Landscape functionality and restoration of degraded sites in the Mokala and Karoo National Parks of South Africa

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Dissertation accepted in fulfilment of the requirements for the degree *Master of Science in Environmental Sciences* at the North-West University

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Graduation May 2024

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Declaration

I, Lufuno Seth Munyai declare that the dissertation entitled ‘Landscape functionality and restoration of degraded sites in the Mokala and Karoo National Parks of South Africa’ which I hereby submit for the degree Masters of Science in Environmental Sciences at the University of North-West is my work and has not previously been submitted by me for a degree at this or any other tertiary institution. Where use has been made of the work of other authors it has been duly acknowledged in the text.

Signature: 

Date: November 2023

ACKNOWLEDGEMENTS

I would like to give thanks to almighty God for all the strength, resources, and wisdom to complete this research study.

I would like to acknowledge the following persons for their contributions throughout this study:

- ✓ Prof. Klaus Kellner (Supervisor) for his guidance and support throughout the study.
- ✓ Dr Ernest Daemane (Co-supervisor) for his meticulous approach and unwavering advice on how to analyse my data and overall enhancement of my scientific writing skills.
- ✓ My family (Mkateko, Unarine and Ndivho Munyai) who supported and motivated me to complete this research. Thanks for your patience and love. Daddy loves you all.
- ✓ Mr. Abel Matsapula for assisting me with data collection and the creation of study maps.
- ✓ Mr. Morena Mapuru for assisting me with the data analysis and proofreading of this dissertation.
- ✓ Mrs. Mokopelo Letlhohonolo, Miss. Clodene Ackerman, Miss. Kelebogile Mohudi who helped me with data collection.
- ✓ I would like to pass my sincere gratitude to Miss Manganye for proofreading of my dissertation
- ✓ Mokala and Karoo National Park management and BSP teams for allowing me to work in their Parks.
- ✓ I would like to pass my sincere gratitude to South African National Parks for the financial support to execute this project.

"***I dedicated this MSc to the Munyai family. Ri livhuwa Mudzimu (We thank God)***"

ABSTRACT

The reduction in plant cover and density, as well as other ecological processes, all contribute to the deterioration of the land in ecosystems. In hyper-arid, arid, and semi-arid regions, frequent and ongoing land degradation may cause desertification as a result of insufficient measures to stop it. The current study looked at the effectiveness of land degradation prevention techniques including soil ponding and brush packing that are a part of the restoration process. The assessment of the restoration technologies over five years (2015, 2017, 2018, 2019 & 2020) at specific sites in the Mokala and Karoo National Parks employed the soil surface analysis (SSA) method as stated in the Landscape Functional Analysis (LFA) monitoring tool. The data showed that using appropriately designed ponding and brush packing procedures produced favourable results. The rehabilitation method of ponding and brush packing collected trash, seeds, and sediments, which improved soil stability, infiltration, nutrient cycling, and boosted species richness and variety. Except for a few empty areas at a few sites, where a negative association between soil stability and infiltration was noticed, researchers generally discovered a positive correlation between soil stability, infiltration, and nutrients. The success of the restoration approaches in thawing the crusted soil, enhancing soil moisture, and encouraging flora re-establishment led to the positive connection. Therefore, in order to improve the functionality of the landscape and restore degraded areas, the research's findings are essential. In the monitoring procedure across the arid parks, the LFA technique is advocated.

Keywords: National parks, land degradation, ecosystem recovery, ponding and brush packing, rehabilitation.

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Abbreviation	Full name
AMSL	Above Mean Sea Level
BWLM	Beufort West Local Municipality
CKBM	Central Karoo Local Municipality
DEA	Department of Environmental Affairs
DFFE	Department of Fisheries, Forestry & Environment
KNP	Karoo National Park
LDN	Land Degradation Neutral
LFA	Landscape Functional Analysis
LO	Land Organisation
MAB	Man of Biosphere
MNP	Mokala National Park
SA	South Africa
SANParks	South African National Parks
SER	Society of Ecological Restoration
SSA	Soil Surface Analysis
UNCCD	United Nations Convention to Combat Desertification
UNESCO	United Nations Scientific & Cultural Organisation

CHAPTER 1: GENERAL INTRODUCTION

1.1. Study Overview

The loss of biodiversity and threat to food production for the expanding population are the two most important negative effects of the global phenomena known as land degradation (IPCC, 2019). Land degradation is defined by the United Nations Convention to Combat Desertification (UNCCD, 2012:6) as "the reduction or loss of biological or economic productivity and complexity of rainfed cropland, irrigated cropland, or range, pasture, and forest resulting from different land uses or from a combination of processes, including processes arising from human activities."

The erosive effects of wind and water on soil are one of the primary causes of land degradation in South Africa (SA) (IPCC, 2019). Hoffman and Todd (2000) found that, to varied degrees, human activities, occupancy patterns, and soil erosion affect more than 70% of SA (Garland *et al*., 2000; Bezuayehu, *et al*., 2002; Le Roux *et al*., 2008). Eroded soil material contributes to reservoir sedimentation/siltation along with increased pollution, all of which have a detrimental effect on the environment and the state of the land (Bezuayehu, *et al*., 2002).

Dynamic, complex ecosystems that are geographically and temporally varied, as well as land degradation, are related with protected areas (Farina, 2007). Ecological patterns and processes need to be assessed throughout time when choosing the restoration techniques to use in degraded areas (Turner, 1989; Turner, 2005; Wu & Hobbs, 2007). Ecological restoration has gained acceptance over the past ten years in both government and science as a strategy to help restore degraded land and enhance ecosystem services (Benayas *et al*., 2009, Bullock *et al*., 2011). Through ecological restoration, the state of the land's repair can be evaluated, and adaptive management techniques can be used (Benayas *et al*., 2009). The recovery of particularly damaged complex ecosystems should be facilitated by adaptive management and restoration techniques that are both affordable and effective (Gunderson & Light, 2006).

To ascertain the structural dynamics of the degraded landscapes and the connections between ecological patterns and processes, the Landscape Function Analysis (LFA) monitoring methodology was applied in this work (Turner, 1989; Wu & Hobbs, 2007).

The functioning of the landscape can be thought of as a biophysical system that is used to evaluate and track the state of the land and identify the biotic and abiotic elements that are contributing to the decline or loss of the biological or productivity of the land (Tongway & Hindley, 2004). The system's levels of nutrients, organic matter, and water cycling are determined by the landscape's functionality assessment (Tongway & Hindley, 2004). The better the usefulness of the landscape, the higher these numbers (Tongway & Ludwig, 1997). Using the LFA monitoring methodology, environmental harm brought on by human activity and the measures of restorative ecology required to repair the damaged area can be identified (Dobson *et al*., 1997; Hobbs & Harris, 2001). Therefore, the rate of land degradation and the characteristics that need to be restored during the management application are determined using the LFA approach.

1.2. Problem statement

One of the biggest problems facing Mokala and Karoo National Park is land degradation. The manner in which the land was used in the past is the reason why these degradations are experienced. For example, the land in Mokala was used for agriculture, specifically for the growing of crops and livestock. Animals overgrazed and tramped on the vegetation that was present in the area, leaving bare areas as a result of the excessive removal of flora that anchors the soil to the ground. These two latter agricultural practices have severely damaged the landscape. Karoo National Park, which is situated in an area with less rainfall that is favourable for vegetation development, also showed similar patterns of degradation. Karoo specifically lacks vegetation cover since the conditions are not as favourable for plant growth. Therefore, in order to maintain the equilibrium of the landscapes' socioeconomic and ecological components, efforts must be made to assure the landscapes' recovery. It has been shown that effective restoration methods to stop the spread of damaged landscapes include brush packing and ponding. Here, the goal of our study was to determine whether brush packing and ponding could both effectively restore the degraded areas in Mokala and Karoo National Parks.

1.2. Key question

- How can the LFA methodology be used to evaluate the landscape functionality in selected degraded and restored sites in the two National Parks?

1.3. Aim

The main aim of this study was to evaluate the effectiveness of soil ponding and brush packing restoration technologies by using LFA in the Mokala and Karoo National Parks.

1.4. Objectives

- To evaluate the effectiveness of soil ponding and brush packing restoration technologies in degraded areas in the Mokala and Karoo National Parks.
- To determine how Landscape Function Analysis (LFA) can be used to assess the soil ponding and brush packing restoration technology implemented at the selected degraded sites.
- To make recommendations regarding the restoration of degraded areas in other arid and semi-arid National Parks.

1.5. Hypothesis

Selected restoration technologies, such as ponding and brush packing implemented in degraded areas will improve rangeland conditions and the vegetation in the Mokala and Karoo National Parks over time.

1.6. Layout of Thesis

- **Chapter 1:** General introduction, aims, objectives and hypothesis of the project.
- **Chapter 2: L**iterature review, as well as how LFA is used to assess the functionality of a landscape.
- **Chapter 3:** Description of study areas (Mokala and Karoo National Park).
- **Chapter 4:** Description of the methodology used.
- **Chapter 5:** Results
- **Chapter 6**: Discussion

- **Chapter 7:** Conclusion and Recommendations
- References
- Appendix

CHAPTER 2: LITERATURE REVIEW

2.1. Land degradation

Desertification is defined as "land deterioration in arid, semi-arid, and dry sub-humid areas as a result of several factors, including climate fluctuations and human activities" (UNCCD, 2005). The loss of commodities and services that have an impact on the socioeconomic (such as poverty and the loss of jobs and income) and biophysical (such as soil conditions) factors affecting the ecological processes taking place within ecosystems is referred to as land degradation (Blaikie, 1985; Scherr & Yadav, 1997; Dumanski & Pieri, 2000; SER, 2003, 2002; Nkonya *et al*., 2011). Degraded landscapes are frequently referred to as "dysfunctional," in which the environment's biological development, which is essential to conserving biodiversity, is constrained (Tongway & Hindley, 2004; Van der Walt *et al*., 2012).

The majority of land degradation takes place in dryland regions, which include arid, semi-arid, and dry sub-humid regions (Pielke, 2013). These places have a variety of environmental conditions that affect vegetation growth, including little and inconsistent yearly rainfall and intensely high temperatures, especially in summer (Verstraete & Schwartz, 1991; UNCCD, 1994; Kassas, 1995; Sehmi & Kundzewicz, 1997; Hoffman et al., 1999; Schwilch *et al*., 2012; Pielke, 2013). Arid and semi-arid landscapes are intricate mosaics of interconnected habitats or units that physically alter and/or have their patterns of important resource availability, such as water and nutrients, changed by the actions of the species that live there (UNCCD, 1994).

As the indicator of aridity used to delimit zones of varied degrees of aridity, the Man and Biosphere (MAB) group that created the UNESCO (1977) map of arid- and semi-arid zones of the world used the ratio P/ET (where P is mean annual precipitation and ET is the meaning of annual evapotranspiration). Because it provides the same result for all climates where potential water loss is proportionally equal to rainfall, the ratio P/ET is utilized.

Land deterioration in arid and semi-arid regions can eventually result in desertification because even small changes in the climate can have a significant impact on the vegetation (Leemans & Eickhout, 2004; Nkonya *et al*., 2011; Pielke, 2013). According to Kellner & Bosch (1992) and Li *et al*. (1998), bare patches in the landscape develop

as a result of a decline in vegetation cover and density. These patches may eventually grow into larger areas, particularly during droughts and as a result of poor management, resulting in longer-lasting denuded areas.

2.1.1. Causes of land degradation

Land degradation has a wide range of factors. One of the primary direct causes of land degradation and the ensuing loss of biodiversity is the conversion of natural vegetation into crop and cultivated lands. Other major direct drivers of land degradation and biodiversity loss are climate change, unsustainable agricultural and forestry practices, urbanization, and the development of infrastructure and industry (Dregne, 1986; Southgate, 1990; Tolba & El-Kholy, 1992; Lambin *et al*., 2001; Peng *et al*., 2005; Palmer *et al*., 2010; Van Oudtshoorn, 2014; Scholes *et al*., 2018). Long-term, extensive deforestation, overgrazing, and poor crop- and soil-management techniques in the watersheds also cause sediment to build up in river channels, lakes, dams, and reservoirs, resulting in a loss of land cover that may result in land degradation (Dregne, 1986; Southgate, 1990; Tefera *et al*., 2002, Dutoit, 1995, Dutoit, 1997).

Soil degradation through erosion, causes nutrient loss and results in undesirable physiochemical soil properties, thereby depressing vegetation productivity (Tolba & El-Kholy, 1992; Nicholson *et al*., 1998; Lambin *et al.,* 2001; Ravi *et al*., 2010; Van Oudtshoorn, 2014, Tolcha, 1991), consequently it has an impact on soil temperature and moisture (HilleRisLambers *et al*., 2001; De Groot *et al*., 2002; Bhark & Small, 2003; Puigdefábregas, 2005; Lin *et al*., 2010). Overgrazing by animals, unrestrained harvesting or the collecting of non-renewable resources, disturbances caused by machinery like tractors and ploughs, and climate effects are all factors that contribute to the loss of plant cover (Lambin *et al*., 2001; De Groot *et al*., 2002; Tefera *et al*., 2002; Peng *et al*., 2005; Palmer *et al*., 2010, Dutoit, 1997).

Despite being visible in the near term, the loss of ecosystem processes and the reduction in vegetation cover, particularly in arid and semi-arid regions, occur over extended periods of time, in part because of various management practices and shifting climatic circumstances (Harrison *et al*., 2000; Bezuayehu *et al*., 2002; Van den Berg & Kellner, 2005, Tolcha, 1991). It can be challenging to determine whether the decline in biodiversity is long-term (caused, for example, by seasonality and long-term

drought conditions) or short-term (caused, for example, by short-term management strategies, type of land use, and irregular rainfall patterns). This is because slow dynamic changes are often observed (Van den Berg & Kellner, 2005). Therefore, it is crucial to comprehend how resilient arid and semi-arid ecosystems are and what their potential for both short- and long-term recovery from perturbations is (Wiegand & Jeltsch, 2000).

2.1.2. Land degradation in SANParks

For management, degraded regions in national parks are a major concern, especially if the main goals are biodiversity protection and conservation (Tongway *et al*., 2003; Van den Berg & Kellner, 2005; Cernea & Schmidt-Soltau, 2006). The Department of Fisheries, Forestry and the Environment (DFFE) produced a national strategy for the preservation and sustainable use of South Africa's biodiversity, which asks for the identification of important areas for rehabilitation. Based on biological and socioeconomic factors, as well as the creation and execution of rehabilitation plans, Mokala and Karoo NP are chosen. A new worldwide goal to attain a land degradation neutral (LDN) world by 2030 is outlined in Target 15.3 of the Sustainable Development Goal (SDG) 15 from 2015 (UNCCD, 2013). The three main goals of the LDN response approach are to prevent deterioration, reduce degradation, and restore degraded areas (UNCCD, 2013). This is true for South African national parks as well.

Through the restoration of damaged lands throughout National Parks, SANParks is helping to achieve the SDG targets at both the corporate and park levels (SANParks, 2019). All of the parks' land degradation types are being mapped, and active restoration technologies are being used, to determine whether the degraded lands restoration indicators are being met. The total number of hectares restored, as specified in the five-year strategic implementation plan and restoration framework, was a subject of constant SANParks reporting (SANParks, 2019, DEA 2015).

According to these global, national, and organizational strategies and implementation plans, large tracts of very valuable grazing land that have been degraded in national parks urgently require restoration, especially in places that have been eroded (Harrison *et al*., 2000; Milton *et al*., 2003; UNEP, 1992; Ntshotsho *et al*., 2011). Before the park was established, overgrazing, excessive use of biomass for fuel and fodder,

bush encroachment, and desertification of the land due to prolonged droughts were the main bio-physical processes identified for contributing to land degradation in national parks. Other processes included changes in composition and structure of natural vegetation, wind and water erosion (mostly expressed as sheet, rill, and gully erosion), and decreases in and changes to natural vegetation (Daemane *et al*., 2014).

Beyond some long-term threshold values, the rate of land degradation can accelerate, which can cause a significant loss in soil fertility and cover, changes in the ecology of the vegetation, and a fall in land productivity (Guerrero-Campo & Montserrat-Mart, 2000; Kar, 2018). In South Africa, the Department of Environmental Affairs and Tourism (DEAT, 2004) identified a few of the effects and costs of land degradation and desertification (Table 2.1).

Table 2.1: The consequences and costs of degradation and desertification in South Africa (DEAT, 2004)

The Consequences and Costs of Degradation and Desertification in South Africa		
Soil erosion costs an estimated R2 billion annually, including off-site costs for the purification of water whose poor quality is caused by dam siltation. Soil loss is in part responsible for farmers abandoning land in many areas, especially in their former homelands. • The **loss of nutrients** from soils costs an estimated R1.5 billion annually. The commercial agriculture sector spends more than R2 billion a year on fertilizers. The	• Invasion of lands by alien plants results in an estimated 7% **decrease in water runoff,** threatens biodiversity and lowers the productivity of agricultural land. The reduction in available water will double in 15 years if no decisive action is taken. • **Poor water quality** is a consequence of several factors, including high silt and nutrient loads from accelerated erosion,	A 1% decline in access to this resource represents a total loss of approximately R150 million per year**.** • **Lower land productivity** affects food security, specifically in areas of subsistence agriculture, where people are more vulnerable to climatic variability. • There is **reduced rural productivity** because more time is needed to access

subsistence farming sector in many instances cannot afford this cost and operates with inadequate fertilization. In both cases, improved land management practices would result in a reduction in fertility loss and a more effective use of natural soil fertility. • Land degradation causes **loss in grazing and arable potential** – 10 million ha of rangeland are moderately to severely degraded by bush encroachment, while loss of topsoil through erosion and mining makes commercial farming financially unviable in many areas.	nutrient loads from excessive fertilisation, mining and industry pollution, and poorly maintained sanitation systems. • **Loss of wood fuel and other non-timber products:** Despite electrification drives, fuel wood is still the main source of energy for an estimated 75% of rural families. Additionally, the rural poor and urban households use a wide variety of wood products, including medicines, with an estimated value of R5 500 per household per year. Access to these resources is declining due to land degradation, and the impact of this decline is more severe for the poorest of the poor.	resources such as fuel and water. • **The severity of flooding** is directly related to soil and vegetation degradation, particularly crusting, compaction, and loss of vegetation cover; these symptoms of degradation and desertification allow less water to seep into the soil, so more flows over the surface of the land, causing flooding. • **Degraded landscape quality** leads to loss of tourism potential.

