# INVESTIGATING THE MOST FAVOURABLE SEED ESTABLISHMENT METHODS FOR RESTORING SAND PLAIN FYNBOS ON OLD FIELDS

**by**

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# DECLARATION

I, Carly Ruth Cowell, declare that the contents of this
thesis represent my own unaided work, and that the thesis has not
previously been submitted for academic examination towards any qualification.
Furthermore,
it represents my own opinions and not necessarily those of the Cape Peninsula University
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Technology.

**Signed** **Date**

## ABSTRACT

Cape Flats Sand Fynbos (CFSF) is one of the most poorly conserved vegetation types in the Cape Floral Kingdom, and a large proportion of unconserved land is degraded, primarily as a result of transformation by agricultural, urban developments and invasion by alien plants. Fynbos restoration is one of the most important management interventions, both within the current conservation areas and in any future land remnants acquired for conservation. Many extant remnants are fragmented and isolated, and if successful restoration protocols are found, it may be possible to improve the conservation targets for this critically endangered vegetation type. On old fields, where indigenous soil seed banks have been lost due to alien plant invasion and anthropogenic action, it is essential to re-introduce the longer-lived fynbos components that contribute to vegetation structure, in order to facilitate the progress of the ecosystem on a more natural trajectory.

This research is built on an earlier study of optimal ground-preparation treatments for restoring Sand Fynbos to old fields. This former study indicated that fossorial mammals (molerats and gerbils) may occur in dense colonies on old fields and present an obstacle to successful seedling establishment. The project aims to provide protocols for the establishment of indigenous seedlings from harvested seed onto old fields, in order to restore Sand Fynbos vegetation. Different pre-sowing treatments and sowing techniques were tested on large field plots to determine the most efficient protocol. The objectives of the research were: a) to investigate optimal pre-sowing treatments of indigenous seed for restoring degraded Sand Fynbos vegetation in old field sites; b) to investigate optimal sowing techniques on large field plots for restoring degraded Sand Fynbos vegetation in old field sites with depleted indigenous seed banks; c) to provide guidelines and disseminate information on optimal sowing protocols, and their costs, for restoring Sand Fynbos vegetation in degraded areas and old fields. A further component of the research was to calculate the costs of all treatments on a per hectare basis in order to assess the cost-effectiveness of the different options.

Several different seed treatments may potentially increase the germination rate and promote fynbos restoration. These are scarifying, smoke, smoke water, chemical, light and temperature pre-sowing treatments. In order to keep the number of treatments (including their interactions) to a manageable level, only soaking in smoke water extract and seed coat scarification with course sand and grit were tested. A seed sample of each species was x-rayed at the Millennium Seed Bank in the United Kingdom, to test for viability in the seed samples, 52 % of the seed collected were empty, a typical indication of wild harvested seed. All species were germinated at 10/25 °C and 16/8 hours light/dark

respectively. Scarification had a larger overall germination success, smoke water had very little effect on CFSF species, it is rather that germination is related to temperatures during a fire that result in seed coat splitting. It was recommended that further investigation using more species across the Sand Fynbos vegetation be conducted on pre-germination effects of heat and scarification.

The study site had been cleared of woody invasive alien vegetation and additional site preparation included the application of a systemic herbicide to kill undesirable herbaceous weeds, prescribed fire to clear the site of woody debris and destroy weed seeds, and the local control of fossorial mammals (gerbils and molerats) by placing raptor perches and owl nesting boxes around the site. This research found that the use of herbicide shortly after the prescribed fire and once again prior to sowing was successful in controlling herbaceous weeds and the indigenous grass *Cynodon dactylon.* The challenge to using prescribed burning on old fields was low fuel loads, which resulted in a cool patchy. It is suggested that cutting and spreading of alien plant biomass is tested as a solution, however, the material must be evenly spread across the site and not stacked into piles which can cause excessively hot fires and scorching of the soil. In order to better understand soil conditions across the site, soil samples were collected prior to sowing, to analyse for soil macronutrients, organic matter and pH. It was established that all the excess nutrients added to the site from agriculture and pasturage over the years had leached from the soil. However, the organic matter content of the soil was extremely low and research needs to be done on the organic carbon content of the soils, how these relate to soil micro biota (which species are present and their relationship with CFSF species) and how best to enrich the site with humic matter for restoration and establishment of Cape Flats Sand Fynbos. The field trial was set up in the Blaauwberg Nature Reserve, a random split-plot block design, was replicated five times and used to investigate the selected seedbed preparation and sowing techniques, namely: broadcast sowing onto unprepared seedbed, broadcast with plank embedding of seed onto disked seedbed, broadcast onto disked seedbed and hydro-seed with disked seedbed. Results from the research found that the most successful methods for sowing seeds were the hydro-seeding and broadcast with plank embed. These methods may have provided better contact between the soil and seeds and better protection from predation and wind. Economically the broadcast and embed was better as machinery was more efficient and effective than manual labour. This study recommended that these two methods be combined with the additional planting of rare and threatened species in clumps to determine the benefits and interactions of each technique over the long term.

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# DEDICATION

*This thesis is dedicated to my husband*

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## GLOSSARY

| Terms/Acronyms/Abbreviations | Definition/Explanation |
|---|---|
| **Alien species** | A species from another biome or continent, a non-native organism. |
| **Anthropogenic** | Caused by humans |
| **Bakkie Sakkie** | A pickup truck vehicle with a water tank, pump and spray equipment fastened on the rear bed. Often used in South Africa for fighting Wildland fires. |
| **Biome** | A geographical region with similar vegetation and climate. |
| **BNR** | Blaauwberg Nature Reserve |
| **CBD** | Convention on Biological Diversity |
| **CCT** | City of Cape Town |
| **CEC** | Cation Exchange Capacity |
| **CFR** | Cape Floristic Region |
| **CFSF** | Cape Flats Sand Fynbos |
| **Composite sample** | The composite sample is formed by combining and mixing all primary samples taken from the seed lot. |
| **CSIR** | Council for Scientific and Industrial Research |
| **Disturbance** | A relatively discrete event in time and space that alters habitat structure and often involves a loss of biomass or soil. |
| **Duplicate sample** | A duplicate sample is another sample obtained for submission from the same composite sample. |
| **EC** | Electrical Conductivity |
| **FDI** | Fire Danger Index |
| **Germination** | The emergence and development of the seedling to a stage where the aspect of its essential structures indicates whether or not it is able to develop further into a satisfactory plant. |
| **Growing media** | The product which provides sufficient pore space for air and water, for the anchorage of the root system and for contact with solutions (water) needed for plant growth. |

| | |
|---|---|
| **Guild** | A suite of species with a similar functional property. |
| **IAS** | Invasive Alien Species |
| **ICC** | Implementation Co-ordination Committee |
| **ISTA** | International Seed Testing Association |
| **IUCN** | International Union for Conservation of Nature |
| **MSB** | Millennium Seed Bank |
| **Mya** | Million Years Ago |
| **NBSAP** | The National Biodiversity Strategy and Action Plan |
| **OC** | Organic Carbon |
| **OM** | Organic Matter |
| **PLS** | Pure Live Seed |
| **PPRI** | Plant Protection Research Institute |
| **Primary sample** | A primary sample is a portion taken from the seed lot during one single sampling action. |
| **Red Data List** | The list of threatened or potentially threatened plant species. |
| **Restoration** | Returning the land to its exact or approximate biological status. |
| **SANBI** | South African National Biodiversity Institute |
| **Seed lot** | A seed lot is a specified quantity of seed that is physically and uniquely identifiable. |
| **SERI** | The Society for Ecological Restoration International |
| **UNDP** | United Nations Development Programme |
| **WfW** | Working for Water Programme |

