the local village to execute the project, the community benefited in terms of members being able to earn a wage, which led to an improvement in their livelihoods. Another indirect benefit was the morale and behavioural changes observed amongst community members. It was obvious that the socio-economic benefits derived from projects such as these far outweigh the negatives and that there is every reason to institute projects of a similar nature elsewhere.

**Keywords:** bush clearing; local community; nature reserve; restoration project; socio economic benefit

## 7.1 Introduction

The complex link between biodiversity and ecosystem services (social benefits) is yet to be understood. Previously, scientists took into account the conservation of biodiversity from a biophysical perspective (Cooper *et al.*, 2007; Mace *et al.*, 2012; Dorondel *et al.*, 2016). In some cases, researchers found that although feasible, these conservation activities were not always sustainable (Berkes & Folke, 1998; Meek *et al.*, 2015). This is mainly because local communities where conservation activities are practised (Simelane & Knight, 2006; Saayman, *et al.*, 2009) were not often involved and did not directly benefit from these activities (Meek *et al.*, 2015; Dorondel *et al.*, 2016).

Recently, there has been more of a focus on how local communities can become involved in and simultaneously benefit from conservation attempts, such as the restoration of degraded lands (Saayman *et al.*, 2009; Alcamo, 2003; Brooks *et al.*, 2006). Some of the proposed strategies include short-term economic interventions aimed at improving the livelihoods of local communities by, for example, creating temporary job opportunities, skills development, and training (Francis *et al.*, 2005). As is evident from the literature, though, the results of some of these efforts are rather contradictory.

Arnold *et al.* (2012) and DeCaro and Stokes (2013) found that community and stakeholder involvement in the decision-making process does not always guarantee positive outcomes, while other studies such as Bernhardt *et al.* (2007) found a positive correlation between direct community involvement and ecological restoration success. A report by Dorondel *et al.* (2016) emphasises that in a great deal of projects that were done in the Danube floodplain, ecological restoration cannot be implemented without the approval and participation of the local community.

This combination of uncertainty about a conservation project's outcomes and the pressure to succeed can result in uneasiness playing a significant role in local community behaviour (Meek

*et al.*, 2015). Usually, this can be ascribed to the community's inability to envisage the long-term benefits they could derive from projects. Although communities expect to derive some form of benefit from conservation activities that will enrich their livelihoods, they tend to see projects as only benefiting project owners. For this reason, in as far as the actual process of restoration implementation is concerned, Druschke and Hychka (2015) argue that communication and mutual cooperation is key, because it shapes the quality of community engagement, which in turn, can translate to all parties benefiting (or at the very least ensure buy-in and support from the local community).

The mixed results obtained regionally and globally despite, Reid (2016) concluded that, in essence, community-based restoration projects not only offer economic benefits but also knowledge and experience that communities can use to empower themselves, which will lead to improvement of their livelihoods.

For example, a study conducted by Fox *et al.* (2017) found that river restoration projects in the United States, Canada and New Zealand have the potential to not only restore ecosystem processes and services but to benefit the community by repairing and transforming human relationships. Even though the latter may not have a direct economic benefit, restored and transformed human relationships serve to create a cooperative space for dialogue and hold the promise of future cultural and educational benefits for the community. Similarly, Browder (2002) found that even though the economic development impacts were mixed in the Brazilian Amazon conservation and development project, approximately 50% of the projects delivered tangible benefits to local communities.

In their study of eight of the river restoration projects being conducted across Europe, Muhar *et al.* (2016) also quantified the effect of restoration on ecosystem services. Included as benefits were the provisioning of agricultural products, wood and infiltrated potable water, as well as regulation and cultural services such as recreation and biodiversity conservation. The latter

study's findings are supported by Vermaat *et al.* (2016) who reported that river restoration projects showed a marked increase in ecosystem services over and above other benefits such as the economic upliftment of the community. The economic evaluation of wetland-based community participation was studied by Roy *et al.* (2012). In that study, it was highlighted that the stakeholders' livelihoods were uplifted through the wetland conservation.

In another study involving the use of bush-encroached and gullied areas in India to produce bio-fuel by planting *Jatropha* spp, Francis *et al.* (2005) found that the restoration activities helped to generate rural employment and increased environmental quality. In this instance, community members were involved in labour-intensive activities of clearing and replanting. The long-term effect of this restoration project was the improvement of degraded lands which could not be used for food production but subsequently put to use to improve the livelihoods of local communities. In principle, land degradation can be effectively managed if the principal ecological, socio-cultural, and economic driving forces are properly understood (Patel *et al.*, 2007). With that said, active involvement of local communities not only benefits them but also plays a crucial role in problem identification, solving and successful implementation at the project site (Patel *et al.*, 2007).

Given that economic and social conditions and resource availability in poor and developing countries differ considerably from those in developed countries (Francis *et al.*, 2005), it is imperative to keep in mind that these communities are largely dependent on land for agriculture, fuel and water to sustain the livelihoods of the rural poor (Dougill *et al.*, 2016; Mokgotsi, 2018). Furthermore, communities in these countries often fall prey to prevailing climatic variations (Reid, 2016) and are characterised by high population densities and low skill levels (Thornton & Gerber, 2010).

Nevertheless, in his study of soil organic carbon pools in developing countries, Lal (2006) demonstrated how acquiring new knowledge and skills (education) with regards to soil

conservation that will eventually lead to higher productivity of land resources can benefit communities directly and indirectly. Note, though, that success in this instance was ascribed to first understanding the needs of the local farmers and then learning how to manage the state of the land.

Another case in point would be that of Namibia where land degradation, involving both bush encroachment and the spread of invasive alien plant species, was found to be an important driver of ecosystem decline (Ward, 2005; Stafford *et al.*, 2017). This realisation led to restoration projects to clear bush-encroached and invaded areas by involving community members. In this instance, Stafford *et al.* (2017) found that the resultant benefits for the socio-economy and social development far outweighed the restoration of the land itself. In sum, as Adams & Hutton (2007) pointed out, “the compatibility of conservation and poverty alleviation” is bound to have social and economic impacts. Moreover, in terms of local community development, restoration activities should be sustainable over the long term and not only impact livelihoods during the course of the activities.

#### 7.1.1 Socio-economic benefits of restoration projects in South Africa

South Africa is a water-scarce country with rangelands covering almost 60% of the country (Mukheibir & Sparks, 2003; Donnenfeld *et al.*, 2018). Some of the worst degradation of these rangelands can be observed in communal areas and can be ascribed not only to poor land management but also to the high density of the population in these areas (Dougill *et al.*, 2016). The Limpopo province, the study area, with a population density of more than 46 people per km<sup>2</sup>, is thought to be one of the most degraded in South Africa, particularly in the communal areas (Hoffman & Ashwell, 2001; Alexander, 2019). Much of the degraded area (56 %) was land primarily used for the grazing of domestic animals (Gibson, 2006). It is further estimated that 16% of the province is infested with alien invasive plants (Gibson, 2006), which necessitated restoration projects. Poor land management combined with drought conditions,

especially in arid- and semi-arid ecosystems, poses a threat to the long-term productivity of the land, especially where communally managed lands are further degraded as a result of bush encroachment and the invasion of alien species (Mokgotsi, 2018; Lukomska, *et al.*, 2014). Recognising this, and that a large proportion of the population is dependent for their livelihoods on services derived from dryland ecosystems, South Africa ratified the United Nations Convention to Combat Desertification (UNCCD) in countries experiencing serious drought and/or desertification in 1997. The country prepared a National Action Programme (NAP) combating land degradation to alleviate rural poverty ( Hoffman & Todd, 2000). Furthermore, a national programme called Working for Water (WfW), launched in 1995, is aimed at removing invasive alien plants to reduce competition of unwanted plants and to increase land productivity potential (Grossman & Holden, 2007).

Given that Lukomska *et al.* (2014) found that de-bushing restoration techniques proved to conserve and increase grazing capacity resulting in generating a higher and sustainable income for local farmers, a detailed study of such projects in semi-arid areas that can be linked directly or indirectly to socio-economic benefits for local communities is warranted.

Relatively little data exists regarding restoration programmes across South Africa, particularly regarding the reconciliation thereof with social goals. By way of background, South Africa's Department of Environment, Forestry and Fisheries (DEFF) has been tasked with the restoration of degraded lands on a national scale, a responsibility which by inference encompasses research and social development projects. In response, the department implemented the Natural Resource Management (NRM) and Expanded Public Works (EPWP) programmes. Given that this study set out to investigate the benefits of bush clearing and restoration projects from a socio-economic rather than a biophysical perspective, only those projects resorting under the NRM are relevant here.

Overall, the objective of the DEFF-NRM programme is to ensure sustainable land management of rangelands and to improve the socio-economic livelihoods and promote the well-being of people in rural areas. It encompasses a number of "working for" projects, all of which are labour intensive. Included here is Working for Water (WfW), which involves projects to control invasive species (alien and indigenous), as well as Working for Ecosystems (WfEco) and Working for Land (WfL), both of which aim to address degraded ecosystems and to provide sustainable ecosystem services for rural communities over the long term ([www.environment.gov.za](http://www.environment.gov.za)). This study resorts under the WfW, WfEco and WfL programmes specifically in as far as controlling bush-encroached rangelands is concerned.

Promoting an understanding of how nature works and how it can provide in everyday needs if protected is the obvious point of departure. However, it is imperative that those responsible for implementing bush clearing and restoration projects should also make it their business to gain an understanding of the value local communities attach to the ecosystem services they derive from natural resources if their projects are to succeed (Druschke & Hychka, 2015). Therefore, the restoration of degraded rangelands should not be restricted to environmental conditions only but should also encompass active intervention in as far as social and economic conditions are concerned (Aronson *et al.*, 2006).

Given South Africa's extremes of unemployment and poverty, many families regularly experience hunger and find it difficult to meet their basic needs (Integrated Development Plan 2018/19). At the Lephalale municipality, the unemployment rate is 22.2% with a dependency ratio of 33.2% and 39.1% female-headed households, mostly in the rural communities (Integrated Development Plan 2018/19). Part of the short-term goals in the municipality was to generate employment especially in projects involving improvement of the environment. Considering the lack of research on how to involve local communities in restoration activities and how to optimise the socio-economic benefits they derive from being involved in such

activities, this study set out to develop a decision support system (DSS) for all stakeholders, especially land users and policy makers. This was so that informed decisions can be made about the benefits derived from the restoration of degraded lands. To this end, two sites in the Lephalale municipality in the Limpopo Province where members from the community partook in bush clearing and restoration activities were investigated in an attempt to quantify the socio-economic benefits addressed in the process.

## **7.2 Methods**

### 7.2.1 Socio-economic surveys

The purpose of the study was to investigate what socio-economic benefits are received from the community members that partook in bush clearing and restoration activities.. Please refer to Chapter 3 (Materials and Methods, section 3.5) for a detailed description of the sampling performed to obtain the results reported in section 7.3.

### 7.2.2 Data analysis

Data was thematically analysed. A thematic analysis is a method commonly used in the analysis of qualitative data (Vaismoradi *et al.*, 2013; Gibbs, 2007). Audio recordings were transcribed and analysed by means of a thematic content-analysis, a six-step procedure. The steps involved 1. data familiarising, 2. assigning preliminary codes to the data in order to describe the content, 3. theme coding across the interviews, 4. reviewing of themes, 5. defining and naming of themes and, lastly, 6. producing results from the thematically categorised data (Gibbs, 2007; Braun & Clarke, 2006). This method allows for a flexible identification of themes and sub-themes; moreover, because this was a deductive study, it was easier to select themes, as the exact interest was known.