Adapted from: Department of Environmental Environment Affairs and Tourism, 2004, South Africa's National Action Programme to Combat Land Degradation and Hoffman and Ashwell (2001)

2.2. Restoration and rehabilitation ecology

The terms "restoration" and "rehabilitation" can be unclear, as was already mentioned. Keep in mind that "rehabilitation" is a component of "restoration". These two terms are therefore frequently used in descriptions and publications. These phrases are also employed, with terminology like reclamation and re-vegetation, depending on the type of restoration or rehabilitation and the type of land use (for example, mining, conservation). The concepts of "rehabilitation" and "restoration" are the main topics of this section of the chapter. The Society of Ecological Restoration (SER 2002) defines restoration as all forms of ecosystem repair, including aspects of reclamation, rehabilitation, mitigation, ecological engineering, and other resource management techniques, such as the control of wildlife and livestock in rangelands. Any losses in ecosystem services stated above are addressed by all of these actions. When a system is "restored" to its previous state, restoration is mostly used. The original condition, the length of time it took, or the causes of the state's degradation are unknown, hence this procedure is hardly ever attained.

The main objective of rehabilitation is to increase an ecosystem's productivity by mending its processes and getting it going as quickly as feasible (Aronson *et al*., 1993; Harris *et al*., 1996; SER, 2002; Clewell & Aronson, 2013). In the course of rehabilitation, efforts are undertaken to adopt the native ecosystem's structure and to recreate a self-sustaining ecosystem (Aronson *et al*., 1993; Clewell & Aronson, 2013). Frequently, the system needs more interventions before it can be deemed a rehabilitated site because it is not self-sustaining (Harris *et al*., 1996). In Figure 2.1, the eight guiding concepts for ecological restoration are summarized (SER 2019).

Figure 2.1: Diagram representing the Eight Principles for Ecological Restoration. (SER, 2019).

In this study, the eight (8) principles as described by the Society for Ecological Restoration (SER, 2019) were followed. These included principles 1 & 2, that effectively engaging a wide range of stakeholders and consider available scientific, traditional and local knowledge respectively; principles 3 & 4, focused on the central approach to ecological restoration by highlighting ecological appropriate reference ecosystem as the target of restoration and clarifying the imperative for restoration activities to support ecosystem recovery processes. Principle 5 underscores the use of measurable indicators to assess progress towards restoration objectives. Principle 6 lays out the mandate for ecological restoration to seek the highest attainable recovery. Tools are provided to identify the levels of recovery aspired to and to track progress. Principle 7 highlights the importance of restoration at large spatial scales for cumulative gains. Finally, ecological restoration is one of several approaches that address damage to the ecosystem and principle 8 clarifies its relationships to allied approaches on a “Restoration continuum”. The standards highlight the role of ecological restoration in connecting social, community, productivity and sustainable goal.

Restoration ecology involves re-establishing vegetation that has shrunk in cover and density as a result of land degradation (Jordan *et al*., 1990; Menke, 1992; Van der Merwe & Kellner, 1999; SER, 2002; Van den Berg & Kellner, 2005; Prach & Hobbs, 2008, Hobbs & Cramer, 2008). The goal is to "repair" damaged or degraded ecosystems to a better state than it was before it was degraded in terms of species diversity and community structure (Jackson *et al*., 1995; SER, 2002, Hobbs & Cramer, 2008).

The two main types of restoration are active restoration and brush packing. Active technologies include weeding, burning, improving soil moisture, thinning, creating depressions to collect nutrients and water (i.e., ponding), and brush packing involves placing woody twigs and other organic material on degraded patches (Allen, 1995; Tongway & Ludwig, 1996 a & b; Schiffman, 2015, Mangani, 2021, Modungwa, 2017). On the other hand, passive restoration does not need any "active" technology because it allows the deteriorated system to undergo successional processes naturally over time (Prach & Hobbs, 2008) (also see below). Since passive restorative actions typically follow a "successional" approach, they may be long-term in many situations (Prach & Hobbs, 2008). Long-term adequate climatic and environmental conditions are necessary. Land managers use active techniques to hasten the recovery process and to encourage the creation of self-sustaining populations because passive restoration must address long-term successional processes (Dobson *et al*., 1997; Prach & Hobbs, 2008, Falk *et al*., 2006).

One or more of the following methods can be used to restore a degraded site: actively using technical measures (active restoration), passively relying on spontaneous succession over time, or combining the two methods in order to manipulate and manage spontaneous succession with the aim of increasing production or biodiversity (Milton & Dean, 1995; Prach & Hobbs, 2008; Aronson *et al*., 2010). The utilization of both active and passive restoration will rely on the extent, rate, and scale of deterioration, the resources available, particularly money and labour, as well as the amount of time needed to restore an area (Kellner, 2010).

In degraded areas, the return of vegetation is quite gradual, particularly in dry and semi-arid regions. Regrowth of the vegetation could even be difficult depending on the level, scope, and rate of deterioration (Harris *et al*., 1996; Van den Berg & Kellner,

2005). To maximize vegetation recovery, a variety of restoration technologies are frequently needed. Active restoration techniques should be used when degradation is particularly bad and has reached a specified threshold (Smit, 2004; Friedel, 1991; Kellner & Bosch, 1992; Van den Berg & Kellner, 2005; Suding, 2011; Van der Vyver *et al*., 2012).

The elimination of stress in a particular ecosystem is another way to explain passive restoration. This is done to safeguard the area from additional disturbance, promote natural colonization, and restore the ecosystem's function, structure, and biodiversity (Lamb & Gilmour, 2003). These pressures could come from excessive animal grazing as well as anthropogenic pollution of the air or soil (Short & Wyllie-Echeverria, 1996). The ideal alternative for use in resilient areas is passive restoration, however it must be kept in mind that this method is event-driven and requires a progressive approach such as ponding and brush packing. Certain management practices that don't require active interventions can be used in these regions to alleviate degradation, such as reducing the grazing pressure on the land to allow for the gradual restoration of plant cover and density. When land users and managers have limited financial resources, this strategy can be used, which is one of its benefits (Lamb & Gilmour, 2003).

Many restoration attempts fail because they are not a quick fix for a serious issue that has existed for a long time. Managers and decision-makers frequently lose interest and lack commitment over such protracted durations. The failure of restoration applications also includes a lack of proper training provided to managers who must carry out the restoration activities, a lack of developing a proper restoration plan that is valid over the long term, and a lack of understanding of the ecological functioning of the ecosystem. Frequently, financing stops before the place is fully rebuilt (Harris *et al*., 1996).

2.3. Stability, resilience and the thresholds of ecosystems

Ecosystem dynamics, which are mechanisms in a system that vary over time and result in a continual change in the biotic composition and structure as well as the surrounding environment, are described by stability and resilience (Walker, 1980). Climate change, habitat loss, and the addition of nutrients to the soil are all ongoing threats to ecosystems that have an effect on their resilience (Scheffer *et al*., 2001).

When an ecosystem loses its resilience, it may transition to a different state (Scheffer *et al*., 2001). The ecosystem may transition to a different state if its resistance is lost (Scheffer *et al*., 2001). When exposed to external stress, stable systems undergo very little compositional and structural change (Walker, 1980) and less frequently transition to alternate states. When the stressor is removed, a more stable system is therefore more resilient and can return to its initial state (Walker, 1980).

When an ecosystem's quality, property, or phenomenon abruptly shifts due to tiny changes in a driving environmental factor, or when both of these things happen at once, it is said to have crossed a threshold (Walker & Salt, 2006). It is challenging to analyze thresholds because of nonlinear dynamics and numerous factor controls that operate at several spatial and temporal dimensions. Despite widespread concern over preventing drastic state changes in significant ecosystems, the requirement to identify critical pollutant loads, and the prevalence of other threshold-based environmental issues, these complexities have made it challenging to use and apply threshold concepts in environmental management (Groffman *et al*., 2006; Walker & Salt, 2006).

An unstable system is less resilient to external changes than a stable system, and so can withstand fewer effects that, for instance, cause a degraded state (Muradian, 2001). See states 1a and 1b, which are depicted in Figure 2.2 below and show the distinctions between stable and unstable ecosystem. The bucket/cup (system/state) in which the ball (changing ecosystem) is more stable (more resilient) does not readily exceed thresholds in a stable state (1a). Since the "bucket" represents stability and stronger resilience, it is deeper and more difficult for the "ball" (ecology) to cross the "threshold" and enter another state (Smit, 2004). The "bucket" is substantially larger for an unstable system (1b in Figure 2.2).

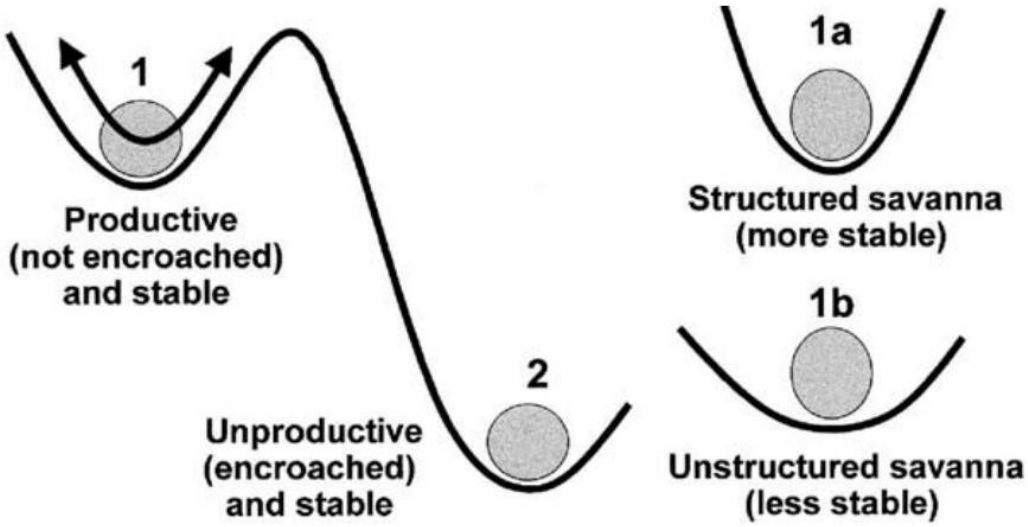

Figure 2.2: A simplification of the principle of stability, resilience, and threshold (from Smit, 2004).

Ecosystems can be resilient but not necessarily stable (Walker, 1980, Walker & Salt, 2006). The system can be changed substantially but is still attracted towards its ecological threshold (Walker, 1980). Resilience is therefore the extent to which a system can absorb stress factors before it flips or switches to another state and crosses an ecological threshold (Muradian, 2001, Walker & Salt, 2006). In a resilient system, the threshold is not easily reached, and the state variables do not change to such an extent that the system exceeds the threshold limits (Walker, 1980). Stable systems do not change often, but when exposed to higher stress values, the systems can reach another state beyond the boundaries of the thresholds (Walker, 1980). When a threshold is crossed, it means that the vegetation resides in a new domain with new rules, structure and often changed composition and will not simply revert to its former state without serious intervention, such as the carrying out of active restoration practices (Friedel, 1991). The state variables will either have a different threshold or they could reach extinction and have other states of variables (Walker, 1980). A fundamental method for using the three state variable idea was put forth by Smit (2004).This example can be applied to degraded areas such as the eroded areas in the National Parks where this study was conducted. Position 1 shows a stage where degradation has not yet occurred, and the system is still in a stable condition (Smit, 2004). Changes may occur due to the impact of drought and/or overgrazing, and when the resilience of the system is not high enough, it will pass the threshold and move to another state (condition) (Smit, 2004; Groffman *et al*., 2006). When the influences of

stress factors (such as drought and/or overgrazing) are removed, the system will revert to its initial state due to the higher resilience. The “ball” will therefore “roll” in the “cup” from one side to the other due to its resilience and will not pass the threshold value (Smit, 2004).

If the system undergoes too many changes under a lot of stress (such as drought, increasing grazing pressure, or the encroachment of bush-woody species), it will transform from a more stable, productive system (Figure 2.2. position 1) to an unproductive system (Figure 2.2.position 2). The "ball" will remain in the "cup" and not go over the threshold, though, if the system remains within the parameters of the thresholds and is able to resist the stress (Smit, 2004). Within the "stability threshold," the system can endure the eradication of species (due to drought or overgrazing, for example) without negatively impacting its ability to handle perturbations (Muradian, 2001). An illustration of this may be a high cover of perennial grasslands that has turned into a region where the grasses are being eliminated by disturbances, such as causes contributing to degradation. When the effects of the alterations reach the limits of the thresholds, the system will switch to a different state (state 2), which is not necessarily unstable but stable in another manner (Smit, 2004). However, if the system is resilient and can withstand the disturbances/degradation, it would not have a significant impact on the system's stability and would remain in its current state. The system appears to be stable and could return to its initial form considerably more easily (May, 1977).

According to Groffman *et al*., (2006), a system can degrade and shift into position 2 (Figure 2.2) by crossing the threshold (from position 1 to position 2); however, the ecosystem can be restored to its original state (position 1) by using mostly active technical efforts (Smit, 2004). In order to offer the ecosystem functioning and processes that happen in that sort of habitat, the active restoration process tries to adopt techniques that will restore the system to its original state (condition) as much as feasible. This will rely on the climate and environmental conditions of the region, including the amount of seed and vegetation that is still present in the soil seed bank, the amount of erosion that is creating runoff, the kind of soil in the area, and the rate and degree of degradation that has happened.

CHAPTER 3: STUDY AREA

3.1. Mokala National Park (MNP)

3.1.1. Location

In the Northern Cape Province of South Africa, Mokala National Park (MNP) is situated at grid reference 29° 10' 20.7" S and 24° 21' 00.5" E, about 80 km southwest of Kimberley and 25 km west of the main route (N12) to Cape Town (Figure 3.1). MNP is located inside the boundaries of the Siyancuma Local Municipality (SLM) and Pixley ka Seme District Municipalities, respectively (Figure 3.1).

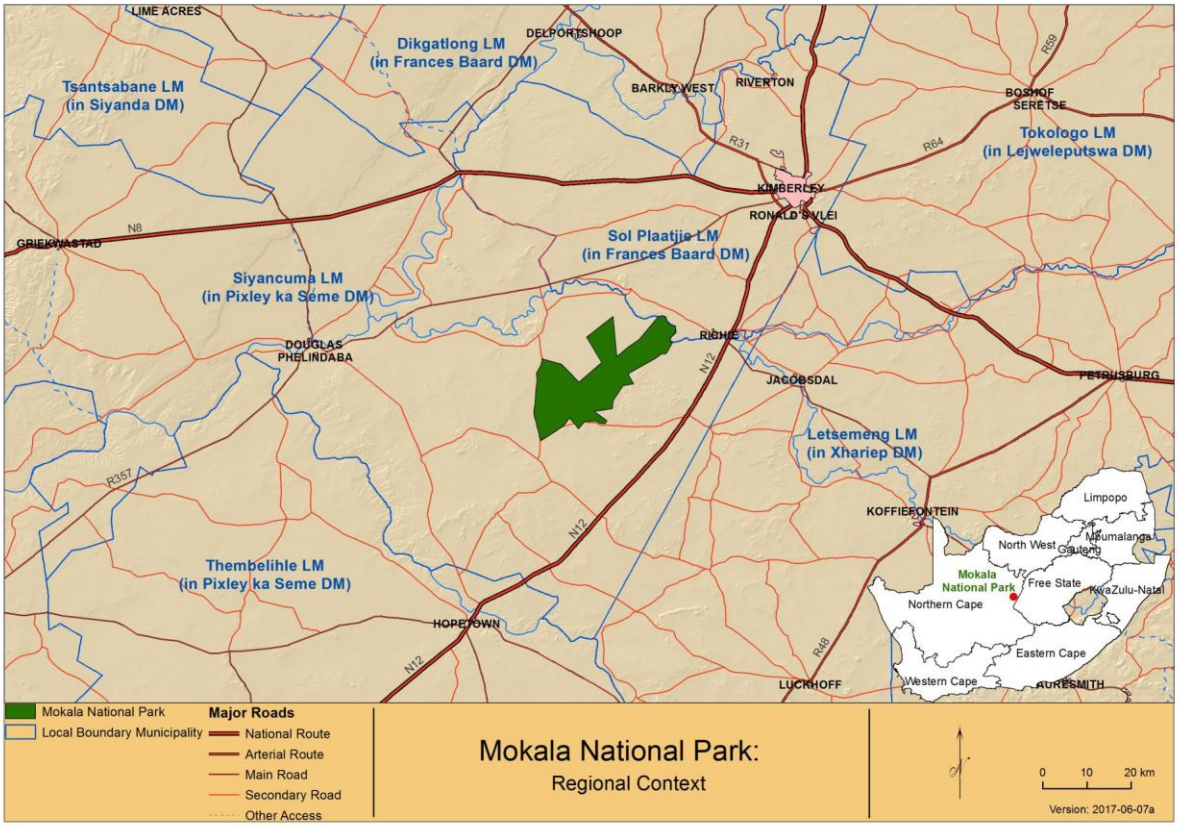

Figure 3.1: Mokala NP location in the regional context in relation to SA and provincial level with relation to N12 (SANParks, 2017).

The park is currently 32 445 hectares in size (ha). Historical records reveal that up until 2003, the farm's management included raising goats and cattle with rotational grazing among 33 camps, and then after, wildlife was gradually reintroduced (SANParks, 2017).

In order to "create, maintain, and promote a system of national parks that represents the biodiversity and heritage assets by using best practice, environmental justice, benefit sharing, and sustainable use," SANParks' stated objective, the MNP (2008), was thus made possible (SANParks, 2017). Additionally, Mokala NP offers a tourism service that aids in fostering regional economic growth (SANParks, 2017). A network of roads, pans, dams, and vacation cottages is part of the infrastructure (Figure 3.2).

