Evaluation of selected restoration technologies in degraded areas of the Mokala National Park, South Africa

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Dissertation submitted in fulfilment of the requirements for the degree *Magister Scientiae* in Environmental Sciences at the Potchefstroom Campus of the North-West University

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May 2017

Abstract

Degradation is a global problem and does not only affect the livelihood of people but also the existence of fauna and flora. In Mokala National Park (MNP) extensive areas of high potential grazing land have been degraded and are in urgent need of restoration. The study was conducted in the Doornlaagte and Lilydale areas where degradation is severe and restoration needed. Degradation of soils in these eroded areas is the consequence of a loss of plant cover and density, mostly due to the overgrazing of sensitive areas before the MNP was established and because the area was used as a cattle farm. To prevent further degradation of the eroded areas, active restoration technologies were implemented. Active restoration is the implementation of techniques that involve the application of structures to improve the moisture and nutrients in the soil, re-seeding, brush packing (placement of woody twigs on degraded patches) and other methodologies to actively halt erosion and improve the ecosystem. If these techniques are successfully implemented it will hopefully contribute to species richness, diversity and soil vegetation cover.

The active restoration technologies that were implemented at Doornlaagte and Lilydale include the brush packing technology, where branches of trees are packed on top of the degraded soil; ponding, where hollows are made in a half-moon shape in the soil to catch water and nutrients; and ponding & brush where the brush and ponding restoration technologies are combined. Some areas were left open where no restoration was applied. These served as control. The technologies were applied in April 2014 and were monitored the day they were implemented, with the second monitoring in October 2015 before the rainy season and the third monitoring at the end of February 2016.

To achieve the mission of South African National Parks (SANParks) to develop, manage and promote a system of National Parks that represents biodiversity and heritage assets by applying best practice, environmental justice, benefit-sharing and sustainable use, persons from the Biodiversity and Social Projects (BSP's) programme that work in MNP were used for the implementation of the restoration technologies and for monitoring. The BSP programme is supported by the Department of Environmental Affairs (DEA).

Data were obtained from vegetation sampling at each technology and soil was collected to determine the soil seed bank and to analyse soil parameters. The Landscape Functional Analysis (LFA) monitoring technique was carried out to evaluate any change in the functionality at the study sites.

Results show that although there were no significant differences, the density and richness of the vegetation did increase especially in the ponding & brush restoration technology at the Doornlaagte study site, whereas the ponding technology was the best technology at the Lilydale study site. The soil seed bank analysis shows that the most seed accumulated where the ponding & brush technology were applied in both the Doornlaagte and Lilydale study sites. The LFA methodology showed that there was an increase in the landscape functionality of both restoration study sites. The change was mostly observed after the first year of restoration, as the area experienced a severe drought which caused less changes to be observed in the second year of the study.

Restoration is a long-term process and it is therefore recommended that this study be carried out over longer time periods.

Keywords: Restoration technologies; ponding; brush; ponding & brush; quadrats; LFA; soil seed bank analysis; soil analysis.

Opsomming

Degradering van landskappe is ‘n wêreldwye probleem wat nie net die lewenswyse van mense beïnvloed nie, maar ook dié van fauna en flora. In Mokala Nasionale Park (MNP) is wye gebiede van hoë weidingswaarde gedegradeer en word restorasie van die gebiede dringend benodig. Die studie is gedoen in die Doornlaagte en Lilydale areas waar degradasie ernstig is en restorasie benodig word. Degradasie van grond in hierdie gedegradeerde gebiede is die gevolge van ’n verlies aan plantbedekking en –digtheid wat meestal veroorsaak is deur oorbeweiding van sensitiewe areas voor die MNP ontstaan het en omdat die gebied vir bees-boerdery gebruik was. Om verdere degradasie van geërodeerde gebiede te voorkom, is aktiewe restorasietegnologieë geïmplementeer. Aktiewe restorasie is die implementering van tegnieke wat die toepassing van strukture insluit om die vog en voedingstowwe in die grond te verhoog, hersaai, pak van takke en ander metodes, om erosie aktief te keer en die ekosisteem te verbeter. As die tegnieke suksesvol geïmplementeer word, sal dit hopelik bydra tot die spesierykheid, diversiteit en plantbedekking op die grond.

Die aktiewe restorasietegnologieë wat toegepas is in die Doornlaagte en Lilydale gebiede sluit pak van takke (“brush”) in, waar takke bo-op die gedegradeerde grond gepak word; “ponding”, waar holtes in die grond gemaak word in die vorm van ‘n halfmaan om water en voedingstowwe op te vang; en ook “ponding en brush” wat ‘n kombinasie is van die “brush”- en “ponding”-tegnieke. Sekere areas is oop gelaat waar geen restorasie toegepas is nie wat gedien het as kontrole. Hierdie tegnologieë is in April 2014 geïmplementeer en is op die dag van implementering, in Oktober 2015 voor die reënseisoen en weer aan die einde van Februarie in 2016 gemonitor.

Om die missie van die Suid-Afrikaanse Nasionale Parke (SANParks) wat die bevordering, beheer en verbetering van ’n sisteem van Nasionale Parke is, wat die biodiversiteit en erfenisbates behels deur toepassing van beste gebruik van hulpbronne, omgewingsgeregtigheid, deling van voordele en volhoubare gebruik, is mense wat deel is van die Biodiversiteits- en Sosiale Projekte (BSP) en in MNP werk, gebruik om die restorasietegnologieë te implementeer en te monitor. Die BSP-program word ondersteun deur die Departement van Omgewingsake.

Data is verkry deur plantopnames by elke restorasie tegnologie en grond is gekry om die grond se saadbank te bepaal om die grondanaliseparameters te verkry. Die

Landskap Funksionaliteit Analise (LFA) moniteringstegniek is uitgevoer om te evalueer of enige veranderinge in die funksionaliteit in die studie-areas plaasgevind het.

Resultate wys dat, al was daar nie beduidende verskille nie, die digtheid en rykheid van die plantegroei wel verbeter het, veral in die “ponding en brush”-tegnologie in die Doornlaagte studie-area, terwyl die “ponding”-tegnologie beter was in die Lilydale-area. Die grondsaadbankanalise wys dat die meeste saad deur die “ponding en brush”-tegnologie vasgevang is in beide die Doornlaagte en Lilydale restorasiegebiede. Die LFA metodologie het gewys dat daar ‘n verhoging in die landskapsfunksionaliteit van beide restorasiegebiede was. Die verandering is meestal waargeneem na die eerste jaar van restorasie omdat ‘n erge droogte ervaar is wat veroorsaak het dat minder verandering na die tweede jaar gesien is.

Na die eerste jaar van implementering is beduidende veranderinge waargeneem in beide restorasiegebiede, maar die jaar daarna was veranderinge nie so groot nie en dit kan wees as gevolg van ’n droogte wat ervaar is in die reënseisoen van 2015. Die grondanaliseresultate wys dat daar nie ’n tekort aan voedingstowwe in die grond was nie en dat dit wel ander faktore is wat ’n rol gespeel het in die degradering van die grond.

Restorasie is ‘n langtermynproses en dus word dit aanbeveel dat die studie verder uitgevoer word oor langer tydperke.

Sleutelwoorde: Restorasietegnologieë; ponding; brush; ponding & brush; kwadrante; LFA; grondsaadbankanalise; grondanalise.

Acknowledgements

I would like to acknowledge the following persons who helped me throughout the project:

Prof Klaus Kellner who supported and guided me throughout the study.

Mr Jacques van Eck who helped with the initiation of the study in the Mokala National Park.

Mr Ernest Daemane and Mr Spencely Motloung who were always willing to help organise the field trips to the Mokala National Park.

The BSP team at the Mokala National Park who helped me with every survey that was done in the park.

Mr Hendrik du Plessis, Mr Jaco Fouché and **Mr. Sampie van Rooyen** who helped with the field surveys.

Mr Dennis Komape for helping with the identification of species.

My parents who continually supported and motivated me while I was working on the project.

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BP	Bare Patch
BSP	Biodiversity and Social Project
CEC	Cation exchangeable capacity
CA	Correspondence analysis
Ca	Calcium
[cmol (+)/kg)]	Centimoles of positive charge per kilogram of soil
cm	Centimetre
DCA	Detrended correspondence analysis
DEA	Department of Environmental Affairs
EC	Electrical conductivity
EPWP	Expanded Public Works Programme
FP	Forb Patch
GP	Grass Patch
GPS	Global Positioning System
Ha	Hectares
H_2O	Water
K	Potassium
KCl	Potassium Chloride
km	Kilometre
LO	Landscape Organisation
LOI	Landscape Organisation Index
LFA	Landscape Function Analysis
LP	Litter Patch
m	Metre
m^2	Square metre
mg/kg	Milligram per kilogram
Mg	Magnesium
mm	Millimetre
MNP	Mokala National Park
mS/m	MilliSiemens per metre
Na	Sodium
NKu 3	Northern Upper Karoo

P & B	Ponding & brush
P	Phosphorus
PP	Ponding Patch
SP	Shrub Patch
pers. comm.	Personal communication
SANParks	South African National Parks
SD	Standard Deviation
SSA	Soil Surface Assessment
SSB	Soil seed bank
SVk 4	Kimberley Thornveld
SVk 5	Vaalbos Rocky Shrubland
TTRP	Trigger-Transfer-Reserve-Pulse
viz.	Videlicet

Chapter 1 Introduction and Literature Review

1.1 General introduction

Arid and semi-arid regions make up more than 30% of the Earth's surface (Okin, *et al*., 2006; Bai *et al*., 2008). Large parts of these areas are not suitable for crop production due to low and unpredictable rainfall patterns, especially in the summer months. These arid and semi-arid areas are therefore used for livestock and/or game production (Van den Berg & Kellner, 2010).

Two-thirds of the African continent's drylands are exposed to degradation (ECOSOC, 2007) and according to Bojö (1995) many parts in Sub-Saharan Africa, need to be restored to meet the demands of ecosystem services for improved human well-being (MEA, 2005). Land degradation, particularly in drylands, has become of global concern and affects many people (Adger *et al*., 2000). Arid and semi-arid areas include up to 86% of the agricultural land in Southern Africa (Van den Berg & Kellner, 2010), much of which is degraded due to climatic and management factors (UNCCD, 1994; Kassas, 1995; Castillo *et al*., 1997; Sehmi & Kundzewicz, 1997; Vitousek *et al*., 1997; Dregne, 2002; Zedler & Kercher, 2004; Foley *et al.*, 2005; Johnson & Lewis, 2007; Schwilch *et al*., 2012). Anthropogenic activities such as industry, mining, agriculture and shipping can also have major impacts on ecosystems (Dailianis, 2011). Rangelands are continuously exposed to droughts and due to mismanagement, especially overgrazing, land degradation often occurs, which reduces vegetation cover and increases soil erosion (Hüttl & Schneider, 1998; Pellant *et al*., 2004; Johnson & Lewis, 2007; Van den Berg & Kellner, 2010; Van Oudtshoorn, 2012). The hydrological cycle (water availability, quality and storage) is also negatively affected by factors which include soil erosion, a decrease in nutrients due to over-exploitation or fires and other forms of land degradation such as floods (Bossio *et al*., 2010).

Land degradation causes changes in global environmental systems and can have major negative effects (Chase *et al*., 2000; Sala *et al*., 2000; Stocking & Murnaghan, 2001) on the environment (Stocking & Murnaghan, 2001; Schwilch *et al*., 2012).

Land degradation occurs in all of the biomes of southern Africa and stretch from the fynbos biome through to the savanna biome, grassland biome, desert biome and Indian Ocean coastal belt (Lloyd *et al*., 2002; Van Wilgen *et al*., 2008).

Ecosystem resilience and rangeland productivity loss are some of the major problems in the semi-arid Savanna environments in South Africa leading to degraded land (Harmse, 2013). There is a need to restore degraded lands in the savanna biome of South Africa because this is one of the biomes which provides the most ecosystem services e.g. eco-tourism and a nursery and refugium function in which wild plants and animals can reproduce (Egoh *et al*., 2009). Mokala National Park (MNP) is situated in the savanna biome (Acocks, 1988; Rutherford *et al*., 2006; SANParks, 2010) where many degraded areas occur mainly due to the historic background of management strategies.

In South Africa ordinary people are using natural resources which improve their lives. They get these resources from nature and can consciously or unconsciously manage resources through rules and beliefs (Fabricius *et al*., 2004). The management of natural resources has only been promoted in recent decades to serve as a strategy for rural development (Fabricius *et al*., 2004). Concerns from the government with community-based natural resource management (CBNRM) arose when a theory was developed that people in rural areas with insufficient knowledge placed too much pressure on their natural environment and depleted the available resources (Fabricius *et al*., 2004). The use of better practices and management systems was thought to halt this degradation in the natural environment to ensure a more sustainable use of resources (Fabricius *et al*., 2004). The participation of local people will enhance the quality of decisions that have to be made because more complete informative contributions will be received from these people (Reed, 2008).

Researchers have the challenge to develop a user-useful management approach where local knowledge can be incorporated with scientific knowledge (Reed, 2008).

By working with South African National Parks (SANParks) and communities surrounding MNP, a social learning process can be implemented when certain restoration technologies are applied and so strategies are developed to respond to rangeland degradation.

1.2 Objectives of the study and hypothesis

Two study areas where land degradation occurs in the MNP were identified by Mr. Ernest Daemane from SANParks scientific services in Kimberley (see chapter 2 section 2.3 where the study sites are described) and certain restoration technologies were applied by the Biodiversity and Social Project (BSP) team (see section 3.2 chapter 3) at the two study sites.

The objectives of this study include to

- monitor and evaluate the effectiveness of the three restoration technologies applied in identified degraded areas of the MNP;
- determine the relationship between landscape functionality, plant species diversity and soil properties; and
- provide advice about restoration technologies that can be applied by SANParks.

1.3 Hypothesis

Selected restoration technologies can be implemented effectively to restore selected degraded areas and increase the rangeland condition and biodiversity of degraded areas in the MNP.

1.4 Structure of dissertation

The dissertation consists of 8 chapters. The present chapter provides a general introduction to the study as well as a literature review. Chapter 2 provides a description of the study area which includes the location of the study area, the type of land use, climate and vegetation. The materials and methods used in the study are described in Chapter 3. Chapter 4 contains the results of the soil analysis and is the first chapter of three describing the results. Chapter 5 gives the results of the quadrats done in the field and the soil seed bank analysis done in the glasshouse as well as what the restoration sites looked like before any restoration technologies were applied. Chapter 6 describes the results of the Landscape Function Analysis. Chapter 7 concludes the study by giving recommendations based on the results. In Chapter 8 a complete reference list is added as well as an appendix.

1.5 Literature review

1.5.1 Land degradation in arid and semi-arid regions

Land degradation may occur in different arid, semi-arid, and dry subhumid areas (UNCCD, 1994; Kassas, 1995; Sehmi & Kundzewicz, 1997; Schwilch *et al*., 2012). Desertification is mostly restricted to dryland areas, whereas land degradation can occur in any environment (Verstraete & Schwartz 1991; Hoffman *et al*., 1999; Kellner, 2009). Vegetation growing in these areas is exposed to very strict conditions such as low annual rainfall, seasonality, intensity and predictability. Only when small changes in climatic conditions occur there could be major impacts on the vegetation (Leemans & Eickhout, 2004; Pielke, 2013).

Land degradation can be described as the loss of goods and services that include soil, vegetation, animal life, and the ecological processes that operate within ecosystems which is beneficial to people (SER, 2002; UNEP.org, 2003; Nkonya *et al*., 2011). Efforts to slow the process of land degradation have always focused on arid and semi-arid areas, which led to desertification (Nkonya *et al*., 2011).

The United Nations Convention to Combat Desertification (UNCCD, 2005) defines desertification as: *"desertification is land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities"*. Different theories exist on how land degradation is initiated and according to Kellner & Bosch (1992) and Li *et al*. (1998) it is started through the formation of bare patches which expand to form areas where the vegetation layer is removed and the soil eventually becomes denuded in the long term.

A similar theory is proposed by Van Oudtshoorn (2012), namely that degradation is caused by the removal of the vegetation layer which serves as a protective layer for the soil surface. The vegetation is removed due to certain activities that include aspects such as over-exploitation by animals, as well as the harvesting or gathering of non-renewable resources and disturbances by machinery such as tractors and ploughs. After the vegetation layer is removed it allows the bare soil to be exposed to the elements of nature such as the wind and water which are major drivers of soil erosion (Van Oudtshoorn, 2012). Other activities leading to land degradation include deforestation (Dregne, 1986; Southgate, 1990), agricultural practices (Tolba & El-Kholy, 1992), urbanisation, rangeland modifications (Lambin *et al*., 2001) and mining (Peng *et al*., 2005; Palmer *et al*., 2010).

Arid and semi-arid ecosystem processes have many changing aspects and because vegetation changes take a long time to occur and observations are done over a shorter time period it makes it difficult to understand these dynamics (Harrison *et al*., 2000; Van den Berg & Kellner, 2005). Due to the latter it is difficult to determine if an area is experiencing a long-term decline in its biodiversity or if it is only experiencing a drought happening over the short term, which can be stopped if the influence of human activities are reduced or totally eradicated (Van den Berg & Kellner, 2005). It is important to know what the resilience of arid and semi-arid ecosystems are and what their capability is of recovering from disturbances when conservation of plant and animal species is needed (Wiegand & Jeltsch, 2000).

The pace at which land degradation happens holds high threats for global food security and the quality of drylands (MEA, 2005). Land degradation causes a loss in food production which may have a negative impact on the economy (Blaikie, 1985; Dumanski & Pieri, 2000; MEA, 2005). As much as 42% of poor people in the world depend on land for food and income (Nkonya *et al*., 2011). When lands are degraded these people are affected and the degradation of land-based ecosystems could cost billions annually (Nkonya *et al*., 2011). This shows a parallel connection between the constant need for resources by people and unpredictable rainfall. Agriculture is a major contributor to the economy and in the case of cattle farming, degradation of rangelands has caused large areas used for grazing in southern Africa to be in a poor condition (Theunissen, 1997; Harrison *et al.,* 2000; Lin *et al*., 2010).

The loss of vegetation cover, grazing pressure and the inadequate number of attempts at soil conservation, leaves drylands to be more vulnerable to soil erosion, which can have major impacts on the climate and desertification of a region (Nicholson *et al*., 1998). Erosion has an impact on the soil by removing nutrient rich soil particles (Ravi *et al*., 2010) which consequently has an impact on soil properties and its moisture dynamics (Bhark & Small, 2003). The transport of soil affects the establishment of vegetation and how it will survive, which in turn affects the structure and function of arid and semi-arid regions (Bhark & Small, 2003). This forms vegetation patterns which are best seen in areas where resources are scarce such as in arid and semi-arid areas (HilleRisLambers *et al*., 2001; Lin *et al*., 2010). The distribution and scale of vegetation patches have impacts on the moisture and nutrients in the soil which determine vegetation growth and species composition (Puigdefábregas, 2005).

The health of people is at risk when degradation of vegetation in landscapes occurs (UNEP, 2006). This is because vegetation covers dust particles and when these particles are set free, people can develop allergies and respiratory diseases such as asthma (UNEP, 2006). If an inadequate amount of micronutrients is consumed by people, morbidity and mortality are increased (Schoendorfer *et al*., 2010). Plants take up micronutrients from the topsoil layer and if land is degraded and soil scalped, plants have inadequate nutrients to grow to its full potential and provide for the need of people (Lal, 2009).

Land degradation can lead to violence between certain social groups (Homer-Dixon, 1999). Degradation causes resources to be reduced which makes a bigger gap between developed and developing countries which may lead to a military confrontation between these countries so that the developing countries could have their share of natural resources (Homer-Dixon, 1999). If an area becomes degraded it could lead to poverty of societies and cause gaps between the rich and poor which may lead to rebellious actions against authorities. Reasons like this may cause people from countries with fewer resources to move across borders to countries rich in resources and cause instability on a domestic level (Homer-Dixon, 1999).

Land degradation is a serious matter globally which affects all people and if it is not taken care of serious consequences may follow (Bai *et al*., 2008).

1.5.2 Land degradation in Mokala National Park

Degraded areas in reserves and national parks are identified and can become of great concern for management, especially if the primary objectives are the conservation, promotion and protection of biodiversity (Tongway *et al.* 2003; Van den Berg & Kellner, 2005; Cernea & Schmidt-Soltau, 2006). Degraded landscapes could be considered as "dysfunctional", in which the biological development in the environment that forms the key component of biodiversity conservation, is limited (Tongway & Hindley, 2004; Van der Walt *et al.,* 2012).

The MNP is one of the latest established national parks in South Africa (Park Management Plan, 2008) (see section 2.1 of Chapter 2 regarding the description of the study site). MNP is a highly productive area which is able to support relatively high numbers of large game and at the same time it serves as a permanent reference area for wider vegetation of the Northern Cape region in South Africa (Bezuidenhout & Bradshaw, 2013).

Extensive areas of high potential grazing land that have been degraded in national parks are in urgent need of restoration, especially in eroded areas (Harrison *et al.,* 2000; Milton *et al.,* 2003; UNEP, 2006; Ntshotsho *et al.,* 2011). Soil erosion causing land degradation in the MNP, can be ascribed to a number of factors, including the loss of plant cover and density as a result of poor grazing practices that were followed in the area before the MNP was established (Guerrero-Campo & Montserrat-Martí, 2000; Daemane *et al*., 2014). Plants have an important role in ecosystem goods and services and serves as regulators of water and nutrients, in which water is purified and nutrients are taken up by plants to be digested by animals (De Groot *et al*., 2002). MNP was formally a cattle-grazing area, often leading to overgrazing and trampling, especially around watering points and near dams and due to the trampling, clay dispersion is induced in susceptible soils (Bezuidenhout *et al*., 2014). Due to the high degree of degradation, active interventions to apply restoration technologies are needed in the identified areas of the MNP.

1.6 Restoration and rehabilitation

The meaning of restoration and rehabilitation can be confusing, as well as terms such as reclamation and re-vegetation. Although this part of the chapter will focus on the terms “rehabilitation” and “restoration”, the definitions of the other two terms generally used, are described in Table 1.1.

Table 1.1: Definitions of reclamation and re-vegetation

Reclamation – when degraded landscapes are repaired in such a way that they differ from the previous state of the landscape and function, but insure public safety and an improvement in aesthetics and can be employed for some useful purpose (SER, 2002; Venter, 2006).
Re-vegetation – Species which are indigenous or invasive to an area are used to re-vegetate a degraded area for rapid effects on restoration, rehabilitation and reallocation and establishing one or more species (SER, 2002; Mains *et al*., 2006).

Reclamation and re-vegetation are often used as part of restoration. According to the Society of Ecological Restoration (SER) (2002) restoration covers all types of repair of an ecosystem and includes aspects of reclamation, rehabilitation, mitigation, ecological engineering and different ways to manage resources which include wildlife management of rangelands, forestry and fisheries. All these activities will address any losses in ecosystem services mentioned above. Rehabilitation shares the primary focus of historical and pre-existing ecosystems as references, but the goals of the two approaches are different (SER, 2002).

Rehabilitation and restoration can be defined according to their differences and similarities (Haagner, 2008) which are discussed below.

1.6.1 Restoration

Restoration ecology is the science behind the natural management practices used to re-establish vegetation which has decreased in cover and density due to land degradation (Jordan *et al*., 1990; Menke, 1992; Van der Merwe & Kellner, 1999; SER, 2002; Van den Berg & Kellner, 2005; Prach & Hobbs, 2008), whereas ecological restoration can be defined as the process of repairing ecosystems, which have been damaged or degraded, to a former condition which existed before it was degraded in terms of species composition and community structure (Allen, 1995; Jackson *et al*., 1995; SER, 2002).

The two main types of restoration include active restoration, where some “active” implementation technique is carried out, such as weeding, burning, soil moisture improvement, thinning, making of depressions to catch nutrients and water, and brush packing (placement of woody twigs on degraded patches) (Allen, 1995; Tongway & Ludwig, 1996 a & b; McIver & Starr, 2001; Schiffman, 2015) and passive restoration that does not include the implementation of an active technology (Prach & Hobbs, 2008). With the latter, the degraded system is left for successional processes to take place over time (Prach & Hobbs, 2008). A site can be restored by one of the following approaches, i.e.: by using technical measures (active restoration), and relying on spontaneous succession over time, or a combination of two approaches, whereby the spontaneous succession is manipulated to reach a goal of increased production or biodiversity (Allen, 1995; Milton & Dean 1995; Prach & Hobbs, 2008; Aronson *et al*., 2010).The use of active and passive restoration will depend on the degree, rate and scale of degradation, as well as the speed required to restore an area and available resources, especially funds and man-power (Kellner, 2010).

The vegetation recovery of degraded areas is very slow or in some cases impossible, depending on the degree and rate of degradation (Harris *et al*., 1996; Van den Berg & Kellner, 2005). When degradation is very severe and has passed a certain threshold (Smit, 2004) active restoration technologies have to be applied (Friedel, 1991; Kellner & Bosch, 1992; Van den Berg & Kellner, 2005; Suding, 2011; Van der Vyver *et al*., 2012).

Passive restoration is described as the removal of stress in a certain ecosystem to protect the site from further disturbance and so allow natural colonisation and success to recover the ecosystem function, structure and biodiversity (Allen, 1995; Lamb & Gilmour, 2003). These stresses may include heavy grazing by animals, as well as air or soil pollution caused by anthropogenic activities (Allen, 1995; Short & Wyllie-Echeverria, 1996). Although passive restoration is the best option to use in areas that are still resilient, it must be considered that it is a gradual approach and event driven. In such areas degradation can be addressed using certain management actions that do not involve active interventions, e.g. a decrease in the grazing pressure on the land so that the vegetation cover and density can be restored over time (Lamb & Gilmour, 2003). One advantage of this approach is that it can be implemented when there are limited financial resources for land users and managers (Lamb & Gilmour, 2003).

In many circumstances, passive restoration activities are long-term, as it follows a “successional” process (Prach & Hobbs, 2008). The climatic and environmental conditions must also be suitable over the long term. Due to these long term successional processes that have to be met by passive restoration, land managers implement active practices to speed up the process of recovery (Dobson *et al*., 1997; Prach & Hobbs, 2008) and to promote the establishment of self-sustaining populations (Falk *et al*., 2006), but this does not mean that restoration is not the immediate solution to degradation (Kellner, 2010).

Many restoration attempts fail, as it is often not an instant solution to a major problem that has occurred over a long time and managers and policy makers lose interest and are not committed over this time period. The failure of restoration is mainly due to factors such as that no proper training is offered to managers having to implement the restoration activities, no proper restoration plan is developed for the long term, no proper knowledge of the ecological functioning of the ecosystem is put across and that funding ceases before the area is properly restored (Harris *et al*., 1996).

1.6.2 Rehabilitation

Rehabilitation is the repair of damaged or blocked ecosystem functions (Aronson *et al*., 1993). The primary goal of rehabilitation is to raise the productivity of an ecosystem as well as to emphasise the reparation of the ecosystem processes, function and productivity in which it also attempts to achieve such changes as rapidly as possible (Aronson *et al*., 1993; Harris *et al*., 1996; SER, 2002; Clewell & Aronson, 2013). When rehabilitating, the project attempts to adopt the structure of the indigenous ecosystem as well as to recreate a self-sustaining ecosystem (Aronson *et al*., 1993; Clewell & Aronson, 2013). This “rehabilitated” system is not necessarily self-sustaining and will need some more interventions to continue over time to be declared a rehabilitated site (Harris *et al*., 1996).

1.6.3 Stability, resilience and the thresholds of ecosystems

Ecosystem dynamics, described by stability and resilience, are the mechanisms in a system which change over time and can cause a continuous change in the biotic composition and structure (Walker, 1980). Ecosystems are continuously exposed to changes in climate, habitat fragmentation and the deposition of nutrients into the soil which have an impact on the resilience of an ecosystem (Scheffer *et al*., 2001). When the resilience of the ecosystem is lost the ecosystem may switch to an alternative state (Scheffer *et al*., 2001). Stable systems are those systems which change only a little in their composition and structure when they are exposed to environmental stress (Walker, 1980). This means that the system is still resilient and can recover to its original state when the stress factor is relieved (Walker, 1980).

A threshold can be defined as a point when there is a sudden change in a quality (e.g. maintenance of soil fertility or production of food), property or phenomenon of an ecosystem or where there are changes in a driver (e.g. amount of pollutant input or the degree of landscape fragmentation) that can have a great impact on an ecosystem (Groffman *et al*., 2006). These thresholds can tell us when an ecosystem has changed and the chance it has to be restored. A stable system has a higher resilience to environmental changes than an unstable system and can resist more impacts that for example lead to a degraded state (Muradian, 2001). In Figures 1.1 a and 1.1 b stable and unstable vegetation conditions are illustrated. A system with stable vegetation is more resilient and does not reach the thresholds easily. The "bucket", illustrating the stability and higher resilience is therefore "deeper" and it is harder for the "ball" (ecosystem) to pass the "threshold" so that the system is changed to another state (Smit, 2004). For a system that is in an unstable state (Figure 1.1 b), the "bucket" is much shallower and the "ball" can change much easier to another state, crossing the threshold value (Smit, 2004).

Ecosystems can be resilient but not necessarily stable (Walker, 1980). 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 to another state and crosses an ecological threshold (Muradian, 2001). 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 and will not return to its previous state without serious intervention, such as the implementation 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).

Smit (2004) proposed a basic approach to the principle of the three state variables (Figure 1.1). This example can be applied to degraded areas. 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 the 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).

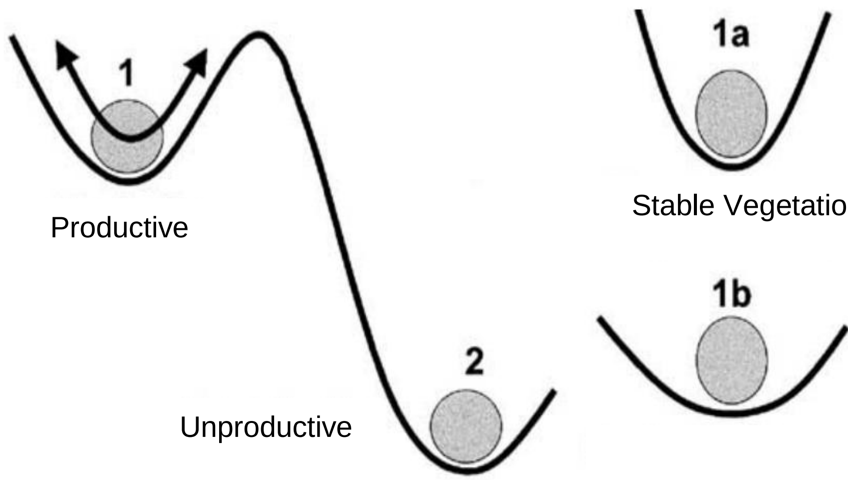

Figure 1.1: A simplification of the principle of stability, resilience and threshold (from Smit, 2004).

This will only happen if the changes in the system are within the limits of the thresholds of the system (Smit, 2004). Within the "stability threshold" the system can withstand the removal of species (by e.g. drought or overgrazing) without damaging the capacity to absorb disturbances (Muradian, 2001). An example of this could be perennial grasslands with many grass species. If only one of the species is removed from the system by disturbances it would not have such a great impact on the stability of the system. The system could return to its previous state and can be seen as being stable (May, 1977). When the impacts of the changes exceed the boundaries of the thresholds, the system will change to another state (position 2) which is not necessarily unstable, but stable in another domain (Smit, 2004).

The application of restoration technologies attempts to restore the ecosystem ("degraded state") to its previous state (position 1) (Smit, 2004). A system can become degraded and move into position 2 (another state - Figure 1.1) due to passing the threshold (Groffman *et al*., 2006). The aim of the active restoration process is to implement strategies that will restore the system to its original state (condition) where possible and fulfil the ecosystem services needed for that habitat. This will depend on the climatic and environmental condition of the area, e.g. how much seed and vegetation is still left in the area and the rate and degree of degradation that has occurred.

1.7 Importance of the Landscape Function Analysis in restoration

The Landscape Function Analysis (LFA) monitoring procedure is used to assess the biophysical functionality of an ecological system rapidly (Tongway & Hindley, 2004; Tongway & Ludwig, 2011). For an explanation of the conceptual framework of the the LFA methodology see section 3.5.1. The LFA uses visual indicators on the soil surface which determine how the landscape operates as a biophysical system (Tongway & Hindley, 2004; Tongway & Ludwig, 2011). The LFA methodology, unlike other survey techniques, focuses more on the functioning of the landscape and not on the composition of the vegetation (Tongway & Hindley, 2004). Eleven indicators (see Chapter 3 section 3.5.1.2) are monitored in the Soil Surface Assessment (SSA) procedure to describe three main functionality parameters i.e. infiltration, stability and nutrient cycling (Tongway & Hindley, 2004; Tongway & Ludwig, 2011). These are derived from information about the physical landscape, the ability of the system divided into patches to retain or lose resources, as well as the soil surface property data (Tongway & Hindley, 2004; Tongway & Ludwig, 2011).

