Investigating the effectiveness of microcatchments at enhancing transplant performance in Nama-Karoo riparian ecosystem restoration

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Declaration

I, Andrew Jackson, 212274066, hereby declare that the thesis for MTech: Nature Conservation is my own work and that it has not previously been submitted for assessment or completion of any postgraduate qualification to another University or for another qualification.

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Abstract

Globally agricultural rangelands have been subjected to degradation through over-utilization. The loss of productivity of agricultural rangelands around the world has led to the development of methods to restore the productivity of these areas. In South Africa, extensive areas of the Nama-Karoo have been degraded or transformed due in part to unsustainable agricultural activities. The development of restoration methods which are easily implementable and financially viable could increase the probability of stakeholders implementing restoration activities on privately owned land.

The removal of the degrading factor is not sufficient to reverse the degradative trend in dryland environments. Active measures must be implemented to arrest the degradation cascade. The climatic conditions of the rangelands of South Africa are limiting to plant performance and the favourable conditions are sporadic. The translocation of plants should be combined with the amelioration of the local conditions. This study tested the restoration technique of microcatchments in association with plant translocation. The effects of microcatchments and planting combinations which were best suited to the survival and performance of the transplants were determined through a field trail.

The results showed that microcatchments created microsites which were conducive to transplant survival and growth, including nutrient accumulation and increased soil moisture. The success of the method was dependent on the planting combination used. Plants which are adapted to inundation and the saline conditions of the site performed better. Plants which were older at the time of translocation had higher survival rates than younger transplants. In the conditions of this site, planting adjacent to the microcatchments was necessary to avoid inundation induced mortalities. The environmental conditions of the Nama-Karoo necessitate the coordination of restoration activities with the predicted favourable conditions in order to improve the success of restoration activities.

Keywords: Ecological restoration, Microcatchments, Microsites, Nama-Karoo, Rangeland agriculture, Sak River,

Chapter 1: Introduction and literature review

Ecological systems are susceptible to disturbances and can recover from disturbances through natural regulatory processes (Mumby *et al*., 2014). Chronic disturbances can cause the system to lose resilience and can lead to a reduction of the associated benefits which humans, and wildlife, rely on (Chazdon, 2008). The loss of resilience also increases the systems vulnerability to disturbing factors which may further reduce its resilience (Mumby *et al*., 2014).

The degradation of land is the result of complex interactions between social, economic and ecological conditions (Eswaran *et al.*, 2001; McKinney, 2006; Zerga, 2015). The increase in human populations is often cited as the cause of ecological degradation (Cropper and Griffiths, 1994), however it is not the high population that degrades the land but what the population does to the land (Eswaran *et al*., 2001). The human component of an ecosystem has major potential to mitigate and reverse degradation trends, provided there is sufficient social and economic motivation (Eswaran *et al*., 2001). Conversely resource scarcity as a consequence of ecological degradation has in some cases lead to social and political instability and in some examples even armed conflict (Raleigh and Urdal, 2007).

Due to the threats to ecological and human well-being the trend of ecological degradation must be reversed (Aronson *et al.*, 2006; Clewell and Aronson, 2006; Guilfoyle and Fischer, 2006; Yüksek and Yüksek, 2011) especially when considered in the context of anthropogenic climate change (Seavy *et al.,* 2009). Clewell and Aronson (2006) state that without active restoration efforts conducted specifically to restore the natural capital of rangelands the well-being of the human population and the habitability of the planet will decrease significantly. However, ecological restoration can potentially improve the ecological function and the ecosystem services of an area in addition to improving the quality of life for the wildlife and human inhabitants (Suding *et al.*, 2015).

In South Africa the productivity of rangelands began decreasing by the late 1800s and no South African rangelands can presently be considered to exist in a pristine condition (Milton *et al.*, 1994). Agricultural rangelands (veld) is the single largest land use type in South Africa, currently occupying over 70% of the land surface, with 66% being moderately to seriously degraded (Snyman, 2003).This dissertation focuses on the restoration of riparian habitat of the dryland region known as the Nama-Karoo, South Africa.

1.1 Degradation of dryland ecosystems

Drylands support approximately one third of the Earth's population and constitute between 30% and 45% of the global land mass (Wilcox *et al.,* 2011). The degradation of arid and semi-arid rangelands is a global phenomenon (Beukes and Cowling, 2003a; Guilfoyle and Fischer, 2006; Yüksek and Yüksek, 2011) and is said to be one of the most pertinent ecological threats in the world today (Scheffer *et al.,* 2001). Globally it is estimated that 70% of arid and semi-arid areas (drylands) are degraded (Helldén and Tottrup, 2008; Wilcox *et al.,* 2011). This is a major cause for concern since dryland ecosystems are known to be particularly vulnerable to crossing resilience thresholds (Wilcox *et al.,* 2011). In general the deterioration that occurs in drylands over a short time span may take far longer to recover without management interventions (Shearing, 1994). Harris *et al.,* (2006) found that pre-degradation conditions could not be recovered without active restoration once a degraded state is reached. Eldridge *et al.,* (2012) state that in dryland ecosystems moisture is a limiting factor to restoration and physical or technological intervention is needed for plant establishment to occur.

Loss of perennial plant cover is characteristic as a first stage of dryland degradation (Whisenant *et al.*, 1995; Zerga, 2015). This increases the amount and connectivity of bare ground which leads to soil crusting and compaction, decreased percolation and infiltration which results in increased runoff, sheet erosion and loss of nutrient rich top soil (Hanke *et al.,* 2011). The exposure of the soil to direct sunlight causes higher soil temperatures (Hanke *et al.,* 2011), increased evaporative water loss from the soil and mortality of the biotic soil component (Belnap and Eldridge, 2001). Thus due to the nature of dryland ecosystems it is necessary for rangeland managers to intervene in order to maintain a productive state.

Rangeland degradation in arid environments caused by unsustainable livestock production has negative effects on biodiversity and the livelihoods of millions of people (Adeel *et al.,* 2005). Overgrazing by livestock has been identified as the most significant agent of change in dryland ecosystems and has occurred to some extent on every continent where these ecosystems occur (Wilcox *et al.,* 2011). In some

Mediterranean regions the process of degradation as a result of overgrazing began centuries ago (Wilcox *et al.,* 2011).

By the early 1900s large areas of the Nama-Karoo had already been degraded through the use of unsustainable agricultural practices (Esler *et al.,* 2006; Hughes *et al.,* 2008) which have mainly occurred on floodplains and in the riparian areas (Hughes *et al.,* 2008). As a result an estimated 60% of riparian habitats in the greater Karoo region have been degraded and transformed (Hughes *et al.,* 2008). The Nama-Karoo region experiences extreme environmental conditions, particularly low amounts of rainfall which is stochastic in nature (Visser *et al.,* 2004; Mucina and Rutherford, 2006). As a result the floral recovery from disturbance occurs over long timescales and is dependent on episodic events (Call and Roundy, 1991). Visser *et al.,* (2007) state that bare patches are found throughout the Nama-Karoo. These can be natural temporary pans which occur in depressions in the landscape (Milton *et al.,* 1992) or they can develop through a combination of physical and chemical processes which are aggravated by poor grazing practices (Visser *et al.,* 2004). This can cause the capping of the soil surface and erosion which leads to a decrease in favourable germination conditions. In the Nama-Karoo physical and chemical crusts can form in extreme cases and are resistant to the establishment of germinating seedlings (Visser *et al.,* 2004). This in turn decreases the likelihood of the establishment of vegetation and veld recovery (Visser *et al.,* 2004; Esler *et al.,* 2006). As a result, degradation and transformation in the Nama-Karoo leads to a loss of natural ecosystems and the valuable services and resources which they provide. Such as improved water quality (Suding *et al*., 2015), the provision of fodder, for livestock and wildlife, and habitat provision for indigenous species (Hughes *et al.,* 2008).

The Nama-Karoo veld has a low capacity to support livestock and the land has a relatively low economic value (Beukes *et al.,* 2002). Overstocking begins a cascading process of degradation which becomes increasingly difficult to reverse as it progresses over time and affects larger areas of the veld (Milton *et al.,* 1994; Scheffer *et al.,* 2001; Simons and Allsopp, 2007). The subsequent reduction of ecosystem services and carrying capacity diminishes the agricultural value of the veld prompting landowners to further over-utilise or abandon the degraded areas (Milton *et al.,* 1994). Overstocking typically leads to the loss of vegetation cover, the trampling of soil, the formation of erosion systems and a loss of topsoil. This typically results in the formation of bare, capped relatively infertile soils which do not recover spontaneously (Beukes and Cowling, 2003b).

1.2 Restoration of dryland ecosystems

Ecological restoration can be defined as the process of mitigating and reversing the degradation to natural ecological systems induced by the long-term exposure to unsustainable anthropogenic activities. In the past contemporary ecological restoration practices have aimed to restore areas to pre-disturbance conditions (Choi *et al.,* 2008). However, restoration practitioners must consider the availability and accuracy of records of past ecological conditions (Choi *et al.,* 2008). Furthermore, in light of the projected rate of climate change (Seavy *et al.,* 2009) and the fact that past ecological and environmental conditions are not accurate indicators of future conditions (Harris *et al.,* 2006), more adaptable restoration aims are required. It is therefore essential that restoration activities aim to return the ecosystem to a state that promotes continuous and effective ecosystem functioning with minimal post application management input (Choi *et al.,* 2008). Recent studies in drylands have made progress in this field by focusing on feedbacks, thresholds, resilience and cross scale interactions concerning vegetation patterns, hydrology and aeolian forces on a vegetation and landscape scale (Wilcox *et al.,* 2011).

Direct abiotic amelioration is a common restoration technique in dryland ecosystems. This includes treatments which will break the crust and roughen the soil surface, create depressions for water collection and increase the organic matter content of the soil (Banerjee *et al.,* 2006). The use of facilitation by nurse plants has been proposed in dryland environments. Since abiotic conditions are amended under established vegetation canopies remnant vegetation could be used as microsites with minimal physical intervention (Pueyo *et al.,* 2009).

In dryland environments plant performance and ecosystem recovery is regulated by episodic events rather than average environmental conditions. It is therefore sensible to implement restoration activities in association with predicted environmental conditions conducive to vegetation growth (Call and Roundy, 1991). The slow stochastic nature of dryland ecosystem recovery means regeneration could take decades (Dreber *et al.,* 2011). In drylands the lack of moisture which limits ecosystem productivity is also a limitation to restoration activities (Edwards *et al.,* 2000). Since irrigation is often unfeasible and can drastically increase implementation costs (Edwards *et al.,* 2000) a focus on *in situ* rainwater conservation is a natural avenue for increasing moisture availability (Mzezewa and Van Rensburg, 2011).

In a study conducted in the Nama-Karoo, Visser *et al.,* (2004) found that restoration methods based on ecological principles and processes are essential to return the system to a functional state. This is typical of arid and semi-arid environments (Call and Roundy, 1991). Visser *et al.,* (2004) determined that passive methods of restoration (e.g: the removal of grazing pressure) do not show success in short to medium timeframes and are thus not financially viable for rangeland managers.

In most cases active restoration is required to restore ecosystem function within time frames that are meaningful to rangeland management (Snyman, 2003; Meyer *et al.*, 2009). Some of the restoration interventions suggested in the literature for South Africa’s arid and semi-arid areas include; the physical disturbance of the soil crust and compaction layers to increase infiltration (Allen, 1995; Beukes and Cowling, 2003b; Snyman, 2003; Visser *et al.,* 2004), the introduction of pioneer and late-succession propagules (Allen, 1995; Visser *et al.,* 2004), the improvement of the soil nutrient and water status potential (Allen, 1995; Visser *et al.,* 2004), the addition of an organic matter layer and the provision of microsites suitable for the establishment and growth of seedlings (O’Connor, 1997).

In the Nama-Karoo, severely degraded systems require a combination of active and passive restoration actions to return the ecosystem to a functional state which does not require any maintenance over the long term (Visser *et al.,* 2004). Visser *et al.,* (2004) state that in the Nama-Karoo, severe degradation leads to the compaction of the soil surface layers and formation of chemical and physical crusts. These form an impenetrable barrier to plant establishment which must be overcome through the application of active restoration techniques. Some of the active restoration techniques suggested in the literature are discussed below.

1.2.1 Microcatchments

The compaction and crusting of the soil surface limit both infiltration of moisture and the establishment of seedlings (Coetzee, 2005; Esler *et al.,* 2006; Kinyua *et al.,* 2010). In order to overcome compaction and crusting a physical disturbance of the degraded soil layers is necessary (Allen, 1995; Beukes and Cowling, 2003b; Snyman, 2003;

Visser *et al.,* 2004). Coetzee (2005) advocates the use of hand dug hollows, termed microcatchments. The use of *in situ* rainwater harvesting catchments (microcatchments) for restoration is a modern adaption of an ancient agricultural technique (Edwards *et al.,* 2000). Microcatchments are inexpensive, can be constructed quickly and use local material and labour (Edwards *et al.,* 2000).