# CHAPTER ONE

# LITERATURE REVIEW AND GENERAL INTRODUCTION

## 1.1 Abstract

Cape Flats Sand Fynbos (CFSF) is a critically endangered vegetation type in the Cape Floral Kingdom and is listed as such in the National Spatial Biodiversity Assessment, 15% of the original CFSF remains, yet only 1% is conserved at present, while the national biodiversity target is 30%. By 2011, 85% of the CFSF has been lost and of the remaining 15%, only 5% is in a good quality state. Six plant species were listed as extinct in the CFSF and approximately 319 were listed on the Red Data List. Ecological restoration of the processes that enable a habitat to be self-sustaining and maintain structure and function, in the case of CFSF, is an urgent requirement to save the many threatened species within this vegetation type and the vegetation type as whole. Numerous research project have been undertaken to investigate restoration of old fields in the northern and southern hemisphere, however, it has been found that each ecosystem and vegetation type has unique restoration requirements. These requirements must be determined before restoration can be successful. Studies on restoration of the cape lowland vegetation types have found that removing the drivers of ecosystem disturbance such as small mammals and alien plant species effectively, increases successful establishment of restoration species. The use of fire as a restoration tool and embracing natural predators to counter predation of plants and seeds by small mammals is highly recommended. This study therefore tested the use of seeds to establish CFSF on old fields at the Blaauwberg Nature Reserve, by testing different pre-germination treatments to break dormancy of CFSF species and seedbed preparation and sowing techniques for the optimum establishment of CFSF.

## 1.2 Introduction to Cape Flats Sand Fynbos

Lowland Sand Fynbos, officially known as Cape Flats Sand Fynbos (CFSF), forms part of the Fynbos Biome and is a fire-driven Mediterranean- type shrubland (Pierce and Moll, 1994; Rebelo et al., 2006) it is found in the south-western corner of the Cape Floristic Region biodiversity hotspot (Myers et al., 2000). Lowland Sand Fynbos occurs on undulating and flat sandy plains along the Cape coast from Hangklip to Namaqualand. CFSF is a dense, fairly tall, ericoid shrubland containing scattered and emergent tall shrubs. Proteas and restios are dominant, with species from the families of Astercaeae and Ericaceae occurring in drier and wetter areas, respectively (Rebelo et al., 2006). CFSF has the conservation status of critically endangered, as listed in the National Spatial Biodiversity Assessment (Rouget et al., 2003), 15% of the original CFSF remains, yet only 1% is conserved at present, while the national biodiversity target is 30%. The National Biodiversity Strategy and Action Plan (NBSAP) was developed in collaboration with the United Nations Development Programme (UNDP), the South African National Biodiversity Institute (SANBI), the Working for Water Programme (WfW), Council for Scientific and Industrial Research (CSIR) and Plant Protection Research Institute (PPRI) in 2004. The targets were set in line with the Convention on Biological Diversity (CBD) Targets (Rouget et al., 2005; Hitchcock, 2006) which aim at conserving a minimum of 30% of critically endangered vegetation types worldwide, among other biodiversity targets. The City of Cape Town is approximately 2469 $km^2$, it has 3250 plant species estimated to occur in the City, 13 are extinct and 319 were threatened according to the IUCN Red List: this is 18% of the threatened Red List species in South Africa (Rebelo et al., 2011). CFSF has deep flat sand and is suitable for agriculture, housing and industrialisation. Much of the area around Cape Town was drained and developed in the earlier part of the 20$^{th}$ century (Rebelo et al., 2006) . By 2011 85% of the CFSF has been lost and of the remaining land, a small portion was in a good quality state. Conservation started in earnest in Cape Town, in 1958 when Table Mountain was declared a National Monument (Rebelo et al., 2011). A few small patches of CFSF remain as small nature reserves scattered across the Cape Metropolitan area; these include the Kenilworth Racecourse (privately owned), Rondevlei and Blaauwberg Nature Reserves and Rondebosch Common (City of Cape Town) and Lower Tokai Plantation (Table Mountain National Park). These “Core Conservation Sites” (Maze and Rebelo, 1999) represent a patchwork of remaining CFSF and together preserve this vegetation type (Turner, 2006; DuToit, 2010) . They are threatened by invasive alien plants and the destructive practice of mowing, which eliminates all the tall and serotinous species and fire exclusion (Van Wilgen and Forsyth, 2010).

**Figure 1.1:** Study site at BNR (foreground), prior to alien clearing and prescribed burning

## 1.3 Threats to Cape Flats Sand Fynbos

The main threats to CFSF in Cape Town are urbanisation, invasive alien plants and agriculture in the form of small holdings. Agriculture changed the landscape and many tracts of natural CFSF were ploughed up for crops such as vegetables, wheat and barley. Urbanisation played a major role in the loss of natural habitat with the building of homes, roads and railways. This is still a major threat to the CFSF, as the CCT has been expanding at a rapid rate since South Africa became a democracy in 1994 (Holmes et al., 2008). According to Rebelo et al. (2011), the minimum conservation targets were not achievable and any remaining pieces of CFSF have to be saved and restored to an ecologically functioning state to attain targets.

Evidence has been found that modern man was in the CFR117 000 years ago, then from approximately 2 500 years ago hunter-gatherer clans (San) were replaced by the nomadic pastoralists (Khoi-Khoi) whom with their cattle and sheep out-competed the San for food. (Smith, 1986; Deacon, 1992). European settlement began with Van Riebeeck in 1652 and continues to this day (Elphick, 1985). Human activities both past and present offer a myriad of threats to fynbos (Cowling and Pierce, 1999). Invasive alien plants were the biggest threat to biodiversity (Rouget et al., 2003) and species introduced to the CFR include: Rooikrans (*Acacia cyclops*), Long-leafed (*Acacia longifolia,* Golden Wattle (*Acacia pycnantha)*, Black Wattle (*Acacia mearnsii*) and Port Jackson (*Acacia saligna)*. The majority of the alien plants originated in other Mediterranean climatic regions and flourished in the absence of their natural pests and parasites (Musil, 1993). These plants reduce water availability, alter fire regimes by increasing fuel loads, increase erosion and cause species extinctions (Richardson et al., 1992).

