

Vegetation establishment and functionality on kimberlite tailings in the afro-alpine zone of Lesotho

B Meyer
22782583

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Supervisor: Prof SJ Siebert

Co-supervisor: Mr P Ayres

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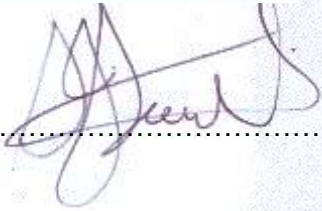
Declaration

I declare that the work presented in this Masters dissertation is my own work, that it has not been submitted for any degree or examination at any other university, and that all the sources I have used or quoted have been acknowledged by complete reference.

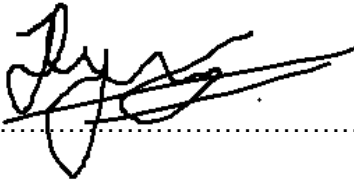
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ABSTRACT

Mining activities can have severe negative impacts on the natural environment. It is therefore important for mines to develop and implement mitigation measures through a rehabilitation strategy. As such, Letšeng Diamond Mine in Lesotho has implemented a rehabilitation strategy that will attempt to meet their legal and contractual obligations for post-mining land-use, as well as adhering to Good International Industry Practice and International Finance Corporation guidelines.

Frequent temperature drops below freezing, snow, a high wind-chill factor and high altitudes make rehabilitation in the afro-alpine zone of Lesotho difficult. These unique conditions present in the mountains of Lesotho have necessitated that Letšeng implement rehabilitation trials of various scales to improve the accuracy of the closure liability, and to explore alternative sustainable and cost-effective rehabilitation methods. The aims of these trials were to determine the most cost-effective growth medium that can sustain indigenous vegetation and minimise the risk of erosion, determine the extent and type of amelioration required to support vegetation establishment and growth, and assess the ability of indigenous vegetation to not only establish on these growth-mediums but also to persist and propagate.

The aim of this study was to assess and compare vegetation establishment and functionality on different types of tailings and topsoil mixes (treatments), and compare these with reference sites within the mine lease area, to determine which treatments would be the most suitable for optimal rehabilitation. To achieve this aim, the plant species richness, abundance and diversity of the various treatments were compared between treatments and the reference sites, as well as within treatments over time. The functionality of the various treatments was assessed using the Landscape Function Analysis (LFA) methodology. The functionality was also compared between treatments and the reference sites and within treatments over time. All treatments at all sites received the same type and extent of amelioration and seed mixture.

It was found that treatments containing topsoil had significantly higher plant diversity and functionality than treatments that did not contain any topsoil. LFA data revealed that there was a positive correlation between patch percentage and total Soil Surface Assessment (SSA) functionality, while there was a weak negative correlation between interpatch length and total SSA functionality. This suggests that vegetation cover contributes directly to the functionality of the treatments. Floristic data revealed that treatments containing topsoil had higher species diversity than treatments without topsoil in almost all cases. NMDS analyses and PCA ordinations of the floristic data revealed that treatments containing topsoil were more similar to the reference sites with regards to species composition than treatments that did not contain

topsoil. PCA ordinations also revealed that the species composition of treatments with higher amounts of topsoil were even more similar to the reference sites than treatments that did not contain topsoil. Treatments containing a mixture of coarse tailings and waste rock, regardless of the presence of topsoil, were found to have lower species diversity and functionality than treatments containing one of the two materials mixed with topsoil. The cause of the poor vegetation establishment is unknown; however, it could be due to chemical or physical factors related to mixing waste rock and coarse tailings, or external factors such as rainfall.

Based on the results of this study, it is recommended that the vegetation be monitored annually, while the functionality is monitored biennially. The decrease in functionality and diversity on treatments containing a mixture of coarse tailings and waste rock should be investigated. The effect that the method of ripping may have on the diversity and functionality of different growth mediums may also be a worthwhile avenue of further study.

The use of traditional rehabilitation species such as *Digitaria eriantha*, *Chloris gayana*, *Eragrostis tef* and *Cynodon dactylon* in the seed mixture should be reconsidered. The establishment of these species on the rehabilitation trials was minimal and they did not seem to provide much biomass or basal cover compared to *Triticum* and the two native species, *Sisymbrium turczaninowii* and *Merxmüllera disticha*.

This study provides scientific insight into the rehabilitation of kimberlite tailings in high-altitude alpine zones. The data on the vegetation establishment, composition and functionality of various potential rehabilitation treatments of kimberlite tailings provides invaluable guidance for cost-effective future management decisions.

Keywords: Rehabilitation; vegetation establishment; diversity; kimberlite tailings; landscape function analysis; functionality; afro-alpine zone; alpine rehabilitation; grasslands; Lesotho; mine rehabilitation; tailings mixes; tailings growth mediums.

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CHAPTER 1: INTRODUCTION

1.1 Background and Rationale

Mining activities can have severe negative impacts on the natural environment, ranging from erosion, habitat loss and changes in water availability, to acid mine drainage and toxic chemical release (Fourie & Brent, 2006). It is therefore important for mines to develop and implement mitigation measures through a rehabilitation strategy. As such, Letšeng Diamond Mine in Lesotho has implemented a rehabilitation strategy as part of their operational and closure plans. Through these plans, Letšeng will attempt to meet their legal and contractual obligations for post-mining land-use, as well as adhering to Good International Industry Practice (GIIP) as set out in International Finance Corporation (IFC) guidelines (Gem Diamonds, n.d.).

However, there is a lack of information available regarding best practices for the rehabilitation of kimberlite tailings in alpine zones. In non-alpine areas of southern Africa, there have been limited studies on the rehabilitation of kimberlite tailings of diamond mines. Van Rensburg and Maboeta (2004) investigated the physical and chemical properties of co-disposed kimberlite tailings at the Finsch mine in South Africa, with the aim of identifying possibilities and limitations for plant establishment and growth. This study did not provide insight into the rehabilitation of separately disposed tailings, as can be found at Letšeng and many other diamond mines in southern Africa.

Van Deventer *et al.* (2008) studied the soil characteristics of kimberlite tailings at Cullinan mine in South Africa, and considered optimum amelioration methods to promote vegetation establishment and growth. Several soil types and amelioration methods were included in the experiment, and the changes in soil properties such as pH, salinity, organic carbon content and water retention were recorded for each treatment over a period of three years. However, their study did not record the success of vegetation on the different treatments.

This lack of applicable information, and unique alpine conditions present in the mountains of Lesotho, has necessitated Letšeng to implement rehabilitation trials of various scales to improve the accuracy of the closure liability, and to explore alternative sustainable and cost-effective rehabilitation methods. An in-depth scientific study of the rehabilitation of kimberlite tailings in an alpine environment will provide much-needed insight that could improve the rehabilitation efforts of Letšeng and other diamond mines in Lesotho, and in the rest of southern Africa.

To implement their operational and closure plans, Letšeng was required to construct rehabilitation trials. The aims of these trials were to determine the most cost-effective growth medium that can sustain indigenous vegetation and minimise the risk of erosion, extent and

type of amelioration required to support vegetation establishment and growth, and ability of indigenous vegetation to not only establish on these growth-mediums but also to persist and propagate (E-Tek Consulting, 2013). Small-scale trials were initially conducted in a nursery environment, and the outcomes of these trials were used to develop and construct the large-scale trials that are considered in this study (E-Tek Consulting, 2013).

This study approached the monitoring of large-scale rehabilitation trials in a scientific way that could provide objective and useful information regarding the effectiveness of the different soil treatments on the rehabilitation trials, as well as comparing these trials with reference sites in afro-alpine grassland. The results of this study provide much needed information on the rehabilitation of kimberlite tailings, as well as the specific rehabilitation within alpine zones.

1.2 Aims and objectives

The aim of this study was to assess and compare vegetation establishment and functionality on different types of tailings and topsoil mixes (treatments) with reference sites within the mine lease area, to determine which treatments would be the most suitable for optimal rehabilitation. To achieve this aim, the following specific objectives were set:

- i. Assess and compare the functionality of the various treatments with each other, as well as the reference sites, using the LFA methodology;
- ii. Compare the changes in functionality of each of the treatments over time;
- iii. Assess and compare the species richness, abundance and diversity of the vegetation on each of the treatments with each other, as well as the reference sites;
- iv. Compare the changes in species richness, abundance and diversity of each treatment over time.

1.3 Hypotheses

Treatments containing topsoil will most closely resemble the natural areas with regards to vegetation composition, diversity and functionality. Therefore, the following specific hypotheses were formulated:

Hypothesis 1: Increasing topsoil content of tailings mixes (treatments) for vegetation establishment on kimberlite tailings enhances species diversity and cover.

Hypothesis 2: Increasing topsoil content of tailings mixes (treatments) for vegetation establishment on kimberlite tailings enhances landscape functionality.

1.4 Layout and approach

Chapter 2: Literature review of rehabilitation as a concept, the rehabilitation of mine sites, as well as the rehabilitation of alpine and high-altitude areas.

Chapter 3: An overview of the study area including the bioregion, the mine lease area and the rehabilitation trial sites.

Chapter 4: Landscape Function Analysis (LFA) is used to compare and discuss the differences in functionality across the different treatments, as well as the reference sites within the mine lease area. Study area, sampling approach and analyses methods specific to LFA is also described.

Chapter 5: Vegetation monitoring is used to compare and discuss the differences in species richness, abundance and diversity, as well as vegetation composition and cover across the different treatments and the reference sites in the mine lease area. Study area, sampling approach and analyses methods specific to community ecology is also described.

Chapter 6: Conclusions and recommendations are made regarding the suitability of the different treatments for rehabilitation based on the main findings of this study. Recommendations are made for future monitoring and some of the limitations of the study are mentioned.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The Society for Ecological Restoration (SER) defines ecological restoration as “the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed” (Society for Ecological Restoration International, 2004). SER defines rehabilitation by contrasting it with restoration. Both have a fundamental focus on historical ecosystems as a reference, but rehabilitation is more concerned with repairing ecosystem services, productivity and processes, where restoration also focuses on the re-establishment of historical biotic integrity in terms of species composition and community structure (Society for Ecological Restoration International, 2004).

Reclamation, as defined by SER, has an even broader application than restoration or rehabilitation. The objectives of reclamation are often to improve the aesthetic quality of an area, stabilise terrain, ensure public safety, and to return the area to a useful purpose or land use. Revegetation, which is often a component of reclamation, may only entail the establishment of one or a few species, but reclamation with a stronger ecological basis may be considered rehabilitation or even restoration in certain cases (Society for Ecological Restoration International, 2004).

Nghenvironmental (2007) defined rehabilitation as a process whereby plants are introduced to a disturbed site to initiate natural processes, and allow nature to re-establish the functioning of the natural ecosystem. Nghenvironmental (2007) considers restoration to be a form of revegetation, which in turn is a form of rehabilitation. They define revegetation as the use of vegetation, indigenous or not, to stabilise sites and to improve the aesthetic value of a site with vegetation cover (Nghenvironmental, 2007). Restoration is defined as the restoration of the ecosystem of a site to a state resembling the condition of the site before the disturbance. As opposed to revegetation, the use of indigenous vegetation is essential to success in restoration (Nghenvironmental, 2007). In this study, the widely accepted SER definitions will be used.

2.2 Rehabilitation of mine sites

Rehabilitation of mine sites follows the same basic principles as rehabilitation for other areas. However, there are other factors that must also be considered when working on mine sites, such as the physical and chemical stability of waste dumps and open pits, the quality of water resources, and the disposal of mine infrastructure (Fourie & Brent, 2004). According to Fourie

and Brent (2004), mine site rehabilitation has similar objectives to other rehabilitation projects, namely to “create a self-sustaining land surface which can in the long term be put to some productive use”. The Western Australian Department of Mines and Petroleum (2015) goes further to state that mines should aim to restore mined areas to a similar state as the surrounding landscape, while Lesotho legislation requires that flora and fauna be returned to disturbed areas (Act 10 of 2008).

A risks and impacts assessment should be conducted before the initiation of a project, and should identify any direct and indirect impacts the project may have on the environment (International Finance Corporation, 2012; Department of Mines and Petroleum & Environmental Protection Authority, 2015). International guidelines of the International Finance Corporation (IFC) indicate that environmental impacts must be avoided, but where this is not possible, measures should be implemented to minimise these impacts and to restore both biodiversity and ecosystem services. The IFC guidelines go on to state that any project that impacts natural habitats (areas where human activity has not modified the essential ecological functions and species composition) must implement mitigation measures that result in no net loss of biodiversity (International Finance Corporation, 2012).

Section 3.2.I. of the Environment Act (10 of 2008) of Lesotho requires an environmental impact assessment to be conducted prior to the commencement of any project or activity that may have adverse effects on the environment. This includes any form of mining activity. This environmental impact assessment must include all direct and indirect, long-term and short-term effects that the project may have on the environment (Section 25.5.e.), as well as the proposed measures to eliminate, minimise or mitigate these effects (Section 25.5.f.). The Environment Act dictates that restoration should include “the replacement of soil, the replanting of trees and other fauna”, as well as to cease damaging activities, prevent further environmental damage, dispose of waste and pollutants, and remove or alleviate damage to the environment (Section 84.4.).

Current best practice for mine closure dictates that environmental impacts should be minimised and impacted ecosystems should be restored. Rehabilitation of these ecosystems should aim to provide a land-use which can provide ecosystem goods and services (Limpitlaw *et al.*, 2005).

2.2.1 Concurrent rehabilitation

The high cost of post-mining rehabilitation often contributes to inadequate long-term rehabilitation (Van Eeden, 2010). Proper planning ahead of closure is therefore necessary to be able to rehabilitate mines in an economically and environmentally sound way. Concurrent ongoing rehabilitation during the operation of the mine site is considered better practice than

only rehabilitating post-closure (MacKenzie *et al.*, 2006; Van Eeden, 2010; Department of Mines and Petroleum & Environmental Protection Authority, 2015). Leaving rehabilitation until after closure may also lead to a situation where the ineffectiveness of the chosen mitigation measures only becomes apparent years later, at which time it may be too late to compel the original mining company to rehabilitate again (Van Eeden *et al.*, 2009). Concurrent rehabilitation also reduces the cost fluctuation and increases the viability of restoration, as the viability of restoration as a stand-alone project decreases as the project reaches the end of its life-span. Synergy regarding the use of staff and equipment on an operational mine site can also greatly reduce the direct costs of a rehabilitation project (MacKenzie *et al.*, 2006; Van Eeden, 2010; Department of Mines and Petroleum & Environmental Protection Authority, 2015).

There are several objectives of rehabilitation within mining, which may include (Limpitlaw *et al.*, 2005; Department of Mines and Petroleum & Environmental Protection Authority, 2015):

- Restoration of land to a pre-mining land-use potential.
- Restoration of the ecological function of site to its pre-mining state.
- Finding alternative uses for mine infrastructure, or infrastructure must be removed before the site is rehabilitated.
- Minimising the current or future impacts on water resources and availability.
- Considering socio-economic factors such as job creation, education and training of local residents.

2.2.2 Limiting factors

An important objective of rehabilitating mine sites is to restore the capability of the land to sustain a variety of land uses. While the site may eventually only be used for grazing or development, the rehabilitation of the site to accommodate the largest number of possible land uses is nonetheless a priority (Limpitlaw *et al.*, 2005). The use of commercially available species with high water and nutrient requirements during rehabilitation often returns lands to a lower level of biodiversity than before the mining disturbance. Over-fertilisation and the use of common rehabilitation grass species such as *Eragrostis* may lead to a grass monoculture. These lands often experience deterioration in the long term and are not sustainable for grazing (Limpitlaw *et al.*, 2005).

The preservation of topsoil is important for the rehabilitation of mine sites, as mine tailings are generally too rocky to sustain economic end land uses (Limpitlaw *et al.*, 2005). Topsoil also provides nutrients, air and water necessary for plant growth, as well as microflora and fauna essential for nutrient cycling (Holmes, 2001; Nghenvironmental, 2007). In chemically or physically disturbed soils, such as those found on mine sites, there may be a lack of natural propagules which can be bulked up by the application of topsoil and re-seeding (Van Eeden,

2010). The seedbank present in topsoil may contribute a significant portion of the vegetation on rehabilitated areas, especially where the native species have long-term persistent seedbanks (Holmes, 2001).

The compaction of topsoil is another factor that can cause rehabilitation to fail. Soils that are graded by heavy machinery may be densely compacted under the weight of these machines, and these soils are too dense for plant roots to penetrate and extract water (Limpitlaw *et al.*, 2005; Croton & Ainsworth, 2007). The thickness of the topsoil layer is also a factor, and compacted soils are more prone to lead to rehabilitation failure when they are thicker, as plants cannot reach the moisture in the underlying material that is not as easily compacted (Limpitlaw *et al.*, 2005). Croton and Ainsworth (2007) found that ripping beyond the critical depth (which is a function of tine width and shape and soil type and moisture content) may increase compaction. According to Limpitlaw *et al.* (2005), deep ripping of compacted re-replaced soils may not be effective, as rain will re-compact the soils if there is a lack of microbial activity and nutrients.

Achieving sustainable vegetation cover after revegetation on mine tailings is often difficult due to the infertility and sometimes toxicity of the medium, and this can often lead to the use of revegetation species that are not indigenous or result in a monoculture (Van Rensburg & Morgenthal, 2004). Studying the effect of uncomposted woodchips as fertiliser on platinum mine tailings, Van Rensburg and Morgenthal (2004) found that woodchips improved early vegetation establishment due to an increase in macronutrients in the soil, and improved water retention by the medium. However, this effect was only short-term and eventually the biomass of control plots and treated plots were the same (Van Rensburg & Morgenthal, 2004). This highlights the importance of long-term studies into rehabilitation methods to determine best practices that can ensure sustainability.

Erosion is a major problem during rehabilitation of mine sites. Soil loss from sloped areas may take several years to reach critical levels, but this loss is usually followed by erosion and upwards salt migration on mine dumps, and as a result rehabilitation failure (Limpitlaw *et al.*, 2005). Mine dumps with even a moderate slope can experience high rates of erosion, and once the underlying waste material is exposed, several further problems may arise such as pollution and acidification of groundwater, depending on the properties of the waste material (Limpitlaw *et al.*, 2005).

Once rehabilitation has been completed, guidelines must be set for the next land owner of these areas. As these areas are usually still sensitive and may degrade easily, especially with regards to nitrogen levels in the soil, it is important to ensure that new land owners use the land in a sustainable manner (Limpitlaw *et al.*, 2005).

2.3 Rehabilitation of high altitude, alpine areas

Good (2006) and Nghenvironmental (2007) developed a set of general guidelines for the rehabilitation of alpine areas:

- Rehabilitation must be approached on a site-by-site basis, with a thorough assessment of the site's characteristics as well as impacts and degradation processes. Each site has different characteristics that must be understood to maximise the potential for success.
- Indigenous species should be used as they cover and protect soils better than exotic species, they require less maintenance and fertiliser as they are adapted to local soil and climatic conditions, they create an ecosystem that is more resistant to invasion and disturbance, and they are ideally suited to provide food and habitat for native animals. The propagules should ideally be sourced as close to the site as possible.
- For rehabilitation to be efficient and successful there must be continuity in management. One person should be responsible for planning, executing, maintaining and monitoring a rehabilitation site.
- Skilled rehabilitation crews should be used, as they will be able to identify ways to use resources more efficiently and increase the chances of successful rehabilitation.
- Rehabilitation plans must make provision for natural time constraints such as seed availability, propagation times and the best seasons for planting.
- Regular monitoring of the rehabilitation site coupled with an adaptive management approach is necessary to ensure that rehabilitation objectives are met.
- The ability of a site to regenerate itself should be maintained or enhanced.
- Rehabilitation should focus on restoring ecological processes and functions to create a self-sustaining ecosystem.
- Rehabilitation should be based on clear and achievable objectives and environmental conditions. The full range of ecological, economic and social values of a site must be considered.
- Rehabilitation objectives must consider the site as part of the surrounding landscape, including degradation processes and impacts active outside the site.

From the above it is clear that certain key aspects should govern rehabilitation actions in afro-alpine zones. A thorough site assessment as part of the initial planning stage of the rehabilitation plan is very important (Good, 2006; Nghenvironmental, 2007). The past land-use of the site should be determined, as this will influence the various biotic and abiotic characteristics of the site. The planned future land-use of the site should also be established, as this will influence the type of rehabilitation that should be implemented (Nghenvironmental, 2007).

2.3.1 Indigenous species

The use of indigenous species during alpine rehabilitation is strongly recommended (Nghenvironmental, 2007). Indigenous species are optimally adapted to high-altitude climates and extreme weather conditions, as well as usually requiring less additional measures to become established (Graiss *et al.*, 2008). Indigenous species make alpine ecosystems more

resilient against threats such as exotic pest species, soil degradation and climate change, as well as making these ecosystems self-sustaining (Nghenvironmental, 2007). However, exotic grass species can be used to provide short-term ground cover and allow permanent native vegetation to establish, on the condition that these exotic species are non-invasive, short-lived and non-persistent, or sterile annuals (Good, 2006). For successful rehabilitation, indigenous species need to be identified on and around the site. This will aid in selecting the most suitable species with which to rehabilitate the site. In alpine vegetation, it is important that these surveys be conducted when there is no snow cover and species that spend part of their life cycle below ground are visible (Nghenvironmental, 2007). However, it is important to keep financial constraints in mind when using site-specific, indigenous species in the seed mixture. These seeds are often not commercially available, have a lower yield than commercial species, require more specialist knowledge to gather, and carry a higher risk for rehabilitation use (Krautzer *et al.*, 2010). Seeds and other propagation materials should be collected at the end of the growing season, usually before winter, in early autumn or late summer. Seeds should be sown when they are most viable, to minimise the rate of attrition, and planting should usually be conducted in November or March (in the southern hemisphere), although this depends on the seasonal snowfall (Nghenvironmental, 2007).

2.3.2 Vegetation cover

To avoid erosion, high-altitude alpine and sub-alpine areas require a vegetation cover of at least 70% (Graiss *et al.*, 2008). In the short term, this can be achieved by using the correct application technique for a site, but for vegetation cover to remain above this threshold in the long term, the use of a seed mixture containing site-specific species is necessary (Graiss *et al.*, 2008). While initial vegetation cover using conventional seed mixtures may be as high or higher than vegetation cover using a site-specific seed mixture, studies indicate a drop in vegetation cover to below threshold levels in the long term on sites where conventional seed mixtures were used (Graiss *et al.*, 2008). It is therefore important to use seed mixtures with a high number of site-specific species to minimise erosion through increased vegetation cover when rehabilitating high-altitude areas.

It is important to maintain rehabilitation sites until good ground cover has established. This can include watering, removal of weeds, re-seeding, and the maintenance or removal of erosion and sediment controls and plant protection structures (Nghenvironmental, 2007). In addition to maintenance, sites should be continually monitored to evaluate the relative success of the rehabilitation. Techniques such as LFA's are recommended for their low cost, ease of use, and their ability to compare sites (Good, 2006; Nghenvironmental, 2007).

2.3.3 Growth medium

The importance of a soil assessment is also emphasised, and the focus should be on the soil's ability to sustain plant growth, as well as the erodibility of the soil (Nghenvironmental, 2007). Knowledge of how easily the soils can be eroded, as well as how fine or coarse the soil particles are, will determine what the best methods for preventing erosion will be during and after construction of the sites. The preservation of topsoil is very important, as this layer of soil provides all the nutrients, air and water necessary for plant growth. If topsoil is absent, then plant species capable of growing in poor soils should be introduced to gradually improve the growth medium (Nghenvironmental, 2007).

Nghenvironmental (2007) listed several basic soil characteristics that should be determined at each site, including:

- the depth of the topsoil;
- the texture and infiltration rate of the soil;
- the composition of the soil (e.g. clay and/or organic content); and
- soil pH.

Soil pH is particularly important, as alpine and sub-alpine vegetation do not grow well in soils with a pH higher than 6.5 (Nghenvironmental, 2007). Detailed soil analyses should also be conducted. Good (2006) claimed that native alpine vegetation are adapted to soils with low micro-nutrient levels. Detailed soil analyses should indicate whether nutrient levels are below or above optimum, and fertilisers should be chosen accordingly.

It is important to note the slope of the rehabilitation site, as slope angle affects the movement of water, and as a result, the development of soils and the species that can grow there (Nghenvironmental, 2007). Slope position also affects the microclimate within a slope, with sites at the top of a slope experiencing stronger winds, and often having thinner and rockier soils than sites lower down on a slope (Nghenvironmental, 2007). To protect topsoil, mulching and seeding must take place directly after the construction of a site has concluded (Nghenvironmental, 2007).

2.3.4 Soil microbes

Soil microbial populations may also have an effect on the vegetation community. In alpine areas, populations of certain microbial species increase during the autumn and winter seasons, and immobilise large amounts of soil nitrogen (N) (Lipson *et al.*, 1999). This increase in

microbial biomass is believed to be caused by plant senescence. The biomass of these microbial populations decrease again as temperatures rise and soil moisture decreases during the spring and nitrogen is re-released into the soil where it is available for plants to use (Lipson *et al.*, 1999). Despite high levels of inorganic nitrogen in high-altitude mountain soils, this nitrogen is not always available for use by plants. A study by Carbutt *et al.* (2013) suggests that the low soil temperatures associated with high-altitude sites inhibits microbial activity and as a result soils can become functionally nutrient-poor, despite intrinsically high levels of nutrients in the soils.

2.3.5 Climatic factors

The exposure of the site to wind and snow, the altitude of the site, as well as the aspect of the site are important factors to take note of during rehabilitation planning. These factors all have a large influence on the microclimate of the site, and this will determine which species will be able to grow there (Nghenvironmental, 2007).

Good (2006) lists several challenges for rehabilitating alpine areas. While precipitation is high, precipitation events can be irregular, and high winds can lead to short-term drought and wind chill. Low ambient temperatures lead to a short growing season and both of these factors limit the species that can be used to rehabilitate these areas (Good, 2006). Freezing temperatures can lead to physiological drought, as plants can no longer utilise moisture in the soil. These low temperatures can also lead to frost-heave, where ice formation disturbs the soil, uproots young seedlings, and increase the risk for soil erosion. Long periods of drought can be followed by heavy storms, which can lead to severe erosion of the vulnerable soils (Good, 2006).

The chemical properties of the soils in this area are influenced by the high altitude, high rainfall and extreme weather conditions. Soil analyses identified the following chemical characteristics (E-Tek Consulting, 2013):

- pH ranges between 4.0 and 6.5;
- low levels of potassium, sodium and phosphorous;
- high levels of organic carbon;
- high levels of calcium;
- moderate to low ratios of magnesium;
- moderate clay content; and
- high leaching status.

According to the soil analyses, no toxic elements or nutrient deficiencies were detected in the soils, but the calcium levels are high and may restrict magnesium uptake.

3.1.2 Land-use capability

The lease area of Letšeng consists of four different land-use capability classes, namely wetlands, arable land, grazing land, and land for conservation (E-Tek Consulting, 2013). The majority of the lease area consists of land for conservation. The shallow soils, steep topography and erosion potential gives the land a low potential for agriculture (E-Tek Consulting, 2013).

3.1.3 Flora

The vegetation of Letšeng falls into the greater Grassland Biome, more specifically the Drakensberg Grassland Bioregion (Mucina & Rutherford, 2006). This bioregion occurs in some of the highest elevation areas in southern Africa, and the topography is usually steep. Precipitation is generally very high and occurs throughout the year, and snow and frost are common in the winter months (Mucina & Rutherford, 2006).

The majority of the lease area of Letšeng falls into the Drakensberg Afro-Alpine Heathland community. This community mainly occurs at altitudes between 2900 and 3400 m above sea level, and may have areas dominated by dwarf shrubs (e.g. *Helichrysum trilineatum*), to grassland without any shrubby vegetation (Mucina & Rutherford, 2006). The most dominant grass species is *Merxmuellera disticha*, with cushion plants such as *Helichrysum sessilioides* and plants forming low mats such as *H. praecurrens* also occurring commonly. *Chrysocoma ciliata* is common, while the grass *Merxmuellera drakenbergensis* can be found near watercourses (Mucina & Rutherford, 2006).

This bioregion is considered to be “least threatened”, and very little of it has been transformed. However, grazing pressure in summer is high and this leads to an increase in *Helichrysum trilineatum*, *Passerina montana* and other species. The increase in *H. trilineatum* may be ascribed to its low palatability. However this is partly counteracted by its usefulness as fuel (Mucina & Rutherford, 2006).

The Drakensberg Afro-Alpine Heathland also falls within the Drakensberg Alpine Centre of Endemism (CE), one of five centres found in the Grassland Biome of South Africa and Lesotho (Mucina & Rutherford, 2006). The Drakensberg Alpine CE and the Wolkberg CE are the only centres of endemism that fall completely inside the Grassland Biome. The Drakensberg Alpine CE contains over 3000 native species and is endemic-rich, with approximately 13% endemism, including 334 endemic taxa and five endemic genera (Mucina & Rutherford, 2006; Carbutt, 2012).

3.1.4 Fauna

Studies on fauna have found that there are several mammal species present in the mine lease area, with species richness and diversity being higher inside the lease area than immediately outside (E-Tek Consulting, 2013). This is believed to be the result of fencing around the lease area that has excluded grazing animals, allowing the natural habitat to recover from overgrazing and providing habitat and a safe haven for wildlife (E-Tek Consulting, 2013). The diversity of reptiles, amphibians and birds in the area is low, however there are a few important bird species in the region, such as *Geronticus calvus* and *Gyps coprotheres* (E-Tek Consulting, 2013; Birdlife International, 2016).

3.1.5 Local climatic conditions

This bioregion experiences summer rainfall, but precipitation from cold fronts in winter is possible. The mean annual precipitation (MAP) is 737 mm, but can vary widely, with MAP in some areas as high as 1600 mm and as low as 600 mm in other areas, with a decline towards the interior from the escarpment. This area has a low mean annual temperature of 4.0°C, and experiences approximately 158 frost days (days where the temperature drops below 0°C). The lowest recorded temperature for Lesotho was recorded at Letšeng: -20.4°C in June 1967 (Mucina & Rutherford, 2006).

3.2 Letšeng Rehabilitation trials

There are five large-scale trial sites at Letšeng, of which three are relevant to this study (Figure 3-2). Sites 4 and 5 were not established according to the same experimental design as Sites 1-3, and were therefore not included in this study. Each site contains multiple soil treatments specific to the rehabilitation of the base material of each site. This includes several different combinations of fine tailings, coarse tailings, waste rock and topsoil. The soils used for rehabilitation purposes at Leseng are a mixture of topsoil and subsoil. Soil taken from stockpiles are a combination of natural occurring soils of varying depths. For the purpose of this study we will refer to this growth medium as ‘topsoil’. The same amelioration (Table 3-1) and seed mixture (Table 3-2) was used on all three sites and across all treatments.



Figure 3-2: Satellite image of Letšeng lease area indicating rehabilitation trial sites (Site 1-3) and reference sites (Ref 1-3).

Table 3-1: Ameliorants and the application ratios used on the rehabilitation sites.

Ameliorant	Application ratio (kg/ha)
Black DAP (19% P; 17% N; 1% S)	140
KNO ₃	30
CaNO ₃	30

Table 3-2: Seed mixture content and application ratio on the rehabilitation sites.

Species	Slopes (kg/ha)	Flat areas (kg/ha)
<i>Eragrostis tef</i>	1	0.5
<i>Cynodon dactylon</i>	5	4
<i>Chloris gayana</i>	3	2
<i>Digitaria eriantha</i>	7	2
<i>Triticum sp.</i>	5	4
<i>Merxmuellera disticha</i>	7	7
<i>Sisymbrium turczaninowii</i>	2	2

3.2.1 Site 1 (De Beers TSF beach)

Site 1 (Figure 3-3) is located on the beach of the slimes dam, and represents the conditions found at the fine tailings facilities. The fine tailings consist of thickened kimberlite waste from the fines DMS (dense media separation) process, which is used to liberate diamonds from the finer fraction (-15+2mm) material after primary and secondary crushing (Bornman, 2010). This site was prepared and seeded in October 2014. This site was not ripped as it was too dangerous to operate heavy machinery on the fines TSF.

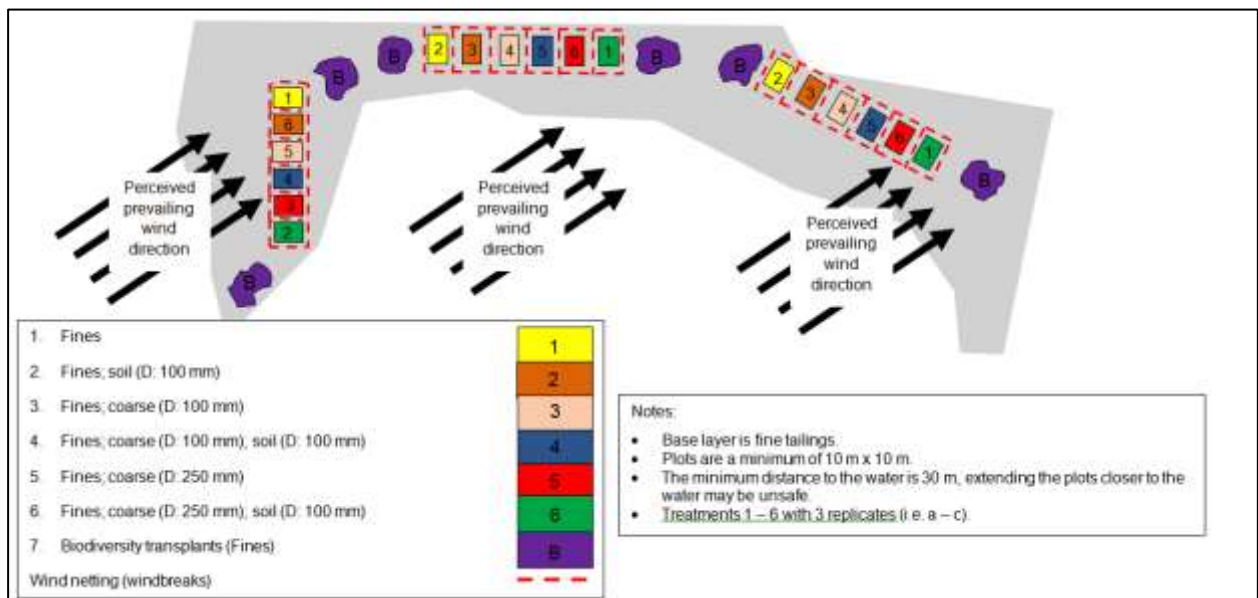


Figure 3-3: Layout and various treatments on rehabilitation trial site 1 (De Beers TSF beach) (E-Tek Consulting, 2014).

3.2.2 Site 2 (De Beers TSF coarse tailings wall)

Site 2 (Figure 3-4) is located on a section of the northwest-facing coarse tailings dam and represents the conditions found on top and on the slopes of the coarse tailings facilities. The coarse tailings consist of coarse kimberlite waste from the coarse DMS and diamond recovery processes where diamonds are liberated from the coarse fraction (-45+15 mm) material after primary and secondary crushing (Bornman, 2010). This site was prepared and seeded in March 2014. Most treatments on this site were ripped on contour, except for treatments 1C, 2C and 3C, which were ripped in a diamond pattern. It should also be noted that this site was the only site to be seeded before winter instead of after.



Figure 3-4: Layout and various treatments on rehabilitation trial site 2 (De Beers TSF coarse tailings wall) (adapted from E-Tek Consulting, 2014).

3.2.3 Site 3 (waste rock terrace – mine offices)

Site 3 (Figure 3-5) is located on the north-facing waste rock terrace behind the main offices and replicates the conditions found on the waste rock dumps. The waste rock dumps consist of blasted basalt waste material (Earth Science Solutions, 2012) separated from the kimberlite ore before the DMS process (Petra Diamonds, n.d.) This site was prepared and seeded in November 2014. This site was ripped on contour.

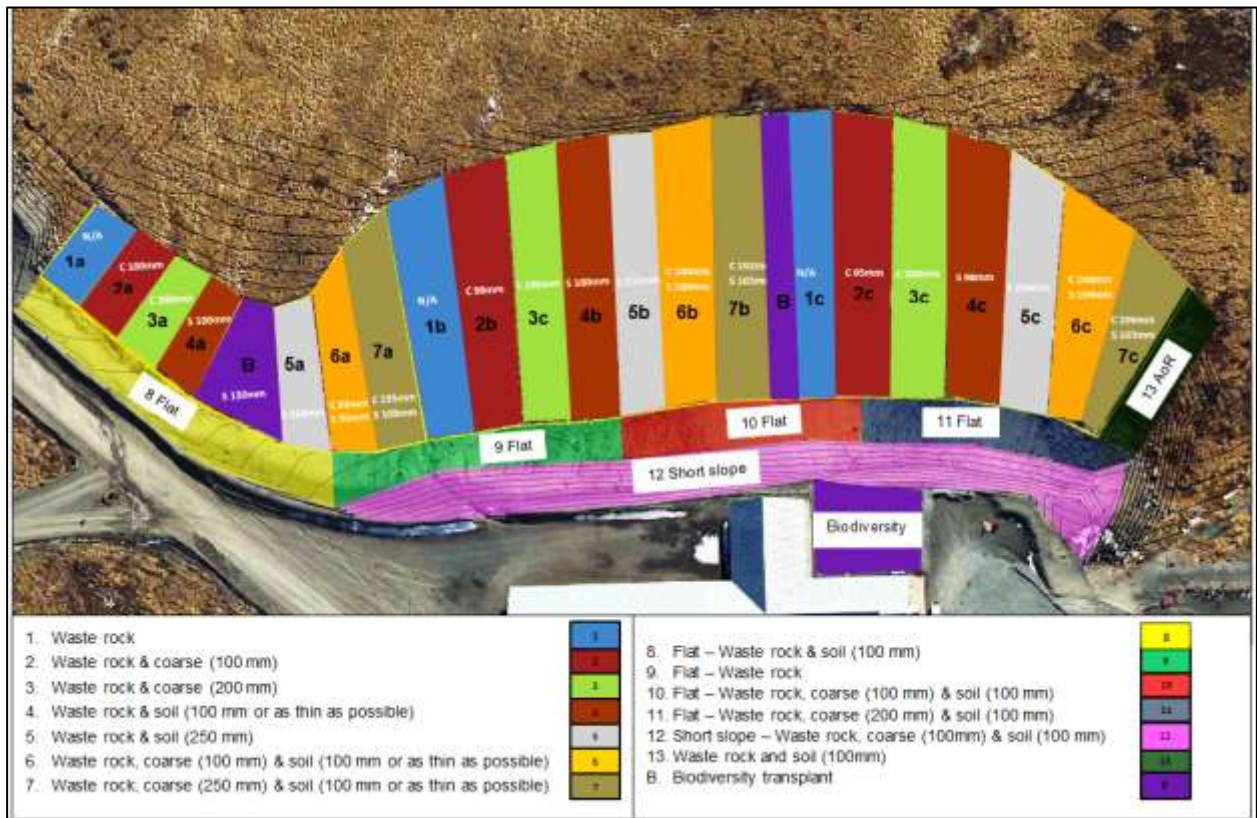


Figure 3-5: Layout and treatments on rehabilitation trial site 3 (waste rock terrace – mine offices) (E-Tek Consulting, 2014).

3.2.4 Reference sites

The three reference sites are all located in confirmed undisturbed areas with indigenous vegetation, inside the Letšeng lease area. Reference site 1 is located on a north-facing hill below a rock bank, where the majority of the site is somewhat protected from wind. Reference site 2 is located on a hill with slopes facing from west-north-west to east-north-east. This site is subjected to heavy winds and is also considerably rockier than the other two reference sites. Reference site 3 is located on a valley slope directly below trial site 3 and labourer accommodation. This site is considered to be the most affected by human activity with water runoff from buildings and tailings present in some areas of the site. Reference sites were chosen inside the mine lease area to provide control over these sites and to prevent overgrazing. The reference sites are undergrazed and are not subject to fire, leading to moribund conditions.

CHAPTER 4: LANDSCAPE FUNCTION ANALYSIS

4.1 Introduction

Landscape Function Analysis (LFA) is defined as a monitoring procedure that uses rapidly acquired field-assessed indicators to assess the biogeochemical functioning of landscapes at the hill slope scale (Tongway & Hindley, 2004a). The LFA method was developed to assess and track the degradation or recovery of landscapes. Monitoring of the functional status of landscapes is achieved by calculating indices based on simple field indicators that reflect the measurable variables of surface stability, water infiltration capacity and nutrient cycling. This method seeks to link vegetation structure and organisation with soil function and the development of habitat for animals. However, this method does not replace traditional botanical vegetation monitoring techniques (Tongway & Hindley, 2004a).

In the LFA methodology “function” refers to the performance of the landscape as a biophysical system. Landscapes with a high functional status will conserve and use resources such as soil, water and nutrients within the landscape. Landscapes with a low functional status will lose materials and fail to capture rainfall or any replacement resources. Patches of vegetation obstruct and divert water flow causing topsoil, litter and seeds to be captured in the system (Van Der Walt *et al.*, 2012). Degraded landscapes can be characterised by a reduction in the size, number and effectiveness of patches and the resulting inability to capture resources that flow across the landscape (Tongway & Hindley, 2004a).

Landscapes are commonly heterogeneous with regards to resource control, consisting of patches and inter-patches. Patches are areas where resources tend to accumulate, and they have enhanced soil properties such as infiltration capacity, nutrient concentration and surface stability. Inter-patches are areas where resources flow more freely and they have low soil properties when compared to patches. Patches and inter-patches tend to be arranged in a characteristic structure for each landscape, but the size, distribution and frequency of patches can vary according to seasonal changes or other conditions (Tongway & Hindley, 2004a).

By measuring the ratio of patches to interpatches, the extent and rate of vegetation establishment can be monitored and this information can be used to determine rehabilitation success (Nghenvironmental, 2007). The LFA method also measures patches and interpatches qualitatively through the use of soil surface indicators, which provides information on the specific processes of a landscape that contribute or detract from its functionality (Nghenvironmental, 2007). The LFA method is a rapid assessment and does not require any special skills to carry out, and it also provides results that can be directly compared, making it ideal to compare the success of rehabilitated sites against reference sites (Nghenvironmental, 2007). For these

reasons, the LFA methodology was chosen to assess and compare the various rehabilitation trial sites at Letšeng.

The aim of this study was to assess and compare functionality on different types of tailings and topsoil mixes (treatments) with reference sites within the mine lease area, to determine which treatments would be the most suitable for optimal rehabilitation. To achieve this aim, the following specific objectives were set, namely; to assess and compare the functionality of the various treatments with each other, as well as the reference sites, using the LFA methodology, and to compare the changes in functionality of each of the treatments over time.

4.2 Methods

The LFA field data acquisition methodology can be divided into three principal steps (Tongway & Hindley, 2004a), namely; describing the geographic setting of the site, characterising landscape organisation by recording the spatial distribution of patches and inter-patches and conducting a Soil Surface Assessment (SSA) of each patch and inter-patch type.

The research approach involved comparing the SSA functionality of the various treatments with each other and the reference sites (Figure 4-1). The change in functionality within treatments over time was also investigated. Any SSA correlations for the treatments at each site along with the reference sites were also investigated.

Research questions and approach

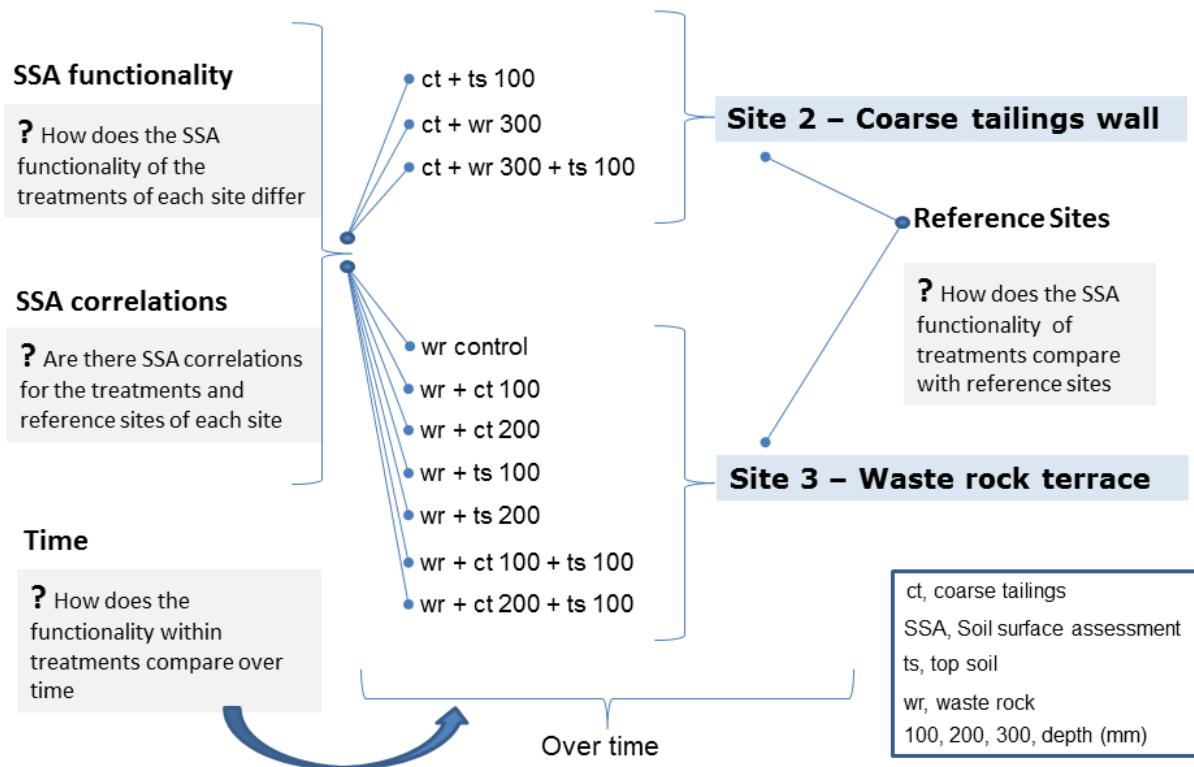


Figure 4-1: Overview of the research questions and approach followed for data analyses and discussion.

4.2.1 Geographical setting

The objective of this first step of the LFA is to identify the location of the monitoring site within the landscape (Tongway & Hindley, 2004a). This step involves the site description and the topographic location (Table 4-1).

4.2.2 Landscape organisation

The second step involves recording the spatial distribution of resource loss and accumulation through the identification of patches and inter-patches (Tongway & Hindley, 2004a). This is done along a fixed transect that must follow the maximum slope and flow of resources down the slope. The cover length of the patches are recorded along the transect line, as well as their obstruction width at right angles to the transect line. The distance between patches, or the interpatch length, is also recorded. The width of interpatches is not recorded. This provides three parameters that can be used to determine the functionality of a site per unit length of

transect, namely the number of obstructions to overland resource flow, width of obstructions and mean length between obstructions (interpatch length) (Tongway & Hindley, 2004a).

Table 4-1: Summary of geographical information gathered during the first step in the LFA method

Site description	Topographic location
GPS co-ordinates	crest; upper slope; mid slope; flat etc
aspect of slope	
slope angle	
vegetation type	
compass bearing	
lithology	
land-use	

4.2.3 Soil surface assessment

Each patch and inter-patch type identified in step 2 must have its soil surface properties classified according to the SSA method detailed in Tongway and Hindley (2004a). The SSA uses visual indicators as surrogates for environmental variables or processes, and is designed to be a rapid assessment method. These indicators are rain splash protection, perennial vegetation cover, litter cover, cryptogam cover, crust brokenness, soil erosion type and severity, deposited materials, soil surface roughness, surface resistance to disturbance, slake test and soil texture.

4.2.4 Field survey

Two LFA surveys were conducted at Letšeng, the first in March 2015 and the second in April 2016. A total of 39 LFA transects were sampled during each survey, comprising nine transects from trial site 2, 21 from trial site 3, and nine from the three reference sites (three per site). Trial site 1 was not sampled, as the treatments in this site were considered to be too small to provide meaningful data. As the treatments at site 1 have no slope, it was also difficult to determine the flow of resources across the treatments, or even if any such flow occurred.