1.2.2 Plant translocation

Edwards *et al.,* (2000) state that the re-establishment of vegetation cover in degraded areas is of primary importance since bare soil is prone to compaction and erosion, while vegetation binds soil particles and prevents the formation of erosion systems. The addition of translocated plants immediately improves the system by adding a biotic component. Apart from increased soil moisture through precipitation combing, transplants increase soil infiltrability through the accumulation of fine soil particles and organic matter at the basal point of the stem (Hanke *et al.,* 2011). Pueyo *et al.,* (2009) found that the early post-germination stages are extremely challenging in dryland ecosystems. They advocate the introduction of seedlings, thereby surpassing the crucial limiting stage and increasing the chances of restoration success (Pueyo *et al.,* 2009).

1.2.3 Mulching

Mulching involves the application of organic matter in the form of woodchips, manure, leaf litter or another external source. Mulching adds an organic component to the soil and protects the soil surface from environmental factors such as solar radiation and raindrop impact (Hanke *et al.,* 2011). Mulch roughens the soil surface and provides points of accumulation for seeds, loose soil and organic matter (Schmiedel *et al.,* 2010). Although mulch may absorb water during low intensity rainfall events depriving the lower soil layers of moisture (Schmiedel *et al.,* 2010) it will however protect accumulated soil moisture from evaporation after high intensity rainfall events. When introducing material from an external source, care must be taken to ensure that there is no contamination of undesirable seeds from the mulch.

1.2.4 Brushpacking

The surface application of cut branches from an external source shades the soil from the sun and breaks the impact of raindrops (Simons and Allsopp, 2007). The presence of the branches causes the accumulation of debris such as seeds, loose soil particles and organic matter, thereby creating microsites for plant establishment (Simons and

Allsopp, 2007; Hanke *et al.,* 2011). The protruding branches provide a degree of protection from herbivory especially if there are thorns present. The protrusions of the branches can intercept moisture from wind driven droplets even if there is no precipitation (Desmet and Cowling, 1999). This moisture can drop to the soil surface or be directed there via stemflow (Hanke *et al.,* 2011).

1.2.5 Mechanical cultivation

Agricultural machinery can be used to ‘rip’ the soil to a predetermined depth. This leaves a furrow or pit which accumulates water, organic matter and topsoil similar to the microcatchment technique (Snyman, 2003). ‘Ripping’ breaks the surface crust and loosens the compacted soil layers allowing for better infiltration (Van der Merwe and Kellner, 1999). Since it is mechanized, this method can be applied over a large area in a relatively short space of time. However, the use of a heavy vehicle can lead to further compaction of the soil both at the surface and deeper in the horizon. The use of vehicles can cause damage to remnant flora and fauna present on the site as well as adding pollutants, such as oil, to the environment. (Snyman, 2003).

1.2.6 Seeding

Seeding involves the application of seeds to degraded areas. It is essential that the application of seed is used in conjunction with another restoration technique as the likelihood of germination depends on the microsite where the seed is deposited (O’Connor, 1997). To increase seeding success, it is particularly important to break the surface crust and increases moisture availability (Snyman, 2003). Banerjee *et al.,* (2006) found that direct application of indigenous seeds was unreliable in re-establishing vegetation in arid climates even with supplementary irrigation.

1.2.7 Microtopography

The use of microtopographic features increases habitat heterogeneity, providing microsites for a diversity of species to establish (Biederman and Whisenant, 2011). The construction of mounds creates a leeward slope which is protected from the desiccating effects of wind (Biederman and Whisenant, 2011). The protruding feature captures moisture much like brushpacking (Biederman and Whisenant, 2011; Hanke *et al.,* 2011). Mounds also provide a point of accumulation for water and wind borne debris similar to microcatchments (Biederman and Whisenant, 2011).

1.3 Objectives of this study

Based on the literature reviewed in this chapter it is assumed that active restoration interventions including translocation of nursery grown plants and *in situ* rainwater harvesting could accelerate the rate of vegetation recovery in the saline environments of the riparian areas and climatic extremes of the arid Nama-Karoo. The study design is set out to test the following hypotheses namely that;

- The species of transplant used in combination with microcatchments influences its survival and growth
- The age of the transplant used in combination with microcatchments influences its survival and growth
- The position, in relation to the microcatchment, in which the transplant is planted influences its survival and growth
- Microcatchments influence the nutrient and moisture content of the soil
- Extreme climatic conditions limit the survival and growth of translocated plants.

Although the study reported in this dissertation focuses on the short term effects of the various treatments the data collection regime was designed to enable long term monitoring. The study provides insight into the plant responses to the effects of the microcatchments. It contributes to the body of knowledge that already exists to inform rangeland managers, conservation authorities and restoration practitioners of practical methods for dryland ecosystem restoration.

The following chapters provide a description of the study site, a description of the field trails, data collection and statistical methods used to test the hypotheses relating to the effect of the climatic conditions on the plant performance, the effect of the treatments on the soil of the study site and the performance of the translocated plants.

Chapter 2: Study site

Extensive areas of the Nama-Karoo have been degraded and transformed over the past two centuries as a result of anthropogenic activities including unsustainable agricultural practices (Esler *et al.,* 2006; Hughes *et al.,* 2008). This has resulted in decreased productivity in the degraded areas (Milton *et al.*, 1994). These agricultural activities, including ploughing for the subsistence production of crops and high stocking densities, have historically been concentrated on the fertile deposits of alluvial floodplains in the riparian areas (Hughes *et al.,* 2008). These activities have continued into present times. Alteration to the stream flow and fuel wood harvesting have compounded these factors by altering the natural hydrological regimes and removing vegetation (Hughes *et al.,* 2008). Consequently, in the greater Karoo region, it has been estimated that 60% of riparian habitats have been degraded and transformed due to such activities (Hughes *et al.,* 2008). In addition to the decrease in the agricultural value of the veld, the remaining indigenous flora and fauna are subjected to pressures which threaten their persistence in the landscape.

2.1 Locality

This study formed part of the work of the Endangered Wildlife Trust's Drylands Conservation Programme (EWT-DCP) based in the town of Loxton in the Northern Cape Province, South Africa. The EWT-DCP has various restoration sites on farms in conservancies in the area surrounding Loxton. The study site is situated on the farm

Figure 1: The locality of the study site

Sakrivierspoort (S 31°49'7.83", E 22° 8'27.29"), approximately 50km south of Loxton (Figure 1). This property is located in the Sak River Riverine Rabbit Conservancy approximately 2.5km east of the confluence of the Sak and Elandsfontien rivers.

2.2 Land use history

The site is located on the south bank of the Sak River which is a historical watering point for livestock and wildlife. Prior to 1983 the riparian ecotone was not fenced off from the main grazing area of the farm. This led to daily utilization of the riparian veld by the livestock, mainly sheep (*Ovis aries*) and to a lesser extent cattle (*Bos taurus*), at a stocking rate of 28 hectares per large stock unit (Scholtz, 2014). This led to the exacerbation of the natural erosion and over utilisation of the vegetation, particularly the young saplings and seedlings (Scholtz, 2014), which altered the vegetation composition and cover. In 1983 an erosion weir was constructed by the Agricultural Technical Services of the Northern Cape who stipulated that the riparian area be fenced off from the main grazing area (Scholtz, 2014). Between 1983 and 2013 the area was utilised as a watering point and for supplementary grazing during dry periods. In 2013, at the start of the study, the site was fenced off and livestock excluded. This is discussed further in section 2.6.

2.3 Climate

The study site is subject to the influence of the subtropical high pressure belt which has characteristically dry air (Cowling *et al.,* 1986). A moderating maritimal influence is absent due to the distance from the coast (Cowling *et al.*, 1986; Mucina *et al.*, 2006). The site occurs at an altitude of 1339 meters above sea level, which contributes to the temperature extremes of the region as well as the rainfall regime (Cowling *et al.,* 1986; Mucina *et al.,* 2006). The region experiences approximately 30 potential frost days per annum (Cowling *et al.,* 1986). The area is subject to hot dry winds which are an almost constant feature of this landscape (Desmet and Cowling, 1999).

The combination of these factors contribute to the long and short-term thermic extremes (Cowling *et al.,* 1986) including high seasonal variation. The Nama-Karoo region has a mean monthly summer high temperature of up to 36 ^{o}C and a mean monthly low of approximately -5 ^{o}C in the winter months with some records of -8 ^{o}C in susceptible areas. There is a mean daily variation of approximately 25 ^{o}C (Mucina *et al.,* 2006). The rainfall of the region is stochastic and sporadic with a mean annual rainfall of approximately 252 mm and an annual precipitation coefficient of variation value of 39%. This is indicative of the unpredictable conditions with long periods of little or no precipitation (Mucina *et al.,* 2006).

2.4 Geology and soils

The study site falls within the boundaries of the Beaufort group of the Karoo supergroup (Keyser *et al.,* 1997). Dolerite dykes occur throughout the region resulting in a very uneven topography, due to their resistance to weathering in the dry climate (Cowling *et al.,* 1986). Mesas, hillocks and sharp ridges are common. The soils of the region are derived predominantly from Mudstones of the Beaufort Group with many of the alluvial deposits being silty, clayey and highly sodic (Mucina *et al.,* 2006). The alluvial nature of the soils contribute to the variability of the soil structure and composition within the site (Naiman and and Décamps, 1997).The soils of the site are highly susceptible to erosion (Couper, 2003). Signs of inundation and white salt crusts were clearly evident at the study site, especially on the bare patches of soil denuded of vegetation (Figure 2). These factors could provide limitations to plant function and ecosystem recovery (Staunton and Nye, 1983; Schile *et al.*, 2011; Morse *et al.*, 2011). Watkeys (1999) demonstrated that the alluvial terraces of the Sak River are weakly structured and stratified as well as being calcareous.

Figure 2: Salinization of the soil surface located on a nearby site. Photo A. Jackson

2.5 Fauna

The region supports important habitat for the Critically Endangered Riverine Rabbit (*Bunolagus monticularis*) (Hughes *et al.,* 2008). The conservation of this species and the restoration of its riparian habitat forms the focus of the work of the EWT-DCP in the Nama-Karoo. The study site is located in a priority area in terms of Riverine Rabbit distribution, this was a consideration when choosing the study site (Schumann, 2013). The study site has been fenced off to exclude the livestock and game species that are present on the property. This fencing is approximately 1.3 meters high with steel strands which excludes the livestock, cattle and sheep, and the large herbivores such as Black Wildebeest (*Connochaetes gnou*) and springbok (*Antidorcas marsupialis*) present on the property. Since this fencing does not adequately exclude smaller mammals such as Riverine Rabbit, Steenbok (*Raphicerus campestris*), Aardvark (*Orycteropus afer*) Porcupine (*Hystrix africaeaustralis*) and insects or birds, the vegetation is not completely protected from herbivory. Spoor and droppings at the study site indicate the presence of various animals including lagomorphs (hares and rabbits), Aardvark and Steenbok. These animals may have been present on the site when it was fenced or are simply not restricted by this type of fencing.

Prior to the major habitat modifications that occurred during the past two centuries (Milton *et al.,* 1994) such as land degradation, overhunting and the erection of fences, the herbivores of the region tended to be migratory due to the aridity and general unpredictability of favourable conditions (Skead *et al.,* 2011). Species present in the area would have included African buffalo (*Syncerus caffer*), the now extinct Quagga (*Equus quagga*), Red Hartebeest (*Alcelaphus buselaphus caama*), Springbok, Eland (*Taurotragus oryx*) and Black Wildebeest (*Connochaetes gnou*). This would have been complemented by populations of the large African predators such as Lion (*Panthera leo*), Spotted Hyena (*Crocuta crocuta*) and Leopard (*Panthera pardus*) (Skead *et al.,* 2011). Local rock art painted by Late Stone Age people indicate that mega-herbivores such as African elephant (*Loxodonta africana*) were transient inhabitants on the Karoo plains within the last 10,000 years (Shearing, 1994; Deacon, 1997).

The capacity of the Karoo to sustain transient large mammal populations is evident in records of the springbok migration phenomenon where huge herds of springbok ‘trekbokken’ would gather on specific areas seeking forage from vegetation that had responded to localised rainfall events. In modern times overhunting, deterioration of veld and fencing has caused the populations of all game species to diminish severely (Skead *et al.,* 2011).

2.6 Flora

The biota of the region is well adapted to moisture limitations (Shearing, 1994). The mean annual potential evaporation is 2692 mm (Mucina *et al.,* 2006) and the hot dry winds, which are a prevalent feature in the region, have negative effects on plant growth due to desiccation (Grace, 1977). These conditions are extremely limiting for the growth of vegetation and subsequent ecosystem recovery following disturbance (Esler *et al.,* 2006).