After each interview, the researcher reflected on and explained the information provided by the participant in an attempt to ensure that the quality of the information is retained. As a further

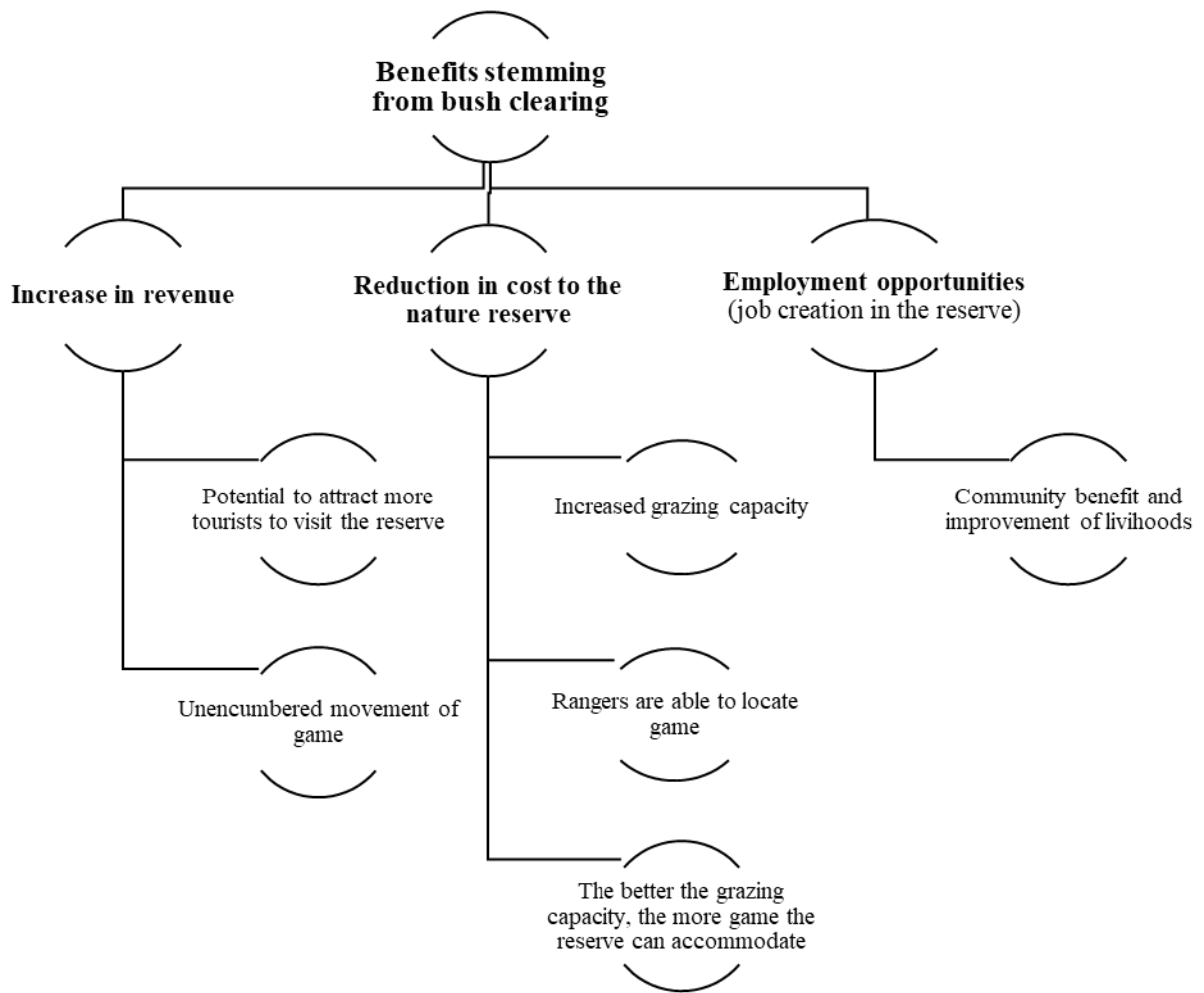
safeguard to ensure that the study's findings were not influenced by researcher bias, a gatekeeper with a deep understanding of the bush clearing and restoration projects in and around the nature reserve was employed to ensure the trustworthiness of the data within the context of the study.

### **7.3 Results**

Based on the analysis, and to illustrate the differences between the benefits derived by participants employed at the D’Nyala Nature Reserve versus participants who reside in Shongoane village, Figure 7.1 and 7.2 below highlight the three most important themes emerging from the nature reserve’s data and the data derived from participants who reside in the village.

#### **7.3.1 Emerging themes: D’Nyala Nature Reserve**

Bush clearing in the reserve commenced in 2016. Up and until that point, the reserve was so heavily encroached that even the entrance area was not quite accessible. As illustrated in Figure 7.1 below, the following themes emerged as direct benefits resulting from bush clearing and restoration work in the reserve.



**Figure 7.1** Thematically analysed benefits for D’Nyala Nature Reserve.

### 7.3.1.1 Increase in revenue

Participants were in agreement that bush clearing definitely improved visibility within the reserve. Where overgrown patches made it difficult for tourists to spot game before, they can now observe wildlife unhindered from afar. If tourists are assured that they are likely to spot game unhindered, they are more likely to be attracted to the nature reserve and if tourists are attracted, the nature reserve’s revenue is bound to increase.

Since the nature reserve also offers opportunities for recreational hunting, participants observed that as a result of bush clearing, game were less encumbered and free to roam more widely. Before, there were areas that even rangers found difficult to navigate.

*“There used to be a lot of bush even closer to the tar road, sometimes you could see the animal but when you try to get closer it would run and hide into the bush and it would be difficult to locate it.” Participant #1, 42*

#### 7.3.1.2 Reduction in costs

The reserve is host to a whole array of animals, including several species of antelope. Bush clearing resulted in increased grazing capacity and a reduction in the need to supply supplementary feed.

In addition, participants working for the reserve remarked that they now have to spend fewer man-hours on tracking and monitoring game because, with lesser camouflage, the animals are easier to spot.

*“So far where it is cleared especially sickle bush, there is a visible change of vegetation of which is beneficial for the animals because there is more grass to graze.” Participant #3, 33*

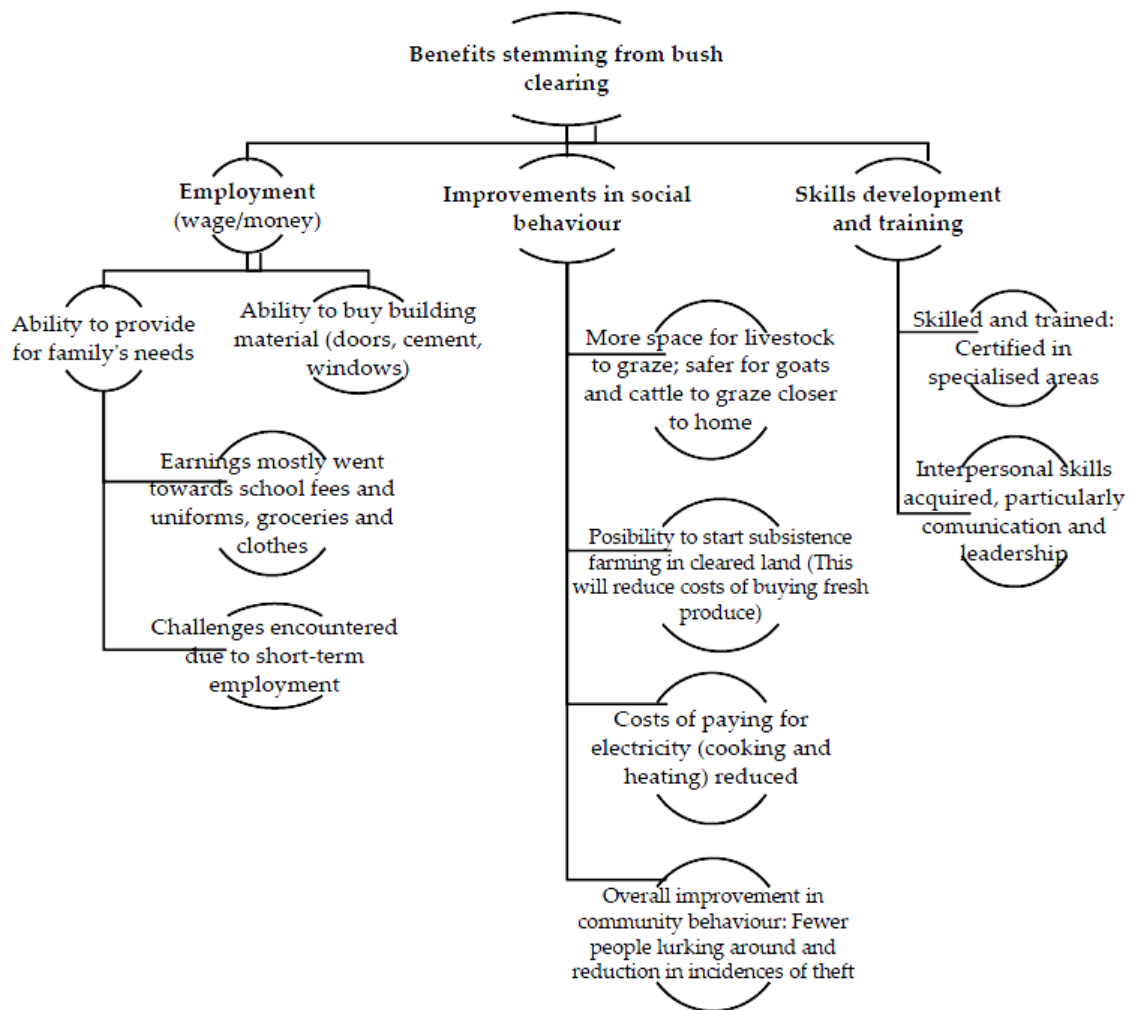
#### 7.3.1.3 Employment opportunities

In addition to the biophysical and financial benefits highlighted above, all participants who work for the nature reserve highlighted the prospect of employment as an added socio-economic benefit. According to them, hundreds of job opportunities can be offered to local disadvantaged “bush clearers” who, by participating in these projects, can lessen the financial burden on their families and improve their livelihoods.

*“I am very happy because the project has employed many people from outside the nature reserve especially from the villages. At least month end the people can get something to buy food, half a loaf is better than nothing.” Participant #2, 56*

### 7.3.2 Emerging themes: Shongoane village

As can be observed from Figure 7.2 below, community participants residing in Shongoane derived several direct and indirect socio-economic benefits from their participation in bush clearing and restoration projects.



**Figure 7.2** Thematically analysed benefits for Shongoane village.

### 7.3.2.1 Employment

The first benefit participants residing in Shongoane alluded to was the wage (money) they earned. With this money, they could take care of their family's basic needs by buying food and clothes and paying for school fees and uniforms. Secondly, the wage enabled them to buy building materials such as doors, windows and cement:

*“This money has helped me because my husband is unemployed. We have a building project and the money has helped to buy doors and windows so that we can finish building the room.” Participant #8, 37*

On the downside, the wage participants earned did not provide for much more than basic needs and perhaps a couple of extras. For example, it did not extend to covering the actual costs of adding another room to a home or to undertaking any other long-term project that would improve participants' well-being:

*“Not much of my well-being has changed because the money is too little, I can only buy small things like groceries.” Participant #7, 31*

Furthermore, participants found that the term of their contracts was too short. In the rule, contracts are renewed on a three-month basis. Nevertheless, most participants said that working on a short-term basis is better than not working at all.