### 1.4 Threatened species within Cape Flats Sand Fynbos

Six species were listed as extinct in the wild on CFSF, these were *Aspalathus variegata, Erica pyramidalis, Erica turgida, Erica verticillata, Liparia graminifolia* and *Serruria foeniculacea* (Goldblatt and Manning, 2000). There were plants growing *ex situ* in botanical gardens of *Erica turgida, Erica verticillata* and *Serruria foeniculaceae.* Rondebosch Common and Rondevlei Nature Reserve have both suffered from frequent mowing over the past years and thus were no longer home to many of the larger CFSF shrub species; however they do host a large geophyte component. The Kenilworth Race Course was protected from fire for over 100 years (Hitchcock, 2006) and the vegetation suffered from senescence, a prescribed burn in 2006 resulted in many of the dormant bulbs and soil seed bank germinating. The most intact piece of CFSF was at Tokai on the lower slopes of the Constantiaberg in Table Mountain National Park, under pine plantations for many years. This site has lost many of the serotinous species and passive restoration using fire is currently been undertaken. The Blaauwberg Nature Reserve is heavily infested with invasive alien species of A*cacia saligna* which has taken over the CFSF area after unsuccessful ploughing for crop production in the 1960's and grazing in the late 1980's. BNR is the largest remaining piece of CFSF, and requires intensive research on alien clearing and ecological restoration methods to rejuvenate the CFSF ecosystem, restoration on such a large scale has not previously been attempted.

### 1.5 Ecological restoration

Restoration is defined as the process of re-establishing a self-sustaining habitat that closely resembles the natural condition in terms of structure and function according to Hobbs and Norton (1996). Active ecological restoration aimed at facilitating a more rapid process of restoring biodiversity than a system may experience (Palmer et al., 1997) when left alone, whilst passive restoration aims at removing drivers of degradation from a system and allowing the system to self-repair over time. An ecosystem's health is a function of the severity and nature of the influences exerted on it by environmental drivers (Brudwig, 2011). Active restoration require the implementation of restoration strategies which seek to influence and rectify these drivers (Brudwig, 2011), manipulations can be used to aid natural processes, so that the desired ending point is reached sooner (Palmer et al., 1997). The Society for Ecological Restoration International (SERI) stated that an ecosystem's trajectory can be determined through a combination of knowledge of the damaged ecosystem's pre-existing structure, composition and functioning, studies on comparable intact ecosystems, information about regional environmental conditions, and analysis of other ecological, cultural and historical reference information (Aronson et al., 2004). By constructively manipulating a system, ecological restoration can be seen as initiated and the ecosystem may potentially then be aligned with its developmental trajectory (Aronson et al., 2004). Ecological restoration efforts and the restoration of a community are a combination of both local and regional constraints (Palmer et al., 1997), these include climatic conditions; regional species pool; and, connectivity to a functioning ecosystem on the regional scale. Local factors that affect community restoration were abiotic factors, habitat structures, and natural disturbance regimes such as flooding or fires and species interactions (Palmer et al., 1997). A holistic understanding of the system, its drivers and trajectory are needed for restoration solutions to be accurate.

Brudwig (2011) stated that passive protection of habitat remnants alone will not suffice in many landscapes, this statement holds true for many disturbed and degraded vegetation types in the Fynbos Biome an example of this was found on old fields along the West Coast where natural succession did not occur as indigenous species did not return to abandoned agricultural fields for decades although these were adjacent to natural areas (Midoko-Iponga et al., 2005). The vegetative community established by the restoration practice must be sustainable and prosper without regular intervention (Hobbs and Norton, 1996), first a thorough understanding of restoration procedures and techniques for fynbos is essential for success in reinstating biodiversity. Restoration practices developed in the Northern Hemisphere may therefore not be applicable to other areas such as the Mediterranean-type systems as in the Western Cape (Hobbs and Cramer, 2007). Since re-establishing all indigenous species is often not economically possible. The establishment of a core pioneer guild is recommended (Cione et al., 2002), these may fulfill the functions of nutrient cycling, soil stabilisation, pollinator habitat or improving hydrological functions (Ewel, 1997). They must in addition provide fuel for fires which drive the fynbos system (Holmes and Richardson, 1999). The role of individual species within the Sand Fynbos Biome suggested that the restios, graminoids and herbaceous perennials form the basis for the establishment of sand fynbos and the 'nurse' plants for the longer lived shrubs (Holmes, 2002). This will create a basis for natural ecological processes to establish a functioning community, by allowing processes to develop and plant species to return naturally.

### 1.5.1 Invasive Alien Plants and Restoration

Human-induced disturbance was the single biggest driver of the reduction in biodiversity, ecosystem services and integrity through the introduction of invasive alien plant species (Wassenaar and Ferreira, 2002; Esler and Holmes, 2008). Clear ecological and conservation consequences due to the loss of species diversity, changes in fire ecology and invasion have occurred in the past and it was the task of restoration ecologists to rectify these changes (Fisher et al., 2009a). The impacts of invasive alien species (IAS) on different components of biodiversity and the seriousness of these impacts was severe in many cases particularly where very little remains of an ecosystem (Foxcroft, 2002). Seedling mortality and growth has been found to be negatively affected by competition from alien grasses (Krug and Krug, 2004; Midoko-Iponga, 2004). The control of alien grasses, herbaceous perennials and woody species had been tested using fire, ploughing and herbicide application. Burning had the desired effect of reducing shrub cover and grass biomass, and increased overall species richness and indigenous seedling recruitment (Midoko-Iponga, 2004). The removal of alien grass species that hinder the establishment of natural vegetation (Holmes and Cowling, 1997) was best done on old fields in the fynbos with herbicide (Musil et al., 2005). The use of a biodegradable systematic herbicide sprayed on a calm day in spring and autumn, has proven effective in reducing the weedy grasses (herbaceous weeds too) for old previously cultivated fields (Holmes, 2002). The mechanical removal of woody acacia species has been found to be adequate if done in the right season and correctly (Holmes et al., 1987; Holmes and Marais, 2000). The use of herbicide was effective in reducing alien competition and thus increasing indigenous species recruitment. Recommendations for old fields restoration through the implementation of disturbance interventions includes the application of herbicide to remove grass competition, and then, after the herbicide has degraded, to oversow the field with seeds of indigenous shrub and grass species of early successional stages to increase overall species diversity’ (Midoko-Iponga, 2004; Gaertner et al., 2007).

Cape Flats Sand Fynbos is characterised by less persistent soil-stored seed banks than mountain fynbos veld types (Holmes, 2002), particularly those of the longer-lived shrubs (Holmes, 1990). Thus revival after alien clearing in this veld type is dominated by herbaceous annual and perennial species. The seeds of myrmecochorus species are buried at greater depths as are bulbs of this vegetation type, averaging 50 mm under the surface (Holmes and Newton, 2004). However, due to the agricultural practice of ploughing, these species have often been removed and only certain herbaceous perennials remain (Holmes, 2002). At old field sites, where indigenous soil seed banks have been lost, it is essential to re-introduce the longer-lived fynbos components, either by sowing or planting propagated plant material, in order to facilitate restoration. Without intervention, a grassy herb land develops both on fallow fields and following the clearance of dense alien acacia stands (Holmes, 2008).This vegetation forms an “alternative stable state” (Suding et al., 2004) to fynbos, causing protracted or non-existent recovery of fynbos. If not rectified this state will result in the erosion of the topsoil and the formation of gullies (Holmes et al., 2000) as a result flooding can occur and the silting up of seasonal rivers and wetlands in lower lying areas.