The treatments sampled at trial site 2 were treatments 1 (coarse tailings and topsoil (100 mm)), 2 (coarse tailings and waste rock) and 3 (coarse tailings, waste rock and topsoil (100 mm)) (Table 4-1). The treatments sampled at trial site 3 were treatments 1 (waste rock), 2 (waste rock and coarse tailings (100 mm)), 3 (waste rock and coarse tailings (200 mm)), 4 (waste rock and topsoil (100 mm)), 5 (waste rock and topsoil (250 mm)), 6 (waste rock, coarse tailings (100 mm) and topsoil (100 mm)) and 7 (waste rock, coarse tailings (250 mm) and topsoil (100 mm)) (Table 4-2).

Table 4-2: Composition of the various treatments on rehabilitation trial sites 2 and 3. 'Base' refers to the composition of the dump and is >250 mm thick. A hyphen denotes the absence of a material.

Site	Treatment	Top soil	Coarse tailings	Waste rock
2	1	100 mm	Base	-
2	2	-	Base	±300 mm
2	3	100 mm	Base	±300 mm
3	1	-	-	Base
3	2	-	100 mm	Base
3	3	-	200 mm	Base
3	4	100 mm	-	Base
3	5	200 mm	-	Base
3	6	100 mm	100 mm	Base
3	7	100 mm	200 mm	Base

The standard LFA field methodology, as described above and in detail in Tongway and Hindley (2004a), was employed to gather data. Transects ran straight down the middle of treatments, following the most likely flow of resources down the slope. Patches were identified as significant obstructions to the flow of resources along the transect line. Only obstructions that showed evidence of, or were very obviously capable of, hindering the flow of resources down the slope were noted as patches. This excluded several smaller seedlings and rocks that did not appear to affect or be able to affect the surface flow of resources.

Patches were identified primarily in two main groups: homogenous and heterogeneous patches. Examples of the former are grass patches, rock patches or shrub patches, while examples of the latter are grassy rock patches, grassy shrub patches or rocky litter patches. It should be noted that the nomenclature of the patches are not meant to be scientific in this case and do not replace or supplement vegetation surveys in any way, and serves mainly to simplify data collection and capturing.

SSA data were collected for each patch and inter-patch type identified in each transect. The 11 SSA indicators (rain splash protection, perennial vegetation cover, litter cover, cryptogam cover, crust brokenness, soil erosion type and severity, deposited materials, soil surface roughness, surface resistance to disturbance, slake test and soil texture) were assessed using the processes described in the LFA manual (Tongway & Hindley, 2004a). The collected data were entered into the LFA data entry sheet (V.3.0). The LFA data entry sheet provided information about 12 different factors that could be used to compare the various treatments. The 12 factors were patch percentage, interpatch percentage, average patch width (cm), number of patches/10 m, average interpatch length (m), longest interpatch (m), total patch area, patch area index, landscape organisation index, and the three SSA indexes: surface stability, infiltration capacity and nutrient cycling.

4.2.5 Statistical analyses

Each survey of each trial site was analysed and compared with the reference sites. ANOVAs were conducted using SPSS version 23 (SPSS, 2016). ANOVA's are used to determine if there are significant differences between the means of two or more groups (Urdan, 2010). Tukey post-hoc tests were conducted on the data (SPSS, 2016), as well as Kruskal-Wallis post-hoc tests using Statistica version 13 (StatSoft Inc., 2016). One-way ANOVA's inform on the likelihood of significant differences between two or more groups, while post hoc testing is required to determine which of these groups differ from each other (Tabachnick & Fidell, 2007). Both parametric and non-parametric tests were conducted, as the dataset was too small to test for normality. The group sizes were uneven and therefore it was decided to only report the Kruskal-Wallis post-hoc tests. Principle component analyses (PCA) were conducted for the data from each site, comparing the rehabilitation treatments with the reference sites with regards to topsoil depth and the three SSA indices. The two trial sites were not compared with each other, as the treatments across the sites were too dissimilar and the base material (coarse tailings versus waste rock) and slope angle (24° versus 18°) differed.

The treatments of each trial site were also compared with themselves over time. Each treatment was compared between the first and second surveys with regards to each of the above-mentioned variables using Paired Sample t-tests and Wilcoxon Signed-Rank tests (SPSS, 2016). However, the small sample size (n=3) per treatment did not allow reliable results with the Wilcoxon Signed-Ranks test, and only the results of the paired sample t-tests are considered for discussion here.

4.3 Results

4.3.1 Trial site 2 (De Beers TSF coarse tailings wall)

4.3.1.1 Comparison of variables between treatments and reference sites

There were significant differences ($p < 0.05$) between treatments for most of the variables for survey 1, while all the variables differed significantly across treatments for survey 2 (Table 4-3).

Table 4-3: ANOVA and Kruskal-Wallis (KW) test results for LFA data from Site 2 comparing treatments with reference sites over two survey periods. Survey 1, March 2015; survey 2, April 2016. Significant values in bold and marked with * ($p < 0.05$).

Variable	Survey 1 (df = 3)			Survey 2 (df = 3)			Survey 1		Survey 2	
	Sum of Squares	Mean Square	F	Sum of Squares	Mean Square	F	ANOVA p-value	KW p-value	ANOVA p-value	KW p-value
Patch %	29358.639	9786.213	213.012	36315.881	12105.294	629.446	*<0.001	*0.0023	*<0.001	*0.0025
Interpatch %	29358.639	9786.213	213.012	36315.881	12105.294	629.446	*<0.001	*0.0023	*<0.001	*0.0025
Average patch width (cm)	211945.686	70648.562	8.181	2888315.962	962771.987	36.648	*0.0021	*0.0047	*<0.001	*0.0030
Number of Patches/10m	15.174	5.058	2.063	4.210	1.403	7.641	0.1512	0.1294	*0.0029	*0.0148
Average Interpatch Length (m)	693.623	231.208	3.155	1600.563	533.521	18.697	0.0584	*0.0028	*<0.001	*0.0026
Longest interpatch (m)	660.570	220.190	2.994	1591.508	530.503	17.710	0.0667	*0.0267	*<0.001	*0.0030
Total Patch Area	89217.793	29739.264	11.531	980518.108	326839.369	1074.090	*<0.001	*0.0026	*<0.001	*0.0027
Patch Area Index	0.351	0.117	11.327	3.895	1.298	1038.294	*<0.001	*0.0026	*<0.001	*0.0027
Landscape Organisation Index	2.914	0.971	216.499	3.632	1.211	629.446	*<0.001	*0.0025	*<0.001	*0.0025
Stability	2492.356	830.785	41.285	2609.527	869.842	15.851	*<0.001	*0.0079	*<0.001	*0.0094
Infiltration	2822.801	940.934	102.267	1628.998	542.999	34.852	*<0.001	*0.0026	*<0.001	*0.0036
Nutrients	2303.144	767.715	60.019	1016.557	338.852	19.705	*<0.001	*0.0038	*<0.001	*0.0032

The Kruskal-Wallis post-hoc tests indicated that treatment 2 (coarse tailings and waste rock) differed significantly from the reference sites for eight of the 12 variables during the first survey (Appendix 2): six were significantly lower (patch percentage, average patch width (cm), total patch area, patch area index, landscape organisation index and infiltration) and two were significantly higher (interpatch percentage and average interpatch length (m)) (Appendix 1).

During the second survey, treatment 2 again differed significantly from the reference for eight of the 12 variables (Appendix 2): five were lower (patch percentage, average patch width (cm), total patch area, patch area index and landscape organisation index) and three were higher (interpatch percentage, average interpatch length (m) and longest interpatch (m)) (Appendix 1). It should be noted that Treatment 2 did not, however, differ significantly from the reference sites

with regards to the three SSA indexes during the second survey. There were significantly less patches/10 m on Treatment 2 than on Treatment 1 (coarse tailings and topsoil).

Treatment 1 (coarse tailings and topsoil) scored significantly lower than the reference sites with regards to surface stability in the SSA index during both surveys, while treatment 3 (coarse tailings, waste rock and topsoil) only scored significantly lower than the reference sites during the first survey (Table 4-4). With regards to the infiltration capacity SSA index, during the first survey treatment 2 (coarse tailings and waste rock) scored significantly lower than the reference sites, while during the second survey treatment 3 scored significantly lower than the reference sites (Table 4-4). For the nutrient cycling SSA index, treatment 1 scored significantly lower than the reference sites during the first survey, while treatment 3 scored significantly lower during the second survey (Table 4-4).

Table 4-4: Significant differences between treatments at Trial site 2 and the reference sites for each variable based on Kruskal-Wallis post-hoc tests. Treatments marked with “a” differed significantly from the reference during survey 1, while treatments marked with “b” differed significantly from the reference during survey 2. Treatments marked with a hyphen did not differ significantly from the reference during either survey. Number of patches/10 m omitted as no significant difference was detected. Treatment 1, coarse tailings (ct) and top soil (ts); Treatment 2, ct and waste rock (wr); Treatment 3, ct, wr and ts. Treatment 4 (control) omitted due to a lack of replicates.

Variable	Treatment		
	1	2	3
Patch %	-	a,b	-
Interpatch %	-	a,b	-
Average patch width (cm)	-	a,b	-
Average Interpatch Length (m)	-	a,b	-
Longest interpatch (m)	-	b	-
Total Patch Area	-	a,b	-
Patch Area Index	-	a,b	-
Landscape Organisation Index	-	a,b	-
Stability	a,b	-	a
Infiltration	-	a	b
Nutrients	a	-	b

4.3.1.2 Grouping of treatments and reference sites according to variables

A PCA ordination on the data from site 2 reveals a clear separation between the reference sites and the rehabilitation treatments (Figure 4-2). Treatments 1 and 3 both form a tight cluster together, with the two samples from treatment 4 (control – coarse tailings) placing near this group. The low relative X-axis values, but comparable Y-axis values, suggest that this cluster had overall lower values for topsoil depth and all three SSA functionality indices, but more so for the stability index. Samples from treatment 2 all clustered together but were removed from the other treatments and the reference sites. The high Y-axis value of this cluster suggests high

stability index values, but low topsoil depth, infiltration index and nutrient cycling index values. It should be noted that high stability index values are divergent from high values for the other two SSA functionality parameters as well as topsoil depth, which was also observed by Van Der Walt *et al.* (2012).

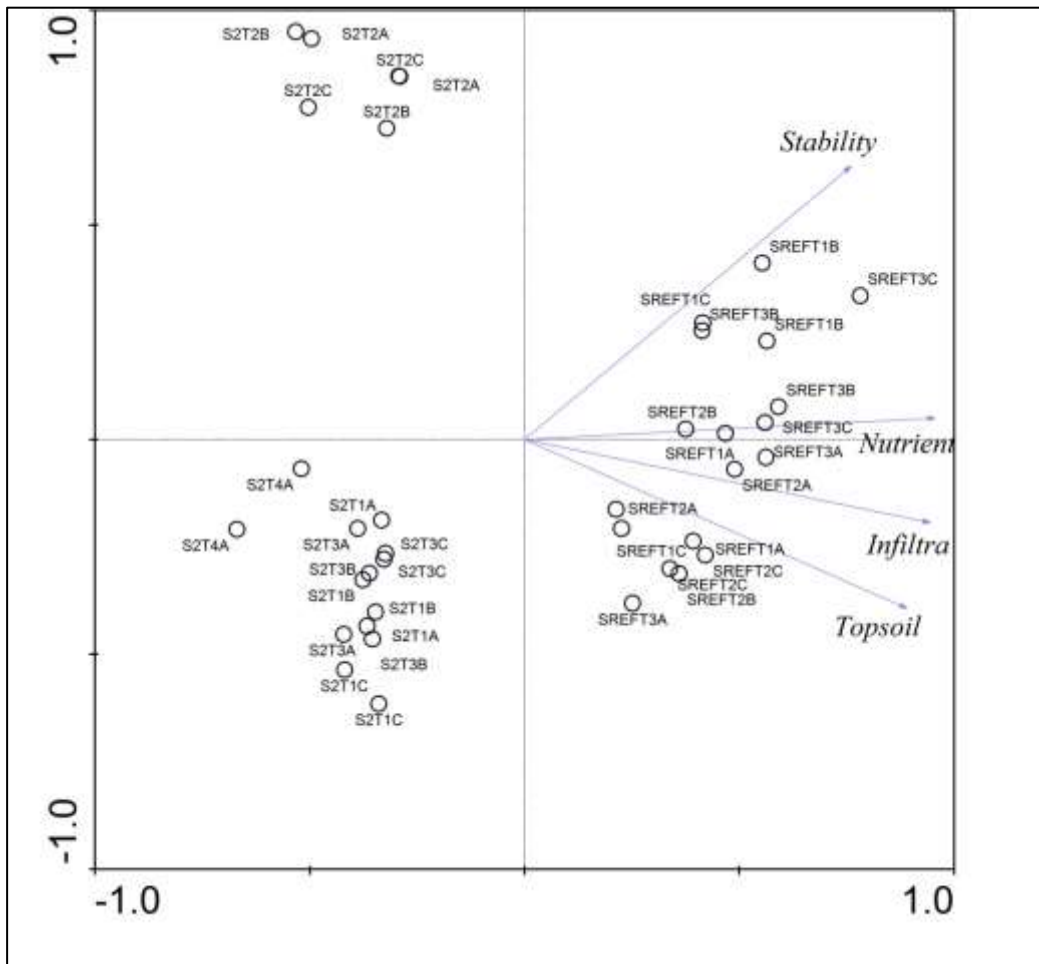


Figure 4-2: PCA ordination of SSA functionality indices and topsoil depth for rehabilitation treatments from site 2 as well as reference sites for both surveys. S2T1, Treatment 1, coarse tailings (ct) and top soil (ts); S2T2, Treatment 2, ct and waste rock (wr); S2T3, Treatment 3, ct, wr and ts S2T4, Treatment 4 (control – ct); SREF, reference site.

4.3.1.3 Comparisons within treatments over time

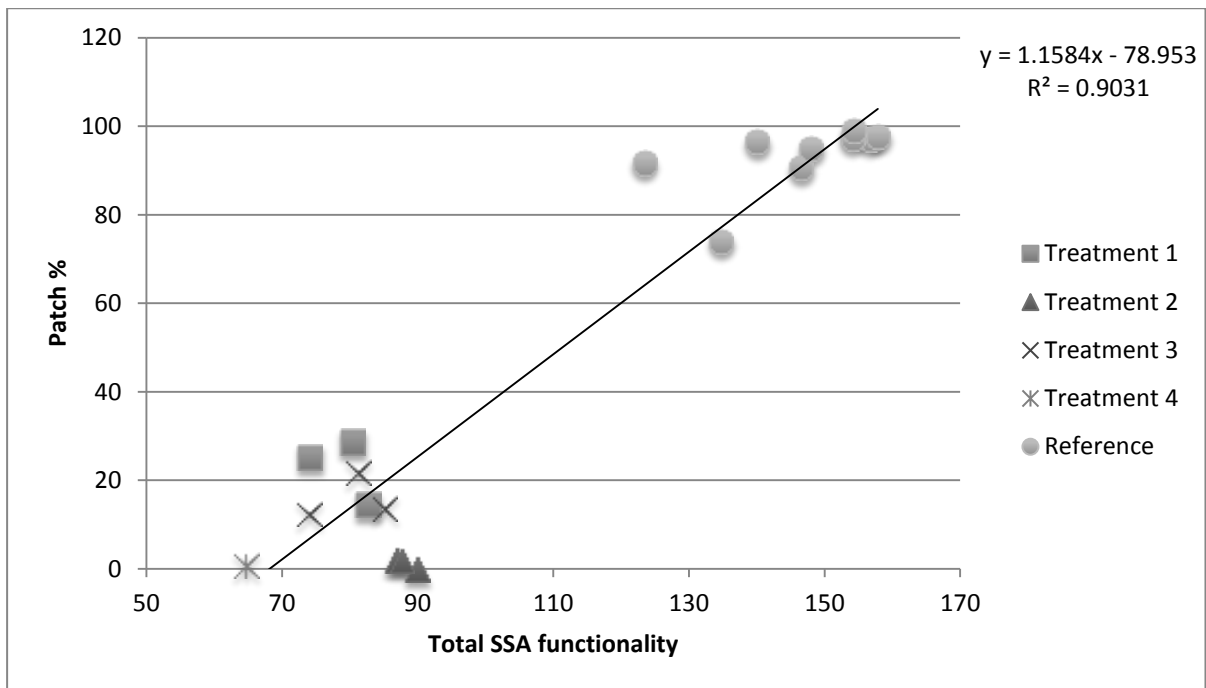
According to the Paired t-tests for the data from Trial Site 2 (Table 4-5) only two variables per treatment changed significantly over time (from March 2015 to April 2016). The nutrient cycling index increased significantly for all three treatments, while the infiltration capacity index decreased significantly for Treatment 3, but increased significantly for Treatment 2. The mean length of the longest interpatch increased significantly for Treatment 1 (Appendix 3).

Table 4-5: Paired t-test and Wilcoxon Signed Ranks test results for LFA data for treatments from Site 2 over time. Treatment 1, coarse tailings (ct) and top soil (ts); Treatment 2, ct and waste rock (wr); Treatment 3, ct, wr and ts. Significant values are in bold and marked with a * (p<0.05)

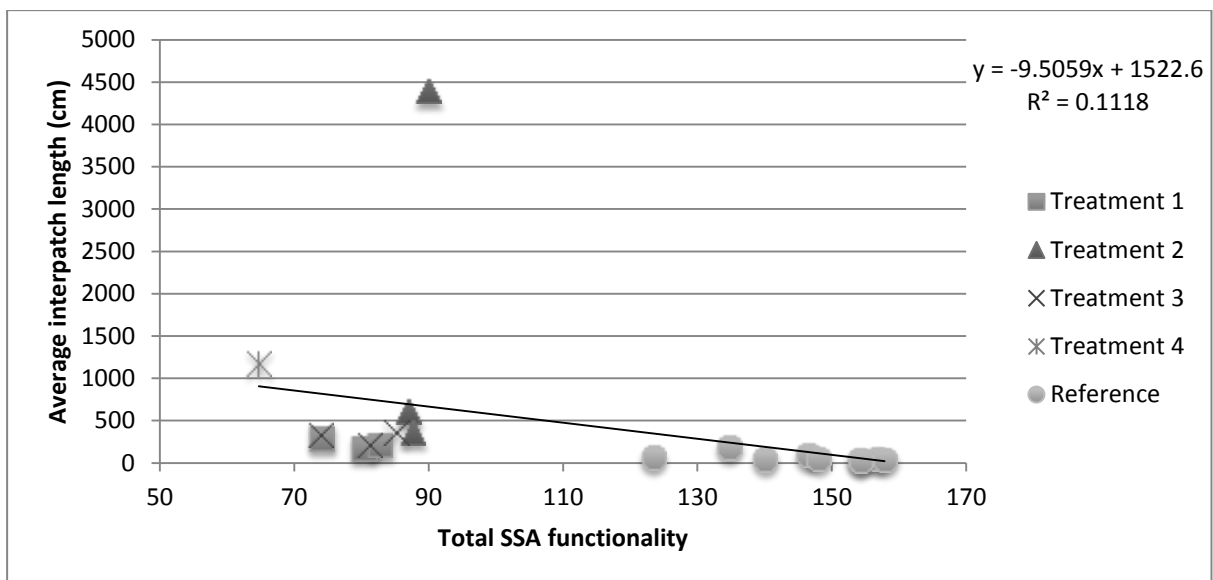
Variables	Treatment 1		Treatment 2		Treatment 3	
	Paired t-test p-value	Wilcoxon p-value	Paired t-test p-value	Wilcoxon p-value	Paired t-test p-value	Wilcoxon p-value
Patch %	0.1412	0.1088	0.6684	0.6547	0.1049	0.1088
Interpatch %	0.1412	0.1088	0.6684	0.6547	0.1049	0.1088
Average patch width (cm)	0.0555	0.1088	0.9643	0.6547	0.6999	1.0000
Number of Patches/10m	0.0750	0.1088	0.1846	0.1797	0.0905	0.1088
Average Interpatch Length (m)	0.1180	0.1088	0.2698	0.2850	0.1751	0.1088
Average interpatch length (cm)	0.1180	0.1088	0.2698	0.2850	0.1751	0.1088
Longest interpatch (m)	*0.0196	0.1088	0.2731	0.2850	0.0791	0.1088
Total Patch Area	0.3484	0.2850	0.9000	0.6547	0.5139	0.5930
Patch Area Index	0.3667	0.2850	0.8942	0.6547	0.3766	0.2850
Landscape Organisation Index	0.1412	0.1088	0.6684	0.6547	0.0647	0.1088
Stability	0.6318	0.5930	0.9306	0.6547	0.7773	0.5930
Infiltration	0.1685	0.1088	*0.0043	0.1088	*0.0387	0.1088
Nutrients	*0.0007	0.1088	*0.0115	0.1088	*0.0411	0.1088

4.3.1.4 SSA Correlations

There was a strong positive correlation ($r^2=0.9031$) between patch percentage and the total SSA functionality of treatments during the first survey (Figure 4-3a). However, there was no correlation ($r^2=0.1118$) between average interpatch length and total SSA functionality during the first survey (Figure 4-3b).



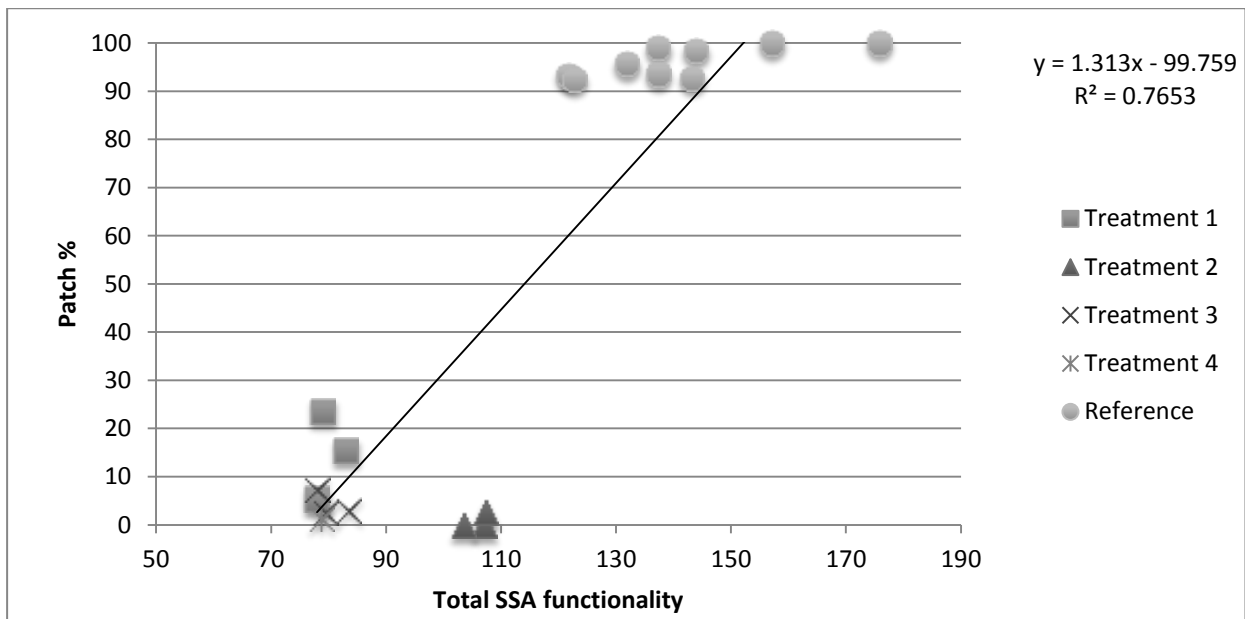
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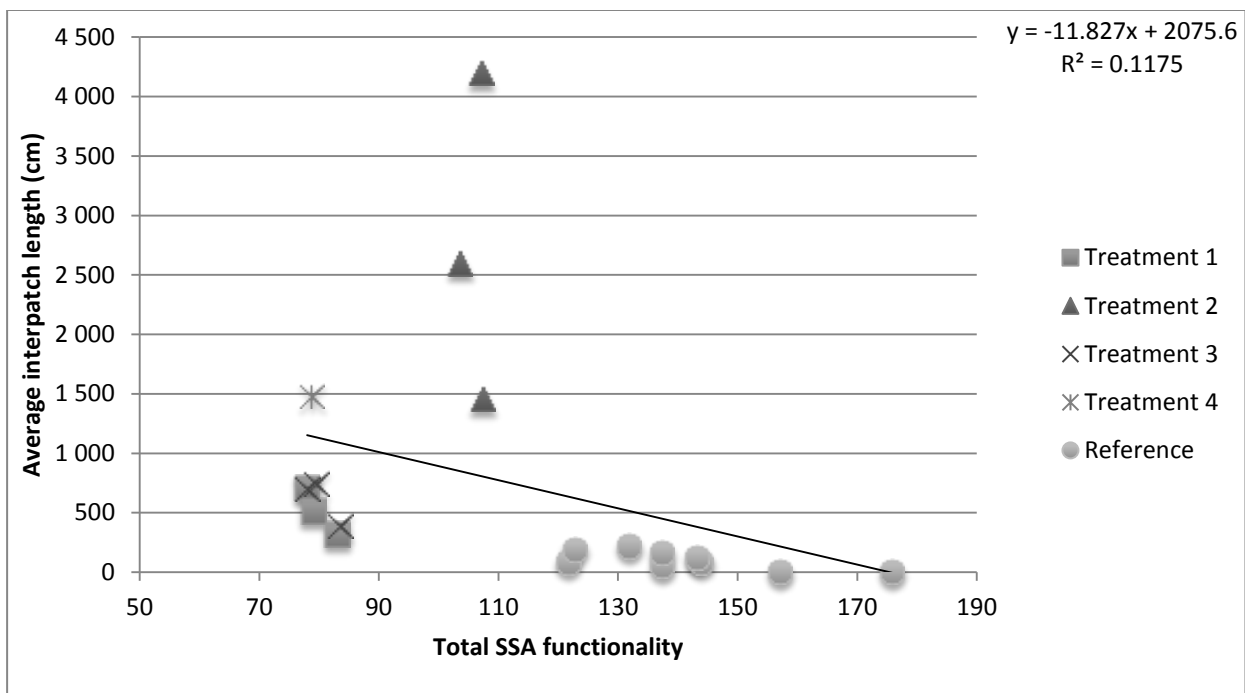
B

Figure 4-3: Scatterplot representing the (A) proportion of a transect consisting of patches and (B) average interpatch length regressed against the total SSA for each treatment at trial site 2, as well as the reference sites during the first survey (2015). Treatment 1, coarse tailings (ct) and top soil (ts); Treatment 2, ct and waste rock (wr); Treatment 3, ct, wr and ts; Treatment 4, ct; Reference, reference sites.

There remained a strong positive correlation ($r^2=0.7653$) between patch percentage and the total SSA functionality of treatments during the second survey (Figure 4-4a). There was once again no correlation ($r^2=0.1175$) between average interpatch length and total SSA functionality during the second survey (2016) (Figure 4-4b).



A



B

Figure 4-4: Scatterplot representing the (A) proportion of a transect consisting of patches and (B) average interpatch length regressed against the total SSA for each treatment at trial site 2, as well as the reference sites during the second survey (2016). Treatment 1, coarse tailings (ct) and top soil (ts); Treatment 2, ct and waste rock (wr); Treatment 3, ct, wr and ts; Treatment 4, ct; Reference, reference sites.

There were moderate to strong positive correlations between average patch width and the surface stability ($r^2=0.452$), infiltration capacity ($r^2=0.6327$) and the nutrient cycling SSA indices ($r^2=0.8054$) during the first survey in 2015 (Figure 4-5a-c)

Inversely there were no correlations between average interpatch length and the surface stability ($r^2<0.001$), infiltration capacity ($r^2=0.2984$) and nutrient cycling SSA indices ($r^2=0.1348$) (Figure 4-5d-f).

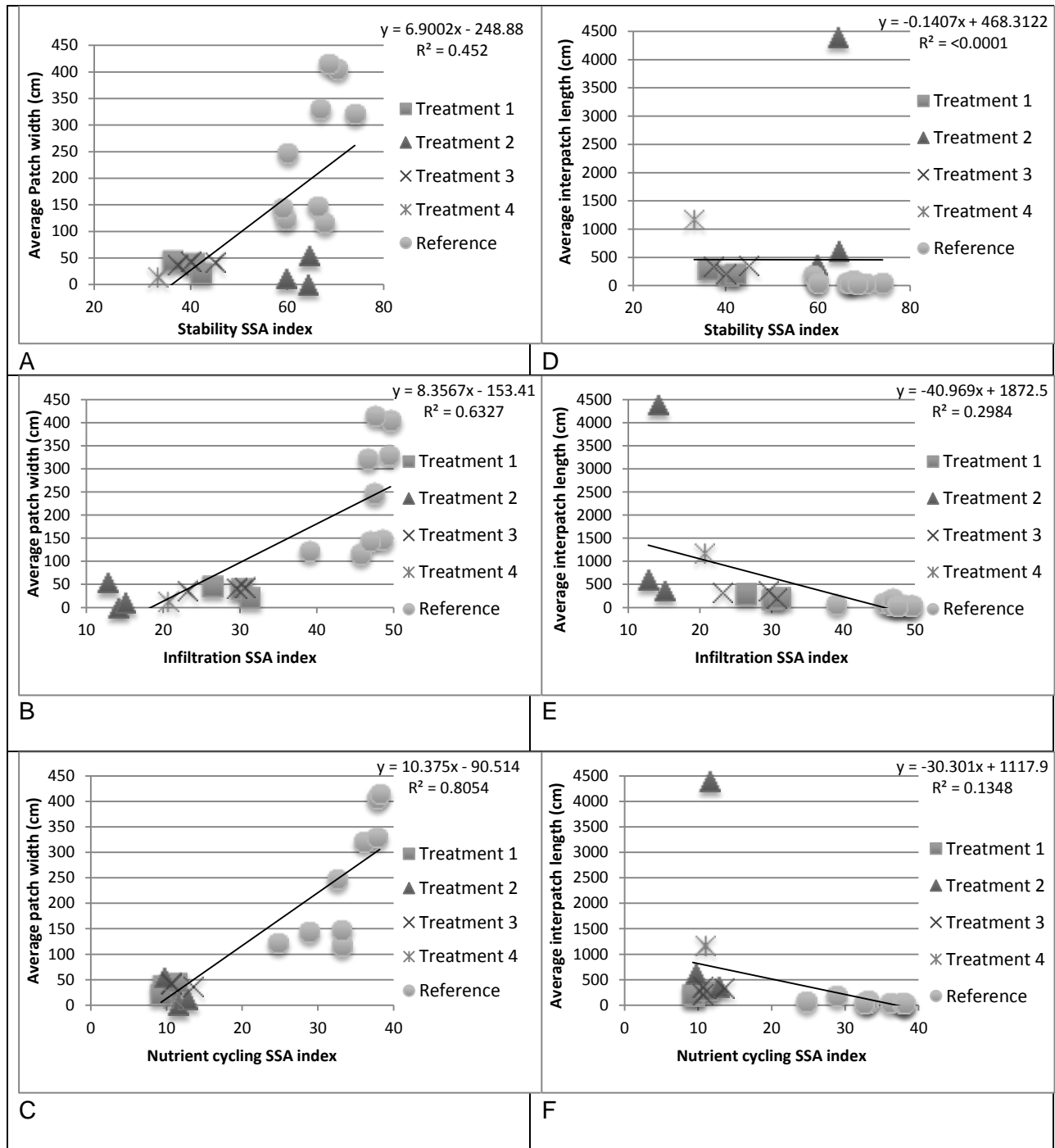


Figure 4-5: Scatterplot representing the average patch width (A-C) and average interpatch length (D-F) regressed against the surface stability, infiltration capacity and nutrient cycling SSA indices for each treatment at Site 2 as well as the reference sites during the first survey (2015). Treatment 1, coarse tailings (ct) and top soil (ts); Treatment 2, ct and waste rock (wr); Treatment 3, ct, wr and ts; Treatment 4, ct; Reference, reference sites.

There were moderate to strong positive correlations between average patch width and the surface stability ($r^2=0.3278$), infiltration capacity ($r^2=0.6976$) and the nutrient cycling SSA indices ($r^2=0.5729$) during the second survey in 2016 (Figure 4-6a-c).

Inversely there were no correlations between average interpatch length and the surface stability ($r^2=0.0037$), infiltration capacity ($r^2=0.2556$) and nutrient cycling SSA indices ($r^2=0.2788$) (Figure 4-6d-f).

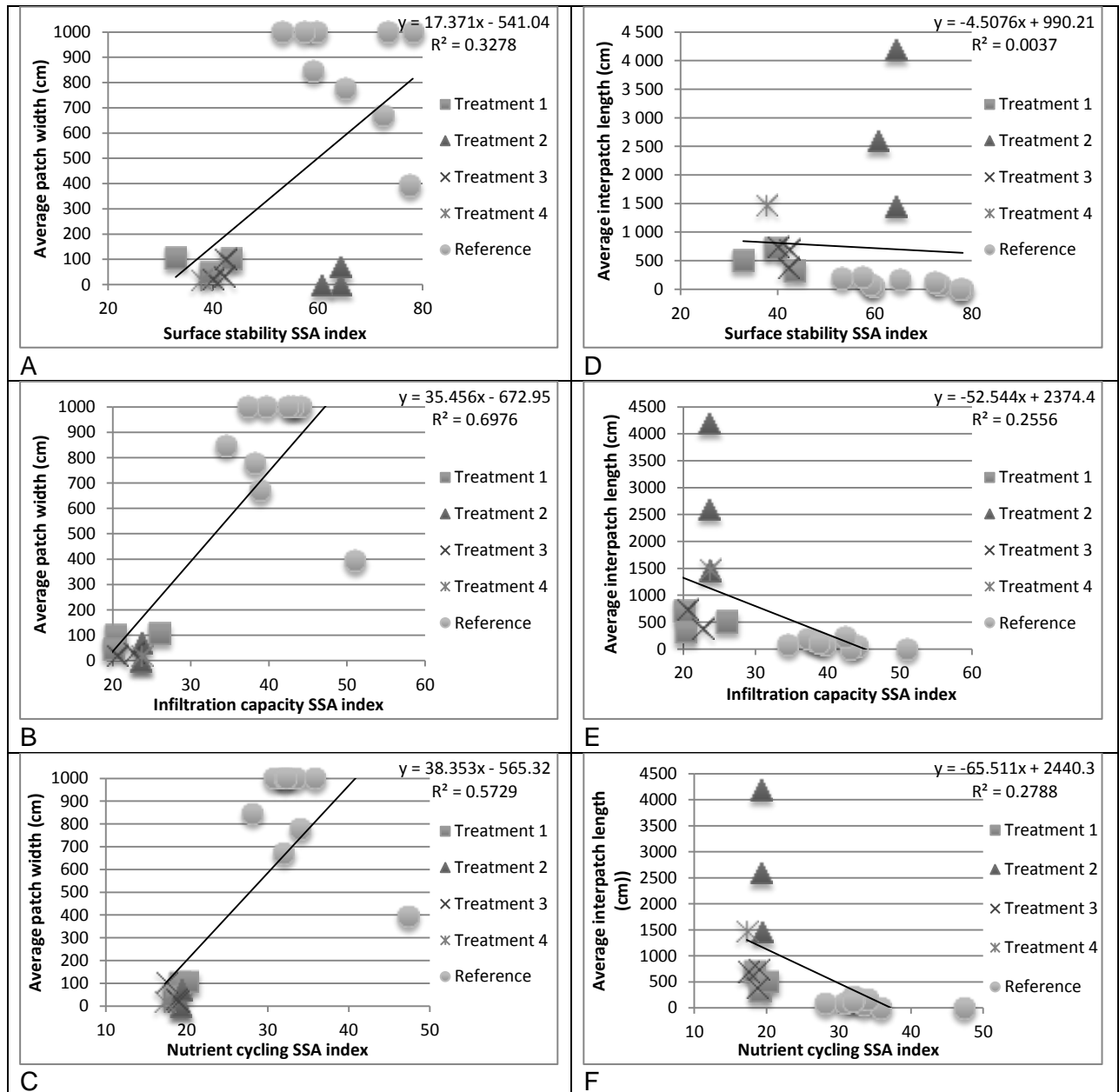


Figure 4-6: Scatterplot representing the average patch width (A-C) and average interpatch length (D-F) regressed against the surface stability, infiltration capacity and nutrient cycling SSA indices for each treatment at Site 2 as well as the reference sites during the second survey (2016). Treatment 1, coarse tailings (ct) and top soil (ts); Treatment 2, ct and waste rock (wr); Treatment 3, ct, wr and ts; Treatment 4, ct; Reference, reference sites.

4.3.2 Trial site 3 (waste rock terrace – mine offices)

4.3.2.1 Comparisons of variables between treatments and reference sites

There were significant differences ($p < 0.05$) between treatments for all of the variables during survey 1, except the number of patches/10 m, while all the variables differed significantly across treatments during survey 2 (Table 4-6). However, the Kruskal-Wallis post-hoc tests could not determine which treatments differed significantly in the number of patches/10 m during the second survey (Appendix 5).

The Kruskal-Wallis post-hoc tests indicated that none of the trial site treatments differed significantly from each other with regards to any variable during any survey, and all significant differences were between trial site treatments and the reference sites (Table 4-7). During the first survey, treatment 3 (waste rock and coarse tailings (200 mm)) differed from the reference site for the most variables (eight) during the first survey, with two being significantly higher (interpatch percentage and average interpatch length (m)) and six being significantly lower (patch percentage, average patch width (cm), total patch area, patch area index, landscape organisation index and stability SSA index) (Appendix 4).

Treatment 7 (waste rock, coarse tailings (250 mm) and topsoil (100 mm)) differed from the reference sites for the most variables (ten) during the second survey, with three being significantly higher (interpatch percentage, average interpatch length (m) and longest interpatch (m)) and seven being significantly lower (patch percentage, total patch area, patch area index, landscape organisation index, stability SSA index, infiltration SSA index and nutrient cycling SSA index) (Appendix 4). Treatment 3 differed significantly from the reference sites for seven of the 12 variables during the second survey, with three being significantly higher (interpatch percentage, average interpatch length (m) and longest interpatch (m)) and four being significantly lower (patch percentage, total patch area, patch area index and landscape organisation index) (Appendix 4).

Table 4-6: ANOVA and Kruskal-Wallis (KW) tests for LFA data from Site 3 comparing treatments with reference sites over two survey periods. Significant values in bold and marked with * (p < 0.05).

Variable	Survey 1 (df=7)			Survey 2 (df=7)			Survey 1		Survey 2	
	Sum of Squares	Mean Square	F	Sum of Squares	Mean Square	F	ANOVA p-value	Kruskal-Wallis	ANOVA p-value	Kruskal-Wallis
Patch %	30047.92	4292.56	43.37	48386.09	6912.30	216.14	*<0.0001	*0.0008	*<0.0001	*0.0015
Interpatch %	30047.92	4292.56	43.37	48386.09	6912.30	216.14	*<0.0001	*0.0008	*<0.0001	*0.0015
Average patch width (cm)	189249.01	27035.57	4.71	3471701.69	495957.38	23.57	*0.0024	*0.0015	*<0.0001	*0.0031
Number of patches/10 m	43.00	6.14	2.55	15.57	2.22	4.23	*0.0442	0.0828	*0.0043	*0.0285
Average interpatch length (m)	15.74	2.25	3.98	827.29	118.18	5.84	*0.0059	*0.0063	*0.0006	*0.0022
Longest interpatch (m)	253.78	36.25	1.75	2131.35	304.48	9.83	0.1486	*0.0130	*<0.0001	*0.0013
Total patch area	134071.24	19153.03	2.11	1362618.81	194659.83	985.54	0.0860	*0.0040	*<0.0001	*0.0013
Patch area index	0.55	0.08	1.88	5.39	0.77	883.44	0.1213	*0.0033	*<0.0001	*0.0020
Landscape organisation index	3.00	0.43	43.37	4.84	0.69	216.14	*<0.0001	*0.0008	*<0.0001	*0.0015
Stability	4668.87	666.98	37.16	4302.37	614.62	14.40	*<0.0001	*0.0020	*<0.0001	*0.0064
Infiltration	3514.23	502.03	38.05	1800.41	257.20	19.73	*<0.0001	*0.0066	*<0.0001	*0.0022
Nutrients	3265.26	466.47	58.25	1639.01	234.14	17.79	*<0.0001	*0.0038	*<0.0001	*0.0016

Table 4-7: Significant differences between treatments at Trial Site 3 and the reference sites for each variable based on Kruskal-Wallis post-hoc tests. Treatments marked with “a” differed significantly from the reference during survey 1, while treatments marked with “b” differed significantly from the reference during survey 2. Number of patches/10 m omitted as no significant difference could be specified. Treatments 1, waste rock (wr); 2, wr and coarse tailings (ct) (100 mm); 3, wr and ct (200 mm); 4, wr and top soil (ts) (100 mm); 5, wr and ts (250 mm); 6, wr, ct (100 mm) and ts (100 mm); 7, wr, ct (250 mm) and ts (100 mm).

Variable	Treatment						
	1	2	3	4	5	6	7
Patch %	a	-	a,b	-	-	-	b
Interpatch %	a	-	a,b	b	-	-	b
Average patch width (cm)	-	b	a	-	-	-	-
Average Interpatch Length (m)	-	-	a,b	-	-	-	b
Longest interpatch (m)	-	-	b	-	-	-	b
Total Patch Area	-	b	a,b	-	-	-	b
Patch Area Index	-	-	a,b	-	-	-	b
Landscape Organisation Index	a	-	a,b	-	-	-	b
Stability	-	a	a	-	-	a	b
Infiltration	-	-	-	-	-	b	b
Nutrients	-	b	a	-	a	-	b

4.3.2.2 Grouping of treatments and reference sites according to variables

PCA ordinations conducted on data from Trial site 3 showed a clear separation between the rehabilitation treatments and the reference sites (Figure 4-7). Treatment 5 clustered separately

from the other treatments and the reference sites because of its deeper topsoil. However, the distance between treatment 5 and the reference sites further suggests that this increased topsoil depth did not lead to an equal increase in SSA functionality.

Treatments 4, 6 and 7 clustered together nearest to the reference sites relative to the Y-axis, due to the similar topsoil depths. The location of these treatments relative to the reference sites suggests that they all had relatively uniformly lower values for the three SSA functionality indices than the reference sites.

Treatments 1, 2 and 3 clustered together due to their lack of topsoil. The location of these treatments relative to the reference sites suggests that they had lower values for all three SSA functionality indices compared to the reference sites, and possibly also compared to treatments 4, 6 and 7.

There was a divergence between topsoil depth and the three SSA functionality indices, suggesting that topsoil depth only had an effect up to a certain point. This is further reinforced by the clustering of the three different groups of treatments based on their topsoil depth, along a perpendicular axis to that of the three SSA functionality indices. The two extreme groups, with topsoil depths of 0 mm and 250 mm, were both further removed from the reference sites than the group that had 100 mm of topsoil.

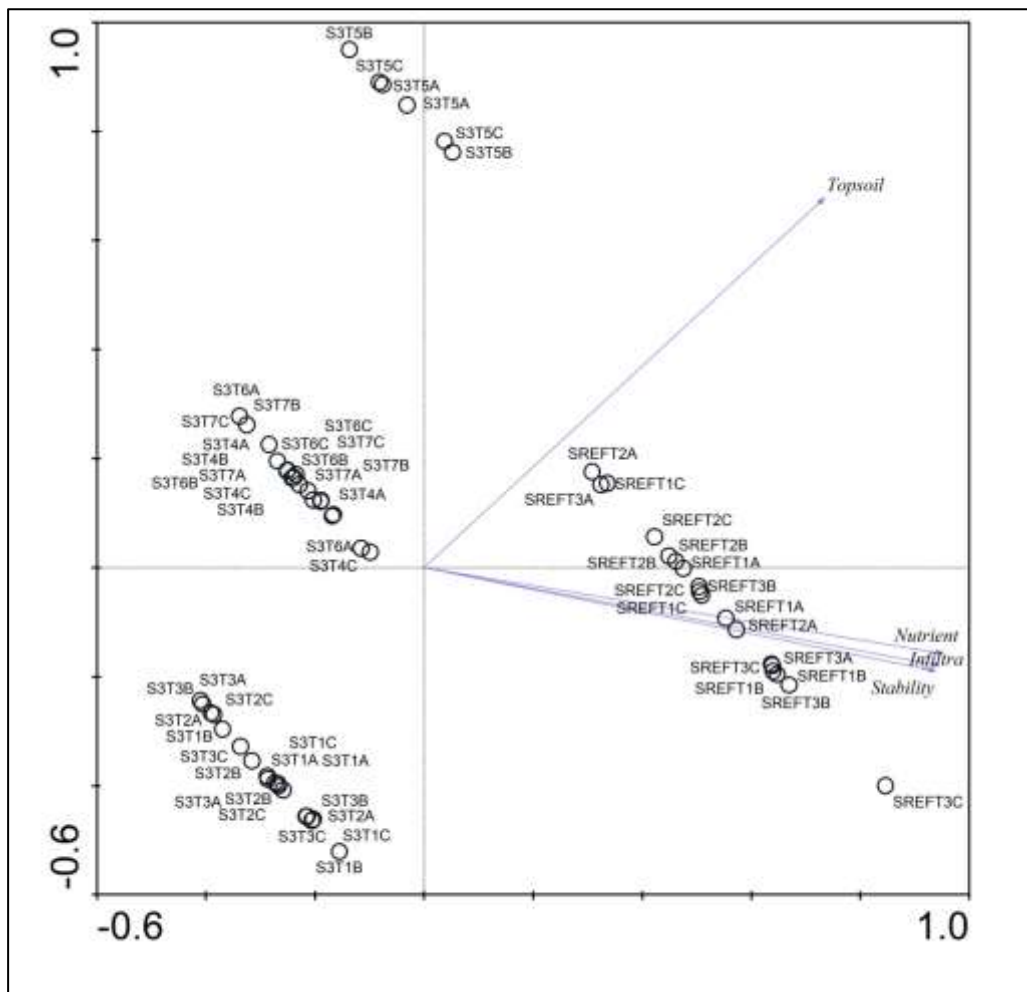


Figure 4-7: PCA ordination of SSA functionality indices and topsoil depth for rehabilitation treatments from site 3 as well as reference sites for both surveys. S3T1, Treatment 1 (control - waste rock (wr)); S3T2, Treatment 2 (wr and coarse tailings (ct) (100 mm)); S3T3, Treatment 3 (wr and ct (200 mm)); S3T4, Treatment 4 (wr and top soil (ts) (100 mm)); S3T5, Treatment 5 (wr and ts (250 mm)); S3T6, Treatment 6 (wr, ct (100 mm) and ts (100 mm)); S3T7, Treatment 7 (wr, ct (250 mm) and ts (100 mm)); SREF, reference.

4.3.2.3 Comparisons within treatments over time

Paired t-tests on the data from Site 3 indicated that several treatments changed significantly over time from March 2015 (survey 1) to April 2016 (survey 2) for multiple variables (Table 4-8). Treatments 4 and 5 both showed significant changes for the highest number of variables, six and seven respectively, while Treatments 1, 2 and 3 showed the least, with only one each. Treatments 1 and 3 both showed a significant decrease in the number of patches/10 m, while treatment 2 showed a significant increase in the nutrient cycling SSA index (Appendix 6). The four treatments containing top soil (treatments 4-7) showed the most significant changes over time.

Treatment 4 showed a significant increase in the interpatch percentage, average interpatch length and nutrient cycling SSA index, and a significant decrease in the patch percentage,

number of patches/10m and landscape organisation index (Appendix 6). Treatment 5 showed a significant increase in the interpatch percentage, average interpatch length (m), longest interpatch (m) and nutrient cycling SSA index, and a significant decrease in the patch percentage, number of patches/10m and landscape organisation index (Appendix 6). Treatment 6 showed a significant increase in the interpatch percentage and nutrient cycling SSA index, and a significant decrease in the patch percentage and landscape organisation index (Appendix 6). Treatment 7 showed a significant increase in the average interpatch length (m), longest interpatch (m) and nutrient cycling SSA index, and a significant decrease in the number of patches/10m (Appendix 6).