Patches have a size, number, a certain spacing and effectiveness (Ludwig & Tongway, 2000; Tongway & Hindley, 2004). When these characteristics are reduced it can be seen as an indicator of land degradation (Bastin *et al*., 2002; Tongway & Hindley, 2004). An example of this could be degraded grasslands where not many patches are available to capture and hold any resources that flow across the landscape system (Tongway & Hindley, 2004).

As mentioned in section 1.1.1 and 1.1.2, a landscape can become dysfunctional when degradation occurs in an area. The LFA methodology is used to determine if a landscape is more functional or dysfunctional, as this will indicate in which state the system occurs and to what extent degradation has taken place (Tongway & Hindley, 2004; Tongway & Ludwig, 2011).

Ecosystem functioning describes the biophysical efficiency of a landscape, and not the biological components of which the system consists (Tongway & Hindley, 2004). The more functional a landscape, the better its holding capacity of resources will be, such as water, organic material and topsoil (Ludwig & Tongway, 2000; Tongway & Hindley, 2004). Landscapes that are dysfunctional or that have a low functional status have a tendency to lose resources (Tongway & Hindley, 2004). Such landscapes are less able to capture resources, such as water after rainfall events and will capture less material to replace materials that were transported out of the system (Tongway & Hindley, 2004).

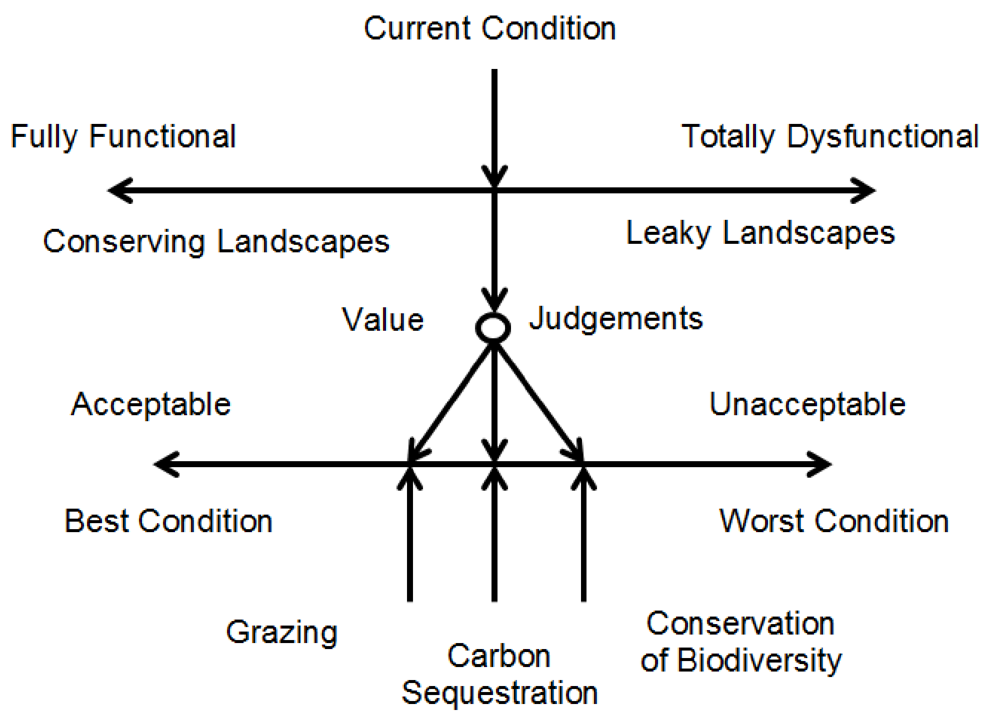

Figure 1.2: The relationship between the functionality of a landscape (which is how well the resources are regulated) and the condition of the landscape (which is how fitting a landscape is to serve a certain purpose) (from Tongway & Hindley, 2004).

Figure 1.2 is a diagram showing a comparison between a functional and a dysfunctional landscape and can be referred to as a function continuum (Tongway & Hindley, 2004). Fully functional landscapes that are more acceptable and in a good condition are also described as landscapes that conserve resources (Bastin, *et al*., 2002), whereas dysfunctional landscapes are unacceptable, in a poor (worst) condition and described as "leaky" landscapes, as the resources are lost from the system (Ludwig *et al*., 1997; Ludwig, *et al*., 2000). The impacts that may cause a change in the system between fully functional and dysfunctional could be aspects such as grazing, carbon sequestration, erosion and changes in biodiversity. To change a system from very dysfunctional (poor condition and leaky) to a fully functional landscape (good condition, where resources are captured and conserved (Ludwig & Tongway, 2000), may need some active restoration interventions.

The Trigger-Transfer-Reserve-Pulse (TTRP) framework (Figure 1.3) explains for example to what extent a system can recover after a certain trigger (e.g. rainfall) has occurred (Tongway & Hindley, 2004; Ludwig *et al*., 2005).

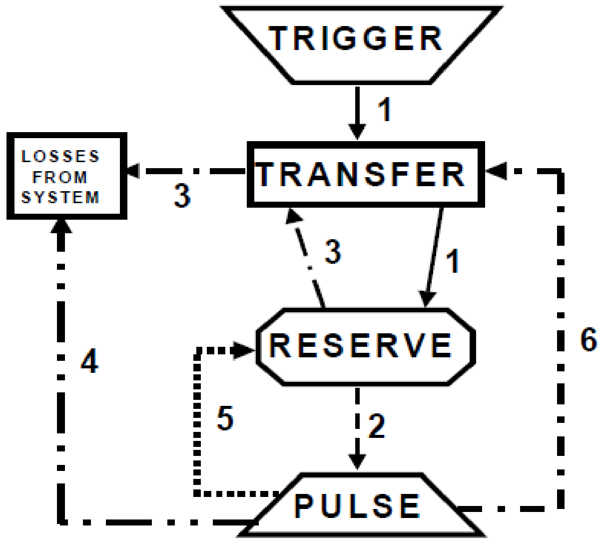

Figure 1.3: An illustration of the Trigger-Transfer-Reserve-Pulse (TTRP) framework (from Tongway & Hindley, 2004).

A trigger (1) in the landscape can be, for example, rainfall which is relocated across the landscape. The trigger (water and/or resources) may be transferred by either getting lost through run-off from the system (e.g. erosion) (3) or absorbed in a reserve (kept as soil surface). The reserve is then used to create a pulse, such as new growth of vegetation or the vegetation may be kept in the reserve (5). With the growth of the plants, some seedlings may die and be lost from the system (4) due to herbivory or fire and the rest of the vegetation is recycled into the reserve of the system. The pulse may give resources back (6) to the system, such as dead plant material which serves as nutrients. The more functional a landscape is, the less resources will be lost from the system (Tongway & Hindley, 2004; Ludwig *et al.*, 2005).

LFA can also be used to assess the success of the restoration technology implemented in the landscape. The restored sites can be compared to a reference or analogue site which is in a highly functional state. The latter will give an indication of the degree of restoration that has been achieved. A reference site is used to set targets for what needs to be reached with restoration as well as to identify values which can be used to meet these targets (Tongway & Hindley, 2004). The data obtained from the reference sites are used for the monitoring of the restoration sites over time to form part of the target set for the restoration. The recorded data obtained from the monitoring procedures can also be used to determine the resilience of the restoration sites when compared to the reference sites (Tongway & Hindley, 2004).

1.8 The definition of a soil seed bank

The soil "seed bank" or "seed reservoir" is a reserve or collection of seeds present in the soil or on the soil surface which have not germinated (Roberts, 1981; Baker, 1989). According to Thompson & Grime (1979) a seed bank may include seed of different species and after germination have the potential to replace adult plants. A soil seed bank is kept productive by the introduction of new seed from reproductive, adult plants (Barbour *et al*., 1999). The presence of different seeds gives important information about some mechanisms which allow species to live together in the same communities (Leck *et al.*, 1989).

Seeds may accumulate in the soil and undergo different periods of dormancy (Silvertown & Charlesworth, 2001). In areas where disturbances frequently occur the seed densities are sometimes the highest (Silvertown & Charlesworth, 2001). The lifetime of seed can be prolonged by dormancy which occurs in different stages including primary- and secondary dormancy (Silvertown & Charlesworth, 2001). Primary dormancy is when seed is unable to germinate when shed from the plant (Mayer & Poljakoff-Mayber, 1982; Silvertown & Charlesworth, 2001). Secondary dormancy is seed that stay dormant after leaving the parent plant (Mayer & Poljakoff-Mayber, 1982; Silvertown & Charlesworth, 2001).

Studies on seed banks started as early as 1856 (Baker, 1989). The seed bank serves as a reservoir with genetic variation which may increase if the seed in it is representative of all the genotypes (Leck *et al*., 1989; Silvertown & Charlesworth, 2001) and stays functional as long as the seed keeps its viability (Baker, 1989).

A soil seed bank analysis was conducted during the study and the methods which were followed for the soil seed bank analysis were those mentioned by Ter Heerdt *et al*. (1996) as well as Dreber (2011).

1.9 Density of vegetation

The usual method for sampling vegetation to describe the floristic composition and density of vegetation is the quadrat method (Stohlgren *et al*., 1998; Barbour *et al*., 1999; Li *et al.*, 2008; Kent, 2012). Quantification of vegetation can be used to assess disturbance by humans and can help with attempts in restoration to see if the density of the vegetation increased after restoration technologies have been applied in a degraded area (Lancaster & Baas, 1997).

1.10 Soil quality and restoration success

When ecosystems are degraded ("dysfunctional") the vegetation or both the vegetation and soil suffer, leading to the suffering of organisms in the area (Bradshaw, 1997). Soil has been studied intensively since the early 20th century (Six *et al*., 2004) and for soil sampling of disturbed sites caused by people or animals there is no special sampling plan (Crépin & Johnson, 1993). The assessment of this type of disturbance has come into great demand which makes it necessary to mention linear disturbances (Crépin & Johnson, 1993). The characteristics of linear disturbances include the following:

It occurs in many landforms, soil types, land uses, and climatic zones (Crépin & Johnson, 1993). Environmental damage can be related to the loss of topsoil, a mix in the soil horizons and changes in the characteristics of the soil (Crépin & Johnson, 1993).

For a system to be "functional", the soil quality is important from the view that the soil holds important non-renewable resources which include the mineral nutrients and the soil organic matter which contains them (Bradshaw, 1997). As can be seen in Figure 1.2 the system will be in a functional condition when the soil is able to hold important resources which help with the growth of vegetation. If the soil components (mineral nutrients) are not intact, it means that original species from the system cannot make a quick new start and vegetation growth will be delayed (Bradshaw, 1997). Soil is therefore a very important factor controlling ecosystems development especially at the early stages of the ecosystem (Bradshaw, 1997). The description of ecosystems can be used for describing the relationship between soil and vegetation, but when the ecosystem is changed it is sometimes difficult to understand which one of the soil or vegetation is the cause and which one is the consequence (Bradshaw, 1997). The dominating effect of soil on an ecosystem and how species are distributed is easier to understand when studies are done in a single climate and at a local scale (Bradshaw, 1997). To maintain or restore a landscape it is important that the fertility of the soil, especially the nutrients phosphorus (P), potassium (K) and magnesium (Mg) (P, K and Mg) are available for plants (PDA, 2011).

Soil analysis is of great importance for managing the fertility of the soil (PDA, 2011) and to get reliable information on a specific soil, in which samples are collected to get information on the bigger soil body which is called the population (Crépin & Johnson, 1993). Information derived from previous studies included salt content, size of the soil particles, pH value and the nitrogen content (Crépin & Johnson, 1993; Li *et al*., 2008). The samples collected may or may not be representative of the population (Crépin & Johnson, 1993). All soils are naturally different because their properties change horizontally across the landscape and in the vertical soil profile (Crépin & Johnson, 1993). The analysis of soil is needed especially when a degraded area is restored where it will help with the monitoring of the restoration attempt to see if the quality of the soil has increased to that of a reference site or if any other factors alter the restoration process (Rhoades *et al*., 1998, Ruiz-Jaen & Mitchell Aide, 2005).

Chapter 2 Study Area

2.1 General description of the study areas

The study for this project took place in the Mokala National Park (MNP) in the Northern Cape Province. Two study sites were selected in collaboration with the SANparks scientific services and the MNP staff. The study sites include degraded areas in Doornlaagte and Lilydale. The location and land use are further discussed from section 2.1 onwards.

2.2 Location and land use

Mokala National Park (MNP) is situated about 80 km south-west of Kimberley in the Siyancuma Local Municipality (Bezuidenhout & Bradshaw, 2013; Bezuidenhout *et al*., 2015; Local Government Handbook, 2015). This municipality is situated in the South-east of the Northern Cape Province of South Africa at Global Positioning System (GPS) point 29° 10’ 20.7” S 24° 21’ 00.5” E (Bezuidenhout & Bradshaw, 2013; Ferreira *et al*., 2013; Bezuidenhout *et al*., 2014). The main economic sectors of the municipality are finance and business services, manufacturing, government services, transport, mining, construction and agriculture (Local Government Handbook, 2015). MNP is named after a tree which is synonymous with the area, namely the Setswana name for the camel thorn tree, generally known in the area as “Kameeldoringboom” (*Vachellia erioloba*) (Bezuidenhout *et al*., 2014). The park was proclaimed in 2007 as the most recently established National Park in South Africa (Park Management Plan 2008; Bezuidenhout *et al*., 2014). MNP contributes to the local economy through tourism (Bezuidenhout *et al*., 2014) and job creation, also helping with the upliftment of the livelihoods of the people living in the communities surrounding MNP (Saayman & Saayman, 2006; Simelane, *et al*., 2006). The park is 27 571 hectares (ha) in size and is situated close to the Free State and Northern Cape Provinces border near the N12 national road (Figure 2.1) (Park Management Plan, 2008; Bezuidenhout *et al*., 2014; Daemane *et al*., 2014).

The two study sites were situated at Lilydale and Doornlaagte which are both used for grazing and browsing by game. Both areas were previously used as cattle farms. Doornlaagte is situated in the centre of the park while Lilydale is located in the North-eastern parts of the park (Figure 2.2).

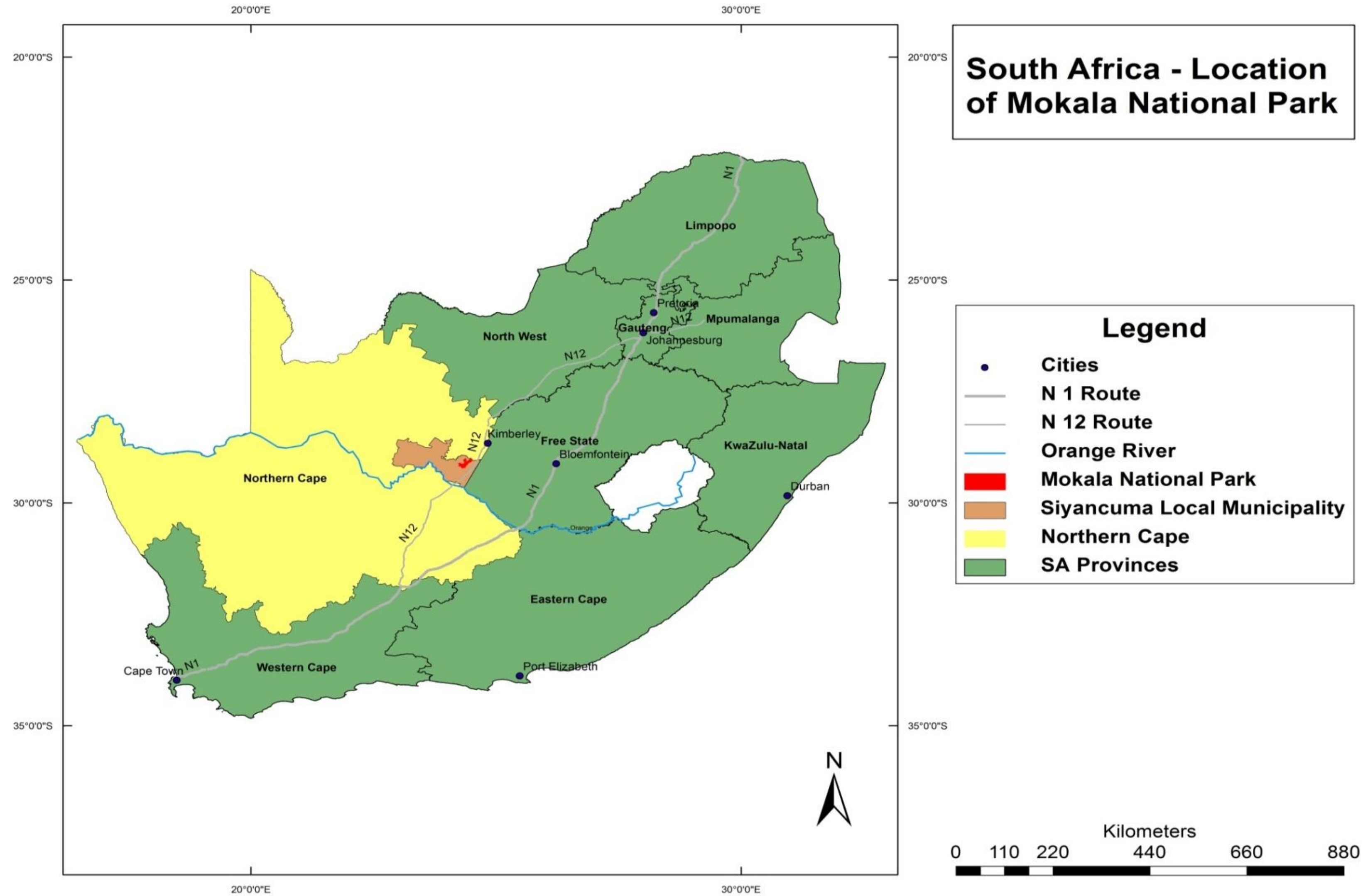

Figure 2.1: Map of South Africa indicating the Northern Cape and other Provinces, the local Municipality and location of the Mokala National Park (MNP) in red near the border of the Northern Cape and Free State Provinces.

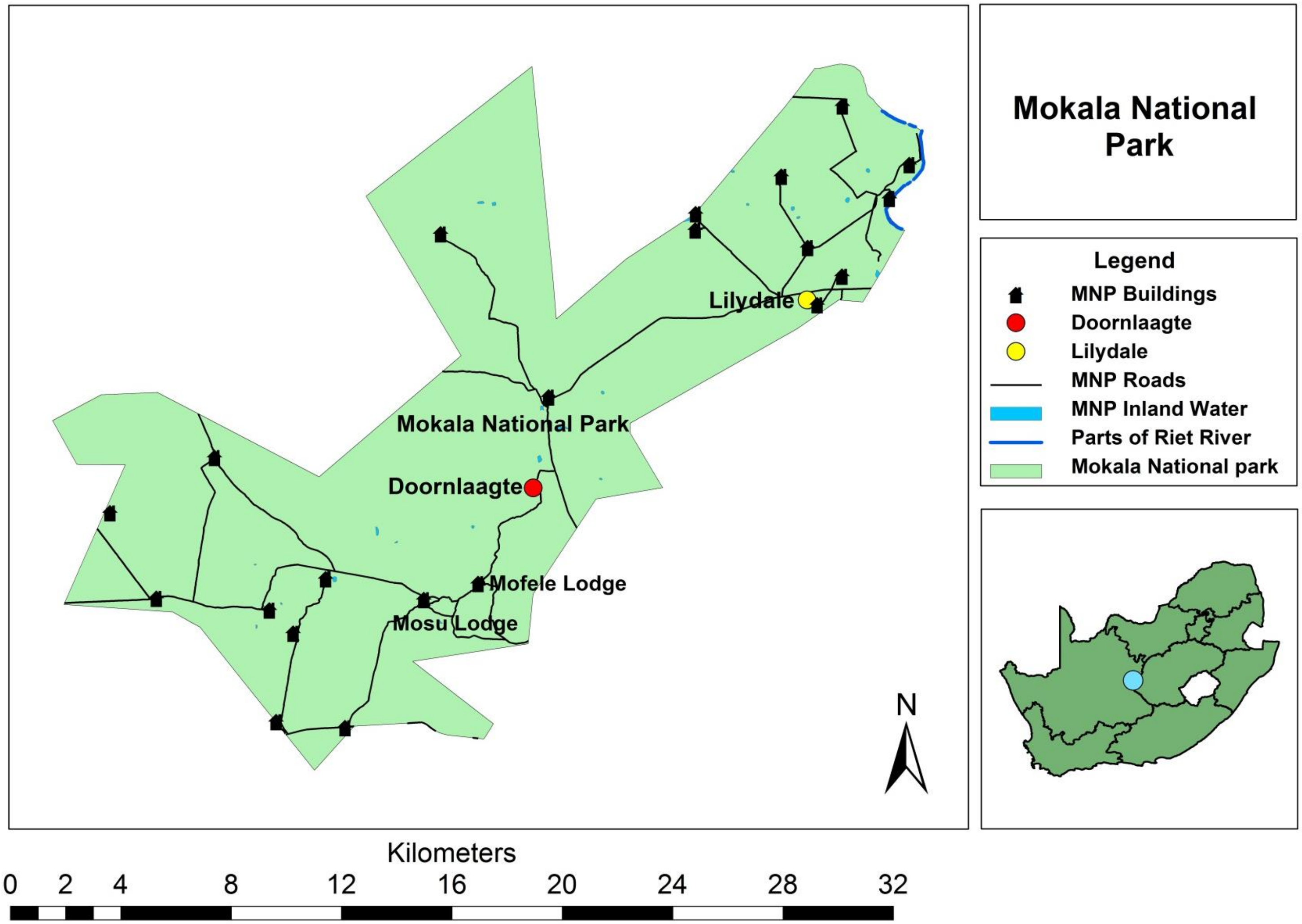

Figure 2.2: Map of the Mokala National Park (MNP) indicating the two study sites at Doornlaagte and Lilydale as well as some other features in the park, such as roads, parts of the Riet River and main buildings.

2.3 Climate

MNP is situated in a (sub)tropical type of climate region with seasonal rainfall of wet summers and dry winters (Rutherford *et al*., 2006). The annual rainfall in the area varies between 300 and 600 mm with its highest rainfall during the summer months January until March (Rutherford *et al*., 2006; Bezuidenhout & Bradshaw 2013; Daemane *et al*., 2014). MNP experiences a dry season during the months of June, July and August when less than 5 mm of rain occurs (Rutherford *et al*., 2006). The long-term average annual rainfall for MNP is 400 mm per annum (Bezuidenhout & Bradshaw, 2013). Figure 2.3 shows the average long-term rainfall per month for two different weather stations within the vicinity of a 12 km radius surrounding MNP. These weather stations include Klokfontein [0258218 6] and Plooysburg [0257391 3] (South African Weather Services, 2016). The data from these weather stations include monthly rainfall figures from 1950 until 2015 (South African Weather Services, 2015). Figure 2.3 shows that most of the rainfall occurs in February and March, although the rainy season starts in October and continues till April. The highest average monthly rainfall is about 62 mm occurring in February with the lowest average rainfall of about 5 mm in July (Figure 2.3).

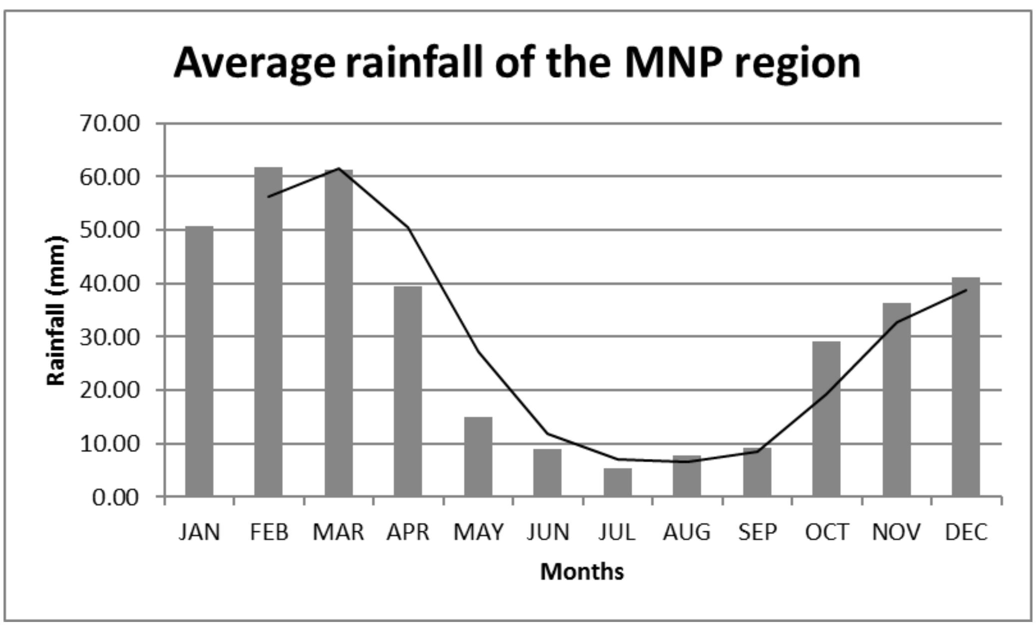

Figure 2.3: The long-term monthly average rainfall for the period 1950 – 2015 for the Plooysburg and Klokfontein weather stations in the vicinity of the Mokala National Park (MNP) (South African Weather Services, 2015). A trend line can be seen showing the average rainfall.

2.4 Topography, Geology & Soils

MNP is situated at an altitude of about 1050 – 1400 m (Rutherford *et al*., 2006, Park Management Plan, 2008; Daemane *et al*., 2014). A number of topographical units are identified which include the plateau, crest, escarp, midslopes, valley bottomlands, drainage lines, pans and the Riet River (Bezuidenhout & Bradshaw, 2013). A few geographical features are also found in MNP, which include continuous rocky hills, rolling sandy plains, degraded old lands, drainage lines, as well as a portion of the Riet River (Bezuidenhout & Bradshaw, 2013; Daemane *et al*., 2014). According to Bezuidenhout & Bradshaw (2013) the geological types include andesitic lava ridges in the northern parts and the Karoo dolorite intrusions in the south, which include the rocky hills surrounding the main Mosu lodge (Figure 2.2). The sequence of sediments comprises different components which include shale deposits of the Tierberg formation, as well as shale of the Whitehill formation (Bezuidenhout & Bradshaw, 2013). The Whitehill shale formation is characterised by soft rocks that weather easily and are mostly covered by aeolian sand and calcretes (Bezuidenhout & Bradshaw, 2013). The Dwyka tillite areas are also covered by aeolian sand (Park Management Plan, 2008; Bezuidenhout, 2009).

The types of soil in the MNP vary and include deeper red and yellow Hutton sand types, to more shallow and stony soils (mostly lime) (Park Management Plan, 2008; Bezuidenhout, 2009; Daemane *et al*., 2014). Near the Riet River in the north, as well as near the pans, more clayey soils occur (>30% clay) (Park Management Plan, 2008; Daemane *et al*., 2014).

In MNP four land type units occur which include Ae, Ag, Ia and Ib (Bezuidenhout *et al*., 2015). The "A" in the latter abbreviations refer to yellow and red apedal, freely drained soil without water tables which underlies most of the park (Bezuidenhout *et al*., 2015). Both Doornlaagte and Lilydale is situated in the Ae land type units which refers to red, high base soil, which is mostly soil deeper than 0.3 m (Bezuidenhout *et al*., 2015). In both the restoration sites high amounts of sand occur. In the Doornlaagte restoration site most parts of the soil is sandy but clayey and silt particles are available in the soil while the largest part of the Lilydale restoration site consists of sandy soils.

1.3 Vegetation

MNP is situated in the Savanna Biome of South Africa (Acocks, 1988; Rutherford *et al*., 2006; SANParks, 2010). This is the largest biome in South Africa, making up almost 33% of the country (Rutherford *et al*., 2006). According to Trollope *et al*. (1990), Savanna is the type of vegetation which consists of a tree and/shrub over story and a more herbaceous under story. The MNP is located in the Eastern Kalahari Bushveld Bioregion with three vegetation units, the Kimberley Thornveld (SVk4), Vaalbos Rocky Shrubland (SVk5) and the Northern Upper Karoo (NKu 3) (Tainton, 1999; Mucina *et al*., 2006; Park Management Plan, 2008). Acocks (1988) classified the area by tropical bush and savanna (Kalahari bushveld) and false Karoo types.

Ten landscape units have been identified in MNP by Bezuidenhout (2009). The landscape units and their location within the park are shown in Figure 2.4. The two study sites are situated in different landscape units. The Doornlaagte study site is situated in the slightly undulating footslopes open shrubland and the Lilydale study site is situated in the flat plains open woodland landscape unit. The 10 landscape units (Figure 2.4) according to Bezuidenhout (2009), include:

1. Undulating plains open woodland;
2. Flat plains open woodland;
3. Flat plains sparse woodland;
4. Rolling hills open shrubland;
5. Slightly undulating footslopes open shrubland;
6. Slightly undulating clayey drainage line open woodland;
7. Slightly undulating rocky drainage line open woodland;
8. Slightly undulating valley bottomlands open forbland;
9. Flat Riet River open Woodland;
10. Flat cultivated lands open forbland

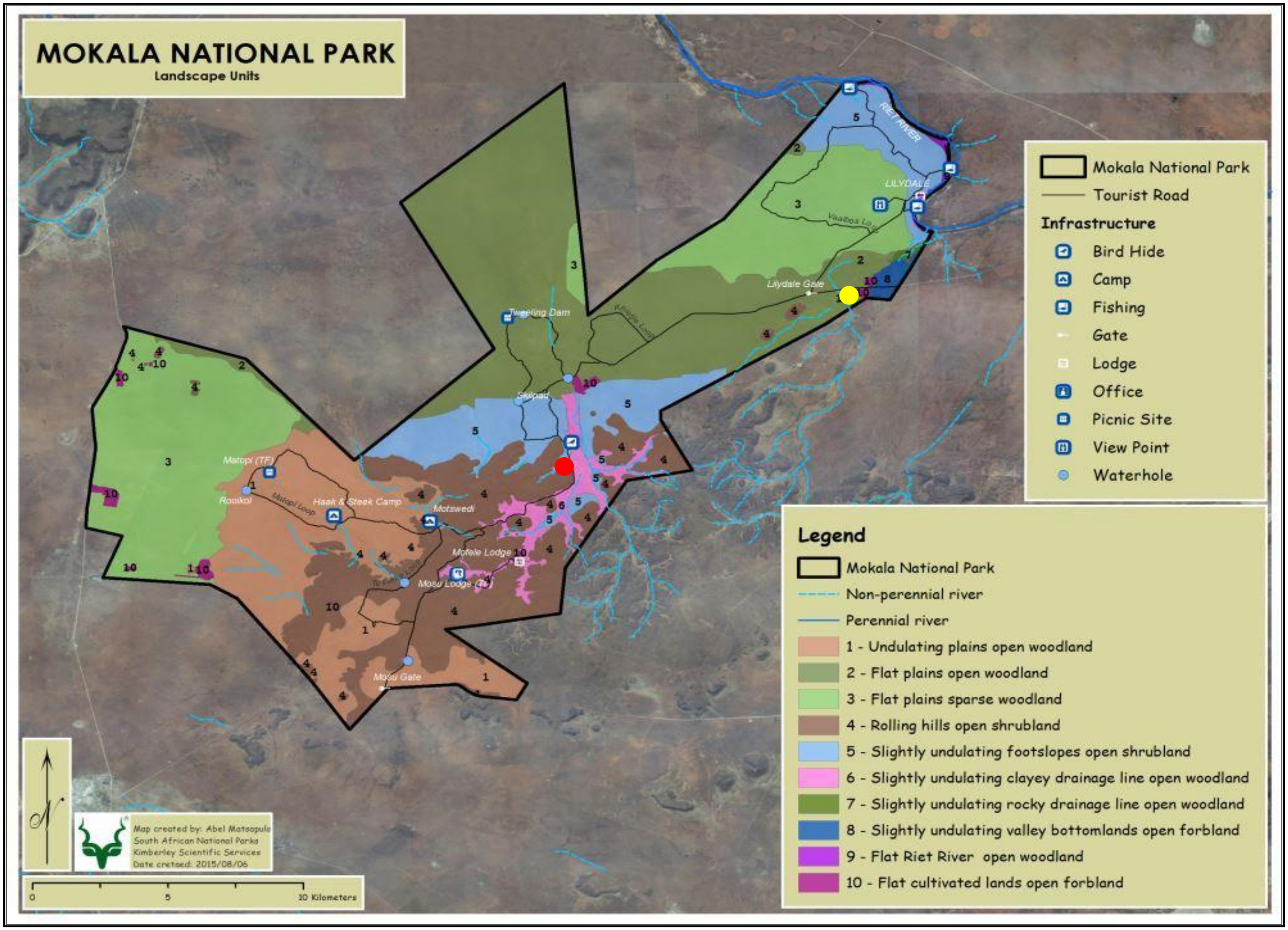

Figure 2.4: A landscape unit map of the Mokala National Park (MNP) (Bezuidenhout pers comm., 2015). The Doornlaagte study site is situated in the slightly undulating footslopes open shrubland (indicated in red) and the Lilydale study site is situated in the flat plains open woodland landscape unit (indicated in yellow) (Bezuidenhout pers. comm., 2015). Other features that occur in the MNP are also indicated in the map.