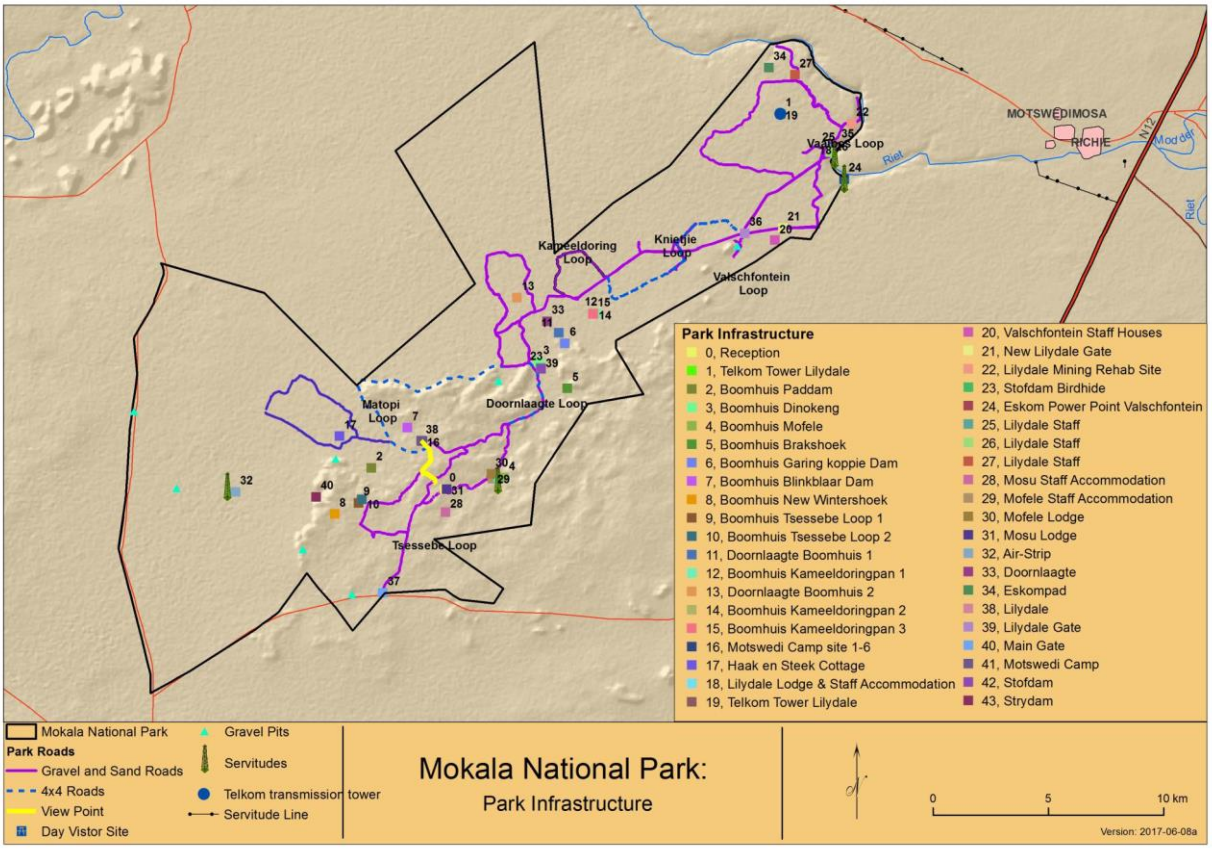

Figure 3.2: Infrastructure map of Mokala National Park (SANParks, 2017).

3.1.2. Climate

Mokala National Park is located in an area with a sub - tropical climate, which features dry winters and wet summers with frequent thunderstorms (Rutherford *et al*., 2006). The region receives between 300 and 600 mm of rain annually, with the summer months beginning from January through March and receives the most rain and June, July, experiencing the least amount of rain in August (Rutherford *et al*., 2006; Bezuidenhout & Bradshaw 2013; Daemane *et al*., 2014, Daemane *et al*., 2007) (Figure 3.3). The long-term average annual rainfall for MNP was 400 mm, which was received between 2008 and 2020 (Bezuidenhout & Bradshaw, 2013) (Figure 3.3). Despite being

sporadic and seasonal, the majority of the rain falls throughout summer (between October and April) (Figure 3.4). With little to no precipitation in February of the same years, 2017 had the highest monthly rainfall total of roughly 114.56 mm. The months of June and July 2017 were dry. The monthly rainfall given in Figure 3.4 indicates that the highest rainfall occurred in April 2018 (73.15 mm), while the lowest rainfall occurred in May 2018. (8.63 mm). The earliest known instance of frost was on April 27, 2010, and it occurs from late April until late September. Bezuidenhout *et al*., 2015 Mokala NP's highest annual rainfall total was over 580 mm in 2011.

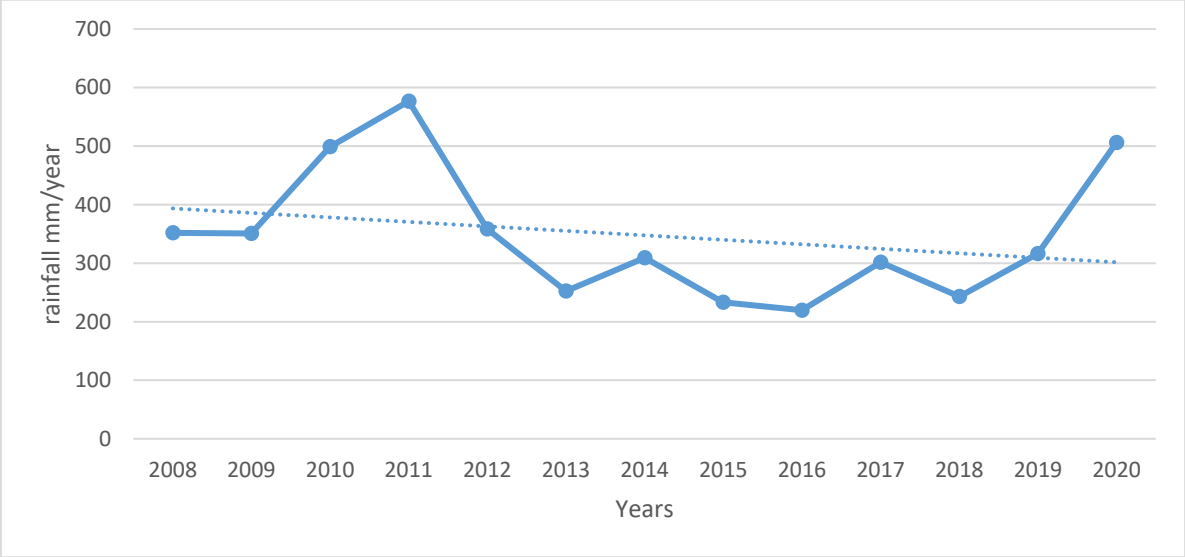

Figure 3.3: Annual rainfall from 2008 – 2020 with a trending line showing average annual rainfall.

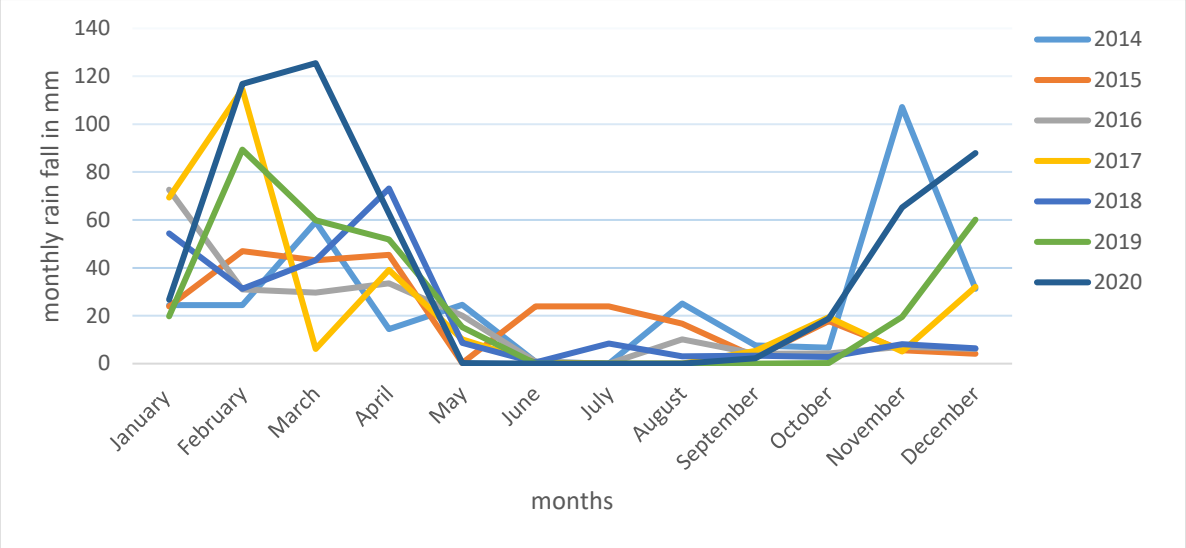

Figure 3.4: Monthly rainfall from 2014 – 2020 for Mokala National Park.

According to projections, MNP's annual average temperature will rise by 1.6 to 2.8 °C by 2050 (Driver *et al*., 2012; DEA, 2013). Additionally, it is anticipated that major rises in daily extreme temperatures increases to 35 Celsius for 50 or more days will have a detrimental effect on wildlife, tourists, and employees who must work under the sun. Intermediate projections of future conditions up to the year 2050 at MNP forecast only minor changes in rainfall (an increase of roughly 3 mm/a) (Driver *et al*., 2012; DEA, 2013). In Mokala National Park, the driest scenario is expected to occur over the next 25 years, with annual rainfall decreasing by 114 mm (Driver *et al*., 2012; DEA, 2013). While the wettest scenario would result in a rise of 94 mm/a in rainfall, the latter would virtually reduce the existing rainfall of 400 mm/a. Amusingly, the Eureka weather station, located outside MNP, has recorded an average rise in annual rainfall of about 134 mm (van Wilgen *et al*., 2016). However, the Eureka weather station's annual rainfall varied more than it had in the past (van Wilgen *et al*., 2016).

3.1.3. Vegetation

The MNP was established to protect the area where the Nama-Karoo and Savanna biomes meet (Mucina & Rutherford, 2006) (Figure 3.5). The Eastern Kalahari Bushveld Bioregion is where the region's vegetation is categorized (Mucina & Rutherford 2006; Bezuidenhout, 2006). The MNP contains two vegetation types: the Vaalbos Rocky Shrubland (SVK 5) and the Kimberley Thornveld (SVK 4). The predominant trees in the Kimberley Thornveld are *Vachellia erioloba* (Camel thorn),

Vachellia tortilis (Umbrella thorn), and *Boscia albitrunca* (Shepherd's tree), and there is also a well-developed shrub layer with sporadic dense stands of *Senegalia mellifera* (Black thorn) and *Tarchonanthus camphoratus* (Wild camphor bush). Within the plains of MNP, the Vaalbos Rocky Shrubland can be found on the slopes, high hills, and ridges. Seven significant plant community-habitat units make up the park (Bezuidenhout & Bradshaw 2013; Bezuidenhout, 2006) (Figure 3.6). These consist of:

1. *Searsia lancea* woodland
2. *Searsia pendulina* open woodland
3. *Senegalia mellifera – Vachellia erioloba* open to closed woodland
4. *Senegalia mellifera – Vachellia tortilis* open woodland
5. *Vachellia erioloba – Vachellia tortilis* open woodland
6. *Rhigozum obavatum – Senegalia mellifera* open shrubland
7. *Cynodon dactylon - Ziziphus mucronata* open woodland
8. *Schimidtia pappophoroides - Vachellia erioloba* sparse woodland
9. *Stipagrostis* species forbland

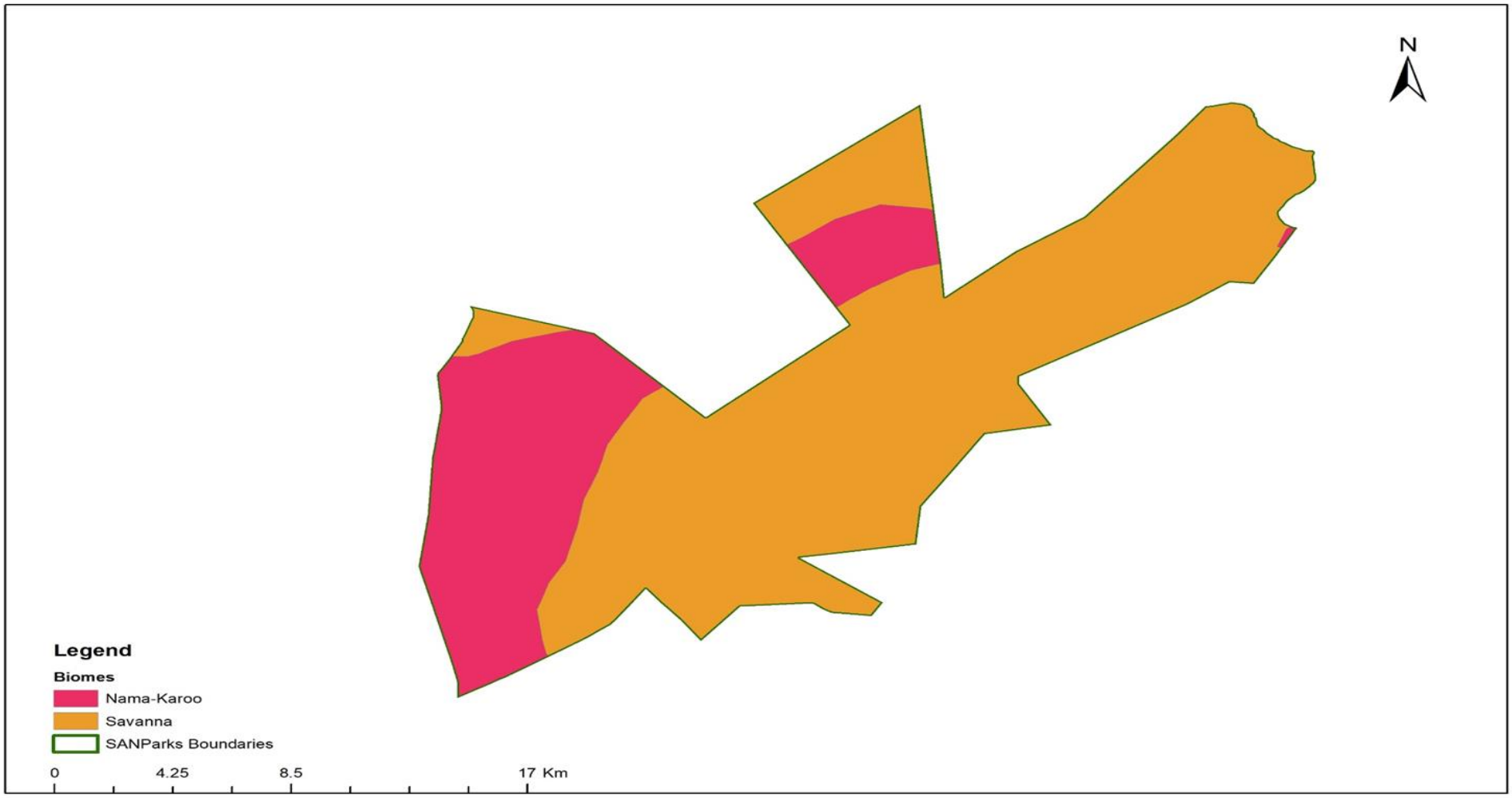

Figure 3.5: The two different biomes that occur in Mokala National Park (Mucina & Rutherford 2006).

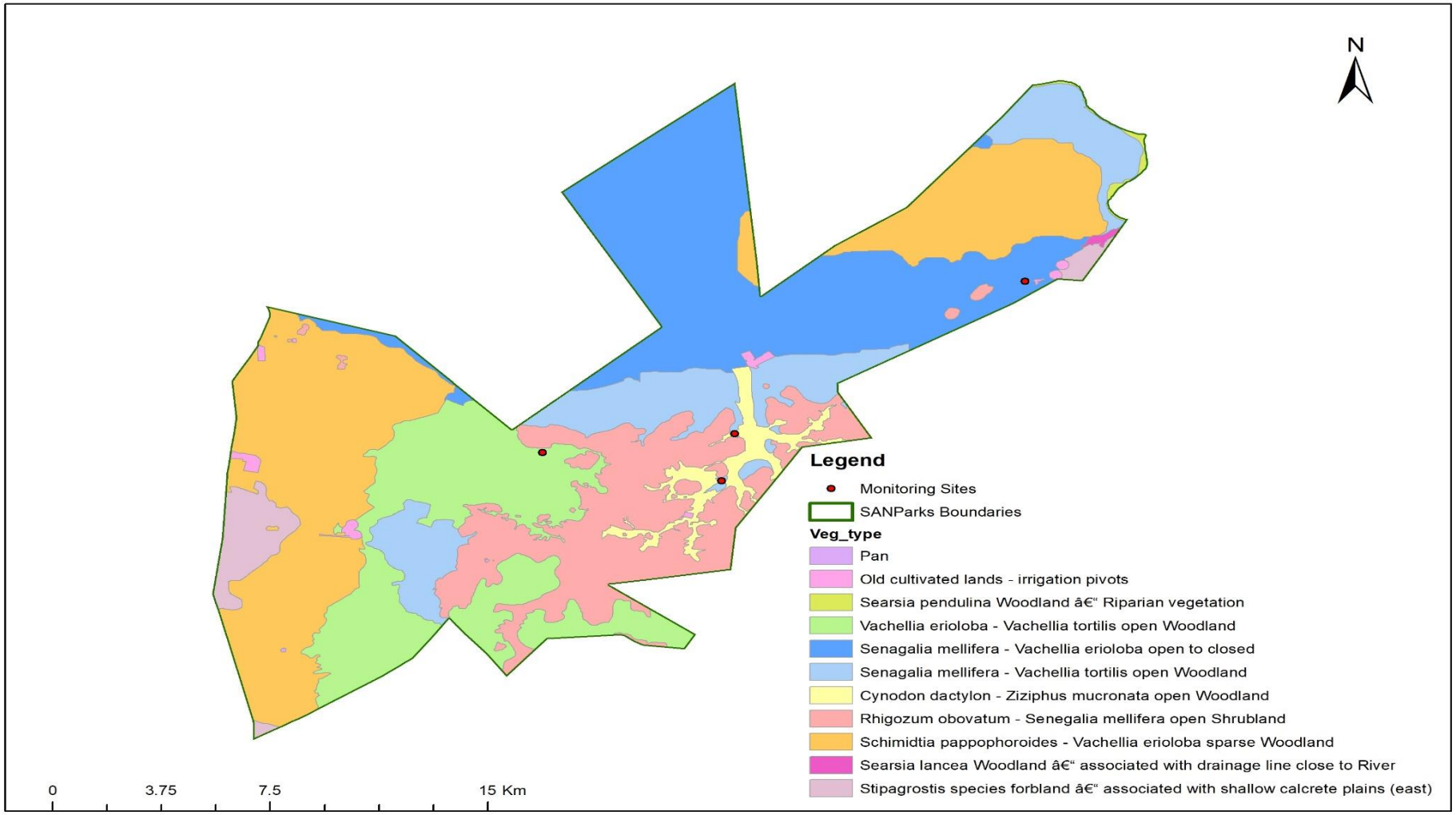

Figure 3.6: Map of the plant communities and monitoring sites at Mokala National Park (Bezuidenhout & Bradshaw 2013).