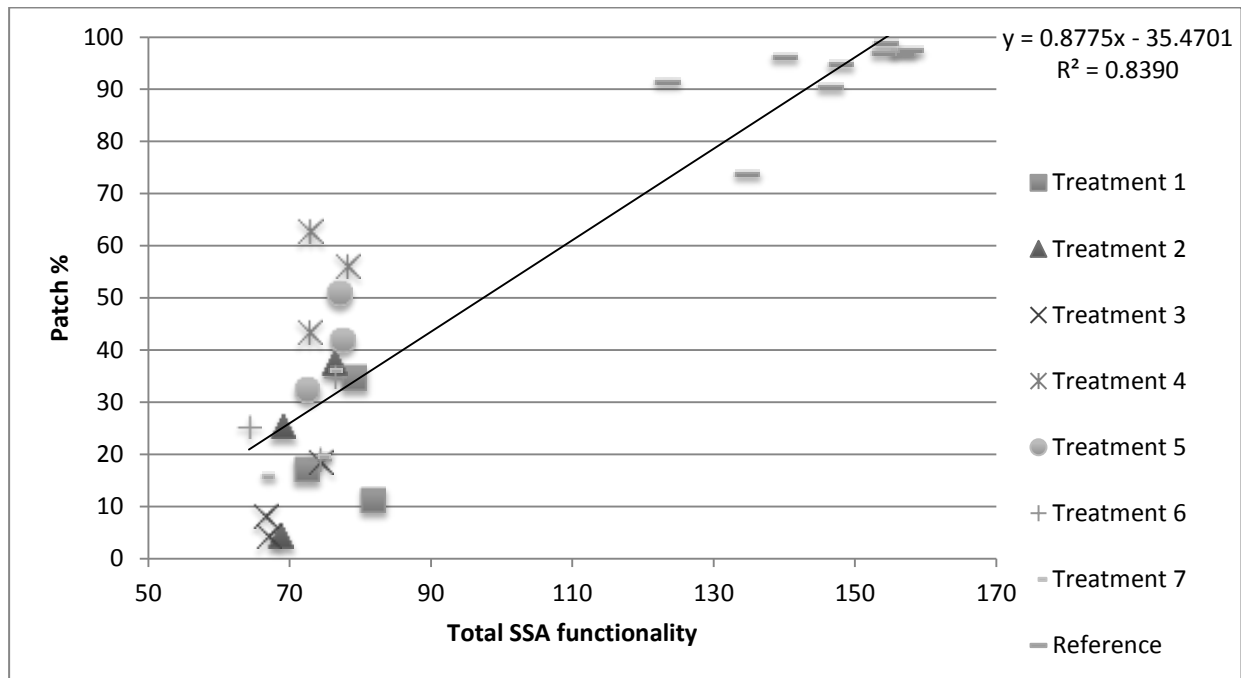
Table 4-8: Paired t-test results for LFA data for treatments from Site 3 over time. Significant values are in bold and marked with a * (p<0.05). Treatments 1, waste rock (wr); 2, wr and coarse tailings (ct) (100 mm); 3, wr and ct (200 mm); 4, wr and top soil (ts) (100 mm); 5, wr and ts (250 mm); 6, wr, ct (100 mm) and ts (100 mm); 7, wr, ct (250 mm) and ts (100 mm).

Variables	Paired t-test (p-value < 0.05)						
	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5	Treatment 6	Treatment 7
Patch %	0.1436	0.3424	0.3939	*0.0356	*0.0451	*0.0113	0.0873
Interpatch %	0.1436	0.3424	0.3939	*0.0356	*0.0451	*0.0113	0.0873
Average patch width (cm)	0.3505	0.9085	0.3476	0.7822	0.6207	0.9980	0.7743
Number of patches/10 m	*0.0156	0.1493	*0.0174	*0.0249	*0.0073	0.0744	*0.0047
Average interpatch length (m)	0.0650	0.2135	0.0998	*0.0447	*0.0506	0.1100	*0.0313
Longest interpatch (m)	0.0747	0.3596	0.0792	0.0793	*0.0404	0.0676	*0.0496
Total patch area	0.1855	0.4249	0.9860	0.0903	0.1000	0.1271	0.0774
Patch area index	0.0904	0.4339	0.6165	0.1082	0.1264	0.1727	0.1046
Landscape organisation index	0.1436	0.3424	0.3939	*0.0356	*0.0451	*0.0113	0.0873
Stability	0.7405	0.2933	0.1234	0.4330	0.5353	0.6819	0.6029
Infiltration	0.2064	0.3367	0.0701	0.3234	0.8058	0.6864	0.7727
Nutrients	0.0944	*0.0153	0.0655	*0.0240	*0.0098	*0.0099	*0.0107

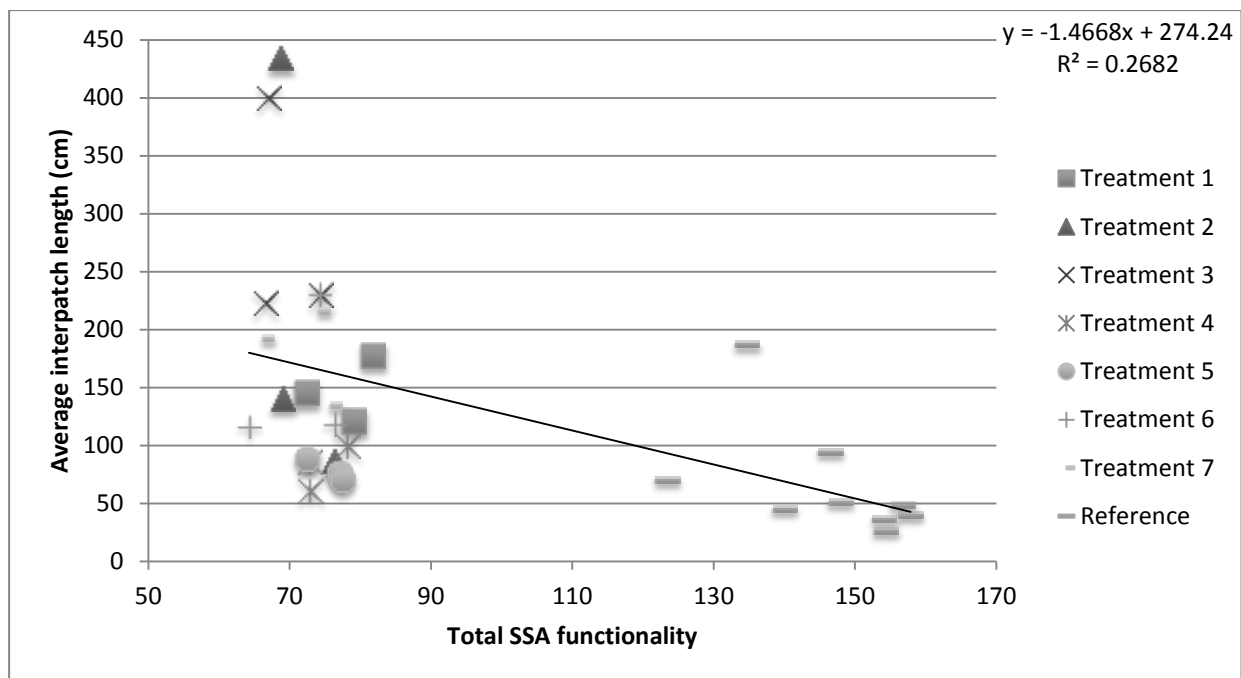
4.3.2.4 SSA Correlations

As with trial site 2, there was a strong positive correlation ($r^2=0.8390$) between patch percentage and total SSA functionality during the first survey (Figure 4-8a). There was also a weak negative correlation ($r^2=0.2682$) between average interpatch length and total SSA functionality (Figure 4-8b). There was a strong positive correlation ($r^2=0.8818$) between patch percentage and total SSA functionality during the second survey (Figure 4-9a). There was also a weak negative correlation ($r^2=0.2851$) between average interpatch length and total SSA functionality (Figure 4-9b). There were strong positive correlations between average patch width and the surface stability ($r^2=0.6262$), infiltration capacity ($r^2=0.5708$) and nutrient cycling SSA indices ($r^2=0.6524$) during the first survey in 2015 (Figure 4-10a-c). There were weak negative correlations between

average interpatch length and the surface stability ($r^2=0.3010$), infiltration capacity ($r^2=0.2543$) and the nutrient cycling SSA indices ($r^2=0.2101$) during the first survey (Figure 4-10d-f).

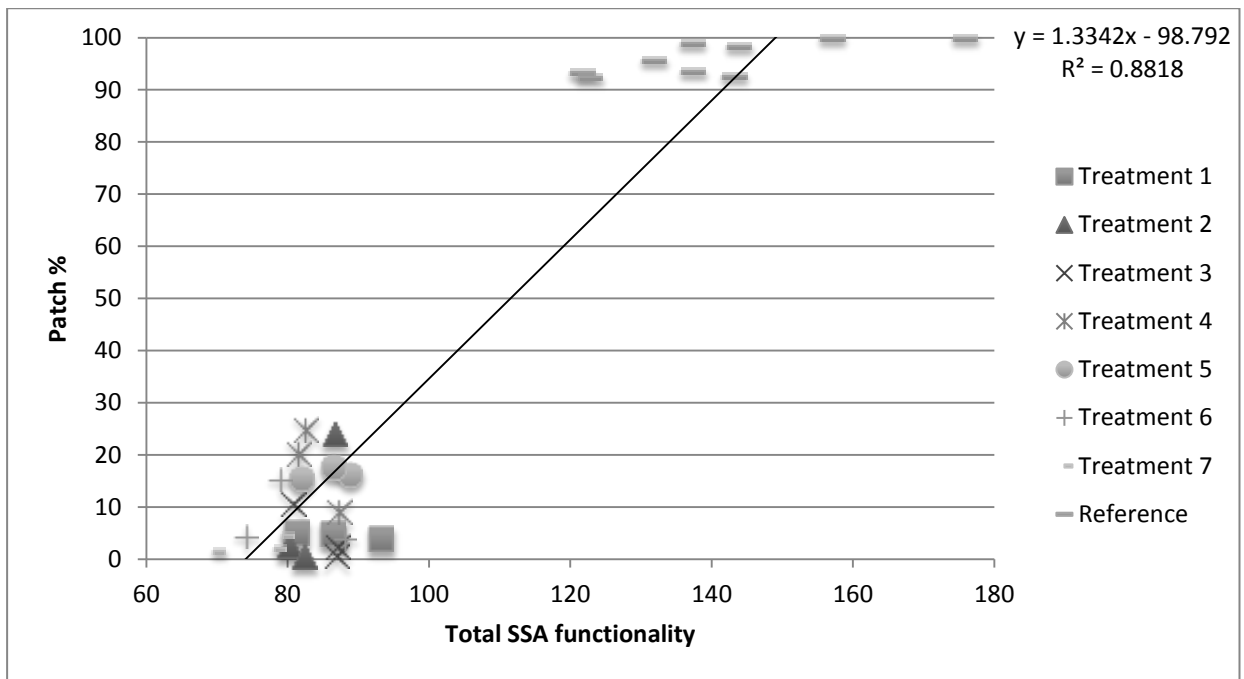


A

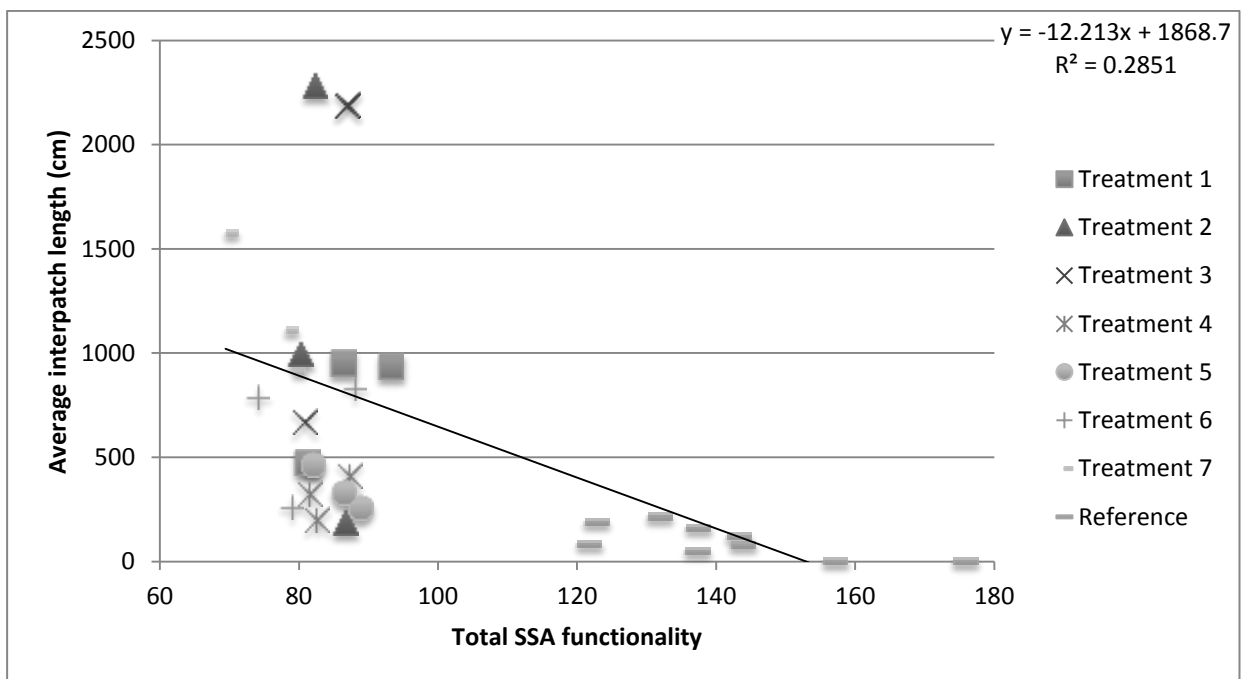


B

Figure 4-8: Scatterplot representing the (A) proportion of a transect consisting of patches and (B) average interpatch length regressed against the total SSA for each treatment at trial site 3 as well as the reference sites during the first survey. Treatments 1, waste rock (wr); 2, wr and coarse tailings (ct) (100 mm); 3, wr and ct (200 mm); 4, wr and top soil (ts) (100 mm); 5, wr and ts (250 mm); 6, wr, ct (100 mm) and ts (100 mm); 7, wr, ct (250 mm) and ts (100 mm); Reference, reference sites.



A



B

Figure 4-9: Scatterplot representing the (A) proportion of a transect consisting of patches and (B) average interpatch length regressed against the total SSA for each treatment at trial site 3 as well as the reference sites during the second survey. Treatments 1, waste rock (wr); 2, wr and coarse tailings (ct) (100 mm); 3, wr and ct (200 mm); 4, wr and top soil (ts) (100 mm); 5, wr and ts (250 mm); 6, wr, ct (100 mm) and ts (100 mm); 7, wr, ct (250 mm) and ts (100 mm); Reference, reference sites.

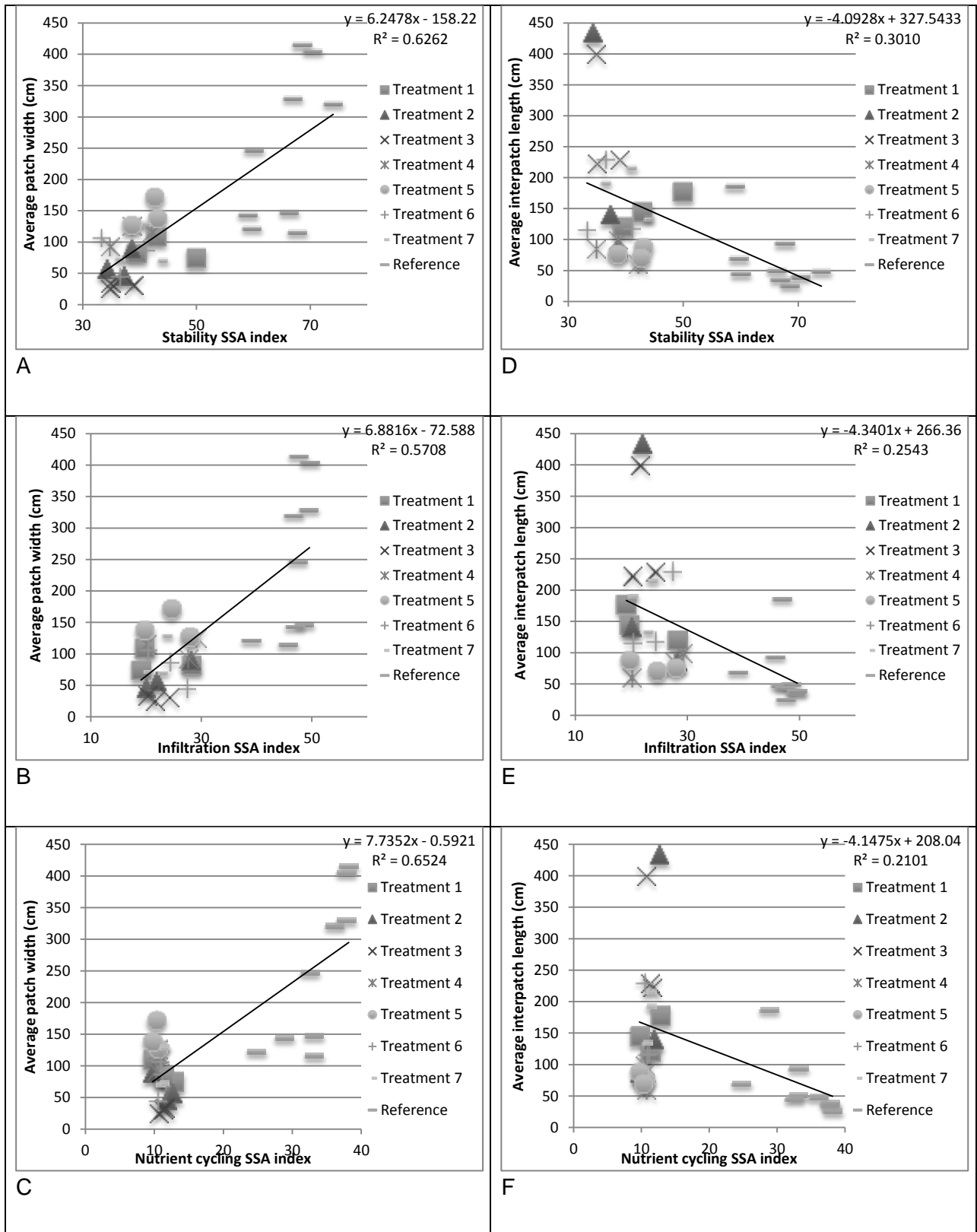


Figure 4-10: Scatterplot representing the average patch width (A-C) and average interpatch length (D-F) regressed against the surface stability, infiltration capacity and nutrient cycling SSA indices for each treatment at Site 3 as well as the reference sites during the first survey. Treatments 1, waste rock (wr); 2, wr and coarse tailings (ct) (100 mm); 3, wr and ct (200 mm); 4, wr and top soil (ts) (100 mm); 5, wr and ts (250 mm); 6, wr, ct (100 mm) and ts (100 mm); 7, wr, ct (250 mm) and ts (100 mm); Reference, reference sites.

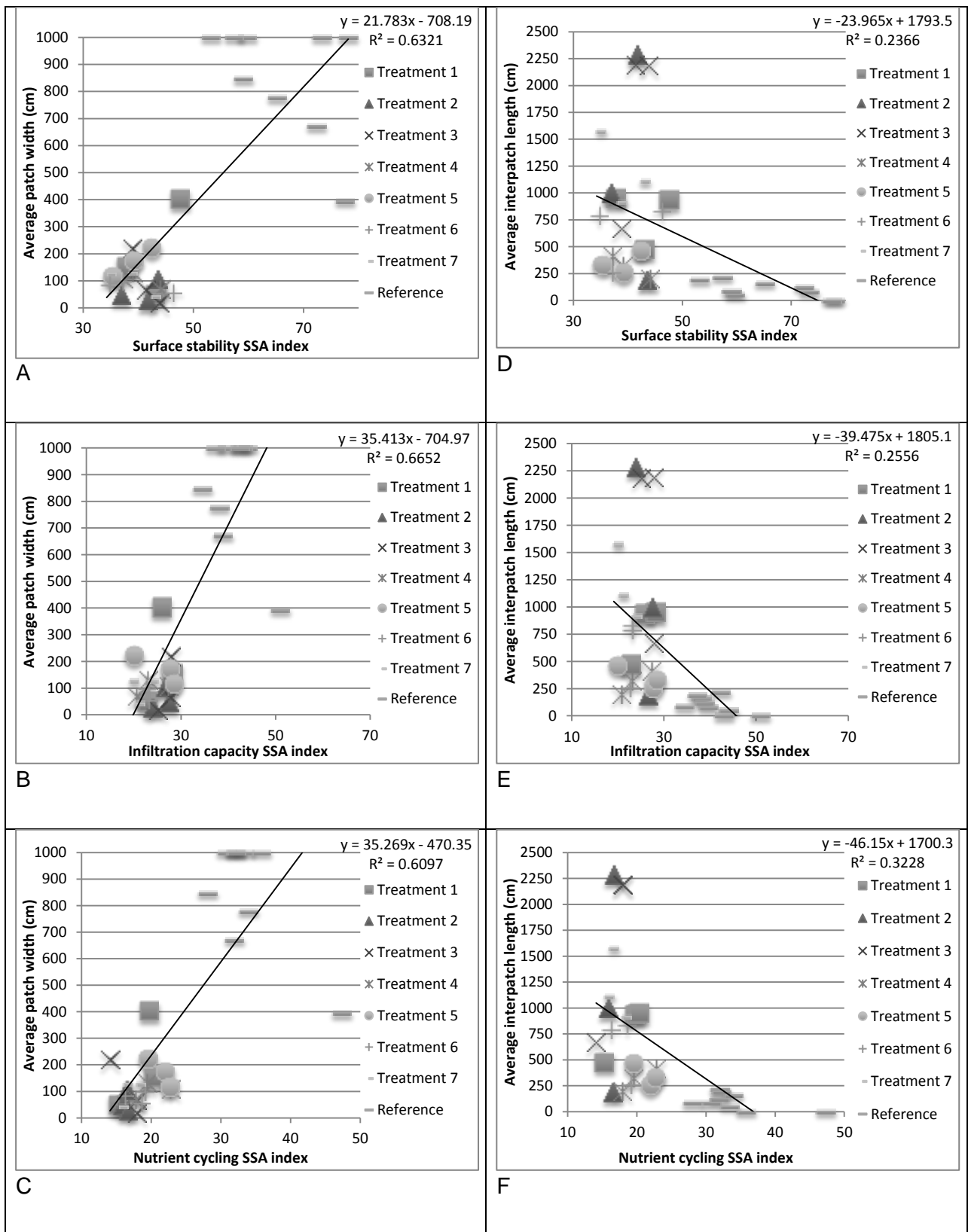


Figure 4-11: Scatterplot representing the average patch width (A-C) and average interpatch length (D-F) regressed against the surface stability, infiltration capacity and nutrient cycling SSA indices for each treatment at Site 3 as well as the reference sites during the second survey. Treatments 1, waste rock (wr); 2, wr and coarse tailings (ct) (100 mm); 3, wr and ct (200 mm); 4, wr and top soil (ts) (100 mm); 5, wr and ts (250 mm); 6, wr, ct (100 mm) and ts (100 mm); 7, wr, ct (250 mm) and ts (100 mm); Reference, reference sites.

4.4 Discussion

At Trial site 2 on the coarse tailings wall, treatment 2 (coarse tailings and waste rock) performed the worst of the three treatments during the second survey, however this treatment did not vary significantly from the reference site with regards to the three SSA indices, whereas the other two treatments, that both contained topsoil, differed significantly from the reference with regards to one or more of the SSA indices. This suggests that the presence of topsoil is important for rehabilitation when considering the overall parameters measured by the LFA methodology, but the correlation between the presence of topsoil and the SSA functionality indices may not be as direct as expected (Tongway & Ludwig, 2010). This can also be observed in the PCA ordination, where treatment 2 was clearly further removed from the reference sites than the other treatments that contained topsoil, while treatment 4 (which also did not contain topsoil) was also somewhat removed from these treatments. The divergence of the stability SSA index from the other two SSA indices also suggested that the relationship between the stability SSA index and topsoil depth, as well as the other two SSA indices, are not necessarily as direct as would be expected. This could lead to a high stability SSA index in treatments without topsoil, and would inflate the total SSA functionality of treatments despite the absence of topsoil and low infiltration and nutrient cycling SSA indices.

However, at Trial site 3 on waste rock, two of the three treatments that showed no significant differences for any variable compared to the reference sites, were treatments that contained topsoil. Treatments 4 (waste rock and top soil (100 mm)) and 5 (waste rock and top soil (250 mm)) showed no significant differences compared to the reference site, while treatment 6 (waste rock, coarse tailings (100 mm) and top soil (100 mm)) only differed significantly from the reference for one of the variables (infiltration SSA index). This further supports a positive correlation between the presence of topsoil in rehabilitation treatments and a favourable performance when compared to the reference sites (Sheoran *et al.*, 2010). However, the PCA ordination did not seem to indicate that an increase in the level of topsoil leads to an increase in functionality, with the treatments containing a moderate amount of topsoil (treatments 4, 6 and 7) grouped nearest to the reference sites, while treatment 5 with a larger amount of topsoil grouped further away from the reference sites, due to the topsoil metric increasing in a perpendicular direction as the SSA indices.

Table 4-9: Performance table comparing each treatment from trial site 2 to the reference sites. Variables where the treatment differed significantly from the reference at the second survey are marked with a cross. Treatments with the highest Total Performance compared the least favourably with the reference site during the second survey.

Variable	Treatments		
	1	2	3
Patch %	-	X	-
Interpatch %	-	X	-
Average patch width (cm)	-	X	-
Number of Patches/10m	-	-	-
Average Interpatch Length (m)	-	X	-
Longest interpatch (m)	-	X	-
Total Patch Area	-	X	-
Patch Area Index	-	X	-
Landscape Organisation Index	-	X	-
Stability	X	-	-
Infiltration	-	-	X
Nutrients	-	-	X
Total Performance	1	8	2

Table 4-10: Performance table comparing each treatment from trial site 3 to the reference sites. Variables where the treatment differed significantly from the reference at the second survey are marked with a cross. Treatments with the highest Total Performance compared the least favourably with the reference site during the second survey.

Variable	Treatment						
	1	2	3	4	5	6	7
Patch %	-	-	X	-	-	-	X
Interpatch %	-	-	X	-	-	-	X
Average patch width (cm)	-	X	-	-	-	-	-
Number of patches/10m	-	-	-	-	-	-	-
Average Interpatch Length (m)	-	-	X	-	-	-	X
Longest interpatch (m)	-	-	X	-	-	-	X
Total Patch Area	-	X	X	-	-	-	X
Patch Area Index	-	-	X	-	-	-	X
Landscape Organisation Index	-	-	X	-	-	-	X
Stability	-	-	-	-	-	-	X
Infiltration	-	-	-	-	-	X	X
Nutrients	-	X	-	-	-	-	X
Total Performance	0	3	7	0	0	1	10

When comparing the performance of treatments with the reference sites (Table 4-9 & 4-10) it seems that treatments containing coarse tailings - waste rock combinations perform poorly compared to treatments that contain only one of the two mixed with topsoil. Treatment 2 (coarse tailings and waste rock) at site 2 compared poorly with the reference sites for eight variables during the second survey, while a treatment at site 3 without coarse tailings, treatment 1 (waste rock only), did not differ significantly compared to the reference sites for any of the variables during the second survey. Not one treatment containing both coarse tailings and waste rock

scored a zero in the performance tables when compared to the reference sites during the second survey. The two treatments that performed the worst during the second survey, treatments 3 and 7 of trial site 3, both contained a mix of waste rock and coarse tailings (>200 mm). These treatments lack the capacity to accept, store and recycle water, nutrients and energy, and to sustain biological productivity and maintain environmental quality (water and air) (Larson & Pierce, 1994).

There are also several treatments that differed significantly from the reference at one of the surveys, but not the other. At trial site 2, treatment 1 differed significantly from the reference for both surface stability and nutrient cycling SSA indices during the first survey, but only for the surface stability SSA index during the second survey. According to the paired t-tests there was an insignificant decrease over time in the surface stability SSA index, and a significant increase over time in the nutrient cycling SSA index, with a very small increase in total SSA functionality over time (Appendix 3). Hooper and Vitousek (1998) found that nutrient cycling through resource use and nitrogen retention both increased with an increase in plant diversity. From Chapter 5 of this study, we know that treatment 1 at site 2 had the highest plant diversity of the rehabilitation treatments at this site, which may explain the increase in nutrient cycling.

Treatment 2 of trial site 2 differed significantly from the reference for seven of the non-SSA variables during the first survey and eight of the non-SSA variables during the second survey. However, it only varied significantly from the reference for the infiltration capacity SSA index at the first survey, but not at the second. The paired t-tests also showed a significant increase in both the infiltration and nutrient cycling SSA indices, as well as an insignificant increase in the surface stability SSA index over time (Appendix 3). The total SSA functionality of the treatment had increased over time despite an overall increase in significant variations from the reference site over time. Craw *et al.* (2007) found a significant negative correlation on quartz material between the percentage of coarse tailings material >2mm and percentage cover, with more natural revegetation on cohesive waste rock than on coarse pebbled areas. From Chapter 5 we know that this treatment had the lowest diversity of the rehabilitation treatments, and it is therefore difficult to explain why the infiltration and nutrient cycling SSA indices increased over time despite an apparent decrease in plant diversity.

Treatment 3 differed significantly from the reference site for the surface stability SSA index during the first survey, but not the second, and also differed significantly from the reference for both the infiltration capacity and nutrient cycling SSA indexes during the second survey, but not the first. The paired t-tests showed a significant decrease over time in the infiltration SSA index and a significant increase over time in the nutrient cycling SSA index, with an insignificant increase over time in the surface stability SSA index (Appendix 3). The total SSA functionality of this treatment had increased by an insignificant amount over time, despite showing an increase

in significant variations over time when compared to the reference sites. From Van Der Walt *et al.* (2012) a negative correlation between interpatch length and total SSA functionality, as increases in interpatch length suggests more open spaces. It is therefore unexpected to see an increase in total SSA functionality as the average interpatch length increases.

At trial site 3, only Treatments 1, 3 and 5 showed a decrease in significant variations from the reference over time. Treatment 1 differed significantly from the reference for three non-SSA variables during the first survey, but did not differ in any variables from the reference during the second survey. The paired t-tests, however, showed no significant increases over time, only a significant decrease in the number of patches/10 m. However, there was a marginal increase in the total SSA functionality of the treatment over time (Appendix 6) and this trend is documented for woodlands (Gould, 2012) but not alpine areas.

Treatment 3 at site 3 differed from the reference site for eight variables including the surface stability SSA index during the first survey, but only seven non-SSA variables during the second survey. The paired t-tests again showed no significant increases over time, only a significant decrease in the number of patches/10 m, which is expected in alpine areas where fertilization is discontinued after seedling establishment (Brown *et al.*, 1984). There was a notable increase in the total SSA functionality of the treatment over time (Appendix 6).

Treatment 5 differed significantly from the reference with regards to the nutrient cycling SSA index during the first survey, but not during the second survey. The paired t-tests, however, showed significant increases in interpatch percentage, average interpatch length (m), longest interpatch (m) and the nutrient cycling SSA index, and significant decreases in patch percentage, number of patches/10 m and the landscape organisation index, suggesting that the treatment had in fact degraded over time. This is especially expected for treatments where soil formation is at an early stage of pedogenesis (Huggett, 1998). Despite this, the total SSA functionality of the treatment had increased over time (Appendix 6).

Treatment 6 differed significantly from the reference site for the stability SSA index during the first survey, and the infiltration SSA index during the second survey. According to the paired t-tests treatment 6 showed a significant decrease in patch percentage and the landscape organisation index, and a significant increase in interpatch percentage and the nutrient cycling SSA index over time. This suggests a loss in the landscape's ability to become organized as a patchy, source-sink systems. Hence, the treatment is showing evidence of water and nutrient losses within the system (Ludwig & Tongway, 1996). The surface stability SSA index increased slightly over time, while the infiltration capacity SSA index decreased slightly over time, although neither change was significant. The total SSA functionality of treatment 6 increased despite the decrease in patch percentage (Appendix 6).

It should be noted that treatment 4 at site 3 did not vary significantly from the reference for any variable during either survey. However, the paired t-tests indicated that treatment 4 showed a significant change over time for six variables, including a significant decrease in patch percentage, number of patches/10m and the landscape organisation index. Despite this the nutrient cycling SSA index still increased significantly over time, and is ascribed to litter derived from successful plant growth of the wheat mother crop in year 1 (Todd *et al.*, 2000). The surface stability SSA index also increased over time, but the infiltration capacity SSA index decreased over time, both insignificantly. There was a slight increase in the total SSA functionality of treatment 4 over time (Appendix 6).

Treatment 2 and Treatment 7 containing waste rock at trial site 3 both showed degradation from the first survey to the second when compared to the reference. Treatment 2 only differed significantly from the reference for the stability SSA index during the first survey, while it differed significantly for the nutrient cycling SSA index and two other variables (average patch width (cm) and total patch area) during the second survey. The paired t-tests however indicated that treatment 2 showed no significant decreases over time for any variable, and that the nutrient cycling SSA index increased significantly over time. The other two SSA indices both increased slightly over time, while average patch width (cm) decreased and total patch area decreased slightly. Patches are considered to be an essential part of a functional landscape because of their ability to capture and store nutrients and release them slowly, which also increases the life span of the perennial plants in these patches (Tongway & Ludwig, 1996). Typically there is a strong correlation between a decrease in patches and a decrease in total SSA functionality (Van Der Walt *et al.*, 2012). The contradictory results found in this study may imply that the rehabilitation treatments were not yet stable enough to react predictably to known environmental factors.

Treatment 7 did not differ from the reference site during the first survey, but during the second survey differed in ten variables, including all three SSA indices. The paired t-tests indicated a significant decrease in the number of patches/10 m and a significant increase in the average interpatch length (m), longest interpatch (m) and the nutrient cycling SSA index over time. Such trends are often perceived in rehabilitation, where initial functionality is compromised as the vegetative cover is reduced over time due to inherent structural and chemical properties of the growth medium mixture that was applied (Morgenthal *et al.*, 2004). Treatment 7 showed only a slight decrease in the surface stability and infiltration capacity SSA indices over time, and a small overall increase in the total SSA functionality.

The above disparities between a change over time in the amount of significant deviations compared to the reference sites and the actual significant changes of variables over time suggests that directly comparing treatments to the reference sites over time may not accurately

identify any increase or decrease in the measured variables that may be occurring on the rehabilitation treatments. The time span of this study was too short to make meaningful assessments of the landscape functionality (Tongway & Hindley, 2004b). While Table 4-9 seems to indicate a decrease in functionality on treatments 3 and 7, both of these treatments have actually improved their total SSA functionality scores over time, as have nearly all the other treatments. It is therefore important to note that even while the treatments that contain a tailings mix did not perform well when compared to the reference sites, these treatments still improved over time, even if only slightly and to a lesser degree than the other treatments. An increase in functionality or nutrient cycling despite a decrease in patches is again contrary to what is seen in the literature (Hooper & Vitousek, 1998; Van Der Walt *et al.*, 2012). Hence, this study might be depicting the initial benefits of the mother crop, and only time will tell whether the established indigenous grasses will be able to maintain positive SSA.

The SSA correlations also provided some unexpected results. While the total SSA functionality was positively correlated to the average patch width and negatively correlated to the average interpatch length for both sites during both surveys, the surface stability SSA index had no correlation ($r^2 < 0.001$) or a very weak negative correlation ($r^2 = 0.0037$) with the average interpatch length at site 2 during both surveys. The same regressions at site 3 indicated a definite negative, albeit weak, correlation ($r^2 > 0.23$). The other two SSA indices showed a negative correlation ($r^2 > 0.13$) with average interpatch length at both sites for both surveys. From Van Der Walt *et al.* (2012) it was expected that there will be a clear negative correlation between the surface stability SSA index and the average interpatch length. Once again, more than two years is probably required for these treatments to settle before clear SSA patterns can be discerned.

Similar to the results of Van Der Walt *et al.* (2012), there were positive correlations between the total SSA functionality and the average patch width at each site during each survey. There were also positive correlations between every individual SSA index and the average patch width at each site during each survey. The total SSA functionality was also negatively correlated with the average interpatch length, and with the exception of the surface stability SSA index at site 2 discussed above, each individual SSA index was also negatively correlated with the average interpatch length at each site during both surveys. These findings indicate that the integrity of the systems increases as the vegetation cover (and subsequent microbial activity) increases, which in turn shows the relation between biodiversity and functionality (Ludwig *et al.*, 2004).

CHAPTER 5: VEGETATION MONITORING

5.1 Introduction

Land-use intensification results in species loss and fluctuations in evenness (Bullock *et al.*, 2011; Crowder *et al.*, 2010) due to transformation of indigenous vegetation by different land-uses (Lavorel *et al.*, 1997). It is estimated that three quarters of all terrestrial biomes have already been transformed to anthromes (anthropogenic biomes) through land-use practices such as cultivation (Ellis *et al.*, 2010). Environmental change is enhanced by an escalating human population, habitat fragmentation, cultivation, invasive aliens, harvesting of natural resources and mining activities.

Mining activities, specifically, transforms fertile land into wasteland through the production of enormous volumes of solid wastes which is deposited at the surface and occupy vast areas of land (Li, 2006). Species react differently to such immense environmental changes (Yachi & Loreau, 1999) and responses are induced on plant community composition and diversity (Díaz & Cabido, 2001). This means that some species will increase in abundance and others will decrease, depending on whether they can overcome environmental stressors. Disturbance severity, frequency and nature, resource requirements of individual species and vegetation type play a significant role in the responses of individual species and communities (Grime, 1977; Pandey & Singh, 1985).

The dynamics of individual species are often altered by different land-use management practices, which could result in the loss of key species making ecosystems more susceptible to degradation (Shackleton, 2000). According to Shackleton *et al.* (1994), disturbance factors override dominant abiotic variables that usually drives species composition and community structure. However, disturbance can result in favourable conditions for a community such as increased nutrient cycling, establishment of seedlings and increased diversity, whereas unfavourable impacts could include reduced canopy cover and increased soil erosion (Shackleton *et al.*, 1994). The disturbance theory is not well explored in alpine ecosystems and considering the fast developing mining industry of Lesotho, it may become essential to understand what the long-term effects will be in the landscape. It is therefore important to monitor these areas to provide valuable information on management practices and relative rehabilitation success, as well as describing changes in vegetation over time (Good, 2006; Nghenvironmental, 2007; Kent, 2012).

Land-uses are a form of land degradation (Rutherford & Powrie, 2011) and are regarded as one of the main causes of biodiversity loss (Scholes & Biggs, 2005; Rutherford & Powrie, 2013). However, some studies revealed that land-use change may have little, or even positive effects, on species richness (Shackleton, 2000; McKinney, 2008; Flynn *et al.*, 2009; Biswas & Mallik, 2010; Rutherford & Powrie, 2013), while the intermediate disturbance hypothesis predicts that some disturbance levels can govern high species diversity (Grime, 1977; Biswas & Mallik, 2010). Therefore, land-use change resulting in moderate levels of disturbance, relative to protected areas, may have comparatively high diversity. Whether this holds for alpine areas in southern Africa is still unknown and requires further investigation. Increased species richness, according to the diversity-stability hypothesis, is necessary to provide insurance and minimize the deterioration of an ecosystem (Chapin *et al.*, 2000; McCann, 2000). Since high species diversity promotes ecosystem resilience and resistance (Chapin *et al.*, 2000), diverse ecosystems will be more stable during environmental disturbances (Mori *et al.*, 2013).

Since rehabilitation of mine dumps in the afro-alpine zone of Lesotho has become a research priority (Section 84.4 of the Environment Act of Lesotho, Act 10 of 2008), an urgent need has arisen to understand the effect of land-use disturbance intensities on its stability and recovery potential. The heavily utilized and transformed mining landscape provides an opportunity to test the effect of soil treatments on plant community composition and diversity. Treatments with various topsoil, waste rock, coarse tailing and fine tailing mixes could be compared to contribute to an understanding of optimal situations required for stability and laying the foundations for long-term monitoring of ecosystem resilience and resistance. Linking the relationship between species diversity and composition with treatments will allow decision makers to make predictions regarding optimal and cost effective rehabilitation plans.

The aim of this study was to assess and compare vegetation establishment on different types of tailings and topsoil mixes (treatments) with reference sites within the mine lease area, to determine which treatments would be the most suitable for optimal rehabilitation. To achieve this aim, the following specific objectives were set, namely to i) compare the species richness, abundance and diversity of the treatments with each other, as well as the reference sites, ii) compare the species composition of the treatments with each other, as well as the reference sites, and iii) assess the changes in species richness, abundance and diversity of each treatment over time.

5.2 Methods

5.2.1 Study design

At trial site 1 (Table 5-1), six treatments were laid out on the fine tailings. Each treatment consisted of three repeats. Nine quadrats were therefore sampled for each treatment, totalling 54 samples per survey. Three surveys were relevant to site 1 from 2014 to 2016. Survey 4 was conducted in December 2014, survey 6 in December 2015 and survey 7 in April 2016.

At trial site 2 (Table 5-1) on the coarse tailings, four treatments were constructed. Each treatment was divided into four topographical positions: top (flat area), upper, mid and lower slopes. Each treatment consisted of three repeats. It should be noted that site 2 did not have an equal number of samples per treatment, as treatment 4 (control) only had one repetition, and the third repetition of treatment 3 did not have a top topographic position. There were 36 samples taken from treatments 1 and 2, 33 from treatment 3, and 12 from treatment 4, totalling 117 samples for site 2 during each survey. Three surveys were relevant to site 2 from 2014 to 2016. Survey 4 was conducted in December 2014, survey 6 in December 2015 and survey 7 in April 2016.

At site 3 (Table 5-1) the treatments were also divided into the same topographic positions as site 2, with the exception of the top position. As at site 2, all topographical positions on each repetition of each treatment were sampled three times. There were 27 samples taken from each treatment, totalling 189 samples from site 3 during each survey. Three surveys were relevant to site 3 from 2015 to 2016. Survey 5 was conducted in April 2015, survey 6 in December 2015 and survey 7 in April 2016.

Reference sites (Table 5-1) were sampled similarly to the rehabilitation trial sites. Sampling was conducted down slope along a transect with the top point marked using GPS co-ordinates (Appendix 16). The transect area was 50 m long and divided into the same three topographical positions as trial site 3. Quadrat sampling was done randomly inside a space measuring no more than 10 m from the centreline of the transect, with three quadrats at each topographical position. There were three reference sites, with three transects each, totalling 81 quadrats from the reference sites during each survey. Every species inside the quadrat was identified and the abundances recorded. Two surveys were conducted at the reference sites, during survey 6 in December 2015 and survey 7 in April 2016. Surveys 1-3 were not used for this study, as species-level data were not collected.

There were three main research questions that had to be addressed during this study (Figure 5-1). Firstly, the differences between the treatments regarding species composition had to be determined. Secondly, the differences between the treatments regarding species diversity had to be determined. Thirdly, the changes over time in the species diversity and composition within treatments had to be determined. To achieve this, treatments at each site were compared with each other and the reference sites. Treatments at different sites were not compared.

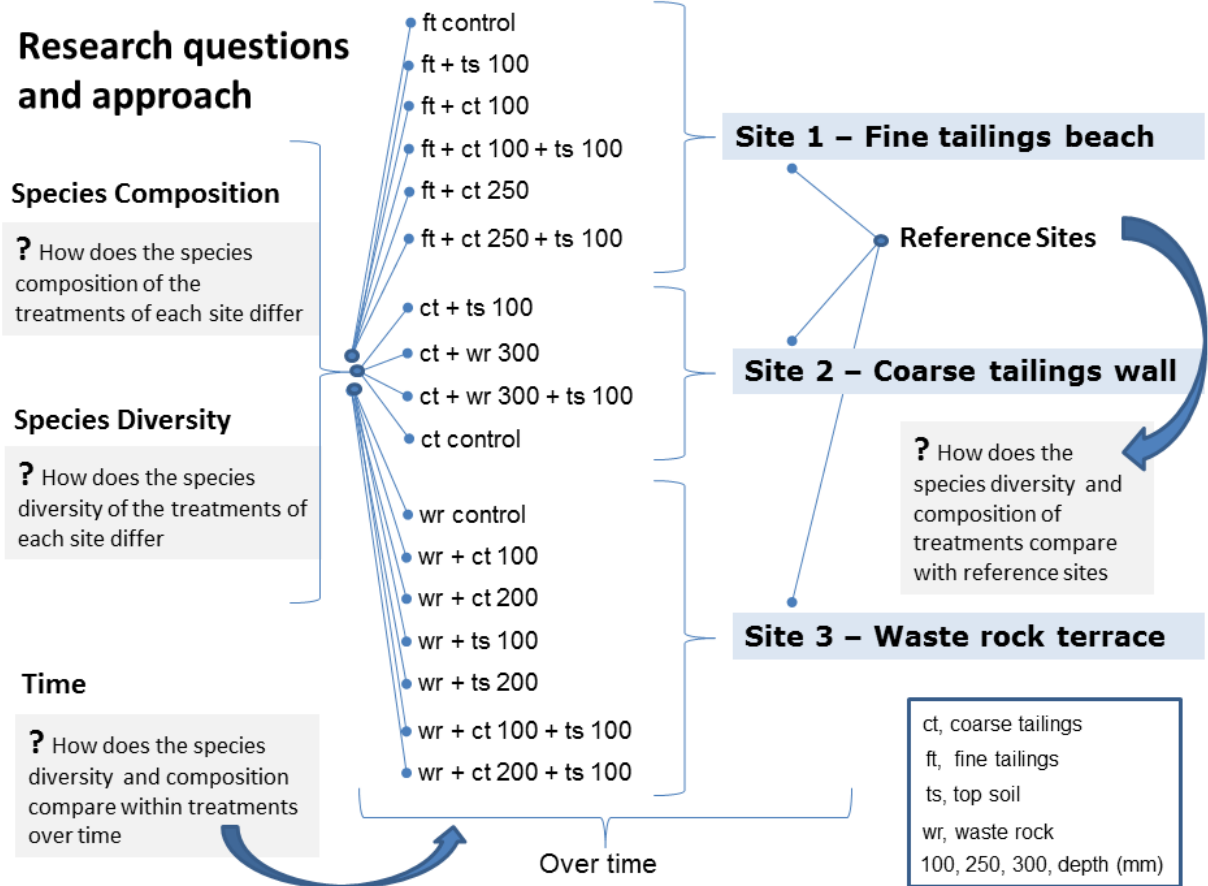


Figure 5-1: Overview of the research questions and approach followed for data analyses and discussion.

Table 5-1: Composition, design and surveys of the various treatments at rehabilitation sites 1, 2 and 3. Survey 4, December 2014; 5, March 2015; 6, December 2015; 7, April 2016.