### 7.3.2.2 Improvements in social behaviour

Given that participants reside in or near the sites where bush clearing and restoration work took place, they were in a position to observe a marked change in the behaviour of fellow community members. The community realised the productiveness of the environment and how it can

eventually be a cost-effective resource in their lives. What they observed was that people living in and around the sites where bush clearing took place came to collect cut branches to use as firewood for cooking and heating. In one instance, a female participant who came to collect firewood with her children said that since it is expensive to operate an electrical stove, the wood they collected helped them to save on electricity. Furthermore, cleared land space resulted in more space where community members' livestock could graze nearby in areas where their owners could keep an eye on their goats and cattle to ensure that they remained safe. This gave them some sense of security knowing that they were able to check on their livestock close by. Although the community has not yet embarked on small-scale crop farming, many alluded to the possibility of being able to start subsistence farming on the cleared land in future, as this would help in reducing expenses of having to buy fresh produce from shops or markets. Regarding the general social environment and the behaviour of the community, participants also remarked that since people were gainfully occupied, fewer were lurking around which, according to them, resulted in a reduction in incidences of theft.

#### 7.3.2.3 Skills development and training

Many young people from the village are unemployed and have never had the opportunity to gain work experience and/or to improve their skills through training. Given that those who participated in the bush clearing and restoration projects were afforded the opportunity to be formally certified in amongst others, snake control and herbicide application, the knowledge and skills they acquired in the course of their participation will undoubtedly improve their prospects of finding gainful employment in future.

*“This project has not only benefited me, but others too because most people were unemployed in our village and now we are gaining experience.” Participant #5, 29*

Besides the practical knowledge and skills participants obtained, many also remarked that their interpersonal skills and ability to communicate with and lead people have improved in the course of their participation.

*“We work well together and we listen to each other. If there is a problem, we solve it well without a fight.” Participant #5, 29*

#### **7.4 Discussion**

Ecosystems provide a range of services, many of which are important to local communities and human well-being (Stafford *et al.*, 2017). In South Africa, an important driver of ecosystem decline is bush encroachment and the spread of invasive alien plant species (Ward, 2005; Stafford *et al.*, 2017).

Given that the D’Nyala Nature Reserve is considered a protected area in South Africa that is earmarked by the Department of Environmental Affairs as an area where biodiversity should be preserved, several projects involving members from surrounding communities were launched in 2016 under the auspices of the department’s Natural Resource Management (NRM) and Expanded Public Works Programmes (EPWP). These projects mostly entailed the removal of invasive alien plants, the restoration of rangeland and land management.

As pointed out by De Klerk (2004) and Arbieu *et al.* (2017), reduced visibility caused by bush encroachment decreases the tourism potential of lands since this phenomenon has an impact on tourists’ ability to view game in their natural habitat. Furthermore, Ward (2005) found that since bush encroachment has a negative impact on game’s ability to graze freely, the carrying capacity of land is reduced considerably.

From a biophysical perspective, the manager of the D’Nyala Nature Reserve reported that the bush clearing and restoration projects conducted under the auspices of the NRM programme succeeded in improving the environmental state of the reserve considerably. This not only led to the perceived increase in revenue because tourists would find the reserve more attractive but also resulted in cost savings since emerging grass species lessened the need to provide game with supplemental feed. In addition, keepers of livestock in Shongoane village found that the bush clearing and restoration projects enabled them to keep their communal goats and cattle safely closer to their homes, and conceded that the improvement in grazing will, in the long run, result in livestock fetching higher prices at market.

The study sought to understand the link between restoration (biodiversity) and ecosystem services (social benefits). The results indicated that bush clearing and restoration projects had a significant impact both on the local community and on the nearby nature reserve in as far as the provision of employment opportunities for community members and increased the nature reserve’s prospects of generating a higher income. These findings regarding socio-economic impacts largely correlate with those reported by Saayman *et al.* (2009) and Stafford *et al.*, (2017) in earlier studies.

From the thematic analysis, it is clear that those participants who are directly associated with the nature reserve (i.e. D’Nyala) as well as those who reside in the nearby village (i.e. Shongoane) view employment, albeit temporarily, as a major benefit derived from bush clearing and restoration projects.

In essence, the value of benefits for community members has two components: firstly, it has a monetary value (i.e. wages earned) and, secondly, it has an empowerment value in as far as participants could improve their employability by being afforded the opportunity to acquire skills and to be trained in specialist areas such as snake control and herbicide application, mastery of which were rewarded with a formal certificate. The notion that participants can

improve their levels of education in the course of working on bush clearing and restoration projects is supported by Lal (2006), who found education to be an important indirect socio-economic benefit associated with the prospect of finding employment in future.

Nevertheless, this study found that there was a marked difference between female and male participants' satisfaction with the monetary benefits derived as a result of being employed to execute bush clearing and restoration projects. Most female participants had families with at least two children in the household and were of the opinion that their participation greatly helped to take care of basic needs (i.e. buying groceries and clothes and paying for school fees and school uniforms). Most male participants, on the other hand, were of the opinion that the wages were too low and could barely cover their basic necessities, let alone provide for major projects such as renovations and additions to their homes. Gcabo (2005) also confirms that money has different meanings to different genders, and therefore influences the different needs on how it is used. Furthermore, results by Gcabo (2005) indicated that money for women was the basis for survival at home as it is used to serve the basic needs, and to take care of the family, while money for men meant economic and social status and pride: The less you have, the less important you are considered in the community (Posel, 2001).

This contradiction despite, it can be concluded that the bush clearing and restoration activities undertaken in Lephalale did indeed help to create temporary employment opportunities for members of the community and resulted in socio-economic benefits being derived, a view that is supported by Francis *et al.* (2005) and Stafford *et al.* (2017).

Of concern here is that even though most community participants were appreciative of the financial relief and the incumbent benefits temporary employment offered (Lal, 2006), they failed to understand why employment would only be of a temporary nature. This concern regarding the sustainability of projects and the ability to keep on supporting participants' livelihoods once employment contracts have expired was also raised in a study conducted by

Akama and Kieti (2007). Of interest here is that the participants employed at the nature reserve remarked that even though the community members were dissatisfied about their income and short-term contracts, “half a loaf is better than nothing”. In the integrated development plan of Lephalale (Integrated Development Plan 2018/19), the importance of the tourism industry to the economy was realised. Even though the expansion of the tourism industry is highly dependent on its strong links to the industrial operations, it will give an opportunity for future income generation for the unemployed rural community members.

As found by Arnold *et al.* (2012) and DeCaro and Stokes (2013), positive outcomes are not always guaranteed in community-based projects. In this instance, too, both the nature reserve and the community had to deal with one common challenge, namely the low compensation offered to workers involved in the bush clearing and restoration projects. As a result, especially the nature reserve had to deal with unhappy and discouraged workers.

Furthermore, since the introduction of the projects first had to be vetted by the village chief, politically motivated and/or personal interests might have resulted in community members not deriving the full benefit of the projects. In this regard, Druschke and Hychka (2015) pointed out that communication and mutual cooperation are key to the process of community-based projects since it shapes the quality of community engagement which, in turn, can translate to all parties benefiting.

Nevertheless, as discussed above, the overall benefits derived from the bush clearing and restoration projects deployed in D’Nyala and Shongoane far outweigh the challenges.

## **7.5 Conclusion**

Bush encroachment and the invasion of alien plant species alter the balance of natural ecosystems. As illustrated by the bush clearing and restoration projects undertaken in the D’Nyala Nature Reserve and the Shongoane village, it is possible for both nature reserves and

communities to derive some socio-economic benefits from communal attempts to address this issue. As is evident from the findings of this study, community members benefited directly and indirectly because the bush clearing and restoration projects created employment opportunities as well as afforded members of the community opportunities to undergo training and to, in the process, acquire marketable skills and knowledge. Likewise, the nature reserve benefitted from the bush clearing and restoration projects because more tourists would potentially now find the reserve more attractive. Increased grazing capacity means that the reserve can cut on supplementary feeds for game.

Despite the challenges encountered in implementing land restoration projects in and around Lephalale, it was obvious that the socio-economic benefits derived far outweigh the negatives and that there is every reason to institute projects of a similar nature elsewhere in future.

## CHAPTER 8

### GUIDELINES FOR THE APPLICATION OF THE BRUSH PACKING RESTORATION TECHNIQUE

#### 8.1 Overview

Bush clearing, followed by the application of the brush packing restoration technique, has been implemented with success to mitigate an increase in the density of woody species (also referred to as ‘bush encroachment’) in an attempt to counter the resultant land degradation caused by this phenomenon in savannas. In short, brush packing involves covering bare degraded soil surfaces with woody branches harvested from bushes that have been cleared in the surrounding area. It was found that this regime can be implemented as a cost-effective restoration technique that enables rangeland managers and land users to restore degraded land. Ultimately, the brush packing restoration technique enhances vegetation establishment, improves ecosystem services and biodiversity and increases biomass production which, in turn, enhances grazing capacity. To restore bush-encroached lands that have been degraded on a large scale, a restoration plan should be followed (Kellner, 2013). The following procedures (steps) can serve as a guideline for restoration specialists, land users, contractors (land-user initiatives), researchers and policy makers (government) in the development of such a restoration plan.

#### 8.2 Steps for implementing the brush packing restoration technique

##### *Step 1 – Site identification*

- Sites that are severely degraded (very little or no herbaceous (grass) cover) must be prioritised. Most of these sites will be composed of large patches of bare grounds.

- When assessing sites, make use of GIS (geographic information systems) and remote sensing (RS) technologies but be sure to also incorporate indigenous knowledge. In the process, pay particular attention to:
  - ✓ Ecosystem condition (soil and vegetation)
  - ✓ Dominant invasive woody species
  - ✓ Climate (rainfall and temperature) over both the short and long term
  - ✓ Socio-economic aspects
  - ✓ Land use

### *Step 2 – Bush clearing*

- Once sites have been identified, notify relevant land users and/or authorities in the area of the intended restoration project and ensure stakeholder buy-in.
- Use guidelines stipulated by the Department of Environment, Forestry and Fisheries on which woody species to remove/clear and at what height.
- Choose appropriate bush clearing methods (i.e. manual, mechanical, chemical and biological or a combination thereof) (Turpie et al., 2019). In general, a combination of manual and chemical methods seems to be preferred.
- If chemical application is to be used, choose the correct registered chemical (arboricide) to control a certain woody species and follow the instructions as provided. The application type and ratio might differ for each chemical application.
- Bush clearing must be carried out by trained workers using effective apparatus/equipment, and the use of the latter must be supervised carefully and properly. Apparatus/equipment can include any or a combination of the following:
  - ✓ Chainsaws
  - ✓ Handsaws
  - ✓ Brush cutters

- ✓ Pruning loppers
- ✓ Bush axes
- Immediately after cutting, an arboricide that has been registered to control certain woody species must be applied effectively to all cut stems to avoid re-growth (coppicing). The arboricide can be sprayed or smeared on the cut stems (Figure 8.1).
- Follow the instructions and correct control methods for the different woody species as developed by the Department of Environment, Forestry and Fisheries (see recommended reading).



**Figure 8.1** Arboricide (Kaput gel) being sprayed/smeared on cut stems after cutting.

*Step 3 – Brush packing (BP)*

- After bush clearing, use the brush packing technique to cover bare and denuded patches (Figure 8.2).
- Use branches/twigs from any woody species (after clearing), including spiny branches and loose leaves if available. Note that this has to be done when the branches are dry and when the trees are not in the flowering stage to avoid the re-introduction of invasive seeds into the seed bank. The spines will provide a degree of protection against grazers

and help to prevent further herbivory by livestock so as to enhance the re-growth of grasses and other herbaceous species, while the leaves will help to recover soil nutrients.