3.1.4. Topography

MNP's topography ranges from flat to moderately sloping plains with hills in the park's center (Bezuidenhout, 1993; Land Type Survey Staff, 2012). In MNP, you can find plateaux, crests, scarps, mid-slopes, valley bottomlands, drainage lines, pans, and rivers (Land Type Survey Staff; 2012; Bezuidenhout 1993). With dolerite outcrops towering 50 m to almost 100 m above the plains, the southernmost portion of the park is the tallest mountain and most topographically diverse. There is a gently descending slope of open grasslands to the Riet River, which forms a crescent to the north of the park, to the west, north, and northeast (Land Type Survey Staff, 2012).

3.1.5. Geology and soils

Various sorts of geological formations underlie Mokala National Park (SRK, 2009). Over much of the park, rocks from the Dwyka Formation are covered with tertiary to recent aeolian sand (SRK, 2009). In the northern part of the park, there are isolated outcrops of the andesitic lavas of the Allanridge Andesite Formation, which are the oldest rocks in the region. The rocky hills surrounding the Mosu Lodge rest camp include karoo dolerite intrusions, most of which appear as sills and dykes. The black shale of the Tierberg Formation and the white weathering shale of the Whitehill Formation make up the majority of the sedimentary sequence. The latter is a moderately brittle rock that weathers quickly and is covered with aeolian sand and calcrete. The different soil types range from shallow (less than 0.3 m) and stony (Mispah-, Prieska-, and Glenrosa soil forms) to deep (>0.6 m) red and yellow sands (Soil Classification Working Group, 1991). The soils of the pans are very deep and quite clayey, including more than 35% clay (Arcadia, Rensburg, and Willowbrook soil types) (Soil Classification Working Group, 1991).

3.2. Karoo National Park (KNP)

3.2.1. Location

The Karoo National Park (KNP) is located at 32° 14' 64.6" S and 22° 17' 58.2" E on a grid reference. The park is currently 90,535 ha in size and is located in the Western Cape Province, 3 km northwest of Beaufort West, next to the Nuweveld Mountain range (Figure 3.7).

The park is located within the jurisdictions of the Beaufort West Local Municipality (BWLM) and the Central Karoo District Municipality (CKDM), respectively (Figure 3.7)

Figure 3.7: Location of Karoo National Park with the regional and national context to South Africa (SANParks, 2017).

3.2.2. Climate

The average annual rainfall in the park varies from 175 mm to 406 mm, with 60 percent to 75 percent dropping in summer (Figure 3.8). The Park experienced the most annual rainfall in 2011 (572.9 mm), and the lowest annual rainfall in 2019 (112.4 mm). As measured by the coefficient of variation in yearly rainfall, the reliability of rainfall decreases from west to east (DEA 2013) (Figure 3.8). In the KNP, the yearly average precipitation decreased between 2008 and 2020. In the plains and valley bottomlands, rainfall is unpredictable and relatively infrequent (Bezuidenhout, 2016). More rain falls on the Karoo National Park throughout the summer, with the most of it falling between January and March. The most precipitation, 68.8 mm, fell in January 2020 (Figure 3.9).

The park experiences cold winters (mean minimum winter temperature is 3.5 °C) and hot summers (mean maximum summer temperature is >32 °C). The mountains of the

Great Escarpment experience a cool steppe climate, with the steep elevation and precipitation gradient rapidly changing to a warm steppe climate in the eastern, southern and western lowland areas of the park. Mild to heavy frost occurs with periodic snow on top of the Nuweveld Mountains (DEA, 2013).

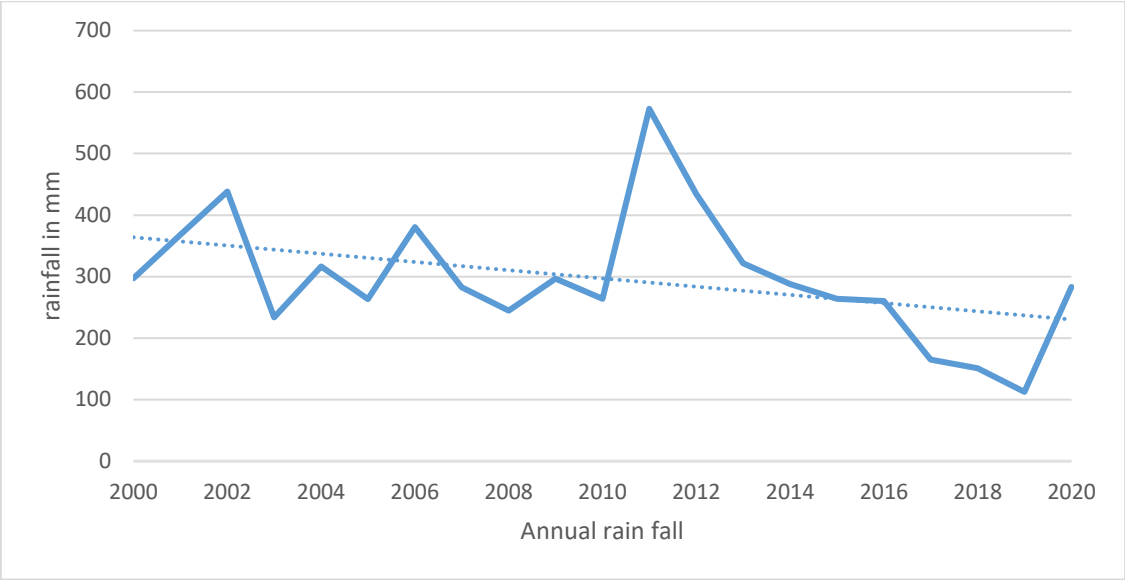

Figure 3.8: Annual rainfall in the Karoo National Park, Western Cape Province for the period of 20 years (2000 – 2020). The trending line shows the average annual rainfall in the Karoo National Park.

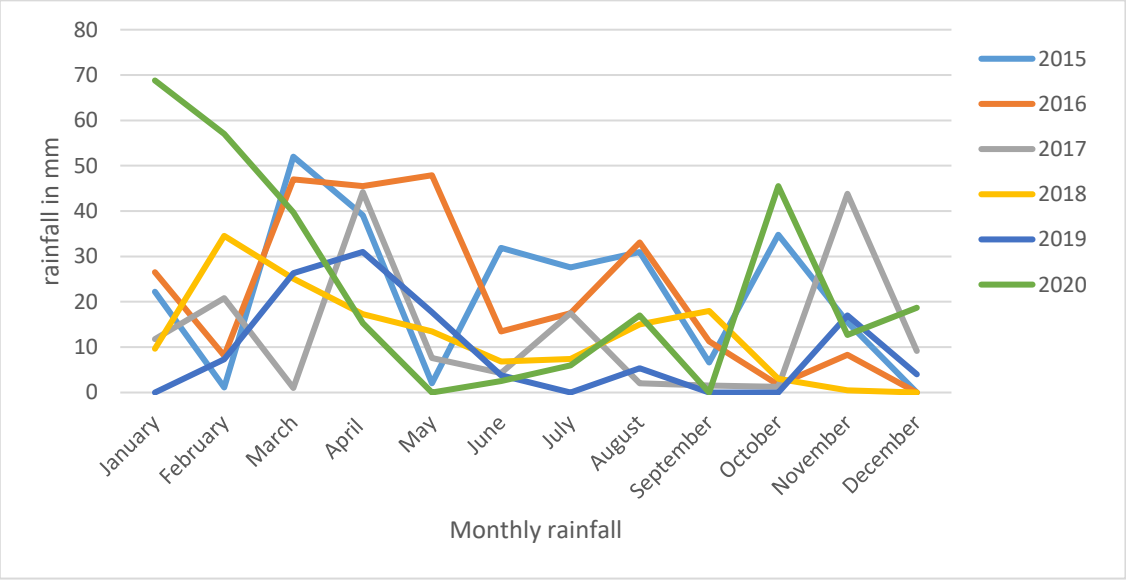

Figure 3.9: Monthly rainfall in the Karoo National Park, Western Cape Province from 2015–2020.

3.2.3. Vegetation

The Great Karoo, which is South Africa's largest ecosystem and makes up 35% of the country's total area, includes the KNP (Rubin *et al*., 2001). It is positioned between the Nuweveld Mountain range and the semi-arid Nama-Karoo (Figure 3.10). The Nama-Karoo biome, which occupies the majority of the park, and a relatively tiny portion of the grassland biome are where the park's vegetation may be found (Mucina & Rutherford, 2006) (Figure 3.10). The Western Upper Karoo, Upper Karoo Hardeveld, and Gamka Karoo vegetation types are represented by the Upper- and Lower Karoo bioregion units. The vegetation type known as Karoo escarpment grassland, which is a member of the dry highveld grassland bioregion, is a representation of the grassland biome (Mucina & Rutherford, 2006, Kraaij, 2006). The vegetation has a variety of physical characteristics, including riparian vegetation, Montane Karoo grassland shrublands, and Karoo grassy dwarf shrublands (Bezuidenhout, 2016).

The diversity of the plant community is directly impacted by the park's steep height and precipitation gradients (Rubin & Palmer, 1996; Bezuidenhout, 2016, Kraaij, 2006). *Merxmuellera disticha* (mountain wire grass), *Cymbopogon pospischilii* (narrow-leaved turpentine grass), and *Themeda triandra* (Red grass) are the dominant grass species in the montane grasslands due to the comparatively high elevation and rainfall. The KNP is home to a variety of grass species, tall forbs associated with fynbos, such as *Elytropappus rhinocerotis* (Rhinoceros bush), *Euryops annae* (Resin bush), and *Passerina montane* (Fire beater), as well as sparse woody plant species like the tree Sterboom, *Cliffortia arborea* (Star tree) and dwarf shrub *Diospyros austro-africana* (Bezuidenhout, 2016). The Montane Karoo dwarf shrublands, which are dominated by plants like *Eriocephalus ericoides* (Wild rosemary), *Rosenia oppositifolia* (Springbok karoo), and *Pteronia tricephala* (Resin daisies), replace these mesic plant communities due to the steeply increasing aridity away from the escarpment edge in a south-western direction (Bezuidenhout, 2016).

The park's unique forest plant ecosystem is supported by the numerous drainage lines, and among its most notable plant species are the trees *Vachellia karroo* (Sweet thorn), *Lycium cinereum* (Kareebos), and Stipagrostis namaquensis (River Bushman Grass) and *Cenchrus ciliaris* (Blue Buffalo Grass). The grass *Stipagrostis uniplumis* (Silky bushman grass), the forbs *Pentzia incana* (African sheepbush), *Hermannia* species,

Aptosimum species, and *Eriocephalus* species, as well as dry forbland plant groups, are found next to the drainage lines (Rubin *et al*., 2001).

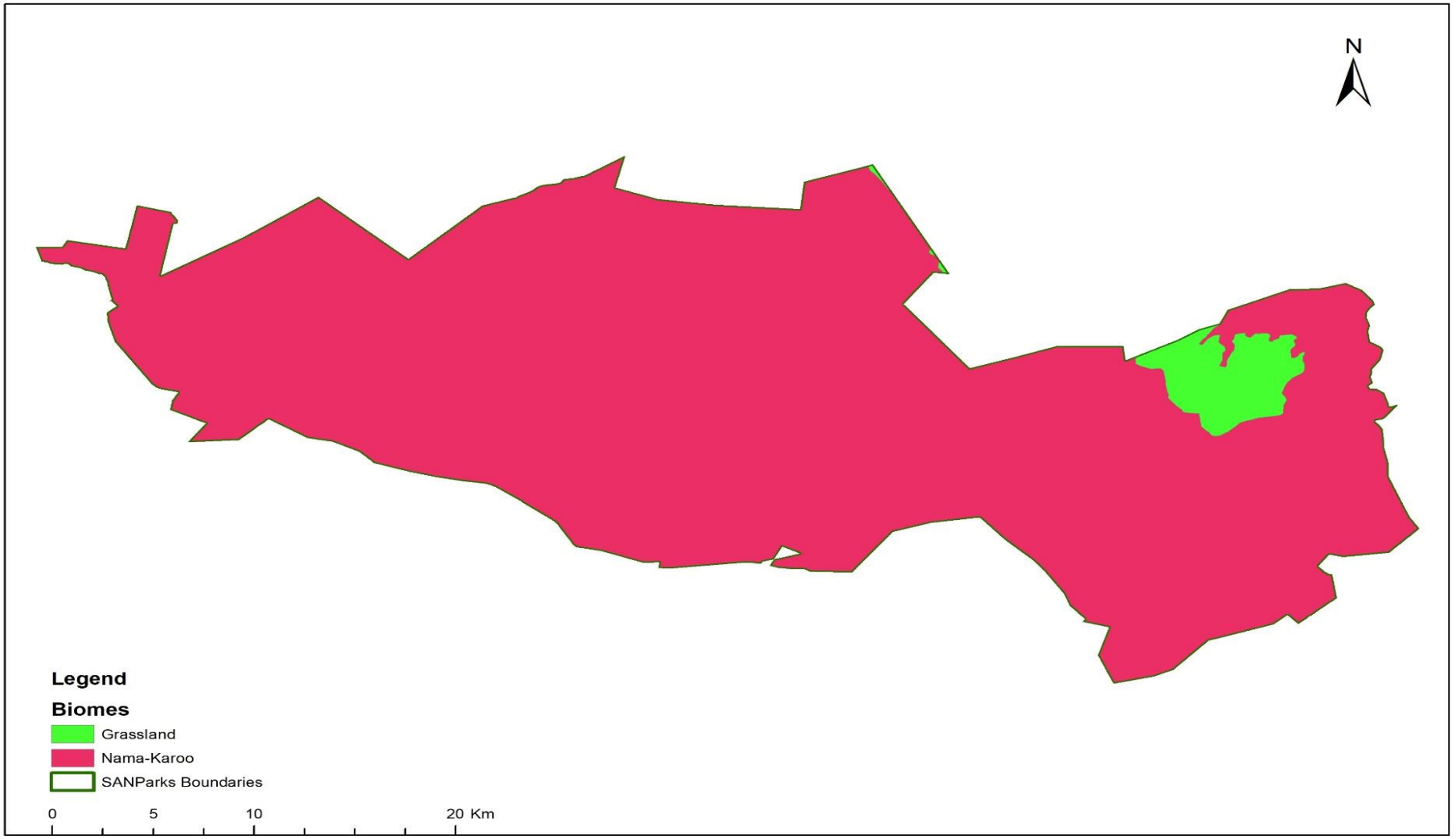

Figure 3.10: Two different biomes that occur in Karoo National Park (Mucina & Rutherford, 2006).

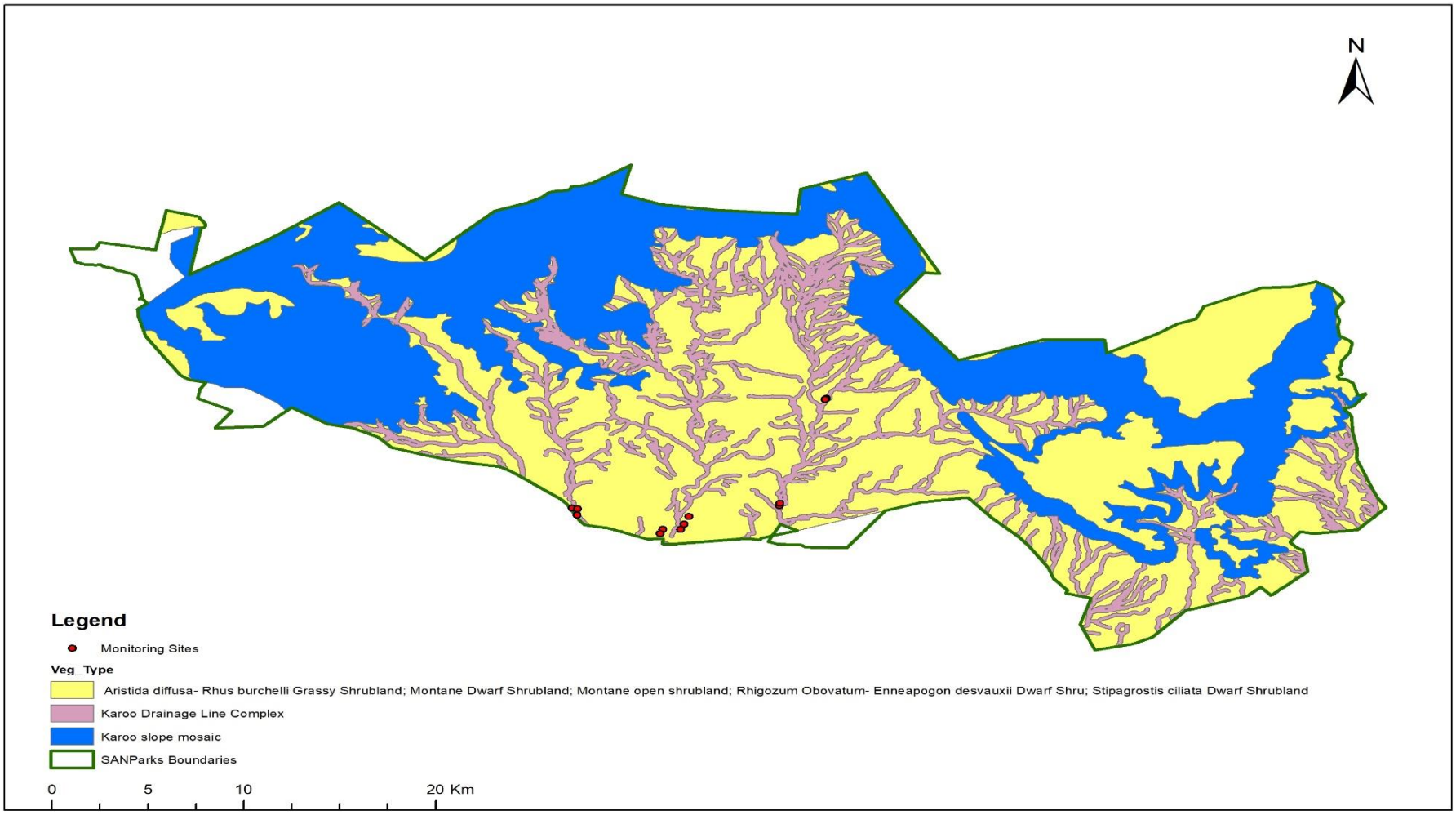

Figure 3.11: Map of plant communities with monitoring sites in the Karoo National Park (Bezuidenhout 2016).