### 1.5.2 Problem Animals and Restoration

The fauna of the CFR in modern times is much less than historic numbers as a result of hunting and habitat destruction (Picker and Samways, 1996). Fynbos vegetation can only support a low density of vertebrates due to its low soil fertility and poor forage quality, however with the additional fertilizers to soil and the introduction of domestic crops, numbers of small fauna may have increased locally. Activity by fossorial mammals such as the common molerat (*Cryptomys hottentotus*), Cape molerat (*Xerorchus capensis*) and Cape Gerbil (*Tatea afra*) was a major obstacle to the establishment of seeds in the soil (Holmes, 2008). The removal of these fossorial mammals in the initial stages of seed germination and seedling establishment is vital, as these rodents eat seeds, uproot and graze on the plants, and displace the soil resulting in mass seedling mortality.

For a functioning ecosystem to establish, a critical first step is to halt the degradation of the existing site and activities that prevent recovery (Hobbs and Norton, 1996). At old field sites the number of individual fossorial mammals has been found to greatly outnumber the predator population and the impact this has on the little remaining vegetation is disastrous (Breytenbach, 1984). As a result of this disturbance of the soils and feeding on young plants establishment of pioneer vegetation is prevented, however when the disturbance to an ecosystem is severe and prolonged the natural balance of predator and prey is broken (Apps et al., 1996). For this reason it has been found that a mass knock down of the population of rodents is necessary (Avery et al., 2005). This is done using chloroform or an aluminium phosphate derived poison (Dickson, 2008). Recolonisation of the area will slowly take place and feeding pressure on the restoration process will be reduced as the vegetation will have had time to get suitably established (Holmes, 2008). Environmentally sensitive solutions have been found to work in the agricultural industry. These include the placing of raptor perches around the site which replicate tree branches and encourage hunting birds to return to the site and prey on these rodents. The erection of owl nesting boxes has been found to be beneficial in the reduction of the nocturnal Cape Gerbil numbers (Potter, 2004). Further, by establishing and maintaining buffer zones around the test area, natural predators (Saunders et al., 1991) such as mole snakes (*Pseudaspis cana),* Honey Badger *(Mellovora capensis),* Cape foxes (*Vulpes chama)* and Caracal (*Felis caracal*) are able to prey on the molerats and gerbils.

### 1.5.3 Soil and Seedbed Preparation for restoration

Restoration of a functioning community that will persist on its own requires that the soil be prepared in such a way that the seedbed favours the indigenous species, allowing them to out-compete other more weedy species. Correct seedbed preparation often determines the success or failure of a restoration project. It is one of the most labour intensive activities and is critical for the long-term establishment of target restoration species, as it provides them with optimal germination environments, allowing them to germinate earlier than existing weed species at the site and thus have an advantage over their competitors (White and Harper, 1970). The model seedbed should be composed of carefully tilled and sufficiently loose soil to enable water absorption yet still firm above and below the seedling depth to resist erosion.

The presence of Mediterranean grasses in CFSF old fields is an indicator that the soils have been enriched (Eliason and Allen, 2000) by agricultural runoff and the action of the woody legume invaders, and the natural symbiotic partnerships may have been disrupted (Vlok, 1988). In order for a stable fynbos community to be established these soils must be tested and the correct treatment applied prior to restoration activities. The addition of organic matter to the soil surface has been shown to increase water penetration and reduce wind erosion effects on the soil. For a stable soil structure to exist there ought to be a continuous input of organic matter (Chepil, 1955). The long-term success of restoration actions rely on a proper functioning hydrological system being established, as well as, adequate nutrient cycling for a particular vegetation type. Therefore, the ability of soils to allow water to percolate through must be tested, as this directly affects the establishment of autogenic processes and the continuity of an ecosystem. The infiltration rate of water into the soil is influenced by soil cover, porosity, and soil crusting, caused by soil biota or hydrophobic chemicals on the soil surface. Soil organic matter is a major biotic regulator of resources and directly affects water infiltration and evaporation. Disturbance regimes that reduce vegetative cover in turn increase the soil temperature in arid and semi-arid environments, this leads to an increase in the decomposition of organic matter until a point is reached where water is no longer available for decomposition processes and the cycle is broken (Lal and Cummings, 1979). Long-term loss of organic matter can have negative consequences for the availability of soil organic carbon (C), nitrogen (N), phosphorus (P) and the micro nutrients within degraded systems. Using wood chip mulch has been shown to have an effect on the nitrogen levels (Slabbert, 2008; Fisher et al., 2009b) in the soils and it is often the case that alien grasses and shrubs have taken up much of the available nitrogen from the soil and rain water has washed out many of macro-nutrients from the soil (Bengtsson et al., 2012). In nutrient poor fynbos soils the accumulation of nutrients has a negative effect on species establishment and leaching of the nutrients is not necessarily negative.

Formation of a hydrophobic layer on the soil surface either as a result of soil compaction or the baking effect of the sun on the open ground (Rokich, 1999), can hamper root penetration and limit the movement of water within the soil. It has been shown that lightly tilling the soil can reduce these effects and increase saturated hydraulic conductivity, therefore increasing the water filtration of the soil (Holmes and Foden, 2001). However, even in sandy soil tilling can have a positive effect on plant growth; trees planted in soil that was tilled to a depth of 1.2 m grew higher than those planted in untilled areas after a period of 5 years on old mined lands in Western Australia (Ashby, 1997). In additional it was found that 4 out of 5 species planted in tilled soils had longer shoot lengths than plants planted in untilled soils (Yates et al., 2000). In another study 62% species tested had tap roots that were longer and fewer lateral roots in tilled soil when compared to undisturbed soil (Rokich et al., 2001). Topical experimental work indicates that some degraded systems are resilient to conventional restoration efforts due to constraints such as fragmentation of habitats, loss of indigenous soil stored seed banks, shifts in species dominance, and invasion by exotics, and associated effects on biogeochemical processes (Suding et al., 2004). Selectively manipulating the soil to prepare a seedbed for restoration sowing can provide good control over competing vegetation and allows for spacing and density control of the initial seeding (Barnett and Baker, 1991).

Preparation of the soil substrate to receive seeds depends on the requirements of the species to be sown and the elements of the site itself. Soil cultivation to produce flat clean seedbeds is generally not recommended where slopes exceed 20% and the soils are sandy and loose, as these are more susceptible to erosion (Banerjee, 1990). Wind and water eroded sands may bury or expose seeds and damage or kill young plants. The creation of a rough surface by ploughing furrows or placing depressions in the seedbed surface reduces wind velocity across these surfaces (Whisenant, 1995; Coetzee, 2005) and seedling survival is highest in the bottom of these depressions (Hull, 1972). Disking and ploughing soils to create furrows and ridges facilities precipitation use by pooling the water to slowly seep into the soils rather than running off down slopes. General guidelines for furrow depth and width in compacted or sandy soils are; between 100 mm-150 mm deep and 450 mm apart (Ward et al., 1996; Visser et al., 2010). This improves water penetration, reduces wind erosion and prevents excessive competition between planted species.