The dominant vegetation unit of the study site has been classified by Mucina and Rutherford (2006) as Eastern Upper Karoo (NKu 4). This vegetation is characterised by the presence of dwarf microphyllous shrubs, particularly those of the genera *Pentzia* and *Salsola*, with a lesser component of grasses of the genera *Aristida* and *Eragrostis* which are especially evident after the sporadic rainfall events (Mucina and Rutherford, 2006).

The specific location of the study site is on the alluvium of the Sak River which hosts the vegetation classified as azonal (AZi 5), Bushmanland Vloere (Mucina *et al.,* 2006). The flora of the Karoo is well adapted to the drought prone conditions of the region (Shearing, 1994). Bushmanland Vloere is an azonal vegetation type typically located in pans and along the intermittent riverbeds within the Eastern Upper Karoo vegetation unit mentioned above and in other vegetation units within the Bushmanland basin (Mucina *et al.,* 2006). Bushmanland Vloere is characterized by patchy vegetation assemblages dominated by assorted species of the genera *Salsola* and *Lycium*, interspersed with various microphyllous shrubs, some of which are halophytic. Bushmanland Vloere remains one of the least studied vegetation types in South Africa (Mucina *et al.,* 2006).

Chapter 3: Methods

The loss of valuable agricultural land has resulted in the development of various restoration techniques aimed at arresting and reversing the degradation cascade (Guilfoyle and Fischer, 2006; Simons and Allsopp, 2007). Due to the extent of the degradation and the low economic value of the land it is essential to develop a method that is easily implemented, uses local materials and minimises the cost of implementation. The development of such easily applicable and cost effective methods should increase the probability of private landowners implementing restoration activities on their land.

The compaction and crusting of the soil surface limits both water infiltration and the establishment of seedlings (Maestre *et al.,* 2003). In order to overcome this a method which involves the physical disturbance of the degraded soil layers is necessary (Allen, 1995; Beukes and Cowling, 2003b; Snyman, 2003; Visser *et al.,* 2004). The use of hand dug hollows termed microcatchments has been advocated in many dryland regions including China (Li *et al.,* 2005), North America (Edwards *et al,* 2000; Banerjee *et al.,* 2006), Iran (Fooladmand and Sepaskhah, 2004), sub-Saharan Africa (Critchley *et al.*, 1994; Biazin *et al.*, 2012) and South Africa (Simons and Allsopp, 2007; Hanke *et al.,* 2011)

This study aims to assess the effectiveness of the water harvesting and soil disturbance techniques of microcatchments in riparian areas of the Nama-Karoo. Plant translocation was applied in combination with the microcatchments to restore riparian veld in the high altitude Nama-Karoo. The research questions to be addressed are; Do survival and growth rates of transplants differ among species? Does the age of the transplants affect their survival and growth rate? Does the position of the transplant, in relation to the microcatchment affect their survival and growth rate? Do microcatchments affect the nutrient and moisture content of the soil? Do extreme climatic conditions limit the survival and growth of the transplants?

3.1 Microcatchments

The 400 microcatchments used for this project were constructed according to the method described by Coetzee (2005). Crescent shaped hollows were excavated with the open edge of the crescent facing the direction of water flow. The dimensions of the hollows were stipulated as 600 millimetres (mm) by 500 mm with a depth of 450 mm however, minor variation in size and shape did occur due to the difficulty of constructing the necessary number of hollows and the environmental conditions during construction. The soil removed was packed and compacted on the bowed edge of the hollow to create a berm on the downslope edge of the microcatchment (Figure 3). During the construction of the berm the need for an overflow was considered. Since the microcatchments were left in the veld indefinitely their orientation both individually and in relation to each other is highly important to avoid negative consequences. The neighbouring microcatchments were positioned to obstruct the overflow from the microcatchments immediately upslope from them. This was vital in order to avoid the creation of erosion systems in the future, which would potentially undermine any restoration efforts implemented. All microcatchments used as treatments were located at least 1 meter from established vegetation in order to reduce the bias caused by competition from the established vegetation (Carrick and Krüger, 2007).

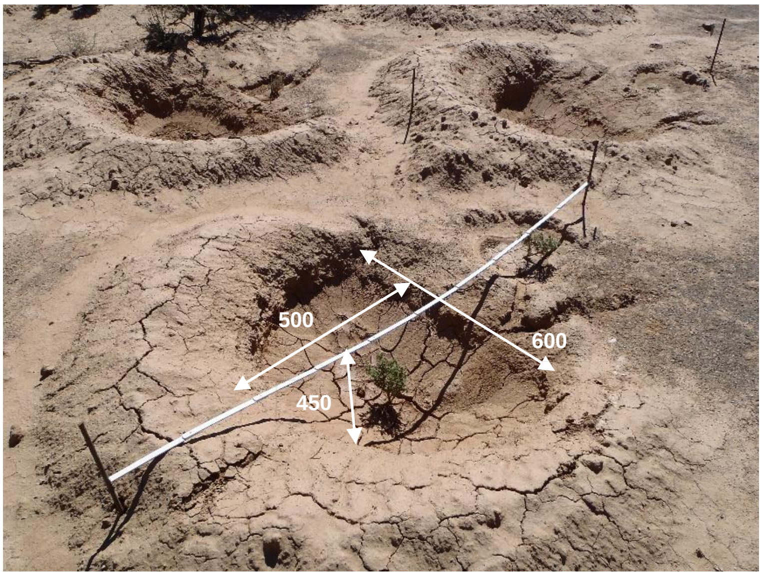

Figure 3: A microcatchment with the two meter folding ruler in place. The flow of water is from the top right to the bottom left. Photo A. Jackson

3.2 Plant materials

The selection of species to be used in restoration activities is highly important, especially if the chosen species have functional traits which allow them to withstand the limiting conditions of the receiving environments (Brown and Amacher, 1997). The plants utilised in the study were sourced from the Endangered Wildlife Trust’s Karoo Indigenous Plant Nursery situated in Loxton, Northern Cape (S 31°28'47.35", E 22°21'38.70"). The selection of species was based on the availability of nursery stock and due to their importance as components in the riparian ecosystems of the region. Both of the species selected are known to be a source of food and shelter for the Riverine Rabbit (Schumann, 2013). This critically endangered lagomorph requires dense, scrubby vegetation in order to raise their young and shelter during daylight hours (Hughes *et al.,* 2008). The plant species chosen for this study were *Tripteris spinescens* Harv. (Rivierdraaibos) (Figure 4) and *Salsola aphylla* L. f. (Riviergannabos) (Figure 5). Species with different functional characteristics were chosen in order to observe how different plant functional types responded to the treatments. Two age classes were used to test for differences in survival and growth to determine the efficiency and costs related to plants utilising resources in the nursery.

Tripteris spinescens is a microphyllous shrub known for its exceptionally strong root system and its ability to withstand drought (Shearing, 1994). These attributes make it ideal for restoration activities due to its general hardiness and its ability to bind the soil and prevent further erosion.

Figure 4: *Tripteris spinescens* showing a flower in early stages of blooming. Photo A. Jackson

S. aphylla is a salt tolerant (halophytic), microphyllous shrub. It is known to be resistant to drought and reasonably palatable with a high protein value (Hobson and Jessop, 1970). It is typically located along river banks and on flood plains (Hobson and Jessop, 1970; Shearing, 1994; Vlok *et al.,* 2010) which indicates a tolerance to inundation.

Figure 5: *Salsola aphylla* with the floral parts protruding from the small flower. Photo A. Jackson

The plants were grown in black nursery bags to facilitate transport and ease of planting. All plants were hardened off outdoors, for a minimum of one month for the younger plants and between one month and a year for the older plants. The plants were regularly irrigated during this period. Four hundred plants of each species were used in order to ensure that enough plants would survive the translocation process and endure to the end of the study period and still allow for statistically meaningful comparisons. All of the plants that were planted were pruned prior to transportation in order to reduce transplant stress (South and Zwolinski, 1997).

3.3 Treatments

The study site comprised an alluvial riverbank with degraded bare patches within a mosaic of remnant vegetation. Five degraded patches, or areas, were selected for the experiment at the study site. The shape and size of each area was determined by the natural microtopography created by the mosaic nature of the patches of remnant vegetation.

In each of these five areas a 5x5 metre (25 m^2) control plot with no microcatchments was set out to determine natural plant recruitment rates (volunteer recruitment) which could be used to compare with the treated areas (Reich *et al.,* 2011). The control plots were representative of the condition of the degraded areas prior to the application of the treatments. Each control plot was assessed using 5 m transects located at 1 meter intervals along the Southern edge of the control plot using the line intercept method (Elzinga *et al.,* 2009). These transects were orientated perpendicular to the edge of the plots. There were 5 transects for each control plot, this gave a total of 125 m of control transects throughout the site.

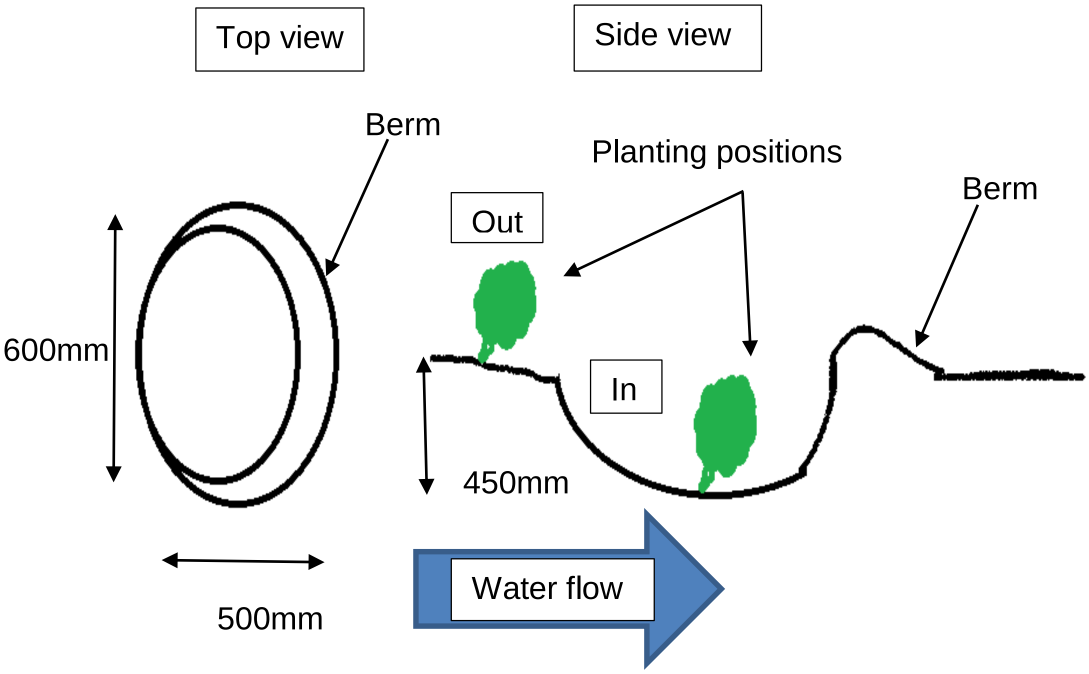

Figure 6: Diagram of the Microcatchments indicating major features

Nursery grown plants of each age class, > 6 months and < 6 months, and of each species were planted in association with the microcatchments. Each microcatchment received two plants of the same age class and species. These plants were planted in two positions, namely within the base of the microcatchments and upslope of the open end of the microcatchment in order to assess the effects of inundation on the transplants (Figure 6).

3.4 Data collection

The data collection took place on Sakrivierspoort farm within the Sak River Riverine Rabbit Conservancy. The data collection consisted of six sampling dates from July 2013 to July 2014. The planting took place during April 2013 and was followed by rainfall events which were beneficial to the establishment of the transplants (Schumann, 2013).

3.4.1 Survival

The transplants were individually monitored to determine the survival of each of the plants for each successive sampling date. This was assessed during the collection of the percentage cover data detailed in section 3.4.2. Each plant was visually assessed and assigned a binomial rank of either '*0'* for plants which were dead or '*1'* for plants which were alive. This provided the variable termed *Survival*. If the transplant displayed green leaves and actively growing shoots the assessment was simple. If there were no visible signs of active growth then the transplants were visually and physically assessed to determine their status. If the plant snapped readily when bent it was considered dead, if it bent without snapping or showed living tissue after snapping it was considered to still be alive.

3.4.2 Percentage cover

The line intercept method was used to assess changes in vegetation cover over time within the individual treated microcatchments (Elzinga *et al.,* 2009). Between July 2013 and July 2014 the method was applied six times during the study period with at least one month between sampling dates to allow for adequate plant growth between measurements. Each microcatchment was individually assessed to detect the changes in above ground plant cover of each of the transplants planted in association with each microcatchment. Transects were aligned to steel droppers positioned at the start and end points of each transect in order to keep the position and direction of the transect consistent and easily discernible on successive sampling dates, thereby ensuring reproducibility during this study and in pending future studies (Tongway and Hindley, 2005).