2.5 Study site selection

After the identification and classification of degradation types in MNP with the help of SANParks's scientific services (Daemane *et al*., 2014), it was decided to carry out the restoration activities at the Doornlaagte and Lilydale restoration sites. A short description of the two study sites are given below.

2.5.1 The Doornlaagte restoration site

The Doornlaagte study site (S -29 07.977; E 024 23.121) (Figure 2.5) is situated close to the main tourist road in MNP. Degradation occurring in this area is mostly characterised by sheet erosion which extends from the footslope of the hill across the tourist road to the lower lying riverine area. Sheet erosion is a continuous process of the removal of the top layers of soil across large areas which is not easily detectable and is associated with soils that have the same texture (Tongway & Hindley, 2004). Sheet erosion mostly occurs in areas where overgrazing or deforestation took place because new soil surface features occur which is the reason why there is such a high run-off in the sediments of the soil (Descroix *et al*., 2008). The trampling of soil by cattle reduces the infiltration in the soil and when the vegetation in the specific area is reduced the effect of rainsplash is increased which causes a sealing of the soil leading to more degradation (Descroix *et al*., 2008). In the end these processes cause an increase in the soil surface run-off (Descroix *et al*., 2008). Sheet erosion is mostly described as fine soil particle removal and the remaining material of gravels, pebbles and blocks, which establish a hard surface on the soil (Descroix *et al*., 2008). Due to these erosion types, different restoration technologies were selected.

This area has been intensively overgrazed by antelope like Impala and Oryx. The size of the study site is approximately 3000 m^2, with the upper, mid- and bottom slopes of 900 m^2 each. SANPark's scientific services highlighted this as an area of concern, as the erosion and flow of water from higher lying areas restricts the accessibility to tourists on the road in the rainy season (Daemane pers. comm., 2016[1]). As for the Lilydale area, this area was also overgrazed resulting in poor vegetation cover and soil capping (Bezuidenhout *et al*., 2014). The Doornlaagte study site is also not fenced

[1]Daemane, M.E., Science Manager: Park Interface Savanna & Arid Research Unit Conservation Services, SANParks, Kimberley, (053) 802 1912, (083) 643 1815

which may contribute to the disturbance of the restoration technologies by animal trampling and negative effects on the soil seed bank (Johnston *et al*., 1969; Iverson & Wali, 1982; Sternberg *et al*., 2003). The increased water run-off from the upper slopes causes a sediment deposition and also decreases the infiltration and capturing of the nutrients, causing not only sheet erosion, but also some rill and gully erosion, thereby denuding the whole landscape (Figure 2.5).

Figure 2.5: The Doornlaagte study site in the Mokala National Park before any restoration technologies were applied.

2.5.2 The Lilydale restoration site

This study site (S -29 04.430; E 024 28.656) is characterised by sheet and rill erosion (Figure 2.6). The Lilydale area where the study sites were selected and restoration technologies were applied is approximately 3000 m^2 in size, characterised by bare soil, contributing to the rill and gully erosion. The soil in rills and gullies are unstable and gullies are formed by channels which are cut by flowing water. It can be classified as the same type of erosion accept for gullies deeper than rills. This is started through water that flows quickly through the landscape in animal paths especially at steeper slopes (Tongway & Hindley, 2004).

In the downward slopes of the site, small rills had already developed before the application of any restoration technologies. The degradation of the Lilydale sites that contributed to the bare patches, excessive trampling and overgrazing could have been due to the large herds of cattle and large game such as rhinoceros and buffalo that roamed the area before (Brothers *et al*., 2011; Bezuidenhout *et al*., 2014; Daemane pers. comm., 2016). Rhinoceros and buffalo still occur in the area and still have a large impact on the vegetation and soil, as the area is not fenced, which may lead to the disturbances, such as trampling that still occurred at the study sites after the application of the restoration technologies. Excessive trampling and disturbances have a negative impact on the soil seed bank, decreasing the success of the restoration applications as seed are transported out of the system due to erosion (Johnston *et al*., 1969; Iverson & Wali, 1982; Sternberg *et al*., 2003). The team who helped to identify the degraded areas as mentioned by Daemane (pers. comm. 2016) is Ernest Daemane from SANParks scientific services, Carlo de Cock and Spencley Motloung (BSP).

Figure 2.6: The Lilydale study site before any restoration technologies were applied.

Different restoration technologies were applied at the Lilydale and Doornlaagte study sites. These are described in the materials and methods in Chapter 3.

Chapter 3 Materials & Methods

3.1 Introduction

Different restoration technologies were applied at the two study sites of Doornlaagte and Lilydale in the MNP. In this chapter the restoration technologies, site layout and sampling methods are described.

3.2 Implementation of restoration technologies and involvement of communities surrounding MNP.

South African National Parks (SANParks) and the formation of MNP help to achieve their mission which is to develop, manage and promote a system of National Parks (Bezuidenhout & Bradshaw, 2013). These National Parks should represent biodiversity as well as heritage assets through the application of best practice, environmental justice, benefit-sharing and sustainable use (Bezuidenhout & Bradshaw, 2013). SANParks', commitment to its mission, is initiated by the Biodiversity and Social Project (BSP) which are supported by the Department of Environmental Affairs (DEA) (Park Management Plan, 2008). In 2002 the BSP started in the Kruger National Park with an alien clearing project (working for water project) which was funded by the Department of Water Affairs and Forestry (DWAF), now known as the DEA (De Kock pers. comm 2015[2]). Since 2002 the project has grown and projects were initiated in all South African National Parks (De Kock pers. comm. 2015). At the moment the BSP is implementing the following projects in MNP (De Kock pers. comm. 2015):

Working for Water (Alien clearing)

Working for Ecosystems (Erosion control and bush clearing)

Environmental Monitoring Program

The DEA is a stakeholder of MNP and is involved in improving the collaboration of the park with the people living in the surrounding areas (SANParks, 2013). Supervised by

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SANParks’ scientific services in Kimberley, jobs were created through social up-liftment initiatives in the local community surrounding MNP (Park Management Plan, 2008). Local communities participating in the BSP project were used to implement restoration technologies in degraded areas within the park, aligned with SANParks’ mission: “to develop, manage and promote a system of national parks that represents biodiversity and heritage assets by applying best practice, environmental justice, benefit-sharing and sustainable use” (Bezuidenhout *et al.* 2013; SANParks, 2013). These people form part of the BSP project which is funded by the Expanded Public Works Programme (EPWP) of the DEA where local unemployed people are targeted for the rehabilitation activities and to acquire skills (De Kock pers. comm., 2016). In Figure 3.1 some of the people who helped with the project can be seen in the uniforms given to them by the EPWP.

Figure 3.1: a) People from the BSP team and students from the NWU who helped with the restoration project in MNP; b) is a uniform given to people who worked on the BSP programme and helped with restoration project.

Restoration technologies were applied in Doornlaagte and Lilydale (see Chapter 2). The BSP were used to appoint contractors to carry out the physical restoration activities at the selected sites i.e. they collected and packed the natural material (brush) found within the park as well as constructing the soil ponds on the uncovered areas (see Figure 3.2). In focusing on restoration of degraded areas due to soil erosion, the BSP project aided in one of MNP’s objectives in its need to reinstate, maintain and mimic hydrological processes to support the long-term persistence of biodiversity that are characteristic of the region (Park Management Plan, 2008). These initiatives form part of the degradation classifications, which include the identification of (1) ecological degradation (soil & vegetation degradation), (2) removal of unwanted structures, (3) roadside erosion and (4) recycling of old and unwanted material in the park (Daemane *et al*., 2014). The removal of unwanted structures and recycling does not form part of this project.

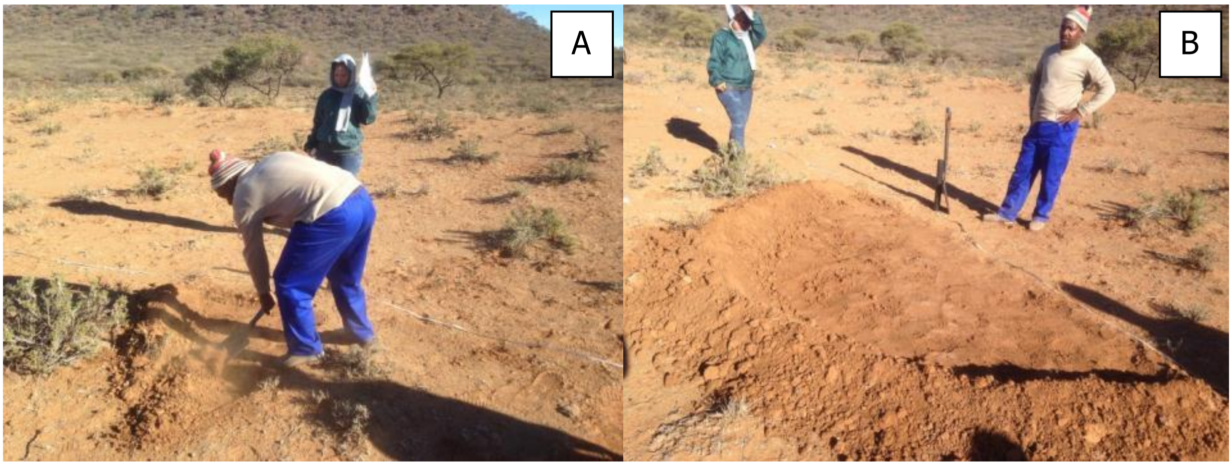

Figure 3.2: a) A worker busy to slope the wall of a pond; b) what a finished pond looked like.

The study focused on the monitoring and evaluation of restoration technologies that were implemented by the BSP team in degraded areas in MNP under the supervision of researchers at the NWU. The restoration technologies are mainly used to slow surface run-off; promote vegetation regrowth and improve water infiltration, which lead to an increase in the functionality of the landscape (Tongway & Hindley, 2004). The results can be used to advise about new technologies in other areas that have not yet been restored and to contribute to the framework for future restoration and monitoring for SANParks' restoration initiatives in semi-arid Savannas.

People from communities surrounding MNP were used to help with the formation of the soil ponds as well as with the packing of the brush material. Restoration technologies were applied in April 2014. Areas where no restoration technologies were applied served as control sites. The restoration sites where the restoration technologies were applied were not fenced off because MNP is a game reserve and fences would limit the movement of animals in the park (Hayward & Kerley, 2009).

3.3 Design of each restoration site

3.3.1 Doornlaagte

An area of 30 m x 100 m was identified and further divided into 30 m x 30 m blocks with spaces of 5 m separating the restoration blocks. The restoration site was divided into an Upper, Mid- and Bottom slope in the direction of the waterflow due to the sloping topography at the site (Figure 3.3). The angle of the slope at the restoration site was not measured. In each of the restoration blocks (Upper slope, Mid-slope and Bottom slope), 2 m x 4 m plots were demarcated, one meter from each other. Each 2 m x 4 m plot represented the different restoration technologies (see section 3.4) (represented in Figure 3.3 as red blocks). The restoration technologies described in section 3.4 were applied in Doornlaagte. These technologies included ponding, brush pack, ponding & brush (P&B) and no treatment which served as the control areas. Two LFA's of 100 m each running along the gradient through the 30 m x 30 m blocks, 5 m from the edge were carried out. Quadrats of 50 cm x 50 cm were placed in the plots where the restoration activities were carried out. Soil samples, representing the different restoration technologies, to a depth of 4 cm were also collected in randomly selected plots.

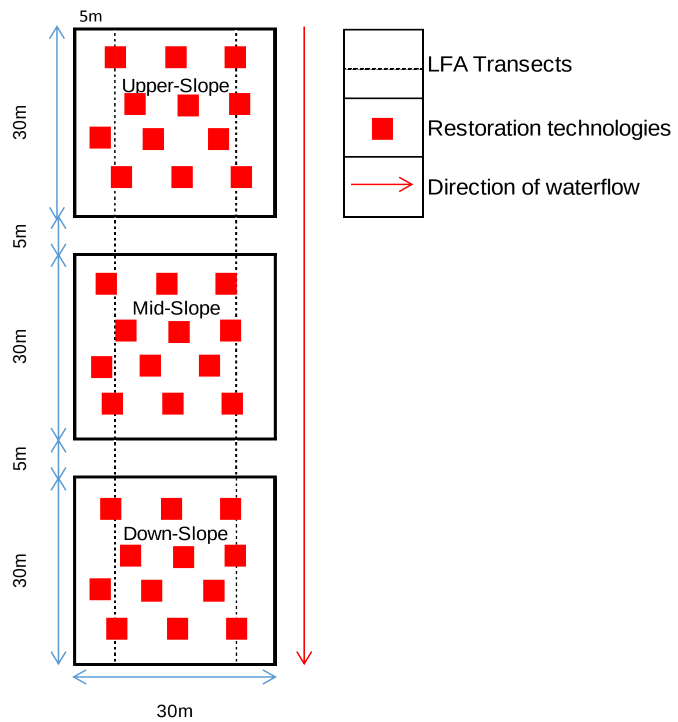

Figure 3.3: The monitoring design for the Doornlaagte restoration site. The site starts at the upper slope which is 30 m in length and width. The red blocks represent the plots where the restoration technologies were applied. Also see Figure 3.4 for a detailed plot design.

3.3.1.1 Layout of the Doornlaagte restoration site

The three different restoration technologies which were applied in the site included ponding (27 times), P&B (25 times), brush pack (26 times), and the control plots (27 times) (Figure 3.4). Two LFA transects were also done in the Doornlaagte restoration site that run across the whole site from the top of the upper slope right through to the lowest part of the bottom slope. The LFA's were conducted 5 m from the sides of the restoration site on the gradsect (see Figure 3.3). In Figure 3.4 is a design of what Doornlaagte looks like. The way the restoration technologies are laid out can also be seen. Note that only the upper slope is shown in this figure because the same layout was followed for the mid- and bottom slopes.

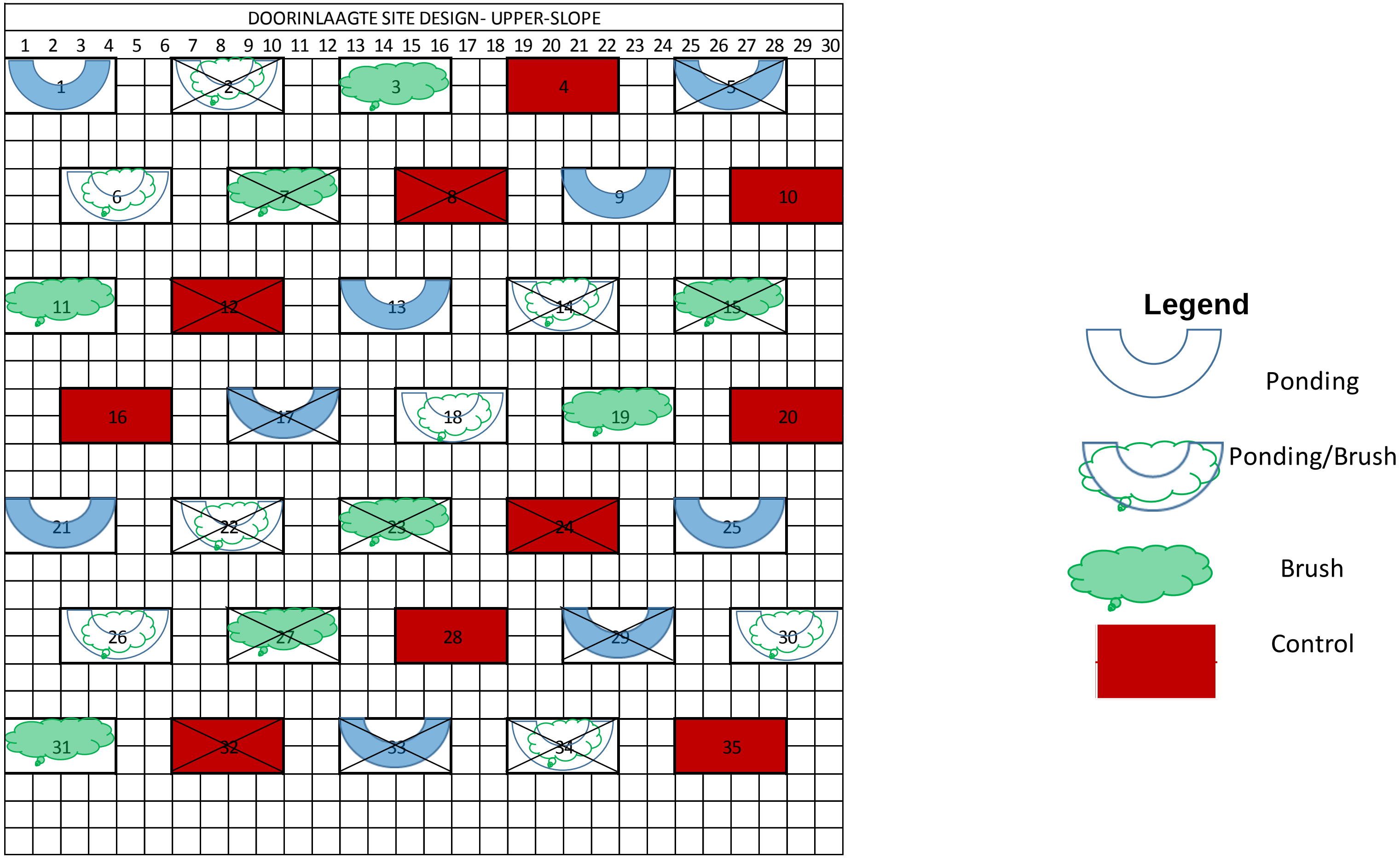

Figure 3.4: An illustration of the upper slope at the Doornlaagte restoration site. Blocks are marked with a cross which is only an indication of which blocks were used for vegetation and soil sampling.

3.3.2 Lilydale

Three blocks of 20 m x 50 m were selected which represented the restoration blocks. In each block the different restoration technologies were applied (see section 3.4) in different plots of 2 m x 4 m in size. Soil samples were collected at randomly selected plots representing the restoration technologies. As for Lilydale, two LFA's were conducted in each block (Figure 3.5). The direction of waterflow was considered, especially for the LFA surveys. In randomly selected plots, representing a certain restoration technology, 50 cm x 50 cm quadrats were used to carry out the vegetation samples. In the same plots where the quadrats were done, soil samples were also taken.

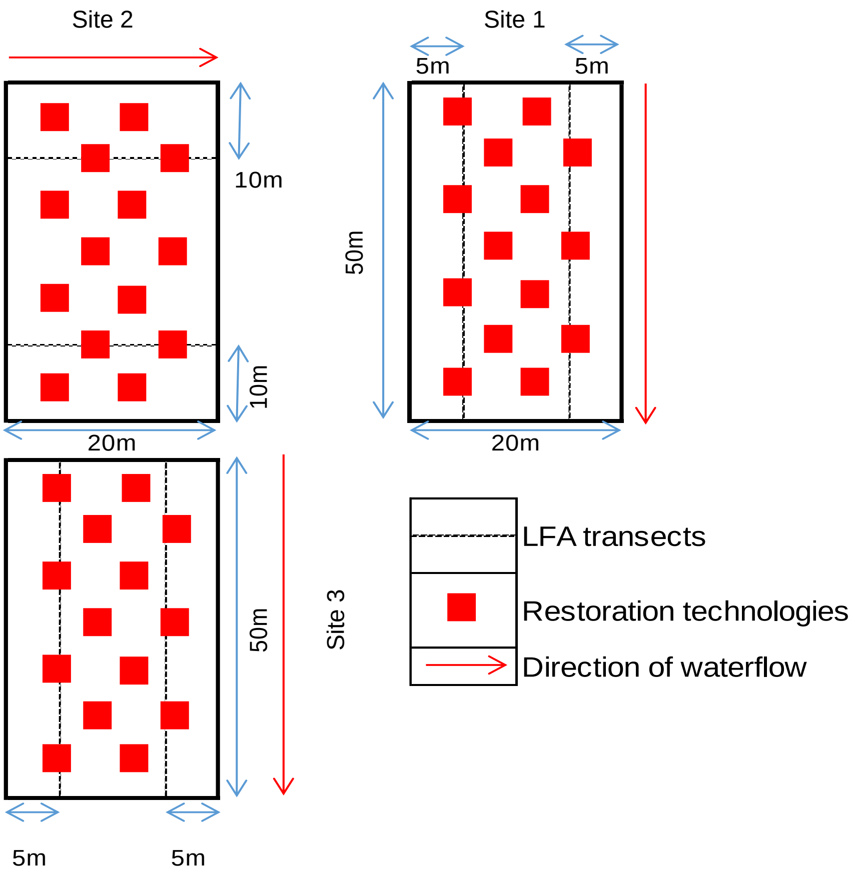

Figure 3.5: The monitoring design for the Lilydale restoration site. Each of the blocks is referred to as a restoration blocks. The red blocks represent the plots where the restoration technologies were applied. Also see Figures 3.6 and 3.7 for a detailed plot design of Lilydale. A dotted line indicates where LFA's were applied and the blue arrows show the length and width of the restoration sites. Direction of the waterflow is indicated by red arrows.

3.3.2.1 Layout of the Lilydale restoration site

The layout of the three blocks at the Lilydale restoration site is shown in Figure 3.6 and 3.7. The restoration site has a total area of 3000 m^2 and was also divided into 3 sections such as in Doornlaagte. The restoration site is situated in the North-eastern parts near the Lilydale tourist gate. The plots marked with black crosses indicate the different restoration technologies which were used to serve as control to be monitored throughout the study. The ponding restoration technology as well as the P&B restoration technology was applied 39 times, the brush technology and the control plots were repeated 38 times. The layout for site 3 is not shown because the same layout was followed for site 1. The layout of site 2 is shown in Figure 3.7.

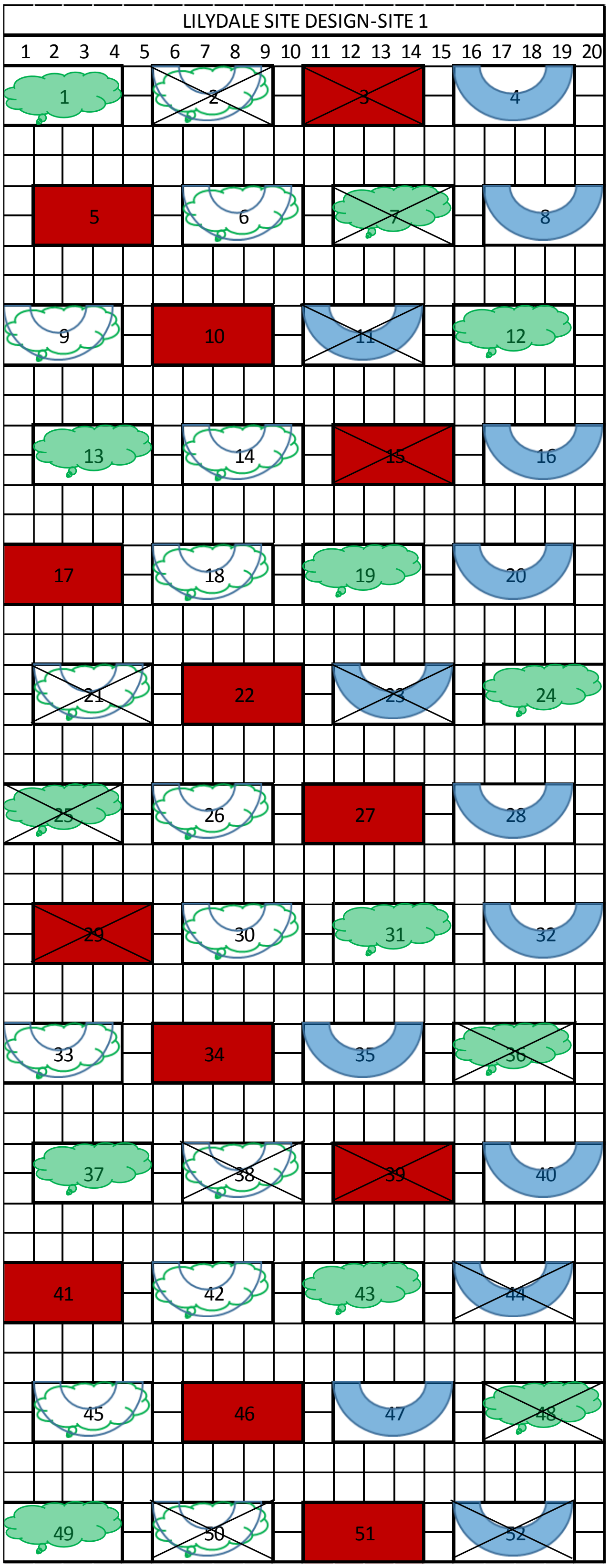

Figure 3.6: An illustration of Lilydale restoration site 1. Blocks are marked with a cross which is only an indication of which blocks were used for vegetation and soil sampling.

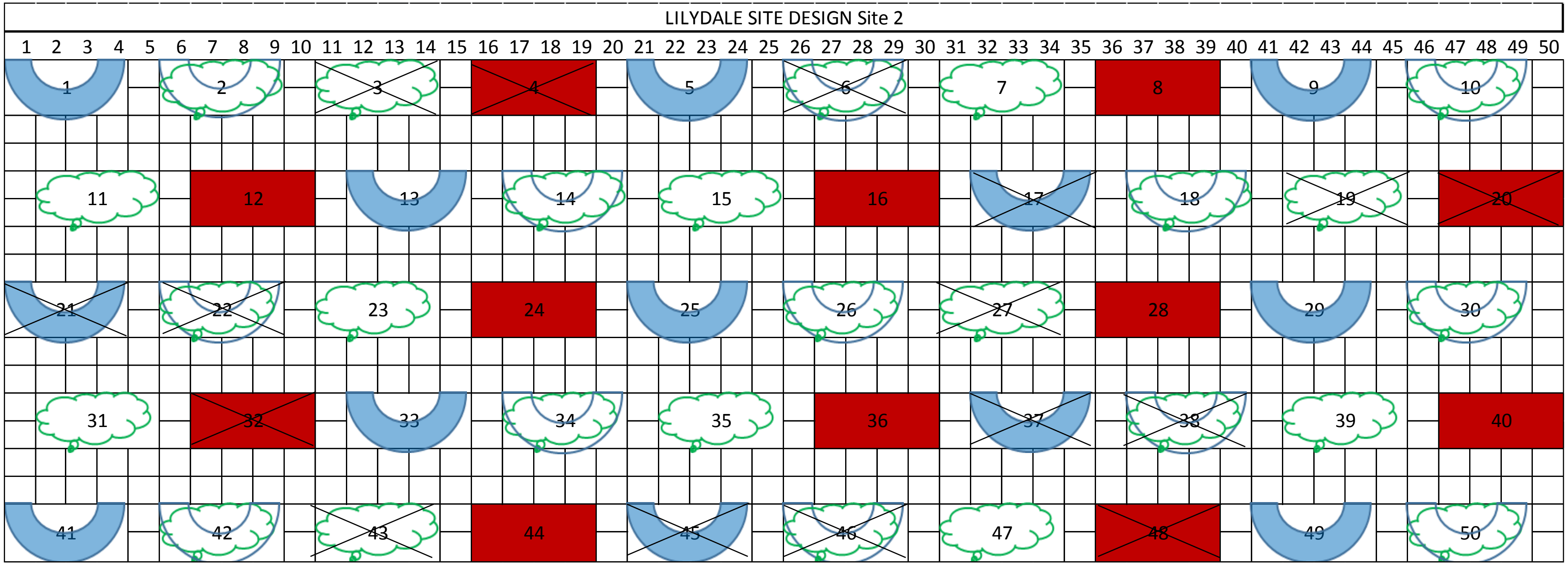

Figure 3.7: The layout of the second restoration site of Lilydale. Different blocks are marked with a cross, which shows what blocks were selected for vegetation and soil sampling.

3.4 Description of restoration technologies

The following restoration technologies were applied at both the study sites:

- Brush pack
- Soil ponding
- Ponding & brush (P&B)
- Control

Biological restoration methods can be described as the use of organic resources in the application of a restoration technology (Rochefort *et al*., 2003), i.e. using branches from woody invader species like *Acacia mellifera* to cover denuded and bare patches, is known as brush pack. This type of restoration method can be seen as an active intervention method.

Mechanical restoration methods include the usage of any machinery or implements to restore a degraded area (Rochefort *et al*., 2003), i.e. axes which is used to cut down trees, or a spade used to build ponds (in the case of MNP).

Combined methods can also be used for restoration. This includes both biological and mechanical restoration methods. This type of restoration was used in some methods which were applied in MNP, i.e. spades were used to build the walls of the ponds used in the different restoration technologies. The biological restoration method was then combined with the mechanical restoration method by placing tree branches in the ponds or on top of the soil.

3.4.1 Brush pack

A study was done by Yates *et al*. (2000) and Van Den Berg & Kellner (2005) where restoration technologies similar to the brush pack restoration technology were used. The study was carried out in the Eastern Mixed Nama Karoo which is part of the semi-arid regions in South Africa (Van Den Berg & Kellner, 2005). This restoration technology helped with the establishment of the seedlings and to increase the soil moisture (Whisenant *et al*., 1995; Coetzee, 2005; Van Den Berg & Kellner, 2005).

In the brush pack only restoration technology, branches of trees with spines (e.g. *V. karroo*) are packed on top of the bare soil patches where degradation has taken place (Figure 3.8) (Yates *et al.*, 2000; Coetzee, 2005). The brush pack was packed to a height of 0.5m and not too dense to allow for the trapping of rainfall, seed and nutrients. The branches and spines prevent further grazing and provide a microhabitat for the seeds in the soil seed bank to germinate and for seedlings to establish (McAuliffe, 1984; Coetzee, 2005). The branches also provide shade, it lowers wind velocity and traps seeds from other plants, as well as sand with nutrients (Perrow & Davy, 2002; Coetzee, 2005; Castro *et al*., 2011). The branches used for this restoration technology were collected from the nearby environment to reduce the labour and financial costs.

One of the disadvantages of this technology is that the flow of water is not slowed down effectively, especially when more severe precipitation occurs. The velocity of the waterflow may remove some of the branches and the water usually flows under the branches, contributing to a higher water run-off. The latter will also depend on how high and at what density the branches are packed. This restoration technology should therefore be used on flat surfaces only.

Figure 3.8: An example of the brush pack restoration technology on bare areas. The red arrow in the picture shows in what direction the water flows.

3.4.2 Ponding

This restoration technology includes the making of ponds (soil ponding) whereby some depression is made in the degraded soil surface with heaped up walls in the shape of a “half-moon” (Figure 3.9). The opening of the pond is located in the direction of the waterflow to ensure that the water and nutrients are trapped in the depression of the “half-moon”. The size of the “half-moon” pond is 2 m x 4 m. The advantage of the ponding technology is that waterflow is slowed down effectively. This technology is applied in areas where a slight elevation occurs in the habitat.

The disadvantage of this technology is that seedlings growing in the ponds are not covered by any material, which may lead to the desiccation of the seedlings in the ponds due to high temperatures. Animals may also utilise the seedlings. In some cases the soil is even further disturbed because the top soil layer is used to build and form the pond wall, which may influence the soil seed bank occurring in the topsoil. This removes any stored nutrients needed for seed germination and establishment in the soil surface (Mantel & Van Engelen, 1999).

Holden & Miller (1996) used a similar treatment to the ponding restoration technology called imprinting which caused depressions to form in the soil. Their imprints had the shape of a pyramid which helped with the infiltration of water, the channeling of seed, topsoil and litter (Holden & Miller, 1996; Coetzee, 2005). This study was carried out in the grasslands and shrublands of the Sonoran, Chihuahuan and Great Basin deserts and has shown that these grasslands can be restored even if they are located in dry areas (Holden & Miller, 1996).

Figure 3.9: The ponding restoration technology. The direction of waterflow is indicated by a red arrow.

3.4.3 Ponding & brush

This restoration technology consists of a combination of the brush pack and ponding technologies and is made for the trapping of water and nutrients. As for the "ponding restoration technology", the depression is made in the direction of waterflow. Branches with spines, e.g. *V. karroo* (if available), are placed within the ponds that will facilitate the growth of seedlings and the control of utilisation by animals (Figure 3.10). The branches can be regarded as "nursing objects", as they form a microhabitat for seeds and seedlings (Perrow & Davy, 2002; Castro *et al*., 2011). Other advantages include the protection of the young seedlings, a higher moisture regime due to the depression and the provision of shade and nutrients (Roberts *et al*., 2005). The disadvantage is that this technology is very labour intensive, especially if woody branches are not available nearby.