Ensuring that seeds are covered with soil and have good seed-to-soil contact can be achieved by covering the seeds with soil once it has been sown. This is done by ‘rolling after broadcasting the seeds to cover seed and firm the soil’ (Whisenant, 1993) and is most effective on freshly ploughed and sown seedbeds (Vallentine, 1989). Rolling is a technique done by dragging a pole, plank or chain across the soil surface to lightly fill in the furrows and stabilize the soils. Seedbed treatments that do not cover the seed directly once sown rely on the rains to erode the sides of the furrow and place soil at the bottom, covering the seeds. To prevent erosion of slopes, furrows and pits must be contoured along a slope; perpendicular to the slope. They also act as water catchments and trap wind-blown soil, nutrients, organic matter and seeds. These have been shown to greatly benefit restoration efforts in arid and semi-arid environments (Whisenant, 1995; Visser et al., 2010).

The use of polyacrylamides (PAM),which are soil conditioners that increase water infiltration, binding soil particles to other soil particles, organic matter and seeds, has been shown to improve seedling emergence (Newquist, 2009). These are applied in granular or water based solutions directly to the soils and is used in the hydro seeding process, whereby seeds are broadcast from a high pressure water tank. This method rapidly stabilizes loose and easily eroded soils and is an ideal method of sowing seed on slopes (Sheldon and Bradshaw, 1977). Seed-to-soil contact is often reduced if mulches are used (Munshower, 1994), as they create barriers between the soil and seeds, yet costs increase the more additives (fertilizers, mulches, binders etc.) are placed into the mix.

#### 1.5.3.1 Timing of sowing

Timing of sowing of seeds is a key factor in the success of the survival of the plants. Germination and seedling establishment require sufficient soil moisture and ideal temperatures. The best time to sow seeds in the Western Cape is just prior to the winter rains in March and April. This allows the seeds the maximum period of favourable conditions to establish before the harsh summer conditions. Sowing seeds in the open natural environment has risks of unanticipated weather events and extreme conditions causing seeding failures (Ries and Hoffman, 1996) and success is not guaranteed when operating in the natural environment with uncontrollable conditions. Other risks of sowing in the autumn include the predation of the seed by rodents including fossorial mammals which are highly active before the cooler winter season (Lefroy et al., 1991) and the potential for spring weeds to outcompete the sown seeds. By sowing seeds of competitive and early germinating species, they are more likely to capture resources at the expense of later-emerging weed seeds (Ross and Harper, 1972). The accessibility of the site to seeding equipment may also affect the timing of sowing, heavy clay soils cannot be worked in the wet rainy season and sowing must be done in the spring (Heady, 1975). On old sandy fields, activity of burrowing animals makes the site unsafe for large tractors and other machinery with a risk of becoming mired in the soft sand. For this reason it is best to prepare the seed beds and sow after the first rains in the autumn and once the foraging activity of the fossorial mammals has ceased and prior to winter burrowing activities.

#### 1.5.3.2 Seeding rates

The amount of seed sown is known as the seeding rate (number of seeds per area, kg/ha). The seeding rates should be high enough to produce the required cover and density for restoration. Rates are often measured by Pure Live Seed (PLS) or bulk seed. PLS is more often used in restoration and repair of ecosystems and guidelines include: 200 - 400 $PLS.m^{-2}$ for grasses and 100 - 300 $PLS.m^{-2}$ for herbaceous perennials on old fields (Vallentine, 1989) which equates to 10 plants. $M^{-2}$. Other recommendations are 5-10 $kg.ha^{-1}$ for larger seeded species (Hull, 1972) and 30 g to 3 $kg.ha^{-1}$ for small seeded species (Kilcher and Heinrichs, 1968). It must be kept in mind that these rates are for the northern hemisphere and very little information is available for CFSF. Holmes (2002) recommended a rate of 50 $kg.ha^{-1}$ mixed species, dried and uncleaned seed, although this appears to be a large amount, losses during germination and establishments necessitate these rates. Restoration contractors, using common annual and herbaceous perennial species, recommend 10 $kg.ha^{-1}$ PLS equivalent for fynbos vegetation (Deon Van Eerden, pers comm.). On average only 10 – 30 % of planted seeds produce seedlings and less than 50 % survive a full growing season (Decker and Taylor, 1985; Vallentine, 1989). Establishment rates for sowing wild species seed are low (5 - 15 %). Total failures can occur should environmental conditions and seed quality be poor. When broadcast or hydro-seeding, rates should be doubled to compensate for the uneven seeding depth, uncovered seed and seed predation by animals (Vallentine, 1989). Rare and endangered plant seeds ought to be planted with more precision due to the low seeding rates as a result of the unavailability of large amounts of seed. Similarly with small amounts of seed, bulking agents such as sawdust, silica sand, vermiculite and other free-flowing inert materials can be used to evenly spread the seed when sowing and aid in embedding it onto and into the soil surface. The depth of seeding is dependent on the species being sown and is a compromise between providing a suitable environment for the seed to germinate and grow, and the seed being able to emerge from the soil. The optimal seed depth varies with the seed size, germination requirements and availability of water. A general calculation is four to seven times the seed diameter (Roundy and Call, 1988; Welch et al., 1993). Seed germination after light rains on sandy soils is highly susceptible to desiccation, whereas deeply buried seeds are protected against rapid loss of moisture and other weather extremes. It has been found by Decker and Taylor (1985) that deeply buried seed emerge more easily in sandy soils than clay soils and the seedlings show more vigor as the energy required to germinate through the sand was less (Harper, 1977; Steffen, 1997). Seeding rates are high when sowing wild species seed as the germination rate is low (Decker and Taylor, 1985b). The broadcast seeding method requires that rates are doubled to compensate for the uneven spread and depth of seeding (Vallentine, 1989).

### 1.5.4 Fire as a tool for restoration

The fynbos vegetation types of the Mediterranean-climate regions of South Africa are a perfect example of a fire-prone and fire-adapted ecosystem that are managed for conservation purposes using prescribed burning (Richardson et al., 1994). Fynbos is known for its diversity and species-richness (Cowling et al., 1997), and fynbos maintenance calls for fynbos to be burned at 12 – 15 year intervals in late summer or early autumn (Van Wilgen et al., 1992). Fire is an important ecological process in the CFR and in many of the world's ecosystems (Van Wilgen et al., 2010). It creates the conditions necessary for reproduction and persistence of plant communities by removing above ground biomass, stimulating germination and recycling nutrients back into the system (Bond and Keeley, 2005). Fires form an important element in the control of invasive alien species (Holmes et al., 2000) and the re-establishment of species as part of ecosystem repair (Hobbs and Harris, 2001). Many of the fire adapted plant species within the CFR are dependent on the fire regime particular to that vegetation type (Bond and Van Wilgen, 1996; Driscoll et al., 2010). The Western Cape Province has warm, dry summers that promote the regular occurrence of fires. The inland zones of the CFR experience a more severe fire climate than the coastal zones, with three times as many days being classified as either high or very high in terms of fire danger rating (Van Wilgen et al., 2010). CFSF occurs in the western coastal region of the CFR and historically natural wildfires took place from November to March. The fire regime of CFSF is characterised by dry-season (November to March) fires at intervals of between 10 and 20 years (Heelmann et al., 2008). The species found in CFSF have adapted to such a fire regime over millennia and rely on burns taking place within this time frame in order to survive. Shifts in fire season are detrimental, and fire managers should seek to burn in appropriate seasons (Van Wilgen et al., 2011), and at appropriate intervals, to prevent population declines (Van Wilgen et al., 1992). The fire seasons for the Southern Hemisphere Fynbos Biome are defined as summer (November–February); autumn (March–April); winter (May–August); and spring (September and October) (Forsyth and Van Wilgen, 2008). It is recommended that prescribed fires in summer and autumn are regarded as optimal for the health of fynbos ecosystems (Van Wilgen et al., 1992), restoration (Hobbs and Harris, 2001), fire safety (Duren and Muir, 2010) and climate change mitigation (Bond and Keeley, 2005). Taking all factors into consideration for restoration of CFSF, a prescribed burn must be done in February, March or April prior to the first rains of the autumn season.