3.2.4. Topography

The park can be divided into five physiographic units: the southern and central plains, which are 1,000 m or less above mean sea level (AMSL), the southern and eastern plains, which are 1,000 m or less above mean sea level, and the middle plateau, which is 1,100–1,200 m AMSL (SANParks, 2017, Land Survey staff, 1987). The flat-topped Korannasfontein Mountain in the west is 1,400–1,550 m AMSL, while the Northern Upper plateau is 1,600–1,900 m AMSL (Land survey staff 1987). The park's placement on the Great Escarpment, with the older, higher African surface to the north and more recently exposed, lower-lying plains sections to the south, which are peppered with typical Karoo koppies, is its most notable topographic feature (Land Type Survey staff, 1987).

3.2.5. Geology and soils

There is a clear connection in KNP between the geological horizons of the Beaufort West plains, which have developed over time in layers, and those at the summit of the Nuweveld escarpment (Land Type Survey Staff, 1987). The Dwyka Formation, Ecca Group, and Beaufort Group make up the Permian Karoo Supergroup. Overlying the Ecca Group, the Beaufort Group is made up of alternating layers of sandstone and reddish mudstone. It is separated arbitrarily at the foot of the so-called "Poortjie Sandstone" between the lower Abrahamskraal Formation, which is 1,500 m to 2,000 m thick, and the upper Teekloof Formation, which is about 1,400 m thick (Land Type Survey Staff, 1987). This formation is made up of thin greenish cherty layers, sandstone, and reddish-orange patches of mudstone. The mudstones are floodplain deposits, while the sandstones are deposits from river channels (Land Type Survey staff, 1987). The nearby host rocks undergo metamorphosis as a result of the dolerite. Sandstones take on a quartzitic look as mudstone is transformed into hornfells. River terrace gravel, calcrete, alluvium, and debris are quaternary deposits. Dolerite-dominant boulders and well-rounded cobbles make up terrace gravel. Along the Gamka River's banks, the terrace gravel clearly identifies steep profiles. These gravels, which are partially calcrete-cemented, are found on terrace ruins that are currently located between a few meters and 30 meters above the ordinary land surface. The highest thickness of calcrete, which forms widespread deposits and

occurs directly on bedrock in some bigger alluvium sites, is a few meters (Rubin & Palmer, 1996).

Rock weathering, which produces orthic topsoil horizons and frequently clay alleviation, which typically results in lithucutanic horizons, is the main process responsible for soil formation. The Nuweveld Mountain, upper steep midslopes, and middle plateau areas are primarily related with the Ib land types (Soil work group, 1991). The other soil types, Glenrosa and Mispah, are typical of these terrain formations aside from the predominate rocky outcrops. The depth of the predominant soil types ranges from 0.05 to 0.3 meters, while the B-horizons' clay concentration ranges from 15% to 35%. The Db terrain type is strongly related to the northeastern quadrant of the top plateau of the Nuweveld Mountain in the park (Soil classification workgroup, 1991). Valsrivier and Oakleaf soil types predominate, with a depth of 0.1 to 0.3 m and a high clay percentage of 20 to 55 percent. More than half of this area is covered in duplex soil with a non-red B horizon. Lower-lying undulating terraces (plateau and midslopes) and valley bottomlands, which are closely related to the Fc land types, predominate in the park's center and southern regions. Glenrosa and Mispah soil types predominate, with a depth of 0.05–0.3 m and a clay concentration of 15–35 percent (Land Type Survey Staff, 1987, Soil Classification Work Group, 1991).

CHAPTER 4: MATERIALS AND METHODS

4.1. Sampling Sites

The sampling sites affected by degradation per plant community were randomly selected from the degradation map of Mokala and Karoo National Parks (Tables 4.1 and 4.2). The selected sampling sites were in the vegetation communities described above (Figure 3.6 and 3.11).

Table 4.1: Names of monitoring sites in Mokala NP in the plant communities with grid references in each plant community

Monitoring sites	Plant communities	Latitude	Longitude
Punberg T1	*Vachellia erioloba - Vachellia tortilis* open woodland	-29.14097	24.32551
Punberg T2	*Vachellia erioloba - Vachellia tortilis* open woodland	-29.14041	24.32337
Punberg T3	*Vachellia erioloba - Vachellia tortilis* open woodland	-29.13991	24.32244
Stofdam T1	*Cynodon dactylon - Ziziphus mucronata* open woodland	-29.13376	24.38511
Stofdam T2	*Cynodon dactylon -Ziziphus mucronata* open woodland	-29.13360	24.38589
Stofdam T3	*Cynodon dactylon - Ziziphus mucronata* open woodland	-29.15194	24.38110
Stofdam T4	*Cynodon dactylon -Ziziphus mucronata* open woodland	-29.15237	24.38038
Braaghoek T1	*Cynodon dactylon - Ziziphus mucronata* open woodland	-29.13368	24.40599
Braaghoek T2	*Cynodon dactylon - Ziziphus mucronata* open woodland	-29.13534	24.40599
Braaghoek T3	*Cynodon dactylon -Ziziphus mucronata* open woodland	-29.13436	24.40593
Vaalsfontein T1	*Senegalia mellifera - Vachellia erioloba* open to close woodland	-29.07496	24.47528
Vaalsfontein T2	*Senegalia mellifera - Vachellia erioloba* open to close woodland	-29.07448	24.47485
Vaalsfontein T3	*Senegalia mellifera - Vachellia erioloba* open to close woodland	-29.074488	24.47475

Table 4.2: Names of monitoring sites in the Karoo National Park with grid references in each plant community.

Site name	Plant community	Latitude S	Longitude E
Boesmankop T1	*Aristida diffusa – Searsia burchellii*	-32.3378	22.24145
Boesmankop T2	*Aristida diffusa – Searsia burchellii*	-32.34022	22.24027
BoesmanKop T3	*Aristida diffusa – Searsia burchellii*	-32.33773	22.24974
Boesmankop T4	*Aristida diffusa – Searsia burchellii*	-32.3347	22.25134
Boesmankop T5	*Aristida diffusa – Searsia burchellii*	-32.3303	22.25359
Grantham T1	Karoo drainage line complex	-32.32574	22.19906
Grantham T2	Karoo drainage line complex	-32.32570	22.20138
Grantham T3	Karoo drainage line complex	-32.32949	22.20117
Sandrivier T1	Karoo drainage line complex	-32.32402	22.29617
Sandrivier T2	Karoo drainage line complex	-32.32240	22.29635
Sandrivier T3	Karoo drainage line complex	-32.32340	22.29645
Kokfontain T1	Karoo drainage line complex	-32.26105	22.31817
Kokfontein T2	Karoo drainage line complex	-32.26171	22.31750
Kokfontein T3	Karoo drainage line complex	-32.26131	22.31850

4.2. Description of the restoration technologies implemented at Mokala and Karoo National Parks

Restoration technologies implemented at the selected degraded sites in both National parks include ponding combined with brush packing. The type of intervention depends on the severity of degradation and the available resources. The following restoration technologies were applied at both MNP and KNP (see description of restoration technologies below).

4.2.1. Ponding and Brush packing

The restoration technology for ponding and brush packing is a combination of biological and mechanical methods (Naudé, 2019) (Figure 4.1). Soil ponding can be done manually using spades or by mechanical means using machinery to make hollows. The hollows made have a half-circle shape (moon-shape) to a depth of approximately 30-50 cm to trap water from the flowing areas above (Rochefort *et al*., 2003). The depression or hollow was made in the direction of water flow (Rochefort *et al.*, 2003). The sizes of the "half-moon" pond in the study area were approximately 1 m in width and 1 m in length. Bigger ponds were avoided as they may result in accelerated erosion during flash floods. The advantage of ponding technology is that it effectively increases soil moisture, protects young seedlings, slows down water flow and traps water as well as nutrients in the pond (Roberts *et al*., 2005). This technology is mainly applied in areas affected by sheet erosion and where there is no or little vegetation cover. To attain successful results, brush packing was applied in the ponds to protect established seedlings from herbivory. Brush packing is a cost-effective restoration technology, as manual labour is used to cover the degraded areas. Brush packing is often described as a biological restoration method, where organic resources (woody twigs, branches, and leaves) are used in the application of a restoration technology (Rochefort *et al*., 2003, Sibitloane *et al.,* 2020, Mangani, 2021, Modungwa, 2017).

Figure 4.1: Application of ponding and brush packing as restoration technologies in Mokala and Karoo National Parks

Branches from woody species, such as *Senegalia mellifera* and *Vachelia tortilis* are used to cover bare and denuded patches, strategically packed with spines in plots at a height of approximately 0.5 meters above the ground. The spines and branches served as protection barriers against grazing animals (Sibitloane *et al.,* 2020, Mangani, 2021). Branches from *Vachelia tortilis* mostly used in the KNP due to the lack of other woody species as compared to MNP. Brush also offers other benefits, such as lowering the temperature and providing shade for the underlying plants that are established (Yates *et al.*, 2000; Coetzee, 2005; Visser *et al*., 2007), trapping seed that was blown into the area, increasing soil organic matter and soil moisture (McAuliffe, 1984; Coetzee, 2005; Sibitloane *et al.,* 2020, Mangani, 2021). The brush packing in combination with ponding method technique is mostly applied in areas affected by sheet erosion.

4.3. Sampling Methods

Two sampling techniques were used: (1) the Landscape Function Analysis (LFA) method to evaluate the ecosystem's functionality using a combination of the 11 soil surface assessment (SSA) indicators, specifically stability, nutrient cycling, and infiltration as parameters to evaluate the restoration process, and (2) the quadrant method to evaluate the composition, richness, and diversity of the vegetation planted along the LFA transects.

4.3.1. The Landscape Function Analysis (LFA)

The functionality of ecosystems following the implementation of the integrated restoration strategies in the identified degraded regions was assessed using the Landscape Function Analysis (LFA) monitoring approach (Tongway & Hindley, 2004, Daemane *et al*., 2011, Tongway, 2000). The LFA is employed to assess a landscape's functionality in order to assist in the management of the resources found there that are used for various ecological processes (Tongway & Hindley, 2004). Instead, than assessing a landscape's biodiversity like most other methodologies do, the LFA analyzes the elements that keep the ecosystem functioning in the landscape (Tongway & Hindley, 2004).

The landscape organization and identification of indicators that contribute to landscape function are carried out using the conceptual framework of the LFA methodology, which is composed of three modules. These modules are (i) the conceptual framework, (ii) field procedures for monitoring the indicators (field data acquisition), and (iii) an interpretational framework (Tongway & Ludwig, 2011).

The values of the SSA indicators change depending on the characteristics of each patch and inter-patch type. These inter-patches and patches were given a unique name that identified the type of surface beneath the measuring tape used for the LFA (Tongway & Hindley, 2004). The widths of each patch were then determined. A data sheet designed to compute and handle LFA data was used for data recording. As long as the data are collected from representative areas and the various patch types are present, the transects can be of any length. This stage marks the beginning of the landscape's organization.

4.3.1.1. The conceptual framework and landscape organisation.

Data on the local landscape organization and the movement of limited resources through a landscape in both space and time are gathered using the conceptual framework (Tongway & Hindley, 2004; Tongway & Ludwig, 2011). The conceptual framework allows for the examination and separation of the landscape's functioning from its biological makeup and structure (Tongway & Hindley, 2004).

Functional and dysfunctional landscapes are the two categories into which a landscape can be divided (Tongway & Ludwig, 2004). Functional landscapes are those that have dense perennial patches of plant because of which the excess of water flows out of the landscape over a longer distance (Tongway & Hindley, 2004; Tongway & Ludwig, 2011). The removal of debris and seed and obstruction of water flow are two effects of vegetation (Tongway & Hindley, 2004). The flow of water is not greatly impacted by a dysfunctional landscape (Tongway & Hindley, 2004; Kakembo, 2009). A disordered landscape allows its limited resources to flow out rather than being contained (Tongway & Hindley, 2004; Bastin *et al*., 2002). These dysfunctional landscapes frequently "leak" resources and fall short in their ability to absorb enough water and other nutrients (Tongway & Hindley, 2004). Reduced size, spacing, and quantity of patches can be used to detect degradation and dysfunction in a landscape (Tongway & Hindley, 2004; Foley *et al*., 2005).

Figure 4.2 depicts the way the landscape was structured by Tongway Hindley (2004) and offers a clear representation of how the LFA transect is divided into several patches and inter-patches. It's possible that each sort of environment will have its own unique approaches to managing constrained resources (Noy-Meir, 1973; Noy-Meir, 1981; Tongway *et al*., 2003). Based on size, location, and characteristics, the field methodology entails locating and measuring directly with a measuring tape an arrangement of various kinds of patches (which accumulate nutrients) and inter-patches (which promote the loss of nutrients) (Tongway & Ludwig, 2004; Haagner, 2008; Van der Walt *et al*., 2012). The patches and inter-patches define the Land organisation (LO), which is then applied to the interpretational framework (Tongway & Hindley, 2004).

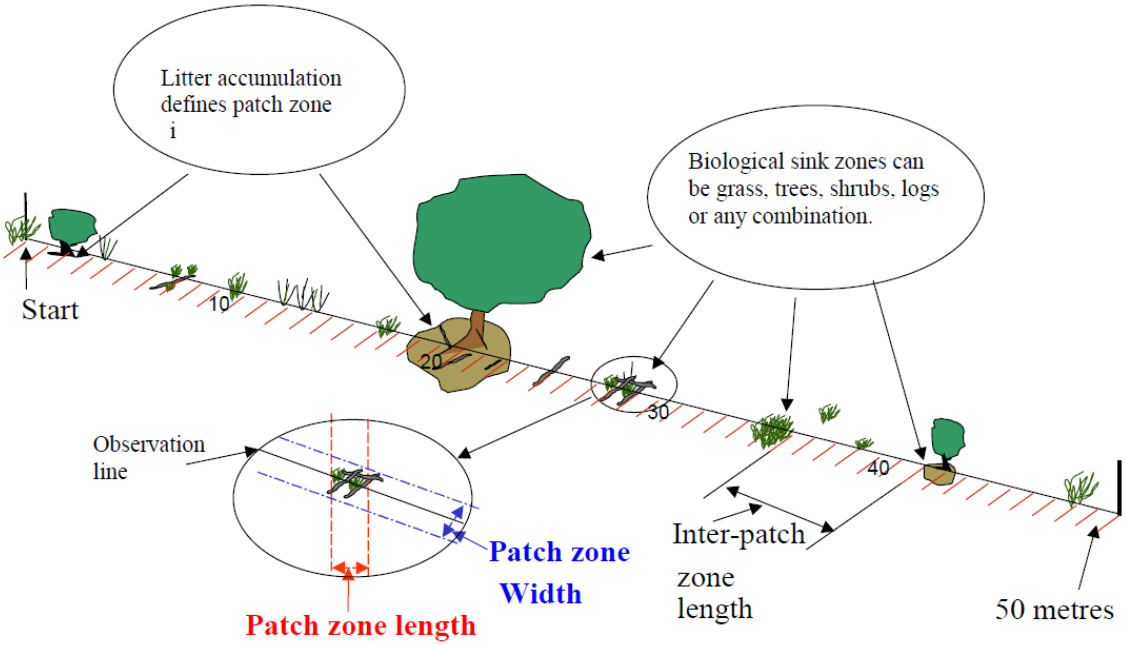

Figure 4.2: An illustration of landscape organisation. Different types of patches and inter-patches found in landscapes are also shown (Tongway & Hindley, 2004).

4.3.1.2. Field data acquisition

This part of the LFA shows how the field data collection step of the LFA technique operates (Tongway & Hindley, 2004). There is no requirement for particular organisms to exist in the landscape for this technique to work on all soils, landscapes, and land uses (Tongway & Hindley, 2004). Following the landscape organisation (LO) step, fine-scale data is collected, and each patch (resource accumulation) and interpatch (increased nutrient loss) type in the field is evaluated using the 11-soil surface analysis (SSA) indicators.

Some of the 11 SSA indicators utilized for fine-scale data collecting are soil texture, slake test, soil surface roughness, perennial vegetation cover, litter cover origin, cryptogam cover, crust brokenness, soil erosion type and severity, deposited materials, and rain splash protection (Tongway & Hindley, 2004; Tongway & Ludwig, 2011 - Table 4.3). The infiltration, stability, and production will be affected by combinations of the 11 SSA indicators (Tongway & Hindley, 2004).

Table 4.3: Summary of the 11 SSA indicators, their values to the summary of the three main functional parameters and purposes in the LFA methodology (Tongway & Hindley, 2004)

SSA Indicator	Values	Objectives
Rain splash protection	5	It shows how the perennial vegetation and surface cover protect the soil from the effects of raindrops.
Perennial vegetation cover	4	Determines the amount of perennial vegetation cover.
Litter cover, origin and degree of composition	10	Estimates the amount of litter, its origin, and the degree to which it is composed.
Cryptogam cover	4	Estimates the amount of cryptogam that is visible on the soil surface.
Crust brokenness	4	Determines the degree to which the soil is broken.
Erosion type & severity	4	Assesses the type and degree of soil erosion.
Deposited materials	4	The amount of alluvium deposited in the landscape is assessed.
Soil surface roughness	5	The roughness of soil and its ability to capture resources.
Surface nature	5	The ability of the soil to withstand mechanical disturbance of erodible material is assessed.
Slake test	4	Assesses the stability of natural soil fragments to rapid wetting.
Soil texture	4	The soil texture and its permeability.

4.3.1.3. Implementation of the LFA in the field

Both KNP and MNP were subjected to the LFA technique prior to and following the use of the restoration technologies. Any modifications to the functionality of the landscape could be evaluated in this way. Nine transects were built at the MNP site and a total of 12 were established at KNP. These transects were established downslope, following the flow of water and the movement of nutrients and debris (Tongway & Hindley, 2004). Each transect measured roughly 30 meters. The 11 SSA indicators were detected at the indicated patches following the completion of the LO on the transects (gradsect). A gradient-oriented transect, sometimes known as a "gradsect," is another name for the direction of water flow (Tongway & Hindley, 2004). Steel pins were used to separate and interconnect the several patches that made up the transect on which the LFA was performed. Five alternative patches and inter-patches were randomly chosen following the LO and evaluated for the eleven SSA indicators (Figure 4.3) as previously stated, the LFA technique includes the 11 SSA indicators.