- Depending on the condition of the ecosystem (surrounding species and soil type), the soil surface can be lightly disturbed, for example using a rake, and re-seeded with seeds of perennial, palatable grasses where necessary. The latter will depend on the project budget and the availability of seeds from suppliers.
- The brush (branches/twigs) used should be placed against the flow of water (perpendicular) to trap any other organic material and, where possible, the height should not exceed 1.5 m. Branches should not be stacked on top of one another but spread evenly over the area for total coverage.
- Since it is not feasible and too expensive to implement BP over the entire degraded land area, so-called 'brush packing plots/islands' should be created on severely affected areas.
- Creating approximately five plots/islands measuring 20 m x 20 m in size per one bush-cleared hectare ought to be a good representation to restore a degraded area. These brush packing plots/islands will serve as a favourable micro-environment for the growth and recruitment of herbaceous species.
- Brush packing plots/islands must be maintained regularly and kept in a good condition. Where possible, especially in communal lands, these plots/islands should be fenced and access prohibited to protect them against human disturbance (e.g. firewood collection) and grazers.



**Figure 8.2** Brush packing technique being deployed to cover bare and denuded patches.

*Step 4 – Monitoring and reporting*

- For research and development purposes, it is important to monitor brush packing plots/islands regularly and to report findings.
- Monitoring should encompass repeated surveys (twice a year) of vegetation and soil parameters over the short and long term to assess and evaluate the effectiveness of the restoration techniques so that adaptations can be made where necessary.
- In the interest of obtaining good and effective restoration results over the long term, scientific feedback and reporting are recommended so as to aid the timely adjustment of restoration plans should the need arise.

**8.3 After-care**

As indicated, involving community and land users/managers in the formulation and adoption of restoration plans from the outset is important (Figure 8.3). For the sake of the long-term sustainability of restoration projects, it is equally important to involve all parties in devising good after-care programmes and to ensure that everyone is continuously kept abreast of progress and any adaptations/amendments that have to be made to these plans.



**Figure 8.3** The success of restoration projects hinges on community involvement.

## CHAPTER 9

### CONCLUSION AND RECOMMENDATIONS

#### 9.1 Summary of research

This thesis covers a study conducted in a semi-arid area of the Lephalale municipality in Limpopo, a province of South Africa, which focused on restoration after bush clearing and the impact bush clearing and restoration activities have on ecosystem services. In particular, the study investigated the effect brush packing as a restoration method had on improving grass biodiversity and aboveground biomass (biophysical). The study was conducted at two sites, namely the D’Nyala Nature Reserve and Shongoane village, representing two different land-use types: a conservation area and a communally managed area. The analysis included comparing the effect brush packing and non-brush packing treatments had on some ecological variables (grass species richness, abundance, structural composition and aboveground biomass) and the cost implication of using brush packing as opposed to non-brush packing methods. Furthermore, the socio-economic contribution of the bush clearing and restoration projects was also evaluated for the two land-use types (i.e. a communal and conservation area). The key findings of this study are summarised below.

##### 9.1.1 Chapter 4

##### **Baseline study**

The aim of the baseline study was to determine the state of bush encroachment prior to bush clearing at the two study sites. Furthermore, the intention was to establish whether there were any marked differences in grass species diversity before and after application of brush packing as restoration method compared to the other methods. The findings of the baseline study revealed that:

- The occurrence of bush encroachment causing an invasion of woody species at the study sites (communal and conservation area) is a complex phenomenon since many different parameters play a role, such as type of vegetation and soil as well as the management and land use at each site (Kgosikoma *et al.*, 2012; Lesoli *et al.*, 2013).
- Huge differences in woody density for the different height classes were recorded at both study sites. A higher woody density at height class five (> 2.5 m) was recorded at the D’Nyala study site, while a lower density was recorded at the Shongoane site for the same height class. *Dichrostachys cinerea* was the dominant encroacher at the D’Nyala study site, while *Senegalia mellifera* was the dominant encroacher at the Shongoane site.

Since the Shongoane study site is a communally managed area, the decreasing woody density in higher height classes can possibly be ascribed to the harvesting of woody species by local community members for use as firewood and kraal fencing material. On the other hand, the opposite was recorded at D’Nyala, with an exponential increase as the height classes get higher, which is mainly due to the conservation of species in the nature reserve (see Figure 4.2). These findings shaped an important understanding as to what kind of restoration activities (management) may be most appropriate for different land-use types as communal areas depend on woody species of particular height classes whereas there is no human disturbance in the conservation area. The findings of the baseline study conducted at the two sites confirmed that bush clearing and restoration needed to take place.

### 9.1.2 Chapter 5

#### **Grass species diversity response to brush packing under different land-use types**

The objective here was to evaluate the effect the brush-packing restoration technique had on grass diversity at the communal and conservation area. This chapter included a comparison of grass diversity (richness, evenness and abundance) between 2017 (prior to bush clearing), 2018

and 2019 (after restoration application) at the two study sites. An assessment of the effect brush packing versus non-brush packing treatments had on rangeland vegetation was also conducted by looking at indicator species and listing their ecological status. Furthermore, this chapter analysed the differences in grass species communities in the brush-packed treatments versus the non-brush packed treatments in both the communal and conservation area. The results in this chapter showed that:

At the D’Nyala study site (conservation area):

- Biodiversity, represented by the Simpson and Shannon index, showed a significant difference between the years, with a higher difference between 2017 and 2019 than 2018 and 2019.
- Grass species richness was slightly reduced in 2019 compared to 2017.
- The overall species evenness was lowest in 2019 compared to the other years.
- Abundance was higher on brush-packed treatments than on non-brush-packed treatments, with a higher effect in 2019.
- Of the 30 grass species recorded within the three years, 26 were listed as increaser II and four as decreasers (Foran *et al.*, 1978; Trollope, 1990). The decreaser grasses recorded mainly included the re-seeded species in the brush packing treatments.
- Brush packing seemingly did not affect species distribution since there was no clear clustering in the non-metric multidimensional scaling (NMDS) ordination.

At the Shongoane study site (communal area):

- The Simpson and Shannon index showed that biodiversity was higher in the treatments with brush packing as opposed to those without.
- Grass species richness was most affected by the brush packing and re-seeding treatment and was higher in the year 2019.

- A tendency that grass evenness increases over the years when brush packing was applied was observed, even though it was not statistically significant.
- Brush packing and re-seeded treatments had a greater effect on increasing grass abundance in the years 2018 and 2019.
- Most of the grasses were listed as increaser II with only four decreaser species. However, a higher number of perennial grass species was identified in the brush packing treatments.
- Brush packing had an effect on species distribution, with a clear grouping of those with high and moderate grazing value in the brush packing treatments and those with low grazing value in the non-brush packing treatments.

The results confirmed that the brush packing treatments had an effect on improving grass species diversity. Brush packing undoubtedly creates a microenvironment that is favourable for the growth and recruitment of grass species. The results also showed that the brush packing restoration technique promotes better biodiversity in communal areas than in conservation areas.

### 9.1.3 Chapter 6

#### **Brush packing as cost-effective restoration technique to improve grass aboveground biomass after bush clearing**

Here the objective was to evaluate the effect the brush packing restoration technique had on improving aboveground biomass at the two study sites. In addition, the cost implications of using the brush packing technique compared to the use of other techniques (treatments) was evaluated. The aboveground biomass was tested after bush clearing and restoration application, while the cost implication was evaluated at the time of establishing the trial. The key findings are summarised below:

### Aboveground biomass at the two sites

- A significant difference in aboveground biomass between the brush packing treatments and non-brush packing treatments was recorded over the two years (2018 and 2019) at both sites.
- Brush packing treatments had a higher aboveground biomass than the non-brush packing treatments, especially in 2019 when the highest biomass was recorded at both sites.
- Aboveground biomass increased by over 87% in 2019 when compared to the aboveground biomass in 2018 at both study sites.
- Treatments that included re-seeding without brush packing showed no improvement for aboveground biomass.
- The brush packing treatments when compared to the control (a plot that was left un-cleared and not restored) showed an improvement in biomass of more than 150% at D’Nyala, while at Shongoane an improvement of more than 1,000% was recorded.

Brush packing improved aboveground biomass considerably, thereby contributing to increased production potential, especially for grazers. At all the experimental sites, in the D’Nyala Nature Reserve and at Shongoane, biomass proved to be higher in the brush-packed treatments compared to the non-brush-packed treatments (see Figures 6.1-6.4). Another key finding, similar to the results reported in Chapter 5, it seems brush packing promotes better plant establishment and growth in communal areas. Thus, biomass improved 10 fold higher (when compared to the control treatment) as a result of brush packing in the communally managed area compared to the conservation area. This implies that through the use of brush packing, grazing capacity can be improved and biodiversity can be increased, ultimately contributing to sustainable land management practices to the benefit of land users.

### Cost implications of using brush packing as restoration method

The objective here was to establish whether brush packing as restoration method can be used effectively and sustainably for future restoration in rural parts of South Africa. The findings are summarised below:

- The most complex treatment – clearing, soil disturbance, re-seeding and brush packing (CSRS-BP) – required more time, thus costing more money.
- Re-seeding cost was reduced to zero as the seeds were donated by a seed company, AGT Foods. If the seed has to be purchased for re-seeding during restoration, it may increase the costs considerably. Seeding cost could amount to an additional ZAR82.20/400 m<sup>2</sup>.
- The total person-time and costs were highest for the brush-packing treatments; nonetheless, those treatments produced the highest biomass by far.

Financial constraints are major challenges in developing countries in as far as restoring degraded land is concerned. Finding a cost-effective restoration method is thus imperative. Even though this study only covered the initial costs of restoration during trial establishment, all indications are that it is the first of its kind in South Africa. It should, however, be noted that the cost analysis in this study focused on the specific experimental sites where the study was conducted and does not estimate costs for every restoration project precisely. It does, however, provide an estimation of the costs when using the brush packing method for the restoration of degraded land on larger scales.

The establishment costs associated with person-time and materials were higher for the brush-packed treatments. However, these treatments were most effective given that they contributed to higher aboveground biomass and increased biodiversity. Labour and re-seeding costs in this study were reduced. Most of the workers who helped with the bush clearing were sourced from the Expanded Public Works Programme (EPWP), a government initiative by the Department

of Public Works and Infrastructure. If labour costs are to be reduced, a suggestion would be to consider involving volunteers from the community to assist with clearing and restoration.

Also of interest to note here is that in a study by Kimiti *et al.* (2017), it was found that for restoration purposes, using branches at a cost of \$0.0030/m<sup>2</sup> is far more cost effective over the long term than using other materials such as nylon mesh at a cost of \$0.0244/m<sup>2</sup>.

#### Costs for re-seeding

The aim with re-seeding in restoration is to improve groundcover especially in bare-patched areas, and in this study, perennial grasses were re-seeded to improve forage production for grazers. Many restoration methods necessitate re-seeding of these grasses to not only increase aboveground biomass production but also to improve soil physical properties (Visser *et al.*, 2007; Brits & Kellner, 2009; Mganga, 2009; Kimball *et al.*, 2015). However, re-seeding with grasses should be done in an area where the chance of success is good. This means that before re-seeding, it is of critical importance to first acquire a thorough knowledge of the type of grass that is adapted to the climatic and soil conditions, the timing of re-seeding and the re-seeding method that would be most cost effective.

- The findings in this study showed that re-seeding in combination with brush packing improved the grass biodiversity and aboveground biomass production, but the results were not statistically significant.
- Re-seeding should be reviewed carefully, especially in areas subject to financial constraints (GeFellers *et al.*, 2020).

#### 9.1.4 Chapter 7

##### **Socio-economic benefits stemming from bush clearing and restoration projects**

By following a qualitative approach, the objective here was to determine whether participation in the bush clearing and restoration projects resorting under this study had any significant sustainable impact on the livelihoods of community members and whether both the village and

the nature reserve derived any socio-economic benefits in the process. The key findings gathered from this part of the study are summarised below:

- The bush clearing and restoration project that was undertaken at the study sites in the D’Nyala Nature Reserve and the Shongoane village illustrated that it is possible for both nature reserves and communally managed land to derive socio-economic benefits.