Winter burns are generally not recommended for the restoration of fynbos as the long interval between burning and the onset of suitable growing conditions (6 - 9 months post-fire) will have detrimental effects on the vegetation (Van Wilgen et al., 1992). These requirements include sufficient moisture (precipitation) once seed has germinated to allow the seedling to establish and survive the dry summer conditions experienced in the Cape (Van De Venter et al., 1986; Holmes, 2001). Holmes (2001) found that fire intensity and heat penetration into the soil were much greater for summer fires than winter burns; this indicates that germination cues were not optimized by winter burning. This research also proposed that soil-heating was much less in large grained soil than finer grained soils due to less air spaces and insulation between particles, thus promoting the use of summer burns for CFSF and possible spring/winter (September) burns on granite fynbos. Sites that have been covered with alien species for more than four decades generally have low seed persistence and remaining seed is buried deeper in the soils (Holmes and Foden, 2001). The penetration of heat into the soil to stimulate germination is therefore vital. Moist soils conduct heat less that dry soils and that deeper seeds were not stimulated to germinate in moist soils (Whelan, 1995), for this reason prescribed burns take place prior to rains when soils are still dry.

The fynbos ericaceous and proteaceous species were found to respond to brief exposures to high temperatures (96.5 °C) (Van De Venter et al., 1986), however moderate temperatures (12 - 20°C) tend to favour most fynbos species to germinate (Brown, 1993). It was found that older seeds required slightly higher temperatures to germinate, therefore, the incorrect fire season and the lack of germination stimulants and post germination grow regulators can lead to the collapse of a species (Bond et al., 1990). From the above it can be seen that the practices employed using fire in restoration programmes in other areas may need comprehensive research for CFSF vegetation.

## 1.6 Vegetation replacement

To increase the rate of repair of a system plants or seeds require being in the soil at the optimum time and under ideal conditions. Re-introduction of indigenous species by seeds may be cheaper in an order of magnitude and possibly offers the potential for restoring greater biodiversity than by planting (Gaertner et al., 2007). As a key step in restoring fynbos in the lowlands, it is important to investigate which different germination treatments and sowing techniques are the optimal for indigenous species re-introduction. Direct sowing of seeds onto the soil has many advantages over planting nursery germinated seedlings or plants. Seeds are more readily collected and are easier and cheaper to store and maintain than scions from plant and living plants respectively. Seeds are easier to transport and require less time to plant (Barnett & Baker, 1991). Using seed requires that species dormancy is broken before sowing so that germination is not delayed and the seedling has the best possible chance of survival. Seed dormancy falls into two categories, internal dormancy which is a result of incomplete digestion of fats, proteins and other complex compounds within the seed (Smith, 1986) over time these are converted to usable substances for the developing embryo. The technique used to over-come this type of dormancy is stratification of the seed at high or low temperatures depending on the species requirements. The second type of dormancy is physical dormancy, caused by hard seed coats that prevent oxygen and water penetration into the seed. Weathering of the seed coat over time allows oxygen and water to enter the seed coat and initiate germination. Mechanisms to overcome this include chemical and/or physical scarification of the seed coat and heat (Pierce and Moll, 1994; Brown and Botha, 1997; Merritt et al., 2007). The use of acids has been found to work on leguminous seeds, by soaking in sulphuric or nitric acid (Baskin and Baskin, 1998). Soaking in hot water has been found to split the seed coat and allow water and air in (Brown et al., 1999). Tumbling seed in a container with coarse sand is an efficient way to mechanically scarify large amounts of seed, rubbing larger seeds with sand-paper or chipping holes in the seed coat is usually done with small amounts of seed and rare species (Pierce and Moll, 1994).

## 1.7 Study Site - Blaauwberg Nature Reserve

The Blaauwberg Nature Reserve currently is being proclaimed under the National Environmental Management: Protected Areas (NEM: PAA Act 57 of 2003) as a Provincial Nature Reserve. It has recently increased in size to 1445 hectares and is situated 25 kilometres north of the City of Cape Town (33° 45’ 29.79”S 18° 27’ 58.13”E). The reserve offers the best viewpoint in the world where two proclaimed world heritage sites (Table Mountain and Robben Island) can be seen. The Blaauwberg Nature Reserve (BBNR) is situated along the West Coast of South Africa between Table Bay and Saldanha Bay, and has a Mediterranean climate with an annual rain falling mainly in the winter months (June, July and August). The parent soils found at BBNR are quaternary sands along the coast and inland flats and Malmesbury Shale on Blaauwberg Hill. The eastern inland slopes of Blaauwberg Hill have been used for agricultural crop cultivation and cattle grazing since the 1960s, in the late 1980s the site was left fallow and invaded by *Acacia saligna*. These plants were a major threat to the Cape Flats Sand Fynbos vegetation type found on the eastern slopes of BBNR, which is a critically endangered vegetation type that supports 47 Red List threatened species. The custodian of BBNR, the City of Cape Town, has declared their intentions to restore the threatened vegetation types and species at BBNR, through appropriate ecological management.

**Figure 1.2:** Aerial photograph of eastern slopes of Blaauwberg Hill and BBNR study site outlined in black

## 1.8 Site description

### 1.8.1 Climate

The BBNR falls within the West Coast Biosphere and has a Mediterranean climate with hot dry and windy summers and cool, wet winter and an annual rainfall of >500 mm. The majority of this rain falls in the winter months with occasional summer showers. The average minimum and maximum winter temperatures are 8°C and 21°C, respectively. The average minimum and maximum summer temperatures are 14°C and 28°C, respectively (Figure 1.3).

Rainfall is extremely variable per month; however the majority of the rain falls from May to August. The mean annual rainfall for the area is 401-500 mm (Figure 1.4).