A similar study on this type of restoration technology was done by Whisenant *et al*. (1995) and Visser *et al*. (2007) where soil was tilled and branches were packed on top of the tilled soil. The tilling of the soil forms troughs which catch water and nutrients and has the same function as that of the pond structure. Results in the study of Visser *et al*. (2007) show that the highest plant density and species richness occur in the treatments where tilling together with the brush pack was applied. This study was carried out in the Nama-Karoo which is located in an arid area (Whisenant *et al*., 1995; Mucina *et al*., 2006; Visser *et al*., 2007).

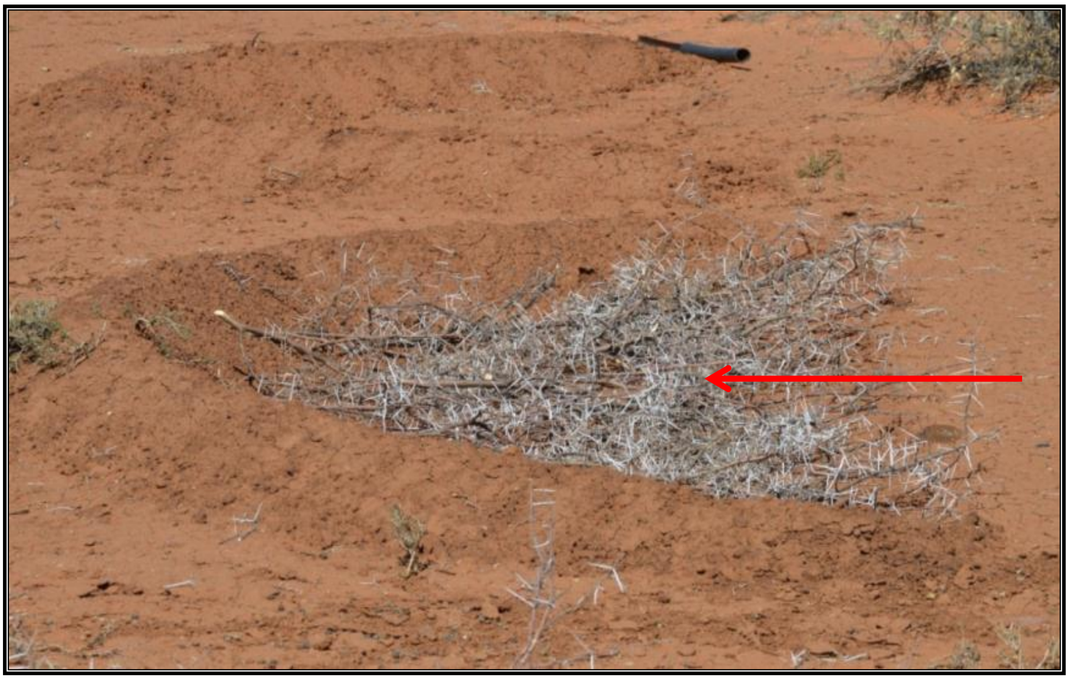

Figure 3.10: This image shows what the ponding & brush restoration technology looks like. A red arrow indicates in which direction the water flows. The branches seen within the pond are from *V. karroo.*

3.4.4 Control

No restoration technologies were applied in certain degraded areas (Figure 3.11). These served as control plots in the blocks mentioned above.

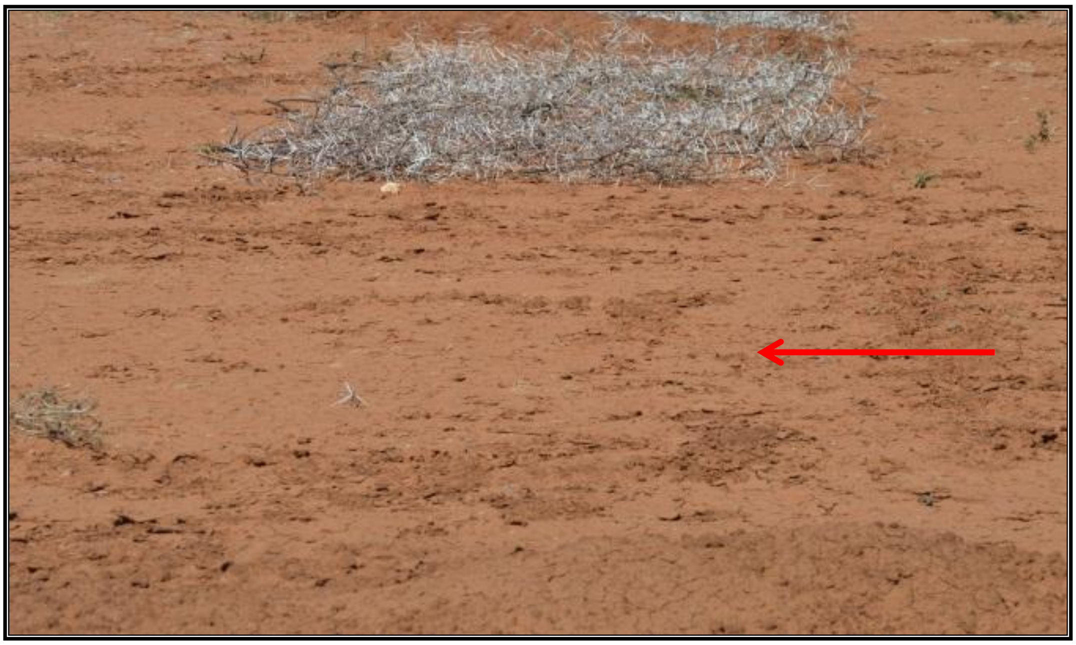

Figure 3.11: An example of the control plot. A red arrow in the picture shows in which direction the water flows.

Research was mostly done on the ponding and the brush pack restoration technologies in previous studies. This opened a gap to do more research on a combination of these two technologies which generated the idea of using the P&B technology in this study.

3.5 Sampling methods

3.5.1 The Landscape Function Analysis (LFA) methodology

The LFA is used to develop an understanding of the functionality of a landscape to help with the management of the resources available in the landscape used for different purposes (Tongway & Hindley, 2004). The LFA is not used to assess biodiversity of a landscape such as most other methods, but rather to analyse the factors which maintain the functionality of a landscape (Tongway & Hindley, 2004).

The LFA methodology is composed of three modules which include the conceptual framework, indicators of landscape function and field procedures for the monitoring of the indicators (field data acquisition) and an interpretational framework (Tongway & Ludwig, 2011).

3.5.1.1 The conceptual framework of an LFA – A Theoretical Basis

The conceptual framework is used to collect data to determine the landscape organisation (LO) in the area as well as how scarce resources are moving through a landscape in space and time (Tongway & Hindley, 2004; Tongway & Ludwig, 2011). With the conceptual framework the functioning of the landscape is examined and can be distinguished from the biological composition and its structure (Tongway & Hindley, 2004).

A landscape can be categorised into two classes: functional or dysfunctional (see chapter 1 section 2.3) (Bastin *et al*., 2002; Tongway & Ludwig, 2004). When a landscape is categorised as being functional it means that dense patches of perennial vegetation causes the overflow of water to take a longer path to flow out of a landscape (Tongway & Hindley, 2004; Tongway & Ludwig, 2011). The vegetation obstructs waterflow and sieves out material like litter and seed (Tongway & Hindley, 2004). A landscape which is dysfunctional does not have a great effect on the waterflow (Tongway & Hindley, 2004; Kakembo, 2009). In a dysfunctional landscape scarce resources are not trapped but rather allowed to flow out of the landscape (Tongway & Hindley, 2004). These dysfunctional landscapes tend to leak resources and fail to capture adequate water and also additional nutrients (Tongway & Hindley, 2004). A reduced size, spacing and number of patches can serve as an indication of degradation and dysfunctionality of a landscape (See Chapter 1 Figure 1.2) (Bastin *et al*., 2002; Tongway & Hindley, 2004; Foley *et al*., 2005).

3.5.1.2 Field data acquisition

This component of the LFA explains how the LFA procedure works to collect data from the field (Tongway & Hindley, 2004). This procedure is used across all soils, landscapes and land uses and does not need specific organisms living in the landscape (Tongway & Hindley, 2004).

The LO step is followed by fine-scale data acquisition where the eleven SSA indicators are assessed at each patch and inter-patch type in the field. In Figure 3.12 is an example of the LO as given by Tongway & Hindley (2004), which gives a basic example of how the LFA transect is divided into different patches and inter-patches.

Each landscape type is likely to have characteristic modes or mechanisms by which scarce resources are regulated (Noy-Meir, 1973; Noy-Meir, 1981; Tongway *et al.,* 2003). With the field methodology a spatial arrangement of various types of patches (accumulate nutrients) and inter-patches (increase the loss of nutrients) are identified and measured directly under the measuring tape according to size, location and characteristics (Tongway & Ludwig, 2004; Haagner, 2008; Van der Walt *et al.,* 2012). The patches and inter-patches are used to define the LO which is then used for the interpretational framework (section 3.5.1.3) (Tongway & Hindley, 2004).

For the fine-scale data acquisition eleven SSA indicators are used which include rain splash protection, perennial vegetation cover, litter cover origin, cryptogam cover, crust brokenness, soil erosion type and severity, deposited materials, soil surface roughness, surface nature (resistance to disturbance), slake test and soil texture (Tongway & Hindley, 2004; Tongway & Ludwig, 2011). A brief description of the SSA indicators is given in Table 3.1.

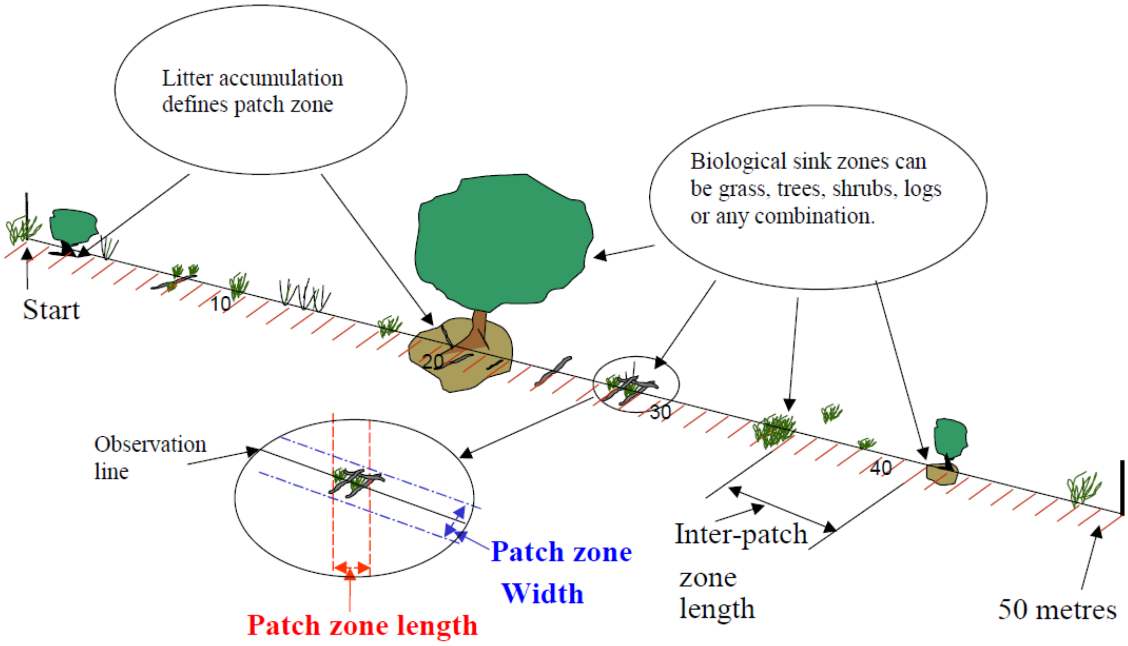

Figure 3.12: An illustration of the landscape organisation. Different types of patches and inter-patches found in landscapes are also shown (from Tongway & Hindley, 2004).

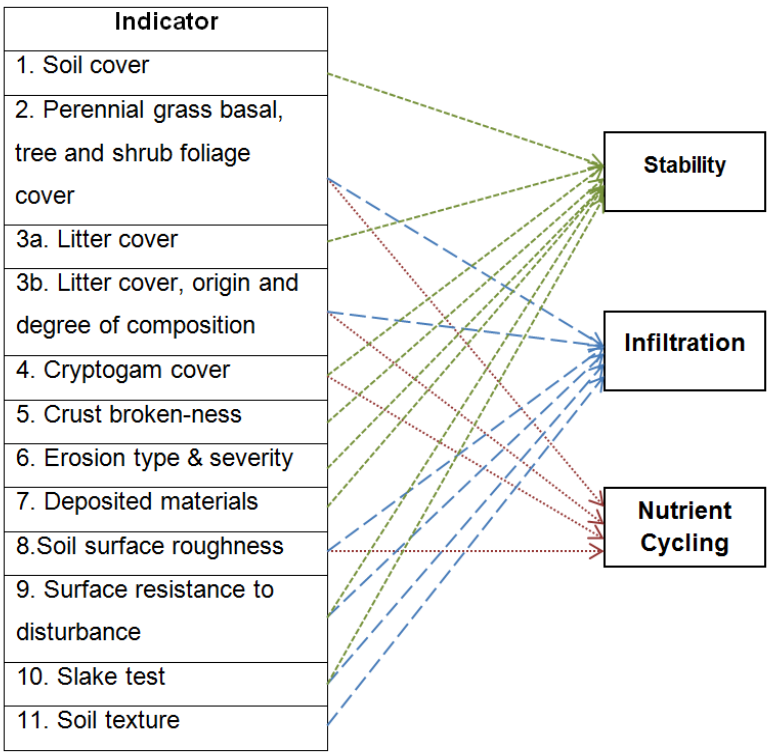

Figure 3.13: A summary which shows the impact of the 11 SSA indicators on the three main functional parameters (from Tongway & Hindley, 2004).

Table 3.1: Summary of the 11 SSA indicators and what their purposes are in the LFA

SSA Indicator	Values	Objective
Rainsplash 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 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 soil to withstand mechanical disturbance for 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 is classified and determined

The combinations of the eleven SSA indicators will reflect in the infiltration, stability and nutrient cycling of the landscape, as a functionality index (Tongway & Hindley, 2004 – Figure 3.13).

3.5.1.3 Implementation of the LFA in the field

The LFA method was applied at both the Doornlaagte and Lilydale restoration sites. Two LFA's were carried out in each block at the two sites, before and after the application of the restoration technologies. In this way any changes in the landscape functionality could be assessed. At the Lilydale site a total of six LFA's and at the Doornlaagte site two LFA's were carried out (see Figures 3.3 and 3.4).

LFA's were always placed in a downslope direction, thus in the direction in which the water flows and in which the nutrients and materials are transported (Tongway & Hindley, 2004). The direction of waterflow can also be called a gradient-orientated transect or in short a “gradsect” (Tongway & Hindley, 2004). The transect on which the LFA was conducted was divided into different patches and inter-patches with steel pins. After the LO, five different patches and inter-patches were randomly selected to be assessed with the eleven SSA indicators (Table 3.1). The SSA indicators have their own values according to the characteristics of each patch and inter-patch type and were assessed within the gradsect. These patches and inter-patches were given a unique identification which described the type of surface underneath the measuring tape laid out for the LFA. Each of the patches was then measured in width. The data were read into a data sheet specifically designed to calculate and process the LFA data. The length of the transects can be any distance as long as the data collected are representative of the area and the different patch types are included. This step makes up the landscape organisation.

There were a total of 17 months in which precipitation took place, with an average rainfall of 42 mm in the summer months and an average of 7 mm in the winter months. The first LFA’s were done in April of 2014 before any precipitation took place. A year later, in October 2015, the second LFA’s were carried out in the blocks at each site before the next rainy season. In February 2016 the last LFA’s were carried out to monitor if the landscape functionality had increased or decreased.

3.5.1.4 Interpretational framework

For the LFA to be valuable there is a way of interpreting monitoring data so that values can emerge which can be useful for determining the status of the landscape functionality (Noy-Meir, 1981; Tongway & Ludwig, 2011). The interpretational framework is the module of the LFA which is used to interpret the data acquired from the field. The recorded data are read into an Excel template which makes calculations to provide a summary of what is happening in the landscape. This module is used to compare the restoration sites to reference sites (Tongway & Ludwig, 2011). This is very important because it helps to evaluate whether a restoration site is progressing towards the goals established for restoration or not (Tongway & Ludwig, 2011).

3.5.2 LFA Patch descriptions

The LO of the LFA's consisted of the identification of different patch and inter-patch types found within the transects. A total of six different patch types were identified. These included:

- Bare Patch
- Ponding patch
- Shrub Patch
- Forb Patch
- Litter Patch
- Grass Patch

3.5.2.1 Bare Patch

A bare patch (BP) was considered as an inter-patch and can be seen in Figure 3.14 (marked in red). Water normally flowed through the inter-patches and transported nutrients out of the system because there were no obstacles which stopped the flow of resources (water and nutrients). BP's are poorer in resources and lower in soil quality (Tongway & Hindley, 2004). If a BP becomes too large, erosion may start occurring in an area. In some BP's annual or small plants did establish. However these plants were too small to capture resources or slow the flow of water. This was the dominant patch type at both study sites.

Figure 3.14: An example of a bare patch (BP). Notice that some vegetation did occur but it consisted only of annuals or was too small to capture resources or slow the flow of water.

3.5.2.2 Ponding patch

Ponding patches (PP) helped with the accumulation of nutrients and water. In the case of the "ponding patch", nutrients were much easier accumulated than in the case of other patches. The ponding wall of the restoration technologies are considered as a patch, as it collects water and nutrients to fertilise the soil. These patch types can easily be described as a "bare patch", but were separated due to the above reasons (Figure 3.15). Only the width of the ponding wall (shown between red lines) was measured not the whole width of the pond.

Figure 3.15: Ponding patch. The width of the pond wall (marked with red lines) is measured and analysed only, not the whole pond.

3.5.2.3 Shrub Patch

Shrub patches (SP) are considered to be low growing woody plants with several stems growing from the soil (Oxford Dictionary of Ecology, 1998). They act as barriers against wind and may also catch some resources (i.e. nutrients) flowing from adjacent patches (Figure 3.16 3). An SP is marked in red showing where water will flow past it.

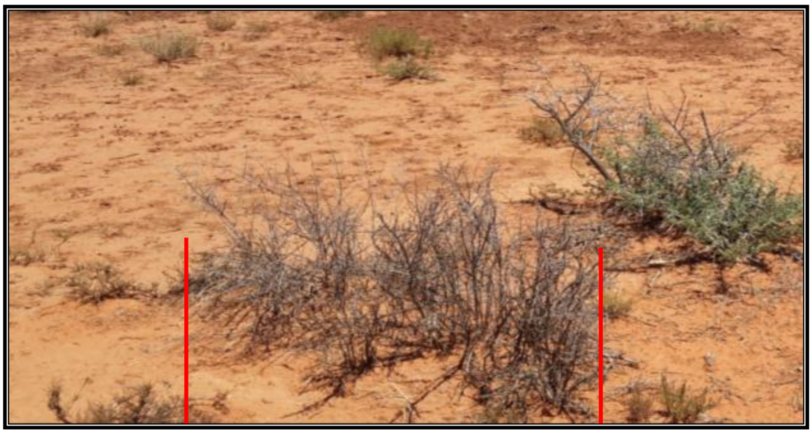

Figure 3.16: Shrub patch type. The red lines indicate a shrub patch which was identified during a LFA.

3.5.2.4 Forb Patch

The forb patches (FP) are considered to be non-woody perennial vegetation (Oxford Dictionary of Ecology, 1998). They also act as barriers against wind and help to catch some resources (water and nutrients), as in the case of the shrub patch. The patch is marked with red lines (Figure 3.17). FP's are important because quick establishment of vegetation helped to prevent further erosion at early stages in the restoration process.

Figure 3.17: The forb patch. Marked between red lines is non-woody vegetation.

3.5.2.5 Litter patch

Litter Patches (LP) consist of dead plant material or any other material deposited by animals or humans. In this study the material that formed the litter was mostly dead plants or animal dung. The higher litter volumes indicate a better functionality of the landscape because more nutrients are available; although with the dry season that was experienced less litter was available (Figure 3.18).

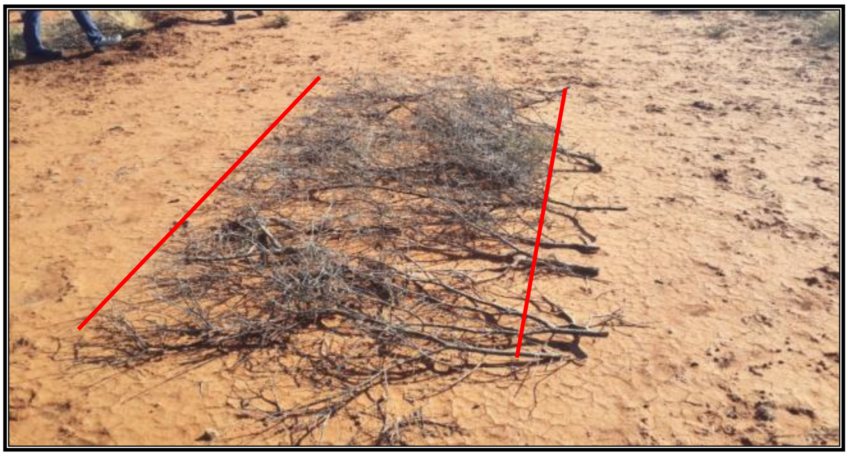

Figure 3.18: Litter patch. This is any dead plant material, animal or human deposited material in an area. In this case tree branches were placed into the patch and served as litter.

3.5.2.6 Grass Patch

Grass patches (GP) consisted mostly of perennial grass. The number of GP's that were found during this study was not high because of the drought that was experienced. Figure 3.19 shows an example of a grass patch. Measures were taken where the roots of the grass tufts went into the soil but in this case a pedestal formed and measures were taken where water runs around the pedestal.

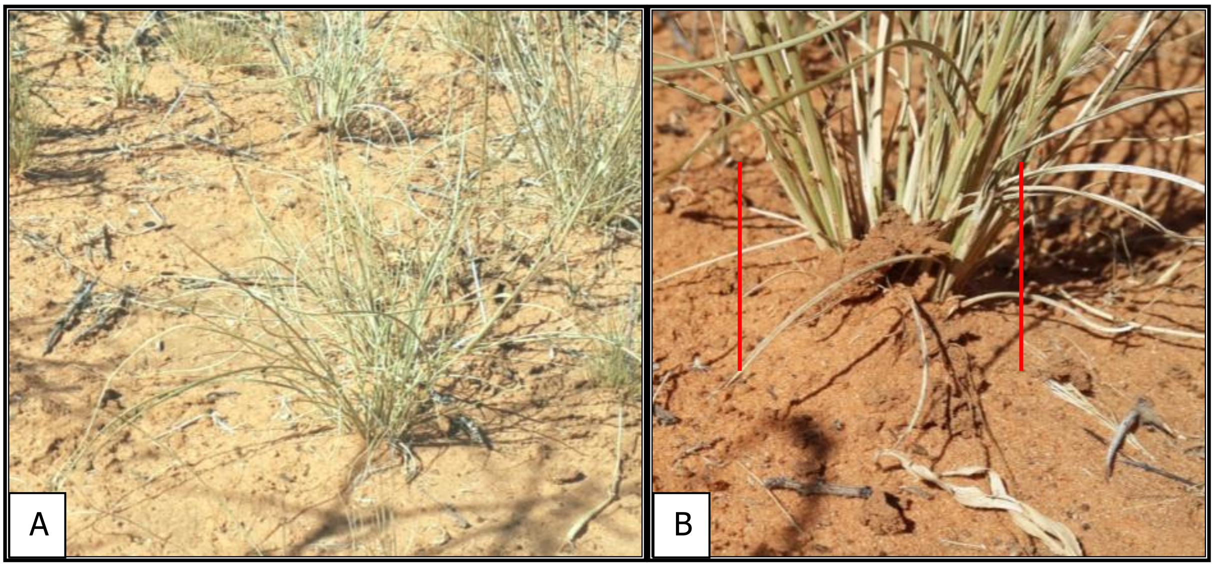

Figure 3.19: Grass patch. Photo A shows the grass patch and in photo B is an illustration of where the measurement of the grass patch was taken.

3.5.3 Quadrat vegetation surveys

A 50 cm x 50 cm quadrat was used to determine the floristic composition and density of each restoration plot (Stohlgren *et al*., 1998; Barbour *et al*., 1999; Kent, 2012). Plots where certain restoration technologies had been applied, as well as the control plots were randomly selected for the quadrat survey at each restoration site (Kent, 2012). The density was determined by counting the species within the quadrat (Kent, 2012). Dinsdale *et al*. (1997) used the same strategy and quadrat sizes when species were counted and sampled. This data can be compared to the surrounding vegetation composition occurring in the larger community.

3.5.4 Soil Seed Bank Analysis

3.5.4.1 Determining the soils seed bank

The direct germination method was used to study the soil seed bank (SSB) (Gross, 1990; Dreber, 2011). This method is used to count the number of seeds in a seed bank and does not need sophisticated technological apparatus or skills for the identification of the vegetation (Dreber, 2011).

An SSB analysis was conducted during January to April 2016. Five soil samples per restoration technology were collected in October 2015 just before the rainy season to a depth of 4 cm in each of the blocks at Doornlaagte and Lilydale (Dreber, 2011). The soil was spread onto flat surfaces in 32 cm x 32 cm trays under controlled conditions (temperature of 28°C and daily watering of 200 ml per sample and natural daylight) in the glasshouse to enhance the growth of as many seeds in the soil sample as possible. Before the SSB analysis was conducted, the soil was kept in a dark room at low temperatures to allow for the ripening of any mature, fresh seeds (Morris, *et al*., 2002; Dreber, 2011). The litter was not removed from the samples (Dreber, 2011). The soil was however sieved to remove any unwanted material, such as larger rocks and twigs (Morris, *et al*., 2002; Dreber, 2011). Permeable frost cover sheets were placed in the bottom of the trays to prevent soil loss and ensure good water drainage (Figure 3.20). A layer of sterile soil was placed in the trays on top of the frost cover to prevent any contamination to the sampled soil (Tekle & Bekele, 2000; Snyman, 2004; Dreber, 2011). The seedlings in each of the trays were counted daily until the germination rate approached zero. The whole process of the SSB analysis took about 17 weeks.

Thereafter establishment and growth of the seedlings from the SSB analysis was compared to the field data to determine which restoration technology was the most efficient.

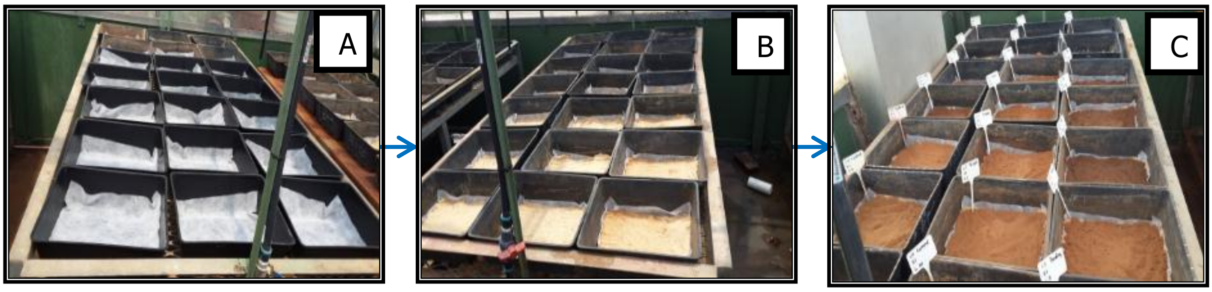

Figure 3.20: The SSB analysis in a glasshouse at the NWU. a) The trays with frost cover; b) trays with sterile soil on which the soil from MNP was placed; and c) the trays with the soil samples.

3.5.5 Soil Analysis

Soil analysis can be very expensive and for this reason a composite sampling procedure was used (Crépin & Johnson, 1993). A composite sample implies that three samples are taken representative of the same area and then mixed to form one composite sample. The collected samples were only analysed after the implementation of the restoration technologies.

Composite sampling can be used with the stratified random sampling technique, which means that the landscape is divided into useful units and a good average of each of the soil properties can be obtained (Crépin & Johnson, 1993; Li *et al*., 2008). The statistics obtained from the soil samples can be used to calculate the mean, standard deviation and other statistics needed to describe the soil characteristics in the landscape (Crépin & Johnson, 1993).

Composite soil samples were collected from both the A-horizon and B-horizon from plots characterising the different restoration technologies at both restoration sites (Figure 3.21). The soil collected for the A-horizon was collected to a depth of 4 cm. A soil sample from the B-horizon was sampled using the soil auger to a depth deeper than 4 cm and was compared to the results of the A-horizon (Figure 3.22). The soil samples were analysed to determine the mineral composition of the soil at the Eco-Analytica soil analysis laboratory of the North-West University[3]. The results obtained

[3] North West University Potchefstroom Campus 11 Hoffman Street, Potchefstroom 2531. Tel: (+27 18) 299-1111

from the A- and B-horizons were then compared to determine if there were any unusual differences between these horizons.

Figure 3.21: Taking of composite soil samples of the A-horizon at a depth of 4 cm using a coupler and spatula at each restoration plot. The soil sample was used to analyze the soil parameters and soil seed bank.

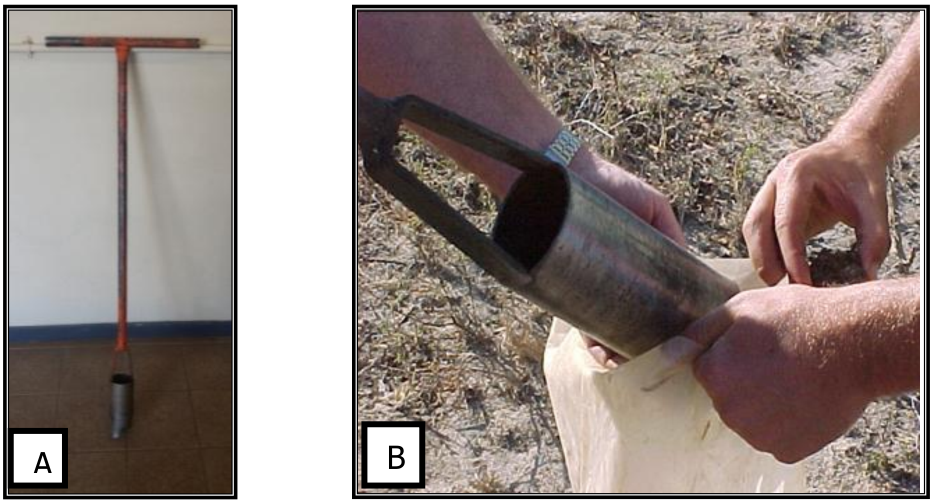

Figure 3.22: a) The soil auger used to take the (b) soil sample of the B-horizon at each restoration plot.

Chapter 4 Soil analysis of the Doornlaagte and Lilydale restoration sites

4.1 Introduction

Soil samples were taken in the A- and B-horizon soils at the different plots where restoration technologies had been applied. Five soil samples for the A and B horison each were combined to form a composite sample. The samples were then analysed by Eco-Analitica[4] at the North-West University to determine the chemical parameters as discussed below. Recommended ratios by the Fertilization Society of South Africa (FSSA) were mostly used to compare the nutrient status and other soil properties too. These ratios are based on agriculture because not much information is available for the recommended values needed in rangelands. Although soil carbon was not measured certain Soil Surface Assessment (SSA) indicators (Figure 3.13) had an influence on the soil carbon content which is shown as stability.

Standard soil testing methods:

- Exchangeable cations: 1M NH_4-Asetate pH=7
- CEC 1M Na-Asetate pH=7
- Extractable, exchangeable micro-elements: 0.02M $(NH_4)_2$ EDTA.H_2O
- EC: Saturated extraction
- pH H_2O/KCl: 1:2.5 Extraction
- Phosphorus: P-Bray 1 Extraction

4.2 Doornlaagte restoration site

4.2.1 Calcium, magnesium and potassium

Calcium (Ca) is a soluble cation and occurs in most soils. It is not directly involved in the reactions of proton transfer which is involved in pH-buffering, but it does provide a cation charge for these reactions (Bache, 1984). A high soil buffer is provided when Ca is freely available in the soil and changes the pH when added to the soil (Bache, 1984). High concentrations of Ca occur in areas where not much precipitation occurs,

[4] EcoAnalitica, P.O. Box 19140, Noordbrug, Potchefstroom, 2522. Tel: 018 293 3900

because more water means that Ca will be leaching from the system causing lower concentrations to be available for the plants in the soil (McCauley *et al*., 2009). A low concentration of Ca in soil is less than 200 mg/kg and a high concentration of Ca in soil is more than 3000 mg/kg (FSSA, 2007). Ca concentrations in soil should never be lower than the magnesium (Mg) concentrations because if this happens the levels of toxic metals in the soil will be too high affecting plant growth and development (Brady *et al*., 2005).