Each transect was 2 m in length. These transects were used to detect any change in percentage cover of the transplants as well as to detect any increase in cover of naturally recruited seedlings (volunteer recruitment). Increased natural recruitment was expected due to the accumulation of seeds, litter, moisture and nutrients caused by the creation of microsites in the microcatchments (O'Connor, 1997; Coetzee, 2005; Esler *et al.*, 2006). The species identity of volunteer recruitment, and total canopy cover intercepted by each transect was recorded. The percentage cover value was determined by Equation 1. If 'x' is the percentage cover, 'sv' is the start point value and 'ev' is the endpoint value. The point at which the vegetation first intercepted the transect was recorded as the starting point and the last point of the intercept was taken as the end point. The starting point value was subtracted from the end point value to give a total intercept value. The total intercept value for each plug, in millimetres, was divided by the total length of the transect and multiplied by 100 to produce a percentage cover value for each transplant (Elzinga *et al.,* 2009). This method was chosen because change in percentage cover can be used as a proxy for plant performance. Additionally since the exposure of the soil to raindrop impact and direct sunlight further degrades the soil and its biotic component (Hanke *et al.*, 2011) the increase in percentage cover is a reversal of the first stage of dryland degradation identified by Whisenant *et al*. (1995) and assists in initiating the autogenic recovery processes.

Equation 1: $$x = \left(\frac{ev - sv}{2000}\right) * 100$$

A 2000 mm wooden folding ruler was use to demarcate the transect by placing the ends of the ruler between the two steel pegs demarcating the start and end points of the transect. The measurements were consistently taken on the left side of the transect with a straight rod held perpendicular to the transect. This was done to reduce potential bias created by the varying position of the observer (Elzinga *et al.,* 2009). The percentage cover values collected over the six successive sampling dates were assessed to determine the change in percentage cover over time.

3.4.3 Soil

Due to the concentration of nutrients in the soil surface layers (Jobbágy and Jackson, 2001), the data collected focuses on the surface layers of the soil and the amelioration of the soil surface conditions to create microsites conducive to germination and establishment of seedlings. Only the upper soil layers were monitored and therefore this section of the study should not be considered to address all the necessary aspects of a comprehensive investigation of the soils of the study site. The soil was sampled only once during the study. The soil samples were collected during the November sampling period to allow for 7 months of accumulation of silt and debris within the microcatchments. Samples of the top layer (50 mm) of soil were collected from 25 microcatchments throughout the site. These were paired with samples taken from the soil surface immediately adjacent to the sampled microcatchments. The soil surface was cleared of organic debris before the sample was taken. The microcatchments sampled were not associated with transplants as were those referred to in section 3.3. The soil samples were prepared using a 2 mm sieve and sent for laboratory analysis. The soil nutrients tested were; nitrogen (N), carbon (C), calcium (Ca), potassium (K), magnesium (Mg), sodium (Na) and phosphorus (P). In addition to the nutrients the pH of the soil was tested. The bulk density of the samples was also determined. The analysis of the nitrogen content of the soil was performed using a LECO-nitrogen analyser at a commercial laboratory, Bemlab, De Beers Road, Somerset West, South Africa (Bemlab) and the analysis of the other nutrients and pH was performed at the Elsenburg Laboratory, Institute for Plant Production Stellenbosch, South Africa (Elsenburg). The values received from the laboratories were converted to a standard unit; milligrams per kilogram (mg/kg), in order to standardize the units of measurement and allow for statistical comparison. The samples from within the base of the microcatchments were compared to those directly adjacent to the microcatchments to determine the effect of the microcatchments on topsoil and nutrient accumulation on the study site.

The volumetric soil water content (VWC) was measured during each sampling period using a Campbell scientific, Hydrosense soil water measurement probe with 200 mm rods. The probe uses a measure of conductivity of the soil to determine the amount of moisture present in the soil. Readings were taken from within the treated areas amongst, but not within, the microcatchments and were paired with readings from the control plots. The data derived from this analysis was assessed to determine the effects of the microcatchments on localized soil water content.

3.4.4 Climate

Over the study period the rainfall, which was recorded on site as 311,8 mm (Davis Instruments, Automated Rain Gauge) was above the annual average of approximately 252 mm (Mucina *et al.,* 2006). The temperature was recorded, hourly, using a Campbell Scientific Weather Station. The weather station was situated on Dunedin Farm (31°56'32.81"S 22°24'48.01"E) approximately 26.5 km South-East of the study site. The data pertaining to the *Survival* and *Percentage Cover* was used to determine the change in percentage cover and survival of the transplants over the study period relative to the initial measurements of the survival and percentage cover variables. This was correlated to the climatic variables to determine the relationship between the environmental conditions and the performance of the transplants.

3.5 Statistical analysis

All data was analysed using Statistica 12 (StatSoft Inc, 2013). The terms given in italics refer to the variables used in the analyses. In this dissertation the differences were considered statistically significant if the probability of the difference being due to random effects was less than 5% ($p < 0.05$).

3.5.1 Survival and change in percentage cover

The survival data was analysed using a Simple Logistic Regression (Zar, 2010). The survival data was analysed for each species separately. These results were then compared to determine which combination of planting parameters were best suited for the survival of the transplants. The variable *Survival* was set as the dependent variable while the variables *Age* and *Position* were set as the factors for comparison (Ashcroft and Pereira, 2003). Logistic regression employs the concept of the odds of an event occurring or not occurring, namely the probability of a plant surviving expressed relative to the probability of the plant not surviving (Zar, 2010).

A non-parametric Mann-Whitney U Test was used to analyse the change in percentage cover over the duration of the study period (Ashcroft and Pereira, 2003).The percentage cover data was arcsine transformed and then tested for normality using a Shapiro-Wilk Normality Test. The distribution was found to be non-normal therefore the Mann-Whitney U test was used (Ashcroft and Pereira, 2003). The data for the two *Species* were analysed separately and the variables identified for testing were *Percentage Cover* as the dependant variable, *Age*, as the independent variable and *Position* and *Sampling Date* as the grouping variables. A General Linear Model was used to represent the results of the Mann-Whitney U Test (Figure 8 and Figure 9).

Due to the nature of the data collected the transplants which suffered mortality in the early stages of the data collection period were assigned the value ‘0’ and were repeatedly recorded as ‘0’ throughout the study period. This created bias due to the subsequent repetition of the ‘0’ readings resulting in an over-representation of the percentage cover value ‘0’. In order to minimise this bias the percentage cover data was analysed in two ways. Firstly, the percentage cover of the transplants was calculated from the entire dataset with repeated mortalities included. Secondly the percentage cover was calculated with the mortalities removed. The two separate analyses complement each other.

3.5.2 Soil

The data regarding the nutrient content, the pH and the bulk density were tested for normality using a Shapiro-Wilk Normality Test. The data which conformed to a normal distribution was analysed using a Student’s t-test (Ashcroft and Pereira, 2003). The data which showed a non-normal distribution were analysed using a Wilcox Signed Rank Test (Ashcroft and Pereira, 2003). Both tests were performed and the results compared to confirm the validity of the results of the parametric tests.

The data regarding the volumetric water content (VWC) were tested for normality using a Shapiro-Wilk Normality Test. The instrument used to measure the VWC expresses the output as a percentage. The percentage values were arcsine transformed to normalise the data. A General Linear Model was applied to determine the effects of the progression of time and the treatments on the VWC.

3.5.3 Climate and transplant performance

The data for the rainfall, mean, maximum and minimum temperatures and the overall percentage cover were tested for normality using a Shapiro-Wilk Normality Test (Ashcroft and Pereira, 2003). The rainfall for the month preceding each sampling date was utilised for the analysis. The data for the temperatures was recorded hourly. For use in the analysis the mean, maximum and minimum temperatures were calculated for the periods between the sampling dates. The resultant climatic data provided a representation of the environmental conditions preceding the sampling date. Descriptive statistics were used to determine the means of the climatic variables and overall *Percentage Cover* for the study period. Pearson’s Correlation Analysis was used to determine the relationship between the climatic variables, the *Survival* and *Growth* of the transplants (Zar, 2010). The survival and growth of the transplants relative to the initial measurements was calculated to provide the *Relative Survival* and *Relative Growth*. There were 6 sampling dates which resulted in 5 periods of change to be used for analysis, this resulted in a low number of cases for analysis (n).

The robustness of the analyses with small sample size is questionable, however the results are useful in informing the interpretation of the analyses described in section 3.5.1. The results of the methods discussed above are presented in Chapter 4.

Chapter 4: Results

This study investigated the effects that the application of microcatchments had on soil and plant properties. The hypotheses tested in this study were that; microcatchments affect the survival and growth of transplants with regard to the *Species* used, the *Age* of the transplant and the planting *Position* in relation to the microcatchment, the microcatchments influence the nutrient and moisture content of the soil and the extreme climatic conditions influence the survival and growth of the transplants. This chapter will detail the results of the field experiment described in Chapter 3.

4.1 Overview of climate and vegetation cover

During the study period, from July 2013 until July 2014, the maximum temperature was recorded as 31.14°C and the minimum was recorded as -2.22°C.The mean maximum temperature was 23 °C (SD = 6.2 °C) and the mean minimum temperature was 4.8 °C (SD = 6 °C). The mean monthly rainfall over the study period was 24

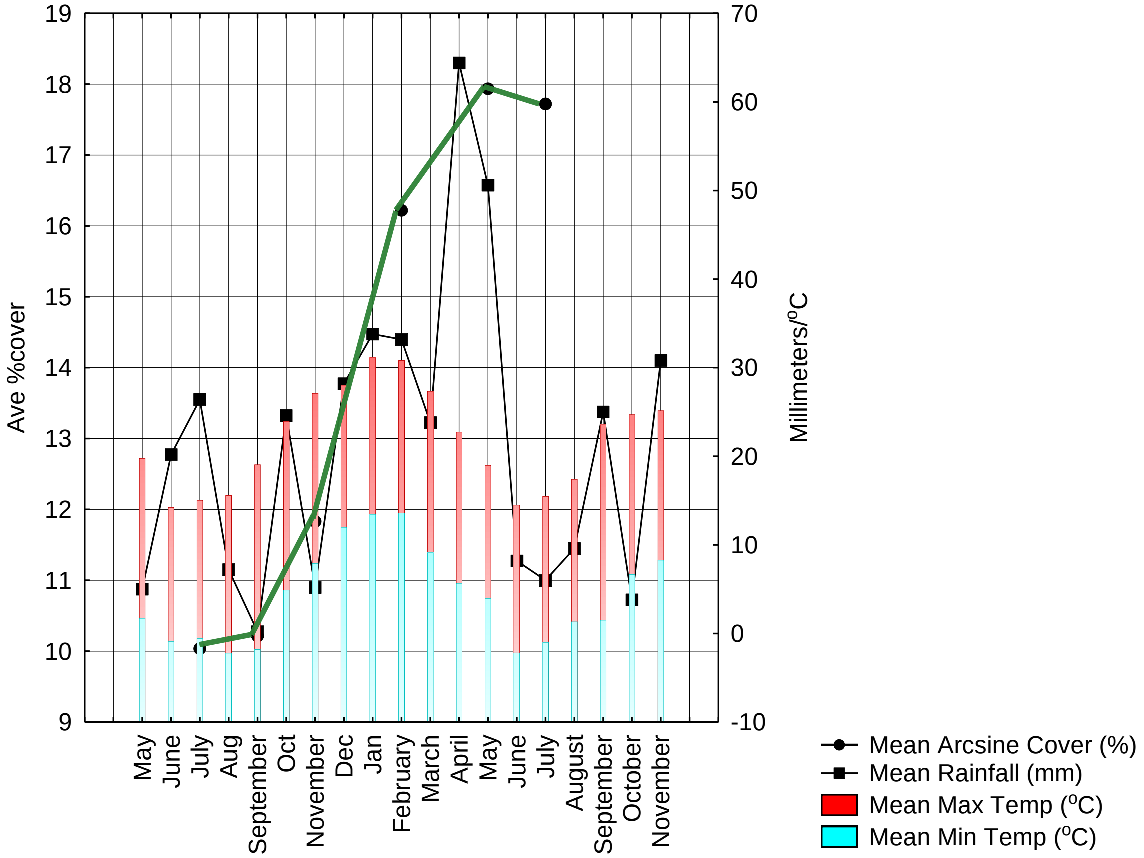

Figure 7: The mean vegetation cover expressed as an arcsine percentage plotted with the climatic conditions; Rainfall (mm/Month), Maximum and Minimum temperatures (°C)

millimetres (SD = 19 mm). The mean of the arcsine percentage cover over the study period was 14 % (SD = 3.7%) (Figure 7).