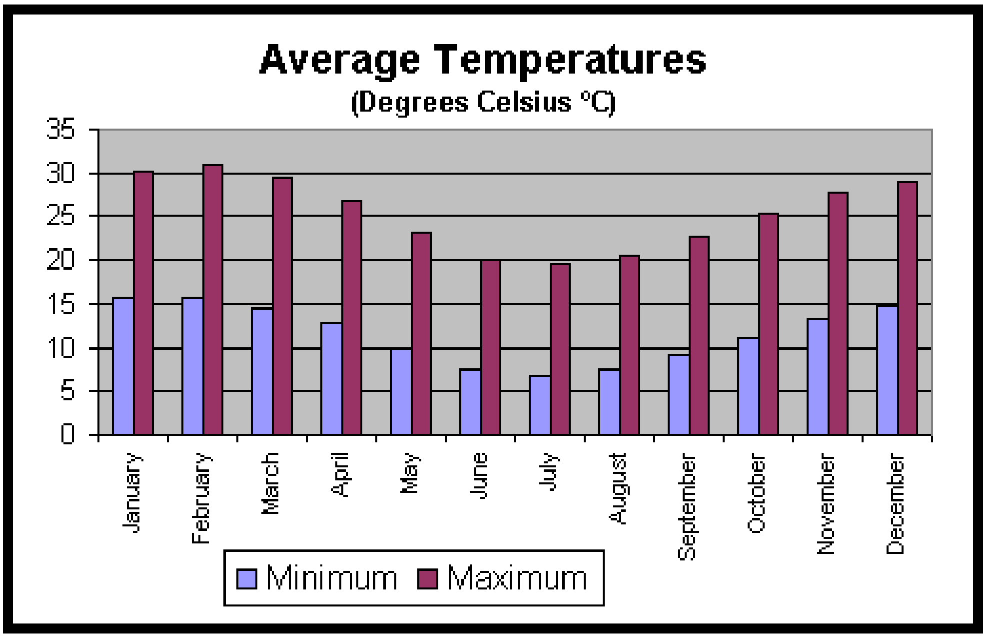


**Figure 1.3:** Monthly maximum and minimum air temperatures (averaged over 5 years) for the Blaauwberg Nature Reserve

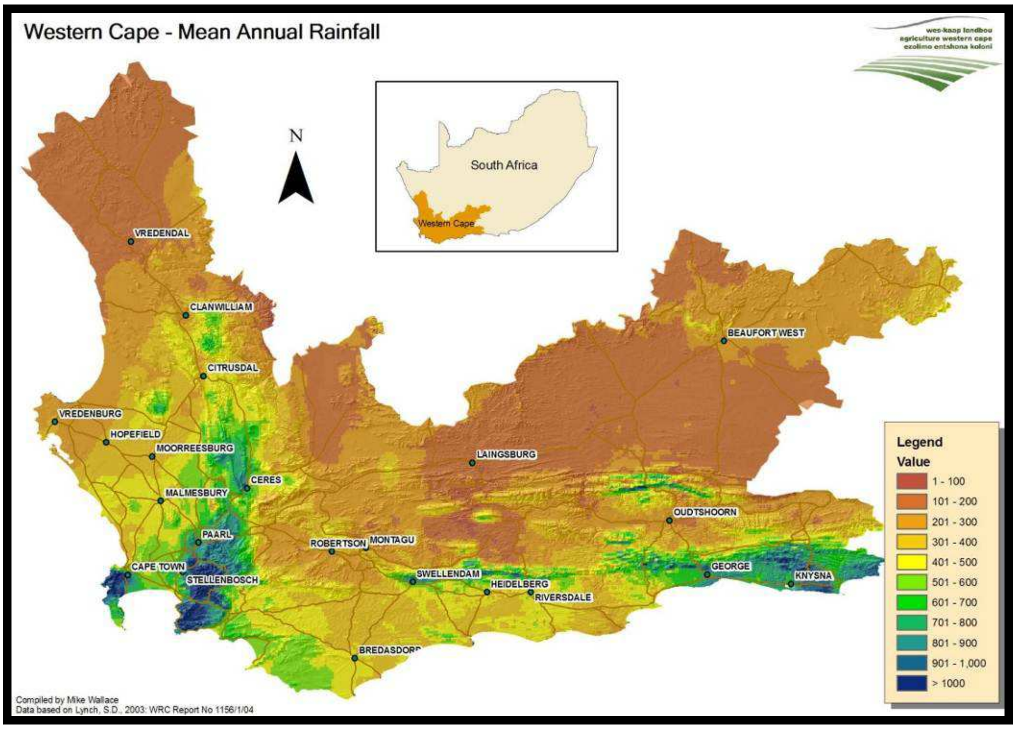


**Figure 1.4:** Mean Annual Rainfall for Western Cape Province, South Africa

### 1.8.2 Geology and soils

The Cape has an ancient landscape that predates the separation of the Gondwana super-continent and the formation of the African continent. Sediments deposited between 450 and 350 million years ago in the sea that had separated the African and South American continents and formed the substrate of the Cape and are now known as the Cape Supergroup (Compton, 2004). Roughly about 65 million years ago continental collision formed the Cape Fold Mountains and subsequent weathering of the softer shales of the Cape Supergroup resulted in undulating valleys and flats. These highly weathered areas exposed Pleistocene sands which later formed the basis of the Cape Flats Sand Fynbos habitat (Cowling and Pierce, 1999). These soils are typically highly leached, acidic soils and have a low nutrient status.

### 1.8.3. Vegetation

Three threatened vegetation types (Figure 1.5) occur within the BBNR: Cape Flats Dune Strandveld (endangered), Swartland Shale Renosterveld (critically endangered), and Cape Flats Sand Fynbos (critically endangered), as listed in the National Spatial Biodiversity Assessment (Rouget et al., 2005). Approximately 598 plant species have been identified in the BBNR, 47 of these are Red List threatened species (Raimondo et al., 2009). The keystone floral species occurring at the study site and listed as characteristic of Sand Fynbos, Strandveld and those occurring in the Renosterveld/Sand Fynbos ecotone (Rebelo et al., 2006),are listed in Table 1 below, a full list of floral species found at BBNR is in Appendix A.

**Table 1.1**. Floral species occurring in the vegetation types found at Blaauwberg Nature Reserve.

| Sand Plain Fynbos | Strandveld | Renosterveld/Sand Fynbos Ecotone |
|---|---|---|
| ***Staavia radiata*** | *Eriocephalus africanus* | *Jordaaniella dubia* |
| ***Erica mammosa*** | *Chrysanthemoides monilifera* | *Asparagus capensis* |
| ***Leucadendron salignum*** | *Euclea racemosa* | *Dimorphotheca pluvialis* |
| ***Protea repens*** | *Olea exasperata* | *Ursinia anthemoides* |
| ***Protea scolymocephala*** | *Salvia Africana-lutea* | *Metalasia densa* |
| ***Serruria decipiens*** | *Putterlickia pyracantha* | *Hermannia linifolia* |
| ***Passerina corymbosa*** | *Ruschia macowanii* | *Dicerothamnos rhinocerotis* |
| ***Thamnochortus punctatus*** | *Phyllobolus canaliculatus* | |
| ***Pelargonium capitatum*** | | |
| ***Staberoha distachyos*** | | |


***a)***


***b)***


c)

**Figure 1.5:** Vegetation types at BBNR. a) Cape Flats Dune Strandveld (back ground); b) Swartland Shale Renosterveld, dominated by geophytes and Dicerothamnos rhinocerotis; c) Cape Flats Sand Fynbos, dominated by small shrubs and restios

### 1.8.4 Animals

There are a total of 42 mammals recorded at the BBNR site and this includes whales, dolphins and seals found along the Strandveld coast and Aardvark, Honey Badger and the White-tailed mouse (Raubenheimer, 2009) inland. Twenty-eight reptile species, 30 butterfly species and 5 amphibian species have been listed at the BBNR and 140 bird species, including the rare Layard's Titbabbler.