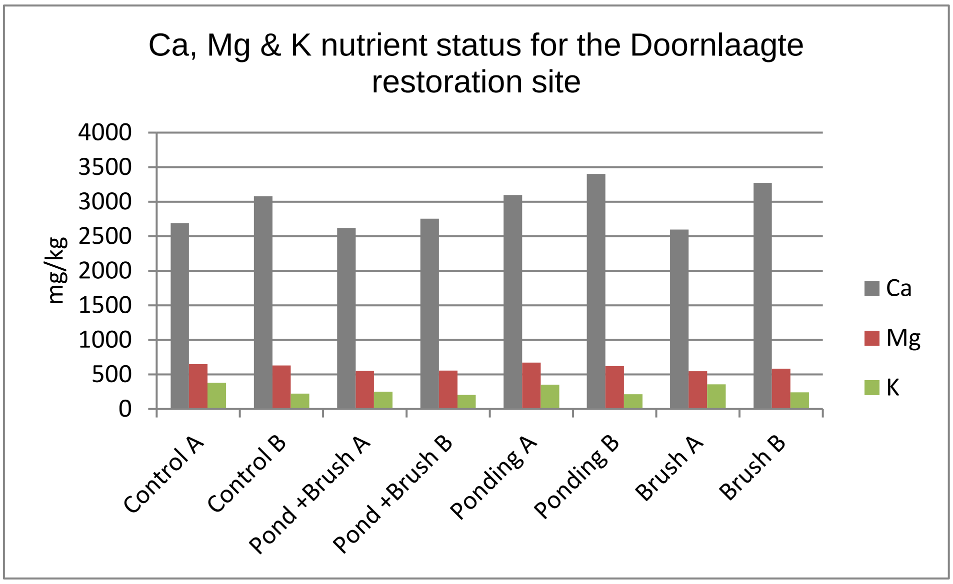

Figure 4.1: The Calcium (Ca), Magnesium (Mg) and Potassium (K) status in the restoration technologies of the Doornlaagte restoration site.

According to Figure 4.1 the Ca concentration in the B-horizon was the highest where the ponding restoration technology had been applied with a total of 3401.5 mg/kg and the lowest where the P&B technologies had been applied with a total of 2753.5 mg/kg respectively. The Ca in the A-horizon was generally lower, but the highest concentration of calcium was found where the ponding technology had been applied with an concentration of 3097.5 mg/kg. The lowest concentration of Ca was found where the brush technology had been applied with an concentration of 2598 mg/kg. These concentrations show that the Ca content in the soils at the Doornlaagte restoration site is high, making the soil alkaline.

A number of enzymes in plants are involved in the transportation of phosphate and need Mg (Tisdale *et al*., 1990). When there is insufficient Mg in soils these enzymes will not be able to assimilate carbon dioxide and in the process photosynthesis will be diminished (Tisdale *et al*., 1990). According to the FSSA (2007), a high concentration of Mg in soil is more than 300 mg/kg and a very low concentration is less than 50 mg/kg.

The highest concentration of Mg was found where the ponding technology had been applied with a total of 672 mg/kg in the A-horizon and the lowest concentration of Mg was 548 mg/kg found where the brush technology had been applied. In the B-horizon the most Mg namely 630 mg/kg was found where the control technology had been applied and the lowest concentration was found where the P&B technology had been applied with a total of 554.5 mg/kg.

A favourable calcium to magnesium ratio (Ca:Mg) is 4:1 (FSSA, 2007). The Ca:Mg ratio that was found, is between 4.1:1 and 5.6:1 which is higher than needed, meaning the higher concentrations of Ca, make the soils more alkaline. The reason for this could be that this study area received less rainfall and that both Ca and Mg could not have leached from the upper soil stratum.

Potassium (K) is important for plants in the sense that enzymes are activated which help with the formation of cells especially in the growth tips (Cakmak, 2005). When there is a deficiency of K, plants are unable to take up the water and this makes them less resistant to droughts (Cakmak, 2005). Another important factor why K must occur in plants is that it forms high-energy phosphate molecules needed for the functioning of the plant (Cakmak, 2005). The concentration of K needed in the soil should be between 40 and 250 mg/kg (FSSA, 2007).

Potassium was the highest where the control plots had been applied with a total of 380 mg/kg in the A-horizon (Figure 4.1). The lowest concentration of K in the A-horizon was found where the P&B technology had been applied with a total of 251 mg/kg. In the B-horizon the highest concentration of potassium was found where the brush technology had been applied with a total of 243 mg/kg and the lowest concentration of 202 mg/kg was found where the P&B technology had been applied.

4.2.2 Sodium and phosphorus

Sodium (Na) is important for a plant to keep its stem in a rigid shape (Tisdale *et al*., 1990). Insufficient concentrations of sodium in the soil will decrease the osmotic pressure in plants reducing the uptake of water (Tisdale *et al*., 1990). Too much sodium in the soil on the other hand causes the soil to become impenetrable by water because large pores in the soil are blocked, which may have consequences of topsoil being transported out of the system which could lead to land degradation (Tisdale *et al*., 1990). The infiltration tempo of substances into the soil is decreased and the root distribution of plants is weaker when the Na concentrations in soils are too high (FSSA, 2007). If the concentration of Na passes the 15 mg/kg mark the soils can be classified as sodium rich or alkaline soils (MacVicar, 1991).

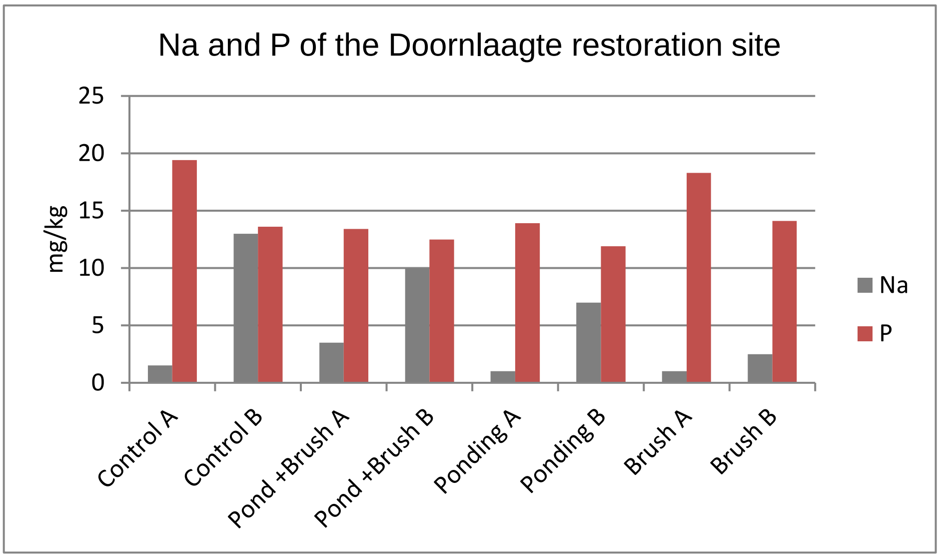

Figure 4.2: The Sodium (Na) and Phosphorus (P) status in the restoration technologies applied in the Doornlaagte restoration site.

Figure 4.2 further shows that the Na is higher where the control plots B-horizon is located with a total of 13 mg/kg which is near the limit, characterising high concentrations of Na in the soil. The lowest total of Na in the B-horizon was measured where the brush technology had been applied with a total of 2.5 mg/kg. The highest concentration of Na in the A-horizon of 3.5 mg/kg was in the in the P&B applied restoration technologies and the lowest concentration of 1 mg/kg was found in the brush pack and ponding restoration technologies. This shows that the concentrations of Na fluctuated very much in the Doornlaagte restoration study site which covers a very small area. Although there is a high fluctuation rate, especially between the A- and B – horizons and between the restoration technologies applied, the overall concentrations of Na are not too high and the infiltration of substance into the soil will therefore not be negatively affected. The Na in the A-horizon is lower than in the B-horizon because more physical action happened in the upper parts of the soil than in the B-horizon soil.

Phosphorus (P) plays a vital role in the transfer of energy in plants (Tisdale *et al*., 1990). A deficiency of P reduces the respiration and photosynthesis, as well as the protein and nucleic acid synthesis which eventually inhibits cell growth (Grant *et al*., 2001; Hazelton & Murphy, 2007). This leads to lower plant height, a lower dry matter yield and seed production, as well as to leaves emerging late (Grant *et al*., 2001).

If the P value in soils is higher than 15 mg/kg, it can be regarded as high, especially for rangelands (FSSA, 2007). As seen in Figure 4.2 the highest concentration for P measured in the Doornlaagte site, was 19.4 mg/kg in the A-horizon where the control plots had been applied. The lowest total P value is 13.4 mg/kg in the P&B applied restoration technologies. For the B-horizon the highest P value was found where the brush only restoration technology had been applied with a total of 14.1 mg/kg and the lowest concentration of 11.9 mg/kg. The average P value in the soil is therefore within the allowed limits and thus will not negatively affect the growth of the plants.

4.2.3 pH

The pH in soil is the measure of alkalinity or acidity and affects most soil properties and also determines the growth of the vegetation. The stability of soil, its availability of nutrients and microbe activity are also influenced by the pH level.

The pH of soil can be determined by using water (H_2O) or potassium chloride (KCl) (Van Schoor *et al.*, 2000). The pH (H_2O) is referring to as the soil solution acidity, while the pH (KCl) refers to the soil acidity and the reserve acids in the soils which have the potential to acidify the soil (Tisdale *et al*., 1990). When the pH in soil is too low, hydrogen ions (H+) are very high and the acid concentrations in the soil will have negative effects on the root development of vegetation (Van Schoor *et al.*, 2000). Plants will be exposed to toxic elements such as aluminium when the soil becomes too acidic (FSSA, 2007).

When the soil is too alkaline elements such as molybdenum can become toxic which affects animals consuming the vegetation (McGrath *et al*., 2010). Soil pH is neutral when the value is between 6.8 and 7.2 for both the pH (H_2O) and pH (KCl) analysis (FSSA, 2007). When the pH levels are below 6.8 the soil becomes acidic and over 7.2 the soil becomes alkaline (FSSA, 2007). A study was done by Provin and Pitt (2001) who found that arid and semi-arid areas have a natural pH between 7.5 and 8.3.

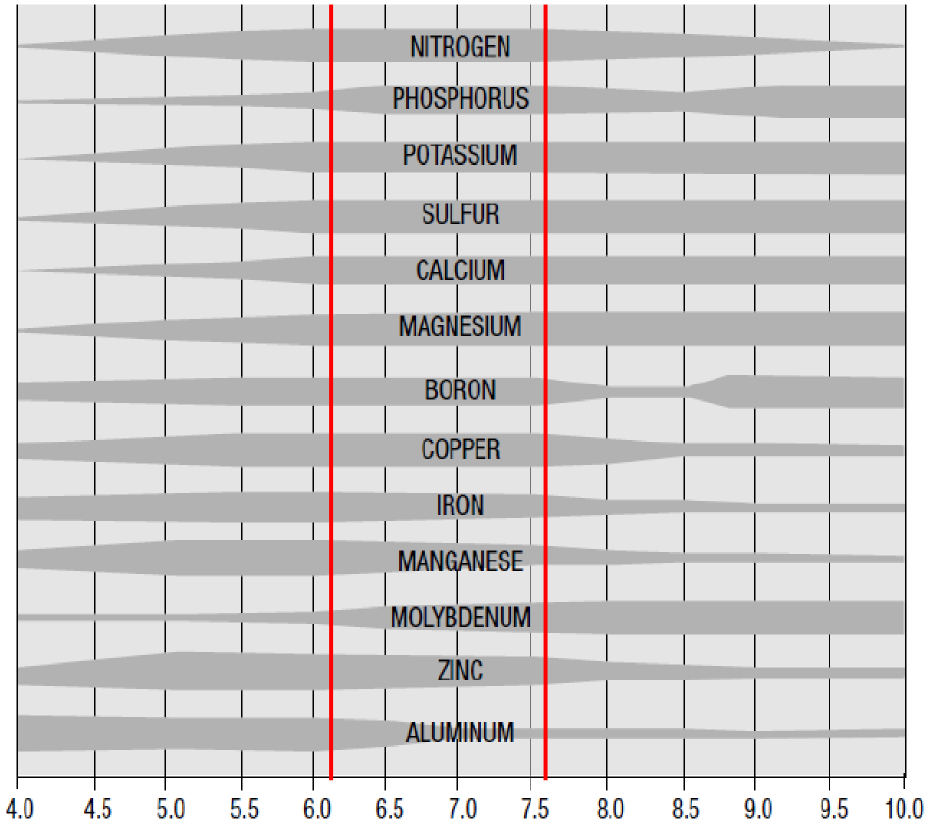

Figure 4.3: A graph which shows at what pH level elements in the soil becomes available for plants (from FSSA, 2007).

Figure 4.3 is a graph that shows at what pH level nutrients in the soil become available for uptake by plants. The red lines indicate the range of the pH level where all nutrients in the soil will be available for use by plants and ranges between a pH of 6 and 7.5. Most plants prefer to grow in soils with a pH of 5.5 to 7 (Hazelton & Murphy, 2007).

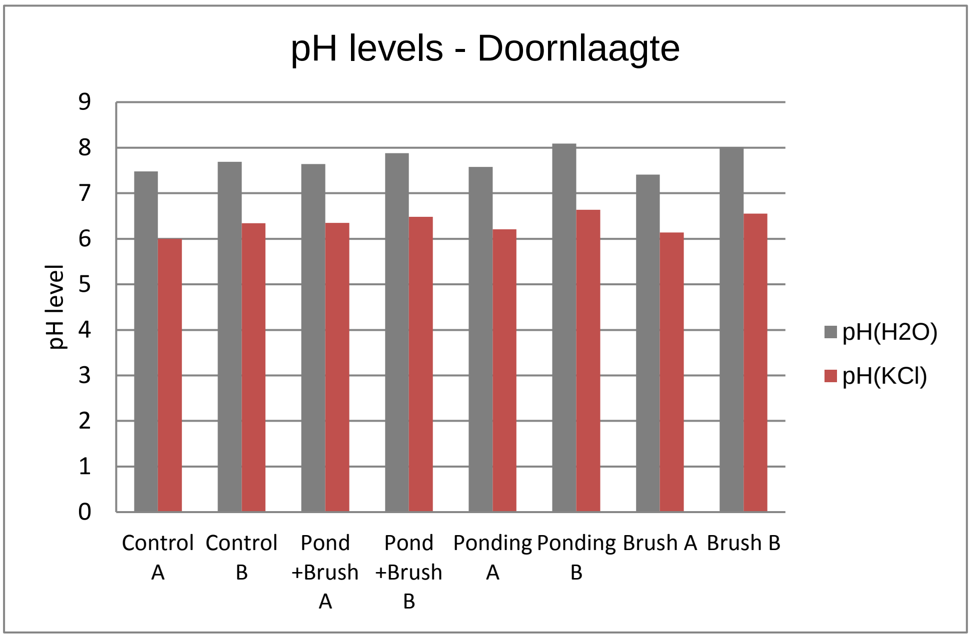

Figure 4.4: The pH levels of the soil in the different restoration technologies in the Doornlaagte restoration site.

From Figure 4.4 it is evident that the pH (H_2O) levels of the soils where all restoration technologies were applied especially for the A- horizon, is above 7, meaning that the soils are alkaline which explains the higher concentrations of Ca and Na (Figure 4.1). The pH values for the B-horizon are also above 6, meaning that the soil just below the A-horizon is making most of the nutrients soluble and available to plants (Figure 4.4). The average for the pH (KCl) level is 6.3 which is a good condition for vegetation to establish (FSSA, 2007). The pH values for both the A- and B- horizons are therefore relatively similar for all areas where the restoration technologies were applied at the Doornlaagte study site.

4.2.4 Electrical conductivity

Electrical conductivity (EC) is the capability of materials to conduct an electrical current and can be expressed in milliSiemens per metre (mS/m) (Grisso *et al*., 2005). The EC is used to determine the salinity of soil and increases as the concentration of salts in the soil increases (Sparks, 2003). The salinity in soils inhibits plant growth by limiting the uptake of water by plants because the osmotic potential is reduced (Corwin & Lesch, 2005). Lower EC can be expected to occur in sandy soil types, medium EC in soil with a high silt content and a high EC in clayey soils (Grisso *et al*., 2005). Salt starts to affect the growth of vegetation at an EC higher than 200 mS/m, while a good quality soil has an EC of 10 - 150 mS/m (FSSA, 2007).

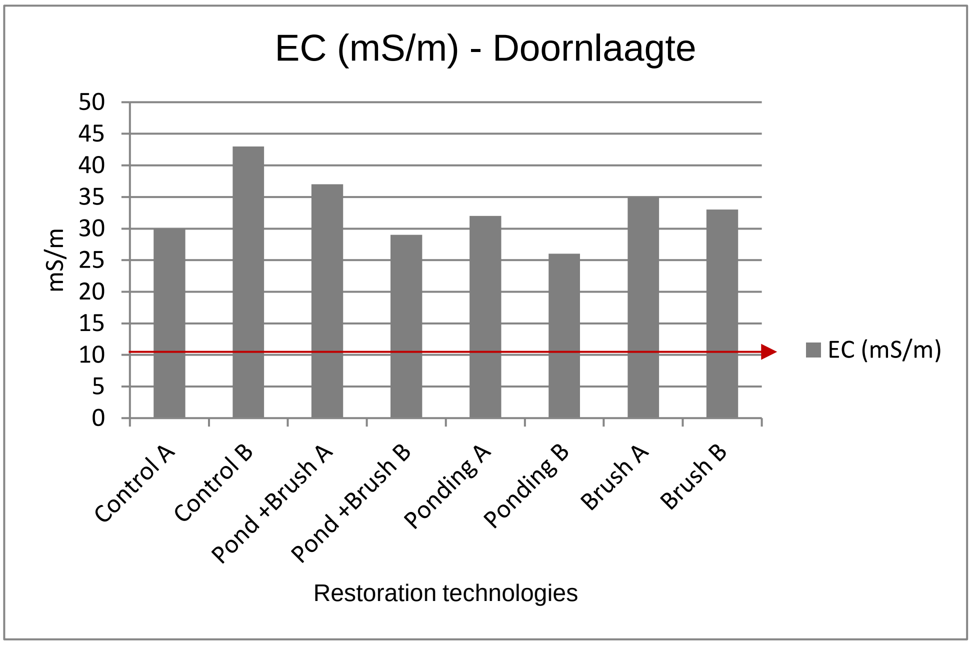

Figure 4.5: The electrical conductivity of soils measured in the Doornlaagte restoration.

Due to the sandy soil type (Figure 4.7) at the Doornlaagte study site, the EC is rather low with fluctuations between 26 mS/m and 43 mS/m (Figure 4.5). A red arrow in Figure 4.5 shows the lowest EC in soil can be 10 mS/m before it is too low. The EC has no negative effect on the plant growth at Doornlaagte.

4.2.5 Particle size distribution

The particle size distribution measures the size distribution of the individual particles in the soil (Gee & Or, 2002). According to the results shown in Figure 4.6, all the soils where the restoration technologies were applied, at the Doornlaagte study site, are sandy with a little silt and clay content.

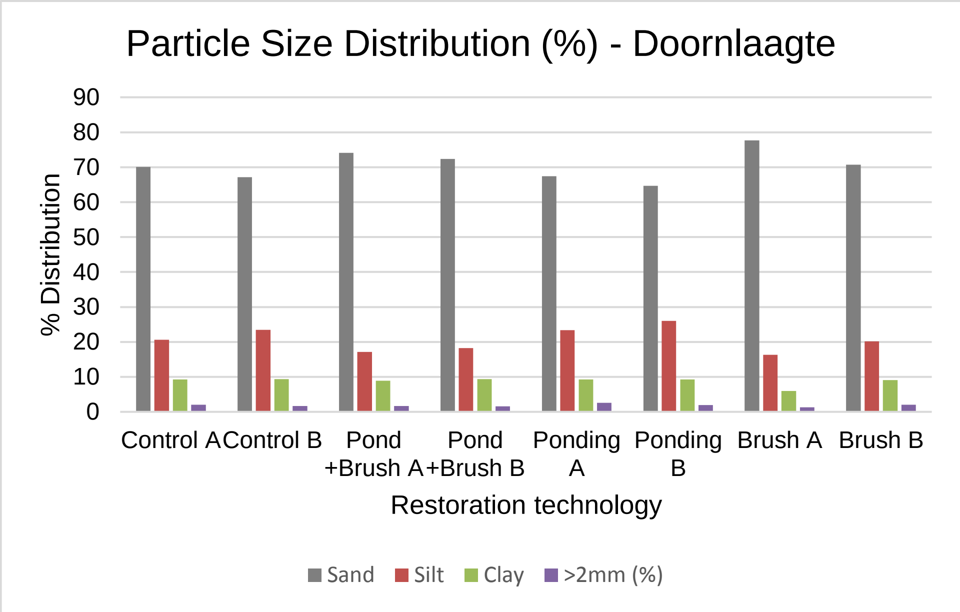

Figure 4.6: The percentage distribution of different particle sizes in the different restoration technologies plots at the Doornlaagte restoration site.

Silt makes up 23.4% of the soil found in the A-horizon of the location of the ponding technology. The lowest concentration of silt was found in the A-horizon where the brush technology had been applied with a total of 16.3%. In the B-horizon the highest concentration of silt was found where the ponding technology was located with a total of 26% and the lowest concentration was found in the area where P&B technology had been applied with a total of 18.2%.

Clay is mostly found in the B-horizon where both the control plots and P&B technologies were applied with a total of 9.4%. The lowest concentration of clay was found where the brush technology had been applied with a total of 9.1%. In the A-horizon clay had the highest concentration where the control plots and ponding technology was located with a total of 9.3% while the lowest concentration was found in the locations of the brush technology with a total of 6%.

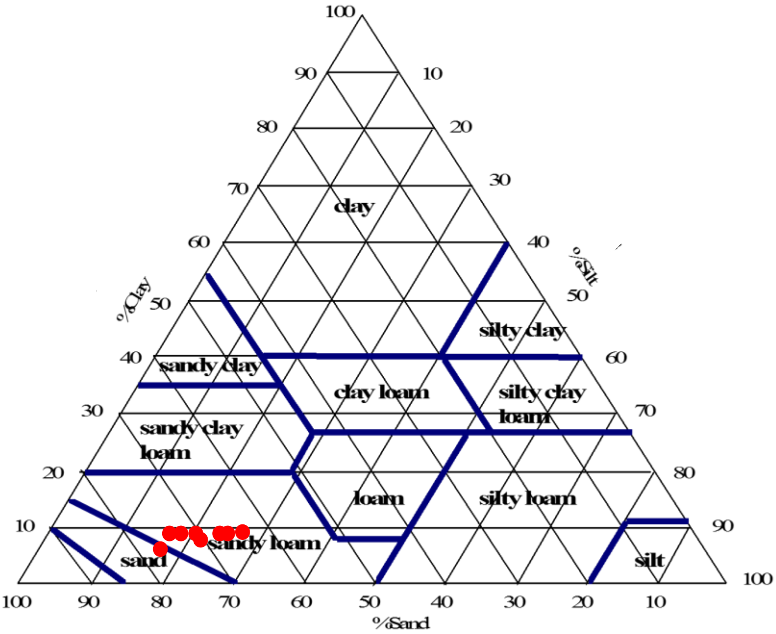

Figure 4.7: Texture triangle for the analysis of soil texture (from Hillel, 2004). Red marks indicate the soil type of Doornlaagte.

The numbers obtained from the analysis were only used to determine what type of soil was sampled in the different restoration sites and in Figure 4.7 markers (red) indicate in which class the soils of the Doornlaagte restoration site fall. The sand, silt and clay percentages were used to determine the type of soil that occurs in the restoration sites. These percentages are used on the texture chart and where the three percentages cross one another, the type of soil in the area is determined. As seen from Figure 4.7, most of the samples analysed at the Doornlaagte restoration study site fall into a sandy loam class and it is only one soil sample from the brush pack restoration technology, that falls into the sandy class. If soil becomes too fine the chance that the soil becomes compacted is higher, especially when overgrazing occurs (Azarnivand *et al*., 2010) or when heavy rain falls onto soil that is not covered by vegetation, as the impact of the raindrops can compact the soil surface (Belnap, 2001). This means the soil will become impenetrable to water and it will be more difficult for smaller plants to establish and for their root systems to develop.

4.2.6 Cation Exchangeable Capacity

The cation exchangeable capacity (CEC) is the capacity that soil has to exchange and to retain cations (Hazelton & Murphy, 2007). The CEC in soil provides a buffering effect for changes occurring in the pH, nutrient abundance and changes in the structure of the soil (Hazelton & Murphy, 2007). A low CEC means that the soil has a low resistance to changes happening to the chemistry of the soil (Hazelton & Murphy, 2007). CEC is generally articulated as centimoles of positive charge per kilogram of soil [cmol (+)/kg)]. A very low CEC is less than 6 [cmol (+)/kg)], an adequate amount is 12-25 [cmol (+)/kg)] and a high amount is more than 40 [cmol (+)/kg)] (Hazelton & Murphy, 2007).

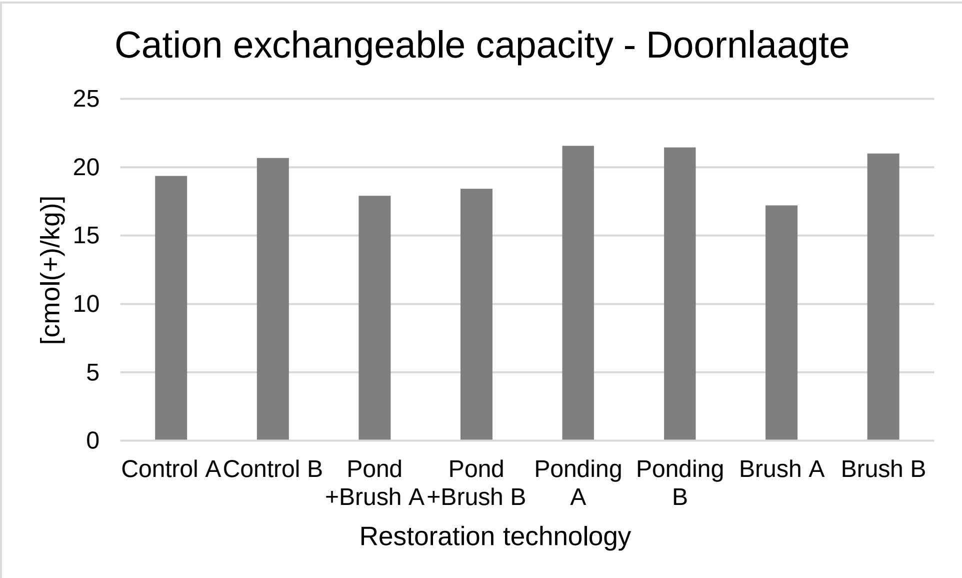

Figure 4.8: The cation exchangeable capacity of the Doornlaagte restoration site.

The CEC at the Doornlaagte study site is overall good and ranges between 17 and 22 cmol (+)/kg, meaning that the cations are available for plant absorption. The highest CEC was found in the soil of the A-horizon of the ponding restoration technology with an amount of 21.6 cmol (+)/kg and the lowest CEC in the A-horizon was found in the location of the brush pack technology with an amount of 17.2 cmol (+)/kg. The highest CEC in the B-horizon was found where the ponding technology was applied with a total of 21.45 cmol (+)/kg. The lowest CEC in the B-horizon was found in the P&B technology with a total of 18.43 cmol (+)/kg. The CEC of the soil in Doornlaagte is good and cations will be available for plants to absorb.

4.3 Lilydale restoration site

The following section describes the soil analysis results which were obtained from the A- and B-horizon soil in the Lilydale restoration site.

4.3.1 Calcium, magnesium and potassium

Figure 4.9 shows the results of the calcium (Ca), magnesium (Mg) and potassium (K) availability in the Lilydale restoration site. The highest concentration of Ca was found in the A-horizon soil where the control plots were located with a total of 3232.25 mg/kg. According to the standard concentration of Ca usually found in soils, this concentration is quite high (see section 4.1.1). The lowest concentration of Ca in the A-horizon soil was found where the P&B technology had been applied with a total of 1942.5 mg/kg which is a more acceptable concentration. In the B-horizon where the control plots are located the most Ca was found with a total of 2930.5 mg/kg. The lowest concentration of Ca in the B-horizon was found in the location of the brush technology with a total of 2043.25 mg/kg which is still regarded as a high concentration of Ca in the soil. The high concentrations of Ca in both the A- and B-horizons indicate that the soil in Lilydale is alkaline.

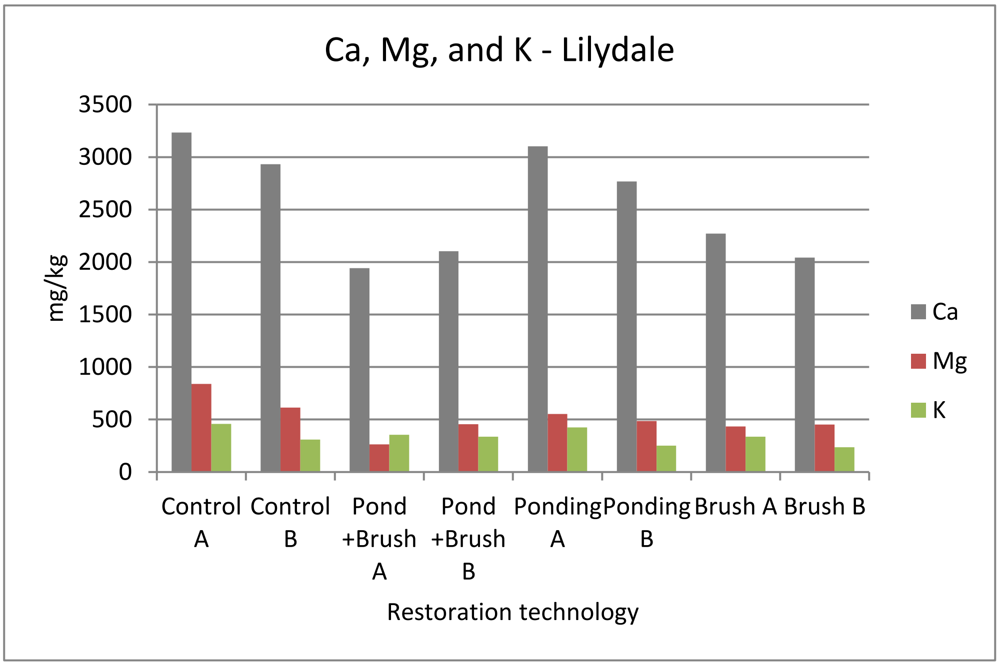

Figure 4.9: The calcium (Ca), magnesium (Mg) and potassium (K) found in the A- and B-horizon soils of the Lilydale restoration site.

The Mg found in the restoration technologies is overall very high. The most Mg was found in the A-horizon of the control plots with a total of 838 mg/kg which is far above the suggested concentration of 300 mg/kg (FSSA, 2007). The lowest concentration of Mg was found in the A-horizon soil in the location of the P&B technology with a total of 263.5 mg/kg which is in a good range of Mg needed in soil. In the control sites, the Mg concentration in the B-horizon was 612.5 mg/kg. The lowest concentration of Mg in the B-horizon was located where the brush pack technology had been applied with a total of 451.5 mg/kg. The Mg in the Lilydale restoration site is very high which could have been caused by too little precipitation that was experienced during the rainy season. This contributed to the Mg not leaching out of the soil system or was a result of the high animal concentration found at these sites.

The Ca:Mg ratio in the Lilydale restoration site on average is 5.2:1 which means there is a very high Ca concentration in the soil because the suggested ratio (for agricultural use) is only 4:1 (see section 4.1.1).

The total K found in the restoration sites in Lilydale is the highest in the A-horizon in the location of the control plots with a total concentration of 458 mg/kg. The lowest concentration of K in the A-horizon was found where the brush technology had been applied with a total of 336.5 mg/kg. These figures show that there is an abundance of K found in the soil. Plants tend to absorb only a small concentration of K even if this element is found in abundance. In the B-horizon the highest K value of 335.25 mg/kg was found where the P&B technology had been applied and the lowest concentration was found in the location of the brush technology with a total of 237.5 mg/kg. Although the K value in the B-horizon at the Lilydale restoration site is very high, it is still within the range normally found in soils.

4.3.2 Sodium and Phosphorus

Figure 4.10 shows the availability of sodium (Na) and phosphorus (P) in the soil at the Lilydale restoration site. High concentrations of Na were found in the soil especially in the B-horizon where the control plots were located (26 mg/kg). This concentration is very high and exceeds the amount of Na suggested by the FSSA (2007). The lowest concentration of Na in the B-horizon was found where the ponding restoration technology had been applied with a total of 6.5 mg/kg which is a good concentration normally needed in soils. In the A-horizon the most Na was found in the location of the P&B technology with a total of 9.5 mg/kg, which is also within a good range. The least Na of 7.5 mg/kg was found where the ponding restoration technology had been applied. The Na concentrations at the Lilydale restoration site, especially in the topsoil, are within the normal range as suggested by the FSSA (2007). Naturally the Na in soil will be higher in the B-horizon than in the A-horizon, because less water reaches the lower soil parts with less physical action interfering with the nutrients in the B-horizon. This also occurs at Lilydale and could be ascribed to the ponding walls made during the building of these restoration sites.