4.2 Microcatchment effects on plant performance

The effects of the *Species* used, the *Age* of the transplant and the *Position* of the transplant in relation to the microcatchments were examined. The effects of these variables were assessed, with regard to the survival of the transplants and the increase in percentage cover of those transplants which survived the initial planting.

4.2.1 Survival

The data pertaining to the survival of the transplants was analysed using Simple Logistic Regression expressed with a 95% confidence limit. For the *Tripteris spinescens* transplants there was no significant difference between the probability of survival of the two *Age classes* ($z = 0.01$; $p > 0.05$) (Table 1). The difference between the probability of survival of the two *Positions* in relation to the microcatchment was significant ($z = 36.02$; $p < 0.01$) (Table 1). The probability of survival, expressed as a percentage, for the plants in the microcatchments was 36% for the young plants and 30% for the older plants. The probability of survival for those planted out of the microcatchments was 61% for the young plants and 66% for the older plants.

For the *Salsola aphylla* transplants the difference between the probability of survival for both of the factors, *Age* ($z = 20.9$; $p < 0.01$) and *Position* ($z = 79.2$; $p < 0.01$) was significantly different (Table 1). The probability of survival, expressed as a percentage, of the plants in the microcatchments was 19% for the younger plants and 37% for the older plants. The probability of survival for those planted out of the microcatchments was 74% for the young plants and 97% for the older plants.

Table 1: The summarised results of a Simple Logistic Regression show the p-value and significance of the probability of survival of the factors tested. (**-Highly significant, *-Significant and NS-Not significant

Factor	*T. spinescens*	Significance	*S. aphylla*	Significance
Age	0.897	NS	**0.001**	**
Position	**0.001**	**	**0.001**	**

4.2.2 Percentage cover – Full dataset

Percentage cover was analysed using the Mann-Whitney U Test. For the *T. spinescens* transplants planted out of the microcatchments there was a significant difference between the percentage cover of the two *Age classes* throughout the study period ($z = 5.73$; $p < 0.05$; $n1 = 98$; $n2 = 101$)(Figure 8). For those planted in the microcatchments there was a significant difference ($z = 8.25$; $p < 0.05$; $n1= 100$; $n2 = 99$) between the percentage cover values until February 2014 when the difference was not significant ($z =-0.23$; $p > 0.05$; $n1 = 96$; $n2 =104$). The difference between the

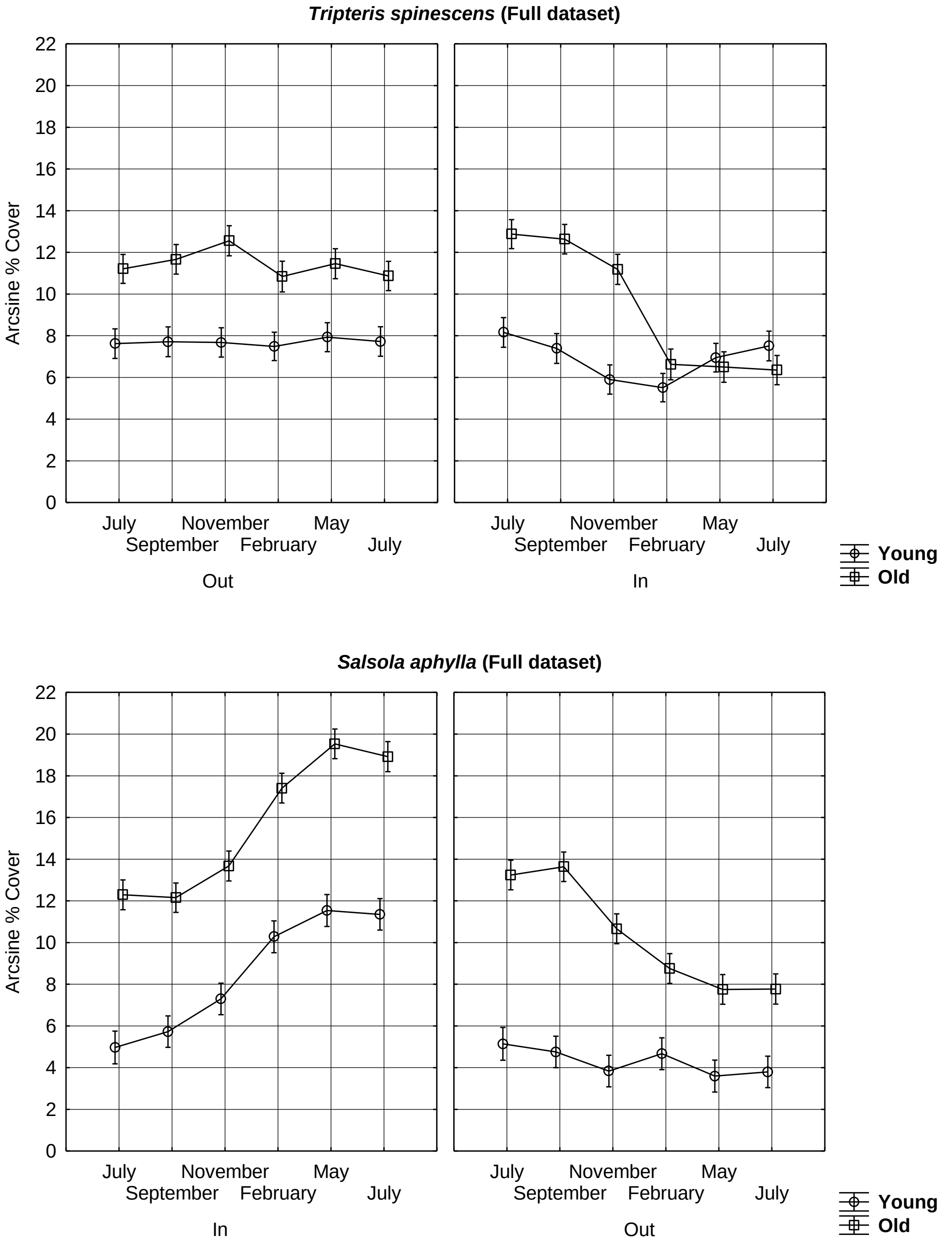

Figure 8: The arcsine percentage cover of the full dataset for *Tripteris spinescens* and *Salsola aphylla.* The vertical bars denote standard error of the mean.

percentage cover values of the two *Age classes* remains not significant for the remainder of the study period (Figure 8).

For the *S. aphylla* transplants the difference in percentage cover between the *Age classes* in both *Positions* was significant throughout the study period ($z = 7.03$; $p < 0.05$; $n1 = 98$; $n2 = 87$) (Figure 8). Although there was a reduction in the significance between the two *Age classes* from February 2014 until the end of the study, the difference remained significant (Figure 8).

4.2.3 Percentage cover – Mortalities removed

For the *T. spinescens* transplants planted outside of the microcatchments the difference between the percentage cover of the two *Age classes* was significant ($z = -6.02$; $p < 0.01$; $n1 = 79$; $n2 = 83$) throughout the study period (Figure 9). For the transplants planted within the microcatchments the difference between the percentage cover values for the two *Age classes* was significant from the beginning of the study period until February 2014 ($z = -7.58$; $p < 0.01$; $n1 = 79$; $n2 = 93$). Thereafter the difference between the percentage cover values of the two *Age classes* was not significant until the end of the study period ($z = -0.74$; $p > 0.05$; $n1 = 36$; $n2 = 30$) (Figure 9).

For *S. aphylla* the difference between the percentage cover values of the two *Age classes* of the transplants planted out of the microcatchments was significant throughout the study period ($z = -7.05$; $p < 0.01$; $n1 = 69$; $n2 = 96$) (Figure 9). For the transplants planted in the microcatchments the difference between the *Age classes* was significant at the beginning of the study period ($z = -8.42$; $p < 0.01$; $n1 = 55$; $n2 = 92$) but becomes not significant after February 2014 and remains so until the end of the study period ($z = -0.69$; $p > 0.05$; $n1 = 18$; $n2 = 37$) (Figure 9).

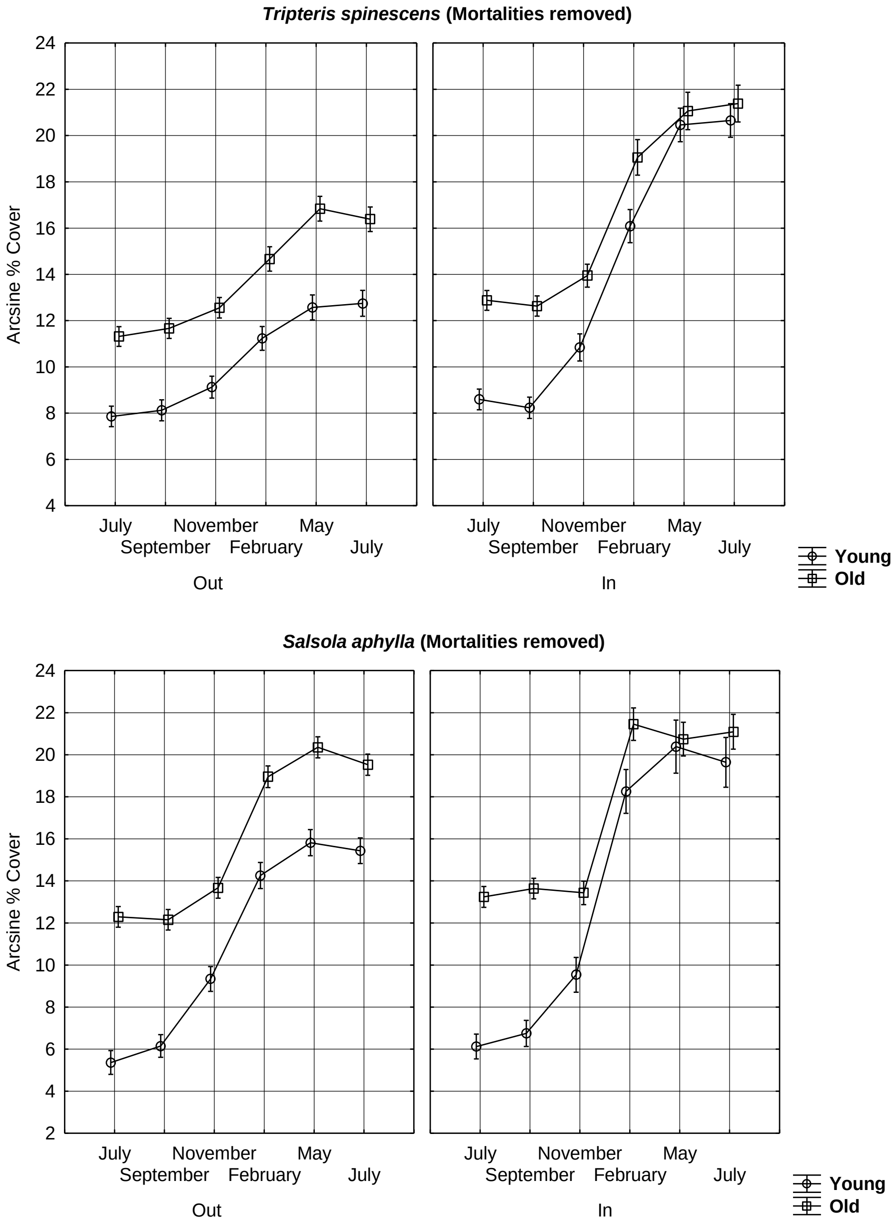

Figure 9: The arcsine percentage cover of the data set with the repeated mortalities removed for *Tripteris spinescens* and *Salsola aphylla.* The vertical bars denote standard error of the mean

4.1 Soils

The soil conditions of the study site are a major limiting factor to plant establishment and growth and ecosystem recovery from disturbance. It was therefore pertinent to assess the conditions of the soil and the effects that the treatments had on the soil conditions of the treated areas.

4.1.1 Nutrients, pH and bulk density

Results of the Students t-test showed that the 25 soil samples ($df = 24$) taken *in* and *out* of the microcatchments differed significantly for all factors tested (Table 2); nitrogen ($t = 3.03$; $p < 0.01$), carbon ($t = 6.41$; $p < 0.01$), calcium ($t = 3.62$; $p < 0.01$), potassium ($t = 1.12$; $p = 0.01$), magnesium ($t = 6.18$; $p < 0.01$), sodium ($t = -2.67$; $p < 0.05$) and phosphorus ($t = 1.29$; $p = 0.01$). The difference between the *in* and *out* sample was also significant for the pH ($t = -6.47$; $p < 0.01$) and the bulk density ($t = -2.36$; $p < 0.05$). The concentrations were higher *in* than *out* of the microcatchments for all nutrients except Na which was higher *out* of the microcatchment than *in*. The pH and bulk density were also higher *out* of than *in* the microcatchments as shown in Table 2.