Trial site	Treatment	Top soil	Coarse tailings	Waste rock	Fine tailings	Re-peats	Pos-itions	Qua-drats	Sub-total	Sur-veys	Survey no.	Total
1	1	-	-	-	Base	3	-	3	9	3	4, 6, 7	27
1	2	100 mm	-	-	Base	3	-	3	9	3	4, 6, 7	27
1	3	-	100 mm	-	Base	3	-	3	9	3	4, 6, 7	27
1	4	100 mm	100 mm	-	Base	3	-	3	9	3	4, 6, 7	27
1	5	-	250 mm	-	Base	3	-	3	9	3	4, 6, 7	27
1	6	100 mm	250 mm	-	Base	3	-	3	9	3	4, 6, 7	27
Total									54			162
2	1	100 mm	Base	-	-	3	4	3	36	3	4, 6, 7	108
2	2	-	Base	±300m m	-	3	4	3	36	3	4, 6, 7	108
2	3	100 mm	Base	±300m m	-	2/1	4/3	3	24 + 9	3	4, 6, 7	99
2	4	-	Base	-	-	1	4	3	12	3	4, 6, 7	36
Total									117			351
3	1	-	-	Base	-	3	3	3	27	3	5, 6, 7	81
3	2	-	100 mm	Base	-	3	3	3	27	3	5, 6, 7	81
3	3	-	200 mm	Base	-	3	3	3	27	3	5, 6, 7	81
3	4	100 mm	-	Base	-	3	3	3	27	3	5, 6, 7	81
3	5	200 mm	-	Base	-	3	3	3	27	3	5, 6, 7	81
3	6	100 mm	100 mm	Base	-	3	3	3	27	3	5, 6, 7	81
3	7	100 mm	200 mm	Base	-	3	3	3	27	3	5, 6, 7	81
Total									189			567
Ref	1	Base	-	-	-	3	3	3	27	2	6, 7	54
Ref	2	Base	-	-	-	3	3	3	27	2	6, 7	54
Ref	3	Base	-	-	-	3	3	3	27	2	6, 7	54
Total									81			162
Overall									441			1242

5.2.2 Quadrat sampling

The herbaceous layer of treatment was sampled by means of the fixed quadrat method (Kent, 2012) during December 2014, April 2015, December 2015 and April 2016. Three quadrats (1 x 1 m) were sampled per point, one fixed and two randomly placed and the positions recorded with a GPS (Appendix 16). All grass and forb species were counted in each quadrat and were identified to species level with the use of a field guide (Pooley, 2003) and expert knowledge (B. Ntloko pers. comm.).

5.2.3 Data analysis

PRIMER v6 (Clarke & Gorley, 2006) was used to determine the species richness, abundance and diversity for each treatment. The variables calculated were species richness (S) of forbs,

graminoids and all herbaceous plants, abundance (N) of forbs, graminoids and all herbaceous plants, Margalef's diversity index (D), Pielou's evenness index (J'), Shannon diversity index ($H' \log_e$) and the Simpson diversity index ($1 - \lambda$). SPSS version 23 (SPSS, 2016) was used to conduct one-way analysis of variance (ANOVA) of the data to test for significant variation between treatments as well as the reference sites with regards to species richness, abundance and diversity. ANOVA's are used to determine if there are significant differences between the means of two or more groups (Urdan, 2010). Due to the large sample size, the data was considered to be normally distributed (Rice, 2007). Tukey-B post-hoc pair-wise tests of treatment data were conducted where statistical significant results were obtained. While one-way ANOVA's inform on the likelihood of significant differences between two or more groups, post hoc testing is required to determine which of these groups differ from each other (Tabachnick & Fidell, 2007). Paired t-tests were performed to assess the changes over time in species richness, abundance and diversity for each treatment. Non-metric multidimensional scaling (NMDS) and principal component analysis (PCA) ordinations were performed on the data to graphically compare the species composition and turn-over of rehabilitation treatments and reference sites.

5.3 Results: Site 1 (Old TSF beach)

5.3.1 Comparisons of diversity patterns between treatments and reference sites

There were significant differences between treatments and reference sites for all variables during all three surveys (

Table 5-2). The Tukey-B post-hoc tests indicated that most of the rehabilitation treatments differed significantly from the reference sites with regards to most variables (Table 5-3). The reference sites had mean values higher than all the rehabilitation treatments for all variables, with only a few exceptions during survey 6 when the reference site had the second lowest S of graminoids, lowest N of forbs, second highest N of graminoids and lowest N total (Appendix 7).

5.3.1.1 Treatment 1 (control – fine tailings)

Treatment 1 did not differ significantly from the reference for S of graminoids, N of graminoids and N total during survey 6, and N of forbs during surveys 4 and 6 (Table 5-3).

Treatment 1 had significantly higher means than treatment 3 (fine tailings and coarse tailings (100mm)) for two variables (Pielou's evenness and Simpson index), and a significantly lower

mean than treatment 2 (fine tailings and top soil (100 mm)) for one variable (Pielou's evenness) during survey 4 (Table 5-4). During survey 6, treatment 1 had the highest mean in one variable (Pielou's evenness) and the lowest for another variable (S of forbs) (Appendix 7), and had significantly higher means than treatments 3 and 4 for one variable (N of graminoids) and treatment 5 for four variables (S of graminoids, N of graminoids, Pielou's evenness and Simpson index). Three variables (S of graminoids, N of forbs and N total) had mean values higher than those of the reference site during survey 6, but none were significant (Appendix 7). During survey 7, treatment 1 had the lowest means for six variables (S of graminoids, N of graminoids, Margalef's index, Pielou's evenness, Shannon index and Simpson index) and had the highest mean for one variable (N of forbs) (Appendix 7). Treatment 1 also had significantly lower means than treatment 2 for five variables (S of graminoids, N of graminoids, Pielou's evenness, Shannon index and Simpson index), treatment 3 for one variable (Pielou's evenness) and treatments 4 and 6 for four variables (S of graminoids, Pielou's evenness, Shannon index and Simpson index) during survey 7.

Table 5-2: ANOVA tests for vegetation monitoring data from Site 1 comparing treatments with reference sites over three survey periods. Survey 4, December 2014; survey 6, December 2015; survey 7, April 2016. Significant values in bold and marked with * ($p < 0.05$). Sf, forb richness; Sg, grass richness; Nf, forb abundance; Ng, grass abundance; d, Margalef species richness index; J', Pielou's evenness; H', Shannon Wiener diversity index; 1-Lambda, Simpson's index.

Variable	Survey 4 (df=6)			Survey 6 (df=6)			Survey 7 (df=6)			Survey 4	Survey 6	Survey 7
	Sum of Squares	Mean Square	F	Sum of Squares	Mean Square	F	Sum of Squares	Mean Square	F	ANOVA p-value	ANOVA p-value	ANOVA p-value
Sf	2845.73	474.29	58.26	2563.04	427.17	52.12	2753.38	458.90	55.65	<0.0001*	<0.0001*	<0.0001*
Sg	180.52	30.09	37.31	30.17	5.03	5.00	145.90	24.32	28.27	<0.0001*	0.0001*	<0.0001*
S total	4428.09	738.02	70.88	2387.58	397.93	37.26	4066.98	677.83	64.27	<0.0001*	<0.0001*	<0.0001*
Nf	63664.15	10610.69	10.01	238937.75	39822.96	3.35	99110.76	16518.46	18.08	<0.0001*	0.0042*	<0.0001*
Ng	20373.80	3395.63	27.51	11151.28	1858.55	12.54	16178.08	2696.35	18.82	<0.0001*	<0.0001*	<0.0001*
N total	154326.38	25721.06	19.16	193338.91	32223.15	2.63	186125.49	31020.91	25.36	<0.0001*	0.0196*	<0.0001*
d	204.44	34.07	82.99	122.13	20.35	48.32	171.12	28.52	66.49	<0.0001*	<0.0001*	<0.0001*
J'	7.18	1.20	26.73	6.70	1.12	49.13	7.31	1.22	34.26	<0.0001*	<0.0001*	<0.0001*
H'	99.21	16.53	141.58	73.44	12.24	83.44	86.02	14.34	115.39	<0.0001*	<0.0001*	<0.0001*
1-Lambda	12.26	2.04	101.47	10.17	1.69	79.84	10.56	1.76	82.50	<0.0001*	<0.0001*	<0.0001*

Table 5-3: Significant differences between treatments at Trial site 1 and the reference sites for each variable based on Tukey-B post-hoc tests. Treatments marked with “a” differed significantly from the reference during survey 4, treatments marked with “b” differed significantly from the reference during survey 6, and treatments marked with “c” differed significantly from the reference during survey 7. Sf, forb richness; Sg, grass richness; Nf, forb abundance; Ng, grass abundance; d, Margalef species richness index; J', Pielou's evenness; H', Shannon Wiener diversity index; 1-Lambda, Simpson's index. Treatment 1 (control), fine tailings (ft); Treatment 2, ft and top soil (ts) (100 mm); Treatment 3, ft and coarse tailings (ct) (100 mm); Treatment 4, ft, ct (100 mm) and ts (100 mm); Treatment 5, ft and ct (250 mm); Treatment 6, ft, ct (250 mm) and ts (100 mm).

Variable	Treatment					
	1	2	3	4	5	6
Sf	a,b,c	a,b,c	a,b,c	a,b,c	a,b,c	a,b,c
Sg	a,c	a,c	a,c	a,c	a,c	a,c
S total	a,b,c	a,b,c	a,b,c	a,b,c	a,b,c	a,b,c
Nf	c	c	a,c	c	a,c	a,c
Ng	a,c	a	a,b,c	a,b,c	a,b,c	a,b,c
N total	a,c	a,c	a,c	a,c	a,c	a,c
d	a,b,c	a,b,c	a,b,c	a,b,c	a,b,c	a,b,c
J'	a,b,c	b,c	a,b,c	a,b	a,b,c	b
H'	a,b,c	a,b,c	a,b,c	a,b,c	a,b,c	a,b,c
1-Lambda	a,b,c	a,b,c	a,b,c	a,b,c	a,b,c	a,b,c

5.3.1.2 Treatment 2 (fine tailings and topsoil (100 mm))

Treatment 2 did not differ significantly from the reference for S of graminoids and N total during survey 6, N of forbs during surveys 4 and 6, N of graminoids during surveys 6 and 7, and Pielou's evenness during survey 4 (Table 5-3).

This treatment had the highest means in four variables (N of forbs, N of graminoids, N total and Pielou's evenness) (Appendix 7), and had significantly higher means than treatment 1 for one variable, treatment 3 for three variables (Pielou's evenness, Shannon index and Simpson index) and treatment 5 for two variables (Pielou's evenness and Simpson index) during survey 4 (Table 5-4). During survey 6, treatment 2 had the highest means of the rehabilitation treatments in nine variables (S of forbs, S of graminoids, S total, N of forbs, N of graminoids, N total, Margalef's index, Shannon index and Simpson index) (Appendix 7), and had significantly higher means than treatment 3 for two variables (N of graminoids and Simpson index), treatment 4 for one variable (N of graminoids), treatment 5 for five variables (S of graminoids, N of graminoids, Pielou's evenness, Shannon index and Simpson index) and treatment 6 for two variables (N of graminoids and Simpson index). Mean values of four variables were higher than those of the reference site (S of graminoids, N of forbs, N of graminoids and N total), but none were significantly higher. During survey 7, treatment 2 had the highest means for two variables (N of graminoids and N total) (Appendix 7), and had significantly higher means than treatment 1 for five variables, treatment 3 for two variables (S of graminoids and N of graminoids) and treatment 5 for five variables (S of graminoids, N of graminoids, Pielou's evenness, Shannon

index and Simpson index), as well as significantly lower means than treatments 4 and 6 for two variables each (Pielou's evenness and Simpson index). Treatment 2 had the lowest means for one variable (N of forbs) during survey 7.

5.3.1.3 Treatment 3 (fine tailings, coarse tailings (100 mm))

Treatment 3 did not differ significantly from the reference for S of graminoids, N of forbs and N total during survey 6 (Table 5-3).

This treatment had the lowest means for seven variables (S of graminoids, S total, N of graminoids, Margalef's index, Pielou's evenness, Shannon index and the Simpson index) (Appendix 7), and had significantly lower means than treatment 1 for two variables, treatment 2 for three variables, treatment 4 for two variables (Pielou's evenness and Simpson index) and treatment 6 for four variables (S of graminoids, Pielou's evenness, Shannon index and Simpson index) during survey 4 (Table 5-4). During survey 6, treatment 3 had significantly lower means than treatment 1 for one variable and treatment 2 for three variables. Three variables had mean values higher than those of the reference site (S of graminoids, N of forbs and N total), but none were significantly higher (Appendix 7). During survey 7, treatment 3 had significantly higher means than treatment 1 for one variable, and significantly lower means than treatment 2 for two variables and treatments 4 and 6 for four variables each (S of graminoids, Pielou's evenness, Shannon index and Simpson index).

5.3.1.4 Treatment 4 (fine tailings, coarse tailings (100 mm) and top soil (100 mm))

Treatment 4 did not differ significantly from the reference for S of graminoids and N total during survey 6, N of forbs during surveys 4 and 6, and Pielou's evenness during survey 7 (Table 5-3).

This treatment had the highest means for one variable (S of forbs) (Appendix 7), and had significantly higher means than treatment 3 for two variables and treatment 5 for one variable (Pielou's evenness) during survey 4 (Table 5-4). During survey 6, treatment 4 had a significantly higher mean than treatment 5 for one variable (S of graminoids) and significantly lower means than treatments 1 and 2 for one variable each. Three variables had mean values higher than those of the reference site (S of graminoids, N of forbs and N total), but none were significant. During survey 7, treatment 4 had the highest means for three variables (Pielou's evenness, Shannon index and Simpson index), and had significantly higher means than treatments 1 and

3 for four variables, treatment 2 for two variables and treatment 5 for four variables (S of graminoids, Pielou's evenness, Shannon index and Simpson index).

5.3.1.5 Treatment 5 (fine tailings and coarse tailings (250 mm))

Treatment 5 did not differ significantly from the reference for S of graminoids, N of forbs and N total during survey 6 (Table 5-3).

Treatment 5 had the lowest means for three variables (S of forbs, N of forbs and N total) (Appendix 7), and had significantly lower means than treatment 2 for two variables, treatment 4 for one variable and treatment 6 for two variables (Pielou's evenness and Simpson index) during survey 4 (Table 5-4). During survey 6, treatment 5 had the lowest means for seven variables (S of graminoids, S total, N of graminoids, Margalef's index, Pielou's evenness, Shannon index and Simpson index), and had significantly lower means than treatment 1 for four variables, treatment 2 for five variables and treatment 4 for one variable. Two variables had mean values higher than those of the reference site (N of forbs and N total), but were not significant. During survey 7, treatment 5 had the lowest means for three variables (S of forbs, S total and N total), and had significantly lower means than treatment 2 for five variables, treatment 4 for four variables and treatment 6 for four variables (S of graminoids, Pielou's evenness, Shannon index and Simpson index).

5.3.1.6 Treatment 6 (fine tailings, coarse tailings (250 mm) and top soil (100 mm))

Treatment 6 did not differ significantly from the reference for S of graminoids, N of forbs and N total during survey 6, and Pielou's evenness during surveys 4 and 7 (Table 5-3).

This treatment had the highest means for five variables (S of graminoids, S total, Margalef's index, H'loge and Simpson's index), and had significantly higher means than treatment 3 for four variables and treatment 5 for two variables during survey 4. During survey 6, treatment 6 had significantly lower means than treatment 2 for two variables. Three variables had mean values higher than those of the reference site (S of graminoids, N of forbs and N total), but were not significant. During survey 7, treatment 6 had the highest means for four variables (S of forbs, S of graminoids, S total and Margalef's index), and had significantly higher means than treatments 1, 3 and 5 for four variables and treatment 2 for two variables.

Table 5-4: Significant differences between treatments at Trial site 1 during surveys 4, 6 and 7. “<” indicates treatments which have values significantly higher than that treatment for that variable. “>” indicates treatments which have values significantly lower than that treatment for that variable. Sf, forb richness; Sg, grass richness; Nf, forb abundance; Ng, grass abundance; d, Margalef species richness index; J’, Pielou’s evenness; H’, Shannon Wiener diversity index; 1-Lambda, Simpson’s index. Treatment 1 (control), fine tailings (ft); Treatment 2, ft and top soil (ts) (100 mm); Treatment 3, ft and coarse tailings (ct) (100 mm); Treatment 4, ft, ct (100 mm) and ts (100 mm); Treatment 5, ft and ct (250 mm); Treatment 6, ft, ct (250 mm) and ts (100 mm).

Variable	Treatment					
	1	2	3	4	5	6
Survey 4						
Sf	-	-	-	-	-	-
Sg	-	-	<6	-	-	>3
S total	-	-	-	-	-	-
Nf	-	-	-	-	-	-
Ng	-	-	-	-	-	-
N total	-	-	-	-	-	-
d	-	-	-	-	-	-
J'	<2, >3	>1, >3, >4	<1, <2, <4, <6	>3, >5	<2, <4, <6	>3, >5
H'	-	>3	<2, <6	-	-	>3
1-Lambda	>3	>3, >5	<1, <2, <4, <6	>3	<2, <6	>3, >5
Balance	1	6	-11	3	-5	6
Survey 6						
Sf	-	-	-	-	-	-
Sg	>5	>5	-	>5	<1, <2, <4	-
S total	-	-	-	-	-	-
Nf	-	-	-	-	-	-
Ng	>3, >4, >5	>3, >4, >5, >6	<1, <2	<1, <2	<1, <2	<2
N total	-	-	-	-	-	-
d	-	-	-	-	-	-
J'	>5	>5	-	-	<1, <2	-
H'	-	>5	-	-	<2	-
1-Lambda	>5	>3, >5, >6	<2	-	<1, <2	<2
Balance	6	10	-3	-1	-10	-2
Survey 7						
Sf	-	-	-	-	-	-
Sg	<2, <4, <6	>1, >3, >5	<2, <4, <6	>1, >3, >5	<2, <4, <6	>1, >3, >5
S total	-	-	-	-	-	-
Nf	-	-	-	-	-	-
Ng	<2	>1, >3, >5	<2	-	<2	-
N total	-	-	-	-	-	-
d	-	-	-	-	-	-
J'	<2, <3, <4, <6	>1, >5, <4, <6	>1, <4, <6	>1, >2, >3, >5	<2, <4, <6	>1, >2, >3, >5
H'	<2, <4, <6	>1, >5	<4, <6	>1, >3, >5	<2, <4, <6	>1, >3, >5
1-Lambda	<2, <4, <6	>1, >5, <4, <6	<4, <6	>1, >2, >3, >5	<2, <4, <6	>1, >2, >3, >5
Balance	-14	8	-9	14	-13	14
Total	-2.3	8	-7.6	5.3	-9.3	6

5.3.2 Comparisons of species composition between treatments and reference sites

Non-metric multidimensional scaling (NMDS) analyses indicated the presence of several outliers from treatments 1, 3 and 5 (without top soil) that contained no species or only one species, while the rest of the quadrats from the rehabilitation treatments and the reference sites appeared narrowly clustered together (Figure 5-2A). The NMDS analyses showed separation between the reference sites and the rehabilitation treatments (Figure 5-2B).

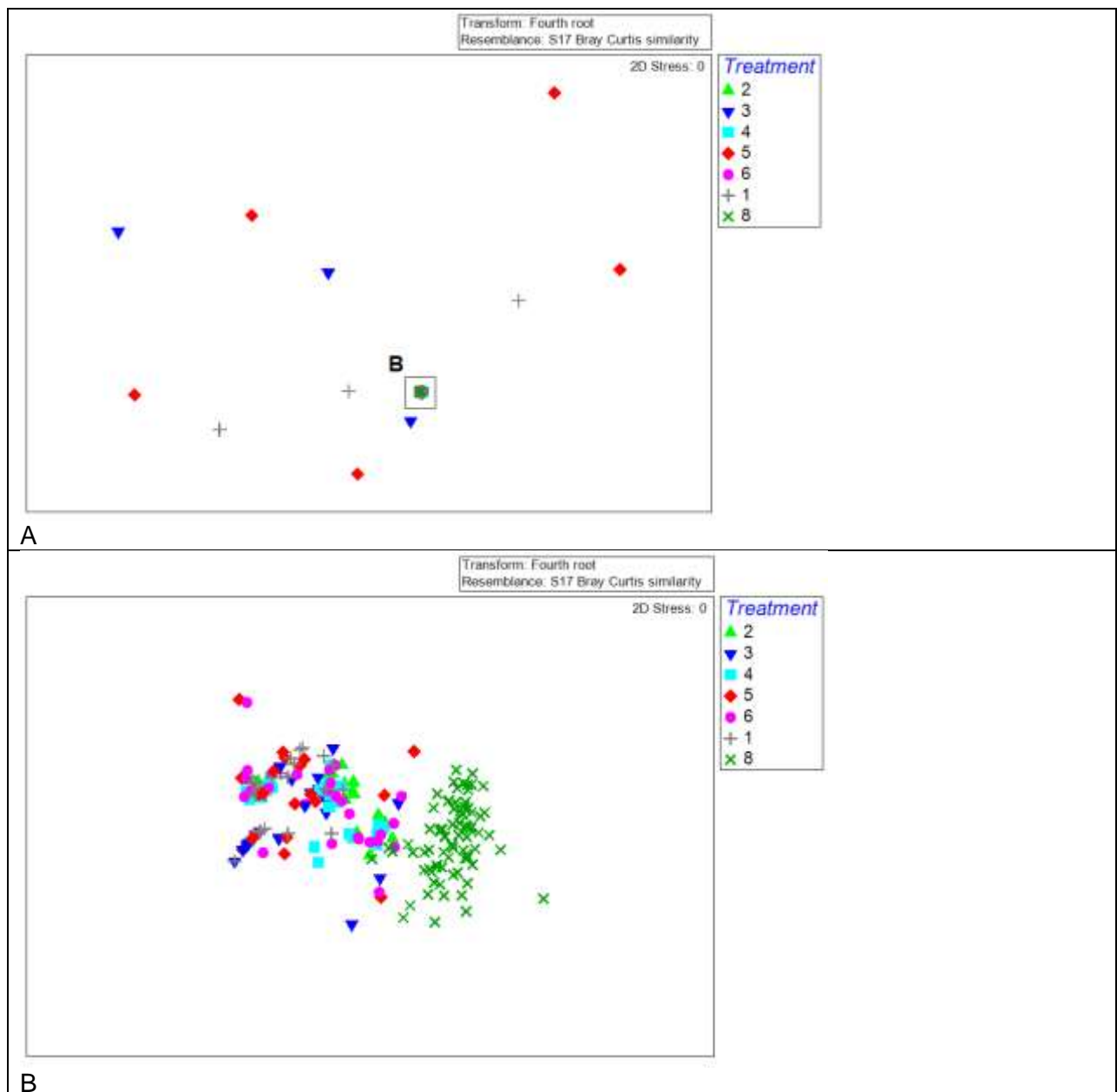
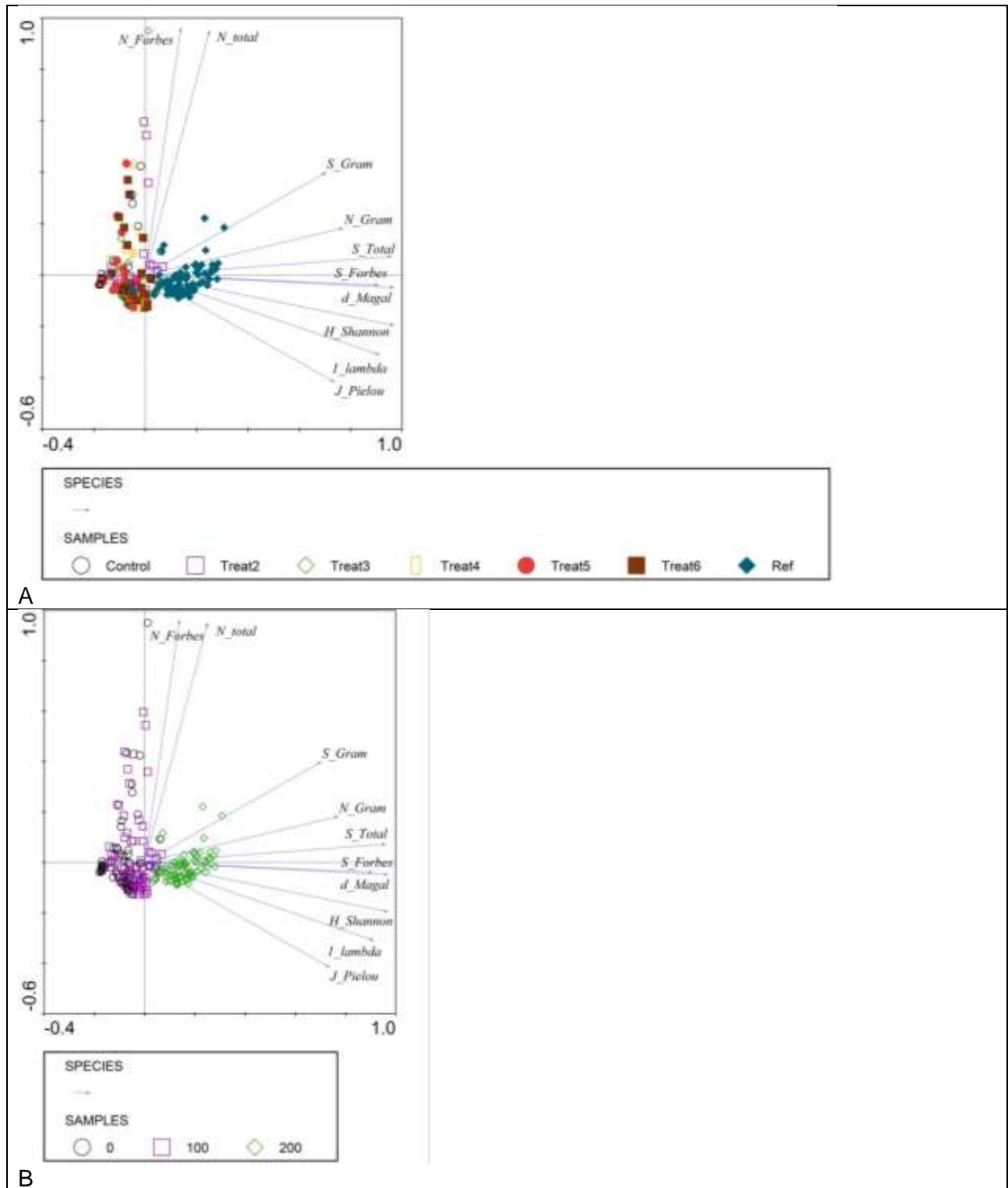


Figure 5-2: Non-metric multidimensional scaling analyses based on total plant species composition for Site 1 and the reference sites during surveys 4, 6 and 7. A: All quadrats. B: Enhanced image of area marked "B". Treatment 1 (control), fine tailings (ft); Treatment 2, ft and top soil (ts) (100mm); Treatment 3, ft and coarse tailings (ct) (100mm); Treatment 4, ft, ct (100mm) and ts (100mm); Treatment 5, ft and ct (250 mm); Treatment 6, ft, ct (250 mm) and ts (100 mm); 8, reference.

PCA ordinations for treatments from trial site 1 and the reference sites revealed a clear separation (Figure 5-3A) with the reference sites separated from the treatments. When considering the same PCA ordination coded for top soil depth instead of treatments (Figure 5-3B), it is clear that treatments with no top soil grouped further away from the reference sites, while treatments containing an intermediate amount of top soil (100 mm) grouping nearest to the reference sites, the latter which is considered to have a high amount of top soil (± 200 mm).

The abundance of forbs and the combined total abundance of the herbaceous layer were divergent from the other variables, and an increase in these two variables ran perpendicular to an increase in the four diversity indices (Margalef, Shannon, Simpson and Pielou). The reference sites also did not group strongly towards this variable, while some treatments, especially treatments 1, 2, 5 and 6, did. This suggests that some of the samples within the rehabilitation treatments had a high abundance of forbs, higher than the average for reference sites, but that this was not necessarily an indication of high species richness or diversity with regards to the diversity indices.



B Figure 5-3: PCA ordination of all assemblage variables and diversity indices for all treatments from site 1 as well as the reference sites (surveys 4, 6 and 7). A: Arranged according to treatment, B: Arranged according to top soil depth. Treatment 1 (control), fine tailings (ft); Treatment 2, ft and top soil (ts) (100 mm); Treatment 3, ft and coarse tailings (ct) (100 mm); Treatment 4, ft, ct (100 mm) and ts (100 mm); Treatment 5, ft and ct (250 mm); Treatment 6, ft, ct (250 mm) and ts (100 mm); Ref, reference.

5.3.3 Comparisons within treatments over time

Several treatments showed significant changes over time from survey 4 to survey 7 (Table 5-5). Treatment 1 (control) showed a significant decrease in six variables (S of graminoids, S total, N of graminoids, Pielou's evenness, Shannon index and Simpson index). Treatment 2 showed a significant increase over time in four variables (S of graminoids, S total, N of graminoids and Margalef's index) and a significant decrease in one (N of forbs). Treatment 3 showed a significant increase over time in five variables (S of graminoids, S total, Pielou's evenness, Shannon index and Simpson index). Treatment 4 showed a significant increase in seven variables (S of forbs, S of graminoids, S total, N of graminoids, Margalef's index, Shannon index and Simpson index). Treatment 5 showed no significant changes over time for any variable. Treatment 6 showed a significant increase in seven variables (S of forbs, S of graminoids, S total, N of graminoids, Margalef's index, Shannon index and Simpson index) (Appendix 10).

Table 5-5: Paired t-test results for vegetation monitoring data for treatments from Site 1 over time. Significant values are in bold and marked with a * (p<0.05). Treatment 1 (control), fine tailings (ft); Treatment 2, ft and top soil (ts) (100mm); Treatment 3, ft and coarse tailings (ct) (100mm); Treatment 4, ft, ct (100mm) and ts (100mm); Treatment 5, ft and ct (250 mm); Treatment 6, ft, ct (250 mm) and ts (100 mm). Sf, forb richness; Sg, grass richness; Nf, forb abundance; Ng, grass abundance; d, Margalef species richness index; J', Pielou's evenness; H', Shannon Wiener diversity index; 1-Lambda, Simpson's index.

Variable	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5	Treatment 6
	Paired t-test p-value	Paired t-test p-value	Paired t-test p-value	Paired t-test p-value	Paired t-test p-value	Paired t-test p-value
Sf	0.3466	0.5943	0.5943	0.0133*	0.3466	0.0222*
Sg	0.0039*	0.0022*	0.0353*	0.0022*	0.7599	0.0039*
S total	0.0353*	0.0171*	0.0133*	<0.0001*	0.6811	0.0005*
Nf	0.1398	0.0129*	0.2280	0.0798	0.3587	0.4838
Ng	0.0345*	0.0291*	0.2997	0.0444*	0.8939	0.0114*
N total	0.0899	0.1451	0.9414	0.2467	0.2586	0.7489
d	0.0710	0.0193*	0.0929	0.0001*	0.7402	0.0005*
J'	0.0139*	0.1601	0.0382*	0.0892	0.9128	0.3969
H'	0.0102*	0.6342	0.0382*	0.0004*	0.9128	0.0046*
1-Lambda	0.0157*	0.8380	0.0393*	0.0040*	0.9540	0.0493*

5.4 Results: Site 2 (Old TSF coarse tailings wall)

5.4.1 Comparisons of diversity patterns between treatments and reference sites

There were significant differences between the treatments and reference sites for all variables during all three surveys (Table 5-6). The Tukey-B post-hoc tests indicated that most of the rehabilitation treatments differed significantly from the reference sites with regards to most variables (Table 5-7). The reference site had the highest mean values for each variable compared to the rehabilitation treatments during surveys 4 and 7. However, during survey 6

treatments 1 and 3 both had higher mean values for the N of forbs than the reference sites, but not significantly so (Appendices 10, 11).

Table 5-6: ANOVA tests for vegetation monitoring data from Site 2 comparing treatments with reference sites over three survey periods. Survey 4, December 2014; survey 6, December 2015; survey 7, April 2016. Significant values in bold and marked with * ($p < 0.05$). Sf, forb richness; Sg, grass richness; Nf, forb abundance; Ng, grass abundance; d, Margalef species richness index; J', Pielou's evenness; H', Shannon Wiener diversity index; 1-Lambda, Simpson's index.

Variable	Survey 4 (df=4)			Survey 6 (df=4)			Survey 7 (df=4)			Survey 4	Survey 6	Survey 7
	Sum of Squares	Mean Square	F	Sum of Squares	Mean Square	F	Sum of Squares	Mean Square	F	ANOVA p-value	ANOVA p-value	ANOVA p-value
Sf	4279.37	1069.84	192.26	3509.16	877.29	143.12	4036.95	1009.24	173.62	<0.0001*	<0.0001*	<0.0001*
Sg	40.34	10.09	10.35	137.36	34.34	34.98	258.72	64.68	103.05	<0.0001*	<0.0001*	<0.0001*
S total	5051.95	1262.99	167.20	4970.07	1242.52	152.47	6323.68	1580.92	213.89	<0.0001*	<0.0001*	<0.0001*
Nf	108736.00	27184.00	28.41	103567.66	25891.91	15.08	163004.12	40751.03	67.91	<0.0001*	<0.0001*	<0.0001*
Ng	11870.45	2967.61	20.94	23136.56	5784.14	55.18	28492.71	7123.18	76.24	<0.0001*	<0.0001*	<0.0001*
N total	186510.92	46627.73	40.03	174199.54	43549.88	23.86	326247.55	81561.89	101.38	<0.0001*	<0.0001*	<0.0001*
d	210.93	52.73	155.59	209.02	52.26	132.37	236.48	59.12	137.71	<0.0001*	<0.0001*	<0.0001*
J'	1.96	0.49	10.71	6.89	1.72	28.04	7.28	1.82	19.97	<0.0001*	<0.0001*	<0.0001*
H'	84.34	21.09	151.67	115.69	28.92	195.49	128.78	32.19	222.40	<0.0001*	<0.0001*	<0.0001*
1-Lambda	7.15	1.79	58.16	12.80	3.20	66.89	11.80	2.95	44.40	<0.0001*	<0.0001*	<0.0001*

Table 5-7: Significant differences between treatments at Site 2 and the reference sites for each variable based on Tukey-B post-hoc tests. Treatments marked with "a" differed significantly from the reference during survey 4, treatments marked with "b" differed significantly from the reference during survey 6, and treatments marked with "c" differed significantly from the reference during survey 7. Sf, forb richness; Sg, grass richness; Nf, forb abundance; Ng, grass abundance; d, Margalef species richness index; J', Pielou's evenness; H', Shannon Wiener diversity index; 1-Lambda, Simpson's index. Treatment 1, coarse tailings (ct) and top soil (ts) (100 mm); Treatment 2, ct and waste rock (wr); Treatment 3, ct, wr and ts (100 mm); Treatment 4, ct (control).

Variable	Treatment			
	1	2	3	4
Sf	a,b,c	a,b,c	a,b,c	a,b,c
Sg	b,c	a,b,c	a,b,c	a,b,c
S total	a,b,c	a,b,c	a,b,c	a,b,c
Nf	a,c	a,b,c	a,c	a,b,c
Ng	b,c	a,b,c	a,b,c	a,b,c
N total	a,c	a,b,c	a,c	a,b,c
d	a,b,c	a,b,c	a,b,c	a,b,c
J'	b	a,b,c	b,c	a,b
H'	a,b,c	a,b,c	a,b,c	a,b,c
1-Lambda	a,b,c	a,b,c	a,b,c	a,b,c

5.4.1.1 Treatment 1 (coarse tailings and top soil (100 mm))

Treatment 1 differed from the reference sites for all variables during survey 7, except Pielou's evenness (Table 5-7). There were no significant differences from the reference for S of graminoids and N of graminoids during survey 4, N of forbs and N total during survey 6, and Pielou's evenness during both surveys 4 and 7.

Treatment 1 had the highest mean values of the rehabilitation treatments compared to the reference sites for six variables (S of graminoids, S total, N of forbs, N of graminoids, N total and Margalef's index) during survey 4 (Appendix 10). Treatment 1 also had significantly higher mean values than treatment 2 (coarse tailings and waste rock) for four variables (S of graminoids, N of graminoids, N total and Shannon index) and treatment 4 (coarse tailings) for three variables (Pielou's evenness, Shannon index and Simpson index) during survey 4 (Table 5-8). During survey 6, treatment 1 had the highest means compared to the reference sites for four variables (S of forbs, S of graminoids, S total, N of graminoids). Treatment 1 also had significantly higher means than treatment 2 for three variables (S of graminoids, N of forbs and N total) and treatment 4 for three variables (N of forbs, N total and Simpson index) during survey 6. During survey 7, treatment 1 had the highest means compared to the reference sites for six variables (S of graminoids, S total, N of forbs, N of graminoids, N total and Shannon index). Treatment 1 also had significantly higher means than treatment 2 for four variables (S of graminoids, Pielou's evenness, Shannon index and Simpson index) during survey 7.

5.4.1.2 Treatment 2 (coarse tailings and waste rock)

Treatment 2 differed significantly from the reference for all variables during all three surveys (Table 5-7). This treatment had the lowest values of the rehabilitation treatments compared to the reference sites for five variables (S of graminoids, S total, N of forbs, N of graminoids, N total) during survey 4 (Appendix 10). In addition to the significant differences with the reference sites, treatment 2 also had significantly lower mean values than treatment 1 for four variables, treatment 3 (coarse tailings, waste rock and top soil) for four variables (N of graminoids, Pielou's evenness, Shannon index and Simpson index) and treatment 4 for one variable (N of graminoids) during survey 4 (Table 5-8). During survey 6, treatment 2 had the lowest means for five variables (S of graminoids, S total, N of graminoids, Margalef's index and Shannon index). Treatment 2 also had significantly lower means than treatment 1 for three variables, treatment 3 for two variables (N of forbs and N total) and treatment 4 for one variable (S of graminoids) during survey 6. During survey 7, treatment 2 had the lowest means compared to the reference sites for all ten variables. Treatment 2 also had significantly lower means than treatment 1 for four variables and treatment 4 for four variables (Margalef's index, Pielou's evenness, Shannon index and Simpson index).

5.4.1.3 Treatment 3 (coarse tailings, waste rock and top soil (100 mm))

Treatment 3 differed significantly from the reference site for all variables during survey 7 (Table 5-7). There were no significant differences with the reference for N of forbs and N total during

survey 6 and Pielou's evenness during survey 4. This treatment had the highest means of the rehabilitation treatments compared to the reference sites for four variables (S of forbs, Pielou's evenness, Shannon index and Simpson index) during survey 4 (Appendix 10). In addition to the significant differences with the reference sites, treatment 3 also had significantly higher means than treatment 2 for four variables and treatment 4 for three variables (Pielou's evenness, Shannon index and Simpson index) during survey 4 (Table 5-8). During survey 6, treatment 3 had the highest means compared to the reference sites for two variables (N of forbs and N total) and the lowest means for two other variables (Pielou's evenness and Simpson index). Treatment 3 also had significantly higher means than treatment 2 for two variables and treatment 4 for two variables (N of forbs, N total), and significantly lower means than treatment 4 for two variables (Pielou's evenness and Simpson index) during survey 6. During survey 7, treatment 3 had a significantly lower mean than treatment 4 for one variable (Simpson index).

5.4.1.4 Treatment 4 (control - coarse tailings)

Treatment 4 differed significantly from the reference for all variables during all three surveys, except Pielou's evenness during survey 7 (Table 5-7). This treatment had the lowest means compared to the reference sites for five variables (S of forbs, Margalef's index, Pielou's evenness, Shannon index and Simpson index) during survey 4 (Appendix 10). In addition to the significant differences with the reference sites, treatment 4 also had significantly higher means than treatment 2 for one variable, and significantly lower means than treatments 1 and 3 for three variables during survey 4 (Table 5-8). During survey 6, treatment 4 had the highest means for four variables (Margalef's index, Pielou's evenness, Shannon index and Simpson index) and the lowest for three other variables (S of forbs, N of forbs and N total). Treatments 4 also had a significantly higher mean than treatment 2 for one variable, and significantly lower means than treatment 1 for three variables and treatment 3 for two variables during survey 6. During survey 7, treatment 4 had the highest means for four variables (S of forbs, Margalef's index, Pielou's evenness and Simpson index), and had significantly higher means than treatment 2 for four variables and treatment 3 for one variable.

Table 5-8: Significant differences between treatments at Trial site 2 during surveys 4, 6 and 7. “<” indicates treatments which have values significantly higher than that treatment for that variable. “>” indicates treatments which have values significantly lower than that treatment for that variable. Sf, forb richness; Sg, grass richness; Nf, forb abundance; Ng, grass abundance; d, Margalef species richness index; J', Pielou's evenness; H', Shannon Wiener diversity index; 1-Lambda, Simpson's index. Treatment 1, coarse tailings (ct) and top soil (ts) (100 mm); Treatment 2, ct and waste rock (wr); Treatment 3, ct, wr and ts (100 mm); Treatment 4, ct (control)

Variable	Treatment			
	1	2	3	4
Survey 4				
Sf	-	-	-	-
Sg	>2	<1	-	-
S total	-	-	-	-
Nf	-	-	-	-
Ng	>2	<1, <3, <4	>2	>2
N total	>2	<1	-	-
d	-	-	-	-
J'	>4	<3	>2, >4	<1, <3
H'	>2, >4	<1, <3	>2, >4	<1, <3
1-Lambda	>4	<3	>2, >4	<1, <3
Balance	7	-9	7	-5
Survey 6				
Sf	-	-	-	-
Sg	>2	<1, <4	-	>2
S total	-	-	-	-
Nf	>2, >4	<1, <3	>2, >4	<1, <3
Ng	-	-	-	-
N total	>2, >4	<1, <3	>2, >4	<1, <3
d	-	-	-	-
J'	-	-	<4	>3
H'	-	-	-	-
1-Lambda	<4	-	<4	>1, >3
Balance	4	-6	2	0
Survey 7				
Sf	-	-	-	-
Sg	>2	<1	-	-
S total	-	-	-	-
Nf	-	-	-	-
Ng	-	-	-	-
N total	-	-	-	-
d	-	<4	-	>2
J'	>2	<1, <4	-	>2
H'	>2	<1, <4	-	>2
1-Lambda	>2	<1, <4	<4	>2, >3
Balance	4	-8	-1	5
Mean	5	-7.6	2.6	0

5.4.2 Comparisons of species composition between treatments and reference sites

Non-metric multidimensional scaling (NMDS) analyses indicated several outliers from treatments 2, 3 and 4 (due to several quadrats containing only one or no species), while the majority of the quadrats from the rehabilitation treatments and all of the quadrats from the reference sites were clustered together (Figure 5-4A). Although the reference sites formed a distinguishable cluster, there was some overlap with the clusters of all three rehabilitation treatments, with no one treatment appearing to group closer to the reference site than any other (Figure 5-4B).

PCA ordinations for treatments from trial site 2 showed a clear separation between the reference sites and the rehabilitation treatments (Figure 5-5A). When looking at the same PCA ordination coded for top soil depth instead of treatments (Figure 5-5B), it is clear that treatments with no top soil grouped further away from the reference sites, with treatments containing an intermediate amount of top soil (100 mm) grouping nearest to the reference sites that is comprised of a high amount of top soil (± 200 mm).

It should also be noted that the abundance of forbs is divergent from the other variables, and an increase in this variable runs roughly perpendicular to an increase in the four diversity indices (Margalef, Shannon, Simpson and Pielou). Many samples from treatments 1-3 had high Y-axis values towards the N of forbs, but also along a perpendicular line to the other variables. This suggests that some of the samples within the rehabilitation treatments had a high abundance of forbs, but that this was not necessarily an indication of high species richness or diversity with regards to the diversity indices.

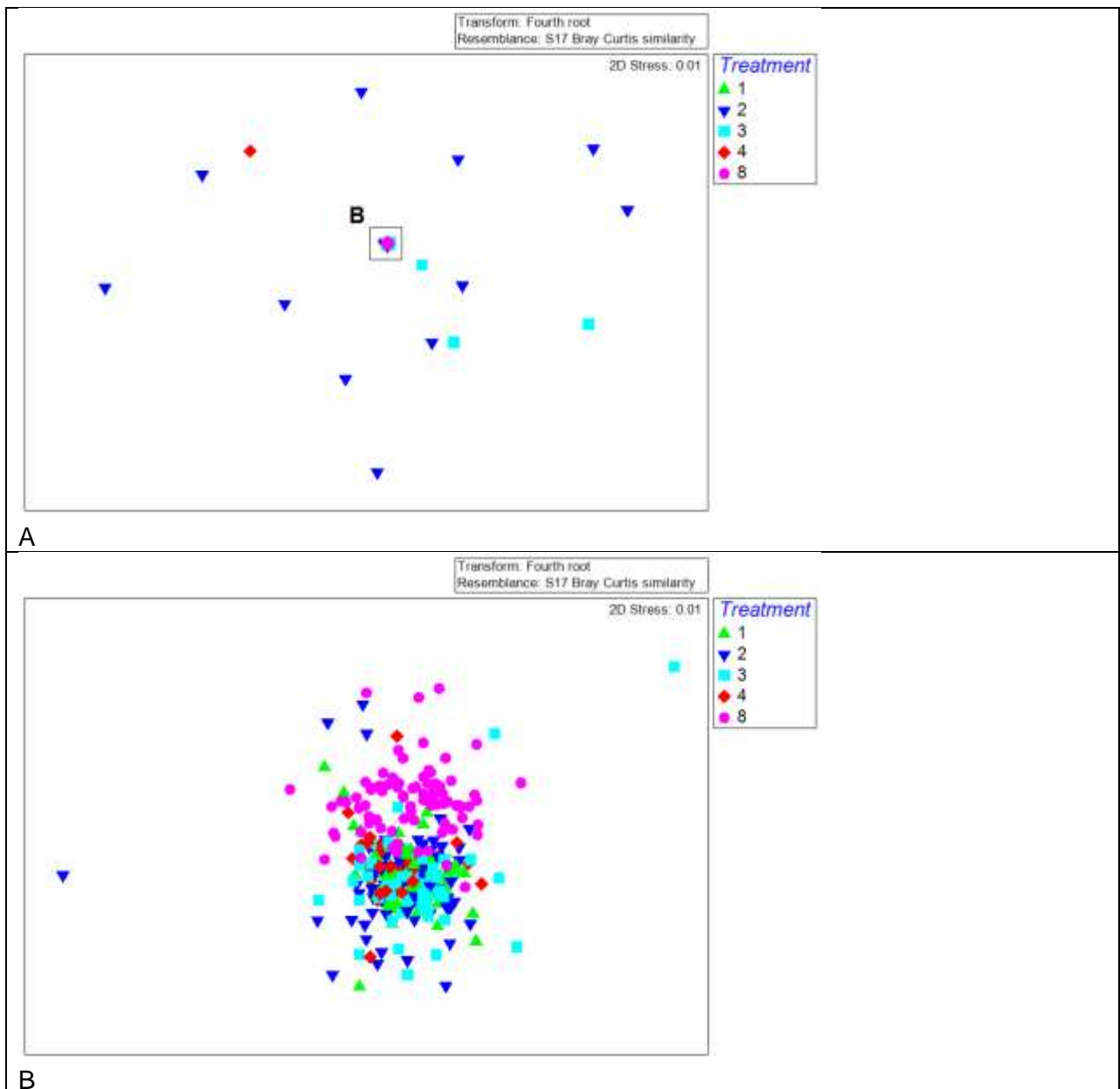


Figure 5-4: Non-metric multidimensional scaling analyses based on total plant species composition for Site 2. A: All quadrats. B: Enhanced image of area marked "B". Treatment 1, coarse tailings (ct) and top soil (ts) (100mm); Treatment 2, ct and waste rock (wr); Treatment 3, ct, wr and ts (100 mm); Treatment 4, ct (control); Treatment 8, reference.