In terms of Shongoane:

- The main socio-economic benefit from the bush clearing and restoration projects (brush packing application) was the creation of employment opportunities for members of the community.
  - ✓ This enabled them to cover basic needs such as food, school fees and clothes.
  - ✓ In addition, they were afforded an opportunity to gain new skills as a result of the training that was offered.
- The overall social behaviour and moral of the community improved, with fewer incidents of theft being reported in the community.

In terms of the D’Nyala:

- The nature reserve benefitted from the bush clearing and restoration projects since the clearing of the woody thickets causing bush encroachment contributed to improved game viewing, stimulating more tourists to visit the reserve and resulting in a potential increase in revenues.
- Furthermore, another impact of the bush clearing and restoration project was an increase in aboveground biomass which could be used by grazers and, ultimately, reduce the cost of having to provide additional feed for game at the reserve.
- For the duration of the project, the nature reserve was also in a position to create employment opportunities for members of the surrounding communities.

It is evident from the findings that the bush clearing and restoration project was beneficial for the local communities and for the nature reserve. While the project aimed to restore the environment, it also benefited the socio-economy of the area.

At the time of conducting the research, though, the participants (community members) revealed that the one issue they had with bush clearing and restoration projects in the area is the short-term nature of employment contracts, resulting in fear that they will be unable to sustain their livelihoods. Nevertheless, despite some challenges encountered by community members, the results showed that the socio-economic benefits derived from these projects far outweigh the challenges and suggest that such projects could be instituted elsewhere in the country.

## **9.2 Recommendations**

Findings in this study add to an understanding of the effects of bush clearing and brush packing as a restoration technique, particularly when applied to different land-use types in semi-arid areas. Consequently, this study could be used as a framework to develop scientific management techniques for restoring degraded areas in semi-arid savannas. However, some limitations were encountered that will require further research to cover certain hitherto unexplored aspects.

### **9.2.1 Management implications**

- Application of restoration methods to different land-use types

It seems that the brush packing restoration technique is very effective to improve biodiversity and aboveground biomass after bush clearing in both communal and conservation areas. However, it is important for scientific researchers and land users to note that the management thereof at the two sites differed considerably. The brush-packed experimental plots at the D’Nyala Nature Reserve study site remained intact even two years after they were implemented. This can be ascribed to little or no disturbance by animals and humans experienced at the nature reserve. In contrast, the study site at the Shongoane village was very

different. The community members harvested the brush pack for personal use such as fire wood and fencing material (as found in the baseline study, Chapter 4), while they also removed the brush packing from the plots since these plots had more grass for livestock to graze.

- Community involvement

Consultation with and involvement of local communities in restoration projects such as those carried out in this study cannot be emphasised enough. This is because communities can help to identify the best solutions and play a critical role in devising and approving ecological restoration proposals that are in harmony with their local socio-economic interests (Mureva *et al.*, 2014; Dorondel *et al.*, 2016). The indigenous knowledge of land users should be incorporated and regular feedback sessions/meetings should be held with all stakeholders/community members. The outcomes of the research should be discussed at feedback sessions, and long-term monitoring possibilities that include the community members should be investigated. This will encourage wider adoption of and the possible expansion of the brush packing restoration method and encourage monitoring over the long term.

While conducting the study, there were instances where community members took up residence (marked stands) in some of the bush-cleared experimental sites, resulting in tampering with the research results (biodiversity changes and biomass production reduction). This indicates that while implementing restoration projects, the success of restoration over the long term should be clearly planned involving community members so that the adoption of the project by community members can be ensured, especially near villages where expansion by the local community is still a necessity.

As indicated by the results, the community members did, indeed, benefit as a result of the creation of employment opportunities. Nevertheless, the restoration plan should include and also clearly explain which ecosystem services (ES) will be addressed and how this will improve the well-being of the community and simultaneously reduce land degradation.

### 9.2.2 Synthesis

The results reflected in this thesis cover research and monitoring conducted over a very short period of time. Long-term studies on permanent plots in the communal area and in the conservation area are required to investigate vegetation and diversity changes and to evaluate the success and effectiveness of restoration, especially where bush clearing, brush packing and re-seeding methods were applied. In addition, there is a dire need for more research investigating the impact land use has on the population structures and dynamics of woody species, perhaps also in other parts of the country. Such research will provide evidence of the recruitment and regeneration of woody species in relation to human land use.

The study also identified and evaluated the ecosystem benefits and services derived by local community members. In conducting the study, it came to the fore that a possible limitation might be that bush clearing and brush packing restoration activities are labour-intensive activities demanding workers to clear many woody species and to then re-pack cleared areas. Given that the EPWP is structured so as to give precedence to the employment of women (65%), this directive is not always plausible in instances such as these and ought to be reconsidered. This is not to say, though, that women did not prove to be good workers in the course of this study.

Although the initial target of the projects was the ecological restoration of the environment, it also contributed towards addressing the unemployment issue in South Africa, developed participants' skills and improved the nature reserve's tourism attraction.

It is recommended that for all projects of this nature (i.e. bush clearing and restoration), attention should be paid to the human factor as well and that the focus should not only be on the biophysical aspects. Furthermore, these projects should involve not only scientific experts (researchers) but also local people who know the sites targeted for restoration well. In this way,

sites that are not used frequently or those that have not been earmarked for settlement purposes by the local community can be identified in an attempt to prevent tampering.

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## Annexures

**Annexure A:** Common names of woody species occurring in the study area.


<b>Scientific name</b>	<b>Common English name</b>
<i>Asparagus larycinus</i>	Bushveld Asparagus
<i>Combretum imberbe</i>	Leadwood
<i>Combretum zeyheri</i>	Bushwillow
<i>Dichrostachys cinerea</i>	Sickle bush
<i>Dombeya rotundifolia</i>	Wild pear
<i>Grewia bicolor</i>	White raisin
<i>Grewia flava</i>	Velvet raisin, Wild currant or Brandybush
<i>Grewia flavescens</i>	Sandpaper raisin or Rough-leaved raisinbush
<i>Lantana camara</i>	Cherry pie
<i>Sclerocarya birrea</i>	Marula
<i>Senegalia mellifera</i>	Black thorn
<i>Tarchonanthus camphoratus</i>	Camphor bush
<i>Vachellia tortilis</i>	Umbrella thorn
<i>Ziziphus mucronata</i>	Buffalo thorn

**Annexure B:** Common names of grass species occurring in the study area.

<b>Grass species name</b>	<b>Common English name</b>
<i>Andropogon chinensis</i>	Hairy Blue grass
<i>Aristida adscensionis</i>	Annual Three-awn, Annual bristle grass
<i>Aristida bipartita</i>	Rolling Three-awned grass
<i>Aristida canescens</i>	Pale Three-awn grass
<i>Aristida congesta</i>	Spreading Three-awn, Tassel Three-awn grass
<i>Aristida diffusa</i>	Iron grass
<i>Aristida rhinochloa</i>	Large-seeded Three-awn grass
<i>Aristida stipitata</i>	Long-awned Three-awn grass
<i>Bothriochloa radicans</i>	Stinking grass
<i>Bracharia deflexa</i>	False Signal grass
<i>Bracharia distachya</i>	Armgrass millet, Green summer grass
<i>Cenchrus ciliaris</i>	Blue Buffalo grass
<i>Centropodia glauca</i>	Gha grass
<i>Chloris gayana</i>	Rhodes grass
<i>Chloris virgata</i>	Feathered Chloris grass
<i>Cynodon dactylon</i>	Bermudagrass, Buffelgrass, Couch grass
<i>Cynodon nlemfuensis</i>	Star grass
<i>Digitaria eriantha</i>	Finger grass
<i>Digitaria longiflora</i>	False Couch Finger Grass
<i>Digitaria ternata</i>	Black-seed Finger grass
<i>Enneapogon cenchroides</i>	Nine-awned grass
<i>Enneapogon desvauxii</i>	Nine-awn Pappus grass
<i>Eragrostis curvula</i>	Weeping Love grass
<i>Eragrostis lehmaniana</i>	Lehmann's Love grass
<i>Eragrostis pallens</i>	Broom Love grass
<i>Eragrostis rigidior</i>	Broad-leaved Curly Leaf grass
<i>Eragrostis tef</i>	Teff grass
<i>Eragrostis trichophora</i>	Hairy Love grass
<i>Lintonia nutans</i>	Unknown (not found)
<i>Melinis repens</i>	Natal Red Top grass
<i>Panicum deustum</i>	Broad-leaved Panicum
<i>Panicum maximum</i>	Guinea grass
<i>Perotis patens</i>	Cat's Tail grass
<i>Pognarthria squarrosa</i>	Herringbone grass
<i>Schmidtia pappophoroides</i>	sand Quick grass
<i>Tragus berteronianus</i>	Common Carrot-seed grass
<i>Urochloa mosambicensis</i>	Bushveld Signal grass
<i>Urochloa panicoides</i>	Graden Signal grass

## Annexure C: Supplementary document relating to Chapter 7


### C 1: Ethics approval letter for the study conducted at D’Nyala Nature Reserve and Shongoane village.

	Private Bag X1290, Potchefstroom South Africa 2520  Tel: 018 299-1111/2222 Fax: 018 299-4910 Web: <a href="http://www.nwu.ac.za">http://www.nwu.ac.za</a>  <b>Research Ethics Regulatory Committee</b> Tel: 018 299-4849 Email: <a href="mailto:nkosinathi.machine@nwu.ac.za">nkosinathi.machine@nwu.ac.za</a>																														
31 March 2019																															
<b>ETHICS APPROVAL LETTER OF STUDY</b>																															
Based on approval by the North West University Health Research Ethics Committee (NWU-HREC) on 31/03/2019, the NWU Health Research Ethics Committee hereby approves your study as indicated below. This implies that the North-West University Research Ethics Regulatory Committee (NWU-RERC) grants its permission that, provided the special conditions specified below are met and pending any other authorisation that may be necessary, the study may be initiated, using the ethics number below.																															
<b>Study title:</b> Restoration after bush control and impact on ecosystem services in the Lephalale district, Limpopo Province. <b>Study Leader/Supervisor (Principal Investigator)/Researcher:</b> Prof K Kellner <b>Student:</b> RT Modungwa																															
<b>Ethics number:</b>	<table border="1"><tr><td>N</td><td>W</td><td>U</td><td>-</td><td>0</td><td>0</td><td>1</td><td>2</td><td>0</td><td>-</td><td>1</td><td>8</td><td>-</td><td>A</td><td>1</td></tr><tr><td colspan="3">Institution</td><td colspan="5">Study Number</td><td colspan="2">Year</td><td colspan="5">Status</td></tr></table> <i>Status:</i> S = Submission; R = Re-Submission; P = Provisional Authorisation; A = Authorisation	N	W	U	-	0	0	1	2	0	-	1	8	-	A	1	Institution			Study Number					Year		Status				
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<b>Application Type:</b> Single Study <b>Commencement date:</b> 31/03/2019 <b>Expiry date:</b> 31/03/2020	<b>Risk:</b> <table border="1"><tr><td style="text-align: center;">Minimal</td></tr></table>	Minimal																													
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<b>Approval of the study is initially provided for a year, after which continuation of the study is dependent on receipt and review of the annual (or as otherwise stipulated) monitoring report and the concomitant issuing of a letter of continuation.</b>																															
<b>Special in process conditions of the research for approval (if applicable):</b>																															
<b>General conditions:</b> <i>While this ethics approval is subject to all declarations, undertakings and agreements incorporated and signed in the application form, the following general terms and conditions will apply:</i> <ul style="list-style-type: none"><li>• The study leader/supervisor (principle investigator)/researcher must report in the prescribed format to the NWU-HREC:<ul style="list-style-type: none"><li>- annually (or as otherwise requested) on the monitoring of the study, whereby a letter of continuation will be provided, and upon completion of the study; and</li><li>- without any delay in case of any adverse event or incident (or any matter that interrupts sound ethical principles) during the course of the study.</li></ul></li><li>• The approval applies strictly to the proposal as stipulated in the application form. Should any amendments to the proposal be deemed necessary during the course of the study, the study leader/researcher must apply for approval of these amendments at the NWU-HREC, prior to implementation. Should there be any deviations from the study proposal without the necessary approval of such amendments, the ethics approval is immediately and automatically forfeited.</li><li>• Annually a number of studies may be randomly selected for an external audit.</li><li>• The date of approval indicates the first date that the study may be started.</li><li>• In the interest of ethical responsibility the NWU-RERC and NWU-HREC reserves the right to:<ul style="list-style-type: none"><li>- request access to any information or data at any time during the course or after completion of the study;</li><li>- to ask further questions, seek additional information, require further modification or monitor the conduct of your research or the informed consent process;</li><li>- withdraw or postpone approval if:<ul style="list-style-type: none"><li>- any unethical principles or practices of the study are revealed or suspected;</li></ul></li></ul></li></ul>																															