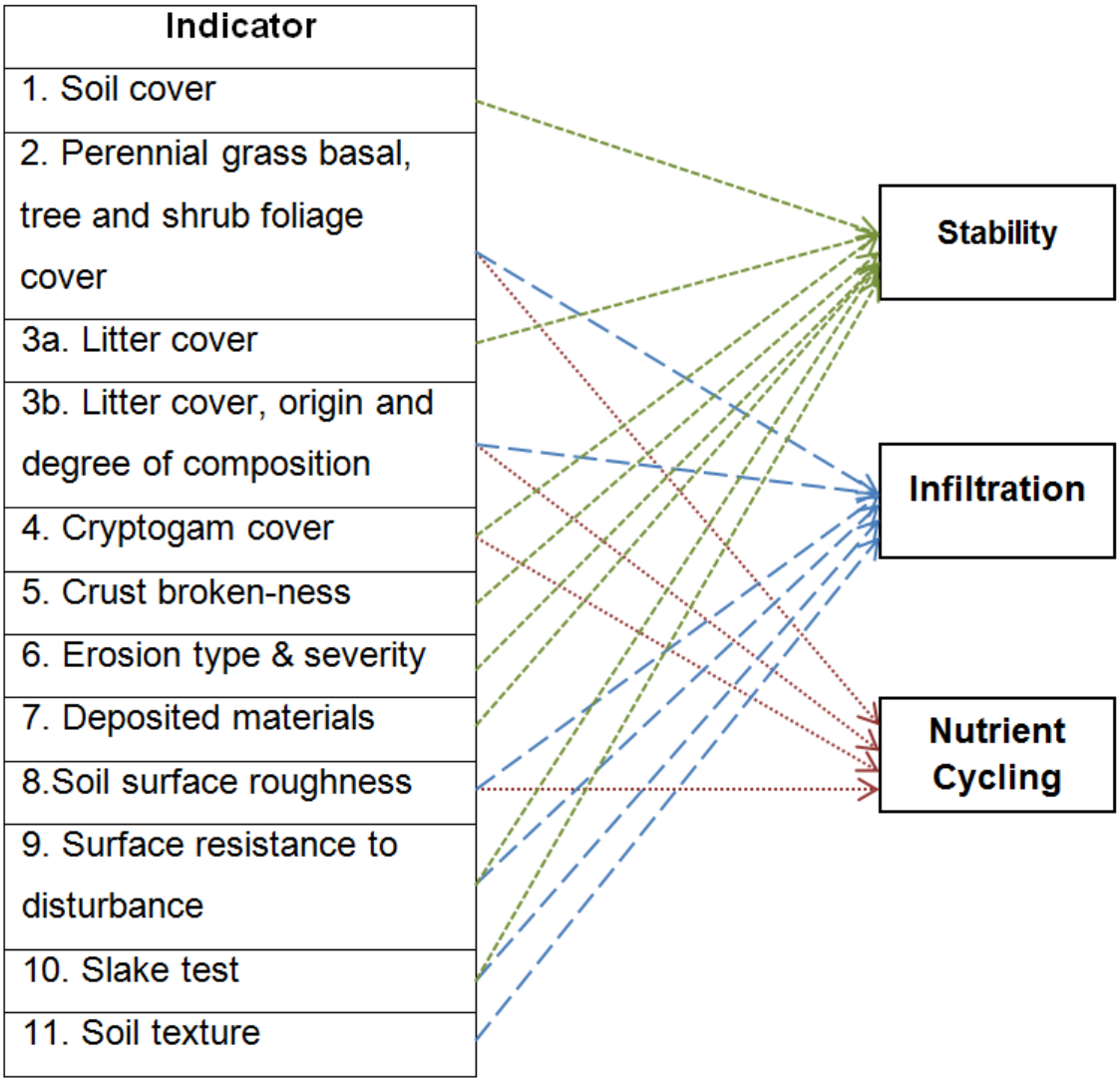

Figure 4.3: A summary shows the impact of the 11 SSA indicators on the three main functional parameters (from Tongway & Hindley, 2004).

4.3.1.4. Interpretational framework of LFA

For the LFA to be meaningful, monitoring data must be interpreted in a way that makes it possible to use the values that result for assessing the functionality of the landscape (Noy-Meir, 1981; Tongway & Ludwig, 2011). The LFA module's interpretation framework is used to analyse the data collected in the field. The recorded data are read into an Excel template that computes to produce a summary of what is happening in the landscape and condenses the 11 SSA indicators into three landscape parameters (stability, nutrient cycling and infiltration). The percentage ranges from 0 to 100. This module is designed to compare the restoration sites that have undergone

restoration throughout a variety of years (Tongway & Ludwig, 2011). Because it aids in evaluation, this is crucial.

4.3.2. Vegetation Sampling

At each restoration site, a 1 m × 1 m quadrant was set up along the LFA transects, according to Jim Baxter's (2014) description (Stohlgren *et al*., 1998; Barbour *et al*., 1999; Kent, 2012). To identify the plant species and assess species diversity and richness, a total of 10 quadrants were distributed at 3 m intervals. According to the Plants of Southern Africa checklist, the plant species were identified (SANBI, 2022). For each quadrant and the entire transect that represents the degraded area, the number of plants were counted for each species.

4.4. Statistical analysis

4.4.1. Landscape Function Analysis

The LFA data were analysed using the LFA's data capturing and analysis procedures in Microsoft Excel (LFA-SSA-data-entry-V3.0xls) (Tongway & Hindley, 2004).

4.4.2. Diversity Analysis

Analysis of diversity indices (Simpson index for dominance, evenness, and Shannon index for diversity) from the vegetation data was undertaken using the PAST 4.03 programme (Hammer *et al*., 2001).

Shannon-Weiner Index

$$(H) = -\sum_i \frac{n_i}{n} ln \frac{n_i}{n}$$ ..... *equation 4.1*

Dominance (Simpson index) ranges from 0 (all taxa are equally present) to 1 (one taxon dominates the community completely).

$$D = \sum_i \left(\frac{n_i}{n}\right)^2$$ .....*equation 4.2*

Where n_i is the number of individuals of taxon i

Simpson index 1-*D*. Measure the ‘‘Evenness” of the community from 0 to 1. Where 1 is low diversity and 0 is infinite diversity.

A bootstrap approach was used to calculate the approximate confidence intervals for each of these indices to assess accuracy (bias, variance, confidence intervals, prediction error, etc.). Each of the generated random samples (default: 9999) has the same total number of subjects as the initial sample (Harper, 1999). The taxon is chosen for each member of the random sample with probability proportionate to the initial abundances. Then it was determined what the 95 percent confidence interval was.

Chapter 5. Results

5.1. Mokala National Park

Infiltration, stability, and nutrient cycling were assessed during a five-year period (2015, 2017, 2018, 2019 & 2020) at Braaghoek, Vaalsfontein, Punberg, and Stofdam restoration sites. The results are described in this section of this Chapter. In the figures below, the scores for the stability, nutrient cycling, and infiltration criteria are displayed as percentages on the Y-axes. Results of species richness and diversity for the sites at Braaghoek, Vaalsfontein, Punberg, and Stofdam throughout a two-year survey are also included in this section (2019 & 2020).

5.1.1. Stability patterns at sites in Mokala National Park

At the Braaghoek site, the soil stability increased from 38% to 46% over the five years (2015–2020) after restoration application (Figure 5.1). The soil stability at the Vaalsfontein site increased from 37% to 46%, while it increased at the Stofdam site from 37% to 41% during 2015–2018, after which it slightly decreased again in 2019 to 40%, and then increased again in 2020 to 46% (Figure 5.1). It seems that the soil stability at the Punberg site was the most resilient with the highest increase from 39% in 2015 after which it was quite stable at 47% until 2020 (Figure 5.1). The overall increase in the soil stability pattern at the restoration sites in Mokala NP may be due to improvements in vegetation.

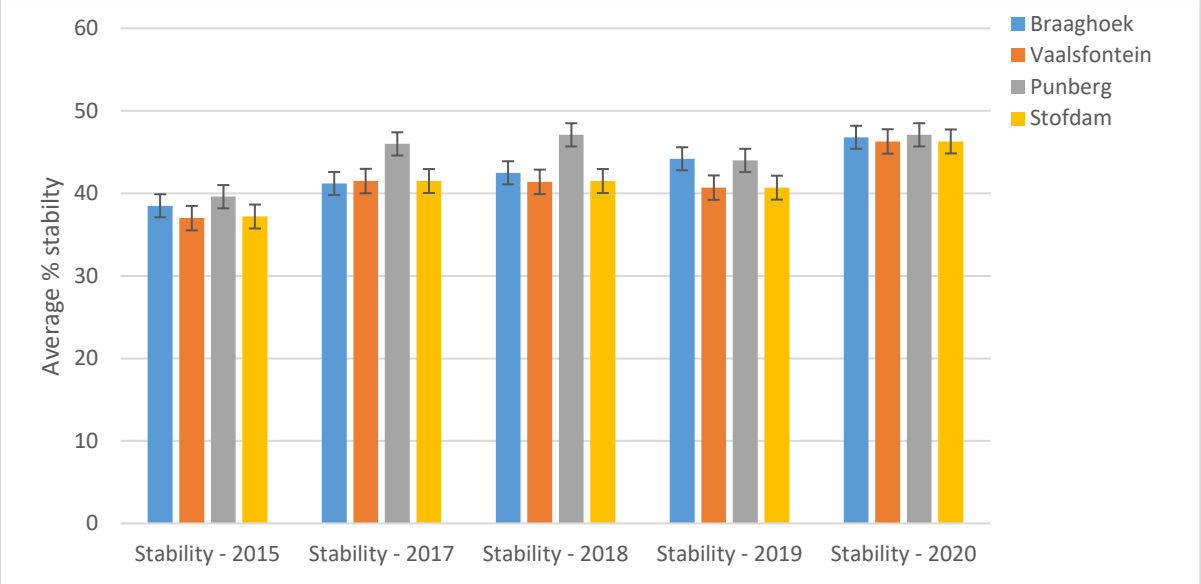

Figure 5.1: Average percentage (%) of change in soil stability from 2015 to 2020 for the sites sampled at Mokala National Park restoration sites after the restoration technologies were applied

5.1.2. Infiltration patterns at sites in Mokala National Park

Infiltration increased at the Braaghoek site in 2015 to 27% but decreased again in 2017–2019 from 24% to 23%, after which it slightly decrease again in 2020 to 20% (Figure 5.2). The infiltration at the Vaalsfontein site was high in 2015 at 25%, after which it decreased to 21% in 2017 and increased again in 2018 to 23% and 25% in 2020 (Figure 5.2). The infiltration rate at the Punberg site was 28% in 2015, after which it decreased in 2019 to 24% and slightly increased to 25% from 2017 to 2020 (Figure 5.2). The rate of infiltration at the Stofdam restoration site was high in 2015 at 25%, after which it decreased to 21% in 2017, then it increased again to 25% in 2020 (Figure 5.2). It seems that the infiltration rate was higher at the beginning of the restoration application (2015), after which it decreased (2016–2019) with a slight increase again in 2020. From this data and due to the changes and fluctuations in the infiltration parameter, it seems that infiltration is a poor indicator of restoration success at this particular site. The latter will depend on the soil types that were monitored at each site, as they may be different at each restoration site.

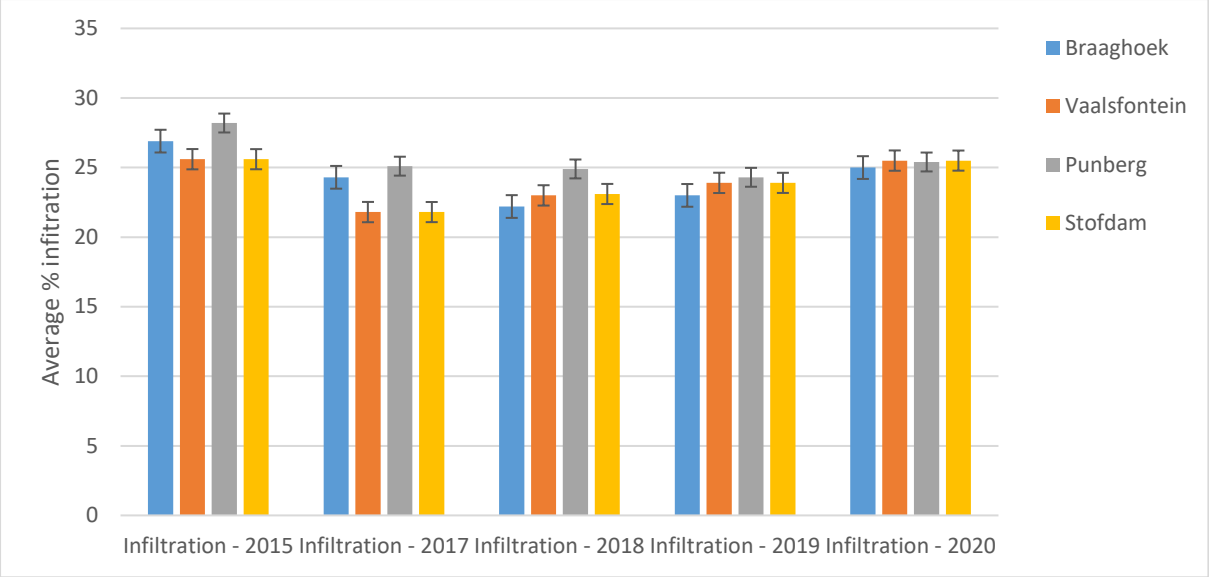

Figure 5.2: Average percentage (%) of change in infiltration from 2015 to 2020 for the sites sampled at Mokala National Park after the restoration technologies were applied

5.1.3. Nutrient cycling patterns at the sites in Mokala National Park

In 2015 the nutrient cycle at the Braaghoek site was 12% but decreased during 2017–2018 from 12% to 10%, after which it slightly increased to 14% in 2020 (Figure 5.3). The nutrient cycle at the Vaalsfontein site in 2015 was 12%, after which it decreased to 10% in 2017, further decreasing in 2018 to 9% and increased to 16% in 2020 (Figure 5.3). The nutrient cycle pattern at the Punberg site was 13% in 2015, after which it decreased in 2017–2019 to 12%, but increased slightly to 17% in 2020 (Figure 5.3). The rate of nutrient cycling at the Stofdam restoration site was 12% in 2015 after which it decreased to 10% in 2017 and 2019, with 9% recorded in 2018, it then increased to 16% in 2020 (Figure 5.3). From this data, and due to the changes and fluctuations in the nutrient cycle parameter, it seems that the nutrient cycle increased at the sites sampled over the five years of the surveys.

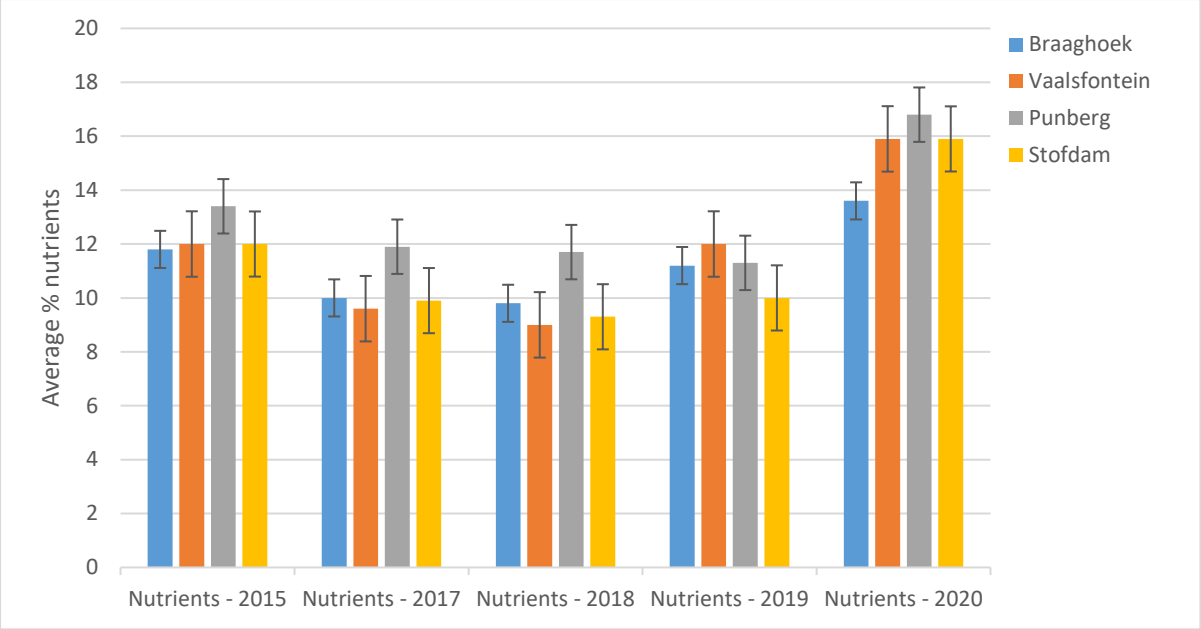

Figure 5.3: Average percentage (%) of change in the nutrient cycle from 2015 to 2020 for the sites sampled at Mokala National Park after the restoration technologies were applied

5.1.4. Species richness pattern at sites of Mokala National Park (2019-2020)

The species richness at the Braaghoek restoration site was eight plant species in 2019, which declined to six in 2020 (Figure 5.4, Appendix 1 & 2). At the Vaalsfontein restoration site, six plant species were recorded in 2019, which increased to seven in 2020 (Figure 5.4, Appendix 1 & 2). A total of eight species were recorded at the Punberg restoration site in 2019, this increased to nine plant species in 2020 (Figure 5.4, Appendix 1 & 2). A total of nine species were recorded at the Stofdam restoration site in 2019, declining to eight in 2020 (Figure 5.4, Appendix 1 & 2). The change of one or two species over the two years of assessment could be due to the short period of data recording and other factors that could have influenced these changes, such as the different soil types, soil moisture and the life span of the plant species that occurred at the sites. Other factors include the herbivory of certain plant species by game, reducing the number of species, or the differences in soil seed banks that occurred at each site before and during the surveys. This emphasises that this parameter is not a good indicator to measure restoration success when soil types differ and samples are taken over such a short time in a national park.