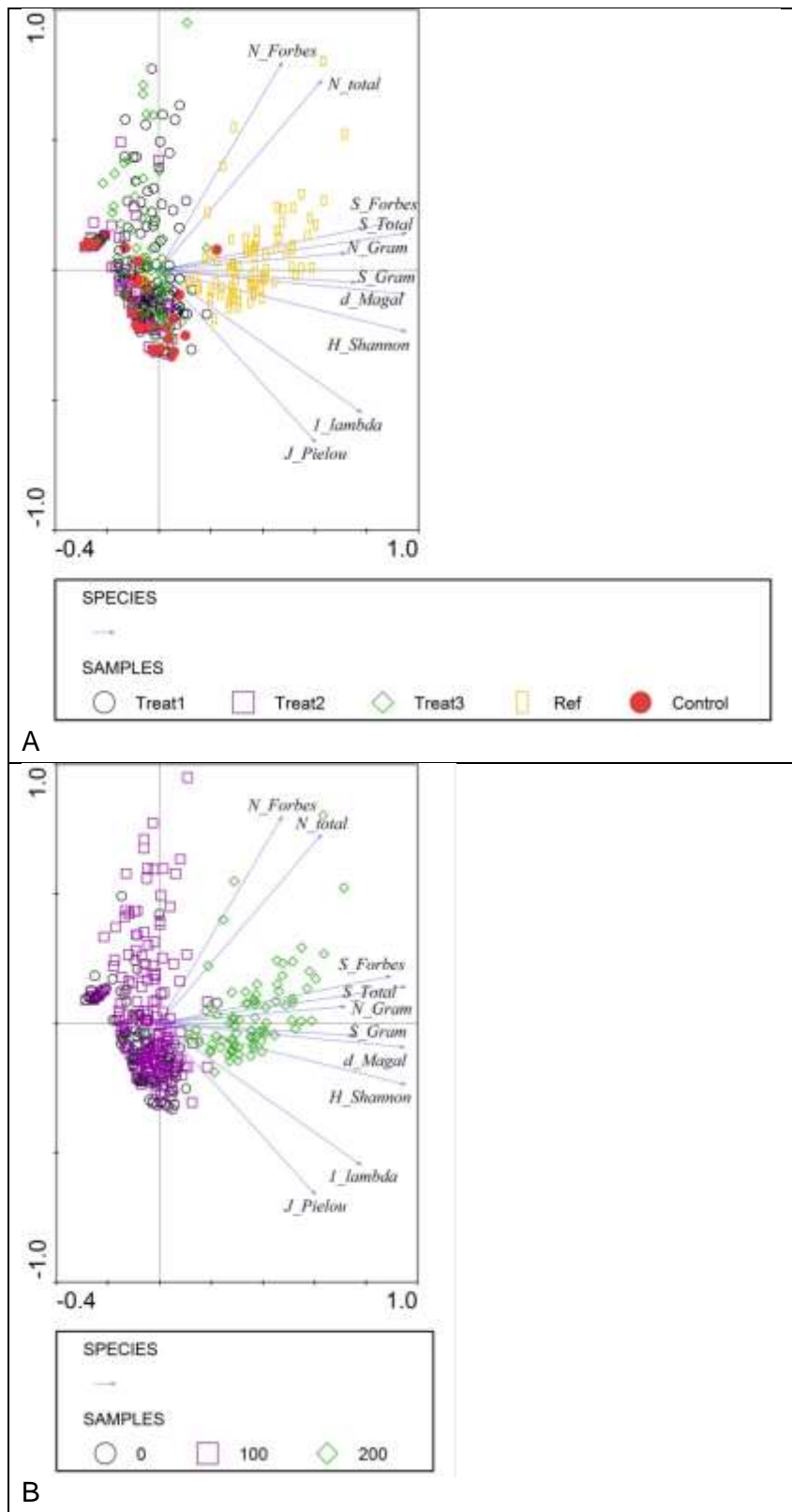


Figure 5-5: PCA ordination of all assemblage variables and diversity indices for all treatments from site 2 as well as the reference sites for surveys 4, 6 and 7. A: Arranged according to treatment, B: Arranged according to top soil depth. Treatment 1, coarse tailings (ct) and top soil (ts) (100 mm); Treatment 2, ct and waste rock (wr); Treatment 3, ct, wr and ts (100 mm); Treatment 4, ct (control); Ref, reference.

5.4.3 Comparisons within treatments over time

All treatments showed some significant changes over time (Table 5-9). Treatment 1 showed a significant increase in one variable (S of forbs) and a significant decrease in six variables (S of graminoids, S total, N of forbs, N of graminoids, N total and Shannon index) over time from survey 4 to survey 7. Treatment 2 showed a significant decrease over time for all variables except one (S of forbs). Treatment 3 showed a significant decrease over time for all variables except two (S of forbs and Margalef's index). Treatment 4 showed a significant increase over time for one variable (S of forbs) and a significant decrease over time for three variables (S of graminoids, N of graminoids and N total).

Table 5-9: Paired t-test results for vegetation monitoring data for treatments from Site 2 over time. Significant values are in bold and marked with * ($p < 0.05$). Sf, forb richness; Sg, grass richness; Nf, forb abundance; Ng, grass abundance; d, Margalef species richness index; J', Pielou's evenness; H', Shannon Wiener diversity index; 1-Lambda, Simpson's index. Treatment 1, coarse tailings (ct) and top soil (ts) (100 mm); Treatment 2, ct and waste rock (wr); Treatment 3, ct, wr and ts (100 mm); Treatment 4, ct (control).

Variable	Paired t-test p-value			
	Treatment 1	Treatment 2	Treatment 3	Treatment 4
Sf	0.0354*	0.3605	0.8688	0.0053*
Sg	<0.0001*	<0.0001*	<0.0001*	0.0043*
S total	<0.0001*	<0.0001*	<0.0001*	0.3172
Nf	0.0008*	0.0036*	0.0033*	0.2390
Ng	<0.0001*	<0.0001*	<0.0001*	0.0050*
N total	<0.0001*	<0.0001*	<0.0001*	0.0103*
d	0.4358	0.0330*	0.1039	0.0882
J'	0.4750	0.0005*	0.0008*	0.1847
H'	0.0085*	0.0001*	<0.0001*	0.7592
1-Lambda	0.2907	0.0262*	0.0032*	0.0503

5.5 Results: Site 3 (waste rock terrace – mine offices)

5.5.1 Comparisons of diversity patterns between treatments and reference sites

ANOVA results indicated there were significant differences between treatments and the reference sites for all variables during all three surveys (Table 5-10). Tukey-B post-hoc tests indicated that the rehabilitation treatments differed significantly from the reference sites for most variables during all three surveys (Table 5-11). The reference site had the highest means for each variable compared to the rehabilitation treatments during each survey, with only a few exceptions: S of graminoids during survey 5 and N of forbs during survey 6 (Appendix 13).

Table 5-10: ANOVA tests for vegetation monitoring data from Site 3 comparing treatments with reference sites over three survey periods. Survey 5, April 2015; survey 6, December 2015; survey 7, April 2016. Significant values in bold and marked with * ($p < 0.05$). Sf, forb richness; Sg, grass richness; Nf, forb abundance; Ng, grass abundance; d, Margalef species richness index; J', Pielou's evenness; H', Shannon Wiener diversity index; 1-Lambda, Simpson's index.

Variable	Survey 5 (df=7)			Survey 6 (df=7)			Survey 7 (df=7)			Survey 5	Survey 6	Survey 7
	Sum of Squares	Mean Square	F	Sum of Squares	Mean Square	F	Sum of Squares	Mean Square	F	ANOVA p-value	ANOVA p-value	ANOVA p-value
Sf	4739.64	677.09	164.63	4817.59	688.23	165.16	4858.03	694.00	157.83	<0.0001*	<0.0001*	<0.0001*
Sg	109.62	15.66	9.37	302.11	43.16	62.71	260.90	37.27	53.24	<0.0001*	<0.0001*	<0.0001*
S total	5411.27	773.04	115.34	7319.27	1045.61	184.17	7170.64	1024.38	175.56	<0.0001*	<0.0001*	<0.0001*
Nf	131536.16	18790.88	35.75	147867.92	21123.99	8.57	189657.69	27093.96	59.51	<0.0001*	<0.0001*	<0.0001*
Ng	20335.02	2905.00	22.70	33003.27	4714.75	54.59	32697.15	4671.02	31.94	<0.0001*	<0.0001*	<0.0001*
N total	251488.21	35926.89	44.52	274159.40	39165.63	15.49	353556.70	50508.10	74.00	<0.0001*	<0.0001*	<0.0001*
d	210.86	30.12	92.51	331.77	47.40	168.07	265.40	37.91	97.11	<0.0001*	<0.0001*	<0.0001*
J'	0.97	0.14	2.82	11.91	1.70	19.74	6.02	0.86	8.26	0.0076*	<0.0001*	<0.0001*
H'	82.75	11.82	75.12	167.75	23.96	193.91	137.94	19.71	129.54	<0.0001*	<0.0001*	<0.0001*
1-Lambda	5.54	0.79	20.68	20.68	2.95	69.18	11.12	1.59	21.16	<0.0001*	<0.0001*	<0.0001*

Table 5-11: Significant differences between treatments at Site 3 and the reference sites for each variable based on Tukey-B post-hoc tests. Treatments marked with "a" differed significantly from the reference during survey 5, treatments marked with "b" differed significantly from the reference during survey 6, and treatments marked with "c" differed significantly from the reference during survey 7. Sf, forb richness; Sg, grass richness; Nf, forb abundance; Ng, grass abundance; d, Margalef species richness index; J', Pielou's evenness; H', Shannon Wiener diversity index; 1-Lambda, Simpson's index. Treatments 1, waste rock (wr); 2, wr and coarse tailings (ct) (100 mm); 3, wr and ct (200 mm); 4, wr and top soil (ts) (100 mm); 5, wr and ts (250 mm); 6, wr, ct (100 mm) and ts (100 mm); 7, wr, ct (250 mm) and ts (100 mm).

Variable	Treatment						
	1	2	3	4	5	6	7
Sf	a,b,c	a,b,c	a,b,c	a,b,c	a,b,c	a,b,c	a,b,c
Sg	b,c	a,b,c	a,b,c	b,c	b,c	b,c	b,c
S total	a,b,c	a,b,c	a,b,c	a,b,c	a,b,c	a,b,c	a,b,c
Nf	a,b,c	a,b,c	a,b,c	a,c	a,c	a,c	a,c
Ng	a,b,c	a,b,c	a,b,c	a,b,c	a,b	a,b,c	a,b,c
N total	a,b,c	a,b,c	a,b,c	a,c	a,c	a,b,c	a,b,c
d	a,b,c	a,b,c	a,b,c	a,b,c	a,b,c	a,b,c	a,b,c
J'	b,c	b,c	b,c	b	b	b	b
H'	a,b,c	a,b,c	a,b,c	a,b,c	a,b,c	a,b,c	a,b,c
1-Lambda	a,b,c	a,b,c	a,b,c	a,b,c	a,b,c	a,b,c	a,b,c

5.5.1.1 Treatment 1 (waste rock)

Treatment 1 differed significantly from the reference for all ten variables during survey 6 and 7, and all variables during surveys 5 except S of graminoids and Pielou's evenness during survey 5 (Table 5-11). Treatment 1 had significantly higher values than treatment 3 (waste rock and coarse tailings (200 mm)) for two variables (S of graminoids and Shannon index) and significantly lower values than treatment 5 (waste rock and top soil (250 mm)) for two variables (S of graminoids and N total) during survey 5 (Table 5-12). During survey 6, treatment 1 had significantly lower values than treatment 4 for three variables (S of graminoids, N of forbs and N total) and treatment 5 for four variables (S of graminoids, N of forbs, N of graminoids and N total). During survey 7, treatment 1 had the highest mean of all the rehabilitation treatments for

one variable (N of forbs) (Appendix 13). Treatment 1 also had a significantly higher mean than treatment 3 for one variable (S of graminoids) and significantly lower means than treatment 4 for one variable (N of graminoids) and treatment 5 for two variables (S of graminoids and N of graminoids) during survey 7.

5.5.1.2 Treatment 2 (waste rock and coarse tailings (100 mm))

Treatment 2 differed significantly from the reference for all ten variables during all three surveys, except for Pielou's evenness during survey 5 (Table 5-11). Treatment 2 had significantly lower values than treatment 4 (waste rock and top soil (100mm)) for three variables (S of graminoids, N of graminoids and N total) and treatment 5 for six variables (S of graminoids, S total, N of graminoids, N of forbs, N total and Shannon index) during survey 5 (Table 5-12). During survey 6, treatment 2 had significantly lower mean values than treatment 4 for three variables (S of graminoids, N of forbs and N total) and treatment 5 for four variables (S of graminoids, N of forbs, N of graminoids and N total). During survey 7, treatment 2 had the highest mean of all the rehabilitation treatments for one variable (S of forbs). It also had significantly lower means than treatment 4 for two variables (S of graminoids and N of graminoids), treatment 5 for three variables (S of graminoids, N of graminoids and Pielou's evenness), treatment 6 for one variable (S of graminoids) and treatment 7 for one variable (S of graminoids).

5.5.1.3 Treatment 3 (waste rock and coarse tailings (200 mm))

Treatment 3 differed significantly from the reference sites for all ten variables during all three surveys, except for Pielou's evenness during survey 5 (Table 5-11). Treatment 3 had the lowest means of the rehabilitation treatments for all ten variables (Appendix 13), and had significantly lower values than treatment 1 for two variables, treatment 4 for six variables (S of graminoids, S total, N of forbs, N of graminoids, N total and Shannon index), treatment 5 for seven variables (S of graminoids, S total, N of forbs, N of graminoids, N total, Margalef's index and Shannon index), treatment 6 (waste rock, coarse tailings (100 mm) and top soil (100 mm)) for two variables (S of graminoids and Shannon index) and treatment 7 (waste rock, coarse tailings (250 mm) and top soil (100 mm)) for two variables (S of graminoids and Shannon index) during survey 5 (Table 5-12). During survey 6, treatment 3 again had the lowest mean values for all ten variables of all the rehabilitation treatments. This treatment also had significantly lower mean values than treatment 4 for six variables (S of graminoids, N of forbs, N of graminoids, N total, Pielou's evenness and Shannon index), treatment 5 for eight variables (S of graminoids, S total, N of forbs, N of graminoids, N total, Pielou's evenness, Shannon index and Simpson index),

treatment 6 for two variables (N total and Pielou's evenness) and treatment 7 for two variables (N of forbs and N total) during survey 6. During survey 7, treatment 3 had the lowest means for all variables except one (N of forbs). Treatment 3 also had significantly lower means than treatment 1 for one variable, treatment 4 for four variables (S of graminoids, N of graminoids, Pielou's evenness and Shannon index), treatment 5 for five variables (S of graminoids, N of graminoids, N total, Pielou's evenness and Shannon index), treatment 6 for three variables (S of graminoids, Pielou's evenness and Shannon index) and treatment 7 for three variables (S of graminoids, Pielou's evenness and Shannon index) during survey 7.

5.5.1.4 Treatment 4 (waste rock and topsoil (100 mm))

Treatment 4 differed from the reference for all variables during all surveys, except for S of graminoids during survey 5, N of forbs and N total during survey 6 and Pielou's evenness during surveys 5 and 7 (Table 5-11). Treatment 4 had significantly higher values than treatment 2 for three variables and treatment 3 for six variables during survey 5 (Table 5-12). During survey 6, treatment 4 had the highest mean values of all the rehabilitation treatments for two variables (N of forbs and N total) (Appendix 13). Treatment 4 also had significantly higher mean values than treatment 1 for three variables, treatment 2 for three variables and treatment 3 for six variables, as well as significantly lower mean values than treatment 5 for one variable (S of graminoids) during survey 6. During survey 7, treatment 4 had significantly higher means than treatment 1 for one variable, treatment 2 for two variables, treatment 3 for four variables and treatment 7 for one variable (N of graminoids).

5.5.1.5 Treatment 5 (waste rock and topsoil (250 mm))

Treatment 5 had the least significant differences with the reference sites of all the rehabilitation treatments across all three surveys (Table 5-11). Treatment 5 differed significantly from the reference for all variables during all three surveys, except S of graminoids during survey 5, N of forbs and N total during survey 6, N of graminoids during survey 7 and Pielou's evenness during surveys 5 and 7. This treatment had the highest means of the rehabilitation treatments for all variables except one (Pielou's evenness) during survey 5 (Appendix 13). Treatment 5 also had significantly higher values than treatment 1 for two variables, treatment 2 for six variables, treatment 3 for seven variables, treatment 6 for one variable (S of graminoids) and treatment 7 for three variables (S of graminoids, N of graminoids and N total) during survey 5. During survey 6, treatment 5 had the highest mean values of all the rehabilitation treatments for all variables except two (N of forbs and N total). Treatment 5 also had significantly higher mean values than

treatment 1 for four variables, treatment 2 for four variables, treatment 3 for eight variables, treatment 4 for one variable, and treatments 6 and 7 both for two variables (S of graminoids and N of graminoids). During survey 7, treatment 5 had the highest means for all variables except three (S of forbs, N of forbs and Simpson index). Treatment 5 also had significantly higher means than treatment 1 for two variables, treatment 2 for three variables, treatment 3 for five variables and treatments 6 and 7 for one variable each (N of graminoids) during survey 7.

5.5.1.6 Treatment 6 (waste rock, coarse tailings (100 mm) and topsoil (100 mm))

Treatment 6 differed significantly from the reference for all ten variables during all three surveys, except for S of graminoids during survey 5, N of forbs during survey 6 and Pielou's evenness during surveys 5 and 7 (Table 5-11). Treatment 6 had significantly higher values than treatment 3 for two variables, and significantly lower values than treatment 5 for one variable during survey 5. During survey 6, treatment 6 had significantly higher values than treatment 3 for two variables, and significantly lower values than treatment 5 for two variables. During survey 7, treatment 6 had significantly higher means than treatment 2 for one variable and treatment 3 for three variables, and a significantly lower mean than treatment 5 for one variable.

5.5.1.7 Treatment 7 (waste rock, coarse tailings (250 mm) and topsoil (100 mm))

Treatment 7 had the highest means of all the rehabilitation treatments for one variable (Pielou's evenness) (Appendix 13) and had significantly higher values than treatment 3 for two variables, and significantly lower values than treatment 5 for three variables during survey 5 (Table 5-12). During survey 6, treatment 7 had significantly higher values than treatment 3 for two variables, and significantly lower values than treatment 5 for two variables. During survey 7, treatment 7 had the highest mean of all the rehabilitation treatments for one variable (Simpson index). It also had significantly higher means than treatment 2 for one variable and treatment 3 for three variables, and significantly lower means than treatments 4 and 5 for one variable each.

5.5.2 Comparisons of species composition between treatments and reference sites

Non-metric multidimensional scaling (NMDS) analyses indicated a large number of outlying quadrats from treatments 1 and 3 (without top soil) due to quadrats containing one or no species, with a smaller number of outlying quadrats from treatments 2 and 4 (Figure 5-6A). The quadrats from the reference site and the majority of the remaining quadrats from the

rehabilitation treatments all clustered tightly together, with the reference site forming its own distinguishable cluster (Figure 5-6B).

Table 5-12: Significant differences between treatments at Trial site 3 during surveys 5-7. “<” indicates treatments which have values significantly higher than that treatment for that variable. “>” indicates treatments which have values significantly lower than that treatment for that variable. Sf, forb richness; Sg, grass richness; Nf, forb abundance; Ng, grass abundance; d, Margalef species richness index; J’, Pielou’s evenness; H’, Shannon Wiener diversity index; 1-Lambda, Simpson’s index. Treatments 1, waste rock (wr); 2, wr and coarse tailings (ct) (100 mm); 3, wr and ct (200 mm); 4, wr and top soil (ts) (100 mm); 5, wr and ts (250 mm); 6, wr, ct (100 mm) and ts (100 mm); 7, wr, ct (250 mm) and ts (100 mm).

Variable	Treatment						
	1	2	3	4	5	6	7
Survey 5							
Sf	-	-	-	-	-	-	-
Sg	>3, <5	<4, <5	<1, <4, <5, <6, <7	>2, >3	>1, >2, >3, >6, >7	>3, <5	>3, <5
S total	-	<5	<4, <5	>3	>2, >3	-	-
Nf	-	<5	<4, <5	>3	>2, >3	-	-
Ng	-	<4, <5	<4, <5	>2, >3	>2, >3, >7	-	<5
N total	<5	<4, <5	<4, <5	>2, >3	>1, >2, >3, >7	-	<5
d	-	-	<5	-	>3	-	-
J'	-	-	-	-	-	-	-
H'	>3	<5	<1, <4, <5, <6, <7	>3	>2, >3	>3	>3
1-λ	-	-	-	-	-	-	-
Balance	0	-9	-19	9	19	1	-1
Survey 6							
Sf	-	-	-	-	-	-	-
Sg	<4, <5	<4, <5	<4, <5	>1, >2, >3, <5	>1, >2, >3, >4, >6, >7	<5	<5
S total	-	-	<5	-	>3	-	-
Nf	<4, <5	<4, <5	<4, <5, <7	>1, >2, >3	>1, >2, >3	-	>3
Ng	<5	<5	<4, <5	>3	>1, >2, >3, >6, >7	<5	<5
N total	<4, <5	<4, <5	<4, <5, <6, <7	>1, >2, >3	>1, >2, >3	>3	>3
d	-	-	-	-	-	-	-
J'	-	-	<4, <5, <6	>3	>3	>3	-
H'	-	-	<4, <5	>3	>3	-	-
1-λ	-	-	<5	-	>3	-	-
Balance	-7	-7	-18	11	21	0	0
Survey 7							
Sf	-	-	-	-	-	-	-
Sg	>3, <5	<4, <5, <6, <7	<1, <4, <5, <6, <7	>2, >3	>1, >2, >3	>2, >3	>2, >3
S total	-	-	-	-	-	-	-
Nf	-	-	-	-	-	-	-
Ng	<4, <5	<4, <5	<4, <5	>1, >2, >3, >7	>1, >2, >3, >6, >7	<5	<4, <5
N total	-	-	<5	-	>3	-	-
d	-	-	-	-	-	-	-
J'	-	<5	<4, <5, <6, <7	>3	>2, >3	>3	>3
H'	-	-	<4, <5, <6, <7	>3	>3	>3	>3
1-λ	-	-	-	-	-	-	-
Balance	-2	-7	-16	8	12	3	2
Balance	-3	-7.6	-17.6	9.3	17.3	1.3	0.3

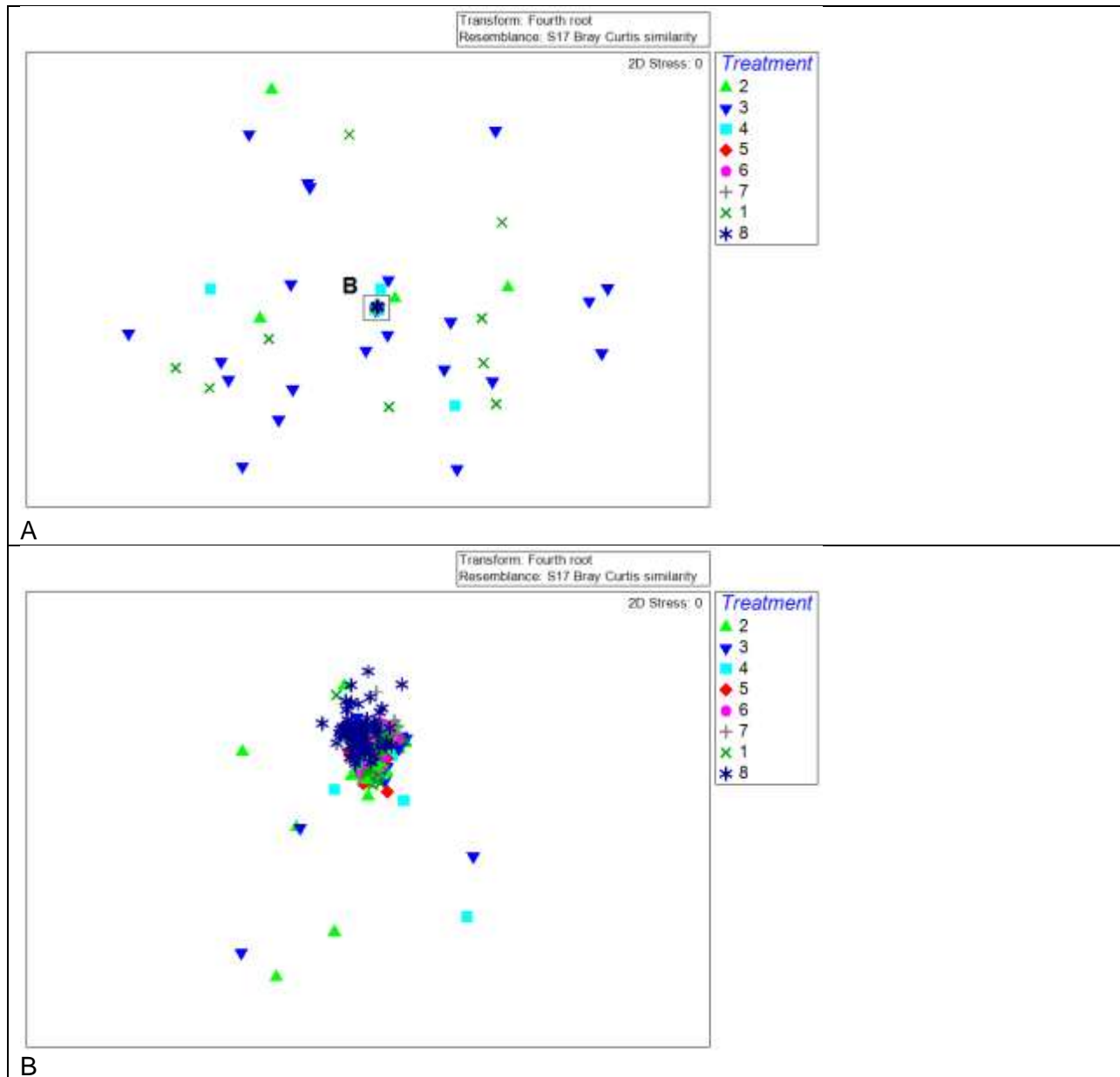


Figure 5-6: Non-metric multidimensional scaling analyses based on total plant species composition for Site 3. A: All quadrats. B: Enhanced image of area marked “B”. Treatments 1, waste rock (wr); 2, wr and coarse tailings (ct) (100 mm); 3, wr and ct (200 mm); 4, wr and top soil (ts) (100 mm); 5, wr and ts (250 mm); 6, wr, ct (100 mm) and ts (100 mm); 7, wr, ct (250 mm) and ts (100 mm); 8, reference.

PCA ordinations for treatments from trial site 3 showed some overlap between the reference sites and the rehabilitation treatments, however, there was still a clear separation between the treatments and the reference sites (Figure 5-7A). When looking at the same ordinations coded for top soil depth instead of treatment (Figure 5-7B), it would appear that treatments containing a high amount of topsoil (250 mm) were slightly more similar to the reference sites (± 200 mm thickness) than treatments containing an intermediate amount of topsoil (100 mm), while treatments containing no top soil were the least similar to the reference sites.

The abundance of forbs was slightly divergent from the other variables, with an increase in the N of forbs being roughly perpendicular to an increase in the four diversity indices (Shannon, Margalef, Simpson and Pielou). This suggests that a high abundance of forbs did not necessarily lead to high values for the other variables, especially the diversity indices.

5.5.3 Comparisons within treatments over time

All treatments showed some significant changes over time (Table 5-13). Treatment 1 showed a significant decrease in six variables (S of graminoids, S total, N of forbs, N of graminoids, N total and Shannon index), treatment 2 in eight variables (S of graminoids, S total, N of forbs, N of graminoids, N total, Pielou's evenness, Shannon index and Simpson index), treatment 3 in six variables (S of graminoids, S total, N of graminoids, N total, Pielou's evenness and Shannon index), treatment 4 in five variables (S of graminoids, S total, N of forbs, N total and Shannon index), treatment 5 in seven variables (S of forbs, S of graminoids, S total, N of forbs, N total, Margalef's index and Shannon index), treatment 6 in five variables (S of graminoids, S total, N of forbs, N total and Shannon index) and treatment 7 in seven variables (S of graminoids, S total, N of forbs, N of graminoids, N total, Margalef's index and Shannon index). No treatment showed any significant increases over time (Appendix 15). No treatment, except treatment 5, showed a significant decrease in the species richness of forbs, despite a significant decrease in the species richness of graminoids over time. The only treatments without a significant decrease in the abundance of graminoids were treatments 4, 5 and 6, which all contained topsoil.

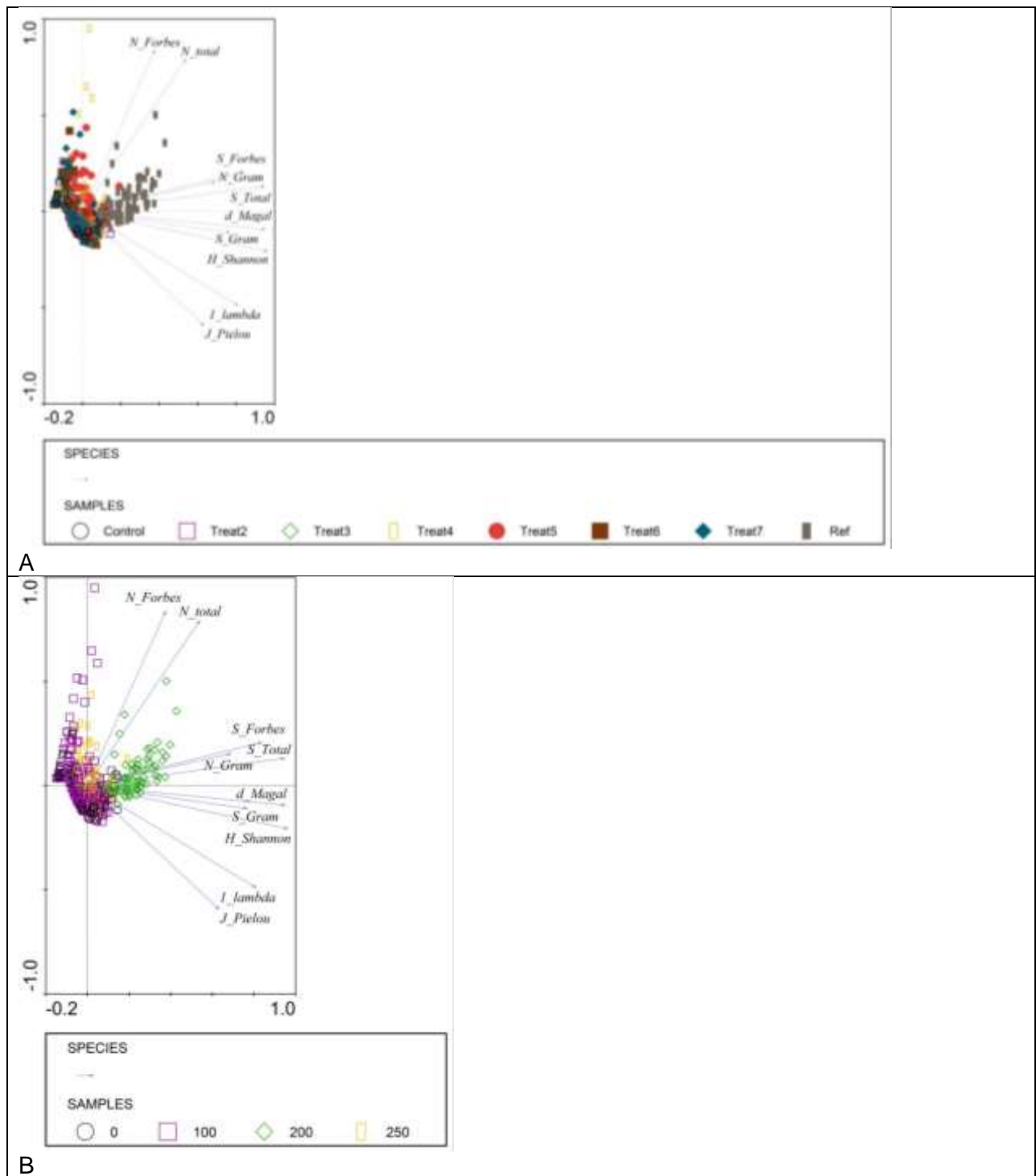


Figure 5-7: PCA ordination of all assemblage variables and diversity indices for all treatments from site 3 as well as the reference sites for surveys 5, 6 and 7. A: Arranged according to treatment, B: Arranged according to top soil depth. Treatments 1, waste rock (wr); 2, wr and coarse tailings (ct) (100 mm); 3, wr and ct (200 mm); 4, wr and top soil (ts) (100 mm); 5, wr and ts (250 mm); 6, wr, ct (100 mm) and ts (100 mm); 7, wr, ct (250 mm) and ts (100 mm).

Table 5-13: Paired t-test results for vegetation monitoring data for treatments from Site 3 over time. Significant values are in bold and marked with a * (p<0.05). Sf, forb richness; Sg, grass richness; Nf, forb abundance; Ng, grass abundance; d, Margalef species richness index; J', Pielou's evenness; H', Shannon Wiener diversity index; 1-Lambda, Simpson's index. Treatments 1, waste rock (wr); 2, wr and coarse tailings (ct) (100 mm); 3, wr and ct (200 mm); 4, wr and top soil (ts) (100 mm); 5, wr and ts (250 mm); 6, wr, ct (100 mm) and ts (100 mm); 7, wr, ct (250 mm) and ts (100 mm).

Variable	Paired t-test p-value						
	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5	Treatment 6	Treatment 7
Sf	0.8235	0.8458	1.0000	0.2297	0.0086*	0.5735	0.6262
Sg	0.0001*	0.0001*	<0.0001	<0.0001*	<0.0001*	<0.0001*	<0.0001*
S total	0.0004*	0.0003*	0.0002*	<0.0001*	<0.0001*	0.0001*	<0.0001*
Nf	0.0284*	0.0001*	0.1151	<0.0001*	<0.0001*	<0.0001*	0.0004*
Ng	0.0027*	0.0002*	<0.0001*	0.3083	0.7358	0.0591	0.0217*
N total	0.0024*	<0.0001*	<0.0001*	<0.0001*	0.0007*	<0.0001*	0.0003*
d	0.2217	0.0558	0.1500	0.0787	0.0012*	0.3348	0.0329*
J'	0.2223	0.0301*	0.0140*	0.3677	0.8490	0.3452	0.3991
H'	0.0041*	0.0014*	0.0039*	0.0013*	0.0003*	0.0023*	0.0007*
1-λ	0.2368	0.0427*	0.1259	0.0765	0.0872	0.1782	0.1851

5.6 Discussion

There were significant differences in diversity between all of the rehabilitation treatments at all three sites and the reference sites during all three surveys. This is similar to findings by Zaloumis and Bond (2011), reporting significant differences in species richness between restoration treatments and reference sites. The PCA ordinations showed that the rehabilitation treatments were also clearly dissimilar to the reference sites with regards to species composition, also similar to the results of Zaloumis and Bond (2011). As there were so many significant differences between the rehabilitation treatments and the reference sites, it is difficult to distinguish between treatments that performed well and treatments that did not, based purely on the number of significant differences from the reference sites. However, it is possible to identify treatments that had higher diversity than the other treatments, based on the significant differences occurring between treatments and within treatments over time.

At site 1, the ANOVA results and the Tukey-B post-hoc tests indicated that treatments 2, 4 and 6 (which all contained top soil) had significantly higher diversity than treatments 1, 3 and 5 (which did not contain top soil). The non-metric multidimensional scaling (NMDS) analysis indicated the same with regards to species composition, with treatments 1, 3 and 5 all having several outliers far removed from the other three treatments and the reference sites, due to having one or no species in a quadrat. Treatments 2, 4 and 6 are also the treatments that are the most similar to the reference sites in the NDMS analysis. The Principal Component Analysis (PCA) ordinations did not fully support this, however, with treatment 1 grouping closer to the reference sites instead of treatment 6. However, the PCA ordinations coded for top soil depth showed a distinct pattern of treatments containing top soil grouping closer to the reference sites than treatments that contained no top soil. These results are similar to other studies where

treatments containing topsoil had higher plant density, cover and species richness (Holmes, 2001), as well as seedling establishment and persistence (Van Wyk, 2003) than treatments that did not contain topsoil.

From this it is evident that 100 mm on top of top soil on fine tailings is the best option to stimulate vegetation establishment to improve the functionality of the TSF beach over time (Figure 5-8). If this is not feasible, the second most promising treatment is a 250 mm covering of coarse tailings on fine tailings, capped with 100 mm top soil (Figure 5-8).

At site 2, the ANOVA and post-hoc tests indicated that treatment 1 (coarse tailings and top soil) had significantly higher species diversity than the other three treatments. Treatment 2 (coarse tailings and waste rock) consistently had the lowest diversity compared to the other treatments. Treatments 3 (coarse tailings, waste rock and top soil) and 4 (control – coarse tailings) did not appear to differ significantly from each other with regards to the variables measured, despite the presence of top soil in one, but not the other. This could be due to the formation of patches where salts form and accumulate as a result of the mixing of coarse tailings and waste rock in treatment 3 (Parraga-Aguado *et al.*, 2013). The NMDS analysis did not seem to indicate that any of the treatments had species compositions closer to the reference sites than any other treatment, with only treatment 1 having less outliers than the other treatments. The PCA ordinations again indicated that treatments containing top soil were more similar to the reference sites than treatments that did not contain top soil.

From this it is evident that 100 mm of top soil on top of coarse tailings is the best option to stimulate vegetation establishment to improve the functionality of the rock wall over time (Figure 5-8). If this is not feasible, the second most promising treatment is a fill in of 100 mm coarse tailings on waste rock, capped with 100 mm top soil (Figure 5-8).

Site	Treatment	Performance score (functionality)	Rehab choices
1	(1) ft control	-2.3	i. Fine tailings base with 100mm of top soil
	(2) ft + ts 100	8	
	(3) ft + ct 100	-7.6	ii. Fine tailings base, coarse tailings 250mm with 100mm of top soil
	(4) ft + ct 100 + ts 100	5.3	
	(5) ft + ct 250	-9.3	
	(6) ft + ct 250 + ts 100	6	
2	(1) ct + ts 100	5 (11)	i. Coarse tailings base with 100mm of top soil
	(2) ct + wr 300	-7.6 (4)	ii. Coarse tailings base with waste rock and 100mm of top soil
	(3) ct + wr 300 + ts 100	2.6 (10)	
	(4) ct control	0 (4)	
3	(1) wr control	-3 (12)	i. Waste rock base with 200mm of top soil, but 100mm is sufficient
	(2) wr + ct 100	-7.6 (9)	
	(3) wr + ct 200	-17.6 (5)	
	(4) wr + ts 100	9.3 (12)	ii. Waste rock base with 100mm of coarse tailings and 100mm of top soil
	(5) wr + ts 200	17.3 (12)	
	(6) wr + ct 100 + ts 100	1.3 (11)	
	(7) wr + ct 200 + ts 100	0.3 (2)	

Figure 5-8: Treatments that performed the best in terms of diversity indices (and functionality in brackets) in comparison to other treatments of the same trial site. Performance scores were derived from the number of significant better performances averaged over three years (from Tables 5-4, 5-8 and 5-12) and functionality from Chapter 4. A first and second choice is selected from the scores and proposed for application in rehabilitation. Treatments in red should not be considered as they performed worse than untreated base mine tailings.

At site 3, the ANOVA and post-hoc tests indicated that treatment 5 (waste rock and top soil (250 mm)) had the highest species diversity of all seven rehabilitation treatments, significantly higher than all treatments except treatment 4 (waste rock and top soil (100 mm)). Holmes (2001) found that treatments containing a higher amount of topsoil (300 mm) had a lower plant density, but higher cover, than treatments containing a lower amount of topsoil (100 mm), at least up to 18 months after seeding. This may suggest that treatment 5 at site 3 (with 250 mm of topsoil) could begin to show significantly higher species diversity as time goes on. These two treatments had significantly higher species diversity than the other two treatments that also contained top soil: treatments 6 (waste rock, coarse tailings (100 mm) and top soil (100 mm)) and 7 (waste rock, coarse tailings (250 mm) and top soil (100 mm)). However, all four treatments containing top soil still had higher species diversity than the three treatments that did not contain top soil. Of these three, treatment 3 (waste rock and coarse tailings (200 mm)) had the lowest species diversity, significantly less than even the control treatment. The NMDS analysis indicated a small amount of overlap between the reference sites and the four treatments that contained top soil. The PCA ordinations did not indicate a higher similarity for any one treatment to the reference, but again indicated that treatments containing topsoil were more similar to the reference than treatments that did not contain any topsoil.

From this it is evident that 200 mm of top soil filling in waste rock is the best option to stimulate vegetation establishment to improve the functionality of the waste rock dump over time (Figure 5-8). However, 100 mm of top soil produced similar results. If this is not feasible, the second most promising treatment is a covering of waste rock on coarse tailings, filled in with 100 mm top soil (Figure 5-8). When looking at the paired t-test results for changes over time, the treatments containing top soil at site 1 had the most significant increases over time. The only treatment not containing top soil that showed any increase over time was treatment 3, while treatment 5 showed no change and treatment 1 showed a decrease in species diversity. At site 2 however, all treatments showed a decrease in species diversity, with treatment 4 (control) showing the least, followed by treatment 1. Treatments 2 and 3 showed nearly equal decreases over time. This seems to further suggest a negative effect of mixing coarse tailings and waste rock on rehabilitation success, even when combined with top soil (Reid & Naeth, 2005; Rossouw *et al.*, 2009). Vegetation establishment on kimberlite tailings can be difficult because they often exhibit unsuitable substrate properties for plant colonization, including poor water- and nutrient-holding capacities, low nutrients, and serpentine conditions (Whittaker, 1954). At site 3, all treatments showed some decreases over time, with treatments 4 and 6 (which contained topsoil) decreasing the least. However, treatments 1 and 3 (which did not contain topsoil) only had slightly more variables decrease over time as treatments 4 and 6, and less

than treatments 5 and 7. Similar to Van Wyk (2003), the control treatments had low diversity and generally showed a decrease in diversity over time.

The PCA ordinations at all three rehabilitation trial sites suggested that the treatments were dominated by forbs, and that this was not necessarily an indication of high species diversity. Trial sites 1 and 3 also showed increases in the diversity of forbs. Huguenin-Elie *et al.* (2010) found that forb species were more likely to establish in grasslands with low biomass. While the biomass was not measured, it was clear that it was lower on the rehabilitation treatments than the reference sites, which may explain why there was such a high abundance of forbs on the rehabilitation treatments. The dominant forbs on the treatments were pioneers, especially *Sisymbrium turczaninowii*, *Senecio* sp., *Senecio asperculus* and *Chrysocoma ciliata*.

At site 1, treatments containing topsoil showed a significant increase in the diversity of graminoids, while one topsoil treatment showed a significant decrease in the abundance of forbs over time. This was not the case at site 2, however, where the species richness of forbs either increased significantly or did not change, while the diversity of graminoids decreased significantly on topsoil treatments as the pioneer grasses were replaced by more persistent tussock grasses such as *Merxmeullera disticha* and *Festuca caprina*. At site 3, treatments containing topsoil (except treatment 7) were the only treatments not to show a significant decrease in the abundance of graminoids over time. Wang *et al.* (2014) found that the species composition of grasslands shifted from sedge and grass dominated to forb dominated along a degradation gradient. They also found a decrease in species richness, Pielou's evenness and the Shannon diversity index along a degradation gradient in grasslands (Wang *et al.*, 2014). This may suggest that the higher diversity of graminoids on topsoil treatments is indicative of these treatments being in a less degraded state than other treatments. The high diversity of forbs across the treatments may then also be indicative of the degraded state of the rehabilitation treatments compared to the natural grassland.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 Functionality

The specific hypothesis related to this chapter states that an increase in topsoil will enhance the functionality of a treatment. This hypothesis is supported by the results that were obtained. On Site 2 the treatment that performed the best compared to the reference sites was Treatment 1, which contained topsoil. Treatments 1 and 3 both contained the same amount of topsoil (100 mm). However, treatment 3 did not perform as well as treatment 1 when compared to the reference sites. Treatment 3 contained a mixture of coarse tailings and waste rock. However, the PCA ordinations indicated that treatments 1 and 3 were much more similar to each other than to treatment 2, and also more similar to the reference sites in terms of the infiltration and nutrient cycling SSA indices than treatment 2.

At Trial site 3, the treatments that performed the best were all treatments that contained topsoil. Treatment 4, which contained an intermediate amount of topsoil (100 mm), performed the best with no significant deviations at either survey compared to the reference sites. The next best treatment was Treatment 5, which contained the maximum amount of topsoil (250 mm), followed by Treatment 6 with 100 mm of topsoil. However, the fourth treatment to contain topsoil was Treatment 7 with 100 mm of topsoil. As discussed, this treatment performed exceptionally poorly when compared to the reference sites during the second survey. Likewise to Treatment 3 of Site 2, this treatment also contained a mixture of coarse tailings and waste rock. The PCA ordination indicated that treatments 4, 6 and 7 were the most similar to the reference sites with regards to functionality, followed by Treatment 5 with the deeper 250 mm top soil.

Overall, the treatments with top soil outperformed the treatments without top soil in terms of functionality. With regards to top soil treatments, in both of the instances of poor landscape functionality for both trial sites, the treatments with a mixture of top soil, coarse tailings and waste rock performed the worst. Treatments where top soil is mixed with either coarse tailings or waste rock performed better.

6.2 Vegetation establishment

The stated hypothesis that top soil application to tailings mixes on rehabilitation treatments would enhance the species diversity of the vegetation was supported. The results from the various analyses on trial sites 1 and 3 all indicated that treatments containing top soil had higher species diversity than treatments that did not contain top soil. On site 2, this was less apparent, with one top soil treatment performing worse than the control treatment, but it was still true for the remaining top soil treatments. However, it does not appear that an increase in the amount of

top soil thickness larger than 100 mm is more beneficial to an increase in richness, abundance or diversity.

When comparing the changes over time for each of the treatments at the various rehabilitation sites, it was also apparent that treatments containing top soil showed slightly less species loss than treatments that did not contain top soil. However, this was not as strongly supported and was not the case for all treatments or all sites.

By assessing and comparing the species richness, abundance and diversity of the vegetation on each of the treatments with each other and the reference sites, and comparing the changes in these parameters on each treatment over time, the aim of the study could be met and the optimal treatment for rehabilitation could be determined. At site 1 (fine tailings), the optimal treatments for rehabilitation were the three treatments containing top soil, especially treatments 2 (100 mm top soil on fine tailings) and 6 (250 mm coarse tailings capped with 100 mm top soil on fine tailings). It did not appear as if the presence or absence of coarse tailings made a significant difference, as long as top soil was present. At site 2 (coarse tailings), the optimal treatment for rehabilitation was treatment 1 (coarse tailings and top soil) and to a lesser extent treatment 3 (coarse tailings mixed with waste rock and capped with 100 mm top soil). At site 3 (waste rock), the optimal treatments for rehabilitation were treatments 4 (waste rock and top soil (100 mm)) and 5 (waste rock and top soil (250 mm)). The higher amount of top soil on treatment 5 did not appear to have an increased effect on the diversity compared to treatment 4. It should be noted that at trial sites 2 and 3, treatments containing a mix of coarse tailings and waste rock in addition to topsoil, performed noticeably worse than treatments that contained only one type of tailings with top soil.

In general it is therefore recommended that rehabilitation treatments on kimberlite tailings contain at least 100 mm of topsoil mixed with the base tailings, and that coarse tailings and waste rock mixes should be avoided as much as possible. The causes of the poor plant diversity on the coarse tailings and waste rock mixes are not understood. It is possible that it is caused by some combination of physical or chemical factors present in this combination of tailings. Further study is recommended.

6.3 General conclusions

When comparing the changes over time for each of the treatments at the various rehabilitation sites, it was also apparent that treatments containing top soil showed slightly less decreases with regards to species richness, abundance and diversity than treatments that did not contain top soil. However, this was not as strongly supported and was not the case for all treatments or all sites.

By assessing and comparing the vegetation establishment and functionality of the various rehabilitation treatments with each other, the aim of determining which treatments would be the most suitable for optimal rehabilitation was achieved.

At trial site 1 (fine tailings), the optimal treatments for rehabilitation were the three treatments containing top soil (treatments 2, 4 and 6). It did not appear as if the presence or absence of coarse tailings made a significant difference, as long as top soil was present.

At trial site 2 (coarse tailings), the optimal treatment for rehabilitation was treatment 1 (coarse tailings and top soil).