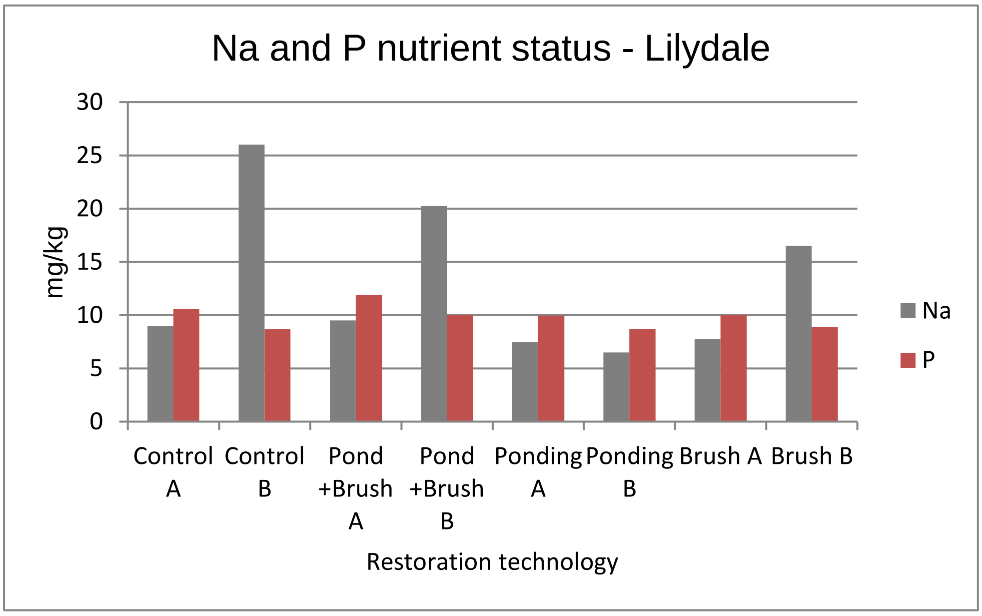

Figure 4.10: The sodium and phosphorus levels of the A- and B-horizon soils in the Lilydale restoration site.

On average the concentration of P found in the Lilydale restoration site was within the normal range and depicts a good condition soil within both the A- and B-horizons with concentrations ranging between 11.9 and 8.7 mg/kg. The highest P concentration of

10 mg/kg was found in the B-horizon where the P&B technology had been applied with the lowest concentration of 8.7 mg/kg in the sites of ponding alone technology. The highest P concentration in the A-horizon was also found in the P&B restoration sites with a total of 11 mg/kg. The concentration of P found in the soil is good and does not exceed a limit which affects the growth of plants negatively.

4.3.3 pH

All pH (H_2O) levels (Figure 4.11) are higher than 7.2 which means that the soil is alkaline. In the B-horizon the overall pH levels are on average higher than 7.8. The levels for the pH (KCl) are higher than 6.3 and lower than 6.8 in the A-horizon which indicates that the pH values are within a good range. In the B-horizon the pH levels are higher than 6.7 and lower than 7. All of the above-mentioned pH levels depict soils that are in a good condition (see section 4.1.3) and show that there is a low level of acidity in the soil which explains why the Ca and Mg concentrations (Figure 4.9) are high.

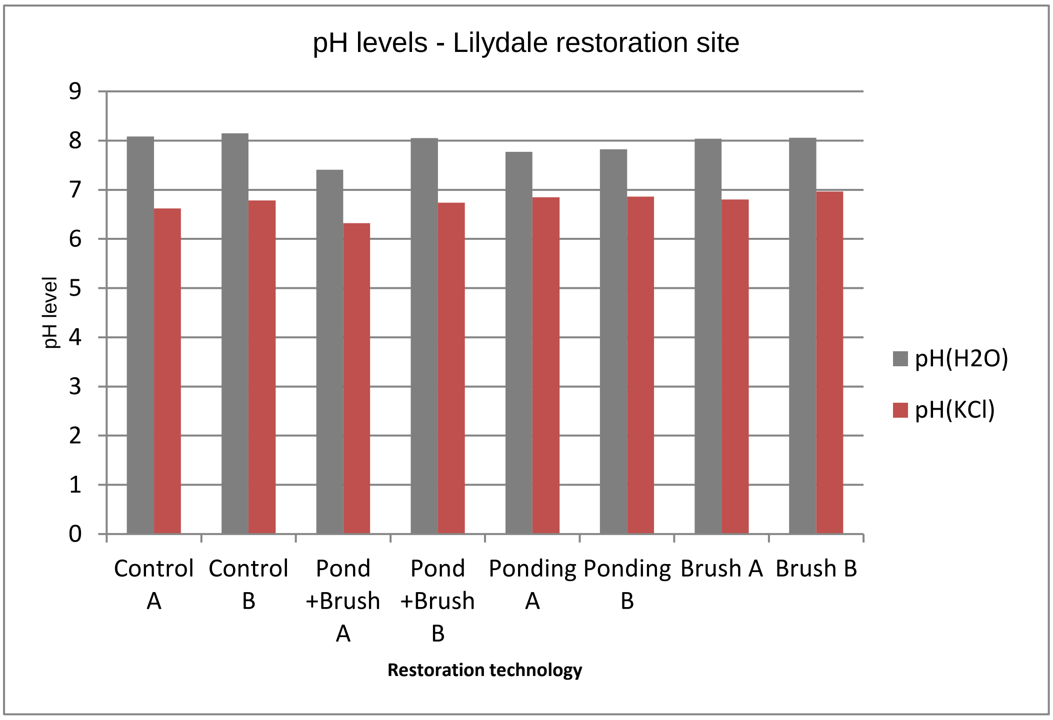

Figure 4.11: The pH levels of the soil in the Lilydale restoration site.

4.3.4 Electrical conductivity

The **electrical conductivity (EC)** (Figure 4.12) in all the soils at the Lilydale restoration site is higher than the minimum EC (red line) needed before the EC becomes too low and will affect the growth of plants negatively. Most of the EC scores recorded are between 20 and 30 mS/m. In the location of the ponding technology the EC is high in both the A- and B-horizons with scores of 50 and 60.5 mS/m. The lowest EC scores recorded for the B-horizon soil were found in the control plots with an amount of 24.5 mS/m and the lowest in the A-horizon were also found in the control plots with an amount of 27 mS/m. These scores are under average but fall between the boundaries of 10 and 150 mS/m which are good scores for EC needed in soil and will not affect the growth of plants negatively.

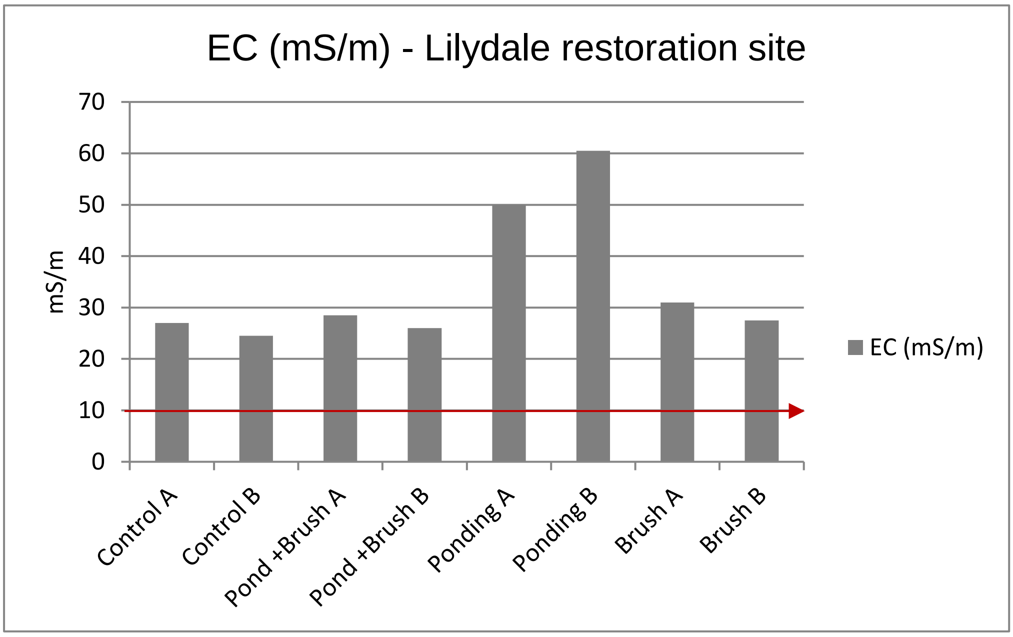

Figure 4.12: The electrical conductivity for soil in the Lilydale restoration site.

The EC in the Lilydale restoration site is overall lower than the average, meaning that there is a low concentration of salt in the soil except for the soil in the ponding restoration technology which is higher than the EC of the other restoration technologies. Although this score looks like an "outlier", it explains the best soil condition. The EC values were compared to those of the FSSA (2002) which are based on values needed in agricultural soils, as the information needed for soils under rangeland conditions is currently lacking.

4.3.5 Particle size distribution

The particle size distribution in the Lilydale restoration site is the same for all the areas where the restoration technologies were applied (Figure 4.13). All the soils are sandy (60-80%) with limited amounts of clay and silt, like the soils at the Doornlaagte site. The soils with the most sand were at the sites where the P&B technology had been applied (94%).

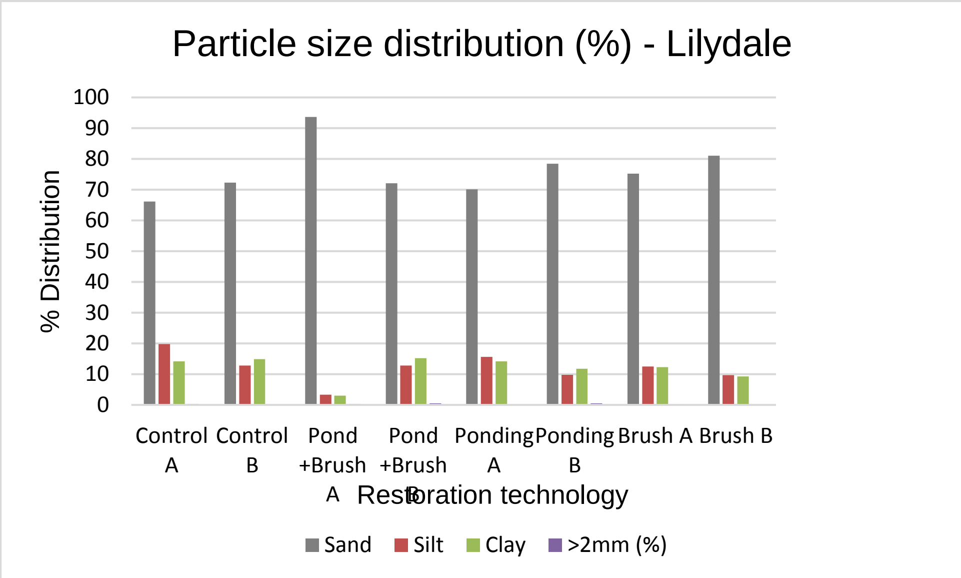

Figure 4.13: The soil particle distribution of soil in the Lilydale restoration site.

Figure 4.14 shows the soil texture chart. The black dots indicate that the soils at the Lilydale site are very sandy.

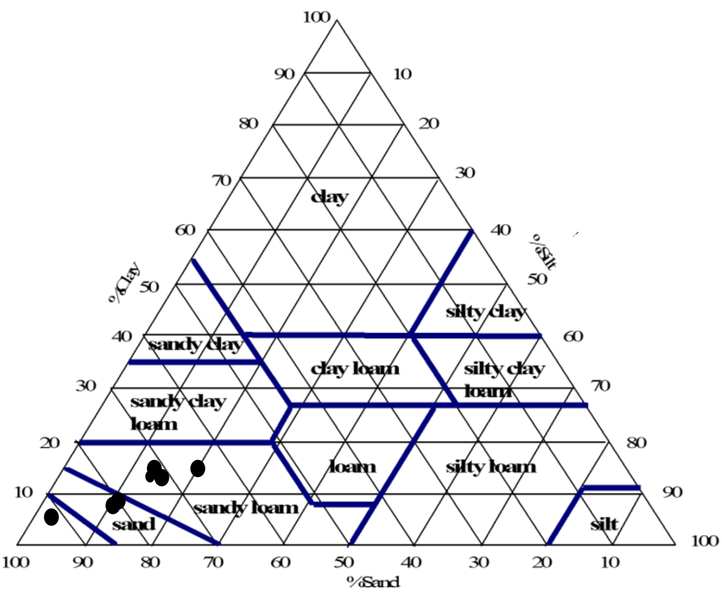

Figure 4.14: A texture chart for the analysis of soil texture (from Hillel, 2004). Black dots indicate the soil type of the Lilydale restoration site.

4.3.6 Cation exchangeable capacity

The cation exchangeable capacity (CEC) (Figure 4.15) in the Lilydale restoration site is high but it is not constant between the different restoration technologies applied. The CEC ranges between 6 and 24 cmol (+)/kg, with the highest measured in the A-horizon of the control plots (23.7 cmol (+)/kg) and the lowest in the P&B plots (6.3 cmol (+)/kg) (Figure 4.15). The CEC in all of these restoration plots shows that the soil is in a good condition, except for the P&B plots, where the very low CEC could have negative effects on the growth of plants.

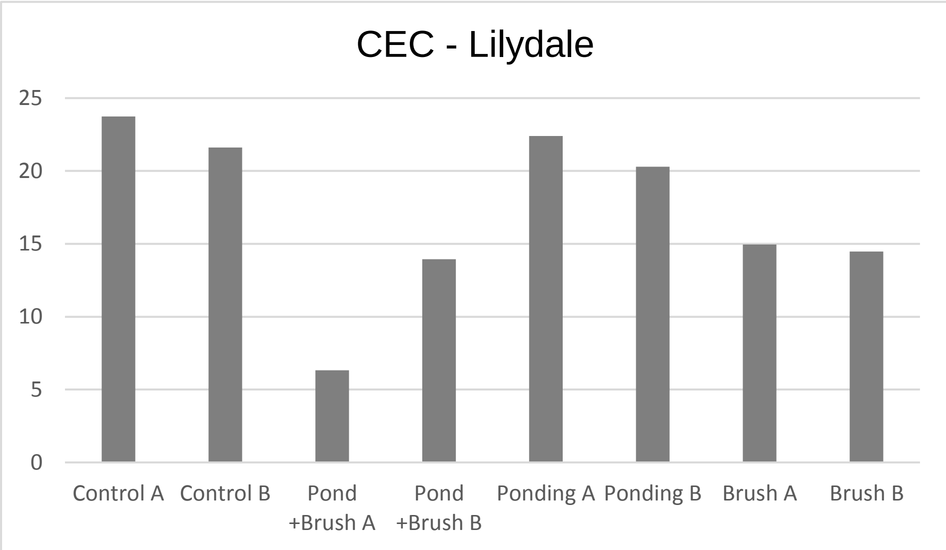

Figure 4.15: The cation exchangeable capacity of soil in the Lilydale restoration site.

4.4 Conclusion

The overall levels of nutrients in the soils for both the Doornlaagte and Lilydale restoration sites are within the standards for agriculture as described by the FSSA (2007) and the soils can be regarded to be in a condition which is typical for these types of soils according to agricultural standards. Although the scores of the nutrients differ between the A- and B-horizons and between the types of restoration technologies applied, these concentrations are not toxic or harmful to the vegetation growth. The soils in the different restoration sites have high concentrations of Ca and Mg, making the soils very alkaline. It could be ascribed to the low precipitation that occurred, especially in the second year of the study, decreasing the leaching of the nutrient to lower soil concentrations. The nutrient concentrations differ slightly between the plots where the restoration technologies were applied and the control plots.

The soils at both the Doornlaagte and Lilydale restoration sites are also very sandy with low amounts of clay and silt. In the P&B and ponding technologies the soil was loosened to build the ponding walls. This definitely influenced the chemical composition of especially the A- and B-horizons in these plots. These results also indicate that more soil samples need to be taken over a longer time span to determine the effect of the soil conditions at the different restoration sites.

Other factors could have caused the degradation at both the sites including aspects such as overgrazing by especially livestock, as the Mokala National Park was a cattle farming area before proclaimed as a national park. The Lilydale site was near old watering sites where high concentrations of livestock occurred previously and the Doornlaagte site is situated between two stony ridges on a slight slope near the river, where overgrazing by livestock was high, contributing to the degradation and increasing erosion. The high amounts of the fine sand particles are also easily compacted by the cattle grazing and movement, contributing to the degradation of these areas.

Chapter 5 Vegetation dynamics at the Doornlaagte and Lilydale restoration sites

5.1 Introduction

Plants are often grouped in so-called “fertile islands” due to the accumulation and enrichment of nutrients, especially in semi-arid areas where less rainfall occurs (Garner & Steinberger, 1989; Whisenant, 1996). Whisenant (1996) further explains that these “fertile islands” affect the seedling establishment and soil characteristics of the landscape. The resources in the “fertile islands” are often higher and can be regarded as fertile patches which can promote the restoration process (Schlesinger *et al*., 1990). Such “fertile islands” and high nutrient patches where water, nutrients, organic matter and even seed are accumulated are formed when the restoration technologies include the physical construction of for example ponding structures used as a restoration technology in the MNP (Whisenant, 1996; Prach & Hobbs, 2008).

5.2 Doornlaagte

The different restoration technologies that were applied in the Doornlaagte restoration site and how they changed over the study period (2014-2016) are shown in Figure 5.1.

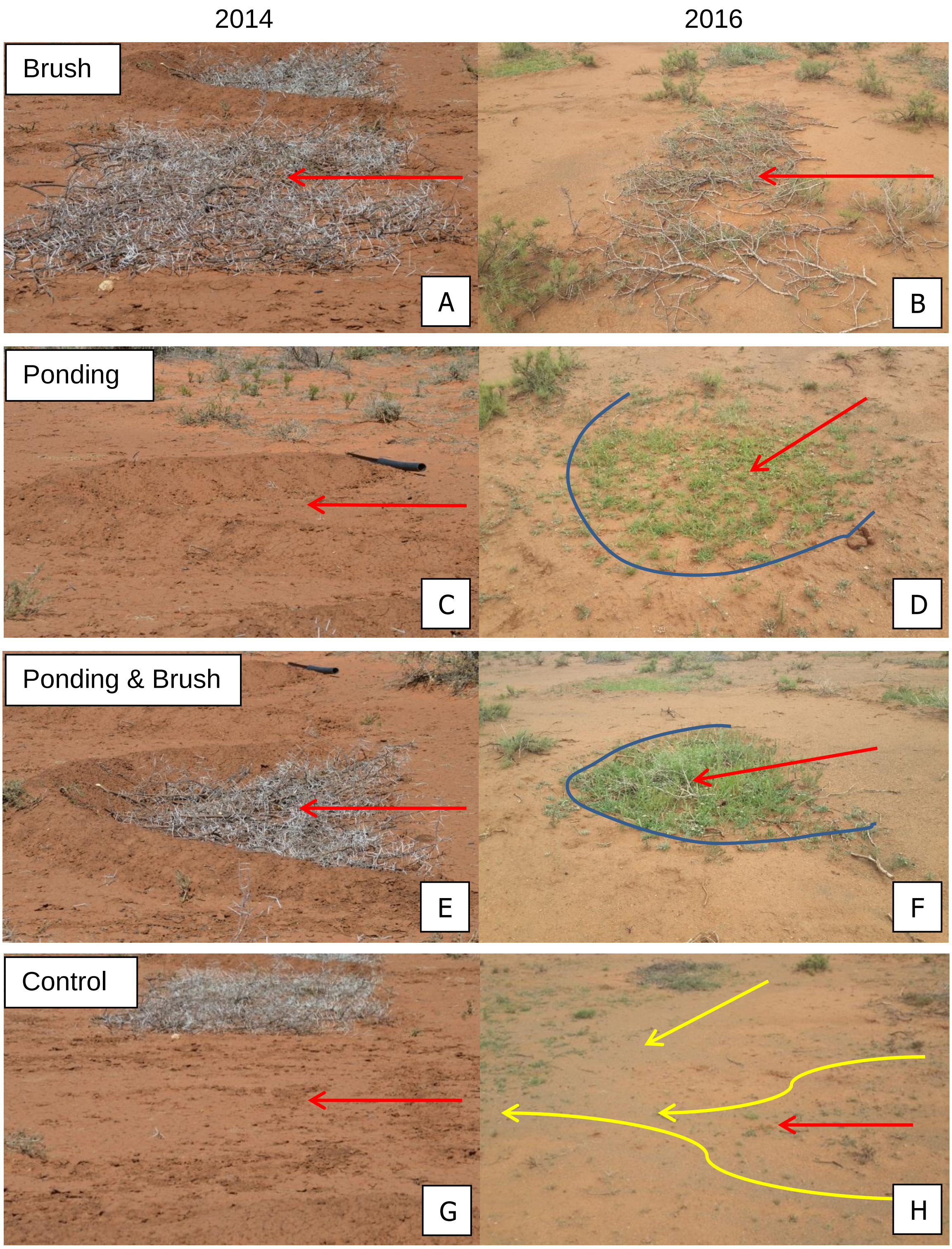

Figure 5.1: Vegetation dynamics (2014-2016) in the different restoration technology plots at the Doornlaagte restoration site. The Figures show the restoration technologies at the start of the study (2014) and at the end of the study (2016). Blue lines indicate what the structure of the ponds looked like before deterioration. Red arrows indicate the direction of water flow. Yellow arrows show where sheet erosion occurred.

- **Brush**

Figure 5.1 A (2014) and B (2016) display the brush technology that was applied in the Doornlaagte restoration site. After two years some vegetation established in the restoration plots. Facilitation by nursing objects (branches) gave the advantage that the microhabitat for the seedlings was improved (Kleier & Lambrinos, 2005; Castro *et al*., 2011) and that seedlings were protected from physical disturbances (Coop & Schoettle, 2009). The branches helped with the growth of the seedlings by forming a fertile island, as most vegetation established in the areas where the branches were packed. In the areas surrounding the brush, little or no vegetation established.

- **Ponding**

The vegetation change in the ponding technology from 2014 to 2016 can be observed in Figure 5.1 C & D. Good vegetation establishment could be seen after two years where the ponding technology had been applied. If compared to the ponding & brush (P&B) technology (see below), the vegetation established more slowly where the ponding technology was applied because no brush (branches) was available to keep seedlings from desiccating from the heat of the sun. After two years the walls of the pond structures started to deteriorate. The walls could still be recognised but were much lower after the two year period. This can be ascribed to the movement of the animals and the erosion that took place in the area.

- **Ponding & brush**

P&B also changed over the two year study period, as the walls of the ponds deteriorated and the brush decomposed or was disturbed by the animal movement (Figure 5.1, E & F). It is evident that the vegetation is much denser where P&B was applied. The branches packed in the ponds facilitated the growth of the seedlings by protecting them from damage by herbivores, as well as the high temperatures (Coop & Schoettle, 2009).

Although the walls of the ponds started to deteriorate, the ponds were still able to capture water and nutrients flowing from the landscape. The walls can be rebuilt and how it is done is discussed in chapter 7.

- **Control**

The control plots were characterised by the sites in between the areas where the restoration technologies were applied (Figure 3.4, 3.6 & 3.7, Chapter 3). Very little vegetation established in the control plots and the sheet erosion was still visible (Figure 5.1, G & H). This illustrates how important it is to apply any restoration technology if some vegetation establishment is expected.

From the subjective evaluation of the restoration technologies shown in Figure 5.1, it seems as if the P&B technology worked the best. This qualitative assessment is proved by qualitative data described below.

The above results are further supported by the results of the quadrats (section 5.2.1) and the SSB analysis (section 5.2.2).

5.2.1 Vegetation change at the Doornlaagte restoration plots

Quadrats were used to determine the density of the vegetation establishment in the different restoration technology plots. The species richness, total abundance and mean abundance of the vegetation per restoration technology were determined. An average of the number of plant individuals counted in the different restoration plots was calculated to get the mean abundance vegetation at each restoration technology. These data were compared to the SSB analysis carried out in the glasshouse at the NWU.

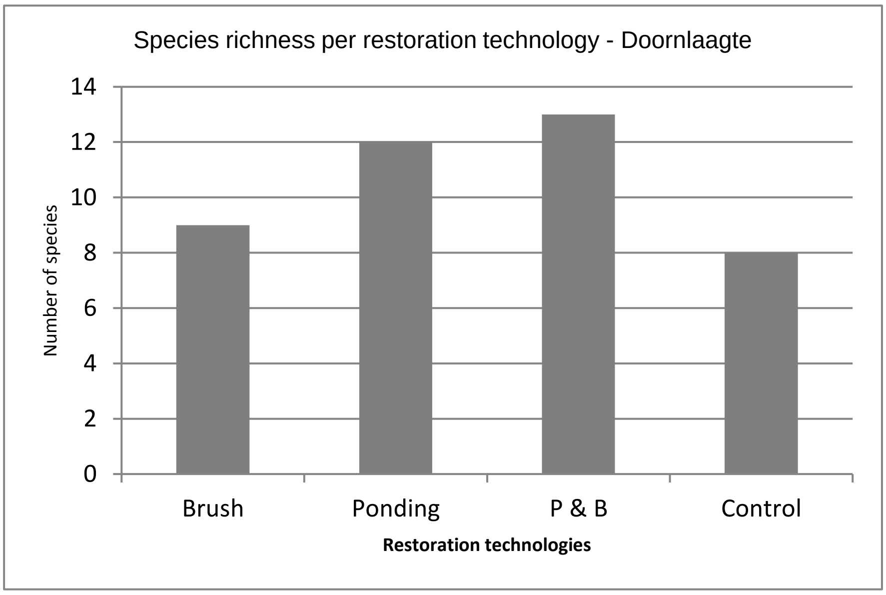

Figure 5.2: The species richness in the different restoration technologies at the Doornlaagte restoration site. (P&B = Ponding & brush).

The restoration technology with the highest species richness and highest mean plants density was the P&B technology where 13 plants species were identified and an average abundance of nearly 70 per restoration plot (Figures 5.2 & 5.3). The ponding helped with the capturing of water and nutrients and the brush cover helped to trap seed and protect the seedlings from the heat and animal disturbance. The ponding technology also provided more moisture to the seedlings. It seems that this restoration technology therefore created the best conditions for species growth. The brush technology had the lowest species richness and abundance (Figures 5.2 & 5.3) as less seed, water and nutrients were captured by the branches. The lowest species richness and abundance occurred in the control and brush plots with only 11 plants on average in the brush plots (Figures 5.2 & 5.3).

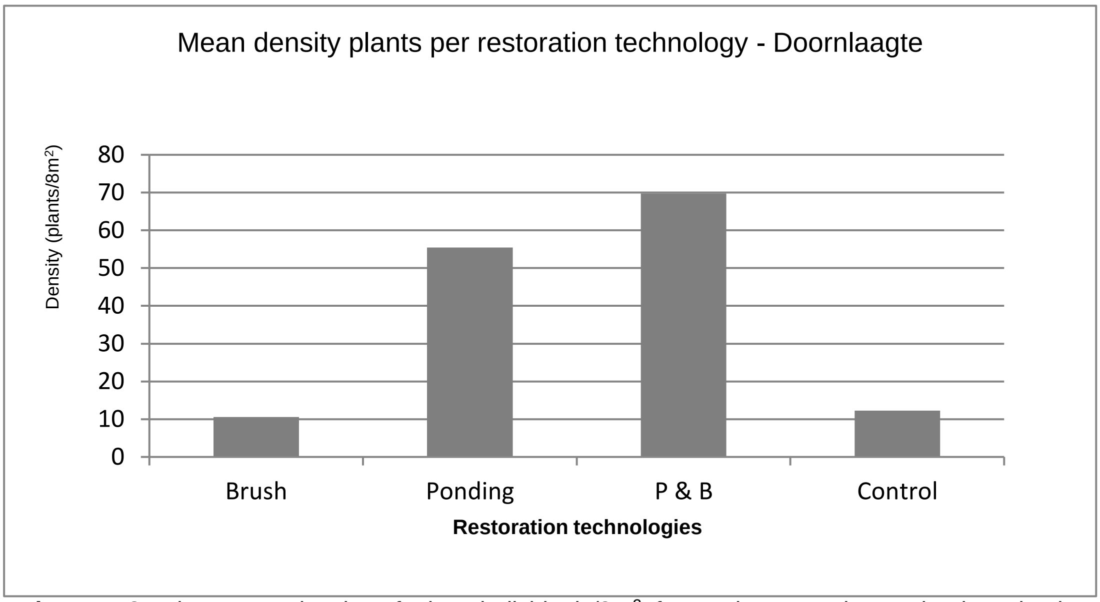

Figure 5.3: The mean density of plant individuals/8m^2 for each restoration technology in the Doornlaagte restoration site. (P&B = Ponding & brush).

5.2.2 Soil seed bank analysis (SSB) from the Doornlaagte restoration plots

An SSB analysis was conducted to see what type of species was still abundant in the soil. This analysis was conducted after the application of the restoration technologies (See Section 3.5.4 Chapter 3 where the soil sampling procedure for the SSB analysis is described).

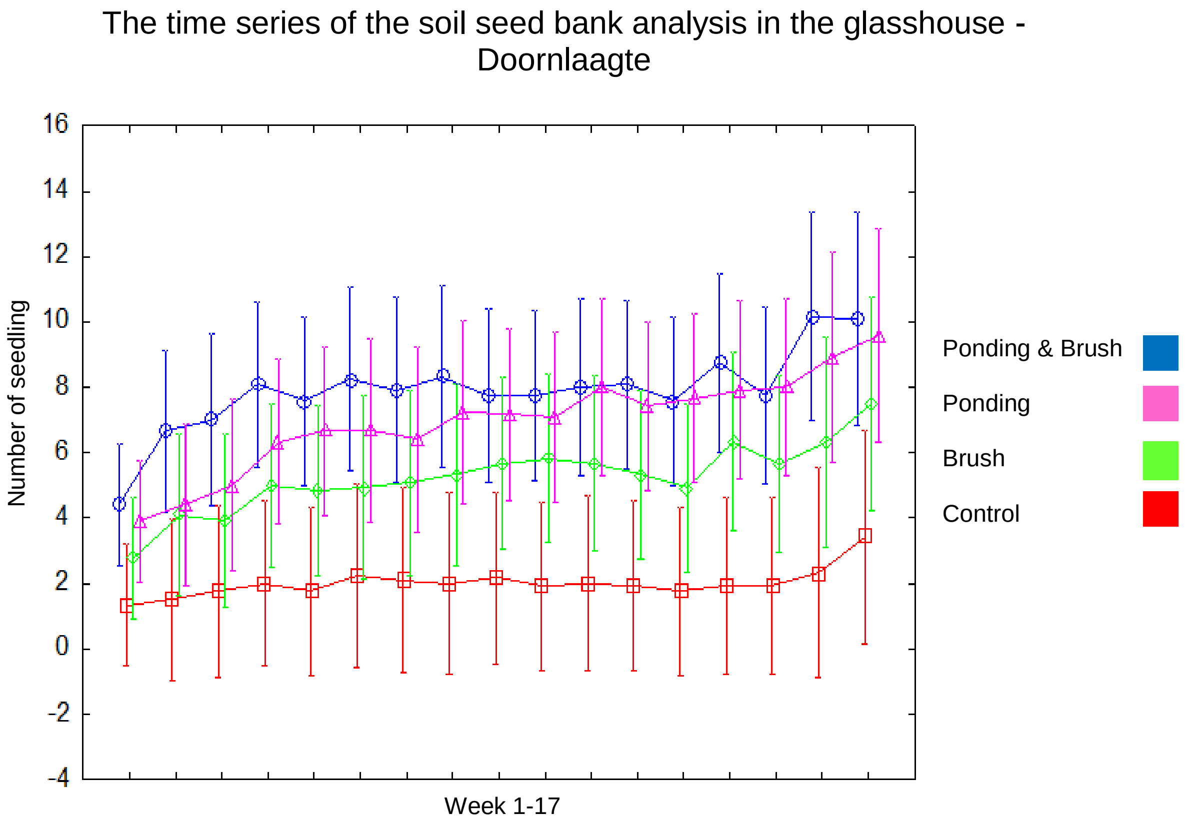

Figure 5.4: The time series of seedling emergence in the SSB analysis of species in the different restoration technologies and the control plots.

The abundance of seed that germinated over a period of 17 weeks in the soils collected at the restoration plots are shown in Figure 5.4. Most seeds were available in the soil seed bank where the P&B restoration technology had been applied while the control plots had the lowest seed abundance. The second highest seed abundance was found in the ponding restoration technology.

From the DCA ordination carried out to determine the correlation of seed in the seed bank per restoration technology applied, it is also clear that groupings can be seen between the different technologies and that there is some sort of a gradient from “ponding” to “control” (Figure 5.5). Each of the points on the graph represents the different restoration technologies for a week in the glasshouse in which the soil samples was left so that seed could germinate. The highest variance was found in the ponding technology and the lowest in the P&B technology. This means that there was a high germination rate of seed in the soil of the P&B restoration technology from the beginning to the end of the 17 weeks and that the fastest vegetation establishment occurred in the shortest period of time in the soil of this restoration technology. This supports the results found in Figures 5.2-5.4 that the most seed were captured and the most vegetation established in the P&B restoration plots.