Article

# Socio-Economic Benefits Stemming from Bush Clearing and Restoration Projects Conducted in the D’Nyala Nature Reserve and Shongoane Village, Lephhalale, South Africa

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**Abstract:** This study aimed to investigate the socio-economic benefits stemming from bush clearing and restoration projects conducted in the Lephhalale municipality, within the Limpopo Province of South Africa. The study was conducted at two sites: the D’Nyala Nature Reserve and a nearby local village, Shongoane. A qualitative thematic content analysis approach and semi-structured interviews were used to gather data from 14 purposively selected participants between the ages of 22 and 55 (male = 9 and female = 5). The results indicated that the nature reserve benefited from the project via the improved visibility of the landscape features and game viewing, which made the reserve more attractive for tourists and resulted in increased revenue. The costs of buying feed for game could also be curbed since the grazing capacity increased. Since the nature reserve sourced temporary labour from the local village to execute the project, the community benefited in terms of members being able to earn a wage, which led to an improvement in their livelihoods. Another indirect benefit was the morale and behavioural changes observed amongst community members. It was obvious that the socio-economic benefits derived from projects such as these far outweigh the negatives and that there is every reason to institute projects of a similar nature elsewhere.

**Keywords:** bush clearing; local community; nature reserve; restoration project; socio-economic benefit

## 1. Introduction

The complex link between biodiversity and ecosystem services (social benefits) is yet to be understood. Previously, scientists took into account the conservation of biodiversity from a biophysical perspective [1–3]. In some cases, researchers found that although feasible, these conservation activities were not always sustainable [4,5]. This is mainly because local communities where conservation activities are practised [6,7] were not often involved and did not directly benefit from these activities [3,5].

Recently, there has been more of a focus on how local communities can become involved in and simultaneously benefit from conservation attempts, such as the restoration of degraded lands [7–9]. Some of the proposed strategies include short-term economic interventions aimed at

improving the livelihoods of local communities by, for example, creating temporary job opportunities, skills development, and training [10]. As is evident from the literature, though, the results of some of these efforts are rather contradictory.

For example, Arnold et al. [11] and DeCaro and Stokes [12] found that community and stakeholder involvement in the decision-making process does not always guarantee positive outcomes, while other studies such as Bernhardt et al. [13] found a positive correlation between direct community involvement and ecological restoration success. A report by Dorondel et al. [3] emphasised that in a great deal of projects that were done in the Danube floodplain, ecological restoration could not be implemented without the approval and participation of the local community.

This combination of uncertainty about a conservation project's outcomes and the pressure to succeed can result in uneasiness playing a significant role in local community behaviour [5]. Usually, this can be ascribed to the community's inability to envisage the long-term benefits they could derive from projects. Although communities expect to derive some form of benefit from conservation activities that will enrich their livelihoods, they tend to see projects as only benefiting project owners. For this reason, as far as the actual process of restoration implementation is concerned, Druschke and Hychka [14] argued that communication and mutual cooperation are key, because they shape the quality of community engagement, which in turn, can translate to all parties benefiting (or at the very least ensure buy-in and support from the local community).

Despite the mixed results obtained regionally and globally, Reid [15] concluded that, in essence, community-based restoration projects offer not only economic benefits but also knowledge and experience that communities can use to empower themselves, which will lead to the improvement of their livelihoods.

For example, a study conducted by Fox et al. [16] found that river restoration projects in the United States, Canada and New Zealand have the potential to not only restore ecosystem processes and services but to benefit the community by repairing and transforming human relationships. Even though the latter may not have a direct economic benefit, restored and transformed human relationships serve to create a cooperative space for dialogue and hold the promise of future cultural and educational benefits for the community. Similarly, Browder [17] found that even though economic development impacts were mixed in the Brazilian Amazon conservation and development project, approximately 50% of the projects delivered tangible benefits to local communities.

In their study of eight of the river restoration projects being conducted across Europe, Muhar et al. [18] also quantified the effect of restoration on ecosystem services. Included as benefits were the provisioning of agricultural products, wood and infiltrated potable water, as well as regulation and cultural services such as recreation and biodiversity conservation. The latter study's findings are supported by Vermaat et al. [19] who reported that river restoration projects showed a marked increase in ecosystem services over and above other benefits such as the economic upliftment of the community. The economic evaluation of wetland-based community participation was studied by Roy et al. [20]. In that study, it was highlighted that the stakeholders' livelihoods were uplifted through wetland conservation.

In another study involving the use of bush-encroached and gullied areas in India to produce biofuel by planting *Jatropha*, Francis et al. [10] found that the restoration activities helped to generate rural employment and increased environmental quality. In this instance, community members were involved in labour-intensive activities of clearing and replanting. The long-term effect of this restoration project was the improvement of degraded lands which could not be used for food production but were subsequently put to use to improve the livelihoods of local communities. In principle, land degradation can be effectively managed if the principal ecological, socio-cultural, and economic driving forces are properly understood [21]. With that said, the active involvement of local communities not only benefits them but also plays a crucial role in identifying and solving problems at the project site [21].

Given that economic and social conditions and resource availability in poor and developing countries differ considerably from those in developed countries [10], it is imperative to keep in mind

that these communities are largely dependent on land for agriculture, fuel and water to sustain the livelihoods of the rural poor [22,23]. Furthermore, communities in these countries often fall prey to prevailing climatic variations [15] and are characterised by high population densities and low skill levels [24].

Nevertheless, in his study of soil organic carbon pools in developing countries, Lal [25] demonstrated how acquiring new knowledge and skills (education) with regard to soil conservation that will eventually lead to higher productivity of land resources can benefit communities directly and indirectly. Note, though, that success in this instance was ascribed to first understanding the needs of the local farmers and then learning how to manage the state of the land.

Another case in point would be that of Namibia where land degradation, involving both bush encroachment and the spread of invasive alien plant species, was found to be an important driver of ecosystem decline [26,27]. This realisation led to restoration projects to clear bush-encroached and invaded areas by involving community members. In this instance, Stafford [27] found that the resultant benefits for the socio-economy and social development far outweighed the restoration of the land itself.

In sum, as Adams and Hutton [28] pointed out, “the compatibility of conservation and poverty alleviation” is bound to have social and economic impacts. Moreover, in terms of local community development, restoration activities should be sustainable over the long term rather than only impacting livelihoods during the course of the activities.

#### *Socio-Economic Benefits of Restoration Projects in South Africa*

South Africa is a water-scarce country with rangelands covering almost 60% of the country [29,30]. Some of the worst degradation of these rangelands can be observed in communal areas and can be ascribed not only to poor land management but also to the high density of the population in these areas [22]. The Limpopo province, the study area, with a population density of more than 46 people per km<sup>2</sup>, is thought to be one of the most degraded in South Africa, particularly in the communal areas [31,32]. Much of the degraded area (56%) was land primarily used for the grazing of domestic animals [33]. It is further estimated that 16% of the province is infested with alien invasive plants [33], which have necessitated restoration projects. Poor land management combined with drought conditions, especially in arid- and semi-arid ecosystems, poses a threat to the long-term productivity of the land, especially where communally managed lands are further degraded as a result of bush encroachment and the invasion of alien species [23,34]. Recognising this, and that a large proportion of the population is dependent for their livelihoods on services derived from dryland ecosystems, South Africa ratified the United Nations Convention to Combat Desertification (UNCCD) in countries experiencing serious drought and/or desertification in 1997. The country prepared a National Action Programme (NAP) combating land degradation to alleviate rural poverty [35]. Furthermore, a national programme called Working for Water (WfW), launched in 1995, is aimed at removing invasive alien plants to reduce competition from unwanted plants and to increase land productivity potential [36].

Given that Lukomska et al. [34] found that de-bushing restoration techniques proved to conserve and increase grazing capacity resulting in generating a higher and sustainable income for local farmers, a detailed study of such projects in semi-arid areas that can be linked directly or indirectly to socio-economic benefits for local communities is warranted.

Relatively few data exist regarding restoration programmes across South Africa, particularly regarding the reconciliation thereof with social goals. By way of background, South Africa’s Department of Environment, Forestry and Fisheries (DEFF) has been tasked with the restoration of degraded lands on a national scale, a responsibility which by inference encompasses research and social development projects. In response, the department implemented the Natural Resource Management (NRM) and Expanded Public Works (EPWP) programmes. Given that this study set out to investigate the benefits of bush clearing and restoration projects from a socio-economic rather than a biophysical perspective, only those projects under the NRM are relevant here.

Overall, the objective of the DEFF-NRM programme is to ensure the sustainable land management of rangelands and to improve the socio-economic livelihoods and promote the well-being of people in rural areas. It encompasses a number of “working for” projects, all of which are labour-intensive. Included here is Working for Water (WfW), which involves projects to control invasive species (alien and indigenous), as well as Working for Ecosystems (WfEco) and Working for Land (WfL), both of which aim to address degraded ecosystems and to provide sustainable ecosystem services for rural communities in the long term ([www.environment.gov.za](http://www.environment.gov.za)). This study reports on the WfW, WfEco and WfL programmes specifically in as far as controlling bush-encroached rangelands is concerned.

Promoting an understanding of how nature works and how it can provide for everyday needs if protected is the obvious point of departure. However, it is imperative that those responsible for implementing bush clearing and restoration projects should also make it their business to gain an understanding of the value local communities attach to the ecosystem services they derive from natural resources if their projects are to succeed [13]. In short, the restoration of degraded rangelands should not be restricted to environmental conditions only, but should also encompass active intervention in as far as social and economic conditions are concerned [37].

Given South Africa’s extremes of unemployment and poverty, many families regularly experience hunger and find it difficult to meet their basic needs [38]. In the Lephalale municipality, the unemployment rate sits at 22.2% with a dependency ratio of 33.2% and 39.1% female-headed households, mostly in rural communities [38]. One of the short-term goals in the municipality was to generate employment, especially in projects involving the improvement of the environment. Considering the lack of research on how to involve local communities in restoration activities and how to optimise the socio-economic benefits they derive from being involved in such activities, this study set out to develop a decision support system (DSS) for all stakeholders, especially land users and policy makers. This was so that informed decisions could be made about the benefits derived from the restoration of degraded lands. To this end, two sites in the Lephalale municipality in the Limpopo Province where members from the community partook in bush clearing and restoration activities were investigated in an attempt to quantify the socio-economic benefits addressed in the process.

## 2. Methods

### 2.1. Study Area

This study was carried out at Lephalale, a municipality in the Limpopo Province, South Africa (23°40′ S 27°45′ E) (Figure 1). Lephalale is a coal-mining town and has a semi-arid climate, with a rainfall of 350–500 mm/y and maximum temperatures rising to 38.2 °C. The municipality has a population of 140,240 with 43,002 households in total and a dependency ratio of 33.2% [38]. Two sites where bush clearing and restoration projects have been implemented were visited to conduct interviews, namely: (1) D’Nyala Nature Reserve, which lies 15 km south-east of Lephalale, and (2) Shongoane, a village in the north-eastern rural part of Lephalale.