At site 3 (waste rock), the optimal treatments for rehabilitation were treatments 4 (waste rock and top soil (100 mm)) and 5 (waste rock and top soil (250 mm)). However, the higher amount of top soil on treatment 5 did not appear to have a significant effect on the vegetation diversity or functionality. It would seem that an increase beyond 100 mm of topsoil in the tailings mix for rehabilitation treatments does not have a significant effect. It is therefore recommended that the already scarce topsoil be used only to this level (100 mm) and not beyond, to ensure that as much rehabilitated surface area as possible receives at least some topsoil.

Importantly, it seems that waste rock and coarse tailings mixes reduces the functionality and diversity of the system when mixed with top soil, and it is therefore recommended that these types of treatments be avoided where possible. The causes of this decrease in functionality and diversity are not known, and it could be physical or chemical or both.

In conclusion, it can therefore be said that rehabilitation treatments on kimberlite tailings containing at least 100 mm of topsoil mixed with the base tailings, while avoiding mixes of coarse tailings and waste rock, would be optimal for rehabilitation success.

6.4 Limitations of this study

The greatest limitation to the study was the study period. The data used in this study were collected over a 17-month period from December 2014 to April 2016. While this was enough time to detect patterns in the data, data collection over a longer time would increase the confidence in the study even with regards to unexpected results (Holmes, 2001; Van Eeden, 2010). One also has to consider the age of the rehabilitation treatments. At the beginning of the study, the sites were between three and nine months old. While this allowed initial vegetation to be captured, the study period was not long enough to allow for pedogenesis and a successional trajectory of the rehabilitation treatments. There was also a severe regional drought during 2015. This may have impacted the data and further reinforces the need for monitoring over the longer term.

6.5 Recommendations for future monitoring and management

It is important that these rehabilitation trials continue to be monitored regularly for the foreseeable future. The data gathered from the first three years of the trials suggests that both functionality and plant diversity change slowly over time on rehabilitated kimberlite tailings in the afro-alpine zone of Lesotho. It is therefore recommended that the vegetation be monitored annually, while the functionality is monitored biennially.

The decrease in functionality and diversity on treatments containing a mixture of coarse tailings and waste rock should be investigated. It could be indicative of a problem that may pose serious problems for rehabilitation of diamond mines. Further study into this phenomenon should ideally try to determine whether this issue is unique to the rehabilitation trial sites, or whether it is something that could be expected on the actual rehabilitation areas in future.

It should be noted that the method of ripping differed between sites 2 and 3. Site 1 was not ripped at all, due to the nature of the terrain on the TSF beach. What effect, if any, the method of ripping may have on the diversity and functionality of different growth mediums may also be a worthwhile avenue of further study.

The use of traditional rehabilitation species such as *Digitaria eriantha*, *Chloris gayana*, *Eragrostis tef* and *Cynodon dactylon* (Rethman, 2000) in the seed mixture should be reconsidered. While there was some establishment of these species on the rehabilitation trials, it was minimal and they did not seem to provide much biomass or basal cover compared to *Triticum* (which still contributes litter cover two years after sowing) and the two native species, the forb *Sisymbrium turczaninowii* and perennial tussock grass *Merxmuellera disticha*. It is recommended that the seed mix for future rehabilitation contain less or even none of the non-wheat commercial species, and a higher application of the latter two indigenous species, along with a potential doubling of the application ratio of wheat.

It should also be noted that the current rehabilitation plan at Letšeng involves the use of 50 mm of top soil for rehabilitation. The results of this study may therefore not be applicable to the rehabilitation method the mine plans to implement.

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APPENDICES

Appendix 1: ANOVA results for LFA for trial site 2 (SPSS, 2016). Includes Kruskal-Wallis (KW) p-values (StatSoft, 2016). Treatment 1, coarse tailings (ct) and top soil (ts) (100mm); Treatment 2, ct and waste rock (wr); Treatment 3, ct, wr and ts (100mm); Ref, reference sites. Treatment 4, ct (control) was excluded due to a lack of repetitions. Significant values in bold ($p > 0.05$).

			Survey 1				Survey 2			
Variable	Treatment	N	Mean	Std. Dev.	ANOVA p-value	KW p-value	Mean	Std. Dev.	ANOVA p-value	KW p-value
Patch %	1	3	22.762	7.404	*0.0000	*0.0023	14.754	9.124	*0.0000	*0.0025
	2	3	1.338	1.161			0.911	1.578		
	3	3	15.970	5.055			4.307	2.621		
	Ref	9	93.133	7.744			96.104	3.241		
	Total	18	53.245	42.010			51.381	46.390		
Interpatch %	1	3	77.238	7.404	*0.0000	*0.0023	85.246	9.124	*0.0000	*0.0025
	2	3	98.662	1.161			99.089	1.578		
	3	3	84.030	5.055			95.693	2.621		
	Ref	9	6.867	7.744			3.896	3.241		
	Total	18	46.755	42.010			48.619	46.390		
Average patch width (cm)	1	3	35.550	12.690	*0.0021	*0.0047	84.414	33.378	*0.0000	*0.0030
	2	3	22.000	28.852			23.667	40.992		
	3	3	41.173	3.686			53.533	44.507		
	Ref	9	249.632	121.904			854.257	211.614		
	Total	18	141.270	139.925			454.064	437.648		
Number of Patches/10m	1	3	3.401	0.718	0.1512	0.1294	1.648	0.734	*0.0029	*0.0148
	2	3	1.067	1.007			0.222	0.385		
	3	3	3.223	0.856			1.284	0.400		
	Ref	9	3.622	1.930			0.600	0.332		
	Total	18	3.093	1.706			0.826	0.632		
Average Interpatch Length (m)	1	3	2.253	0.591	0.0584	*0.0028	5.123	1.963	*0.0000	*0.0026
	2	3	17.933	22.608			27.530	13.769		
	3	3	3.062	0.779			6.131	1.964		
	Ref	9	0.663	0.494			1.006	0.782		
	Total	18	4.206	10.058			6.967	10.847		
Average interpatch length (cm)	1	3	225.283	59.098	0.0584	*0.0028	512.333	196.347	*0.0000	*0.0026
	2	3	1793.250	2260.813			2753.000	1376.890		
	3	3	306.182	77.885			613.133	196.436		
	Ref	9	66.261	49.431			100.639	78.210		
	Total	18	420.583	1005.790			696.731	1084.666		

			Survey 1				Survey 2			
Variable	Treatment	N	Mean	Std. Dev.	ANOVA p-value	KW p-value	Mean	Std. Dev.	ANOVA p-value	KW p-value
Longest interpatch (m)	1	3	4.697	0.696	0.0667	*0.0267	10.800	1.498	*0.0000	*0.0030
	2	3	19.047	21.700			27.530	13.769		
	3	3	6.480	1.624			11.303	3.689		
	Ref	9	1.998	3.195			1.283	1.031		
	Total	18	6.036	9.971			8.914	10.876		
Total Patch Area	1	3	3.754	3.033	*0.0004	*0.0026	5.585	4.172	*0.0000	*0.0027
	2	3	0.121	0.179			0.097	0.168		
	3	3	2.183	1.037			1.210	1.876		
	Ref	9	142.809	67.164			469.076	22.962		
	Total	18	72.414	85.861			235.687	240.683		
Patch Area Index	1	3	0.010	0.005	*0.0005	*0.0026	0.020	0.017	*0.0000	*0.0027
	2	3	0.001	0.001			0.001	0.001		
	3	3	0.009	0.004			0.003	0.005		
	Ref	9	0.286	0.134			0.938	0.046		
	Total	18	0.146	0.171			0.473	0.480		
Landscape Organisation Index	1	3	0.228	0.074	*0.0000	*0.0025	0.148	0.091	*0.0000	*0.0025
	2	3	0.013	0.012			0.009	0.016		
	3	3	0.169	0.042			0.043	0.026		
	Ref	9	0.931	0.077			0.961	0.032		
	Total	18	0.534	0.418			0.514	0.464		
Stability	1	3	39.743	3.078	*0.0000	*0.0079	38.646	5.381	*0.0000	*0.0094
	2	3	62.861	2.639			63.095	2.062		
	3	3	40.759	3.919			41.507	1.304		
	Ref	9	65.852	5.222			66.234	9.344		
	Total	18	56.820	12.774			56.992	14.096		
Infiltration	1	3	29.292	2.537	*0.0000	*0.0026	22.173	3.316	*0.0000	*0.0036
	2	3	14.002	1.144			23.619	0.060		
	3	3	27.788	4.046			20.469	2.270		
	Ref	9	46.772	3.174			41.026	4.819		
	Total	18	35.233	13.177			31.557	10.424		
Nutrients	1	3	10.072	1.165	*0.0000	*0.0038	19.232	0.895	*0.0000	*0.0032
	2	3	11.335	1.555			19.277	0.081		
	3	3	11.572	1.692			18.371	0.779		
	Ref	9	33.597	4.552			33.978	5.453		
	Total	18	22.295	12.084			26.469	8.600		

Appendix 2: Kruskal-Wallis post-hoc tests for LFA data from trial site 2 (StatSoft, 2016). Treatment 1, coarse tailings (ct) and top soil (ts) (100mm); Treatment 2, ct and waste rock (wr); Treatment 3, ct, wr and ts (100mm); Treatment 8, reference sites. Treatment 4, ct (control) was excluded due to a lack of repetitions.

Patch %

Survey#=1.0 Multiple Comparisons p values (2-tailed); Patch (MeyerB_site2) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (3, N= 18) =14.49708 p =.0023				
Depend.: Patch	1 R:7.6667	2 R:2.0000	3 R:5.3333	8 R:14.000
1		1.000000	1.000000	0.450934
2	1.000000		1.000000	0.004482
3	1.000000	1.000000		0.089320
8	0.450934	0.004482	0.089320	

Survey#=2.0 Multiple Comparisons p values (2-tailed); Patch (MeyerB_site2) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (3, N= 18) =14.31610 p =.0025				
Depend.: Patch	1 R:7.6667	2 R:2.3333	3 R:5.0000	8 R:14.000
1		1.000000	1.000000	0.450934
2	1.000000		1.000000	0.006272
3	1.000000	1.000000		0.068676
8	0.450934	0.006272	0.068676	

Interpatch %

Survey#=1.0 Multiple Comparisons p values (2-tailed); Interpatch (MeyerB_site2) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (3, N= 18) =14.49708 p =.0023				
Depend.: Interpatch	1 R:11.333	2 R:17.000	3 R:13.667	8 R:5.0000
1		1.000000	1.000000	0.450934
2	1.000000		1.000000	0.004482
3	1.000000	1.000000		0.089320
8	0.450934	0.004482	0.089320	

Survey#=2.0 Multiple Comparisons p values (2-tailed); Interpatch (MeyerB_site2) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (3, N= 18) =14.31610 p =.0025				
Depend.: Interpatch	1 R:11.333	2 R:16.667	3 R:14.000	8 R:5.0000
1		1.000000	1.000000	0.450934
2	1.000000		1.000000	0.006272
3	1.000000	1.000000		0.068676
8	0.450934	0.006272	0.068676	

Average Patch Width (cm)

		Survey#=1.0 Multiple Comparisons p values (2-tailed); Averagepatchwidthcm (MeyerB_site2) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (3, N= 18) =12.95322 p =.0047			
Depend.:		1	2	3	8
Averagepatchwidthcm		R:5.3333	R:4.0000	R:5.6667	R:14.000
1			1.000000	1.000000	0.089320
2		1.000000		1.000000	0.029747
3		1.000000	1.000000		0.115250
8		0.089320	0.029747	0.115250	

		Survey#=2.0 Multiple Comparisons p values (2-tailed); Averagepatchwidthcm (MeyerB_site2) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (3, N= 18) =13.93354 p =.0030			
Depend.:		1	2	3	8
Averagepatchwidthcm		R:7.0000	R:3.0000	R:5.0000	R:14.000
1			1.000000	1.000000	0.295217
2		1.000000		1.000000	0.011980
3		1.000000	1.000000		0.068676
8		0.295217	0.011980	0.068676	

Number of Patches/10m

		Survey#=1.0 Multiple Comparisons p values (2-tailed); NumberofPatches10m (MeyerB_site2) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (3, N= 18) =5.658853 p =.1294			
Depend.:		1	2	3	8
NumberofPatches10m		R:11.333	R:2.8333	R:10.667	R:10.722
1			0.307033	1.000000	1.000000
2		0.307033		0.433928	0.159908
3		1.000000	0.433928		1.000000
8		1.000000	0.159908	1.000000	

		Survey#=2.0 Multiple Comparisons p values (2-tailed); NumberofPatches10m (MeyerB_site2) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (3, N= 18) =10.49579 p =.0148			
Depend.:		1	2	3	8
NumberofPatches10m		R:15.500	R:4.0000	R:14.333	R:7.7222
1			0.049997	1.000000	0.173172
2		0.049997		0.106547	1.000000
3		1.000000	0.106547		0.379388
8		0.173172	1.000000	0.379388	

Average Interpatch length (m)

		Survey#=1.0 Multiple Comparisons p values (2-tailed); AverageInterpatchLengthm (MeyerB_site2) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (3, N= 18) =14.06823 p =.0028			
Depend.:		1	2	3	8
AverageInterpatchLengthm		R:11.000	R:17.000	R:13.667	R:5.1111
1			1.000000	1.000000	0.587991
2		1.000000		1.000000	0.005018
3		1.000000	1.000000		0.097326
8		0.587991	0.005018	0.097326	

		Survey#=2.0 Multiple Comparisons p values (2-tailed); AverageInterpatchLengthm (MeyerB_site2) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (3, N= 18) =14.27789 p =.0026			
Depend.:		1	2	3	8
AverageInterpatchLengthm		R:12.000	R:17.000	R:13.000	R:5.0000
1			1.000000	1.000000	0.295217
2		1.000000		1.000000	0.004482
3		1.000000	1.000000		0.147531
8		0.295217	0.004482	0.147531	

Average interpatch length (cm)

		Survey#=1.0 Multiple Comparisons p values (2-tailed); Averageinterpatchlengthcm (MeyerB_site2) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (3, N= 18) =14.06823 p =.0028			
Depend.:		1	2	3	8
Averageinterpatchlengthcm		R:11.000	R:17.000	R:13.667	R:5.1111
1			1.000000	1.000000	0.587991
2		1.000000		1.000000	0.005018
3		1.000000	1.000000		0.097326
8		0.587991	0.005018	0.097326	

		Survey#=2.0 Multiple Comparisons p values (2-tailed); Averageinterpatchlengthcm (MeyerB_site2) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (3, N= 18) =14.27789 p =.0026			
Depend.:		1	2	3	8
Averageinterpatchlengthcm		R:12.000	R:17.000	R:13.000	R:5.0000
1			1.000000	1.000000	0.295217
2		1.000000		1.000000	0.004482
3		1.000000	1.000000		0.147531
8		0.295217	0.004482	0.147531	

Longest interpatch (m)

		Survey#=1.0 Multiple Comparisons p values (2-tailed); Longestinterpatchm (MeyerB_site2) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (3, N= 18) =9.202729 p =.0267			
Depend.:		1	2	3	8
Longestinterpatchm		R:10.667	R:14.667	R:14.000	R:5.8889
1			1.000000	1.000000	1.000000
2		1.000000		1.000000	0.081900
3		1.000000	1.000000		0.135993
8		1.000000	0.081900	0.135993	

		Survey#=2.0 Multiple Comparisons p values (2-tailed); Longestinterpatchm (MeyerB_site2) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (3, N= 18) =13.95007 p =.0030			
Depend.:		1	2	3	8
Longestinterpatchm		R:12.333	R:16.667	R:13.000	R:5.0000
1			1.000000	1.000000	0.236111
2		1.000000		1.000000	0.006272
3		1.000000	1.000000		0.147531
8		0.236111	0.006272	0.147531	

Total patch area

		Survey#=1.0 Multiple Comparisons p values (2-tailed); TotalPatchArea (MeyerB_site2) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (3, N= 18) =14.26316 p =.0026			
Depend.:		1	2	3	8
TotalPatchArea		R:7.0000	R:2.0000	R:6.0000	R:14.000
1			1.000000	1.000000	0.295217
2		1.000000		1.000000	0.004482
3		1.000000	1.000000		0.147531
8		0.295217	0.004482	0.147531	

		Survey#=2.0 Multiple Comparisons p values (2-tailed); TotalPatchArea (MeyerB_site2) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (3, N= 18) =14.13740 p =.0027			
Depend.:		1	2	3	8
TotalPatchArea		R:7.6667	R:2.6667	R:4.6667	R:14.000
1			1.000000	1.000000	0.450934
2		1.000000		1.000000	0.008704
3		1.000000	1.000000		0.052382
8		0.450934	0.008704	0.052382	

Patch area index

		Survey#=1.0 Multiple Comparisons p values (2-tailed); PatchAreaIndex (MeyerB_site2) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (3, N= 18) =14.21637 p =.0026			
Depend.:		1	2	3	8
PatchAreaIndex		R:6.6667	R:2.0000	R:6.3333	R:14.000
1			1.000000	1.000000	0.236111
2		1.000000		1.000000	0.004482
3		1.000000	1.000000		0.187372
8		0.236111	0.004482	0.187372	

		Survey#=2.0 Multiple Comparisons p values (2-tailed); PatchAreaIndex (MeyerB_site2) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (3, N= 18) =14.13740 p =.0027			
Depend.:		1	2	3	8
PatchAreaIndex		R:7.6667	R:2.6667	R:4.6667	R:14.000
1			1.000000	1.000000	0.450934
2		1.000000		1.000000	0.008704
3		1.000000	1.000000		0.052382
8		0.450934	0.008704	0.052382	

Landscape organisation index

		Survey#=1.0 Multiple Comparisons p values (2-tailed); LandscapeOrganisationIndex (MeyerB_site2) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (3, N= 18) =14.35673 p =.0025			
Depend.:		1	2	3	8
LandscapeOrganisationIndex		R:7.3333	R:2.0000	R:5.6667	R:14.000
1			1.000000	1.000000	0.366268
2		1.000000		1.000000	0.004482
3		1.000000	1.000000		0.115250
8		0.366268	0.004482	0.115250	

		Survey#=2.0 Multiple Comparisons p values (2-tailed); LandscapeOrganisationIndex (MeyerB_site2) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (3, N= 18) =14.31610 p =.0025			
Depend.:		1	2	3	8
LandscapeOrganisationIndex		R:7.6667	R:2.3333	R:5.0000	R:14.000
1			1.000000	1.000000	0.450934
2		1.000000		1.000000	0.006272
3		1.000000	1.000000		0.068676
8		0.450934	0.006272	0.068676	

Surface stability

Survey#=1.0 Multiple Comparisons p values (2-tailed); Stability (MeyerB_site2) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (3, N= 18) =11.84600 p =.0079				
Depend.: Stability	1	2	3	8
	R:3.3333	R:10.667	R:3.6667	R:13.111
1		0.554969	1.000000	0.036051
2	0.554969		0.649762	1.000000
3	1.000000	0.649762		0.047774
8	0.036051	1.000000	0.047774	

Survey#=2.0 Multiple Comparisons p values (2-tailed); Stability (MeyerB_site2) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (3, N= 18) =11.46798 p =.0094				
Depend.: Stability	1	2	3	8
	R:3.0000	R:12.000	R:4.0000	R:12.667
1		0.233685	1.000000	0.039634
2	0.233685		0.398745	1.000000
3	1.000000	0.398745		0.089320
8	0.039634	1.000000	0.089320	

Infiltration capacity

Survey#=1.0 Multiple Comparisons p values (2-tailed); Infiltration (MeyerB_site2) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (3, N= 18) =14.26316 p =.0026				
Depend.: Infiltration	1	2	3	8
	R:7.0000	R:2.0000	R:6.0000	R:14.000
1		1.000000	1.000000	0.295217
2	1.000000		1.000000	0.004482
3	1.000000	1.000000		0.147531
8	0.295217	0.004482	0.147531	

Survey#=2.0 Multiple Comparisons p values (2-tailed); Infiltration (MeyerB_site2) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (3, N= 18) =13.52858 p =.0036				
Depend.: Infiltration	1	2	3	8
	R:4.6667	R:7.0000	R:3.3333	R:14.000
1		1.000000	1.000000	0.052382
2	1.000000		1.000000	0.295217
3	1.000000	1.000000		0.016355
8	0.052382	0.295217	0.016355	

Nutrient cycling

Survey#=1.0 Multiple Comparisons p values (2-tailed); Nutrients (MeyerB_site2) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (3, N= 18) =13.42105 p =.0038				
Depend.: Nutrients	1	2	3	8
	R:3.0000	R:6.0000	R:6.0000	R:14.000
1		1.000000	1.000000	0.011980
2	1.000000		1.000000	0.147531
3	1.000000	1.000000		0.147531
8	0.011980	0.147531	0.147531	

Survey#=2.0 Multiple Comparisons p values (2-tailed); Nutrients (MeyerB_site2) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (3, N= 18) =13.80957 p =.0032				
Depend.: Nutrients	1	2	3	8
	R:5.3333	R:7.0000	R:2.6667	R:14.000
1		1.000000	1.000000	0.089320
2	1.000000		1.000000	0.295217
3	1.000000	1.000000		0.008704
8	0.089320	0.295217	0.008704	

Appendix 3: Paired sample statistics for LFA data from trial site 2 over time (March 2015 to April 2016). Includes Paired Sample t-test p-values and Wilcoxon Signed Rank test p-values (SPSS, 2016). Significant values are in bold ($p < 0.05$). Treatment 1, coarse tailings (ct) and top soil (ts) (100mm); Treatment 2, ct and waste rock (wr); Treatment 3, ct, wr and ts (100mm); Treatment 8, reference sites. Treatment 4, ct (control) was excluded due to a lack of repetitions.

Treatment	Variable	Mean	N	Std. Dev.	Paired t-test p-value	Wilcoxon p-value
1	Pair 1 Patch %	22.762	3	7.404	0.1412	0.1088
	Patch %	14.754	3	9.124		
	Pair 2 Interpatch %	77.238	3	7.404	0.1412	0.1088
	Interpatch %	85.246	3	9.124		
	Pair 3 Average patch width (cm)	35.550	3	12.690	0.0555	0.1088
	Average patch width (cm)	84.414	3	33.378		
	Pair 4 Number of Patches/10m	3.401	3	0.718	0.0750	0.1088
	Number of Patches/10m	1.648	3	0.734		
	Pair 5 Average Interpatch Length (m)	2.253	3	0.591	0.1180	0.1088
	Average Interpatch Length (m)	5.123	3	1.963		
	Pair 6 Average interpatch length (cm)	225.283	3	59.098	0.1180	0.1088
	Average interpatch length (cm)	512.333	3	196.347		
	Pair 7 Longest interpatch (m)	4.697	3	0.696	0.0196	0.1088
Longest interpatch (m)	10.800	3	1.498			
Pair 8 Total Patch Area	3.754	3	3.033	0.3484	0.2850	
Total Patch Area	5.585	3	4.172			
Pair 9 Patch Area Index	0.010	3	0.005	0.3667	0.2850	
Patch Area Index	0.020	3	0.017			
Pair 10 Landscape Organisation Index	0.228	3	0.074	0.1412	0.1088	
Landscape Organisation Index	0.148	3	0.091			
Pair 11 Stability	39.743	3	3.078	0.6318	0.5930	
Stability	38.646	3	5.381			
Pair 12 Infiltration	29.292	3	2.537	0.1685	0.1088	
Infiltration	22.173	3	3.316			
Pair 13 Nutrients	10.072	3	1.165	0.0007	0.1088	
Nutrients	19.232	3	0.895			

Treatment	Variable	Mean	N	Std. Dev.	Paired t-test p-value	Wilcoxon p-value
2	Pair 1 Patch %	1.338	3	1.161	0.6684	0.6547
	Patch %	0.911	3	1.578		
	Pair 2 Interpatch %	98.662	3	1.161	0.6684	0.6547
	Interpatch %	99.089	3	1.578		
	Pair 3 Average patch width (cm)	22.000	3	28.852	0.9643	0.6547
	Average patch width (cm)	23.667	3	40.992		
	Pair 4 Number of Patches/10m	1.067	3	1.007	0.1846	0.1797
	Number of Patches/10m	0.222	3	0.385		
	Pair 5 Average Interpatch Length (m)	17.933	3	22.608	0.2698	0.2850
	Average Interpatch Length (m)	27.530	3	13.769		
	Pair 6 Average interpatch length (cm)	1793.250	3	2260.813	0.2698	0.2850
	Average interpatch length (cm)	2753.000	3	1376.890		
	Pair 7 Longest interpatch (m)	19.047	3	21.700	0.2731	0.2850
	Longest interpatch (m)	27.530	3	13.769		
Pair 8 Total Patch Area	0.121	3	0.179	0.9000	0.6547	
Total Patch Area	0.097	3	0.168			
Pair 9 Patch Area Index	0.001	3	0.001	0.8942	0.6547	
Patch Area Index	0.001	3	0.001			
Pair 10 Landscape Organisation Index	0.013	3	0.012	0.6684	0.6547	
Landscape Organisation Index	0.009	3	0.016			
Pair 11 Stability	62.861	3	2.639	0.9306	0.6547	
Stability	63.095	3	2.062			
Pair 12 Infiltration	14.002	3	1.144	0.0043	0.1088	
Infiltration	23.619	3	0.060			
Pair 13 Nutrients	11.335	3	1.555	0.0115	0.1088	
Nutrients	19.277	3	0.081			

Treatment	Variable	Mean	N	Std. Dev.	Paired t-test p-value	Wilcoxon p-value
3	Pair 1 Patch % Patch %	15.970 4.307	3 3	5.055 2.621	0.1049	0.1088
	Pair 2 Interpatch % Interpatch %	84.030 95.693	3 3	5.055 2.621		
	Pair 3 Average patch width (cm) Average patch width (cm)	41.173 53.533	3 3	3.686 44.507	0.6999	1.0000
	Pair 4 Number of Patches/10m Number of Patches/10m	3.223 1.284	3 3	0.856 0.400	0.0905	0.1088
	Pair 5 Average Interpatch Length (m) Average Interpatch Length (m)	3.062 6.131	3 3	0.779 1.964	0.1751	0.1088
	Pair 6 Average interpatch length (cm) Average interpatch length (cm)	306.182 613.133	3 3	77.885 196.436	0.1751	0.1088
	Pair 7 Longest interpatch (m) Longest interpatch (m)	6.480 11.303	3 3	1.624 3.689	0.0791	0.1088
	Pair 8 Total Patch Area Total Patch Area	2.183 1.210	3 3	1.037 1.876	0.5139	0.5930
	Pair 9 Patch Area Index Patch Area Index	0.009 0.003	3 3	0.004 0.005	0.3766	0.2850
	Pair 10 Landscape Organisation Index Landscape Organisation Index	0.169 0.043	3 3	0.042 0.026	0.0647	0.1088
	Pair 11 Stability Stability	40.759 41.507	3 3	3.919 1.304	0.7773	0.5930
	Pair 12 Infiltration Infiltration	27.788 20.469	3 3	4.046 2.270	0.0387	0.1088
	Pair 13 Nutrients Nutrients	11.572 18.371	3 3	1.692 0.779	0.0411	0.1088

Treatment	Variable	Mean	N	Std. Dev.	Paired t-test p-value	Wilcoxon p-value
Reference	Pair 1 Patch %	93.133	9	7.744	0.2846	0.3743
	Patch %	96.104	9	3.241		
	Pair 2 Interpatch %	6.867	9	7.744	0.2846	0.3743
	Interpatch %	3.896	9	3.241		
	Pair 3 Average patch width (cm)	249.632	9	121.904	0.0003	0.0109
	Average patch width (cm)	854.257	9	211.614		
	Pair 4 Number of Patches/10m	3.622	9	1.930	0.0017	0.0077
	Number of Patches/10m	0.600	9	0.332		
	Pair 5 Average Interpatch Length (m)	0.663	9	0.494	0.2525	0.4413
	Average Interpatch Length (m)	1.006	9	0.782		
	Pair 6 Average interpatch length (cm)	66.261	9	49.431	0.2525	0.4413
	Average interpatch length (cm)	100.639	9	78.210		
Pair 7 Longest interpatch (m)	1.998	9	3.195	0.5310	0.7671	
Longest interpatch (m)	1.283	9	1.031			
Pair 8 Total Patch Area	142.809	9	67.164	0.0000	0.0077	
Total Patch Area	469.076	9	22.962			
Pair 9 Patch Area Index	0.286	9	0.134	0.0000	0.0077	
Patch Area Index	0.938	9	0.046			
Pair 10 Landscape Organisation Index	0.931	9	0.077	0.2846	0.3743	
Landscape Organisation Index	0.961	9	0.032			
Pair 11 Stability	65.852	9	5.222	0.9007	0.9528	
Stability	66.234	9	9.344			
Pair 12 Infiltration	46.772	9	3.174	0.0212	0.0284	
Infiltration	41.026	9	4.819			

Appendix 4: ANOVA results for LFA for Site 3 (SPSS, 2016). Includes Kruskal-Wallis (KW) p-values (StatSoft, 2016). Significant values in bold (p > 0.05). Treatment 1, waste rock (wr); Treatment 2, wr and coarse tailings (ct) (100 mm); Treatment 3, wr and ct (200 mm); Treatment 4, wr and top soil (ts) (100 mm); Treatment 5, wr and ts (250 mm); Treatment 6, wr, ct (100 mm) and ts (100 mm); Treatment 7, wr, ct (250 mm) and ts (100 mm). Ref, reference sites.

Variable	Treatment	N	Survey 1				Survey 2			
			Mean	Std. Deviation	ANOVA p-value	KW p-value	Mean	Std. Deviation	ANOVA p-value	KW p-value
Patch %	1	3	21.072	12.208			4.601	0.620		
	2	3	22.522	16.843			9.094	13.062		
	3	3	10.398	7.360			4.553	5.321		
	4	3	54.149	9.863			18.121	8.096		
	5	3	41.773	9.236			16.457	1.087		
	6	3	26.417	7.958			7.877	6.411		
	7	3	24.035	10.772			2.734	1.625		
	Reference	9	93.133	7.744			96.104	3.241		
	Total	30	47.977	33.335	*0.0000	*0.0008	35.175	41.143	*0.0000	*0.0015
Interpatch %	1	3	78.928	12.208			95.399	0.620		
	2	3	77.478	16.843			90.906	13.062		
	3	3	89.602	7.360			95.447	5.321		
	4	3	45.851	9.863			81.879	8.096		
	5	3	58.227	9.236			83.543	1.087		
	6	3	73.583	7.958			92.123	6.411		
	7	3	75.965	10.772			97.266	1.625		
	Reference	9	6.867	7.744			3.896	3.241		
	Total	30	52.023	33.335	*0.0000	*0.0008	64.825	41.143	*0.0000	*0.0015
Average patch width (cm)	1	3	88.710	18.115			202.611	181.370		
	2	3	64.353	22.539			60.200	40.449		
	3	3	30.529	4.338			101.667	105.140		
	4	3	111.706	16.815			103.947	30.794		
	5	3	145.741	23.141			171.103	53.073		
	6	3	79.938	31.296			79.861	22.241		
	7	3	91.004	33.211			99.167	49.513		
	Reference	9	249.632	121.904			854.257	211.614		
	Total	30	136.088	104.328	*0.0024	*0.0015	338.133	368.339	*0.0000	*0.0031
Number of Patches/10 m	1	3	5.017	0.573			0.968	0.317		
	2	3	4.750	2.523			1.427	1.670		
	3	3	3.011	0.731			0.372	0.255		
	4	3	5.630	1.078			2.424	0.619		
	5	3	7.292	0.797			2.355	0.613		
	6	3	4.965	1.524			1.559	1.250		
	7	3	4.032	0.548			0.578	0.261		
	Reference	9	3.622	1.930			0.600	0.332		
	Total	30	4.556	1.820	*0.0442	0.0828	1.148	0.967	*0.0043	*0.0285

			Survey 1				Survey 2			
Variable	Treatment	N	Mean	Std. Deviation	ANOVA p-value	KW p-value	Mean	Std. Deviation	ANOVA p-value	KW p-value
Average Interpatch Length (m)	1	3	1.477	0.284			7.878	2.712		
	2	3	2.207	1.871			11.583	10.575		
	3	3	2.843	1.003			16.840	8.777		
	4	3	0.821	0.197			3.136	1.074		
	5	3	0.783	0.091			3.505	1.053		
	6	3	1.549	0.653			6.273	3.182		
	7	3	1.807	0.420			12.004	3.390		
	Reference	9	0.663	0.494			1.006	0.782		
	Total	30	1.348	0.986			*0.0059	*0.0063		
Average interpatch length (cm)	1	3	147.730	28.379			787.756	271.241		
	2	3	220.724	187.128			#####	1057.483		
	3	3	284.324	100.316			#####	877.725		
	4	3	82.092	19.693			313.607	107.369		
	5	3	78.305	9.112			350.493	105.322		
	6	3	154.876	65.333			627.259	318.203		
	7	3	180.668	42.007			#####	338.981		
	Reference	9	66.261	49.431			100.639	78.210		
	Total	30	134.750	98.569			*0.0059	*0.0063		
Longest interpatch (m)	1	3	4.723	1.792			15.043	4.567		
	2	3	9.257	10.783			17.610	12.772		
	3	3	9.327	6.321			24.737	10.131		
	4	3	2.357	0.861			8.930	3.985		
	5	3	2.470	0.417			6.570	1.129		
	6	3	4.870	1.366			15.067	5.218		
	7	3	7.867	4.963			22.840	2.347		
	Reference	9	1.998	3.195			1.283	1.031		
	Total	30	4.686	4.945			0.1486	*0.0130		
Total Patch Area	1	3	9.575	6.914			3.696	3.293		
	2	3	167.209	285.879			2.236	3.382		
	3	3	1.459	1.587			1.427	1.826		
	4	3	24.981	8.418			6.395	4.254		
	5	3	28.086	8.709			10.391	2.698		
	6	3	10.113	6.328			2.892	3.271		
	7	3	9.493	2.978			1.248	1.371		
	Reference	9	142.809	67.164			469.076	22.962		
	Total	30	67.934	107.335			0.0860	*0.0040		
Patch Area Index	1	3	0.023	0.010			0.009	0.008		
	2	3	0.367	0.618			0.014	0.023		
	3	3	0.004	0.003			0.008	0.013		
	4	3	0.077	0.031			0.020	0.008		
	5	3	0.073	0.014			0.034	0.016		
	6	3	0.025	0.014			0.008	0.008		
	7	3	0.024	0.011			0.003	0.003		
	Reference	9	0.286	0.134			0.938	0.046		
	Total	30	0.145	0.224			0.1213	*0.0033		

			Survey 1				Survey 2			
Variable	Treatment	N	Mean	Std. Deviation	ANOVA p-value	KW p-value	Mean	Std. Deviation	ANOVA p-value	KW p-value
Landscape Organisation Index	1	3	0.211	0.122			0.046	0.006		
	2	3	0.225	0.168						
	3	3	0.104	0.074						
	4	3	0.541	0.099						
	5	3	0.418	0.092						
	6	3	0.264	0.080						
	7	3	0.240	0.108						
	Reference	9	0.931	0.077						
	Total	30	0.480	0.333			*0.0000	*0.0008		
Stability	1	3	44.090	5.339			42.827	4.898		
	2	3	36.661	2.233						
	3	3	36.201	2.385						
	4	3	38.509	3.637						
	5	3	41.412	2.481						
	6	3	36.893	3.935						
	7	3	39.734	3.782						
	Reference	9	65.852	5.222						
	Total	30	47.106	13.214			*0.0000	*0.002		
Infiltration	1	3	22.348	5.130			25.692	2.686		
	2	3	23.319	4.240						
	3	3	21.987	2.054						
	4	3	25.625	4.827						
	5	3	24.066	4.128						
	6	3	23.965	3.558						
	7	3	21.609	1.825						
	Reference	9	46.772	3.174						
	Total	30	30.324	11.454			*0.0000	*0.0066		
Nutrients	1	3	11.334	1.525			18.443	2.770		
	2	3	11.375	1.499						
	3	3	11.148	0.451						
	4	3	10.498	0.179						
	5	3	10.189	0.431						
	6	3	10.773	0.301						
	7	3	10.589	0.326						
	Reference	9	33.597	4.552						
	Total	30	17.670	10.894			*0.0000	*0.0038		

**Appendix 5: Kruskal-Wallis post-hoc tests for LFA data for trial site 3 (StatSoft, 2016).
Treatments 1, waste rock (wr); 2, wr and coarse tailings (ct) (100 mm); 3, wr and ct (200 mm); 4, wr and top soil (ts) (100 mm); 5, wr and ts (250 mm); 6, wr, ct (100 mm) and ts (100 mm); 7, wr, ct (250 mm) and ts (100 mm); 8, reference sites.**

Patch %

Survey#=1.0 Multiple Comparisons p values (2-tailed); Patch (MeyerB_site3) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (7, N= 30) =24.81935 p =.0008								
Depend.: Patch	1 R:7.6667	2 R:9.6667	3 R:3.6667	4 R:19.667	5 R:16.000	6 R:10.667	7 R:9.6667	8 R:26.000
1		1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.04999
2	1.00000		1.00000	1.00000	1.00000	1.00000	1.00000	0.15079
3	1.00000	1.00000		0.72849	1.00000	1.00000	1.00000	0.00396
4	1.00000	1.00000	0.72849		1.00000	1.00000	1.00000	1.00000
5	1.00000	1.00000	1.00000	1.00000		1.00000	1.00000	1.00000
6	1.00000	1.00000	1.00000	1.00000	1.00000		1.00000	0.25158
7	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000		0.15079
8	0.04999	0.15079	0.00396	1.00000	1.00000	0.25158	0.15079	

Survey#=2.0 Multiple Comparisons p values (2-tailed); Patch (MeyerB_site3) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (7, N= 30) =23.32777 p =.0015								
Depend.: Patch	1 R:10.000	2 R:9.0000	3 R:7.0000	4 R:17.667	5 R:17.000	6 R:10.667	7 R:5.6667	8 R:26.000
1		1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.17938
2	1.00000		1.00000	1.00000	1.00000	1.00000	1.00000	0.10562
3	1.00000	1.00000		1.00000	1.00000	1.00000	1.00000	0.03377
4	1.00000	1.00000	1.00000		1.00000	1.00000	1.00000	1.00000
5	1.00000	1.00000	1.00000	1.00000		1.00000	1.00000	1.00000
6	1.00000	1.00000	1.00000	1.00000	1.00000		1.00000	0.25158
7	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000		0.01487
8	0.17938	0.10562	0.03377	1.00000	1.00000	0.25158	0.01487	

Interpatch %

Survey#=1.0 Multiple Comparisons p values (2-tailed); Interpatch (MeyerB_site3) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (7, N= 30) =24.81935 p =.0008								
Depend.: Interpatch	1 R:23.333	2 R:21.333	3 R:27.333	4 R:11.333	5 R:15.000	6 R:20.333	7 R:21.333	8 R:5.0000
1		1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.04999
2	1.00000		1.00000	1.00000	1.00000	1.00000	1.00000	0.15079
3	1.00000	1.00000		0.72849	1.00000	1.00000	1.00000	0.00396
4	1.00000	1.00000	0.72849		1.00000	1.00000	1.00000	1.00000
5	1.00000	1.00000	1.00000	1.00000		1.00000	1.00000	1.00000
6	1.00000	1.00000	1.00000	1.00000	1.00000		1.00000	0.25158
7	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000		0.15079
8	0.04999	0.15079	0.00396	1.00000	1.00000	0.25158	0.15079	

Survey#=2.0 Multiple Comparisons p values (2-tailed); Interpatch (MeyerB_site3) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (7, N= 30) =23.32777 p =.0015								
Depend.: Interpatch	1 R:21.000	2 R:22.000	3 R:24.000	4 R:13.333	5 R:14.000	6 R:20.333	7 R:25.333	8 R:5.0000
1		1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.17938
2	1.00000		1.00000	1.00000	1.00000	1.00000	1.00000	0.10562
3	1.00000	1.00000		1.00000	1.00000	1.00000	1.00000	0.03377
4	1.00000	1.00000	1.00000		1.00000	1.00000	1.00000	1.00000
5	1.00000	1.00000	1.00000	1.00000		1.00000	1.00000	1.00000
6	1.00000	1.00000	1.00000	1.00000	1.00000		1.00000	0.25158
7	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000		0.01487
8	0.17938	0.10562	0.03377	1.00000	1.00000	0.25158	0.01487	

Average Patch Width (cm)

Survey#=1.0 Multiple Comparisons p values (2-tailed); Averagepatchwidthcm (MeyerB_site3) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (7, N= 30) =23.25090 p =.0015								
Depend.: Averagepatchwidthcm	1 R:11.333	2 R:7.6667	3 R:2.0000	4 R:16.333	5 R:22.333	6 R:9.6667	7 R:12.000	8 R:24.556
1		1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.67940
2	1.00000		1.00000	1.00000	1.00000	1.00000	1.00000	0.11217
3	1.00000	1.00000		1.00000	0.13082	1.00000	1.00000	0.00340
4	1.00000	1.00000	1.00000		1.00000	1.00000	1.00000	1.00000
5	1.00000	1.00000	0.13082	1.00000		1.00000	1.00000	1.00000
6	1.00000	1.00000	1.00000	1.00000	1.00000		1.00000	0.31315
7	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000		0.90746
8	0.67940	0.11217	0.00340	1.00000	1.00000	0.31315	0.90746	

Survey#=2.0 Multiple Comparisons p values (2-tailed); Averagepatchwidthcm (MeyerB_site3) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (7, N= 30) =21.48844 p =.0031								
Depend.: Averagepatchwidthcm	1 R:14.667	2 R:5.6667	3 R:9.0000	4 R:12.000	5 R:17.000	6 R:8.3333	7 R:10.667	8 R:25.889
1		1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
2	1.00000		1.00000	1.00000	1.00000	1.00000	1.00000	0.01595
3	1.00000	1.00000		1.00000	1.00000	1.00000	1.00000	0.11217
4	1.00000	1.00000	1.00000		1.00000	1.00000	1.00000	0.50279
5	1.00000	1.00000	1.00000	1.00000		1.00000	1.00000	1.00000
6	1.00000	1.00000	1.00000	1.00000	1.00000		1.00000	0.07779
7	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000		0.26586
8	1.00000	0.01595	0.11217	0.50279	1.00000	0.07779	0.26586	

Number of Patches/10m

		Survey#=1.0 Multiple Comparisons p values (2-tailed); NumberofPatches10m (MeyerB_site3) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (7, N= 30) =12.58983 p =.0828							
Depend.:		1	2	3	4	5	6	7	8
NumberofPatches10m		R:17.000	R:16.500	R:8.0000	R:21.000	R:28.667	R:17.000	R:13.000	R:11.278
1			1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
2		1.00000		1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
3		1.00000	1.00000		1.00000	0.11306	1.00000	1.00000	1.00000
4		1.00000	1.00000	1.00000		1.00000	1.00000	1.00000	1.00000
5		1.00000	1.00000	0.11306	1.00000		1.00000	0.82009	0.08534
6		1.00000	1.00000	1.00000	1.00000	1.00000		1.00000	1.00000
7		1.00000	1.00000	1.00000	1.00000	0.82009	1.00000		1.00000
8		1.00000	1.00000	1.00000	1.00000	0.08534	1.00000	1.00000	

		Survey#=2.0 Multiple Comparisons p values (2-tailed); NumberofPatches10m (MeyerB_site3) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (7, N= 30) =15.65459 p =.0285							
Depend.:		1	2	3	4	5	6	7	8
NumberofPatches10m		R:17.667	R:15.000	R:6.3333	R:26.000	R:25.667	R:20.167	R:11.000	R:11.056
1			1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
2		1.00000		1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
3		1.00000	1.00000		0.17410	0.20025	1.00000	1.00000	1.00000
4		1.00000	1.00000	0.17410		1.00000	1.00000	1.00000	0.30478
5		1.00000	1.00000	0.20025	1.00000		1.00000	1.00000	0.35811
6		1.00000	1.00000	1.00000	1.00000	1.00000		1.00000	1.00000
7		1.00000	1.00000	1.00000	1.00000	1.00000	1.00000		1.00000
8		1.00000	1.00000	1.00000	0.30478	0.35811	1.00000	1.00000	

Average Interpatch length (m)

		Survey#=1.0 Multiple Comparisons p values (2-tailed); AverageInterpatchLengthm (MeyerB_site3) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (7, N= 30) =19.68387 p =.0063							
Depend.:		1	2	3	4	5	6	7	8
AverageInterpatchLengthm		R:20.333	R:20.667	R:27.333	R:11.000	R:10.667	R:20.333	R:22.667	R:7.3333
1			1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.74918
2		1.00000		1.00000	1.00000	1.00000	1.00000	1.00000	0.64668
3		1.00000	1.00000		0.64588	0.57152	1.00000	1.00000	0.01833
4		1.00000	1.00000	0.64588		1.00000	1.00000	1.00000	1.00000
5		1.00000	1.00000	0.57152	1.00000		1.00000	1.00000	1.00000
6		1.00000	1.00000	1.00000	1.00000	1.00000		1.00000	0.74918
7		1.00000	1.00000	1.00000	1.00000	1.00000	1.00000		0.25158
8		0.74918	0.64668	0.01833	1.00000	1.00000	0.74918	0.25158	

		Multiple Comparisons p values (2-tailed); AverageInterpatchLengthm (MeyerB_site3) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (7, N= 30) =22.33830 p =.0022 Include condition: v1=2							
Depend.:		1	2	3	4	5	6	7	8
AverageInterpatchLengthm		R:21.667	R:21.000	R:25.333	R:13.333	R:14.667	R:18.000	R:25.000	R:5.3333
1			1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	0.150799
2		1.000000		1.000000	1.000000	1.000000	1.000000	1.000000	0.212750
3		1.000000	1.000000		1.000000	1.000000	1.000000	1.000000	0.018339
4		1.000000	1.000000	1.000000		1.000000	1.000000	1.000000	1.000000
5		1.000000	1.000000	1.000000	1.000000		1.000000	1.000000	1.000000
6		1.000000	1.000000	1.000000	1.000000	1.000000		1.000000	0.865424
7		1.000000	1.000000	1.000000	1.000000	1.000000	1.000000		0.022548
8		0.150799	0.212750	0.018339	1.000000	1.000000	0.865424	0.022548	

Average interpatch length (cm)

		Survey#=1.0 Multiple Comparisons p values (2-tailed); Averageinterpatchlengthcm (MeyerB_site3) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (7, N= 30) =19.68387 p =.0063							
Depend.:		1	2	3	4	5	6	7	8
Averageinterpatchlengthcm		R:20.333	R:20.667	R:27.333	R:11.000	R:10.667	R:20.333	R:22.667	R:7.3333
1			1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	0.749180
2		1.000000		1.000000	1.000000	1.000000	1.000000	1.000000	0.646680
3		1.000000	1.000000		0.645880	0.571520	1.000000	1.000000	0.018339
4		1.000000	1.000000	0.645880		1.000000	1.000000	1.000000	1.000000
5		1.000000	1.000000	0.571520	1.000000		1.000000	1.000000	1.000000
6		1.000000	1.000000	1.000000	1.000000	1.000000		1.000000	0.749180
7		1.000000	1.000000	1.000000	1.000000	1.000000	1.000000		0.251580
8		0.749180	0.646680	0.018339	1.000000	1.000000	0.749180	0.251580	

		Survey#=2.0 Multiple Comparisons p values (2-tailed); Averageinterpatchlengthcm (MeyerB_site3) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (7, N= 30) =22.33830 p =.0022							
Depend.:		1	2	3	4	5	6	7	8
Averageinterpatchlengthcm		R:21.667	R:21.000	R:25.333	R:13.333	R:14.667	R:18.000	R:25.000	R:5.3333
1			1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	0.150799
2		1.000000		1.000000	1.000000	1.000000	1.000000	1.000000	0.212750
3		1.000000	1.000000		1.000000	1.000000	1.000000	1.000000	0.018339
4		1.000000	1.000000	1.000000		1.000000	1.000000	1.000000	1.000000
5		1.000000	1.000000	1.000000	1.000000		1.000000	1.000000	1.000000
6		1.000000	1.000000	1.000000	1.000000	1.000000		1.000000	0.865424
7		1.000000	1.000000	1.000000	1.000000	1.000000	1.000000		0.022548
8		0.150799	0.212750	0.018339	1.000000	1.000000	0.865424	0.022548	