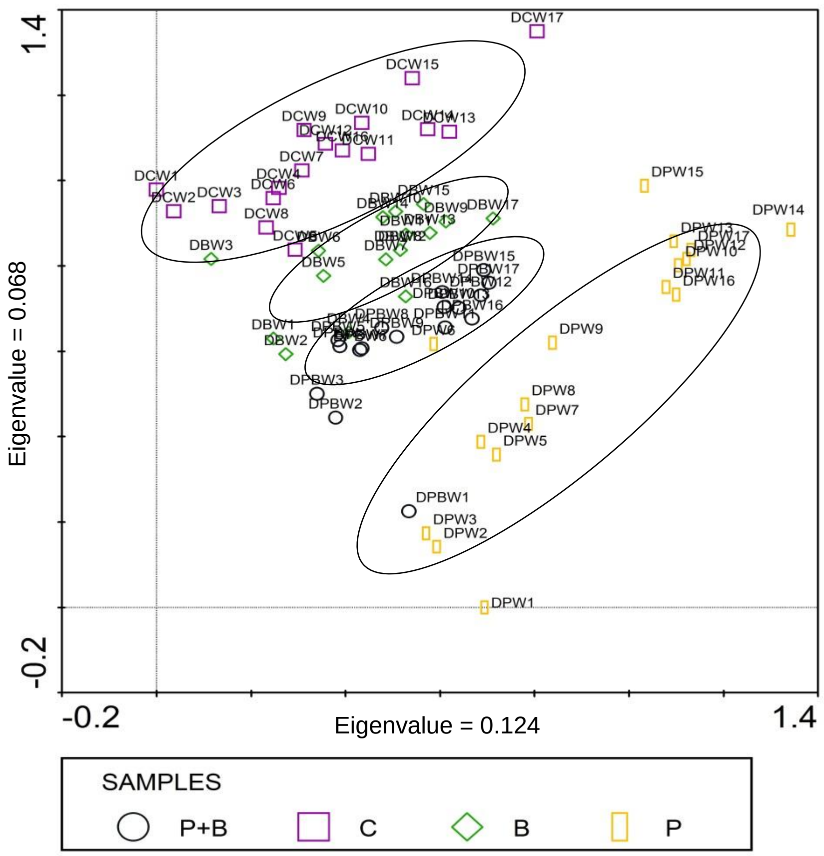

Figure 5.5: The Detrended Correspondence Analysis (DCA) of the Doornlaagte restoration site. Letters and numbers (e.g. DPBW 15) can be seen. D = Doornlaagte, P = ponding, B = brush and W = Week. The 15 is the week that the point on the graph represents.

From the results above it is evident that where the pond structures are included in the restoration technologies, the mean abundance and species richness was higher (Figures 5.2 to 5.5 and Table 5.1). The lowest species richness and abundances were at the control and brush sites. Comparison of these results to the field data supports the finding that the P&B technology performed the best of all three restoration technologies in the Doornlaagte restoration site.

5.3 Lilydale

The different restoration technologies that were applied in the Lilydale restoration site and how they changed (2014-2016) are shown in Figure 5.6.

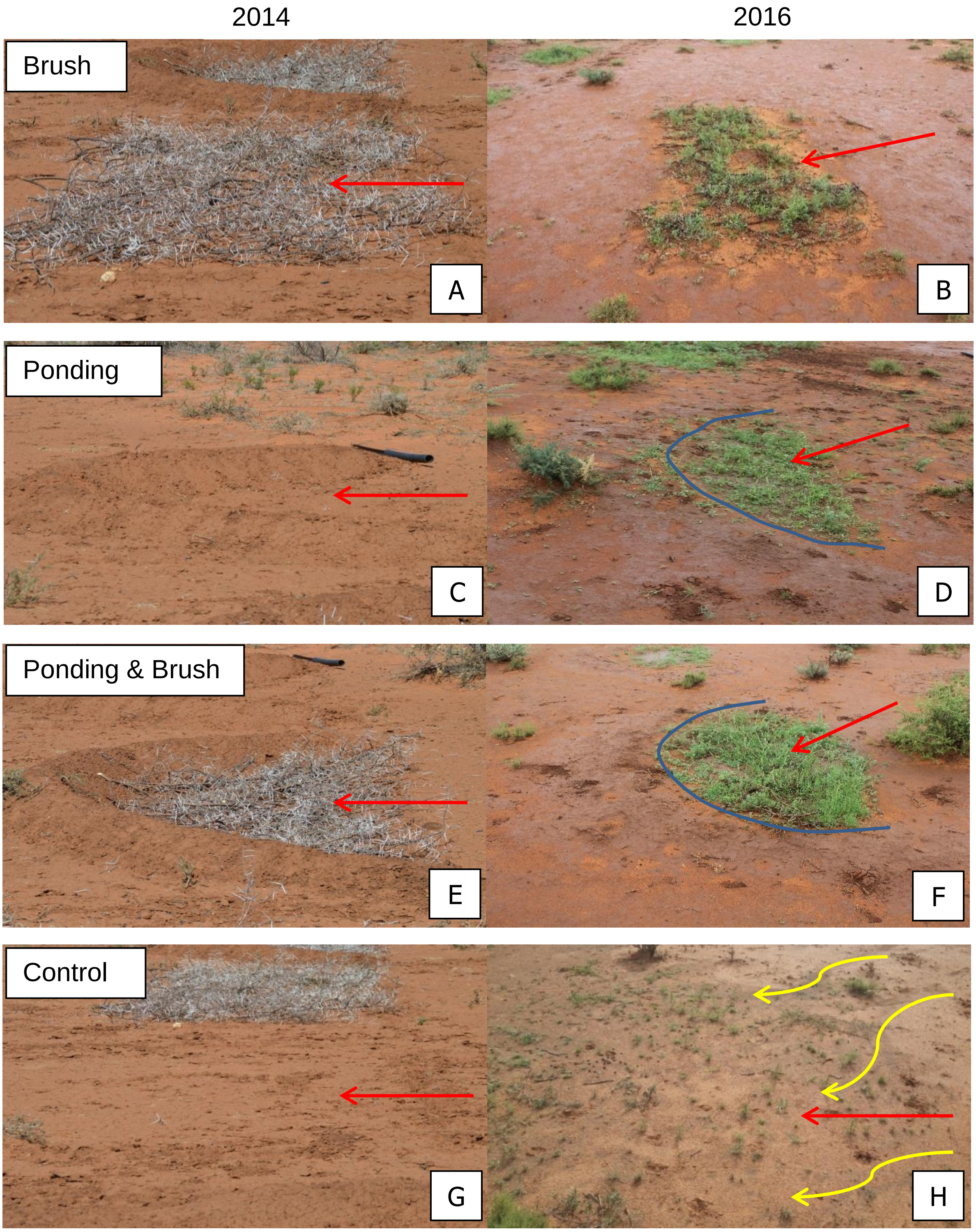

Figure 5.6: Vegetation dynamics (2014-2016) in the different restoration technology plots at the Lilydale restoration site. The photos show the restoration technologies at the start of the study (2014) and at the end of the study (2016). Blue lines indicate what the structure of the ponds looked like before deterioration. Red arrows indicate the direction of waterflow. Yellow arrows show where sheet erosion occurred.

When the figures between the Doornlaagte and Lilydale sites, where the restoration technologies were applied, i.e. brush, ponding, P&B and control, are compared, it seems that the results are very similar and the differences will therefore not be described in detail (Figure 5.6).

As for the Doornlaagte site, the best restoration technology applied at Lilydale was P&B (Figure 5.6). From visual assessment, it seems that the vegetation density is higher in areas where P&B is applied. Although the vegetation density was very low in the brush technology sites, it was higher than at the Doornlaagte site. This could be due to the fact that the Doornlaagte site was on a slope where more erosion occurred and could have caused more water run-off containing seed which were transported out of the system, while the sites at Lilydale were situated on a flat surface.

5.3.1 Vegetation change at the Lilydale restoration plots

This section describes the species richness and the mean abundance of plant individuals that were counted in theN different restoration technologies at the Lilydale restoration site.

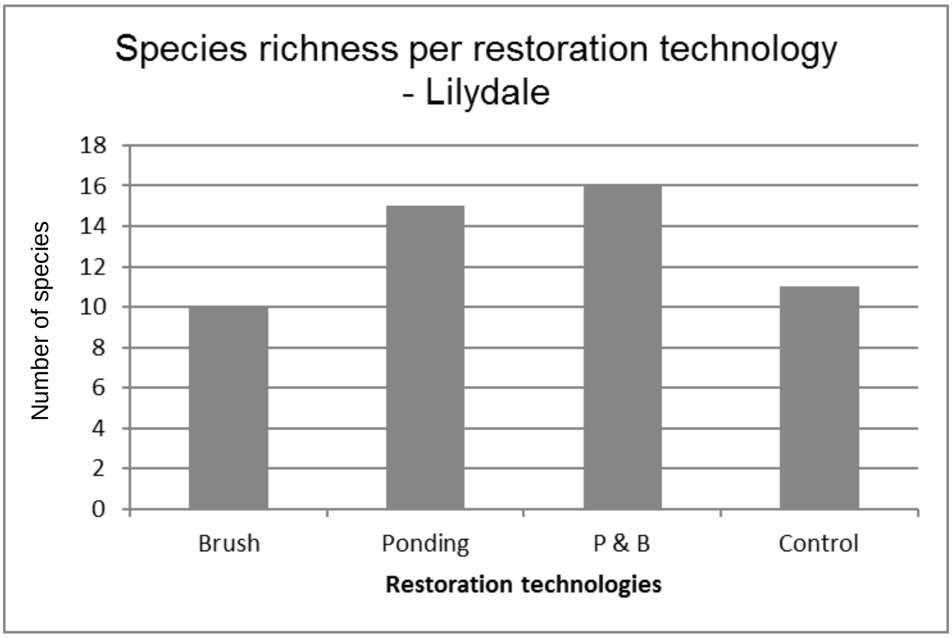

Figure 5.7: The species richness of the different restoration technologies in the Lilydale restoration site.

Although only very slightly, the species richness was higher in areas where the P&B restoration technology had been applied than for the ponding technology (Figure 5.7). A total of 16 different species were counted and identified in this restoration plot. The restoration technology with the lowest species richness was the brush technology with a total of 10 species (Figure 5.7). It seems that resources, such as water and nutrients needed for vegetation establishment was not captured by the brush cover. The brush was also destroyed by the animal movement in the area.

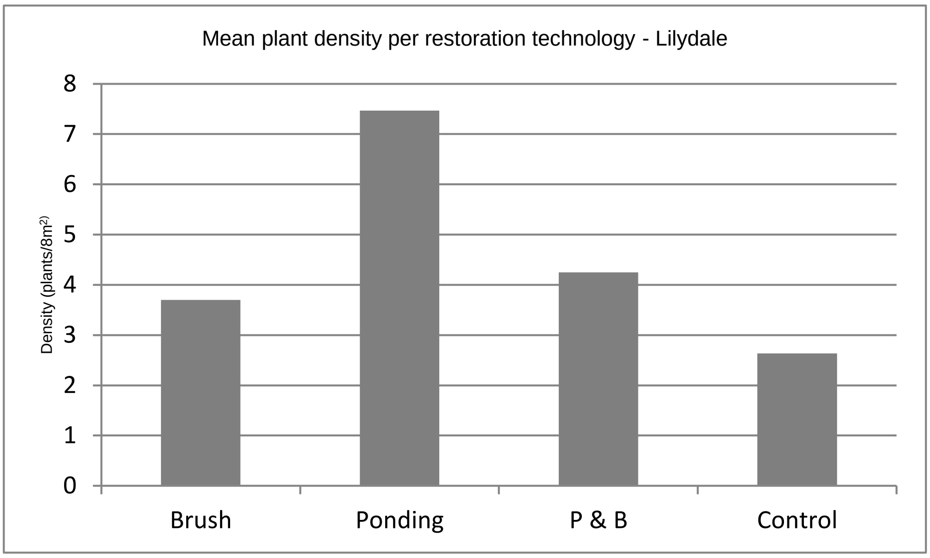

Figure 5.8: The mean density of plant individuals /8m^2 for each restoration technology in the Lilydale restoration site. (P&B = Ponding & brush).

From Figure 5.8 it is evident that the ponding restoration technology was the best regarding the mean density of plant individuals at Lilydale. The average individuals monitored throughout the whole restoration site at Lilydale was low. The mean abundance per treatment in the Lilydale restoration was much lower than in the Doornlaagte restoration site and this could be due to the movement of especially large game animals in the area that could have destroyed some of the restoration plots.

5.3.2 Soil Seed Bank (SSB) Analysis from the Lilydale restoration plots

This section describes the results obtained from the SSB analysis that was conducted for the Lilydale restoration site.

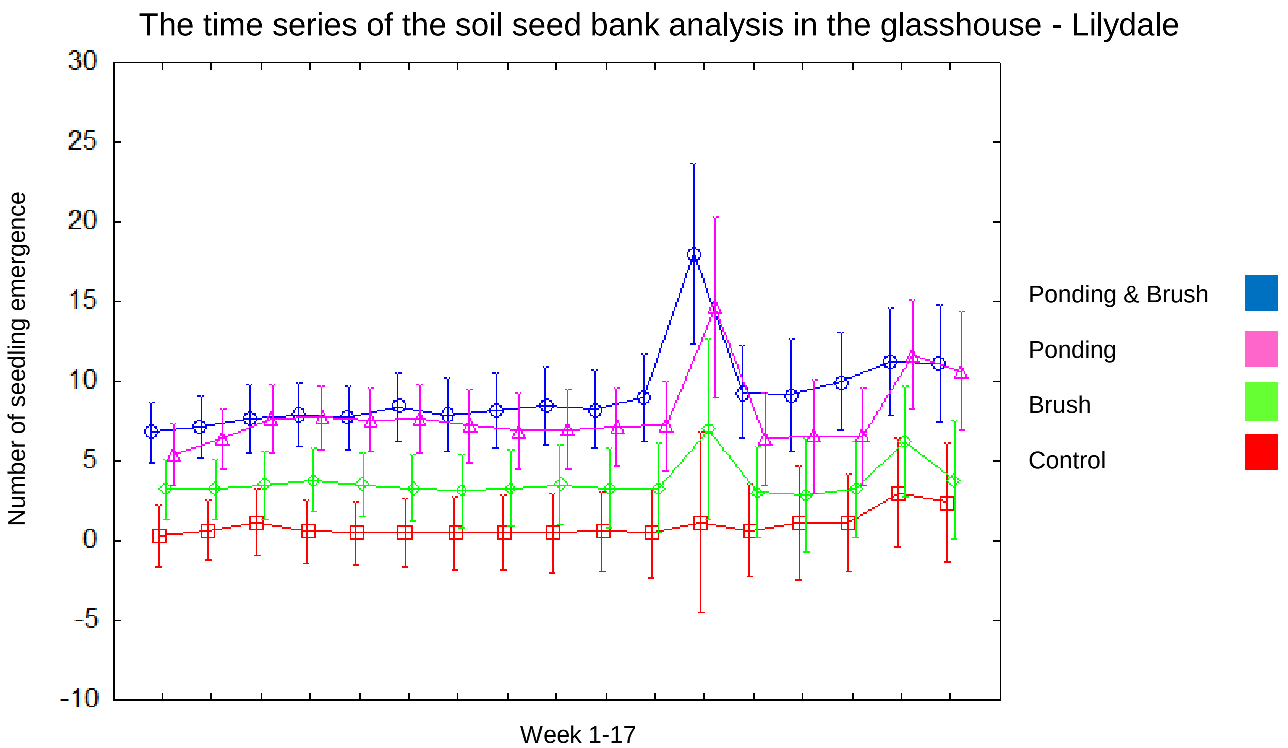

Figure 5.9: The time series of the seedling emergence in the SSB analysis of species in the different restoration technologies and the control plots.

The P&B and ponding restoration technologies had almost the same amount of seed germinating over the 17 week trial period (Figure 5.9). As for the Doornlaagte site, the control plot had the lowest seed germination abundance. Although the brush restoration technology had more seed germinating than in the control plots, this was very low, indicating that the brush trapped a few seeds. The latter can also be ascribed to the flat surface of the Lilydale site with little movement of seed by water erosion over the landscape.

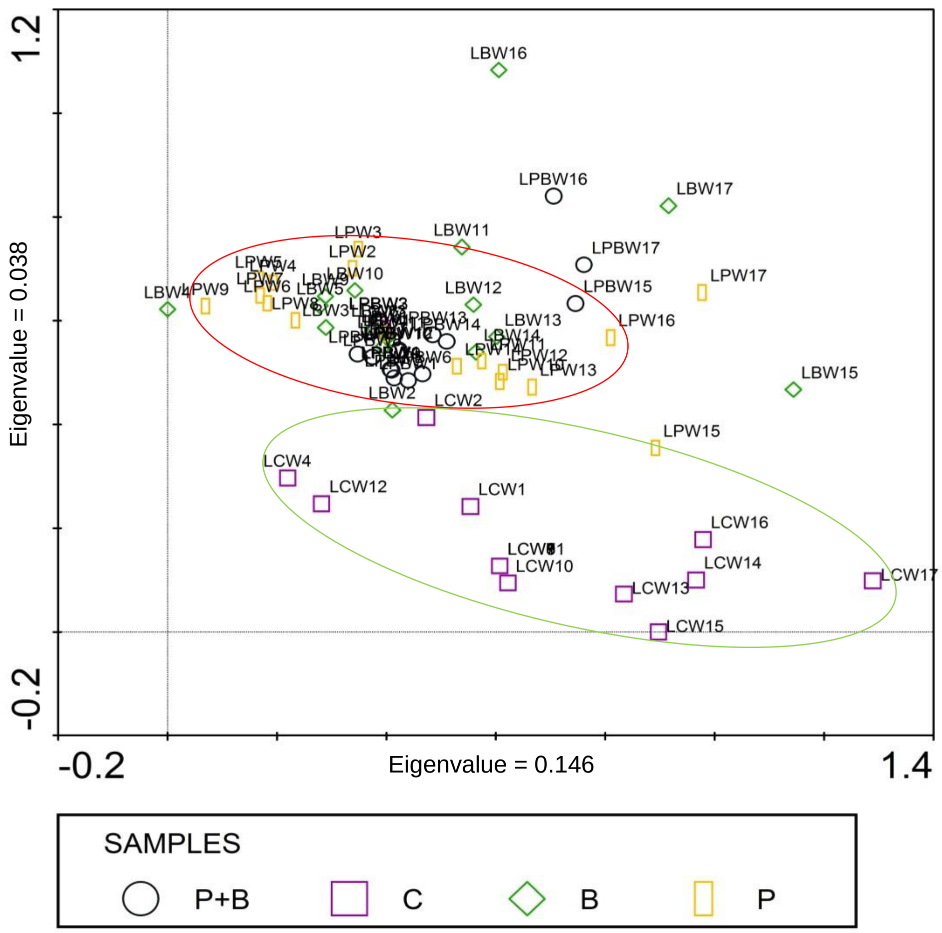

Figure 5.10: The Detrended Correspondence Analysis (DCA) of the Lilydale restoration site. Two groups formed in the graph viz. the restoration technologies (marked in red) and the control plots (marked in green). Letters and numbers (e.g. DPBW 15) can be seen. D = Doornlaagte, P = ponding, B = brush and W = Week. The 15 is the week that the point on the graph represents.

The DCA ordination only shows two distinct groups representing the abundance of seed found at the Lilydale restoration site where the restoration technologies were applied. One group clearly shows the difference between the control plots and the second group represents all the plots where active restoration was applied (Figure 5.10). A great variance occurred in the data in especially the brush only technology, as well as the control plots. It seems that the seed germination was also very low and occurred over a longer time in the control plots.

The grouping of all active restoration technologies characterise the good correlation between these plots (Figure 5.10) and vegetation establishment was also much quicker in these plots.

There was no major variance found between the different restoration technologies in the Lilydale restoration site. As there is a difference between the restoration and control plots, it seems that all restoration activities had a positive impact on the degraded area.

5.4 Synthesis between field surveys and glasshouse surveys

By comparing the field trials with the SSB analysis some correlations can be observed.

In the Doornlaagte restoration site the species richness of the P&B technology was the highest with the ponding technology second (Figure 5.2 and Table 5.1). The mean vegetation abundance where the P&B restoration technology had been applied, was also the highest (Figure 5.3). More seed was found in the P&B technology plots than in the ponding plots, similar as to what was observed in the SSB analysis. The latter could be due to the brush trapping seed through wind and water erosion.

Areas where brush or no restoration was applied (control), very little or no vegetation occurred (Figure 5.2). The abundance of vegetation found in the control plots was higher than that of the brush technology even if the species richness was lower (Figure 5.3) at the Doornlaagte site. According to the SSB analysis (Figure 5.4) the amount of seed found in the soil of the control plots was the lowest if compared to the brush technology. The higher species richness in the control plots could be due to a higher seed bank already present in these plots before the SBB analysis. The soil composition and structure did not change when the brush technology was applied, which means that it will take longer than two years to see the difference in species establishment between the brush only technology and the control plots, as restoration in rangelands are an event driven process, which may also be affected by inter-rain droughts.

In the Lilydale restoration site, the species richness was the highest where the P&B technology had been applied and the mean species abundance was the highest for the ponding technology (Figures 5.7 and Table 5.2). As for the Doornlaagte site, the highest species richness and vegetation abundance in the seed bank was where the P&B technology had been applied (Figure 5.9).

Although the P&B technology seemed to be the best restoration technology at both sites, a distinct difference could be seen between the restoration technologies at the

Doornlaagte site (Figure 5.5), but for the Lilydale site, all restoration activities grouped together (Figure 5.10). The soil parameters differed only slightly between the sites, because the topography was different from the Doornlaagte site situated at a slight slope where more erosion was expected and the Lilydale site was on a flat surface with more animal movement. This means that the restoration technologies differed between sites and have to be clearly selected according to the local landscape.

5.5 Rangeland conditions before and after application of restoration technologies at the Doornlaagte and Lilydale restoration sites

No quantitative surveys were carried out to determine the changes in rangeland condition between the two restoration sites over the two year study period (2014 – 2016). Some photos, however, depict some changes in the condition before and after restoration applications. These changes are shown by the Figures below.

From the Figures below (Figure 5.11 – 5.14), it is evident that some vegetation did establish in the former degraded, overgrazed sites at Doornlaagte and Lilydale due to the application of the restoration technologies, increasing the biodiversity and vegetation richness, cover and density. When analysing the landscape functionality data, it also seems that the sites which were previously "dysfunctional" were now more "functional" due to the soil enrichment and higher vegetation cover, even in the drought period that occurred in the 2015/2016 growing season. The breaking of the soil crust through the making of the ponds and the protection of the brush, increased the vegetation establishment at both sites. Where the soil crust was not broken (control and brush plots), the vegetation establishment was poorer. The compaction of the soil to form the soil crusts is higher in these two study areas, due to the higher animal trampling causing overgrazing and higher concentrations of Na found in the soil.

- Doornlaagte

Figure 5.11: The Doornlaagte restoration site before any restoration technologies has been applied.

Figure 5.12: The result of the Doornlaagte restoration site two years after restoration technologies was applied.

- Lilydale

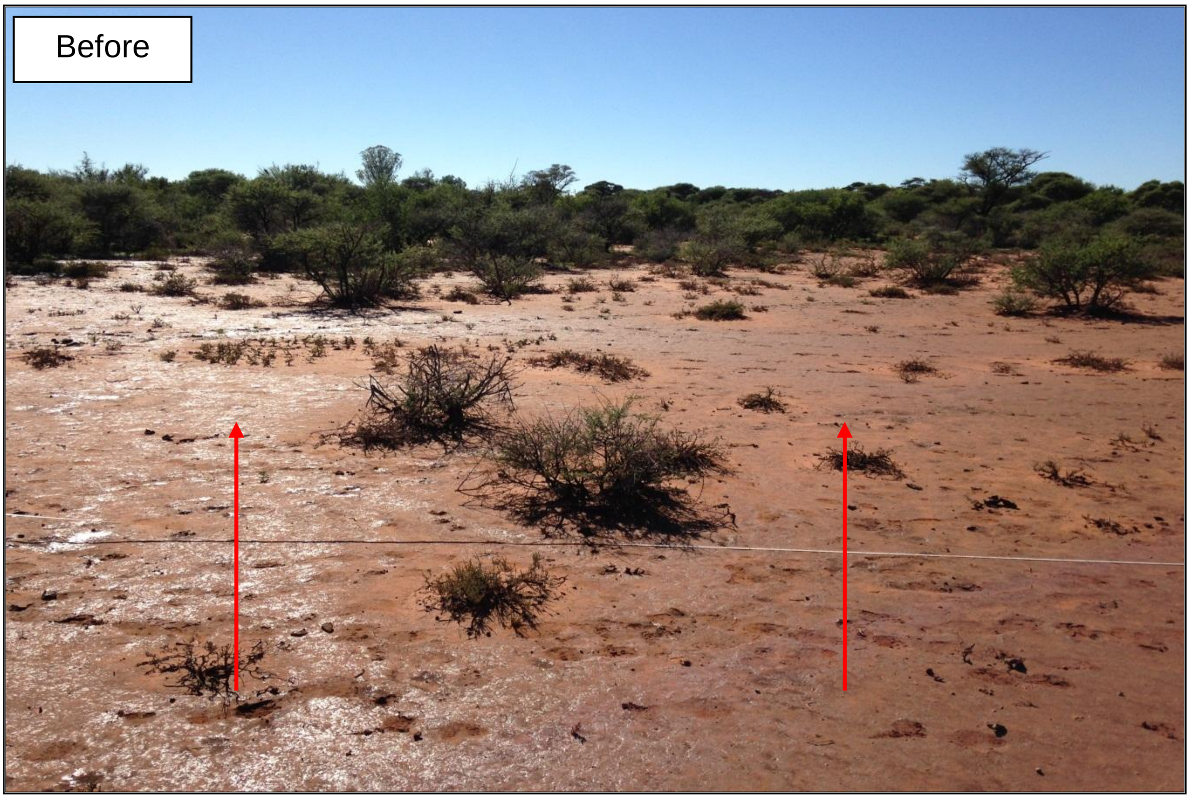

Figure 5.13: The Lilydale restoration site before any restoration technologies had been applied. Sheet erosion mostly occurred in the Lilydale restoration site. Red lines indicate waterflow.

Figure 5.14: The Lilydale restoration site at the end of the study. Red arrows indicate the waterflow direction.

From Figure 5.14, it also seems that the animal movement at the Lilydale site increased during the study period, which might be due to the higher vegetation occurrence at this site after the implementation of the restoration technologies.

Apart from the drought period, especially in the second study year, the constant movement and disturbance by the game animals could also have slowed down the restoration process.

Chapter 6 Landscape Functionality at the Doornlaagte and Lilydale restoration sites

6.1 Introduction

The Landscape Function Analysis (LFA) monitoring methodology was used to determine how the landscape functionality changed during the study period (2014 – 2016) at the Doornlaagte and Lilydale restoration sites in the MNP (Chapter 1 section 1.7 for the description of the LFA methodology). LFA transects were laid out over the whole area where the restoration technologies were applied and not per restoration plot. The changes in functionality are therefore described for the whole area where the methods were applied and not for each restoration technology separately.

6.2 Doornlaagte

This section describes the results of how the three main LFA parameters that were obtained by the Soil Surface Analysis (SSA), namely stability, nutrient cycling and infiltration, as well as the landscape organisation index (LOI) changed over time during three assessments (2014, 2015 & 2016) at the Doornlaagte restoration site. Note that the scores for the stability, nutrient cycling and infiltration are out of 100 (or percentage) and are presented as such in each figure on the Y-axis below.

6.2.1 Soil stability

Stability is defined by Tongway & Hindley (2004) as the ability of soil to resist the impact of erosive forces and to reform after a disturbance occurred.

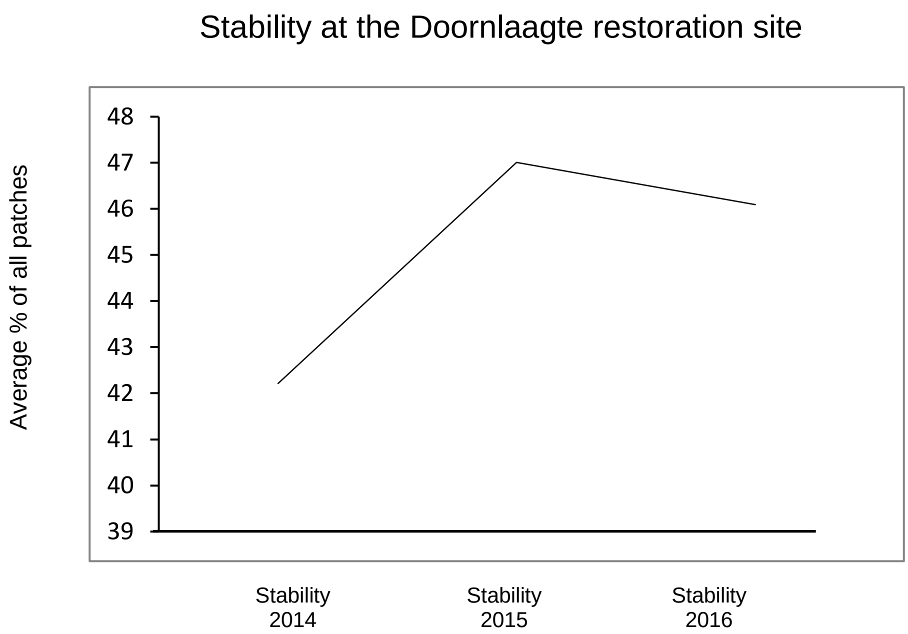

Figure 6.1: Change in soil stability from 2014 to 2016 over the whole landscape at the Doornlaagte restoration site after the restoration technologies were applied.

Although the variation in stability was very high during the 2015 survey, it did not change much from 2014 to 2016 (Figure 6.1). Higher stability values contribute to lower soil erosion and therefore less loss of resources (e.g. water and nutrients) by erosion from the landscape. Higher stability may also indicate less water infiltration and increased soil compaction which will lead to a decrease in seed germination and vegetation establishment.

6.2.2 Nutrient cycling

Nutrient cycling is defined as “how efficiently the organic matter is cycled back into the soil” (Tongway & Hindley, 2004).

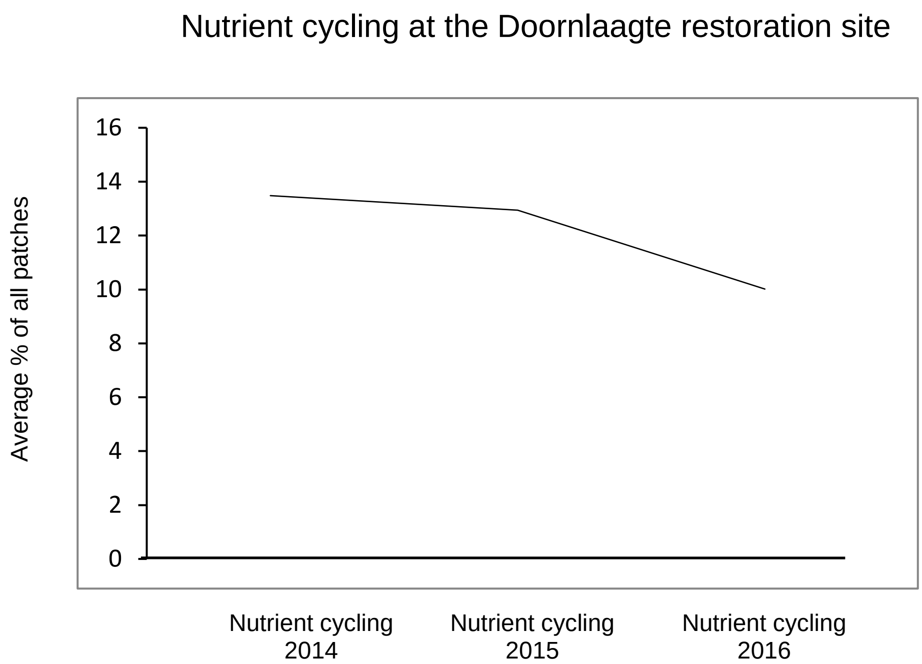

Figure 6.2: Change in nutrient cycling from 2014 to 2016 over the whole landscape at the Doornlaagte restoration site after the restoration technologies were applied.

Although the nutrient cycling value decreased slightly from 2014 to 2016, there were no major changes in this parameter from 2014 – 2016 at the Doornlaagte restoration site (Figure 6.2). This decrease could be ascribed to the very dry conditions that prevailed at the MNP from 2014 to 2016, which had a negative influence on the decomposition of the low litter cover and the growth of the few perennial plants present, as well as the low cryptogam cover. There was a great variance in the nutrient cycling data in the first two years. The decrease in nutrient cycling could also have been brought about by the fewer animals utilising the area due to the low vegetation cover, resulting in less dung being deposited.