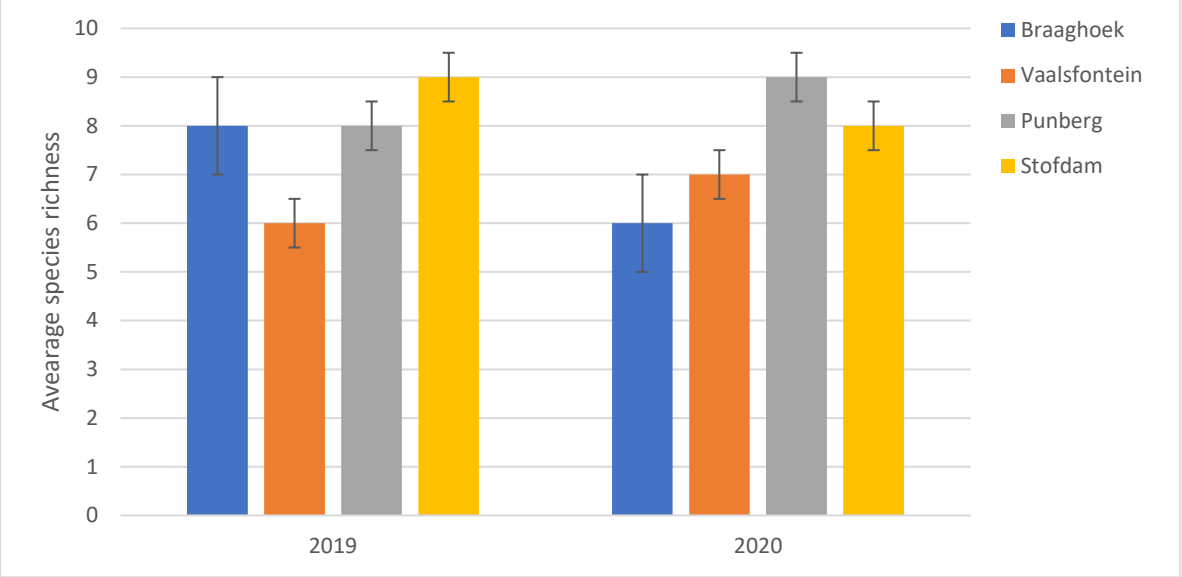

Figure 5.4: Average species richness from 2019 - 2020 for the sites sampled at Mokala National Park after the restoration technologies were applied.

5.1.5. Species diversity at restoration sites of Mokala National Park (2019-2020)

The average species diversity at the Braaghoek restoration site was 1.5 in 2019, which declined to 1.2 in 2020 (Figure 5.5). The average species diversity at the Vaalsfontein restoration site was 1.5 in 2019, then it increased to 1.6 in 2020 (Figure 5.5). The average species diversity at the Braaghoek restoration site was 1.3 and increased to 1.9 by 2020 (Figure 5.5). The average species diversity recorded at the Stofdam restoration site was 1.6 in 2019, which increased to 1.7 in 2020 (Figure 5.5).

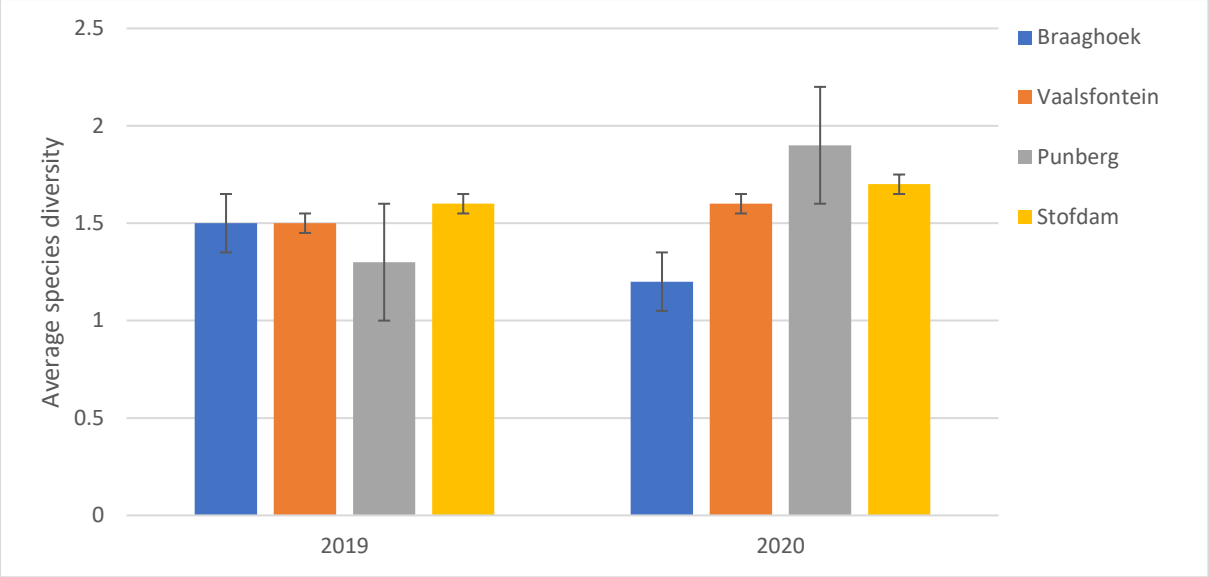

Figure 5.5: Average species diversity from 2019 to 2020 for the sites sampled at Mokala NP after the restoration technologies were applied.

5.1.6. Correlation between the three parameters stability, infiltration and nutrient cycling in Mokala National Park

The three parameters used in the soil surface analysis (SSA) of the landscape function analysis (LFA) monitoring methodology include stability, infiltration and nutrient cycling (also called "nutrients"). According to the overall results of this study at the four restoration sites in the Mokala NP, a positive correlation between soil stability, infiltration and nutrients (nutrient cycling) was detected (Table 5.1). At the Braaghoek study site, a negative correlation was detected between the infiltration and nutrient cycle ("nutrients") parameters, while a positive correlation was detected between stability and the nutrient cycle as well as stability and infiltration (Table 5.1). At the Vaalsfontein restoration site, a negative correlation was detected between the infiltration and nutrient cycling parameters, while a positive correlation was detected between stability and nutrient cycling, as well as stability and infiltration parameters (Table 5.1). At the Stofdam restoration site, a positive correlation was detected between infiltration and nutrients, stability and nutrients as well as stability and infiltration (Table 5.1). At the Punberg restoration site, a negative correlation was detected between the infiltration and nutrients cycle parameters and a positive correlation was detected between the infiltration and nutrients parameters, as well as

a positive correlation between the stability and nutrients along with stability and infiltration parameters (Table 5.1).

Table 5.1: Correlation of stability, Infiltration & nutrients cycle ("nutrients') at the four restoration sites in Mokala NP.

Braaghoek			
	Stability	**Infiltration**	**Nutrients**
Stability		0.50543	0.45514
Infiltration	-0.39931		0.28794
Nutrients	0.44287	0.59688	
Vaalsfontein			
	Stability	**Infiltration**	**Nutrients**
Stability		0.61502	0.58743
Infiltration	-0.30727		0.13366
Nutrients	0.33013	0.76277	
Stofdam			
	Stability	**Infiltration**	**Nutrients**
Stability		0.88892	0.3534
Infiltration	0.08735		0.095551
Nutrients	0.53451	0.81132	
Punberg			
	Stability	**Infiltration**	**Nutrients**
Stability		0.14802	0.69777
Infiltration	-0.74559		0.48469
Nutrients	0.23969	0.41716	

5.2. Karoo National Park

The results of the three primary LFA parameters obtained by the soil surface analysis (SSA), namely stability, nutrient cycling, and infiltration over a four-year assessment (2017–2020) at the Boesmankop, Grantham, Kokfontein, and Sandrivier restoration sites, are described in this section of the chapter. The figures below show the scores for the stability, nutrient cycling, and infiltration LFA criteria as percentages on the Y-axes. Results of species diversity and richness for the sites at Boesmankop,

Grantham, Kokfontein, and Sandrivier throughout a two-year assessment are also included in this section (2019 & 2020).

5.2.1. Stability patterns at sites in Karoo National Park

At the Boesmankop site, the soil stability increased from 41% to 43% over the five years after restoration (Figure 5.6). The Grantham site recorded 42% in 2017 which decreased to 41% in 2018, thereafter it slightly increased in 2019–2020 to 43% (Figure 5.6). The soil stability at the Kokfontein site recorded 43% in 2017, which slightly decreased in 2018 to 42%, and decreased to 41% in 2019–2020 (Figure 5.6). It seems, however, that the soil stability at the Sandrivier site was the most resilient and had the highest increase from 34% in 2017 to 41% in 2019–2020 (Figure 5.6). The overall increase in the soil stability pattern at the restoration sites in Karoo NP may be due to improved vegetation cover and species richness.

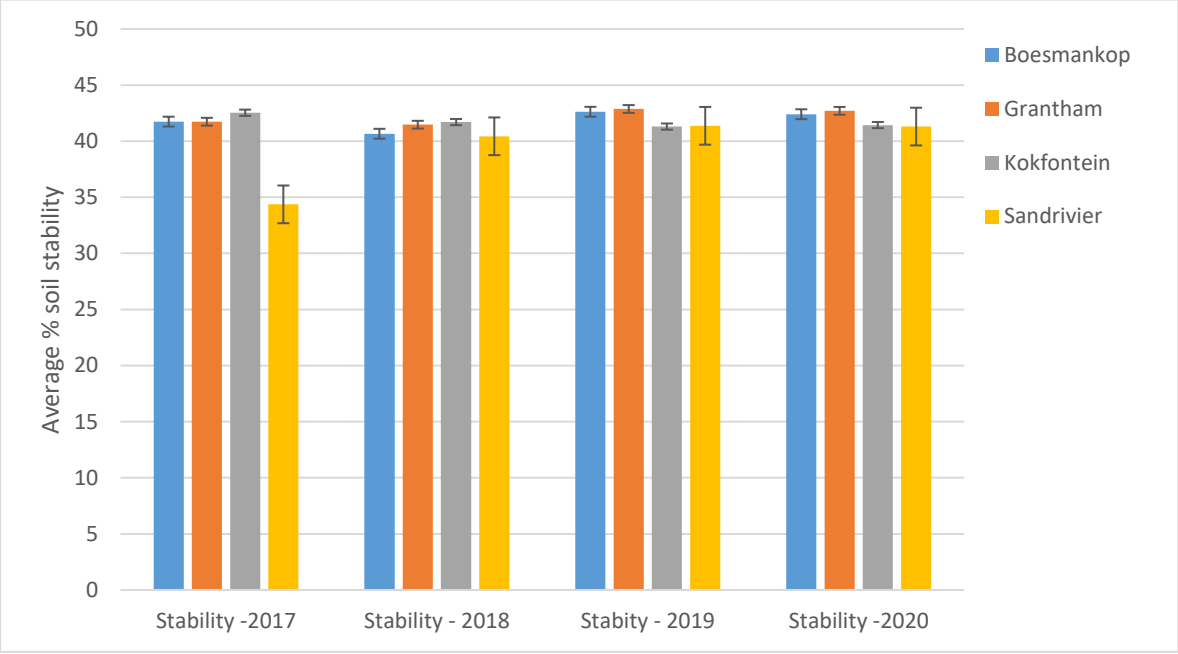

Figure 5.6: Average percentage (%) of change in soil stability from 2017 to 2020 for the sites sampled at Karoo National Park restoration sites after the restoration technologies were applied.

5.2.2. Infiltration patterns at sites in Karoo National Park

Infiltration at the Boesmankop site in 2017 was 22%, which decreased to 21% in 2018 to 21%, after which it slightly decreased again in 2019–2020 to 20% (Figure 5.7). The

infiltration at the Grantham site in 2017–2018 was 22%, after which it decreased to 20% in 2019–2020 (Figure 5.7). The infiltration trend at Kokfontein was 22% in 2017, after which it also decreased in 2018 to 18%, after which it increased slightly to 21% in 2019, to again slightly decrease to 19% in 2020 (Figure 5.7). The rate of infiltration at the Sandrivier restoration sites was high in 2017 at 27%, after which it decreased to 23% in 2018–2020 (Figure 5.7). It seems that the infiltration rate was higher at the beginning of the restoration application (2017), after which it decreased. From this data and due to the changes and fluctuations in the infiltration parameter, it seems that it is a poor indicator for determining restoration success. The latter will depend on the soil types that were monitored at each site, as they may be different at each restoration site.

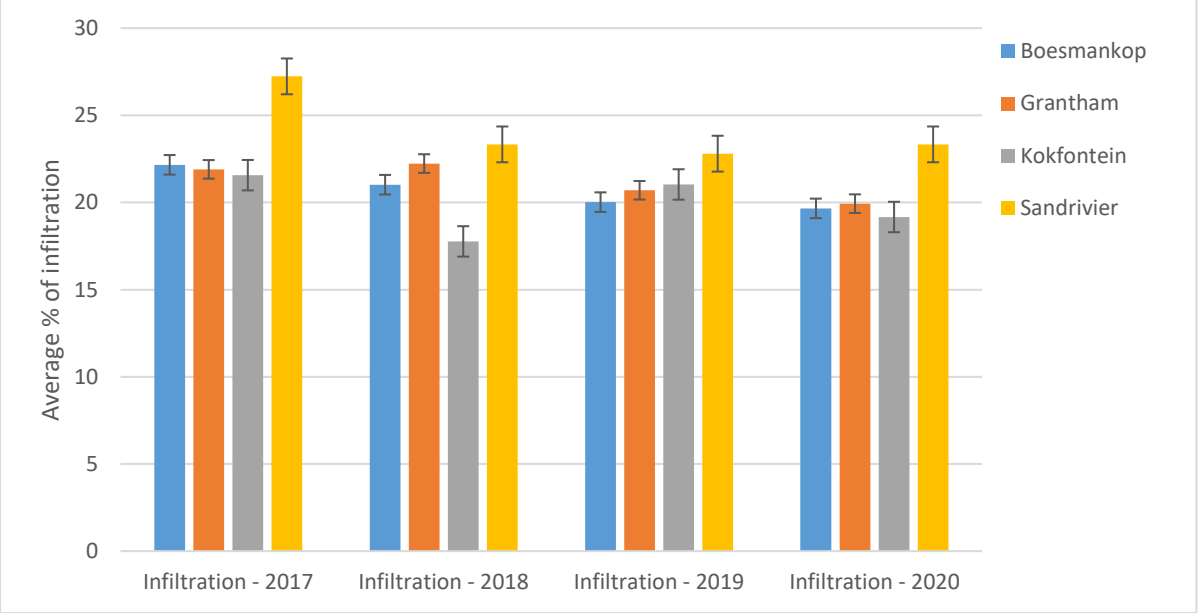

Figure 5.7: Average percentage (%) of change in infiltration from 2017 to 2020 for the sites sampled at Karoo National Park after the restoration technologies were applied.

5.2.3. Nutrient cycling patterns at sites in Karoo National Park

The nutrient cycle remained constant at the Boesmankop site in 2017–2020 at 9% (Figure 5.8). The nutrient cycle at the Grantham site was initially 10% in 2017–2018, after which it decreased to 9% in 2019 and then increased to 10% in 2020 (Figure 5.8). The nutrient cycle trend at Kokfontein was 10% in 2017, after which it decreased in 2018–2019 to 9%, then increased to 10% again in 2020 (Figure 5.8). The rate of nutrient cycling at Sandrivier restoration sites was 8% in 2017, it then increased to 9%

in 2018–2019 and further increased to 11% in 2020 (Figure 5.8). From this data, and due to the changes and fluctuations in the nutrient cycle parameter, it seems that the nutrient cycle increased over the four years of surveys.

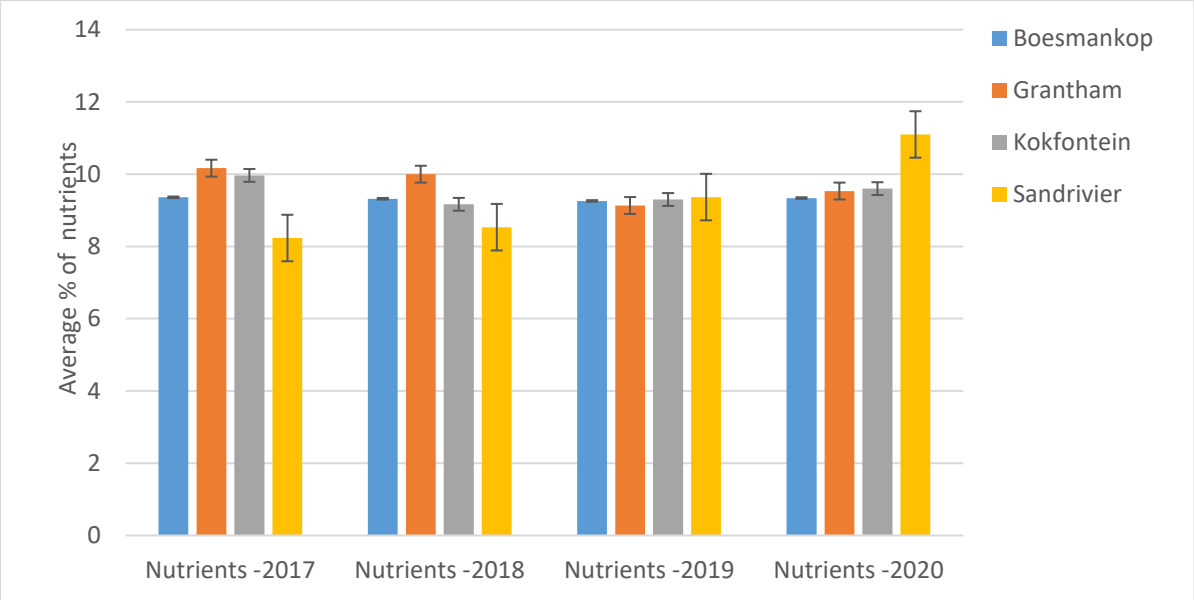

Figure 5.8: Average percentage (%) change in nutrient cycling from 2017 to 2020 for the sites sampled at Karoo National Park after the restoration technologies were applied.

5.2.4. Species richness pattern at sites of Karoo National Park (2019-2020)

At the Boesmankop restoration site, in 2019, plant species richness was six, this declined to five in 2020 (Figure 5.9, Appendix 3 & 4). The Kokfontein restoration site recorded six plant species in 2019, which increased to eight in 2020 (Figure 5.9, Appendix 3 & 4). An average of four plant species were recorded at the Sandrivier restoration site in 2019, which remained at four in 2020 (Figure 5.9, Appendix 3 & 4). A total of six plant species were recorded at the Grantham restoration site in 2019, this increased to eight by 2020 (Figure 5.9, Appendix 3 & 4). The change of one or two species over the two-year period of assessment could be due to the short period of data recording and other factors that could have influenced these changes, such as the different soil types, soil moisture and the life span of the plant species that occurred at the sites. Other factors include the herbivory of certain plant species by game, reducing the number of species, or the differences in soil seed banks that occurred at each site before and during the surveys.