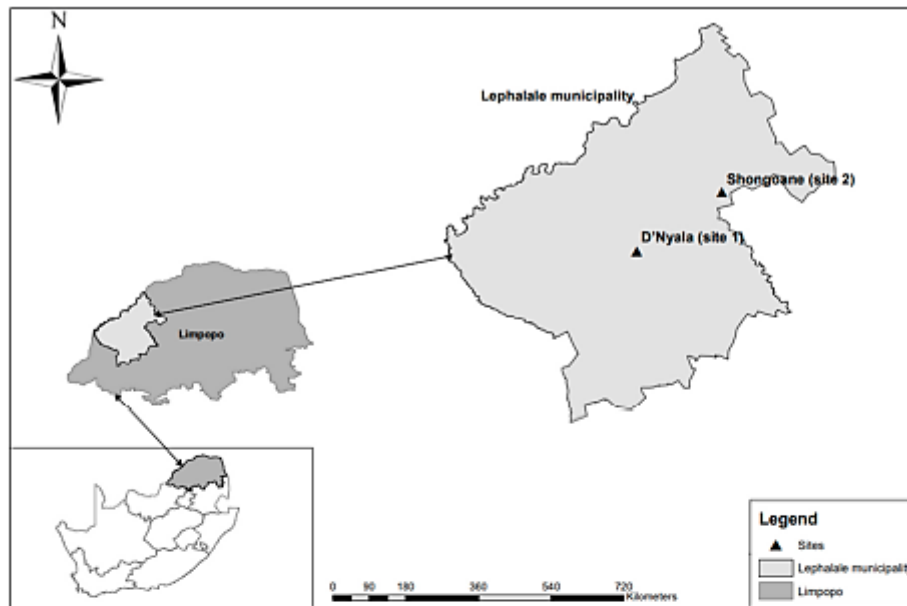


Figure 1. Study area.

Here, it ought to be noted that D'Nyala is considered a protected area in South Africa and is earmarked by the Department of Environmental Affairs as an area where projects to curb bush encroachment should be prioritised in order to protect biodiversity and to ensure the long-term sustainability of the reserve.

The D'Nyala Nature Reserve is approximately 8000 ha in size [38]. Socio-economically, the reserve plays an important role since it employs many people from surrounding villages, but mostly Shongoane, to take care of bush clearing and restoration work within its boundaries. Shongoane, one of many villages dotted around Lephale, is managed communally. Here, livestock is allowed to graze freely and, unlike in the nature reserve, the number of animals accommodated within the area is not kept in check. In the case of Shongoane, most of those employed to handle bush clearing and restoration reside in the village.

## 2.2. Approach and Strategy

The purpose of the study was to investigate what socio-economic benefits were received by the community members that partook in bush clearing and restoration activities. The objective was therefore to evaluate and quantify the socio-economic benefits addressed in the process on a small scale. A qualitative, thematic content analysis approach was used.

Given that qualitative research is defined by the nature of the questions asked [39,40], the concept and methodologies were adapted during the design of this study, and the analysis and interpretation were associated with assumptions made when collecting the data [41]. This approach was followed because the study sought to arrive at an understanding of the benefits derived from bush clearing and restoration projects from the perspective of those who actually benefited and, as pointed out by Hammersley [42], because qualitative research provides a more comprehensive and better understanding of the relationships between people and the environment.

### 2.3. Participants

Although around 400 people from villages in Lephalale partook in the bush clearing and restoration activities, only 25 of those were directly involved at both the D’Nyala and Shongoane sites. Some of the participants were employed at D’Nyala, with some being part of the management, and others residents from Shongoane. Out of these, a sample of eight workers involved in bush clearing at Shongoane and six involved in bush clearing and management in D’Nyala were purposively selected to partake in the study.

Comprised of both males and females ranging between 22 and 55 years in age, most of the participants had at least six months’ experience of bush clearing and restoration projects and were previously unemployed or recently retrenched. In sum, the group consisted of 6 general workers, 2 group supervisors, 2 nature conservationists, 3 tax and revenue collectors and 1 project coordinator, representing all the skillsets and functions within the project.

Purposive sampling was used because this study aimed to target those who were directly involved and could provide a first-hand/informed account of how they benefited from the bush clearing and/or restoration projects [43].

### 2.4. Procedure and Ethical Considerations

The North-West University’s Research Ethics Regulatory Committee (NWU-00120-18-A1) granted permission for the study. The principles and the regulations issued by the university’s registered ethics committee regarding research where human subjects are involved were taken into consideration during all of the phases in the study. Participation was voluntary and, having been assured that their identities would remain confidential, participants consented to partaking in the study individually. Interviews lasting approximately 20 to 35 min were conducted at participants’ places of work, in the field at the village or at the offices of the nature reserve. In all instances, participants could choose a venue and time that suited them best.

### 2.5. Data Gathering

Data were gathered by means of semi-structured interviews after the bush clearing and restoration projects had been completed. The questions asked during the interviews focused on participants’ first-hand experiences as direct beneficiaries of these projects from the time of the inception of the project right up until completion. The three questions asked were similar in nature, with the exception that question 3 was adopted for the sake of site relevance (see Table 1). Given that interviews were conducted face-to-face, a participant’s response to question 3 led to follow-up questions being asked where necessary in an attempt to gain a better understanding.

At D’Nyala Nature Reserve, all participants were interviewed. However, at Shongoane only nine workers were interviewed because at that point, saturation had been reached. In other words, it was clear at this point that no new information would be discovered and that conducting further interviews would lead to redundancy in the data collected. In total, data were collected from 14 participants from the two sites. All interviews were recorded digitally.

**Table 1.** Interview schedule for Shongoane village and D’Nyala Nature Reserve.

Topics	Questions
(1) Bush clearing programme’s main benefit	Can you please describe what the main benefit that you received was and how you used the provision from participating in the bush clearing project? What was your involvement directly or indirectly in the bush clearing and restoration project?
(2) Programme influences and the outcome	Can you describe how you experienced the programme: did it help in any way, or not at all?
(3) Possible lasting/sustainable impact of the bush clearing programme	(a) Shongoane participants: What changes, if any, have you seen in your well-being (included here are money for school fees, food and basic needs, etc.) as a result of participating in the bush clearing and restoration project? Is there anything that you gained from the project that will help you in future? Please describe if there are any. (b) D’Nyala participants: What changes, if any, have you seen in the nature reserve (included here are generating money, enhancing game/nature viewing, etc.) as a result of participating in the bush clearing and restoration project?

### 2.6. Data Analysis

Data were thematically analysed. Thematic analysis is a method commonly used in the analysis of qualitative data [44,45]. Audio recordings were transcribed and analysed by means of a thematic content analysis, a six-step procedure. The steps involve (1) data familiarising, (2) assigning preliminary codes to the data in order to describe the content, (3) theme coding across the interviews, (4) the reviewing of themes, (5) the defining and naming of themes and lastly (6) producing results from the thematically categorised data [45,46]. This method allows for the flexible identification of themes and sub-themes; moreover, because this was a deductive study, it was easier to select themes, as the exact interest was known.

After each interview, the researcher reflected on and explained the information provided by the participant in an attempt to ensure that the quality of the information was retained. As a further safeguard to ensure that the study’s findings were not influenced by researcher bias, a gatekeeper with a deep understanding of the bush clearing and restoration projects in and around the nature reserve was employed to ensure the trustworthiness of the data within the context of the study.

### 3. Results

This study set out to investigate the socio-economic benefits addressed by means of bush clearing and restoration projects deployed in and around the Lephalale municipality in the Limpopo Province. The study was conducted at two sites, namely the D’Nyala Nature Reserve and Shongoane, a rural village in the north-eastern part of Lephalale.

As explained above, data collected by means of interviews conducted with purposively selected participants were thematically analysed. Based on the analysis and to illustrate the differences between the benefits derived by participants employed at the D’Nyala Nature Reserve versus participants who resided in Shongoane village, Figures 2 and 3 below highlight the three most important themes emerging from the nature reserve’s data and the data derived from participants who resided in the village.

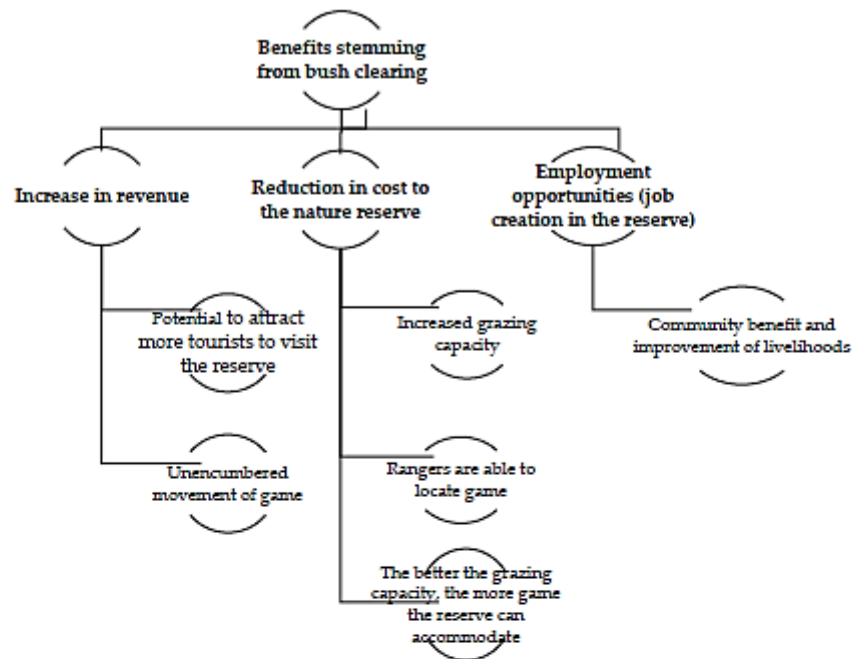


Figure 2. Thematically analysed benefits for D’Nyala Nature Reserve.

### 3.1. Emerging Themes: D’Nyala Nature Reserve

Bush clearing in the reserve commenced in 2016. Up until that point, the reserve was so heavily encroached upon that even the entrance area was not quite accessible. As illustrated in Figure 2 below, the following themes emerged as direct benefits resulting from bush clearing and restoration work in the reserve.

#### 3.1.1. Increase in Revenue

Participants were in agreement that bush clearing definitely improved visibility within the reserve. Where overgrown patches made it difficult for tourists to spot game before, they could now observe wildlife unhindered from afar. If tourists were assured that they were likely to spot game unhindered, they were more likely to be attracted to the nature reserve and if tourists were attracted, the nature reserve’s revenue was bound to increase.

Since the nature reserve also offers opportunities for recreational hunting, participants observed that as a result of bush clearing, game was less encumbered and free to roam more widely. Before, there were areas that even rangers found difficult to navigate.

*“There used to be a lot of bush even closer to the tar road, sometimes you could see the animal but when you try to get closer it would run and hide into the bush and it would be difficult to locate it.”*

*Participant #1, 42*

#### 3.1.2. Reduction in Costs

The reserve is host to a whole array of animals, including several species of antelope. Bush clearing resulted in increased grazing capacity and a reduction in the need to supply supplementary feed.

In addition, participants working for the reserve remarked that they now had to spend fewer man-hours on tracking and monitoring game because, with less camouflage, the animals were easier to spot

*“So far where it is cleared especially sickle bush, there is a visible change of vegetation of which is beneficial for the animals because there is more grass to graze.” Participant #3, 33*

### 3.1.3. Employment Opportunities

In addition to the biophysical and financial benefits highlighted above, all participants who worked for the nature reserve highlighted the prospect of employment as an added socio-economic benefit. According to them, hundreds of job opportunities could be offered to local disadvantaged “bush clearers” who, by participating in these projects, could lessen the financial burden on their families and improve their livelihoods.