6.2.3 Infiltration

Infiltration indicates how penetrable soil is for the infiltration of rainfall into the soil to be used by plants (Tongway & Hindley, 2004).

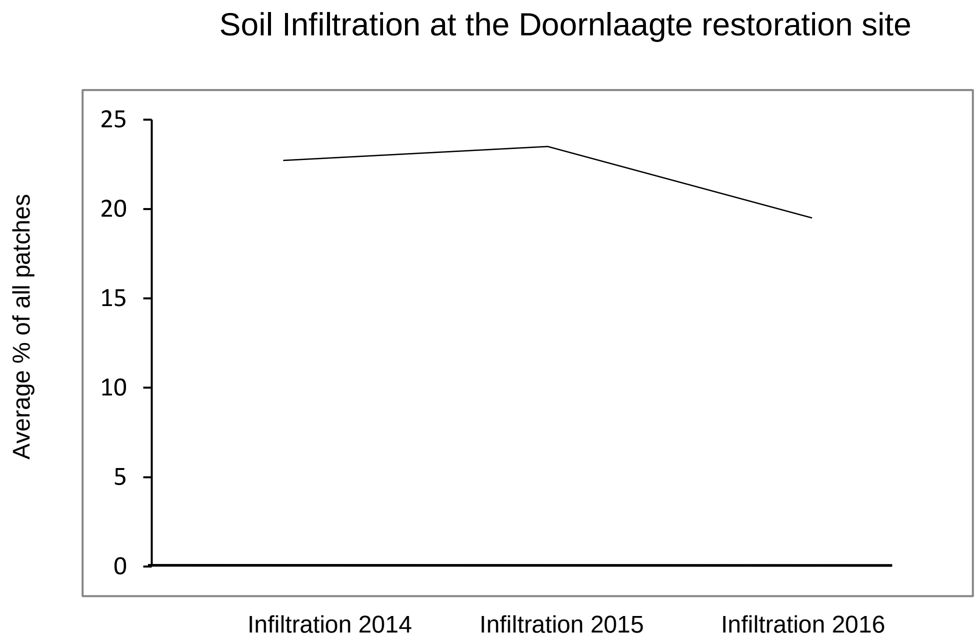

Figure 6.3: Change in the soil infiltration from 2014 to 2016 over the whole landscape at the Doornlaagte restoration site after the restoration technologies were applied.

The infiltration varied a lot within each year of the survey but did not differ much between the three years of sampling (Figure 6.3) Lower infiltration occurred in 2016 which could be due to the soil compaction caused by the heavier hoof action of animals in previous years, as well as the low rainfall in the 2015/2016 season. The latter contributed to the formation of a crust in the topsoil, decreasing the rate of infiltration. The higher concentrations of sodium (Na) and finer sand texture (see Chapter 4) may also have contributed to the increased compaction, especially in drought years. The low amounts of precipitation do not allow Na to be transported out of the system and finer soils cause higher soil compaction.

6.2.4 Total patch area cover (m^2)

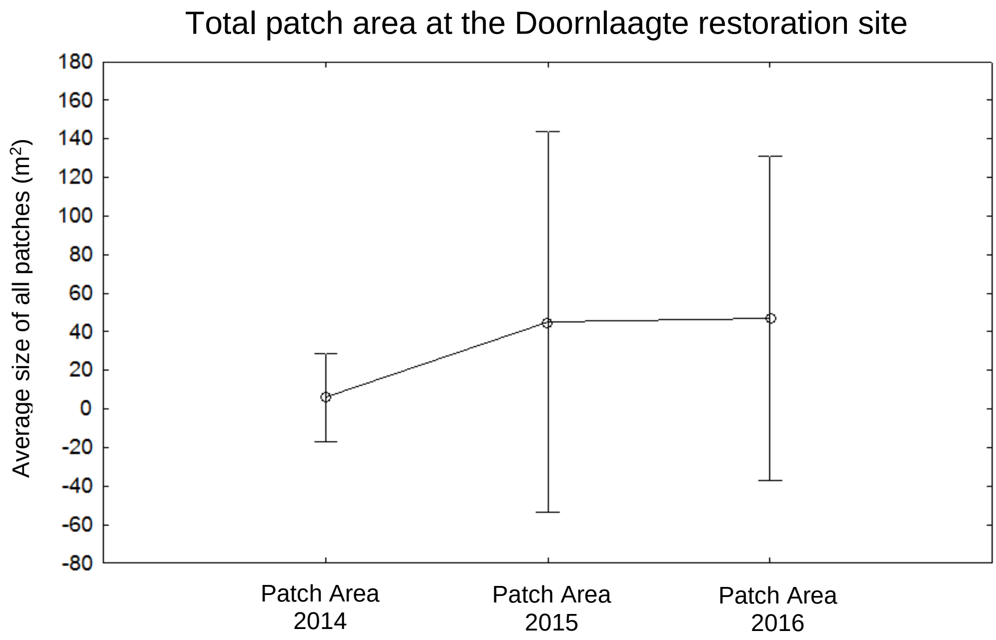

Figure 6.4: The total patch area (m^2) in the restoration site of Doornlaagte and how it changed from 2014 to 2016.

The total patch area, which is measured in square meters, is the size of all the patches combined which covers an area (Tongway & Hindley, 2004). The increase in the area of patch cover especially from 2014 to 2015 (5.8 m^2 to 44.9 m^2) could be due to the restoration technologies that were established in 2014. The plots where the restoration technologies were applied, were counted as patches which had a high contribution to the total patches in the restoration site. The increase from 2015 to 2016 was very low, since it increased with only 3.1 m^2 (Figure 6.4).

6.2.5 Landscape organisation index (LOI)

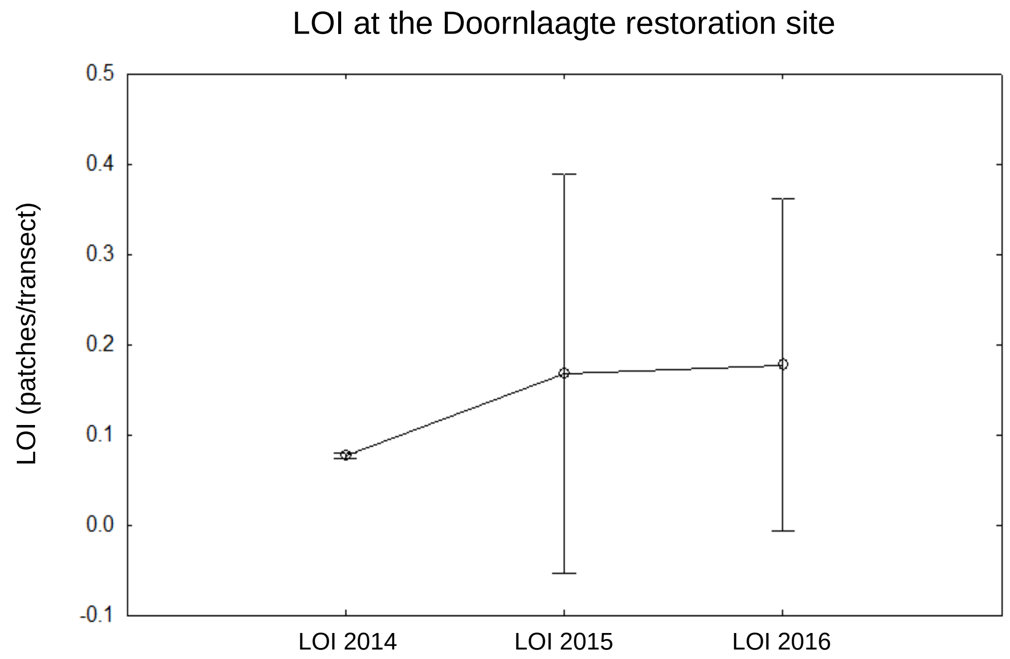

Figure 6.5: The Landscape Organization Index (LOI) of the Doornlaagte restoration site from 2014 to 2016.

The landscape organisation index (LOI) is the number of patches divided by the length of the LFA transect (Tongway & Hindley, 2004). An area which is bare will have an index of 0, but an area which is completely a patch will have an index of 1 (Tongway & Hindley, 2004).

The LOI for 2014 was only 7.1%, meaning that only 7.1% of the area was covered by patches. These patches were mainly made up of vegetation, woody material or any material that could have obstructed the flow of resources. The LOI increased from 2014 to 2015 by 16.8%, which is an increase of almost 10%. The latter can be ascribed to the establishment of the restoration technologies which resulted in patches of higher vegetation and brush cover. From 2015 to 2016 the increase was only 1.2% which could be due to the drought conditions that prevailed during that period and the establishment of less vegetation (Figure 6.5).

6.3 Lilydale

This section describes the results of how the three main LFA parameters that were sampled for the SSA and the LOI changed over time at the Lilydale restoration site.

6.3.1 Soil stability

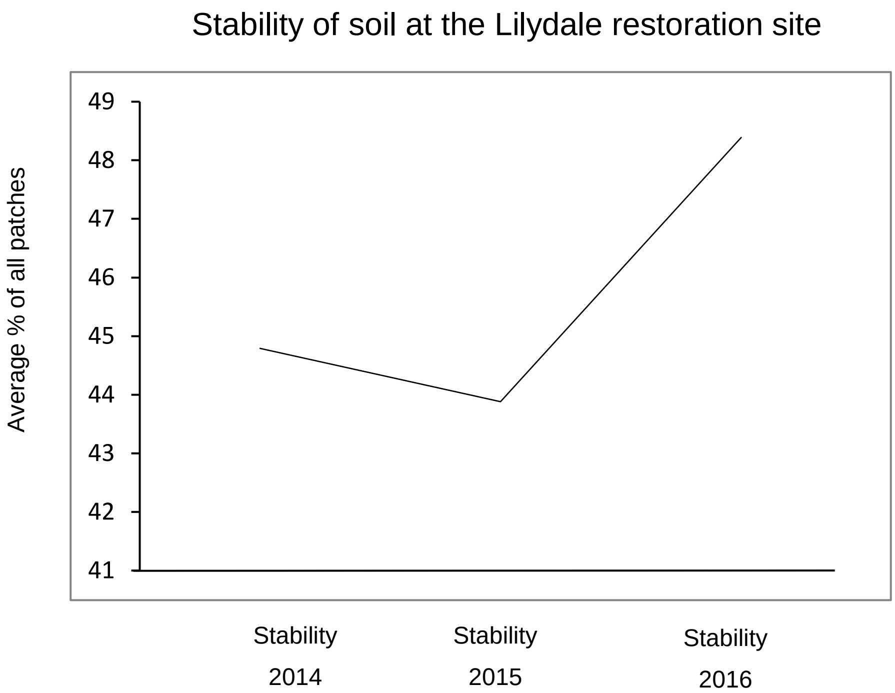

Figure 6.6: Change in soil stability from 2014 to 2016 over the whole landscape at the Lilydale restoration site after the restoration technologies were applied.

There are many indicators that contribute to the soil stability SSA parameter (see Chapter 3, Figure 3.13). The stability at the Lilydale site decreased slightly from 2014 to 2015 but then increased considerably from 2015 to 2016 (Figure 6.6). The increase from 2015 to 2016 could be ascribed to the higher soil cover due to the vegetation establishment and litter in the restoration plots. More materials were also deposited by the increased movement of game animals in the area, which could have contributed to the higher stability. The higher stability from 2015 to 2016 also contributed to less soil having been transported out of the system by erosion, especially in the restoration activities that involved the making of ponds (i.e. P&B and ponding). There was a great variance in the sampling of the soil stability for each year (Figure 6.6). This could be caused by the many changes that took place in the area due to the establishment of the restoration sites and increased animal movement.

6.3.2 Nutrient cycling

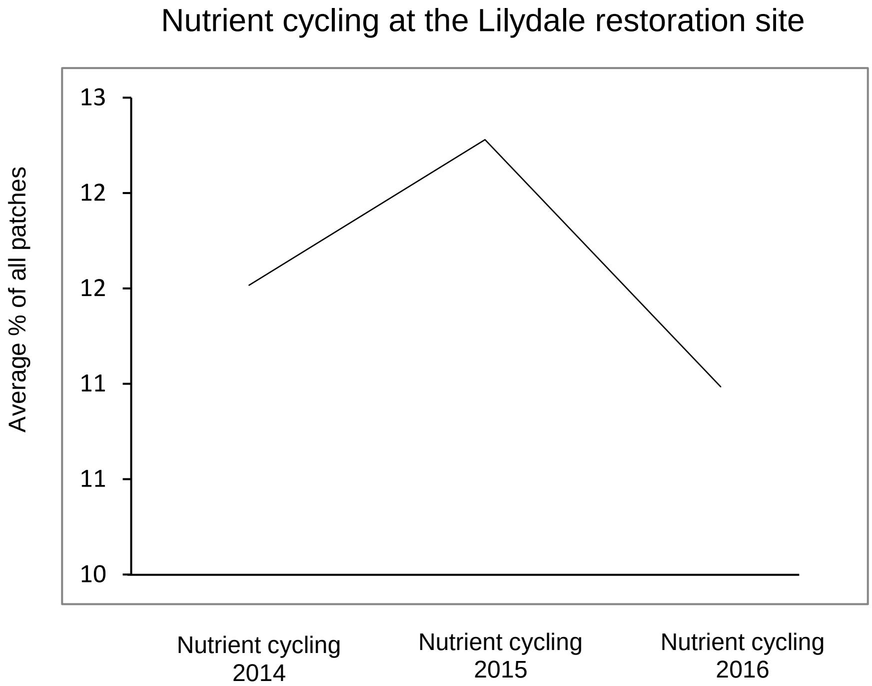

Figure 6.7: Change in nutrient cycling from 2014 to 2016 over the whole landscape at the Lilydale restoration site after the restoration technologies were applied.

As for the stability LFA parameter, the variance in sampling mainly increased in 2015 and 2016, due to the increased activities in the area (Figure 6.7). The nutrient cycling increased slightly from 2014 to 2015, after which it dropped quite considerably in the 2016 survey (Figure 6.7). The increase from 2014 to 2015 could be due to the additional vegetation (> foliage cover) that established and the brush (> litter) applications during the restoration applications. The higher amount of especially organic material could have increased the soil nutrient cycle. Notice that the nutrient cycling increased when the stability showed a decrease. Fewer nutrients were available because of the drought conditions experienced in 2015 to 2016, meaning less plant material had formed to be cycled back into the soil.

6.3.3 Infiltration

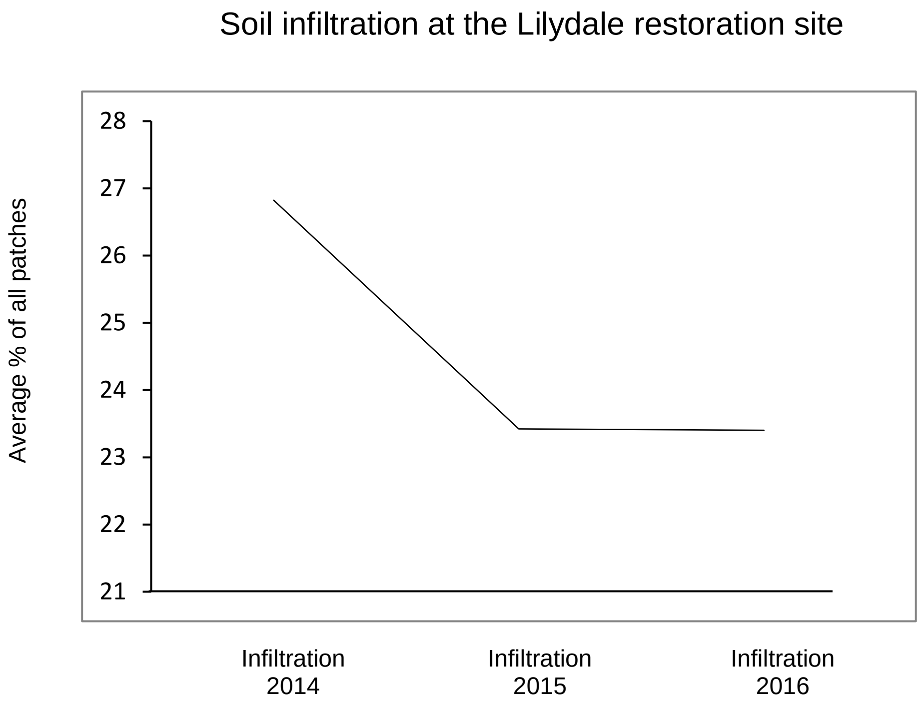

Figure 6.8: Change in the soil infiltration from 2014 to 2016 over the whole landscape at the Lilydale restoration site after the restoration technologies were applied.

A great variance was found in the data when considering the sampling of the infiltration parameter between the three years (Figure 6.8). The soil infiltration decreased from 2014 to 2015 and increased slightly from 2015 to 2016. The infiltration of the soil could have declined because of high amounts of salt which could have contributed to the soil compaction, as well as the increased movement of the animals (Zhao *et al*., 2007). The low precipitation rate in the 2015/2016 season also did not allow for Na to leach from the soil which could have contributed to the higher soil compaction. The infiltration in the soil declined as the soil stability increased which could be due to the higher soil compaction.

6.3.4 Total patch area (m^2)

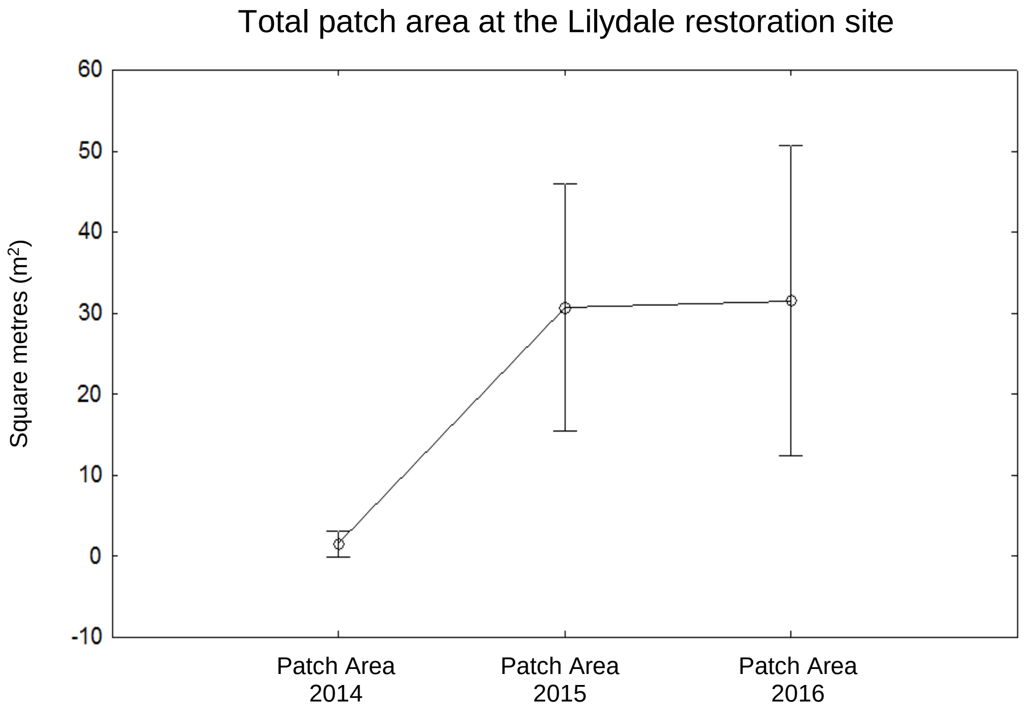

Figure 6.9: The total patch area (m^2) in the restoration site of Lilydale and how it changed from 2014 to 2016.

The total patch area of the restored landscape at the Lilydale study site increased considerably from 2014 to 2015, namely 1.5 m^2 to more than 30.7 m^2 respectively (Figure 6.9). This increase could be due to the establishment of the restoration technologies which were counted as patches and therefore had a major contribution to the total patch area. From 2015 to 2016 the total patch area was quite constant (30.7m^2 to 31.5m^2) and this could be because no more restoration technologies were added and not much change occurred due to the dry season that was experienced with less vegetation established.

6.3.5 Landscape organisation index (LOI)

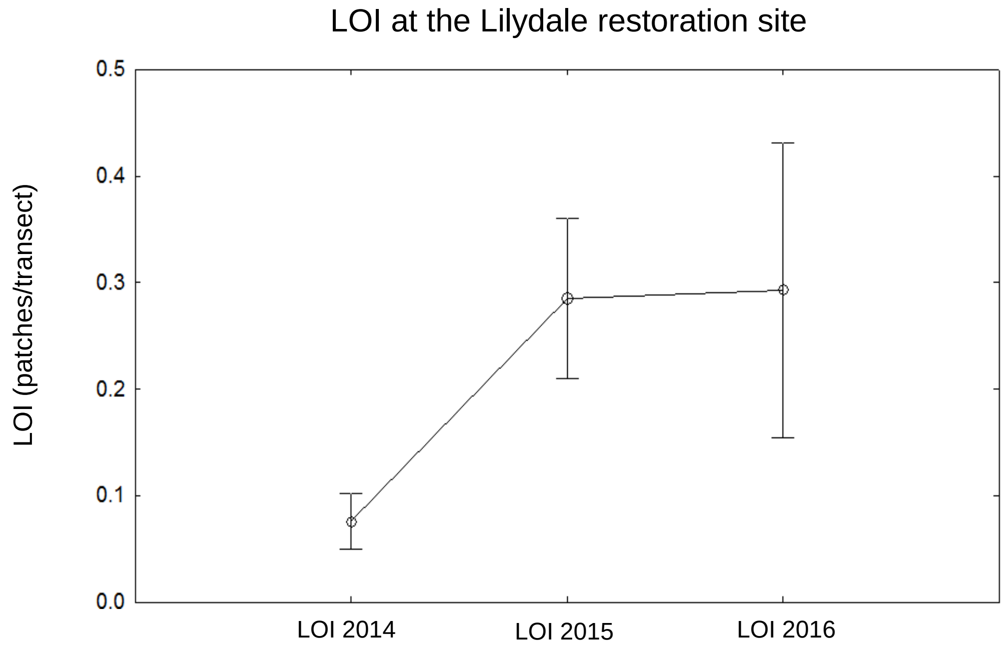

Figure 6.10: The Landscape Organization Index (LOI) of the Lilydale restoration site from 2014 to 2016.

The LOI at the Lilydale restoration site increased considerably from 2014 to 2015, namely 7.6% to 28.5% respectively (Figure 6.10). This 21% increase could be ascribed to the restoration activities that took place in that year, such as the making of ponds and brush pack which contributed to the higher moisture availability and vegetation growth. There was an increase of only 1% from 2015 to 2016 (Figure 6.10) which could be due to the already established restoration plots, as well as the drought period experienced in that season causing less vegetation to grow.

6.4 Conclusion

From the above results and considering the three main SSA parameters (nutrient cycling, stability and infiltration) that were measured by the LFA monitoring methodology, it is evident that there is considerable variation between the parameters and the two restoration sites of Lilydale and Doornlaagte. Overall it seems that the functionality increased at both sites after the application of the restoration technologies, but that more long-term data and more surveys are needed. The results were also influenced by the movement of the animals, which was more at Lilydale than at Doornlaagte, especially in the drought season of 2015/2016. The soil parameters, especially the higher Na concentrations at both sites and the very little rain that occurred from 2015 to 2016 could also have had a negative influence on the results. However, the results serve as a reference for further and long-term monitoring to assess if the restoration activities did have a positive influence in the landscape functionality over time.

Chapter 7 Conclusion and recommendations

7.1 Introduction

Although the results of this study do serve as a background to assess how effective the implementation of different restoration technologies are at two sites in the MNP, more data over a longer time period are necessary. The low rainfall in the second season (2015/16) also considerably influenced the assessment of the different types of restoration.

The degradation and soil physical crust formation by overgrazing and specific soil parameters in the denuded areas at the Lilydale and Doornlaagte study sites was not properly addressed when looking at the data and results of the brush technology and control plots. It seems that the degradation problem was, however, addressed in areas where ponding technologies were applied, such as the ponding and the P&B restoration activities. The physical soil crust which was formed was broken, promoting the soil moisture and contributing to the increased vegetation establishment. The soil seed bank was also higher in these plots, which could be ascribed to the loosening of the soil and the higher plant diversity caused by these technologies.

The first objective of the study was to monitor and evaluate the effectiveness of the three restoration technologies applied in identified degraded areas of the MNP. The restoration technology which contributed the most to the plant species diversity of the Doornlaagte restoration site was the P&B technology because it had the highest species richness in both the field trials and SSB analysis. Although the brush technology contributed the least to address the degradation problem at first, it did improve the plant biodiversity to some extent over the two year period, as the results obtained were better than where no restoration had been applied (control plots). At the Lilydale restoration site the P&B technology contributed the most to the plant species diversity but the ponding technology had the greatest vegetation abundance and therefore addressed the degradation problem best. The control plots showed a higher species richness than the brush technology. The brush plots, however, had a higher vegetation abundance than the control plots. This shows that using the brush had more impact on the soil than just leaving the soil for a passive restoration approach.

The second objective of the study was to determine the relationship between the functionality of the landscape, species diversity and soil properties. Most vegetation establishment occurred in the restoration plots that involved the making of ponds, as the physical soil crust was disturbed through this activity. The latter promoted water infiltration, the soil properties and increased the plant establishment (higher species richness) and plant diversity which on the other hand created more patches and increased the LOI and therefore had a positive effect on the functionality of the landscape. Although the ponding improved plant establishment which was available for the grazing animals, these sites were protected by the brush of the woody material with spines. The P&B technology can therefore be regarded as the best restoration technology for the two degraded sites at the MNP.

The hypothesis which was that selected restoration technologies can be effectively implemented to restore selected degraded areas and increase the rangeland condition and biodiversity of degraded areas in the MNP can be accepted. The restored area should be rested and disturbance by animals should be limited. In areas where farms are located, areas such as these can be fenced off but since MNP is a national park with game, no fences can be erected.

The results obtained from this study will surely help to reach the third objective of the study to provide advice to managers and policy makers at SANParks regarding the best restoration technology to be used in similar degraded areas.

7.2 Recommendations

7.2.1 How to re-slope the ponding walls

The walls of the “half-moon” ponding structures in the ponding and P&B restoration technologies started to deteriorate after a period of two years. For better water and nutrient retention, it is therefore recommended that the walls of the ponding structures be maintained and be re-shaped after two years. The re-shaping and re-building of the walls does not have to be from soil in the pond itself, especially if some vegetation has already established in the “half-moon hollow”, but can be from the soil next to the pond (Figure 7.1). These areas include areas 2 and 3 as shown in Figure 7.1. If no or very little vegetation is already established in the “half-moon hollow”, then the soil can also be used from area 1, where some nutrients and seed already occur. Fertile islands can thereby be created which will contribute to the restoration of degraded areas in the long term. Soil taken from area 3 (Figure 7.1) will be most suitable, as this area will have low nutrient concentrations and seeds captured as they are behind the previously constructed pond wall. The size of the ponds should not be too small either. The size as constructed for this study, namely 2 m wide and 4 m long is the minimum size for a pond, as it will enhance the collection of resources (water and nutrients), especially on a down-slope topography. The ponds should also be staggered so that the resources can flow from one pond to the next (see Figures 3.4, 3.6 & 3.7). The ponding wall should not exceed a height of 30 cm.

The ponds should also be constructed close to each other not to allow too much erosion and to decrease the velocity of water run-off.

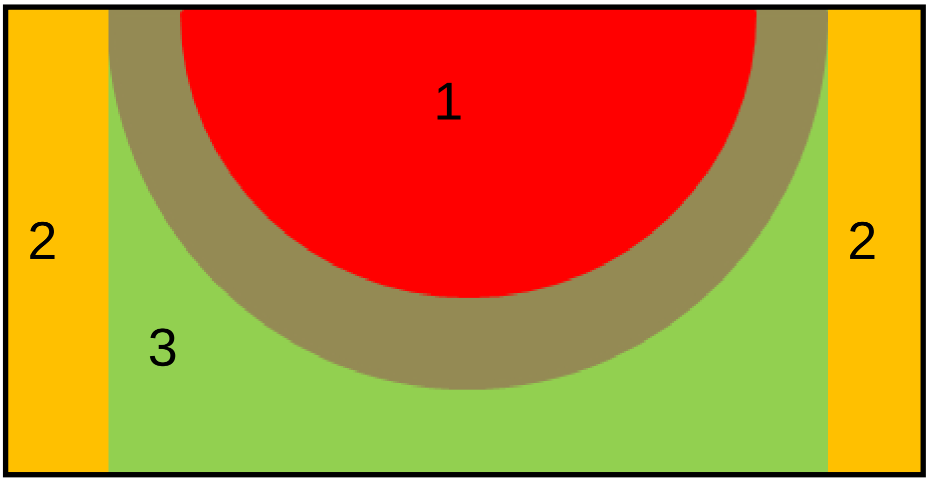

Figure 7.1: Areas around the ponding structure indicating where soil should and should not be collected. 1 = where most vegetation establish in the pond. 2 = where water flows past the restoration technologies. 3 = area where soil can be collected to rebuild pond wall. Blue arrows indicate waterflow.

The brush technology can be incorporated with the ponding technology. The brush (woody branches with spines) can be packed (area 2 – Figure 7.1) between restoration plots, especially in areas where animal movement may destroy the ponding structures and in restoration areas that are not protected by fences. The brush does not stop the water from flowing through an area but it will keep animals from moving through the area and prevent them from grazing on seedlings established in the restoration plots. The latter technique will, however, need much more material and labour and might increase the restoration costs.

7.2.2 The use of different restoration technologies

The three restoration technologies are not suitable for all degraded areas. The brush technology should be used in areas where surfaces are flat and the velocity of the water run- off is lower. The brush should be packed denser and twigs should have a diameter of 30mm to be more effective especially on sloped areas and should be packed to a height of 300mm. This technology can be used best in areas where water accumulates naturally, for example in areas where there already are depressions. The ponding and the P&B technologies can be applied in areas that have a slope and where water and resources can flow downwards. To break the velocity of the water, the ponding will have to be constructed closer to one another as explained above. After the application of all the restoration technologies, water availability in the soil can be determined by using a theta probe.

7.3 Vegetation and soil surveys

7.3.1 Soil analysis

The soil analysis of both the restoration sites was carried out a year after the establishment of the restoration technologies in 2015. Considering the standards of cultivated agricultural land which are currently available, the nutrient status of the soils were good (FSSA, 2007). The high Na concentrations could, however, cause a problem and lead to increased soil compaction. Soil analysis will have to be conducted in analogue sites as well, to compare it with the soils of the restoration sites. If no analogue sites are available, soil analysis should be done before any restoration technologies are applied. More soil sampling over a longer period is also recommended to assess the impact of the restoration technologies over time. Soil analysis should also be carried out after a good rainy season and not only in periods of drought. This will provide data regarding the leaching of nutrients in the soil profile, especially where Na is accumulated.

7.3.2 Vegetation sampling

The quadrat (0.5 m X 0.5 m) vegetation sampling technique that was used to determine the species richness and density in the restoration plots seems to be the most useful technique. It is, however, recommended that the sampling be carried out over longer periods of time and if possible include dry and wet seasons, as this will provide better data about the establishment of annual and perennial species. Over time pioneer and annual plant species will be outcompeted by perennial species causing a change in the species composition and forming a more stable vegetation cover. The use of more quadrats will also improve the dataset and provide better results, especially if the landscape functionality, which includes the sampling of perennial plants and the abundance thereof, has to be assessed over time.

Ludwig & Tongway (1996) developed a method to assess the survival and establishment of individual plants. This is done by mapping the location of each plant as it is a good indicator for biodiversity assessment and ecological development over time (Ludwig & Tongway, 1996).

7.3.3 Soil Seed Bank Analysis (SSB)

The SSB analysis was only carried out once and mainly after the drought period. It is recommended that the SSB analysis be carried out at least twice after a good rainy season, as it should include seeds from plants that established when soil moisture was more abundant and has been transported to the restoration sites. The once-off SSB analysis may be a problem to assess the impact of the restoration technology over time, as the minimum amount of seed transportation during the short study period and only low amounts of water run-off occurred. Samples can be taken at more restoration plots to have a better representative indication of seed that is available in the restoration site. The increase in the SSB should be measured before and after the application of the restoration technologies.

7.3.4 Landscape Function Analysis (LFA) methodology

In this study the LFA monitoring methodology was carried out over the three year study period, namely before and after the restoration applications. The 11 SSA indicators were used to determine the three main parameters (nutrient cycling, stability and infiltration) that are used to determine the landscape functionality. The data were used to assess if there was a change in the landscape functionality over time. One of the main problems was that no SSA was carried out in an analogue site for better comparison. Analogue site data should be considered in the future for better comparison and to assess the impact of the restoration technologies regarding landscape functionality. More LFA’s should also be carried out over a longer time period that include wet and dry seasons to determine changes in landscape functionality.

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