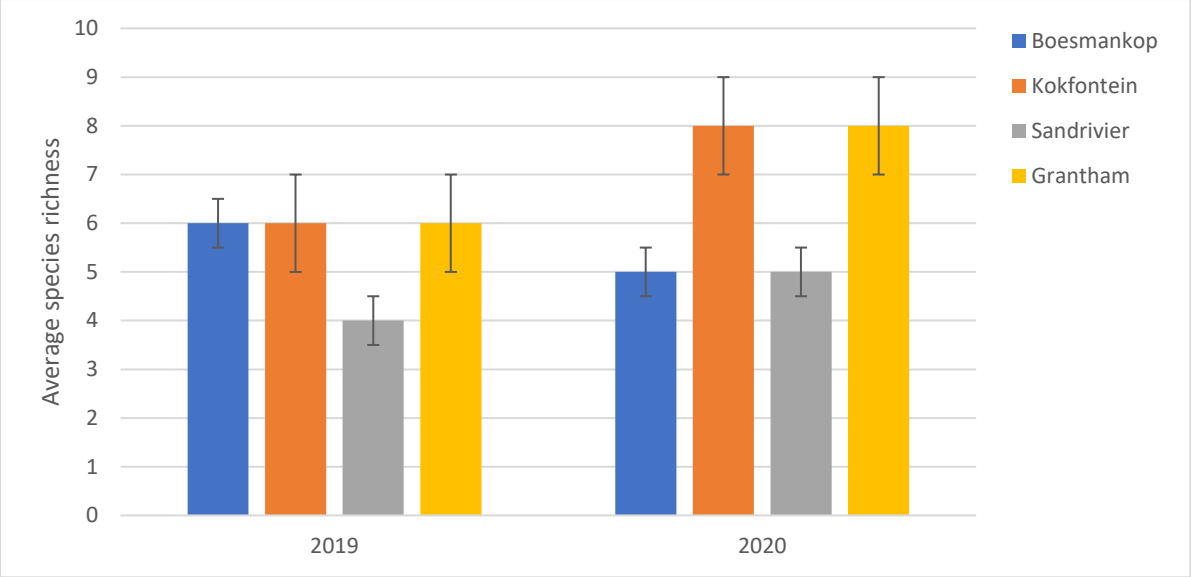

Figure 5.9: Average species richness from 2019 - 2020 for the sites sampled at Karoo National Park after the restoration technologies were applied.

5.2.5. Species diversity pattern at sites of Karoo National Park (2019-2020)

The average species diversity at the Boesmankop restoration site was 1.1 in 2019 and 2020 (Figure 5.10). The average species diversity at the Kokfontein restoration site was 1.2 in 2019–2020 (Figure 5.10). At the Sandrivier restoration site, the average species diversity was 0.8 and increased to 1.2 in 2020 (Figure 5.10). The average species diversity at the Grantham restoration site was 0.9 in 2019, this increased to 1.5 in 2020 (Figure 5.10).

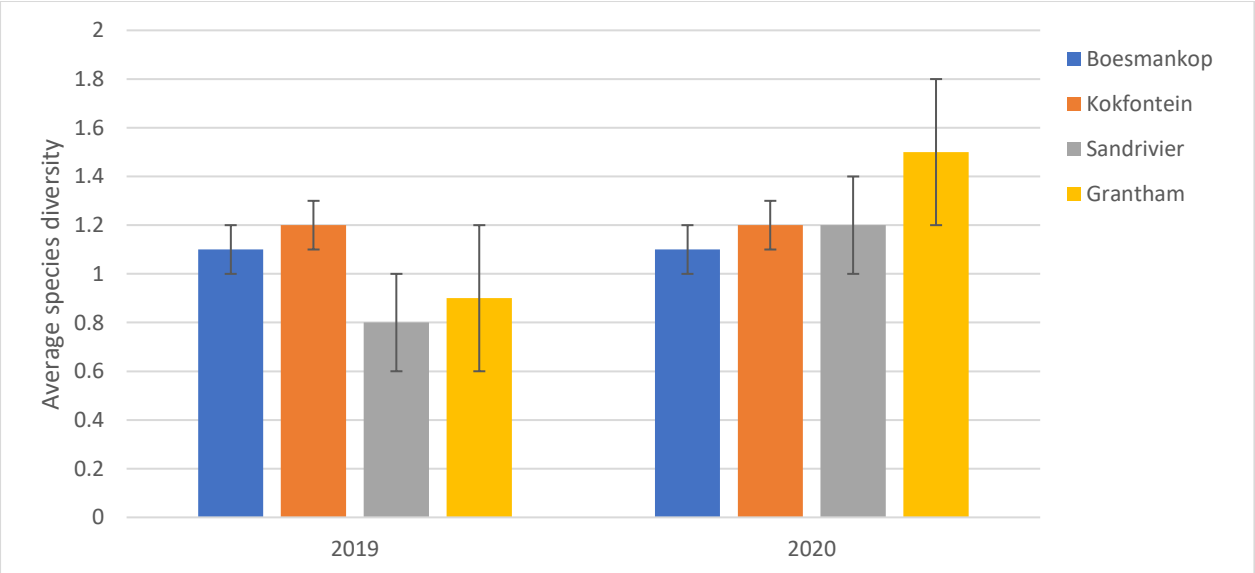

Figure 5.10: Average species diversity from 2019 - 2020 for the sites sampled at Karoo National Park after the restoration technologies were applied.

5.2.6. Correlation between the three parameters stability, infiltration and nutrient cycling in Karoo National Park

The three parameters used in the soil surface analysis (SSA) of the landscape function analysis (LFA) monitoring methodology include stability, infiltration and nutrient cycling (also called "nutrients"). The table below indicates the strength of the relationship between all three parameters. According to the overall results of this study at the four restoration sites of the Karoo NP, a positive correlation between soil stability, infiltration and nutrients (nutrient cycling) was depicted (Table 5.2).

At the Boesmankop study site, there was no relationship detected between the infiltration and nutrient cycle ("nutrients") parameters, while no relationship was detected between stability and the nutrient cycle, a strong positive correlation was detected between stability and infiltration (Table 5.2). At the Kokfontein restoration site, a positive correlation was detected between the infiltration and nutrient cycling parameters, while a positive correlation was detected between stability and nutrient cycling as well as stability and infiltration parameters (Table 5.2). At the Sandrivier restoration site, a negative correlation was detected between infiltration and nutrients as well as between stability and nutrients, while a positive correlation was detected between stability and infiltration (Table 5.2). At the Grantham restoration site, a negative correlation was detected between the infiltration and nutrient cycle parameters and a positive correlation was detected between the stability and nutrient parameters, as well as a positive correlation between stability and infiltration (Table 5.2).

Table 5.2: Correlation of stability, infiltration & nutrients cycle (nutrients) at four restoration sites in Karoo National Park.

Boesmankop			
	Stability	**Infiltration**	**Nutrients**
Stability		0.5736	1
Infiltration	-0.4264		1
Nutrients	0	0	
Kokfontein			
	Stability	**Infiltration**	**Nutrients**
Stability		0.61861	0.69849
Infiltration	0.38139		0.68377
Nutrients	0.30151	0.31623	
Sandrivier			
	Stability	**Infiltration**	**Nutrients**
Stability		0.00985	0.2918
Infiltration	-0.99015		0.33773
Nutrients	-0.70820	-0.66227	
Grantham			
	Stability	**Infiltration**	**Nutrients**
Stability		0.18182	0.47777
Infiltration	-0.81818		0.82592
Nutrients	-0.52223	0.17408	

Chapter 6: Discussion

6.1. Mokala and Karoo National Parks

This Chapter discusses the results of both Mokala and Karoo National Park, which include the soil stability patterns, infiltration patterns and nutrient cycle patterns. This section also includes results of species diversity and richness including the correlation between stability, infiltration and nutrient cycling parameters for the sites sampled in Mokala and Karoo National Parks.

6.1.1. Soil stability patterns

The pattern in soil stability improved over the five years from 2015 to 2020 for the assessments in MNP and from 2017 to 2020 for KNP (Figures 5.1 and 5.6). Higher stability values contribute to lower soil erosion and therefore fewer resources are lost from the landscape (e.g. water and nutrients). According to Tongway & Hindley (2004), the most crucial component of vegetation restoration is soil stability due to the high erodibility of most soil types. In the past, before restoration was applied, there was a depletion of vegetation at the sites to stabilize the soil in both MNP and KNP.

The improvement in the vegetation cover caused less erosion (Rezaei *et al.,* 2006; Munro *et al*., 2012; Saaed *et al*., 2022). It seems that the vegetation cover that increased through the restoration application, was better at the sites in the MNP than at the sites of the KNP. The latter may be due to the lower rainfall that occurred at KNP (Figures 5.1 and 5.6). Similar results were obtained by Pelser (2017) who determined that soil stability increased with higher vegetation cover after monitoring the application of similar technologies in MNP between 2014 and 2015. The results from both studies, therefore prove that ponding and brush packing as a restoration technique are efficient ways to restore damaged landscapes in arid and semi-arid areas. A more stable environment is associated with less soil erosion and loss of natural resources (Nichols & Toro, 2011). These areas are important in protected areas like the MNP and KNP, where herbivores depend on healthy rangelands to survive and where no enclosures occur.

6.1.2. Infiltration patterns

In both the MNP and KNP, infiltration rates increased due to the improvement of vegetation cover (Figure 5.2 and 5.7). As for the stability patterns, it appears that an increase in vegetation cover also causes higher infiltration rates and not only decreases run-off by erosion. Higher infiltration rates, particularly in arid and semi-arid parks, normally also increase soil moisture content, which may lead to the improvement of vegetation establishment and cover (Tongway & Hidndly, 2004). Soil surfaces with higher moisture content may also lead to better decomposition of organic matter in the soil, which increases the amount of nutrients in the soil (Tongway & Ludwig, 2011). Infiltration of water is decreased in compacted soil patches, but an increase in soil moisture leads to higher vegetation cover, as in the restored sites in MNP (2017-2020) (Saaed *et al*., 2022). To improve plant growth, reduce grazing effects, protect seedlings, trap litter and sediments in the restoration sites, brush packing is commonly used in the ponding area (Sebitloane *et al.,* 2020; Kellner *et al*., 2021; Kellner *et al.,* 2022; Mangani *et al.,* 2022).

6.1.3. Nutrient cycling patterns

An increase in vegetation cover also draws grazing animals to the restored site, which sustains a direct increase in nutrient cycling through dung and urine deposition (Visser *et al*., 2007; Kellner, 2008). Due to the decomposition and fertilizing effects of the dung, these aid in reintroducing nutrients to the soil (Tongway & Ludwig, 2011). The nutrient cycle for sites where restoration was applied at both MNP and KNP increased over time. This took place when vegetation components, such as leaves and tree branches, which are typically used for brush packing, decomposed and nutrients were directly returned to the soil (Tongway & Ludwig, 2011). These results are also observed at the sites in the MNP and KNP as increased nutrient cycling due to the application of the restoration technologies at the degraded sites.

6.1.4. Species richness and diversity

During the study period, from 2015 to 2020, species richness and diversity varied in both MNP (Figures 5.4 and 5.5) and KNP (Figures 5.9 and 5.10), which may be due to the differences in soil type, soil moisture, terrain, elevation, biotic interactions and

climatic conditions. Although often very small, the species richness and diversity, improved in both the MNP and KNP after the application of the restoration technologies, mainly due to the changes in vegetation composition and cover, but also due to the herbivory of certain game animals at both the two National Parks. Species diversity and species richness are affected by several environmental factors, including soil type, soil moisture content, terrain, elevation, biotic interactions, factors relating to past land use and other climatic conditions (Stein *et al*., 2014). In studies of restoration ecology, the diversity of species has been widely used as a measure of changes in vegetation over time (Saaed *et al*., 2022). In degraded ecosystems, a variety of restoration technologies are frequently used to increase species richness and diversity (Tongway, 2004). For instance, ponding and brush packing trap sediments, litter and seeds from the surrounding landscape, increasing the richness and diversity of species (Stein *et al*., 2014).

6.1.5. Correlation between stability, infiltration, and nutrient cycling parameters

In both the MNP and KNP, soil stability was positively correlated to both infiltration and nutrient cycling (Tables 5.1 and 5.2). As mentioned above, the higher soil stability was mainly due to the increase in vegetation cover, which decreases run-off from erosion and leads to an increase in infiltration rates across sites. Higher infiltration rates, particularly in arid and semi-arid areas, normally increase soil moisture content (Tongway & Hindley, 2004). Soil surfaces with higher moisture content lead to better decomposition of organic matter, which increases the amount of nutrients in the soil (Tongway & Ludwig, 2011). Restoration ecology relies on an understanding of the interrelationships between these three SSA parameters, as it helps decision-makers in protected areas make better choices regarding the protection and conservation of the habitat.

Chapter 7: Conclusion and Recommendation

7.1. Conclusion

The current study aimed to assess the efficacy of ponding and brush packing as restoration techniques, determine whether they will enhance the functionality of the landscape and restore degraded land in both MNP and KNP, and determine whether LFA can be used to evaluate the improvement of soil stability, infiltration, and nutrients. It is clear from the results above and when taking into account the three primary SSA parameters (stability, infiltration, and nutrient cycling) that were assessed using LFA monitoring methodology that there is a significant difference between the parameters at MNP and KNP restoration sites. This variation is primarily caused by variations in the soil, climate, and managerial practices. Following the use of restoration technologies, functionality improved overall at all locations in both Mokala and Karoo National Parks. When taking into account the three SSA parameters assessed across the periods of 2018 to 2020, the greater rainfall events that occurred in 2020 may have contributed to the improvement in the functionality of the landscape.

The suggested methods for preserving soil include covering it to shield it from raindrop impact, increasing its ability to absorb water to slow runoff, enhancing its aggregate stability, and enhancing surface roughness to slow runoff (Wall *et al*., 1987; Valentin *et al*., 2005). The results of the current study imply that ponds and brush packing can be helpful in repairing degraded landscapes. Brush packing is good at shielding bare spots from the sun, wind, and presumably also early grazing and other elements of nature (Van Oudtshoorn, 1999, Sebitloane *et al*., 2020; Kellner *et al*., 2022). Many small species, including reptiles, rodents, hares, small predators, and a variety of invertebrates, can find cover in brush packing (Coetzee, 2005). Additionally, these animals leave behind faeces, which disintegrate and aid in enhancing the organic components of the topsoil necessary for plant growth. Many of these creatures also dig burrows into the ground, which helps water to infiltrate into the soil and prevents soil erosion. Additionally, the ability of ponds and brush packing to collect litter, seeds, and sediments is crucial, and the subsequent decomposition of the leaves and tree branches used to produce brush packs resulted in an increase in species richness and diversity in the degraded sites (Coetzee, 2005).

7.2. Recommendations

- Using the three main SSA parameters of LFA to monitor the change over time in the restoration area seems to be effective, therefore, it is recommended that this monitoring technology be used in other National Parks, such as the Camdeboo, Mountain Zebra and Tankwa Karoo National Parks, where bare patches and degraded areas occur, and restoration technologies are needed.
- Further studies recommended to look into vegetation density and biomass as indicator of the productivity of the land.
- There is a need of further studies to look at Land organisation index and to perform other statistical analysis such as T test or Anova.
- This will give conservation management the chance to assess the effectiveness of applied restoration methods in areas with various levels of degradation and different environments.
- Burrowing mammals and invertebrates are typically attracted to restored landscapes with good vegetation cover and nutrient content, which further enhances the performance of ecosystem recovery and a possible increase in biodiversity. There is a need for research on small mammals on restoration sites.
- The results, however, can be used as a guide for long-term monitoring to determine whether the restoration efforts really did improve the functionality of the landscape over time, especially during periods of decreased rainfall.

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Appendix

Appendix 1: Frequency of different species in Mokala National Park monitoring site using Quadrant Method (2019).

Species name	Year	Braaghoek	Vaalsfontein	Punberg	Stofdam
Chloris virgata	2019	8	4	13	1
Tragus berteronianus	2019	20	16	5	23
Eragrostis chloromelas	2019	3	5	2	
Aristida adscensionis	2019	13	18	18	17
Cynodon dactylon	2019	5	0	0	0
Eragrostis obtusa	2019	3	0	2	0
Fingerhuthia africana	2019	2	7	0	7
Urochloa panicoides	2019	15	0	0	0
Eragrostis plana	2019	0	1	0	3
Tribulus zeyheri	2019	0	0	2	4
Eragrostis trichophora	2019	0	0	8	4
Aristida congesta subsp. congesta	2019	0	0	2	0
Aristida junciformis	2019	0	0	0	1
Enneapogon desvauxii	2019	0	0	0	3

Appendix 2: Frequency of different species in Mokala National Park monitoring site using Quadrant Method (2020).

Species name	Year	Braaghoek	Vaalsfontein	Punberg	Stofdam
Chloris virgata	2020	4	2	5	20
Tragus berteronianus	2020	12	11	2	8
Eragrostis chloromelas	2020	3	1	12	7
Aristida adscensionis	2020	22	10	15	8
Cenchrus ciliaris	2020	4	2	1	0
Enneopogon desvauxii	2020	3	7	0	4
Cynodon dactylon	2020	0	2	7	2
Eragrostis racemosa	2020	0	0	3	1
Schmidtia pappophoroides	2020	0	0	1	3
Aristida congesta subsp. congesta	2020	0	0	3	0

Appendix 3: Frequency of different species in Karoo National Park monitoring site using Quadrant Method (2019).

Species name	Year	Boesmankop	Kokfontein	Sandrivier	Grantham
Malephora crocea	2019	2	0	1	8
Aristida congesta subsp. congesta	2019	8	0	1	23
Tragus berteronianus	2019	1	20	4	2
Pentzia incana	2019	5	6	0	5
Psilocaulon utile	2019	1	1	0	0
Lycium cinereum	2019	3	4	0	0
Cenchrus ciliaris	2019	0	2	0	0
Cynodon dactylon	2019	0	8	0	0
Monechma incanum	2019	0	0	7	0
Salsola dealata	2019	0	0	0	1
Atriplex lindleyi subsp. inflata	2019	0	0	0	1

Appendix 4: Frequency of different species in Mokala National Park monitoring site using Quadrant Method (2020).

Species name	Year	Boesmankop	Kokfontein	Sandrivier	Grantham
Malephora crocea	2020	4	4	1	1
Salsola dealata	2020	2	0	1	1
Tragus berteronianus	2020	14	8	3	4
Lycium cinereum	2020	1	2	0	1
Cenchrus ciliaris	2020	2	0	0	0
Pentzia incana	2020	0	4	0	3
Psilocaulon utile	2020	0	1	0	2
Cynodon dactylon	2020	0	3	2	0
Chrysocoma ciliata	2020	0	2	0	0
Aristida congesta subsp. congesta	2020	0	3	0	0
Eberlanzia ferox	2020	0	0	0	2
Atriplex lindleyi subsp. inflata	2020	0	0	0	3