*“I am very happy because the project has employed many people from outside the nature reserve especially from the villages. At least month end the people can get something to buy food, half a loaf is better than nothing.” Participant #2, 56*

### 3.2. Emerging Themes: Shongoane Village

As can be observed from Figure 3 below, community participants residing in Shongoane derived several direct and indirect socio-economic benefits from their participation in bush clearing and restoration projects.

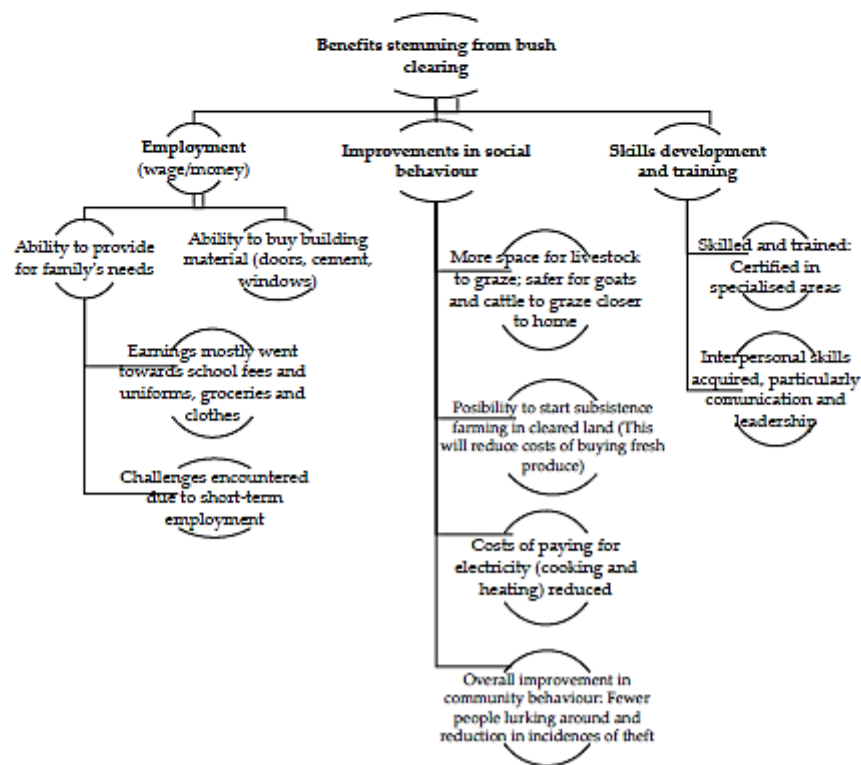


Figure 3. Thematically analysed benefits for Shongoane village.

### 3.2.1. Employment

The first benefit participants residing in Shongoane alluded to was the wage (money) they earned. With this money, they could take care of their family's basic needs by buying food and clothes and paying for school fees and uniforms. Secondly, the wage enabled them to buy building materials such as doors, windows and cement:

*"This money has helped me because my husband is unemployed. We have a building project and the money has helped to buy doors and windows so that we can finish building the room." Participant #8, 37*

On the downside, the wage participants earned did not provide for much more than basic needs and perhaps a few extras. For example, it did not extend to covering the actual costs of adding another room to a home or to undertaking any other long-term project that would improve participants' well-being:

*"Not much of my well-being has changed because the money is too little, I can only buy small things like groceries." Participant #7, 31*

Furthermore, participants found that the term of their contracts was too short. As a rule, contracts were renewed on a three-month basis. Nevertheless, most participants said that working on a short-term basis was better than not working at all.

### 3.2.2. Improvements in Social Behaviour

Given that participants resided in or near the sites where bush clearing and restoration work took place, they were in a position to observe a marked change in the behaviour of fellow community members. The community acknowledged the productiveness of the environment and how it could eventually be a cost-effective resource in their lives. What they observed was that people living in and around the sites where bush clearing took place came to collect cut branches to use as firewood for cooking and heating. In one instance, a female participant who came to collect firewood with her children said that since it was expensive to operate an electrical stove, the wood they collected helped them to save on electricity. Furthermore, cleared land space resulted in more space where community members' livestock could graze nearby in areas where their owners could keep an eye on their goats and cattle to ensure that they remained safe. This gave them some sense of security knowing that they were able to check on their livestock close by. Although the community had not yet embarked on small-scale crop farming, many alluded to the possibility of being able to start subsistence farming on the cleared land in future, as this would help in reducing the expenses of having to buy fresh produce from shops or markets. Regarding the general social environment and the behaviour of the community, participants also remarked that since people were gainfully occupied, fewer were lurking around, which, according to them, resulted in a reduction in incidences of theft.

### 3.2.3. Skills Development and Training

Many young people from the village are unemployed and have never had the opportunity to gain work experience and/or to improve their skills through training. Given that those who participated in the bush clearing and restoration projects were afforded the opportunity to be formally certified in, amongst others, snake control and herbicide application, the knowledge and skills they acquired in the course of their participation would undoubtedly improve their prospects of finding gainful employment in future.

*"This project has not only benefited me, but others too because most people were unemployed in our village and now we are gaining experience." Participant #5, 29*

Besides the practical knowledge and skills participants obtained, many also remarked that their interpersonal skills and ability to communicate with and lead people had improved in the course of their participation:

*“We work well together and we listen to each other. If there is a problem, we solve it well without a fight.” Participant #5, 29*

#### 4. Discussion

Ecosystems provide a range of services, many of which are important to local communities and human well-being [27]. In South Africa, an important driver of ecosystem decline is bush encroachment and the spread of invasive alien plant species [26,27].

Given that the D’Nyala Nature Reserve is considered a protected area in South Africa that is earmarked by the Department of Environmental Affairs as an area where biodiversity should be preserved, several projects involving members of the surrounding communities were launched in 2016 under the auspices of the department’s Natural Resource Management (NRM) and Expanded Public Works (EPWP) programmes. These projects mostly entailed the removal of invasive alien plants, the restoration of rangeland and land management.

As pointed out by De Klerk [47] and Arbieu et al. [48], reduced visibility caused by bush encroachment decreases the tourism potential of lands since this phenomenon has an impact on tourists’ ability to view game in their natural habitat. Furthermore, Ward [26] found that since bush encroachment has a negative impact on game’s ability to graze freely, the carrying capacity of land is reduced considerably.

From a biophysical perspective, the manager of the D’Nyala Nature Reserve reported that the bush clearing and restoration projects conducted under the auspices of the NRM programme succeeded in improving the environmental state of the reserve considerably. This not only led to a perceived increase in revenue because tourists would find the reserve more attractive but also resulted in cost savings since emerging grass species lessened the need to provide game with supplemental feed. In addition, keepers of livestock in Shongoane village found that the bush clearing and restoration projects enabled them to keep their communal goats and cattle safely closer to their homes, and conceded that the improvement in grazing would, in the long run, result in livestock fetching higher prices at market.

The study sought to understand the link between restoration (biodiversity) and ecosystem services (social benefits). The results indicate that bush clearing and restoration projects had a significant impact both on the local community and on the nearby nature reserve in the provision of employment opportunities for community members and increased the nature reserve’s prospects of generating a higher income. These findings regarding socio-economic impacts largely correlate with those reported by Saayman et al. [7] and Stafford et al. in earlier studies.

From the thematic analysis, it is clear that those participants who were directly associated with the nature reserve (i.e., D’Nyala) as well as those who resided in the nearby village (i.e., Shongoane) viewed employment, albeit temporarily, as a major benefit derived from bush clearing and restoration projects.

In essence, the value of benefits for community members has two components: firstly, it has a monetary value (i.e., wages earned) and, secondly, it has an empowerment value in as far as participants could improve their employability by being afforded the opportunity to acquire skills and to be trained in specialist areas such as snake control and herbicide application, mastery of which was awarded a formal certificate. The notion that participants can improve their levels of education in the course of working on bush clearing and restoration projects is supported by Lal [25], who found education to be an important indirect socio-economic benefit associated with the prospect of finding employment in future.

Nevertheless, this study found that there was a marked difference between female and male participants’ satisfaction with the monetary benefits derived as a result of being employed to execute bush clearing and restoration projects. Most female participants had families with at least two children in the household and were of the opinion that their participation greatly helped to take care of basic needs (i.e., buying groceries and clothes and paying for school fees and school uniforms). Most male participants, on the other hand, were of the opinion that the wages were too low and could barely cover basic their necessities, let alone provide for major projects such as renovations and additions

to their homes. Gcabo [49] also confirmed that money has different meanings to different genders, and therefore influences the different needs for which it is used. Furthermore, the results in [49] indicated that for women, money is the basis for survival at home as it is used to serve basic needs, and to take care of the family, while for men, money means economic and social status and pride: the less you have, the less important you are considered in the community [50].

Despite this contradiction, it can be concluded that the bush clearing and restoration activities undertaken in Lephhalale did indeed help to create temporary employment opportunities for members of the community and resulted in socio-economic benefits being created, a view that is supported by Francis et al. [10] and Stafford et al. [27].

Of concern here is that even though most community participants were appreciative of the financial relief and the incumbent benefits temporary employment offered [25], they failed to understand why their employment would only be of a temporary nature. This concern regarding the sustainability of projects and the ability to keep supporting participants' livelihoods once employment contracts have expired was also raised in a study conducted by Akama and Kieti [51]. Of interest here is that the participants employed at the nature reserve remarked that even though the community members were dissatisfied about their income and short-term contracts, "half a loaf is better than nothing". In the integrated development plan of Lephhalale [38], the importance of the tourism industry to the economy was realised. Even though the expansion of the tourism industry is highly dependent on its strong links to industrial operations, it will give an opportunity for future income generation for unemployed rural community members.

As found by Arnold et al. [10] and DeCaro and Stokes [12], positive outcomes are not always guaranteed in community-based projects. In this instance, too, both the nature reserve and the community had to deal with one common challenge, namely the low compensation offered to workers involved in the bush clearing and restoration projects. As a result, the nature reserve especially had to deal with unhappy and discouraged workers.

Furthermore, since the introduction of the projects first had to be vetted by the village chief, politically motivated and/or personal interests might have resulted in community members not deriving the full benefit of the projects. In this regard, Druschke and Hychka [14] pointed out that communication and mutual cooperation are key to the process of community-based projects since they shape the quality of community engagement which, in turn, can translate to all parties benefiting.

Nevertheless, as discussed above, the overall benefits derived from the bush clearing and restoration projects deployed in D'Nyala and Shongoane far outweigh the challenges.

## 5. Conclusions

Bush encroachment and the invasion of alien plant species alter the balance of natural ecosystems. As illustrated by the bush clearing and restoration projects undertaken in the D'Nyala Nature Reserve and Shongoane village, it is possible for both nature reserves and communities to derive some socio-economic benefits from communal attempts to address this issue. As is evident from the findings of this study, community members benefited directly and indirectly because the bush clearing and restoration projects created employment opportunities and afforded members of the community opportunities to undergo training and, in the process, to acquire marketable skills and knowledge. Likewise, the nature reserve benefited from the bush clearing and restoration projects because more tourists would potentially now find the reserve more attractive. The increased grazing capacity meant that the reserve could cut on supplementary feeds for game.

Despite the challenges encountered in implementing land restoration projects in and around Lephhalale, it is obvious that the socio-economic benefits derived far outweigh the negatives and that there is every reason to institute projects of a similar nature elsewhere in future.

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Writing—review and editing, H.C., K.K. and G.C. All authors have read and agreed to the published version of the manuscript.

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