Longest interpatch (m)

		Survey#=1.0 Multiple Comparisons p values (2-tailed); Longestinterpatchm (MeyerB_site3) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (7, N= 30) =17.78280 p =.0130							
Depend.:		1	2	3	4	5	6	7	8
Longestinterpatchm		R:20.000	R:20.000	R:25.000	R:11.333	R:12.000	R:20.667	R:24.000	R:7.3333
1			1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.86542
2		1.00000		1.00000	1.00000	1.00000	1.00000	1.00000	0.86542
3		1.00000	1.00000		1.00000	1.00000	1.00000	1.00000	0.07310
4		1.00000	1.00000	1.00000		1.00000	1.00000	1.00000	1.00000
5		1.00000	1.00000	1.00000	1.00000		1.00000	1.00000	1.00000
6		1.00000	1.00000	1.00000	1.00000	1.00000		1.00000	0.64668
7		1.00000	1.00000	1.00000	1.00000	1.00000	1.00000		0.12639
8		0.86542	0.86542	0.07310	1.00000	1.00000	0.64668	0.12639	

		Survey#=2.0 Multiple Comparisons p values (2-tailed); Longestinterpatchm (MeyerB_site3) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (7, N= 30) =23.62031 p =.0013							
Depend.:		1	2	3	4	5	6	7	8
Longestinterpatchm		R:19.333	R:21.333	R:26.000	R:15.333	R:13.000	R:19.667	R:25.333	R:5.0000
1			1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.40870
2		1.00000		1.00000	1.00000	1.00000	1.00000	1.00000	0.15079
3		1.00000	1.00000		1.00000	1.00000	1.00000	1.00000	0.00968
4		1.00000	1.00000	1.00000		1.00000	1.00000	1.00000	1.00000
5		1.00000	1.00000	1.00000	1.00000		1.00000	1.00000	1.00000
6		1.00000	1.00000	1.00000	1.00000	1.00000		1.00000	0.34869
7		1.00000	1.00000	1.00000	1.00000	1.00000	1.00000		0.01487
8		0.40870	0.15079	0.00968	1.00000	1.00000	0.34869	0.01487	

Total patch area

		Survey#=1.0 Multiple Comparisons p values (2-tailed); TotalPatchArea (MeyerB_site3) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (7, N= 30) =20.81935 p =.0040							
Depend.:		1	2	3	4	5	6	7	8
TotalPatchArea		R:9.0000	R:12.667	R:3.3333	R:17.333	R:17.667	R:10.333	R:9.6667	R:25.000
1			1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.17938
2		1.00000		1.00000	1.00000	1.00000	1.00000	1.00000	0.99682
3		1.00000	1.00000		1.00000	1.00000	1.00000	1.00000	0.00623
4		1.00000	1.00000	1.00000		1.00000	1.00000	1.00000	1.00000
5		1.00000	1.00000	1.00000	1.00000		1.00000	1.00000	1.00000
6		1.00000	1.00000	1.00000	1.00000	1.00000		1.00000	0.34869
7		1.00000	1.00000	1.00000	1.00000	1.00000	1.00000		0.25158
8		0.17938	0.99682	0.00623	1.00000	1.00000	0.34869	0.25158	

Survey#=2.0 Multiple Comparisons p values (2-tailed); TotalPatchArea (MeyerB_site3) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (7, N= 30) =23.58925 p =.0013								
Depend.:	1	2	3	4	5	6	7	8
TotalPatchArea	R:11.333	R:7.3333	R:7.0000	R:15.000	R:19.333	R:10.667	R:6.3333	R:26.000
1		1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.34869
2	1.00000		1.00000	1.00000	1.00000	1.00000	1.00000	0.04115
3	1.00000	1.00000		1.00000	1.00000	1.00000	1.00000	0.03377
4	1.00000	1.00000	1.00000		1.00000	1.00000	1.00000	1.00000
5	1.00000	1.00000	1.00000	1.00000		1.00000	1.00000	1.00000
6	1.00000	1.00000	1.00000	1.00000	1.00000		1.00000	0.25158
7	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000		0.02254
8	0.34869	0.04115	0.03377	1.00000	1.00000	0.25158	0.02254	

Patch area index

Survey#=1.0 Multiple Comparisons p values (2-tailed); PatchAreaIndex (MeyerB_site3) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (7, N= 30) =21.32688 p =.0033								
Depend.:	1	2	3	4	5	6	7	8
PatchAreaIndex	R:9.0000	R:13.333	R:2.6667	R:17.667	R:17.333	R:10.000	R:10.000	R:25.000
1		1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.17938
2	1.00000		1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
3	1.00000	1.00000		1.00000	1.00000	1.00000	1.00000	0.00396
4	1.00000	1.00000	1.00000		1.00000	1.00000	1.00000	1.00000
5	1.00000	1.00000	1.00000	1.00000		1.00000	1.00000	1.00000
6	1.00000	1.00000	1.00000	1.00000	1.00000		1.00000	0.29661
7	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000		0.29661
8	0.17938	1.00000	0.00396	1.00000	1.00000	0.29661	0.29661	

Survey#=2.0 Multiple Comparisons p values (2-tailed); PatchAreaIndex (MeyerB_site3) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (7, N= 30) =22.65161 p =.0020								
Depend.:	1	2	3	4	5	6	7	8
PatchAreaIndex	R:11.000	R:8.6667	R:7.6667	R:15.333	R:18.333	R:9.6667	R:6.3333	R:26.000
1		1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.29661
2	1.00000		1.00000	1.00000	1.00000	1.00000	1.00000	0.08800
3	1.00000	1.00000		1.00000	1.00000	1.00000	1.00000	0.04999
4	1.00000	1.00000	1.00000		1.00000	1.00000	1.00000	1.00000
5	1.00000	1.00000	1.00000	1.00000		1.00000	1.00000	1.00000
6	1.00000	1.00000	1.00000	1.00000	1.00000		1.00000	0.15079
7	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000		0.02254
8	0.29661	0.08800	0.04999	1.00000	1.00000	0.15079	0.02254	

Landscape organisation index

		Survey#=1.0 Multiple Comparisons p values (2-tailed); LandscapeOrganisationIndex (MeyerB_site3) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (7, N= 30) =24.81935 p =.0008							
Depend.:		1	2	3	4	5	6	7	8
LandscapeOrganisationIndex		R:7.6667	R:9.6667	R:3.6667	R:19.667	R:16.000	R:10.667	R:9.6667	R:26.000
1			1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.04999
2		1.00000		1.00000	1.00000	1.00000	1.00000	1.00000	0.15079
3		1.00000	1.00000		0.72849	1.00000	1.00000	1.00000	0.00396
4		1.00000	1.00000	0.72849		1.00000	1.00000	1.00000	1.00000
5		1.00000	1.00000	1.00000	1.00000		1.00000	1.00000	1.00000
6		1.00000	1.00000	1.00000	1.00000	1.00000		1.00000	0.25158
7		1.00000	1.00000	1.00000	1.00000	1.00000	1.00000		0.15079
8		0.04999	0.15079	0.00396	1.00000	1.00000	0.25158	0.15079	

		Survey#=2.0 Multiple Comparisons p values (2-tailed); LandscapeOrganisationIndex (MeyerB_site3) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (7, N= 30) =23.32777 p =.0015							
Depend.:		1	2	3	4	5	6	7	8
LandscapeOrganisationIndex		R:10.000	R:9.0000	R:7.0000	R:17.667	R:17.000	R:10.667	R:5.6667	R:26.000
1			1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.17938
2		1.00000		1.00000	1.00000	1.00000	1.00000	1.00000	0.10562
3		1.00000	1.00000		1.00000	1.00000	1.00000	1.00000	0.03377
4		1.00000	1.00000	1.00000		1.00000	1.00000	1.00000	1.00000
5		1.00000	1.00000	1.00000	1.00000		1.00000	1.00000	1.00000
6		1.00000	1.00000	1.00000	1.00000	1.00000		1.00000	0.25158
7		1.00000	1.00000	1.00000	1.00000	1.00000	1.00000		0.01487
8		0.17938	0.10562	0.03377	1.00000	1.00000	0.25158	0.01487	

Surface stability

		Survey#=1.0 Multiple Comparisons p values (2-tailed); Stability (MeyerB_site3) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (7, N= 30) =22.57419 p =.0020							
Depend.:		1	2	3	4	5	6	7	8
Stability		R:17.333	R:6.6667	R:6.6667	R:10.333	R:15.000	R:7.6667	R:13.333	R:26.000
1			1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
2		1.00000		1.00000	1.00000	1.00000	1.00000	1.00000	0.02763
3		1.00000	1.00000		1.00000	1.00000	1.00000	1.00000	0.02763
4		1.00000	1.00000	1.00000		1.00000	1.00000	1.00000	0.21275
5		1.00000	1.00000	1.00000	1.00000		1.00000	1.00000	1.00000
6		1.00000	1.00000	1.00000	1.00000	1.00000		1.00000	0.04999
7		1.00000	1.00000	1.00000	1.00000	1.00000	1.00000		0.86542
8		1.00000	0.02763	0.02763	0.21275	1.00000	0.04999	0.86542	

Survey#=2.0 Multiple Comparisons p values (2-tailed); Stability (MeyerB_site3) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (7, N= 30) =19.64086 p =.0064								
Depend.: Stability	1 R:14.667	2 R:11.333	3 R:13.000	4 R:11.667	5 R:9.6667	6 R:9.0000	7 R:7.6667	8 R:26.000
1		1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
2	1.00000		1.00000	1.00000	1.00000	1.00000	1.00000	0.34869
3	1.00000	1.00000		1.00000	1.00000	1.00000	1.00000	0.74918
4	1.00000	1.00000	1.00000		1.00000	1.00000	1.00000	0.40870
5	1.00000	1.00000	1.00000	1.00000		1.00000	1.00000	0.15079
6	1.00000	1.00000	1.00000	1.00000	1.00000		1.00000	0.10562
7	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000		0.04999
8	1.00000	0.34869	0.74918	0.40870	0.15079	0.10562	0.04999	

Infiltration capacity

Survey#=1.0 Multiple Comparisons p values (2-tailed); Infiltration (MeyerB_site3) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (7, N= 30) =19.58065 p =.0066								
Depend.: Infiltration	1 R:8.3333	2 R:11.333	3 R:9.6667	4 R:14.667	5 R:12.000	6 R:12.667	7 R:8.3333	8 R:26.000
1		1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.07310
2	1.00000		1.00000	1.00000	1.00000	1.00000	1.00000	0.34869
3	1.00000	1.00000		1.00000	1.00000	1.00000	1.00000	0.15079
4	1.00000	1.00000	1.00000		1.00000	1.00000	1.00000	1.00000
5	1.00000	1.00000	1.00000	1.00000		1.00000	1.00000	0.47764
6	1.00000	1.00000	1.00000	1.00000	1.00000		1.00000	0.64668
7	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000		0.07310
8	0.07310	0.34869	0.15079	1.00000	0.47764	0.64668	0.07310	

Survey#=2.0 Multiple Comparisons p values (2-tailed); Infiltration (MeyerB_site3) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (7, N= 30) =22.31613 p =.0022								
Depend.: Infiltration	1 R:13.000	2 R:13.667	3 R:16.333	4 R:8.6667	5 R:13.333	6 R:7.3333	7 R:4.6667	8 R:26.000
1		1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.74918
2	1.00000		1.00000	1.00000	1.00000	1.00000	1.00000	0.99682
3	1.00000	1.00000		1.00000	1.00000	1.00000	1.00000	1.00000
4	1.00000	1.00000	1.00000		1.00000	1.00000	1.00000	0.08800
5	1.00000	1.00000	1.00000	1.00000		1.00000	1.00000	0.86542
6	1.00000	1.00000	1.00000	1.00000	1.00000		1.00000	0.04115
7	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000		0.00778
8	0.74918	0.99682	1.00000	0.08800	0.86542	0.04115	0.00778	

Nutrient cycling

Survey#=1.0 Multiple Comparisons p values (2-tailed); Nutrients (MeyerB_site3) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (7, N= 30) =20.96559 p =.0038								
Depend.: Nutrients	1	2	3	4	5	6	7	8
	R:13.667	R:13.333	R:14.667	R:8.0000	R:5.3333	R:12.000	R:10.000	R:26.000
1		1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.99682
2	1.00000		1.00000	1.00000	1.00000	1.00000	1.00000	0.86542
3	1.00000	1.00000		1.00000	1.00000	1.00000	1.00000	1.00000
4	1.00000	1.00000	1.00000		1.00000	1.00000	1.00000	0.06054
5	1.00000	1.00000	1.00000	1.00000		1.00000	1.00000	0.01202
6	1.00000	1.00000	1.00000	1.00000	1.00000		1.00000	0.47764
7	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000		0.17938
8	0.99682	0.86542	1.00000	0.06054	0.01202	0.47764	0.17938	

Survey#=2.0 Multiple Comparisons p values (2-tailed); Nutrients (MeyerB_site3) Independent (grouping) variable: Treatment Kruskal-Wallis test: H (7, N= 30) =23.21935 p =.0016								
Depend.: Nutrients	1	2	3	4	5	6	7	8
	R:12.333	R:6.3333	R:8.0000	R:15.000	R:18.333	R:11.000	R:6.0000	R:26.000
1		1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.55658
2	1.00000		1.00000	1.00000	1.00000	1.00000	1.00000	0.02254
3	1.00000	1.00000		1.00000	1.00000	1.00000	1.00000	0.06054
4	1.00000	1.00000	1.00000		1.00000	1.00000	1.00000	1.00000
5	1.00000	1.00000	1.00000	1.00000		1.00000	1.00000	1.00000
6	1.00000	1.00000	1.00000	1.00000	1.00000		1.00000	0.29661
7	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000		0.01833
8	0.55658	0.02254	0.06054	1.00000	1.00000	0.29661	0.01833	

Appendix 6: Paired sample statistics for LFA data from trial site 3 over time (March 2015 to April 2016). Includes Paired Sample t-test p-values and Wilcoxon Signed Rank test p-values (SPSS, 2016). Significant values are in bold ($p < 0.05$). Treatments 1, waste rock (wr); 2, wr and coarse tailings (ct) (100 mm); 3, wr and ct (200 mm); 4, wr and top soil (ts) (100 mm); 5, wr and ts (250 mm); 6, wr, ct (100 mm) and ts (100 mm); 7, wr, ct (250 mm) and ts (100 mm); Reference, reference sites.

Treatment	Variable	Mean	N	Std. Deviation	Paired t-test p-value	Wilcoxon p-value
1	Pair 1 Patch %	21.07	3	12.21	0.1436	0.1088
	Patch %	4.60	3	0.62		
	Pair 2 Interpatch %	78.93	3	12.21	0.1436	0.1088
	Interpatch %	95.40	3	0.62		
	Pair 3 Average patch width (cm)	88.71	3	18.12	0.3505	0.2850
	Average patch width (cm)	202.61	3	181.37		
	Pair 4 Number of Patches/10m	5.02	3	0.57	0.0156	0.1088
	Number of Patches/10m	0.97	3	0.32		
	Pair 5 Average Interpatch Length (m)	1.48	3	0.28	0.0650	0.1088
	Average Interpatch Length (m)	7.88	3	2.71		
	Pair 6 Average interpatch length (cm)	147.73	3	28.38	0.0650	0.1088
	Average interpatch length (cm)	787.76	3	271.24		
	Pair 7 Longest interpatch (m)	4.72	3	1.79	0.0747	0.1088
	Longest interpatch (m)	15.04	3	4.57		
Pair 8 Total Patch Area	9.58	3	6.91	0.1855	0.1088	
Total Patch Area	3.70	3	3.29			
Pair 9 Patch Area Index	0.02	3	0.01	0.0904	0.1088	
Patch Area Index	0.01	3	0.01			
Pair 10 Landscape Organisation Index	0.21	3	0.12	0.1436	0.1088	
Landscape Organisation Index	0.05	3	0.01			
Pair 11 Stability	44.09	3	5.34	0.7405	0.5930	
Stability	42.83	3	4.90			
Pair 12 Infiltration	22.35	3	5.13	0.2064	0.2850	
Infiltration	25.69	3	2.69			
Pair 13 Nutrients	11.33	3	1.53	0.0944	0.1088	
Nutrients	18.44	3	2.77			

Treatment	Variable		Mean	N	Std. Deviation	Paired t-test p-value	Wilcoxon p-value
2	Pair 1	Patch %	22.52	3	16.84	0.3424	0.1088
		Patch %	9.09	3	13.06		
	Pair 2	Interpatch %	77.48	3	16.84	0.3424	0.1088
		Interpatch %	90.91	3	13.06		
	Pair 3	Average patch width (cm)	64.35	3	22.54	0.9085	1.0000
		Average patch width (cm)	60.20	3	40.45		
	Pair 4	Number of Patches/10m	4.75	3	2.52	0.1493	0.1088
		Number of Patches/10m	1.43	3	1.67		
	Pair 5	Average Interpatch Length (m)	2.21	3	1.87	0.2135	0.1088
		Average Interpatch Length (m)	11.58	3	10.57		
	Pair 6	Average interpatch length (cm)	220.72	3	187.13	0.2135	0.1088
		Average interpatch length (cm)	1158.31	3	1057.48		
	Pair 7	Longest interpatch (m)	9.26	3	10.78	0.3596	0.1088
Longest interpatch (m)		17.61	3	12.77			
Pair 8	Total Patch Area	167.21	3	285.88	0.4249	0.5930	
	Total Patch Area	2.24	3	3.38			
Pair 9	Patch Area Index	0.37	3	0.62	0.4339	0.5930	
	Patch Area Index	0.01	3	0.02			
Pair 10	Landscape Organisation Index	0.23	3	0.17	0.3424	0.1088	
	Landscape Organisation Index	0.09	3	0.13			
Pair 11	Stability	36.66	3	2.23	0.2933	0.2850	
	Stability	40.72	3	3.42			
Pair 12	Infiltration	23.32	3	4.24	0.3367	0.2850	
	Infiltration	25.98	3	1.84			
Pair 13	Nutrients	11.38	3	1.50	0.0153	0.1088	
	Nutrients	16.36	3	0.42			

Treatment	Variable	Mean	N	Std. Deviation	Paired t-test p-value	Wilcoxon p-value
3	Pair 1 Patch %	10.40	3	7.36	0.3939	0.2850
	Patch %	4.55	3	5.32		
	Pair 2 Interpatch %	89.60	3	7.36	0.3939	0.2850
	Interpatch %	95.45	3	5.32		
	Pair 3 Average patch width (cm)	30.53	3	4.34	0.3476	0.2850
	Average patch width (cm)	101.67	3	105.14		
	Pair 4 Number of Patches/10m	3.01	3	0.73	0.0175	0.1088
	Number of Patches/10m	0.37	3	0.26		
	Pair 5 Average Interpatch Length (m)	2.84	3	1.00	0.0998	0.1088
	Average Interpatch Length (m)	16.84	3	8.78		
	Pair 6 Average interpatch length (cm)	284.32	3	100.32	0.0998	0.1088
	Average interpatch length (cm)	1684.00	3	877.72		
	Pair 7 Longest interpatch (m)	9.33	3	6.32	0.0792	0.1088
Longest interpatch (m)	24.74	3	10.13			
Pair 8 Total Patch Area	1.46	3	1.59	0.9860	1.0000	
Total Patch Area	1.43	3	1.83			
Pair 9 Patch Area Index	0.00	3	0.00	0.6165	1.0000	
Patch Area Index	0.01	3	0.01			
Pair 10 Landscape Organisation Index	0.10	3	0.07	0.3939	0.2850	
Landscape Organisation Index	0.05	3	0.05			
Pair 11 Stability	36.20	3	2.38	0.1234	0.1088	
Stability	41.35	3	2.49			
Pair 12 Infiltration	21.99	3	2.05	0.0701	0.1088	
Infiltration	26.90	3	1.56			
Pair 13 Nutrients	11.15	3	0.45	0.0655	0.1088	
Nutrients	16.65	3	2.21			

Treatment	Variable	Mean	N	Std. Deviation	Paired t-test p-value	Wilcoxon p-value
4	Pair 1 Patch %	54.15	3	9.86	0.0356	0.1088
	Patch %	18.12	3	8.10		
	Pair 2 Interpatch %	45.85	3	9.86	0.0356	0.1088
	Interpatch %	81.88	3	8.10		
	Pair 3 Average patch width (cm)	111.71	3	16.82	0.7822	0.5930
	Average patch width (cm)	103.95	3	30.79		
	Pair 4 Number of Patches/10m	5.63	3	1.08	0.0249	0.1088
	Number of Patches/10m	2.42	3	0.62		
	Pair 5 Average Interpatch Length (m)	0.82	3	0.20	0.0447	0.1088
	Average Interpatch Length (m)	3.14	3	1.07		
	Pair 6 Average interpatch length (cm)	82.09	3	19.69	0.0447	0.1088
	Average interpatch length (cm)	313.61	3	107.37		
	Pair 7 Longest interpatch (m)	2.36	3	0.86	0.0793	0.1088
	Longest interpatch (m)	8.93	3	3.98		
Pair 8 Total Patch Area	24.98	3	8.42	0.0903	0.1088	
Total Patch Area	6.39	3	4.25			
Pair 9 Patch Area Index	0.08	3	0.03	0.1082	0.1088	
Patch Area Index	0.02	3	0.01			
Pair 10 Landscape Organisation Index	0.54	3	0.10	0.0356	0.1088	
Landscape Organisation Index	0.18	3	0.08			
Pair 11 Stability	38.51	3	3.64	0.4330	0.2850	
Stability	40.10	3	3.53			
Pair 12 Infiltration	25.62	3	4.83	0.3234	0.2850	
Infiltration	23.66	3	3.35			
Pair 13 Nutrients	10.50	3	0.18	0.0240	0.1088	
Nutrients	20.03	3	2.52			

Treatment	Variable	Mean	N	Std. Deviation	Paired t-test p-	Wilcoxon p-value
5	Pair 1 Patch %	41.77	3	9.24	0.0451	0.1088
	Patch %	16.46	3	1.09		
	Pair 2 Interpatch %	58.23	3	9.24	0.0451	0.1088
	Interpatch %	83.54	3	1.09		
	Pair 3 Average patch width (cm)	145.74	3	23.14	0.6207	0.5930
	Average patch width (cm)	171.10	3	53.07		
	Pair 4 Number of Patches/10m	7.29	3	0.80	0.0073	0.1088
	Number of Patches/10m	2.35	3	0.61		
	Pair 5 Average Interpatch Length (m)	0.78	3	0.09	0.0506	0.1088
	Average Interpatch Length (m)	3.50	3	1.05		
	Pair 6 Average interpatch length (cm)	78.30	3	9.11	0.0506	0.1088
	Average interpatch length (cm)	350.49	3	105.32		
	Pair 7 Longest interpatch (m)	2.47	3	0.42	0.0404	0.1088
	Longest interpatch (m)	6.57	3	1.13		
Pair 8 Total Patch Area	28.09	3	8.71	0.1000	0.1088	
Total Patch Area	10.39	3	2.70			
Pair 9 Patch Area Index	0.07	3	0.01	0.1264	0.1088	
Patch Area Index	0.03	3	0.02			
Pair 10 Landscape Organisation Index	0.42	3	0.09	0.0451	0.1088	
Landscape Organisation Index	0.16	3	0.01			
Pair 11 Stability	41.41	3	2.48	0.5353	0.2850	
Stability	38.96	3	3.56			
Pair 12 Infiltration	24.07	3	4.13	0.8058	0.5930	
Infiltration	25.40	3	4.67			
Pair 13 Nutrients	10.19	3	0.43	0.0098	0.1088	
Nutrients	21.40	3	1.66			

Treatment	Variable	Mean	N	Std. Deviation	Paired t-test p-value	Wilcoxon p-value
6	Pair 1 Patch %	26.42	3	7.96	0.0113	0.1088
	Patch %	7.88	3	6.41		
	Pair 2 Interpatch %	73.58	3	7.96	0.0113	0.1088
	Interpatch %	92.12	3	6.41		
	Pair 3 Average patch width (cm)	79.94	3	31.30	0.9980	1.0000
	Average patch width (cm)	79.86	3	22.24		
	Pair 4 Number of Patches/10m	4.96	3	1.52	0.0744	0.1088
	Number of Patches/10m	1.56	3	1.25		
	Pair 5 Average Interpatch Length (m)	1.55	3	0.65	0.1100	0.1088
	Average Interpatch Length (m)	6.27	3	3.18		
	Pair 6 Average interpatch length (cm)	154.88	3	65.33	0.1100	0.1088
	Average interpatch length (cm)	627.26	3	318.20		
	Pair 7 Longest interpatch (m)	4.87	3	1.37	0.0676	0.1088
Longest interpatch (m)	15.07	3	5.22			
Pair 8 Total Patch Area	10.11	3	6.33	0.1271	0.1088	
Total Patch Area	2.89	3	3.27			
Pair 9 Patch Area Index	0.02	3	0.01	0.1727	0.1088	
Patch Area Index	0.01	3	0.01			
Pair 10 Landscape Organisation Index	0.26	3	0.08	0.0113	0.1088	
Landscape Organisation Index	0.08	3	0.06			
Pair 11 Stability	36.89	3	3.94	0.6819	1.0000	
Stability	39.42	3	6.07			
Pair 12 Infiltration	23.96	3	3.56	0.6864	0.5930	
Infiltration	22.99	3	0.27			
Pair 13 Nutrients	10.77	3	0.30	0.0099	0.1088	
Nutrients	17.98	3	1.53			

Treatment	Variable	Mean	N	Std. Deviation	Paired t-test p-	Wilcoxon p-value
7	Pair 1 Patch %	24.03	3	10.77	0.0873	0.1088
	Patch %	2.73	3	1.63		
	Pair 2 Interpatch %	75.97	3	10.77	0.0873	0.1088
	Interpatch %	97.27	3	1.63		
	Pair 3 Average patch width (cm)	91.00	3	33.21	0.7743	1.0000
	Average patch width (cm)	99.17	3	49.51		
	Pair 4 Number of Patches/10m	4.03	3	0.55	0.0047	0.1088
	Number of Patches/10m	0.58	3	0.26		
	Pair 5 Average Interpatch Length (m)	1.81	3	0.42	0.0313	0.1088
	Average Interpatch Length (m)	12.00	3	3.39		
	Pair 6 Average interpatch length (cm)	180.67	3	42.01	0.0313	0.1088
	Average interpatch length (cm)	1200.39	3	338.98		
	Pair 7 Longest interpatch (m)	7.87	3	4.96	0.0496	0.1088
	Longest interpatch (m)	22.84	3	2.35		
Pair 8 Total Patch Area	9.49	3	2.98	0.0774	0.1088	
Total Patch Area	1.25	3	1.37			
Pair 9 Patch Area Index	0.02	3	0.01	0.1046	0.1088	
Patch Area Index	0.00	3	0.00			
Pair 10 Landscape Organisation Index	0.24	3	0.11	0.0873	0.1088	
Landscape Organisation Index	0.03	3	0.02			
Pair 11 Stability	39.73	3	3.78	0.6029	0.5930	
Stability	38.25	3	4.06			
Pair 12 Infiltration	21.61	3	1.82	0.7727	0.5930	
Infiltration	20.86	3	2.09			
Pair 13 Nutrients	10.59	3	0.33	0.0107	0.1088	
Nutrients	16.43	3	1.27			

Treatment	Variable	Mean	N	Std. Deviation	Paired t-test p-value	Wilcoxon p-value
Reference	Pair 1 Patch %	93.13	9	7.74	0.2846	0.3743
	Patch %	96.10	9	3.24		
	Pair 2 Interpatch %	6.87	9	7.74	0.2846	0.3743
	Interpatch %	3.90	9	3.24		
	Pair 3 Average patch width (cm)	249.63	9	121.90	0.0003	0.0109
	Average patch width (cm)	854.26	9	211.61		
	Pair 4 Number of Patches/10m	3.62	9	1.93	0.0017	0.0077
	Number of Patches/10m	0.60	9	0.33		
	Pair 5 Average Interpatch Length (m)	0.66	9	0.49	0.2525	0.4413
	Average Interpatch Length (m)	1.01	9	0.78		
	Pair 6 Average interpatch length (cm)	66.26	9	49.43	0.2525	0.4413
	Average interpatch length (cm)	100.64	9	78.21		
	Pair 7 Longest interpatch (m)	2.00	9	3.20	0.5310	0.7671
	Longest interpatch (m)	1.28	9	1.03		
Pair 8 Total Patch Area	142.81	9	67.16	0.0000	0.0077	
Total Patch Area	469.08	9	22.96			
Pair 9 Patch Area Index	0.29	9	0.13	0.0000	0.0077	
Patch Area Index	0.94	9	0.05			
Pair 10 Landscape Organisation Index	0.93	9	0.08	0.2846	0.3743	
Landscape Organisation Index	0.96	9	0.03			
Pair 11 Stability	65.85	9	5.22	0.9007	0.9528	
Stability	66.23	9	9.34			
Pair 12 Infiltration	46.77	9	3.17	0.0212	0.0284	
Infiltration	41.03	9	4.82			
Pair 13 Nutrients	33.60	9	4.55	0.8390	0.8590	
Nutrients	33.98	9	5.45			

Appendix 7: ANOVA results for vegetation monitoring data for Site 1 (SPSS, 2016).

Significant values in bold ($p > 0.05$). Treatment 1 (control), fine tailings (ft); Treatment 2, ft and top soil (ts) (100mm); Treatment 3, ft and coarse tailings (ct) (100mm); Treatment 4, ft, ct (100mm) and ts (100mm); Treatment 5, ft and ct (250 mm); Treatment 6, ft, ct (250 mm) and ts (100 mm); Ref, reference sites.

Variable	Treatment	N	Survey 4			Survey 6			Survey 7		
			Mean	Std. Deviation	Anova p-value	Mean	Std. Deviation	Anova p-value	Mean	Std. Deviation	Anova p-value
S (Richness) (Forbs)	1	9	1.000	0.000		1.000	0.000		0.778	0.667	
	2	9	1.000	0.000		1.778	0.441		1.111	0.601	
	3	9	0.778	0.441		1.222	0.441		0.889	0.333	
	4	9	1.000	0.000		1.444	0.726		1.556	0.527	
	5	9	0.667	0.500		1.333	0.500		0.444	0.726	
	6	9	0.889	0.333		1.444	0.527		1.556	0.726	
	Reference	81	10.259	3.601		10.259	3.601		10.259	3.601	
	Total	135	6.511	5.386	0.0000	6.704	5.192	0.0000	6.578	5.331	0.0000
S (Richness) (Graminoids)	1	9	1.000	0.866		4.000	0.707		0.333	0.707	
	2	9	1.000	0.000		4.222	0.667		1.889	0.601	
	3	9	0.111	0.333		3.111	1.054		0.556	0.726	
	4	9	0.889	0.333		4.000	0.707		1.778	0.441	
	5	9	0.444	0.527		2.222	0.833		0.556	0.726	
	6	9	1.333	0.500		3.222	1.202		2.000	0.500	
	Reference	81	3.099	1.068		3.099	1.068		3.099	1.068	
	Total	135	2.178	1.455	0.0000	3.244	1.089	0.0001	2.333	1.382	0.0000
S total	1	9	2.000	0.866		5.000	0.707		1.111	1.167	
	2	9	2.000	0.000		6.000	0.866		3.000	1.000	
	3	9	0.889	0.601		4.333	1.414		1.444	0.527	
	4	9	1.889	0.333		5.444	1.014		3.333	0.500	
	5	9	1.111	0.782		3.556	0.882		1.000	0.866	
	6	9	2.222	0.667		4.667	1.225		3.556	0.882	
	Reference	81	13.358	4.054		13.358	4.054		13.358	4.054	
	Total	135	8.689	6.557	0.0000	9.948	5.293	0.0000	8.911	6.358	0.0000
N (Individuals) (Forbs)	1	9	27.667	26.429		135.778	130.379		11.000	10.724	
	2	9	28.667	24.955		176.222	198.019		2.000	1.936	
	3	9	7.111	8.551		141.889	263.479		3.111	2.088	
	4	9	26.889	30.073		139.222	144.521		5.333	5.196	
	5	9	5.444	5.961		114.000	128.445		2.778	5.333	
	6	9	12.222	16.177		150.222	113.326		7.333	8.500	
	Reference	81	60.420	37.903		60.420	37.903		60.420	37.903	
	Total	135	43.452	38.572	0.0000	93.407	114.629	0.0042	38.356	40.153	0.0000

Variable	Treatment	N	Survey 4			Survey 6			Survey 7		
			Mean	Std. Deviation	Anova p-value	Mean	Std. Deviation	Anova p-value	Mean	Std. Deviation	Anova p-value
N (Individuals) (Graminoids)	1	9	3.556	3.972		24.667	13.229		0.667	1.414	
	2	9	9.333	5.123		32.333	14.204		22.444	11.802	
	3	9	0.222	0.667		6.889	4.045		4.000	10.886	
	4	9	3.000	2.828		10.222	5.826		10.667	8.930	
	5	9	1.111	1.537		4.778	2.167		1.000	1.414	
	6	9	4.333	4.000		11.444	5.747		10.889	6.660	
	Reference	81	28.383	13.807		28.383	13.807		28.383	13.807	
	Total	135	18.467	16.431	0.0000	23.052	14.993	0.0000	20.341	16.049	0.0000
N total	1	9	31.222	26.018		160.444	129.885		11.667	11.045	
	2	9	38.000	21.674		208.556	199.158		24.444	12.269	
	3	9	7.333	8.888		148.778	266.811		7.111	9.892	
	4	9	29.889	30.751		149.444	143.103		16.000	9.165	
	5	9	6.556	6.247		118.778	129.938		3.778	4.969	
	6	9	16.556	16.838		161.667	110.800		18.222	10.756	
	Reference	81	88.802	43.566		88.802	43.566		88.802	43.566	
	Total	135	61.919	49.333	0.0000	116.459	114.738	0.0196	58.696	50.573	0.0000
d (Species richness) (Margalef)	1	9	0.331	0.300		0.873	0.216		0.154	0.305	
	2	9	0.295	0.056		1.046	0.270		0.679	0.372	
	3	9	0.037	0.111		0.796	0.305		0.243	0.310	
	4	9	0.323	0.177		1.029	0.409		0.919	0.250	
	5	9	0.167	0.268		0.611	0.253		0.223	0.361	
	6	9	0.557	0.400		0.785	0.308		0.978	0.376	
	Reference	81	2.789	0.787		2.789	0.787		2.789	0.787	
	Total	135	1.787	1.385	0.0000	2.016	1.146	0.0000	1.886	1.299	0.0000
J' (Pielou's evenness)	1	9	0.474	0.372		0.473	0.298		0.123	0.246	
	2	9	0.740	0.307		0.473	0.214		0.494	0.239	
	3	9	0.052	0.156		0.323	0.165		0.354	0.429	
	4	9	0.512	0.351		0.343	0.232		0.778	0.151	
	5	9	0.256	0.397		0.271	0.159		0.233	0.379	
	6	9	0.637	0.324		0.314	0.223		0.727	0.164	
	Reference	81	0.810	0.086		0.810	0.086		0.810	0.086	
	Total	135	0.664	0.310	0.0000	0.632	0.268	0.0000	0.666	0.297	0.0000
H'loge (Shannon)	1	9	0.376	0.312		0.764	0.494		0.135	0.270	
	2	9	0.513	0.213		0.841	0.402		0.590	0.332	
	3	9	0.036	0.108		0.454	0.267		0.245	0.298	
	4	9	0.355	0.243		0.600	0.446		0.934	0.228	
	5	9	0.177	0.275		0.333	0.226		0.162	0.263	
	6	9	0.538	0.302		0.484	0.364		0.920	0.327	
	Reference	81	2.067	0.386		2.067	0.386		2.067	0.386	
	Total	135	1.374	0.923	0.0000	1.472	0.830	0.0000	1.440	0.872	0.0000

Variable	Treatment	N	Survey 4			Survey 6			Survey 7		
			Mean	Std. Deviation	Anova p-value	Mean	Std. Deviation	Anova p-value	Mean	Std. Deviation	Anova p-value
1-Lambda (Simpson)	1	9	0.243	0.209		0.389	0.279		0.077	0.156	
	2	9	0.362	0.180		0.424	0.226		0.338	0.203	
	3	9	0.021	0.063		0.215	0.140		0.194	0.236	
	4	9	0.250	0.206		0.273	0.219		0.580	0.159	
	5	9	0.138	0.221		0.155	0.120		0.146	0.256	
	6	9	0.391	0.247		0.229	0.200		0.550	0.199	
	Reference	81	0.827	0.095		0.827	0.095		0.827	0.095	
	Total	135	0.590	0.333	0.0000	0.609	0.310	0.0000	0.622	0.315	0.0000

Appendix 8: Tukey B post-hoc tests for vegetation monitoring data for trial site 1 (SPSS, 2016). Crosses indicate significant differences between treatments ($p < 0.05$). Treatment 1 (control), fine tailings (ft); Treatment 2, ft and top soil (ts) (100mm); Treatment 3, ft and coarse tailings (ct) (100mm); Treatment 4, ft, ct (100mm) and ts (100mm); Treatment 5, ft and ct (250 mm); Treatment 6, ft, ct (250 mm) and ts (100 mm); Ref, reference sites.

Species richness (S) (forbs)

Survey 4

Treatment	1	2	3	4	5	6	Ref
1							X
2							X
3							X
4							X
5							X
6							X
Ref	X	X	X	X	X	X	

Survey 6

Treatment	1	2	3	4	5	6	Ref
1							X
2							X
3							X
4							X
5							X
6							X
Ref	X	X	X	X	X	X	

Survey 7

Treatment	1	2	3	4	5	6	Ref
1							X
2							X
3							X
4							X
5							X
6							X
Ref	X	X	X	X	X	X	

S (graminoids)

Survey 4

Treatment	1	2	3	4	5	6	Ref
1							X
2							X
3						X	X
4							X
5							X
6			X				X
Ref	X	X	X	X	X	X	

Survey 6

Treatment	1	2	3	4	5	6	Ref
1					X		
2					X		
3							
4					X		
5	X	X		X			
6							
Ref							

Survey 7

Treatment	1	2	3	4	5	6	Ref
1		X		X		X	X
2	X		X		X		X
3		X		X		X	X
4	X		X		X		X
5		X		X		X	X
6	X		X		X		X
Ref	X	X	X	X	X	X	

S total

Survey 4

Treatment	1	2	3	4	5	6	Ref
1	■						X
2		■					X
3			■				X
4				■			X
5					■		X
6						■	X
Ref	X	X	X	X	X	X	■

Survey 6

Treatment	1	2	3	4	5	6	Ref
1	■						X
2		■					X
3			■				X
4				■			X
5					■		X
6						■	X
Ref	X	X	X	X	X	X	■

Survey 7

Treatment	1	2	3	4	5	6	Ref
1	■						X
2		■					X
3			■				X
4				■			X
5					■		X
6						■	X
Ref	X	X	X	X	X	X	■

Number of individuals (N) (forbs)

Survey 4

Treatment	1	2	3	4	5	6	Ref
1	■						
2		■					
3			■				X
4				■			
5					■		X
6						■	X
Ref			X		X	X	■

Survey 6

Treatment	1	2	3	4	5	6	Ref
1	■						
2		■					
3			■				
4				■			
5					■		
6						■	
Ref							■

Survey 7

Treatment	1	2	3	4	5	6	Ref
1	■						X
2		■					X
3			■				X
4				■			X
5					■		X
6						■	X
Ref	X	X	X	X	X	X	■

N (graminoids)

Survey 4

Treatment	1	2	3	4	5	6	Ref
1							X
2							X
3							X
4							X
5							X
6							X
Ref	X	X	X	X	X	X	

Survey 6

Treatment	1	2	3	4	5	6	Ref
1			X	X	X		
2			X	X	X	X	
3	X	X					X
4	X	X					X
5	X	X					X
6		X					X
Ref			X	X	X	X	

Survey 7

Treatment	1	2	3	4	5	6	Ref
1		X					X
2	X		X		X		
3		X					X
4							X
5		X					X
6							X
Ref	X		X	X	X	X	

N total

Survey 4

Treatment	1	2	3	4	5	6	Ref
1							X
2							X
3							X
4							X
5							X
6							X
Ref	X	X	X	X	X	X	

Survey 6

Treatment	1	2	3	4	5	6	Ref
1							
2							
3							
4							
5							
6							
Ref							

Survey 7

Treatment	1	2	3	4	5	6	Ref
1							X
2							X
3							X
4							X
5							X
6							X
Ref	X	X	X	X	X	X	

Margalef diversity index (D)

Survey 4

Treatment	1	2	3	4	5	6	Ref
1							X
2							X
3							X
4							X
5							X
6							X
Ref	X	X	X	X	X	X	

Survey 6

Treatment	1	2	3	4	5	6	Ref
1							X
2							X
3							X
4							X
5							X
6							X
Ref	X	X	X	X	X	X	

Survey 7

Treatment	1	2	3	4	5	6	Ref
1							X
2							X
3							X
4							X
5							X
6							X
Ref	X	X	X	X	X	X	

Pielou's evenness index (J')

Survey 4

Treatment	1	2	3	4	5	6	Ref
1		X	X				X
2	X		X		X		
3	X	X		X		X	X
4			X		X		X
5		X	X	X		X	X
6			X		X		
Ref	X		X	X	X		

Survey 6

Treatment	1	2	3	4	5	6	Ref
1					X		X
2					X		X
3							X
4							X
5	X	X					X
6							X
Ref	X	X	X	X	X	X	

Survey 7

Treatment	1	2	3	4	5	6	Ref
1		X	X	X		X	X
2	X			X	X	X	X
3	X			X		X	X
4	X	X	X		X		
5		X		X		X	X
6	X	X	X		X		
Ref	X	X	X		X		

Shannon diversity index ($H' \log_e$)

Survey 4

Treatment	1	2	3	4	5	6	Ref
1							X
2			X				X
3		X				X	X
4							X
5							X
6			X				X
Ref	X	X	X	X	X	X	

Survey 6

Treatment	1	2	3	4	5	6	Ref
1							X
2					X		X
3							X
4							X
5		X					X
6							X
Ref	X	X	X	X	X	X	

Survey 7

Treatment	1	2	3	4	5	6	Ref
1		X		X		X	X
2	X				X		X
3				X		X	X
4	X		X		X		X
5		X		X		X	X
6	X		X		X		X
Ref	X	X	X	X	X	X	

Simpson diversity index ($1 - \lambda$)

Survey 4

Treatment	1	2	3	4	5	6	Ref
1			X				X
2			X		X		X
3	X	X		X		X	X
4			X				X
5		X				X	X
6			X		X		X
Ref	X	X	X	X	X	X	

Survey 6

Treatment	1	2	3	4	5	6	Ref
1					X		X
2			X		X	X	X
3		X					X
4							X
5	X	X					X
6		X					X
Ref	X	X	X	X	X	X	

Survey 7

Treatment	1	2	3	4	5	6	Ref
1		X		X		X	X
2	X			X	X	X	X
3				X		X	X
4	X	X	X		X		X
5		X		X		X	X
6	X	X	X		X		X
Ref	X	X	X	X	X	X	

Appendix 9: Paired sample statistics for vegetation monitoring data from trial site 1 over time (December 2014 to April 2016) (SPSS, 2016). Significant values are in bold ($p < 0.05$).

Treatment 1 (control), fine tailings (ft); Treatment 2, ft and top soil (ts) (100mm); Treatment 3, ft and coarse tailings (ct) (100mm); Treatment 4, ft, ct (100mm) and ts (100mm); Treatment 5, ft and ct (250 mm); Treatment 6, ft, ct (250 mm) and ts (100 mm); Ref, reference sites.