Table 2: The mean concentrations of the elements tested and the pH in and out of the microcatchments showing the significance of the difference between the two positions and the Standard Deviation of the concentrations. (**-Highly significant, *-Significant and NS-Not significant)

	In	**SD In**	**Out**	**SD Out**	**Significance**
Nitrogen (mg/kg)	772	14,43	576	12,52	**
Carbon (mg/kg)	5500	148,63	260	63,58	**
Calcium (mg/kg)	8978.4	0,22	7035.6	0,22	**
Potassium (mg/kg)	407.92	7,41	373.56	5,70	*
Magnesium (mg/kg)	1289.76	0,03	911.86	0,01	**
Sodium (mg/kg)	691.64	53,59	1177.72	77,41	**
Phosphorus (mg/kg)	230.16	3,36	212	1,99	*
Bulk Density (g/m^3)	1,5	0,13	1,57	0,13	*
pH	7.82	0,09	8.12	0,24	**

4.1.2 Volumetric water content

Volumetric Water Content varied significantly between sampling dates ($F = 8.09$; $df = 5$; $p < 0.05$) and between the treatments and the controls ($F = 41.46$; $df = 1$; $p < 0.05$). The effect of the interaction between the factors time and treatment was not significant ($F = 0.76$; $df = 5$; $p = 0.58$). The VWC was significantly higher in the areas treated with microcatchments than in the control plots (Figure 10).

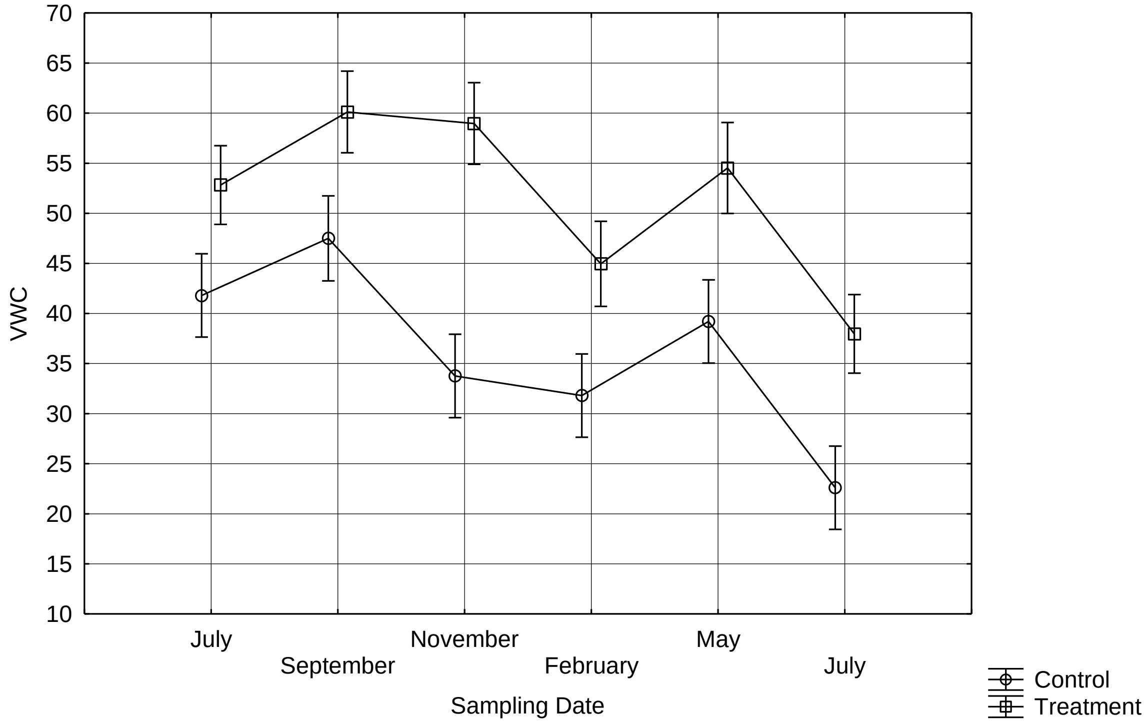

Figure 10: The Volumetric Water Content of the areas treated with microcatchments and control areas expressed as a percentage. The vertical bars denote standard error of the mean.

4.2 Climate and transplant performance

The Pearson's Correlation Analysis was used to determine the correlation between the climatic variables and the plant performance. The $df = 5$ and significance was reported at $p < 0.05$. The correlation coefficients (r^2) for the analysis of the climatic variables are given in Table 3 and only the r^2 which deviate from the norm are reported in the results in section 4.2.1 and 4.2.2.

4.2.1 Growth

The *Growth* of the transplants was positively correlated to the mean temperatures. This correlation was significant for all variable combinations with the exception of the old *S. aphylla* planted in the microcatchments ($r^2 = 0.8$), the old *T. spinescens* planted out of the microcatchments (r^2 = 0.8) and the young *T. spinescens* planted in the microcatchments (r^2 = 0.8) (Table 3). The minimum temperatures were positively correlated to growth of the transplants and these correlations were significant for all variable combinations except the old *S. aphylla* planted in the microcatchments (r^2 = 0.8). The growth was also positively correlated to the maximum temperatures although none of the correlations were significant.

The *Relative Growth* of the transplants was positively correlated to the mean temperature. The correlations were significant for all of the variable combinations except the old *S. aphylla* transplants within the microcatchments (r^2 = 0.8) and the young *S. aphylla* planted outside the microcatchments (r^2 = 0.9). The *Relative Growth* was also positively correlated to the mean temperatures. The correlations were significant for all of the variable combinations except the old *S. aphylla* transplants within the microcatchments (r^2 = 0.8) and the young *S. aphylla* planted outside the microcatchments (r^2 = 0.8). The *Relative Growth* was positively correlated to the maximum temperatures although the correlation was only significant for the young *S. aphylla* (r^2 = 0.9) and *T. spinescens* (r^2 = 0.9) planted out of the microcatchments. The *Growth* and *Relative Growth* of the transplants was positively correlated to the rainfall one month prior to the sampling dates during the study period, however the correlations were not significant.

4.2.2 Survival

The *Survival* of the transplants was negatively correlated to all of the climatic variables but was not significant (Table 3). The *Relative Survival* was also negatively correlated to the climatic variables with a low incidence of significance. The relative survival of the old *T. spinescens* (r^2 = -0.9) and *S. aphylla* (r^2 = -0.9) planted in the microcatchments was significantly negatively correlated to the mean hourly temperatures. The *Relative Survival* for the young *S. aphylla* (r^2 = -0.9) and *T. spinescens* (r^2 = -0.9) planted in the microcatchments was significantly negatively correlated to the maximum hourly temperatures. The *Relative Survival* for the old *T. spinescens* in both in (r^2 = -0.9) and out (r^2 = -0.9) positions was also negatively correlated to the minimum hourly temperatures. The *Survival* and *Relative Survival* of the transplants was negatively correlated to the rainfall one month prior to the sampling dates during the study period, these correlations were also not significant.

Table 3: The correlation coefficients (r^2), for the Growth, Relative growth, Survival and Relative survival, of the variable combinations and the climatic variables. The temperatures were recorded hourly and the rainfall values are the means for the period between the sampling dates. Significant values are reported in bold.

	Species	Age	Posi	Temperature			Rainfall
				Mean	Max	Min	
Growth	S. a	O	In	0,768	0,513	0,783	0,046
	S. a	O	Out	**0,949**	0,818	**0,986**	0,493
	S. a	Y	In	**0,909**	0,792	**0,976**	0,584
	S. a	Y	Out	**0,971**	0,874	**0,997**	0,535
	T.s	O	In	**0,942**	0,758	**0,973**	0,593
	T.s	O	Out	0,781	0,734	**0,883**	0,843
	T.s	Y	In	0,836	0,710	**0,902**	0,842
	T.s	Y	Out	**0,950**	0,816	**0,990**	0,643
R-Growth	S. a	O	In	0,790	0,545	0,816	0,105
	S. a	O	Out	**0,960**	0,816	**0,964**	0,356
	S. a	Y	In	**0,943**	0,835	**0,937**	0,270
	S. a	Y	Out	0,870	**0,940**	0,804	0,211
	T.s	O	In	**0,980**	0,822	**0,974**	0,434
	T.s	O	Out	**0,898**	0,833	**0,968**	0,710
	T.s	Y	In	**0,997**	0,936	**0,969**	0,539
	T.s	Y	Out	**0,987**	**0,905**	**0,981**	0,442
Survival	S. a	O	In	-0,379	-0,054	-0,379	-0,469
	S. a	O	Out	-0,108	0,156	-0,040	-0,247
	S. a	Y	In	-0,459	-0,192	-0,424	-0,531
	S. a	Y	Out	-0,477	-0,271	-0,412	-0,542
	T.s	O	In	-0,352	-0,015	-0,368	-0,468
	T.s	O	Out	-0,255	0,090	-0,288	-0,435
	T.s	Y	In	-0,485	-0,226	-0,445	-0,535
	T.s	Y	Out	-0,054	0,246	-0,043	-0,327
R-Survival	S. a	O	In	**-0,925**	-0,782	-0,873	-0,148
	S. a	O	Out	-0,190	-0,270	0,004	-0,026
	S. a	Y	In	-0,812	**-0,892**	-0,754	-0,103
	S. a	Y	Out	-0,455	-0,711	-0,314	-0,163
	T.s	O	In	**-0,890**	-0,744	**-0,893**	-0,171
	T.s	O	Out	-0,856	-0,662	**-0,900**	-0,264
	T.s	Y	In	-0,781	**-0,880**	-0,686	-0,065
	T.s	Y	Out	-0,776	-0,574	-0,757	-0,699

Chapter 5: Discussion

On a global scale natural ecosystems have been degraded and transformed by anthropogenic activities such as resource extraction (Carrick and Krüger, 2007), urbanisation (McKinney, 2006), invasive species invasions and unsustainable agricultural activities (Wilcox *et al*., 2011). Degradation of natural ecosystems has led to negative effects on ecosystem services (Chazdon, 2008), food security and the quality of life of the inhabitants of the degraded areas (Eswaran *et al*., 2001). Aronson *et al*. (2006) maintains that in order to ensure the ecological sustainability of the planet and the wellbeing of its inhabitants a continual investment of financial and social capital has become essential.

The drylands of South Africa are no exception to this trend of degradation. Milton *et al*. (1994) state that the productivity of South African rangelands began decreasing by the late 1800s. This land use type is the largest in South Africa, occupying 70% of the land surface area. According to Snyman (2003) 66% of these rangelands are moderately to seriously degraded. Due to the extent of the degradation and the importance of these areas to the inhabitants, wildlife and the economy of the country the effective management response of the land managers is of extreme importance.

Ecological restoration involves the mitigation and reversal of the degradation to natural ecological systems caused by the long-term exposure to unsustainable anthropogenic activities (Choi *et al*., 2008). The degradation of ecological systems is caused by complex interactions between all the components of those systems, including the social, ecological and economic factors. Ecological restoration has the potential to increase ecological function as well as improving the quality of life for human inhabitants (Suding *et al*., 2015). For restoration activates to be positive, truly effective and lasting, a method which integrates the social, economic and ecological factors should be devised (Choi *et al*., 2008; Zerga, 2015). The use of a method which requires little or no post application management input and stimulates the natural functioning of the ecosystem on multiple scales would be ideal.

The creation of heterogeneous microsites, favourable to germination and vegetative function, in homogenous degraded veld is an effective practice which has been verified in numerous studies (Kinyua *et al*., 2010; Beukes and Cowling, 2003a;

Allen, 1995; Edwards et al., 2000; Simons and Allsopp, 2007; Visser *et al*., 2007; Biederman and Whisenant, 2011).The purpose of this study was to assess the positive ecological influences that microcatchments have on the performance of transplants and the creation of microsites favourable to plant establishment and growth.

The environmental conditions of the study site are limiting to ecosystem function and the fauna and flora of the area have adapted accordingly (Shearing 1994; Skead *et al*., 2011). The low capacity of the natural vegetation to support mammal populations, particularly livestock, leads to the overutilization of the veld and the subsequent degradation of plant cover and ecological function (Esler *et al.,* 2006). These factors necessitate scientific investigation of the effective methods to improve the conditions of the area, including the restoration of degraded ecosystems in order to benefit the ecosystem function and the wellbeing of the wildlife and inhabitants of the region.

5.1 Discussion of major findings

The effectiveness of the active restoration techniques, microcatchments and plant translocation, on selected plant and soil properties was experimentally tested during this study. The study tested the influence of microcatchments on the survival and growth of the transplants with regard to the *Species* used, the *Age* of the transplant and the planting *Position* in relation to the microcatchment. The effect of the microcatchment treatment on the nutrient and moisture content of the soil was tested. The study also tested the influence of the climatic conditions on the survival and growth rates of the transplants.