Treatment	Variable		Mean	N	Std. Deviation	Paired t-test p-value
1	Pair 1	S (Richness) (Forbs)	1.00	9	0.00	0.3466
		S (Richness) (Forbs)	0.78	9	0.67	
	Pair 2	S (Richness) (Graminoids)	1.00	9	0.87	0.0039
		S (Richness) (Graminoids)	0.33	9	0.71	
	Pair 3	S total	2.00	9	0.87	0.0353
		S total	1.11	9	1.17	
	Pair 4	N (Individuals) (Forbs)	27.67	9	26.43	0.1398
		N (Individuals) (Forbs)	11.00	9	10.72	
	Pair 5	N (Individuals) (Graminoids)	3.56	9	3.97	0.0345
		N (Individuals) (Graminoids)	0.67	9	1.41	
	Pair 6	N total	31.22	9	26.02	0.0899
		N total	11.67	9	11.05	
	Pair 7	d (Species richness) (Margalef)	0.33	9	0.30	0.0710
		d (Species richness) (Margalef)	0.15	9	0.31	
	Pair 8	J' (Pielou's evenness)	0.47	9	0.37	0.0139
		J' (Pielou's evenness)	0.12	9	0.25	
	Pair 9	H'loge (Shannon)	0.38	9	0.31	0.0102
		H'loge (Shannon)	0.13	9	0.27	
	Pair 10	1-Lambda (Simpson)	0.24	9	0.21	0.0157
		1-Lambda (Simpson)	0.08	9	0.16	

2	Pair 1	S (Richness) (Forbs)	1.00	9	0.00	0.5943
		S (Richness) (Forbs)	1.11	9	0.60	
	Pair 2	S (Richness) (Graminoids)	1.00	9	0.00	0.0022
		S (Richness) (Graminoids)	1.89	9	0.60	
	Pair 3	S total	2.00	9	0.00	0.0171
		S total	3.00	9	1.00	
	Pair 4	N (Individuals) (Forbs)	28.67	9	24.95	0.0129
		N (Individuals) (Forbs)	2.00	9	1.94	
	Pair 5	N (Individuals) (Graminoids)	9.33	9	5.12	0.0291
		N (Individuals) (Graminoids)	22.44	9	11.80	
	Pair 6	N total	38.00	9	21.67	0.1451
		N total	24.44	9	12.27	
	Pair 7	d (Species richness) (Margalef)	0.30	9	0.06	0.0193
		d (Species richness) (Margalef)	0.68	9	0.37	
	Pair 8	J' (Pielou's evenness)	0.74	9	0.31	0.1601
		J' (Pielou's evenness)	0.49	9	0.24	
	Pair 9	H'loge (Shannon)	0.51	9	0.21	0.6342
		H'loge (Shannon)	0.59	9	0.33	
	Pair 10	1-Lambda (Simpson)	0.36	9	0.18	0.8380
		1-Lambda (Simpson)	0.34	9	0.20	

Treatment	Variable		Mean	N	Std. Deviation	Paired t-test p-value
3	Pair 1	S (Richness) (Forbs)	0.78	9	0.44	0.5943
		S (Richness) (Forbs)	0.89	9	0.33	
	Pair 2	S (Richness) (Graminoids)	0.11	9	0.33	0.0353
		S (Richness) (Graminoids)	0.56	9	0.73	
	Pair 3	S total	0.89	9	0.60	0.0133
		S total	1.44	9	0.53	
	Pair 4	N (Individuals) (Forbs)	7.11	9	8.55	0.2280
		N (Individuals) (Forbs)	3.11	9	2.09	
	Pair 5	N (Individuals) (Graminoids)	0.22	9	0.67	0.2997
		N (Individuals) (Graminoids)	4.00	9	10.89	
	Pair 6	N total	7.33	9	8.89	0.9414
		N total	7.11	9	9.89	
	Pair 7	d (Species richness) (Margalef)	0.04	9	0.11	0.0929
		d (Species richness) (Margalef)	0.24	9	0.31	
	Pair 8	J' (Pielou's evenness)	0.05	9	0.16	0.0382
		J' (Pielou's evenness)	0.35	9	0.43	
	Pair 9	H'loge (Shannon)	0.04	9	0.11	0.0382
		H'loge (Shannon)	0.25	9	0.30	
	Pair 10	1-Lambda (Simpson)	0.02	9	0.06	0.0393
		1-Lambda (Simpson)	0.19	9	0.24	

4	Pair 1	S (Richness) (Forbs)	1.00	9	0.00	0.0133
		S (Richness) (Forbs)	1.56	9	0.53	
	Pair 2	S (Richness) (Graminoids)	0.89	9	0.33	0.0022
		S (Richness) (Graminoids)	1.78	9	0.44	
	Pair 3	S total	1.89	9	0.33	<0.0001
		S total	3.33	9	0.50	
	Pair 4	N (Individuals) (Forbs)	26.89	9	30.07	0.0798
		N (Individuals) (Forbs)	5.33	9	5.20	
	Pair 5	N (Individuals) (Graminoids)	3.00	9	2.83	0.0444
		N (Individuals) (Graminoids)	10.67	9	8.93	
	Pair 6	N total	29.89	9	30.75	0.2467
		N total	16.00	9	9.17	
	Pair 7	d (Species richness) (Margalef)	0.32	9	0.18	0.0001
		d (Species richness) (Margalef)	0.92	9	0.25	
	Pair 8	J' (Pielou's evenness)	0.51	9	0.35	0.0892
		J' (Pielou's evenness)	0.78	9	0.15	
	Pair 9	H'loge (Shannon)	0.36	9	0.24	0.0004
		H'loge (Shannon)	0.93	9	0.23	
	Pair 10	1-Lambda (Simpson)	0.25	9	0.21	0.0040
		1-Lambda (Simpson)	0.58	9	0.16	

Treatment	Variable		Mean	N	Std. Deviation	Paired t-test p-value
5	Pair 1	S (Richness) (Forbs)	0.67	9	0.50	0.3466
		S (Richness) (Forbs)	0.44	9	0.73	
	Pair 2	S (Richness) (Graminoids)	0.44	9	0.53	0.7599
		S (Richness) (Graminoids)	0.56	9	0.73	
	Pair 3	S total	1.11	9	0.78	0.6811
		S total	1.00	9	0.87	
	Pair 4	N (Individuals) (Forbs)	5.44	9	5.96	0.3587
		N (Individuals) (Forbs)	2.78	9	5.33	
	Pair 5	N (Individuals) (Graminoids)	1.11	9	1.54	0.8939
		N (Individuals) (Graminoids)	1.00	9	1.41	
	Pair 6	N total	6.56	9	6.25	0.2586
		N total	3.78	9	4.97	
	Pair 7	d (Species richness) (Margalef)	0.17	9	0.27	0.7402
		d (Species richness) (Margalef)	0.22	9	0.36	
	Pair 8	J' (Pielou's evenness)	0.26	9	0.40	0.9128
		J' (Pielou's evenness)	0.23	9	0.38	
	Pair 9	H'loge (Shannon)	0.18	9	0.28	0.9128
		H'loge (Shannon)	0.16	9	0.26	
	Pair 10	1-Lambda (Simpson)	0.14	9	0.22	0.9540
		1-Lambda (Simpson)	0.15	9	0.26	

6	Pair 1	S (Richness) (Forbs)	0.89	9	0.33	0.0222
		S (Richness) (Forbs)	1.56	9	0.73	
	Pair 2	S (Richness) (Graminoids)	1.33	9	0.50	0.0039
		S (Richness) (Graminoids)	2.00	9	0.50	
	Pair 3	S total	2.22	9	0.67	0.0005
		S total	3.56	9	0.88	
	Pair 4	N (Individuals) (Forbs)	12.22	9	16.18	0.4838
		N (Individuals) (Forbs)	7.33	9	8.50	
	Pair 5	N (Individuals) (Graminoids)	4.33	9	4.00	0.0114
		N (Individuals) (Graminoids)	10.89	9	6.66	
	Pair 6	N total	16.56	9	16.84	0.7489
		N total	18.22	9	10.76	
	Pair 7	d (Species richness) (Margalef)	0.56	9	0.40	0.0005
		d (Species richness) (Margalef)	0.98	9	0.38	
	Pair 8	J' (Pielou's evenness)	0.64	9	0.32	0.3969
		J' (Pielou's evenness)	0.73	9	0.16	
	Pair 9	H'loge (Shannon)	0.54	9	0.30	0.0046
		H'loge (Shannon)	0.92	9	0.33	
	Pair 10	1-Lambda (Simpson)	0.39	9	0.25	0.0493
		1-Lambda (Simpson)	0.55	9	0.20	

Appendix 10: ANOVA results for vegetation monitoring data for Site 2 (SPSS, 2016). Significant values in bold ($p > 0.05$). Treatment 1, coarse tailings (ct) and top soil (ts) (100mm); Treatment 2, ct and waste rock (wr); Treatment 3, ct, wr and ts (100mm); Treatment 4, ct (control); Reference, reference sites.

Variable	Treatment	N	Survey 4			Survey 6			Survey 7		
			Mean	Std. Deviation	Anova p-value	Mean	Std. Deviation	Anova p-value	Mean	Std. Deviation	Anova p-value
S (Richness) (Forbs)	1	36	1.000	0.676		2.222	1.376		1.361	0.833	
	2	36	0.583	0.554		1.194	0.951		0.722	0.701	
	3	33	1.030	0.467		2.091	1.011		1.061	0.998	
	4	12	0.333	0.492		0.917	1.165		1.417	0.996	
	Reference	81	10.259	3.601		10.259	3.601		10.259	3.601	
	Total	198	4.677	5.213	<0.0001	5.222	4.880	<0.0001	4.838	5.117	<0.0001
S (Richness) (Graminoids)	1	36	2.694	0.920		1.889	0.979		1.083	0.439	
	2	36	1.972	0.910		0.972	0.810		0.500	0.507	
	3	33	2.212	0.696		1.576	1.001		0.879	0.600	
	4	12	2.333	1.435		1.833	0.937		0.667	0.492	
	Reference	81	3.099	1.068		3.099	1.068		3.099	1.068	
	Total	198	2.626	1.077	<0.0001	2.162	1.288	<0.0001	1.742	1.389	<0.0001
S total	1	36	3.694	1.167		4.111	1.670		2.444	0.773	
	2	36	2.556	1.107		2.167	1.384		1.222	0.898	
	3	33	3.242	0.830		3.667	1.472		1.939	1.248	
	4	12	2.667	1.670		2.750	1.485		2.083	1.084	
	Reference	81	13.358	4.054		13.358	4.054		13.358	4.054	
	Total	198	7.303	5.748	<0.0001	7.384	5.763	<0.0001	6.581	6.272	<0.0001
N (Individuals) (Forbs)	1	36	24.806	37.152		63.833	52.735		3.500	4.359	
	2	36	7.167	12.360		14.056	27.144		0.833	0.910	
	3	33	12.333	19.971		69.788	53.974		1.909	2.296	
	4	12	8.333	17.322		1.250	1.603		2.083	1.311	
	Reference	81	60.420	37.903		60.420	37.903		60.420	37.903	
	Total	198	33.091	38.591	<0.0001	50.586	46.984	<0.0001	25.949	37.621	<0.0001
N (Individuals) (Graminoids)	1	36	20.806	12.779		10.528	7.792		8.000	5.539	
	2	36	7.417	5.022		3.250	4.625		1.278	1.951	
	3	33	16.030	9.269		6.848	6.676		4.636	6.679	
	4	12	19.417	15.831		6.667	7.855		2.000	3.643	
	Reference	81	28.383	13.807		28.383	13.807		28.383	13.807	
	Total	198	20.591	14.111	<0.0001	15.662	14.837	<0.0001	14.192	15.368	<0.0001
N total	1	36	45.611	35.908		74.361	49.929		11.500	6.522	
	2	36	14.583	12.618		17.306	27.319		2.111	2.265	
	3	33	28.364	21.523		76.636	51.934		6.545	7.040	
	4	12	27.750	25.997		7.917	8.039		4.083	3.965	
	Reference	81	88.802	43.566		88.802	43.566		88.802	43.566	
	Total	198	53.682	45.693	<0.0001	66.247	51.694	<0.0001	40.141	49.439	<0.0001

Variable	Treatment	N	Survey 4			Survey 6			Survey 7		
			Mean	Std. Deviation	Anova p-value	Mean	Std. Deviation	Anova p value	Mean	Std. Deviation	Anova p-value
d (Species richness) (Margalef)	1	36	0.776	0.359		0.784	0.408		0.693	0.436	
	2	36	0.615	0.409		0.602	0.550		0.364	0.539	
	3	33	0.759	0.338		0.654	0.366		0.581	0.589	
	4	12	0.512	0.403		0.915	0.731		0.904	0.697	
	Reference	81	2.789	0.787		2.789	0.787		2.789	0.787	
	Total	198	1.551	1.184	<0.0001	1.557	1.203	<0.0001	1.485	1.273	<0.0001
J' (Pielou's evenness)	1	36	0.681	0.257		0.461	0.270		0.629	0.309	
	2	36	0.599	0.320		0.461	0.388		0.306	0.423	
	3	33	0.780	0.180		0.358	0.227		0.465	0.413	
	4	12	0.494	0.345		0.577	0.402		0.665	0.419	
	Reference	81	0.810	0.086		0.810	0.086		0.810	0.086	
	Total	198	0.724	0.234	<0.0001	0.593	0.308	<0.0001	0.619	0.355	<0.0001
H'loge (Shannon)	1	36	0.871	0.389		0.592	0.339		0.603	0.340	
	2	36	0.600	0.373		0.441	0.411		0.240	0.341	
	3	33	0.886	0.277		0.465	0.328		0.438	0.426	
	4	12	0.552	0.455		0.673	0.545		0.600	0.435	
	Reference	81	2.067	0.386		2.067	0.386		2.067	0.386	
	Total	198	1.294	0.751	<0.0001	1.152	0.856	<0.0001	1.108	0.892	<0.0001
1-Lambda (Simpson)	1	36	0.498	0.219		0.321	0.206		0.428	0.272	
	2	36	0.388	0.236		0.340	0.347		0.235	0.348	
	3	33	0.547	0.167		0.241	0.188		0.339	0.338	
	4	12	0.324	0.250		0.477	0.392		0.545	0.384	
	Reference	81	0.827	0.095		0.827	0.095		0.827	0.095	
	Total	198	0.610	0.258	<0.0001	0.528	0.334	<0.0001	0.548	0.354	<0.0001

Appendix 11: Tukey B post-hoc tests for vegetation monitoring data for trial site 2 (SPSS, 2016). Crosses indicate significant differences between treatments ($p < 0.05$). Treatment 1, coarse tailings (ct) and top soil (ts) (100mm); Treatment 2, ct and waste rock (wr); Treatment 3, ct, wr and ts (100mm); Treatment 4, ct (control); Reference, reference sites.

Species richness (S) (forbs)

Survey 4

Treatment	1	2	3	4	Ref
1					X
2					X
3					X
4					X
Ref	X	X	X	X	

Survey 6

Treatment	1	2	3	4	Ref
1					X
2					X
3					X
4					X
Ref	X	X	X	X	

Survey 7

Treatment	1	2	3	4	Ref
1					X
2					X
3					X
4					X
Ref	X	X	X	X	

S (graminoids)

Survey 4

Treatment	1	2	3	4	Ref
1		X			
2	X				X
3					X
4					X
Ref		X	X	X	

Survey 6

Treatment	1	2	3	4	Ref
1		X			X
2	X			X	X
3					X
4		X			X
Ref	X	X	X	X	

Survey 7

Treatment	1	2	3	4	Ref
1		X			X
2	X				X
3					X
4					X
Ref	X	X	X	X	

S total

Survey 4

Treatment	1	2	3	4	Ref
1					X
2					X
3					X
4					X
Ref	X	X	X	X	

Survey 6

Treatment	1	2	3	4	Ref
1					X
2					X
3					X
4					X
Ref	X	X	X	X	

Survey 7

Treatment	1	2	3	4	Ref
1					X
2					X
3					X
4					X
Ref	X	X	X	X	

Number of individuals (N) (forbs)

Survey 4

Treatment	1	2	3	4	Ref
1					X
2					X
3					X
4					X
Ref	X	X	X	X	

Survey 6

Treatment	1	2	3	4	Ref
1		X		X	
2	X		X		X
3		X		X	
4	X		X		X
Ref		X		X	

Survey 7

Treatment	1	2	3	4	Ref
1					X
2					X
3					X
4					X
Ref	X	X	X	X	

N (graminoids)

Survey 4

Treatment	1	2	3	4	Ref
1		X			
2	X		X	X	X
3		X			X
4		X			X
Ref		X	X	X	

Survey 6

Treatment	1	2	3	4	Ref
1					X
2					X
3					X
4					X
Ref	X	X	X	X	

Survey 7

Treatment	1	2	3	4	Ref
1					X
2					X
3					X
4					X
Ref	X	X	X	X	

N total

Survey 4

Treatment	1	2	3	4	Ref
1		X			X
2	X				X
3					X
4					X
Ref	X	X	X	X	

Survey 6

Treatment	1	2	3	4	Ref
1		X		X	
2	X		X		X
3		X		X	
4	X		X		X
Ref		X		X	

Survey 7

Treatment	1	2	3	4	Ref
1					X
2					X
3					X
4					X
Ref	X	X	X	X	

Margalef diversity index (d)

Survey 4

Treatment	1	2	3	4	Ref
1					X
2					X
3					X
4					X
Ref	X	X	X	X	

Survey 6

Treatment	1	2	3	4	Ref
1					X
2					X
3					X
4					X
Ref	X	X	X	X	

Survey 7

Treatment	1	2	3	4	Ref
1					X
2				X	X
3					X
4		X			X
Ref	X	X	X	X	

Pielou's evenness index (J')

Survey 4

Treatment	1	2	3	4	Ref
1				X	
2			X		X
3		X		X	
4	X		X		X
Ref		X		X	

Survey 6

Treatment	1	2	3	4	Ref
1					X
2					X
3				X	X
4			X		X
Ref	X	X	X	X	

Survey 7

Treatment	1	2	3	4	Ref
1		X			
2	X			X	X
3					X
4		X			
Ref		X	X		

Shannon diversity index (H'loge)

Survey 4

Treatment	1	2	3	4	Ref
1		X		X	X
2	X		X		X
3		X		X	X
4	X		X		X
Ref	X	X	X	X	

Survey 6

Treatment	1	2	3	4	Ref
1					X
2					X
3					X
4					X
Ref	X	X	X	X	

Survey 7

Treatment	1	2	3	4	Ref
1		X			X
2	X			X	X
3					X
4		X			X
Ref	X	X	X	X	

Simpson diversity index ($1 - \lambda$)

Survey 4

Treatment	1	2	3	4	Ref
1				X	X
2			X		X
3		X		X	X
4	X		X		X
Ref	X	X	X	X	

Survey 6

Treatment	1	2	3	4	Ref
1				X	X
2					X
3				X	X
4	X		X		X
Ref	X	X	X	X	

Survey 7

Treatment	1	2	3	4	Ref
1		X			X
2	X			X	X
3				X	X
4		X	X		X
Ref	X	X	X	X	

Appendix 12: Paired sample statistics for vegetation monitoring data from trial site 2 over time (December 2014 to April 2016) (SPSS, 2016). Significant values are in bold ($p < 0.05$). Treatment 1, coarse tailings (ct) and top soil (ts) (100mm); Treatment 2, ct and waste rock (wr); Treatment 3, ct, wr and ts (100mm); Treatment 4, ct (control); Reference, reference sites.

Treatment	Variable		Mean	N	Std. Deviation	Paired t-test p-value
1	Pair 1	S (Richness) (Forbs)	1.00	36	0.68	0.0354
		S (Richness) (Forbs)	1.36	36	0.83	
	Pair 2	S (Richness) (Graminoids)	2.69	36	0.92	0.0000
		S (Richness) (Graminoids)	1.08	36	0.44	
	Pair 3	S total	3.69	36	1.17	0.0000
		S total	2.44	36	0.77	
	Pair 4	N (Individuals) (Forbs)	24.81	36	37.15	0.0008
		N (Individuals) (Forbs)	3.50	36	4.36	
	Pair 5	N (Individuals) (Graminoids)	20.81	36	12.78	<0.0001
		N (Individuals) (Graminoids)	8.00	36	5.54	
	Pair 6	N total	45.61	36	35.91	<0.0001
		N total	11.50	36	6.52	
	Pair 7	d (Species richness) (Margalef)	0.78	36	0.36	0.4358
		d (Species richness) (Margalef)	0.69	36	0.44	
	Pair 8	J' (Pielou's evenness)	0.68	36	0.26	0.4750
		J' (Pielou's evenness)	0.63	36	0.31	
	Pair 9	H'loge (Shannon)	0.87	36	0.39	0.0085
		H'loge (Shannon)	0.60	36	0.34	
	Pair 10	1-Lambda (Simpson)	0.50	36	0.22	0.2907
		1-Lambda (Simpson)	0.43	36	0.27	

Treatment	Variable		Mean	N	Std. Deviation	Paired t-test p-value
2	Pair 1	S (Richness) (Forbs)	0.58	36	0.55	0.3605
		S (Richness) (Forbs)	0.72	36	0.70	
	Pair 2	S (Richness) (Graminoids)	1.97	36	0.91	<0.0001
		S (Richness) (Graminoids)	0.50	36	0.51	
	Pair 3	S total	2.56	36	1.11	<0.0001
		S total	1.22	36	0.90	
	Pair 4	N (Individuals) (Forbs)	7.17	36	12.36	0.0036
		N (Individuals) (Forbs)	0.83	36	0.91	
	Pair 5	N (Individuals) (Graminoids)	7.42	36	5.02	<0.0001
		N (Individuals) (Graminoids)	1.28	36	1.95	
	Pair 6	N total	14.58	36	12.62	<0.0001
		N total	2.11	36	2.26	
	Pair 7	d (Species richness) (Margalef)	0.61	36	0.41	0.0330
		d (Species richness) (Margalef)	0.36	36	0.54	
	Pair 8	J' (Pielou's evenness)	0.60	36	0.32	0.0005
		J' (Pielou's evenness)	0.31	36	0.42	
	Pair 9	H'loge (Shannon)	0.60	36	0.37	0.0001
		H'loge (Shannon)	0.24	36	0.34	
	Pair 10	1-Lambda (Simpson)	0.39	36	0.24	0.0262
		1-Lambda (Simpson)	0.24	36	0.35	

Treatment	Variable		Mean	N	Std. Deviation	Paired t-test p-value
3	Pair 1	S (Richness) (Forbs)	1.03	33	0.47	0.8688
		S (Richness) (Forbs)	1.06	33	1.00	
	Pair 2	S (Richness) (Graminoids)	2.21	33	0.70	<0.0001
		S (Richness) (Graminoids)	0.88	33	0.60	
	Pair 3	S total	3.24	33	0.83	<0.0001
		S total	1.94	33	1.25	
	Pair 4	N (Individuals) (Forbs)	12.33	33	19.97	0.0033
		N (Individuals) (Forbs)	1.91	33	2.30	
	Pair 5	N (Individuals) (Graminoids)	16.03	33	9.27	<0.0001
		N (Individuals) (Graminoids)	4.64	33	6.68	
	Pair 6	N total	28.36	33	21.52	<0.0001
		N total	6.55	33	7.04	
	Pair 7	d (Species richness) (Margalef)	0.76	33	0.34	0.1039
		d (Species richness) (Margalef)	0.58	33	0.59	
	Pair 8	J' (Pielou's evenness)	0.78	33	0.18	0.0008
		J' (Pielou's evenness)	0.46	33	0.41	
	Pair 9	H'loge (Shannon)	0.89	33	0.28	<0.0001
		H'loge (Shannon)	0.44	33	0.43	
	Pair 10	1-Lambda (Simpson)	0.55	33	0.17	0.0032
		1-Lambda (Simpson)	0.34	33	0.34	

Treatment	Variable		Mean	N	Std. Deviation	Paired t-test p-value
4	Pair 1	S (Richness) (Forbs)	0.33	12	0.49	0.0053
		S (Richness) (Forbs)	1.42	12	1.00	
	Pair 2	S (Richness) (Graminoids)	2.33	12	1.44	0.0043
		S (Richness) (Graminoids)	0.67	12	0.49	
	Pair 3	S total	2.67	12	1.67	0.3172
		S total	2.08	12	1.08	
	Pair 4	N (Individuals) (Forbs)	8.33	12	17.32	0.2390
		N (Individuals) (Forbs)	2.08	12	1.31	
	Pair 5	N (Individuals) (Graminoids)	19.42	12	15.83	0.0050
		N (Individuals) (Graminoids)	2.00	12	3.64	
	Pair 6	N total	27.75	12	26.00	0.0103
		N total	4.08	12	3.96	
	Pair 7	d (Species richness) (Margalef)	0.51	12	0.40	0.0882
		d (Species richness) (Margalef)	0.90	12	0.70	
	Pair 8	J' (Pielou's evenness)	0.49	12	0.35	0.1847
		J' (Pielou's evenness)	0.66	12	0.42	
	Pair 9	H'loge (Shannon)	0.55	12	0.45	0.7592
		H'loge (Shannon)	0.60	12	0.44	
	Pair 10	1-Lambda (Simpson)	0.32	12	0.25	0.0503
		1-Lambda (Simpson)	0.55	12	0.38	

Appendix 13: ANOVA results for vegetation monitoring data for Site 3 (SPSS, 2016).

Significant values in bold ($p > 0.05$). Treatments 1, waste rock (wr); 2, wr and coarse tailings (ct) (100 mm); 3, wr and ct (200 mm); 4, wr and top soil (ts) (100 mm); 5, wr and ts (250 mm); 6, wr, ct (100 mm) and ts (100 mm); 7, wr, ct (250 mm) and ts (100 mm);

Reference, reference sites.

*

Variable	Treatment	N	Survey 5			Survey 6			Survey 7		
			Mean	Std. Deviation	Anova p-value	Mean	Std. Deviation	Anova p-value	Mean	Std. Deviation	Anova p-value
S (Richness) (Forbs)	1	27	1.074	0.550		0.926	0.781		1.037	0.808	
	2	27	1.074	0.267		1.222	0.751		1.111	0.892	
	3	27	0.741	0.526		0.667	0.555		0.741	0.712	
	4	27	1.259	0.526		1.037	0.338		1.000	0.832	
	5	27	1.593	0.636		1.222	0.506		1.000	1.000	
	6	27	1.000	0.277		1.148	0.362		1.074	0.616	
	7	27	1.148	0.362		1.111	0.320		1.074	0.616	
	Reference	81	10.259	3.601		10.259	3.601		10.259	3.601	
	Total	270	3.867	4.650	<0.0001	3.811	4.687	<0.0001	3.781	4.727	<0.0001
S (Richness) (Graminoids)	1	27	2.556	1.476		0.778	0.641		1.000	0.832	
	2	27	2.074	1.639		0.481	0.643		0.704	0.724	
	3	27	1.333	0.734		0.407	0.694		0.296	0.542	
	4	27	3.333	1.664		1.444	0.847		1.556	0.801	
	5	27	3.667	1.569		2.074	0.829		1.889	0.424	
	6	27	2.667	1.074		1.000	0.555		1.333	0.734	
	7	27	2.667	1.240		0.889	0.641		1.296	0.823	
	Reference	81	3.099	1.068		3.099	1.068		3.099	1.068	
	Total	270	2.759	1.426	<0.0001	1.637	1.339	<0.0001	1.737	1.285	<0.0001
S total	1	27	3.630	1.779		1.704	1.171		2.037	1.315	
	2	27	3.148	1.703		1.704	0.993		1.815	1.178	
	3	27	2.074	0.997		1.074	1.035		1.037	0.940	
	4	27	4.593	1.927		2.481	1.014		2.556	1.251	
	5	27	5.259	1.723		3.296	1.103		2.889	0.934	
	6	27	3.667	1.177		2.148	0.662		2.407	0.931	
	7	27	3.815	1.360		2.000	0.734		2.370	0.967	
	Reference	81	13.358	4.054		13.358	4.054		13.358	4.054	
	Total	270	6.626	5.162	<0.0001	5.448	5.722	<0.0001	5.519	5.687	<0.0001
N (Individuals) (Forbs)	1	27	13.148	10.589		15.481	23.986		6.037	11.863	
	2	27	8.704	6.094		11.889	22.015		2.593	2.899	
	3	27	2.741	3.194		6.222	21.277		1.519	1.909	
	4	27	20.963	14.273		74.741	106.256		2.037	1.971	
	5	27	26.556	18.429		64.778	47.007		1.481	1.740	
	6	27	15.037	7.578		40.222	42.375		2.074	1.880	
	7	27	11.630	10.792		46.296	60.143		2.778	2.044	
	Reference	81	60.420	37.903		60.420	37.903		60.420	37.903	
	Total	270	28.004	31.638	<0.0001	44.089	54.325	<0.0001	19.978	33.889	<0.0001

Variable	Treatment	N	Survey 5			Survey 6			Survey 7		
			Mean	Std. Deviation	Anova p-value	Mean	Std. Deviation	Anova p-value	Mean	Std. Deviation	Anova p-value
N (Individuals) (Graminoids)	1	27	11.778	11.308		3.222	4.335		3.741	5.544	
	2	27	6.889	6.699		1.667	3.317		1.667	2.253	
	3	27	4.111	2.833		0.741	1.347		0.519	1.122	
	4	27	18.889	12.001		8.000	6.516		15.481	19.399	
	5	27	19.926	13.815		13.667	9.397		21.333	19.241	
	6	27	12.000	10.012		6.778	7.728		7.963	8.587	
	7	27	11.370	9.328		4.148	7.853		6.296	5.434	
	Reference	81	28.383	13.807		28.383	13.807		28.383	13.807	
	Total	270	17.011	14.150	<0.0001	12.337	14.381	<0.0001	14.215	16.247	<0.0001
N total	1	27	24.926	19.399		18.704	23.731		9.778	12.267	
	2	27	15.593	10.529		13.556	22.628		4.259	3.623	
	3	27	6.852	4.745		6.963	21.398		2.037	2.121	
	4	27	39.852	23.533		82.741	105.449		17.519	19.573	
	5	27	46.481	27.444		78.444	44.757		22.815	19.643	
	6	27	27.037	14.810		47.000	39.208		10.037	8.364	
	7	27	23.000	15.983		50.444	58.721		9.074	5.540	
	Reference	81	88.802	43.566		88.802	43.566		88.802	43.566	
	Total	270	45.015	41.483	<0.0001	56.426	59.009	<0.0001	34.193	44.487	<0.0001
d (Species richness) (Margalef)	1	27	0.825	0.469		0.321	0.394		0.641	0.615	
	2	27	0.804	0.551		0.371	0.499		0.531	0.605	
	3	27	0.634	0.510		0.235	0.450		0.407	0.584	
	4	27	0.966	0.448		0.406	0.246		0.708	0.534	
	5	27	1.142	0.383		0.565	0.280		0.727	0.397	
	6	27	0.830	0.315		0.365	0.269		0.720	0.490	
	7	27	0.952	0.378		0.366	0.341		0.709	0.508	
	Reference	81	2.789	0.787		2.789	0.787		2.789	0.787	
	Total	270	1.452	1.049	<0.0001	1.099	1.228	<0.0001	1.281	1.169	<0.0001
J' (Pielou's evenness)	1	27	0.670	0.270		0.321	0.377		0.550	0.439	
	2	27	0.674	0.310		0.365	0.412		0.434	0.442	
	3	27	0.666	0.381		0.220	0.380		0.353	0.471	
	4	27	0.690	0.233		0.496	0.357		0.620	0.343	
	5	27	0.671	0.192		0.501	0.220		0.683	0.262	
	6	27	0.695	0.191		0.452	0.338		0.614	0.348	
	7	27	0.739	0.178		0.344	0.316		0.673	0.332	
	Reference	81	0.810	0.086		0.810	0.086		0.810	0.086	
	Total	270	0.723	0.227	<0.0001	0.513	0.358	<0.0001	0.636	0.352	<0.0001
H'loge (Shannon)	1	27	0.890	0.462		0.301	0.372		0.528	0.471	
	2	27	0.790	0.459		0.325	0.391		0.428	0.453	
	3	27	0.583	0.386		0.188	0.348		0.259	0.352	
	4	27	1.035	0.415		0.484	0.340		0.621	0.431	
	5	27	1.105	0.367		0.563	0.289		0.681	0.322	
	6	27	0.902	0.333		0.369	0.300		0.560	0.344	
	7	27	0.957	0.370		0.294	0.294		0.609	0.341	
	Reference	81	2.067	0.386		2.067	0.386		2.067	0.386	
	Total	270	1.246	0.679	<0.0001	0.873	0.863	<0.0001	0.989	0.813	<0.0001

Variable	Treatment	N	Survey 5			Survey 6			Survey 7		
			Mean	Std. Deviation	Anova p-value	Mean	Std. Deviation	Anova p-value	Mean	Std. Deviation	Anova p-value
1-Lambda (Simpson)	1	27	0.503	0.236		0.197	0.252		0.405	0.365	
	2	27	0.496	0.263		0.238	0.289		0.324	0.351	
	3	27	0.452	0.304		0.150	0.279		0.291	0.405	
	4	27	0.557	0.199		0.297	0.227		0.428	0.289	
	5	27	0.573	0.185		0.315	0.183		0.453	0.238	
	6	27	0.523	0.174		0.236	0.215		0.423	0.293	
	7	27	0.559	0.192		0.188	0.216		0.464	0.288	
	Reference	81	0.827	0.095		0.827	0.095		0.827	0.095	
	Total	270	0.614	0.241	<0.0001	0.410	0.344	<0.0001	0.527	0.338	<0.0001

Appendix 14: Tukey B post-hoc tests for vegetation monitoring data for trial site 3 (SPSS, 2016). Crosses indicate significant differences between treatments ($p < 0.05$). Treatments 1, waste rock (wr); 2, wr and coarse tailings (ct) (100 mm); 3, wr and ct (200 mm); 4, wr and top soil (ts) (100 mm); 5, wr and ts (250 mm); 6, wr, ct (100 mm) and ts (100 mm); 7, wr, ct (250 mm) and ts (100 mm); Reference, reference sites.

Species richness (S) (forbs)

Survey 5

Treatment	1	2	3	4	5	6	7	Ref
1	■							X
2		■						X
3			■					X
4				■				X
5					■			X
6						■		X
7							■	X
Ref	X	X	X	X	X	X	X	■

Survey 6

Treatment	1	2	3	4	5	6	7	Ref
1	■							X
2		■						X
3			■					X
4				■				X
5					■			X
6						■		X
7							■	X
Ref	X	X	X	X	X	X	X	■

Survey 7

Treatment	1	2	3	4	5	6	7	Ref
1	■							X
2		■						X
3			■					X
4				■				X
5					■			X
6						■		X
7							■	X
Ref	X	X	X	X	X	X	X	■

S (graminoids)

Survey 5

Treatment	1	2	3	4	5	6	7	Ref
1	■		X		X			
2		■		X	X			X
3	X		■	X	X	X	X	X
4		X	X	■				
5	X	X	X		■	X	X	
6			X		X	■		
7			X		X		■	
Ref		X	X					■

Survey 6

Treatment	1	2	3	4	5	6	7	Ref
1	■			X	X			X
2		■		X	X			X
3			■	X	X			X
4	X	X	X	■	X			X
5	X	X	X	X	■	X	X	X
6					X	■		X
7					X		■	X
Ref	X	X	X	X	X	X	X	■

Survey 7

Treatment	1	2	3	4	5	6	7	Ref
1			X		X			X
2				X	X	X	X	X
3	X			X	X	X	X	X
4		X	X					X
5	X	X	X					X
6		X	X					X
7		X	X					X
Ref	X	X	X	X	X	X	X	

S total

Survey 5

Treatment	1	2	3	4	5	6	7	Ref
1								X
2					X			X
3				X	X			X
4		X	X					X
5		X	X					X
6								X
7								X
Ref	X	X	X	X	X	X	X	

Survey 6

Treatment	1	2	3	4	5	6	7	Ref
1								X
2								X
3					X			X
4								X
5			X					X
6								X
7								X
Ref	X	X	X	X	X	X	X	

Survey 7

Treatment	1	2	3	4	5	6	7	Ref
1								X
2								X
3								X
4								X
5								X
6								X
7								X
Ref	X	X	X	X	X	X	X	

Number of individuals (N) (forbs)

Survey 5

Treatment	1	2	3	4	5	6	7	Ref
1								X
2					X			X
3				X	X			X
4			X					X
5		X	X					X
6								X
7								X
Ref	X	X	X	X	X	X	X	

Survey 6

Treatment	1	2	3	4	5	6	7	Ref
1				X	X			X
2				X	X			X
3				X	X		X	X
4	X	X	X					
5	X	X	X					
6								
7			X					
Ref	X	X	X					

Survey 7

Treatment	1	2	3	4	5	6	7	Ref
1								X
2								X
3								X
4								X
5								X
6								X
7								X
Ref	X	X	X	X	X	X	X	

N (graminoids)

Survey 5

Treatment	1	2	3	4	5	6	7	Ref
1								X
2				X	X			X
3				X	X			X
4		X	X					X
5		X	X				X	X
6								X
7					X			X
Ref	X	X	X	X	X	X	X	

Survey 6

Treatment	1	2	3	4	5	6	7	Ref
1					X			X
2					X			X
3				X	X			X
4			X					X
5	X	X	X			X	X	X
6					X			X
7					X			X
Ref	X	X	X	X	X	X	X	

Survey 7

Treatment	1	2	3	4	5	6	7	Ref
1				X	X			X
2				X	X			X
3				X	X			X
4	X	X	X				X	X
5	X	X	X			X	X	
6					X			X
7				X	X			X
Ref	X	X	X	X		X	X	

N total

Survey 5

Treatment	1	2	3	4	5	6	7	Ref
1					X			X
2				X	X			X
3				X	X			X
4		X	X					X
5	X	X	X				X	X
6								X
7					X			X
Ref	X	X	X	X	X	X	X	

Survey 6

Treatment	1	2	3	4	5	6	7	Ref
1				X	X			X
2				X	X			X
3				X	X	X	X	X
4	X	X	X					
5	X	X	X					
6			X					X
7			X					X
Ref	X	X	X			X	X	

Survey 7

Treatment	1	2	3	4	5	6	7	Ref
1								X
2								X
3					X			X
4								X
5			X					X
6								X
7								X
Ref	X	X	X	X	X	X	X	

Margalef diversity index (D)

Survey 5

Treatment	1	2	3	4	5	6	7	Ref
1								X
2								X
3					X			X
4								X
5			X					X
6								X
7								X
Ref	X	X	X	X	X	X	X	

Survey 6

Treatment	1	2	3	4	5	6	7	Ref
1								X
2								X
3								X
4								X
5								X
6								X
7								X
Ref	X	X	X	X	X	X	X	

Survey 7

Treatment	1	2	3	4	5	6	7	Ref
1								X
2								X
3								X
4								X
5								X
6								X
7								X
Ref	X	X	X	X	X	X	X	

Pielou's evenness index (J')

Survey 5

Treatment	1	2	3	4	5	6	7	Ref
1								
2								
3								
4								
5								
6								
7								
Ref								

Survey 6

Treatment	1	2	3	4	5	6	7	Ref
1								X
2								X
3				X	X	X		X
4			X					X
5			X					X
6			X					X
7								X
Ref	X	X	X	X	X	X	X	

Survey 7

Treatment	1	2	3	4	5	6	7	Ref
1								X
2					X			X
3				X	X	X	X	X
4			X					
5		X	X					
6			X					
7			X					
Ref	X	X	X					

Shannon diversity index (H'loge)

Survey 5

Treatment	1	2	3	4	5	6	7	Ref
1			X					X
2					X			X
3	X			X	X	X	X	X
4			X					X
5		X	X					X
6			X					X
7			X					X
Ref	X	X	X	X	X	X	X	

Survey 6

Treatment	1	2	3	4	5	6	7	Ref
1								X
2								X
3				X	X			X
4			X					X
5			X					X
6								X
7								X
Ref	X	X	X	X	X	X	X	

Survey 7

Treatment	1	2	3	4	5	6	7	Ref
1								X
2								X
3				X	X	X	X	X
4			X					X
5			X					X
6			X					X
7			X					X
Ref	X	X	X	X	X	X	X	

Simpson diversity index (1 - λ)

Survey 5

Treatment	1	2	3	4	5	6	7	Ref
1								X
2								X
3								X
4								X
5								X
6								X
7								X
Ref	X	X	X	X	X	X	X	

Survey 6

Treatment	1	2	3	4	5	6	7	Ref
1								X
2								X
3					X			X
4								X
5			X					X
6								X
7								X
Ref	X	X	X	X	X	X	X	

Survey 7

Treatment	1	2	3	4	5	6	7	Ref
1								X
2								X
3								X
4								X
5								X
6								X
7								X
Ref	X	X	X	X	X	X	X	

Appendix 15: Paired sample statistics for vegetation monitoring data from trial site 3 over time (March 2015 to April 2016) (SPSS, 2016). Significant values are in bold ($p < 0.05$).

Treatments 1, waste rock (wr); 2, wr and coarse tailings (ct) (100 mm); 3, wr and ct (200 mm); 4, wr and top soil (ts) (100 mm); 5, wr and ts (250 mm); 6, wr, ct (100 mm) and ts (100 mm); 7, wr, ct (250 mm) and ts (100 mm); Reference, reference sites.

Treatment	Variable		Mean	N	Std. Deviation	Paired t-test p-value
1	Pair 1	S (Richness) (Forbs)	1.07	27	0.55	0.8235
		S (Richness) (Forbs)	1.04	27	0.81	
	Pair 2	S (Richness) (Graminoids)	2.56	27	1.48	0.0001*
		S (Richness) (Graminoids)	1.00	27	0.83	
	Pair 3	S total	3.63	27	1.78	0.0004*
		S total	2.04	27	1.32	
	Pair 4	N (Individuals) (Forbs)	13.15	27	10.59	0.0284*
		N (Individuals) (Forbs)	6.04	27	11.86	
	Pair 5	N (Individuals) (Graminoids)	11.78	27	11.31	0.0027*
		N (Individuals) (Graminoids)	3.74	27	5.54	
	Pair 6	N total	24.93	27	19.40	0.0024*
		N total	9.78	27	12.27	
	Pair 7	d (Species richness) (Margalef)	0.83	27	0.47	0.2217
		d (Species richness) (Margalef)	0.64	27	0.62	
	Pair 8	J' (Pielou's evenness)	0.67	27	0.27	0.2223
		J' (Pielou's evenness)	0.55	27	0.44	
	Pair 9	H'loge (Shannon)	0.89	27	0.46	0.0041*
		H'loge (Shannon)	0.53	27	0.47	
	Pair 10	1-Lambda (Simpson)	0.50	27	0.24	0.2368
		1-Lambda (Simpson)	0.41	27	0.36	

Treatment	Variable		Mean	N	Std. Deviation	Paired t-test p-value
2	Pair 1	S (Richness) (Forbs)	1.07	27	0.27	0.8458
		S (Richness) (Forbs)	1.11	27	0.89	
	Pair 2	S (Richness) (Graminoids)	2.07	27	1.64	0.0001*
		S (Richness) (Graminoids)	0.70	27	0.72	
	Pair 3	S total	3.15	27	1.70	0.0003*
		S total	1.81	27	1.18	
	Pair 4	N (Individuals) (Forbs)	8.70	27	6.09	0.0001*
		N (Individuals) (Forbs)	2.59	27	2.90	
	Pair 5	N (Individuals) (Graminoids)	6.89	27	6.70	0.0002*
		N (Individuals) (Graminoids)	1.67	27	2.25	
	Pair 6	N total	15.59	27	10.53	<0.0001*
		N total	4.26	27	3.62	
	Pair 7	d (Species richness) (Margalef)	0.80	27	0.55	0.0558
		d (Species richness) (Margalef)	0.53	27	0.60	
	Pair 8	J' (Pielou's evenness)	0.67	27	0.31	0.0301*
		J' (Pielou's evenness)	0.43	27	0.44	
	Pair 9	H'loge (Shannon)	0.79	27	0.46	0.0014*
		H'loge (Shannon)	0.43	27	0.45	
	Pair 10	1-Lambda (Simpson)	0.50	27	0.26	0.0427*
		1-Lambda (Simpson)	0.32	27	0.35	

Treatment	Variable		Mean	N	Std. Deviation	Paired t-test p-value
3	Pair 1	S (Richness) (Forbs)	0.74	27	0.53	1.0000
		S (Richness) (Forbs)	0.74	27	0.71	
	Pair 2	S (Richness) (Graminoids)	1.33	27	0.73	<0.0001
		S (Richness) (Graminoids)	0.30	27	0.54	
	Pair 3	S total	2.07	27	1.00	0.0002*
		S total	1.04	27	0.94	
	Pair 4	N (Individuals) (Forbs)	2.74	27	3.19	0.1151
		N (Individuals) (Forbs)	1.52	27	1.91	
	Pair 5	N (Individuals) (Graminoids)	4.11	27	2.83	<0.0001*
		N (Individuals) (Graminoids)	0.52	27	1.12	
	Pair 6	N total	6.85	27	4.75	<0.0001*
		N total	2.04	27	2.12	
	Pair 7	d (Species richness) (Margalef)	0.63	27	0.51	0.1500
		d (Species richness) (Margalef)	0.41	27	0.58	
	Pair 8	J' (Pielou's evenness)	0.67	27	0.38	0.0140*
		J' (Pielou's evenness)	0.35	27	0.47	
	Pair 9	H'loge (Shannon)	0.58	27	0.39	0.0039*
		H'loge (Shannon)	0.26	27	0.35	
	Pair 10	1-Lambda (Simpson)	0.45	27	0.30	0.1259
		1-Lambda (Simpson)	0.29	27	0.40	

Treatment	Variable		Mean	N	Std. Deviation	Paired t-test p-value
4	Pair 1	S (Richness) (Forbs)	1.26	27	0.53	0.2297
		S (Richness) (Forbs)	1.00	27	0.83	
	Pair 2	S (Richness) (Graminoids)	3.33	27	1.66	<0.0001*
		S (Richness) (Graminoids)	1.56	27	0.80	
	Pair 3	S total	4.59	27	1.93	<0.0001*
		S total	2.56	27	1.25	
	Pair 4	N (Individuals) (Forbs)	20.96	27	14.27	<0.0001*
		N (Individuals) (Forbs)	2.04	27	1.97	
	Pair 5	N (Individuals) (Graminoids)	18.89	27	12.00	0.3083
		N (Individuals) (Graminoids)	15.48	27	19.40	
	Pair 6	N total	39.85	27	23.53	<0.0001*
		N total	17.52	27	19.57	
	Pair 7	d (Species richness) (Margalef)	0.97	27	0.45	0.0787
		d (Species richness) (Margalef)	0.71	27	0.53	
	Pair 8	J' (Pielou's evenness)	0.69	27	0.23	0.3677
		J' (Pielou's evenness)	0.62	27	0.34	
	Pair 9	H'loge (Shannon)	1.04	27	0.41	0.0013*
		H'loge (Shannon)	0.62	27	0.43	
	Pair 10	1-Lambda (Simpson)	0.56	27	0.20	0.0765
		1-Lambda (Simpson)	0.43	27	0.29	

Treatment	Variable		Mean	N	Std. Deviation	Paired t-test p-value
5	Pair 1	S (Richness) (Forbs)	1.59	27	0.64	0.0086*
		S (Richness) (Forbs)	1.00	27	1.00	
	Pair 2	S (Richness) (Graminoids)	3.67	27	1.57	<0.0001*
		S (Richness) (Graminoids)	1.89	27	0.42	
	Pair 3	S total	5.26	27	1.72	<0.0001*
		S total	2.89	27	0.93	
	Pair 4	N (Individuals) (Forbs)	26.56	27	18.43	<0.0001*
		N (Individuals) (Forbs)	1.48	27	1.74	
	Pair 5	N (Individuals) (Graminoids)	19.93	27	13.81	0.7358
		N (Individuals) (Graminoids)	21.33	27	19.24	
	Pair 6	N total	46.48	27	27.44	0.0007*
		N total	22.81	27	19.64	
	Pair 7	d (Species richness) (Margalef)	1.14	27	0.38	0.0012*
		d (Species richness) (Margalef)	0.73	27	0.40	
	Pair 8	J' (Pielou's evenness)	0.67	27	0.19	0.8490
		J' (Pielou's evenness)	0.68	27	0.26	
	Pair 9	H'loge (Shannon)	1.11	27	0.37	0.0003*
		H'loge (Shannon)	0.68	27	0.32	
	Pair 10	1-Lambda (Simpson)	0.57	27	0.18	0.0872
		1-Lambda (Simpson)	0.45	27	0.24	

Treatment	Variable		Mean	N	Std. Deviation	Paired t-test p-value
6	Pair 1	S (Richness) (Forbs)	1.00	27	0.28	0.5735
		S (Richness) (Forbs)	1.07	27	0.62	
	Pair 2	S (Richness) (Graminoids)	2.67	27	1.07	<0.0001*
		S (Richness) (Graminoids)	1.33	27	0.73	
	Pair 3	S total	3.67	27	1.18	0.0001*
		S total	2.41	27	0.93	
	Pair 4	N (Individuals) (Forbs)	15.04	27	7.58	<0.0001*
		N (Individuals) (Forbs)	2.07	27	1.88	
	Pair 5	N (Individuals) (Graminoids)	12.00	27	10.01	0.0591
		N (Individuals) (Graminoids)	7.96	27	8.59	
	Pair 6	N total	27.04	27	14.81	<0.0001*
		N total	10.04	27	8.36	
	Pair 7	d (Species richness) (Margalef)	0.83	27	0.31	0.3348
		d (Species richness) (Margalef)	0.72	27	0.49	
	Pair 8	J' (Pielou's evenness)	0.69	27	0.19	0.3452
		J' (Pielou's evenness)	0.61	27	0.35	
	Pair 9	H'loge (Shannon)	0.90	27	0.33	0.0023*
		H'loge (Shannon)	0.56	27	0.34	
	Pair 10	1-Lambda (Simpson)	0.52	27	0.17	0.1782
		1-Lambda (Simpson)	0.42	27	0.29	

Treatment	Variable		Mean	N	Std. Deviation	Paired t-test p-value
7	Pair 1	S (Richness) (Forbs)	1.15	27	0.36	0.6262
		S (Richness) (Forbs)	1.07	27	0.62	
	Pair 2	S (Richness) (Graminoids)	2.67	27	1.24	<0.0001*
		S (Richness) (Graminoids)	1.30	27	0.82	
	Pair 3	S total	3.81	27	1.36	<0.0001*
		S total	2.37	27	0.97	
	Pair 4	N (Individuals) (Forbs)	11.63	27	10.79	0.0004*
		N (Individuals) (Forbs)	2.78	27	2.04	
	Pair 5	N (Individuals) (Graminoids)	11.37	27	9.33	0.0217*
		N (Individuals) (Graminoids)	6.30	27	5.43	
	Pair 6	N total	23.00	27	15.98	0.0003*
		N total	9.07	27	5.54	
	Pair 7	d (Species richness) (Margalef)	0.95	27	0.38	0.0329*
		d (Species richness) (Margalef)	0.71	27	0.51	
	Pair 8	J' (Pielou's evenness)	0.74	27	0.18	0.3991
		J' (Pielou's evenness)	0.67	27	0.33	
	Pair 9	H'loge (Shannon)	0.96	27	0.37	0.0007*
		H'loge (Shannon)	0.61	27	0.34	
	Pair 10	1-Lambda (Simpson)	0.56	27	0.19	0.1851
		1-Lambda (Simpson)	0.46	27	0.29	

Appendix 16: GPS co-ordinates of the three reference sites inside the mine lease area.

Reference site	Transect	Latitude	Longitude
1	A	28°59'21.57"S	28°52'42.45"E
	B	28°59'21.73"S	28°52'37.46"E
	C	28°59'24.74"S	28°52'37.48"E
2	A	28°59'20.96"S	28°52'31.72"E
	B	28°59'21.85"S	28°52'29.15"E
	C	28°59'23.55"S	28°52'28.14"E
3	A	28°59'38.99"S	28°51'30.79"E
	B	28°59'40.43"S	28°51'26.51"E
	C	28°59'41.33"S	28°51'23.78"E