The application of microcatchments had definite effects on the capability of the study site to support the translocated plants. In addition to the increased suitability for transplants the microcatchments had positive effects on the conditions for the germination and growth of naturally recruited seedlings. The aim of this study was to assess the influence of microcatchment treatments on the survival and growth of the translocated plants, the nutrient content and soil moisture of the site and the influence of the climatic conditions on the survival and growth of the transplants.

5.1.1 Controls and volunteer recruitment

Due to the nature of the data collected the experimental and control data differs in such a way that it is not viable to statistically compare the two datasets at this stage.

This is also true for the data obtained for the volunteer recruitment. At this stage it is only possible to infer assumptions from the author's personal observations. Accordingly the change in percentage cover of the remnant vegetation within the 25 m^2 control plots was not detected by the method applied over the duration of the study period.

There was observable change in the volunteer recruitment over the study period however the number of incidences which intercepted the transects was too small for viable statistical comparison. The experimental design is intended to be a long term experiment and therefore the data from the control plots and volunteer recruitment will gain validity, as time progresses so that in future the datasets will be comparable under statistical analysis

5.1.2 Species

The selection of the species used in restoration activities is highly important due to the limiting factors identified in this environment. The survival rates of the *Tripteris spinescens* transplants was lower than the survival rates of the *Salsola aphylla* transplants.

Overall *Tripteris spinescens* had a higher percentage cover value than *Salsola aphylla* at the beginning of the sampling period (July, 2013).This is possibly due to the nature of its shallow root system which could take advantage of light rainfall events (Shearing, 1994). Whereas *T. spinescens* maintained its relatively linear increases and its lower percentage cover value *S. aphylla* showed a relatively large increase in percentage cover between November 2013 and February 2014 (Figure 9). This corresponds with the high rainfall and temperatures during that period as is indicated in Figure 7. However in general *S. aphylla* grows actively during the summer while *T. spinescens* grows during the winter (Schumann, 2015) and monitoring through the *T. spinescens'* growing season could show a different result. The increase in percentage cover was higher for the *S. aphylla* than the *T. spinescens* during the last three months of the study period and there was a decrease in the percentage cover of both species but the *S. aphylla* did not decrease as much as the *T. spinescens.* This could have been due to the fact the *S. aphylla* is both halophytic and tolerant of inundation.

The high sodium content of the soil is a limiting factor in this environment (reported in section 4.1.1). This was evident from the disparity in the growth rates of the different species (Figure 8 and Figure 9). The difference in growth rates of the two species could be due to the halophytic nature of *S. aphylla* which is also tolerant of inundation. This could have allowed the *S. aphylla* transplants to maintain its growth even under inundated and saline conditions. As stated by Brown and Amacher (1997) the selection of species for restoration activities is of major importance, particularly if plant attributes can negate the potentially limiting environmental factors such as the high salinity and low drainage of the soils at this study site.

Overall, both species show a response to the variation in rainfall and temperature with a slight decrease in percentage cover values between May and July 2014. During this period there was a limited amount of rainfall and low temperatures which affected the growth rates of both species. This could be an indication of the moisture limited nature of dryland ecosystems and the associated responses of the vegetation which was mentioned by Esler *et al.,* (2006). However the low temperatures, including extreme lows are more likely to be the cause of the reduced percentage cover as indicated by the correlation analysis referred to in section 4.2 (Table 3).

5.1.3 Age

The age at which the transplants are planted in the veld affects the survival rates. The survival of the younger plants was lower than the older plants, although the significance was only apparent for *S. aphylla*. It was also casually observed by the author that the older plants planted further from the remnant vegetation outperformed the younger ones in similar locations. Due to the fact that the plants older than 6 months had more growing time they had higher initial percentage cover values than the plants younger than 6 months at the beginning of the study period (Figure 8 and Figure 9). Consequently the higher percentage cover values of the older plants was an expected result. The disparity was maintained throughout the study period although it was reduced as time progressed. The results of the study suggest that the younger plants should be planted in ameliorated or naturally favourable conditions to avoid unnecessary mortalities. This is an example of the nurse plant effects of the established vegetation observed by Simons and Allsopp (2007). The author suggests that there is a threshold age below which it would be inadvisable to transplant. The transplants require a minimum period of growth before being subjected to the rigors of translocation. However when considering the space available in a nursery used to produce transplants there should also be a maximum age imposed in order to allow for older plants to be moved out and provide space for younger plants. The older plants should be translocated into harsher locations to increase the probability of the younger transplants surviving the initial phase of establishment in locations which are more favourable to plant growth.

When considered in the context of percentage cover the difference in *age* was reduced over time if the plants survived the initial establishment phase directly after the translocation. The author proposes that once established the difference in percentage cover between the age classes becomes less significant as time progresses and that the effect of *age* will become insignificant over a longer period of observation (Figure 8 and Figure 9).

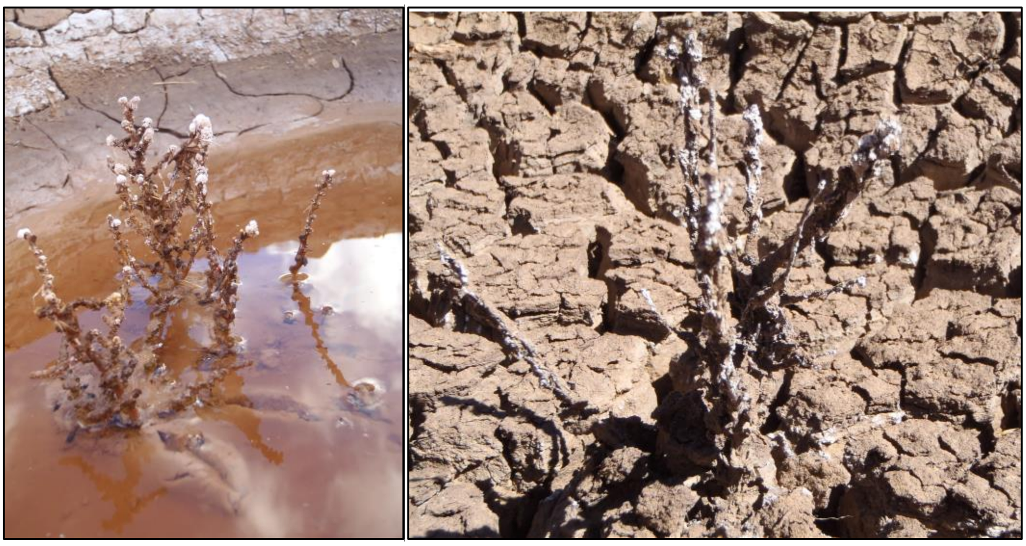

Figure 11: One of the *Salsola aphylla* transplants (left) under stress due to the inundation and subsequent salinization of the apical buds. An unidentifiable transplant (right) with salinization of the apical buds and encrusted silt covering the plant. Photo: A. Jackson

5.1.4 Position

The *position* that transplants were planted in relation to the microcatchments had a highly significant effect on survival. This was most likely due to the fact that the microcatchments hold standing water for extended periods of time after rainfall events which is characteristic of the soil in riparian areas of the Nama-Karoo. This could cause plant stress due to the inundation of the root zone as was found by Schile *et al.* (2011) and in some cases submergence of the above ground plant parts. Plants would also be stressed by the high salt content of the standing water and soil, the salinization of the root zone, soil surface and the above ground plant parts, especially the apical buds (Figure 11). This salinization can cause desiccation, once the moisture has evaporated, resulting in the plants losing moisture to the surrounding environment and ultimately plant mortality as discussed in Morse *et al.* (2011).

The results showed that the transplants which survived the conditions inside the microcatchments performed better than those which were planted outside. However the survival rates of those planted inside the microcatchments was poor relative to those planted outside the microcatchments. The increased infiltration, due to the microcatchments, saturates the soil surrounding the microcatchments. This makes it unnecessary to plant within the microcatchments, as the plants will gain the benefits of increased moisture availability without the negative effects of inundation and excess salinization which caused mortality in so many cases.

Although initially the transplants within the microcatchments seemed to benefit from the sheltered conditions and increased soil moisture of the microcatchments, the continual exposure to the inundation, siltation and salinization of the above ground plant parts caused a reduction in growth and mortalities in many cases. Additionally the cracks which form during times of limited moisture could cause the desiccation of the rooting zone and lead to the reduced performance and mortalities of the plants within the microcatchments (Figure 11).

The inundation and related salinization of the microcatchments at this site means that the planting position, in relation to the microcatchments, is important to the survival and subsequent performance of the transplants. The author suggests that planting on the edge of the microcatchments, in riparian areas, will provide the transplants with benefits of the increased soil moisture without the negative effects of siltation, inundation and excessive salinization. It is further suggested that in areas where the soil has a higher rate of infiltration, microcatchments would hold standing water for shorter periods while still increasing soil moisture. This could improve the survival and performance of transplants and naturally recruited plants.

5.1.5 Nutrients, pH and bulk density

The microcatchments reduced the speed of the surface runoff and caused the flow to eddy within the bowl formed by the microcatchments. This resulted in the settling of the mobile topsoil transported in the runoff as sediment within the bowl during the 6 months since implementation of the treatments. This caused the microcatchments to trap nutrients, debris and organic matter which would otherwise be lost to the site. The nutrient accumulation is evident from the results of the analysis detailed in 4.1.1. The method of data collection and analysis did not account for the organic litter which accumulated within the microcatchments. This organic litter performed the same functions as mulch, protecting the soil from desiccation and solar radiation. This debris also added an organic component to the microcatchments which included seeds from the remnant vegetation of the study site and nutrients which would become available as the debris decomposed. Since the microcatchments and their markers were not removed from the site the accumulation of topsoil and other debris is continuous and the effects can be monitored during future studies.

Of all of the nutrients tested only the sodium content was higher *out* of the microcatchments than *in*. The higher concentration of Na may have been due to its inherent mobility mentioned by Staunton and Nye (1983) which was effected by the evaporation rate leading to high Na concentrations in the surface layers of the soil. The author assumes that the base of the microcatchments would have been relatively protected from direct sunlight. While the soil surface adjacent to the microcatchments would be exposed to the evaporative effect of the sun even when the base of the microcatchment was submerged in standing water or shaded by the sides of the microcatchment. The high concentrations of Na out of the microcatchments could also have contributed to the increased pH of the soil surface adjacent to the microcatchments.

Concentrations of the other nutrients were all higher *in* the microcatchments than *out*. This could be due to the eroded topsoil accumulating in the microcatchments during rainfall events similar to the findings of Edwards *et al.* (2000). As stated by Jobbágy and Jackson (2001) this topsoil would contain a high concentration of nutrients, organic matter and seeds. Carbon had the highest concentration of all the nutrients tested. This was followed by the nitrogen concentration. It is possible that this indicates that the organic matter present on the site has undergone decomposition. As stated above the concentrations of N and C are higher *in* the microcatchments than *out*. This is an indication of the function, also identified in the study by Snyman (2003), of the microcatchments trapping the mobile organic matter which would otherwise be lost to the site due to erosion during rainfall events.

5.1.6 Volumetric water content

The bowl like structure of the microcatchments is designed to accumulate runoff water during rainfall events. Although the microcatchments were designed to allow for overflow of excessive runoff the bowl held the water for extended periods after the rainfall events. This allowed water to infiltrate into the soil as the surrounding soil adjacent to the inundated microcatchments dried out. This would have increased the availability of moisture in the environment for prolonged periods, benefiting the function of moisture dependent ecological processes and the biota of the site.

Although the variation of the VWC in the controls and the experiment appear to correlate, the correlation is not statistically significant (Figure 10).The VWC of the soil in the experimental areas which were treated with the microcatchments was higher than that of the control areas. This was true over the extent of the study period. However, since sodium increases the conductivity of the soil the high Na concentrations in the surface layers of the soil in the microcatchment treated areas may have affected the data obtained from the device. This could have caused a false reading due to the increased conductivity in the surface layers of the soil. Therefore the difference between the VWC in the treated areas and control areas could be caused by the increased concentration of sodium rather than an increased soil water content due to the treatment.

5.1.7 Climatic conditions

The climatic conditions recorded throughout the study period affected the survival and growth of the transplants. Although the change in mean percentage cover is positive for most sampling dates there is a reduction in mean percentage cover from May to July 2014. This could be due to the lower amounts of rainfall after May 2014 (Figure 7). The reduction of the percentage cover could be due to the desiccation and dieback of the plant parts which had not yet undergone sclerification when the lack of rainfall caused susceptibility to the harsh environmental conditions. These unsclerified plant parts are also more susceptible to herbivory due to their softer structure. This could be an additional reason for the reduction of mean percentage cover over the last 3 months of the sampling period.

The correlation between the change in percentage cover and the rainfall was not significant indicating that temperature is more likely to be the driving factor for the reduction of percentage cover. However the rainfall during the study period (311.8 mm) was significantly higher than the annual average recorded in the literature of approximately 252 mm for the region (Mucina *et al.,* 2006). The author suggests that during a year when rainfall is average or below average the correlation between the performance of the transplants and rainfall will be stronger. The effect of rainfall on the transplants was less significant than the effect of temperature.

The temperature extremes and the high level of variation in daily and seasonal variation of temperatures had significant effects on the survival and performance of the transplants. The lower temperatures during the last 3 months of the sampling period correlates significantly to the reduction in percentage cover of the transplants. It is therefore likely that the reduction in percentage cover was caused by environmental conditions associated with the low temperatures during that period. These conditions include frost or hail, both of which have the potential to cause a reduction in above ground biomass which would lead to the reduction in recorded *Percentage Cover.*

The application of microcatchments affected the survival and growth rates of the transplants, however the specific combination of the application of transplants and microcatchments was important to ensure the maximum positive effect of the implemented method. The environmental conditions of the site, specifically the soil conditions which prolong inundation, proved to be an important limiting factor to the performance of the translocated plants. The manner in which transplanting and microcatchments were implemented had a significant effect on the success of the method.

5.1.8 Casual observations

Although the effect of aeolian processes was not within the scope of this study there was a definite effect on the physical structure and accumulation of mobile soil particles in the microcatchments. Further studies are recommended to ascertain the effect of wind on the accumulation and transport of nutrients and plant growth in the Nama-Karoo and other dryland ecosystems.

The size of the degraded area is a significant factor in the process of restoration. Significantly more effort will be needed to restore ecological function on larger degraded areas. The further a patch of bare soil is from a vegetated patch the more exposed it is to the degrading processes such as solar radiation, wind and water erosion. As stated by Belnap (2006) the soil microbiology of such areas will be less likely to persist and contribute to the ecological function, and restorative potential, of these areas.

The placement of microcatchments is critical in the landscape, in relation to the existing microtopography and in relation to each other. The microcatchment treatments should be implemented starting close to the edge of the bare areas and work downstream. This will ensure that the runoff does not build up speed and erosive force before it reaches the first microcatchments, as this could cause damage to the structure and reduce the effectiveness of the microcatchments. The microcatchments should be constructed to complement the remnant vegetation and provide existing plants and clumps with increased soil moisture. The microcatchments should be placed in a staggered formation so that the overflow of each one is caught by the next one. This will reduce the possibility that the overflow will undermine the structure and function of the microcatchments and avoid the chance of the implemented method exacerbating the degradation by creating erosion systems which would further degrade the landscape.

Figure 12: A frog which utilised the inundated microcatchments (left) and a microcatchment containing the spoor of an amphibious mammal (right).

The microcatchments held water for extended periods after rainfall. This created an aquatic habitat on previously bare, capped soil. The presence of amphibious fauna was noted in the form of the spoor of an amphibious mammal, possibly a marsh mongoose (*Atilax paludinosus*), and numerous frogs which were repeatedly observed during sampling periods (Figure 12). The standing water also hosted algal species allowing them to occupy the habitat for extended period. Without the microcatchments these species would be restricted to the limited habitat of the ephemeral water course.

5.2 Significance of this study

This study sought to determine the effects of microcatchment treatments on the survival and performance of translocated indigenous shrubs to facilitate the recovery of riparian habitat in the Nama-Karoo. Although the study was not replicated in the landscape some key aspects contribute to our knowledge of how plants respond to microcatchments in arid environments with saline soils and extreme climatic conditions.

5.2.1 Research

The research conducted during this study has contributed to the understanding of the factors which affect the survival of translocated plants in the Nama-Karoo riparian habitats. The study determined that using microcatchments to enhance the performance of transplants in this environment is a prudent measure. The results of the study indicate that the tolerance to inundation and the halophytic nature of *Salsola aphylla* was important to the survival and performance of these transplants. Techniques which increase the availability of moisture are advisable in dryland environments. This study demonstrates that inundation of the microcatchments causes mortalities of the transplants and indicates that the transplants should be positioned outside of the zone of inundation associated with the microcatchments to avoid unnecessary mortalities in this environment.

The stakeholder relations, data collection regime and the experimental layout were designed to facilitate long term monitoring in order to contribute to the knowledge already accumulated by past research. The information gathered from the study site will continue to inform the relevant stakeholders and land managers of the region, and similar dryland regions, of the effects of passive and active restoration techniques.

This will provide justification and incentives to the land managers for the inclusion of restoration activities in their management regime.

5.2.2 Management

The restoration of degraded dryland ecosystems is a slow process which relies on favourable environmental conditions which occur sporadically. The extent of the degradation and cost of restoration coupled with the low economic capacity of the veld make continual investment of management action unfeasible. This necessitates a method which can be implemented and left to perform its functions with little or no follow-up management input. The removal of the cause of degradation, such as unsustainable utilisation by livestock, is one of the first factors to consider as continued over utilisation would undermine any restorative efforts implemented. However this alone is not adequate to initiate ecosystem recovery and active restoration is required.

Restoration techniques which simulate the natural recovery processes are advisable to initiate autogenic recovery of the ecosystem functions. The cost, in terms of time and finances, of establishing transplants can be prohibitive to many stakeholders. However it is a highly effective method as it immediately improves the biotic component of the degraded system. Due to the effort involved in the establishment of transplants and the process of translocation the improvement of transplant survival is prudent. The implementation of microcatchment treatments is one method which is advisable as it increases the nutrients and moisture available to the transplants. It was observed that the removal of pressure from livestock not only allows the transplants to establish and grow but will allow the remnant vegetation to increase in biomass and produce seeds, this was similar to observations made by Meyer *et al.* (2009). Although this is a slow process in dryland environments these seeds will then germinate and contribute to the ecosystem function and recovery as stated in Hanke *et al.* (2011). Stocking rates and rest periods which allow for the natural recovery of the veld are highly advisable to ensure that further degradation does not occur. The consultation of grazing specialists or ecologists is highly advisable. The prevention of degradation is far more preferable to the implementation of active or passive restoration after degradation has occurred.

5.3 Limitations to the study

The study was conducted on one site and was not replicated in the landscape due to financial constraints. It is therefore impractical to assume that the results obtained from this study will dictate the responses of vegetation throughout the region, especially considering the variation in climate and soil parameters. The methods, or similar methods should be replicated in the landscape in order to provide insight into the responses of transplants at other sites.

Although the control plots provided an example of the untreated environment there were no transplants planted within these plots. Future studies should include the monitoring of translocated plants in areas without microcatchment treatments. This should provide greater insights into the role that microcatchments have on the survival and growth of translocated plants.

The plants were not monitored directly after the planting. This allowed for the weaker plants to die off before the monitoring began. It is suggested that the percentage cover should be recorded from the planting date to provide more detailed information on how the transplants respond to the translocation process.

The transplants were assigned codes to identify the species and age. The codes were repeated for the planting combinations throughout the site. This meant that it was not possible to relate the first microcatchments sampled during the first sampling date with the first microcatchments on the second sampling date and successive sampling dates. In future the microcatchments and transplants should be individually labelled in order to allow for a more detailed comparison of the responses of the transplants to the treatments.

The soils of the study site played an important role in the responses of the transplants to the treatments. The section of this study which investigated the soil parameters was meant to be informative and complement the data collected regarding the vegetation responses, the soils section was therefore not fully comprehensive and future studies should investigate the soil parameters at the beginning of the study period and the effects that the microcatchment treatments have on the change in those parameters.

Although the line intercept method provided a proxy for plant performance and the measure of percentage cover could be related to the recovery of the degraded veld the method is subject to inaccuracies. The loss of percentage cover to herbivory may have contributed to the change in percentage cover however this was not recorded and therefore cannot be quantified. The fencing excluded the majority of the larger mammals so that in this study the loss of percentage cover due to herbivory was minimised. In future studies the exclusion of herbivores is advisable and the monitoring of herbivory is also advised.

Rainfall was recorded on site but the recorder could not provide data on other climatic factors. The temperature data was therefore obtained from another site in the area. The climatic conditions are major drivers of vegetation dynamics and it is desirable to have those conditions recorded on site to ensure that the conditions recorded are comparable to those experienced by the vegetation being monitored.

Chapter 6: Conclusion and Recommendations for future studies

6.1 Conclusion

The results of this study lead the author to conclude that transplanted shrubs benefited from the implementation of the microcatchments. The study indicated that the selection of species should be dictated by the limiting conditions of the receiving environment, such as halophytic plants for saline conditions. The study showed that the age of the transplant is significant in terms of the probability of the transplants surviving the initial stage of establishment. The difference in the percentage cover of the two age classes is reduced as time progresses. The study also shows that the structure of the microcatchment can be prohibitive to transplant survival and growth if planted below the water mark of the microcatchment as this leads to inundation related plant stress and mortalities. It is therefore prudent to plant on the edge of the microcatchment, this allows the transplants to benefit from the increased soil moisture without enduring the stresses associated with inundation.

The accumulation of the soil particles and organic debris, transported by runoff water, in the microcatchments created a localised microsite of increased soil nutrients. These nutrients would otherwise contribute to the siltation and eutrophication of the local river systems. The capture of this soil contributes to the physical structure and chemical characteristics of the microsites created by the microcatchments. In addition to the accumulation of nutrients the microcatchments hold water which would otherwise contribute to runoff, thereby reducing erosion. The prolonged presence of this water allows for increased infiltration into the soil of the site thereby allowing extended utilisation of the moisture by the biota and ecological processes active on the study site.

The results of the study show that the climatic conditions are important drivers of plant performance. The rainfall had a less significant effect on the survival and growth of the transplants than temperature which seems to be the climatic factor which had the most significant effect on the outcome of this study. The temperature extremes typical of the site had significant effects on the results of the study. The extreme high temperatures would have reduced plant performance however the plants of the region are adapted to the high temperatures and the limiting conditions which occur as a result. The extreme low temperatures would also have reduced the performance of the transplants and although the plants would be adapted to the low temperatures the associated environmental conditions, such as frost and hail would have caused damage to the cellular and physical structure of the transplants, thereby reducing plant performance.

6.2 Recommendations

The continuation of the data collection regime is highly advisable. The experimental layout of the study site is designed to monitor the responses at both the plant level and the site level. The expansion of the data set over time will provide clearer information and insights into the plant and ecosystem responses to the exclusion of livestock, plant translocation and the implementation of microcatchment treatments.

Although the sampling methods produced data which provided valuable insights there are possible improvements to the methods which would increase the value of the data collected. The study also provided insights into other possible avenues of investigation for future studies. Aligning methods to past and current studies could allow for the comparison of data sets over a wider range of environments.

The line intercept method did, in some cases, underestimate the actual cover provided by the transplant. This was especially evident if the increase in cover occurred on an axis which was not aligned to the transect used to measure the plant intercepts. The measurement of the stem diameter of transplants could provide a more accurate indication of plant performance. Studies to determine the allometric ratios of the specific species identified for use in restoration activities would contribute to the accuracy of the data collected. The monitoring of stem diameter would also be less susceptible to the effects of herbivory. The assessment of the effects of herbivory would give information on the effects of herbivore exclusion on the success of restoration activities.

Investigations into the levels of tolerance, functional traits and the capabilities to mitigate the limiting conditions of the various species of the region could indicate which species should be utilised to overcome limiting conditions at specific sites. The use of clumps of multiple species and different functional groups is one area of investigation which should be taken forward in future studies. The different functional groups could have complimentary characteristics which may facilitate plant growth and ecosystem recovery. The determination of the minimum age of successful translocation would provide nursery and land managers information to advise the best practice in terms of plant turnover in nursery conditions. It was observed that some of the remnant species resprouted from roots which were exposed during the construction of the microcatchments. This could be a valuable trait to exploit in the expansion of existing vegetation clumps and establishing plant cover in bare areas.

The inclusion of a method to monitor the soil conditions of the site prior to the implementation of treatments and over the duration of the study period would provide valuable insights into the plant responses to the implemented treatments. At sites where soil salinity is known to be a limiting factor a method to monitor the moisture content of the soil which does not rely on conductivity should be implemented. This will decrease the bias created by increased conductivity due to high concentrations of sodium. The measurement of the soil water content at increasing distances from the microcatchment would provide information on the extent of the microcatchments effect on soil moisture. This would give managers information regarding the distance that a transplant could be planted from a microcatchment while still benefiting from the increased soil moisture.

Although many of the techniques suggested in the literature involve the amelioration of the harsh conditions expected in degraded dryland areas, the techniques will not create the ideal conditions which would result in complete success of restoration activities. The people who live on the land have invaluable perspectives pertaining to the environment in which they live including the phenology of plants and climatic conditions. The consultation of local residents regarding the climatic conditions can complement the predictions made by meteorological authorities. Restoration practitioners should accept the conditions imposed by the environment and work with the natural ecological processes and the landscape in order to avoid unnecessary efforts or unintended negative effects.

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