## 1.9 Conclusion

From the above it can be seen that research undertaken on CFSF and restoration of Mediterranean ecosystems in general has highlighted the fact that the reintroduction of indigenous species has become increasingly important in conservation worldwide for the recovery of threatened ecosystems; however, few studies have reported the outcome of reintroduction efforts of plant species (Godefroid et al., 2011). The evidence is there that each vegetation type is unique and requires a unique set of solutions to restore its functions and processes. The approach towards restoration of any system should therefore be to analyse the drivers of disturbance or transformation and decide what the desired state of the system is that restoration is aiming at. Once this has been done the drivers must be halted and the methods of restoring the system to its desired state analysed. For Cape Flats Sand Fynbos the drivers of change include invasive alien plants, agricultural practices and human settlement. On old agricultural fields further agents of change include fossorial mammals whose population numbers have increased beyond normal as a result of the above mentioned anthropogenic factors. Tools for restoration in CFSF include fire, herbicide and sowing or planting of pioneer guilds to initiate a restoration trajectory for the habitat. Soil testing, germination testing and methods of introduction require investigation as each ecosystem is unique and needs its own set of actions for restoration.

The Blaauwberg Nature Reserve has been established on a sound conservation foundation and has been identified by the City of Cape Town as a core conservation site for CFSF. Barriers that have been acknowledged at the reserve include invasive alien species (mainly *Acacia cyclops* and *Acacia saligna*), historical disturbance to the soil by agriculture and a resultant modification of the ecosystem. This study investigated seed germination and application methods onto old fields for the purpose of restoring CFSF. Site and seedling treatments were investigated in order to maximise seedling recruitment, survival and growth at BBNR.

Chapter 2 examines the soil properties at the BBNR site for nutrient content which may have been altered by historical agricultural practices at the site. The condition of the soil surface was recorded and all analyses were summarised and potential soil improvement recommendations made.

Chapter 3 discusses the site and seed bed preparation using prescribed fire to remove alien vegetation and disperse fossorial mammals, the removal of problem causing fauna that could affect the seedling establishment and survival, and the use of herbicides to control perennial weeds, grasses and alien vegetation.

Chapter 4 investigates the collection and germination of twenty-three selected species for CFSF. Collection and storage methods were recorded and x-ray results of seed collections were analysed. Germination requirements included smoke and scarification treatments. The costs associated with both collection and germination treatments are presented and potential methods for reducing costs recommended.

Chapter 5 discusses the seedbed preparation and sowing techniques of; broadcast and planking, broadcast and hoeing, and hydro-seeding as potential solutions of restoring natural vegetation into old fields and initiating autogenic repair. It also examines the costs of each site treatment and recommends the best economic and ecological restoration method.

Chapter 6 presents a synthesis of the findings in this study in terms of the restoration of old field sites for Cape Flats Sand Fynbos.

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# CHAPTER TWO

# SOIL CONDITION AND NUTRIENT CONTENTS ON OLD FIELDS IN SAND FYNBOS AND ITS IMPLICATION FOR RESTORATION

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## 2.1 Abstract

Restoration of Cape Flats Sand Fynbos on old fields is affected by many factors, fossorial mammals, invasive plant species and fire. The effects of previous land use practices on the soils of a Cape Flats Sand Fynbos restoration sites may adversely affect the establishment of restoration plant species. The test site for this study was on the south eastern side of Blaauwberg Hill in the Western Cape Province. A random split-plot replicated block design was used, the trial site covered an area of 118m x 56 m and comprised of five replicate blocks; each block was subdivided into four 20 x 10 m plots with 5 m buffers around the perimeter of the site and 2 m buffers between plots. The dimensions of the site layout were chosen to obtain results applicable to large scale restoration. A visual analysis of the soil surface conditions was done to gather information on the hydrologic, stability and nutrient cycling processes of the soil and soil samples were randomly taken within each of the 5 blocks across the 1 hectare study site and analysed for chemical content. Macro and micro nutrients, salt content, pH level and carbon composition were recorded. The analysis showed that the soil nutrients at the site were within the accepted norms for fynbos soils, which were known to be nutrient poor with minor deficiencies in copper, magnesium and calcium. All of the soils tested showed extremely low levels of organic matter and organic carbon. This has implications for the processing of nutrients within the soils and percolation of water into the soil, and could be a limiting factor in fynbos establishment. Further research is required on the how best to enrich the site with the correct organic matter to promote the establishment of Cape Flats Sand Fynbos and to encourage micro biota to return to the soils.

**Key words:** Seed; rehabilitation; alien invasive; degraded

## 2.2 Introduction

Soil cover protects the soil surface from rain drop impact which can lead to sealed soil surfaces and decreased infiltration and increased water loss as runoff (Thurow and Juo, 1991). The removal of vegetation and biotic materials on old fields accelerates the runoff and degradation cycle by drastically reducing the water available for plant growth. A study undertaken on the Cape Flats Sand Fynbos (CFSF) at Riverlands Nature Reserve in Cape Town indicated that these sandy soils were very infertile and at a risk of severe erosion (Yelenik et al., 2004) through removal of vegetative cover and excess water runoff. Abiotic crust formation on sandy soils greatly lowers the infiltration rates of water. Studies on old fields in Israel found that infiltration rates were reduced from 100 mm $.hr^{-1}$ to 8 mm $.hr^{-1}$ with crust formation on sandy soils (Morin et al., 1981). Long-term loss of organic matter in CFSF can have negative consequences for the availability of soil organic carbon (C), nitrogen (N), phosphorus (P) and the micro nutrients (Yelenik et al., 2004).

Nutrient cycling is an important process in the nutrient-deficient adapted fynbos vegetation that has evolved under low fertility conditions (Stock and Allsopp, 1992). Fynbos can only process nitrogen at low levels, it cannot take advantage of elevated nitrogen levels as can certain legumes and herbaceous species, this is known as a ‘paradox of enrichment’ where high amounts of nitrogen favour certain species to the detriment of others even in their native environments (Rosenweig, 1987). Fynbos plants translocate a high percentage of their nutrients out of old leaves to newer growth before shedding, the resultant leaf litter has a lower nutrient content (Bengtsson et al., 2011; Bengtsson et al., 2012). The leaves decompose slowly releasing the nutrients into the soil, this is a conservation method of nutrient cycling in fynbos, as well as arid and semiarid ecosystems (Poorter et al., 1990). Nitrogen-fixing plants (mainly legumes) are an essential component of restoring ecosystems and returning lost nutrients to soils. It has been found, however, that alien invasive species that are nitrogen fixers may inhibit establishment of natural vegetation (Walker and Chapin, 1986, Morris and Wood, 1989) by increasing the amount of available N in a system beyond what the local plant species can assimilate (Yelenik et al., 2004).

Agricultural activity and alien plant infestation may have altered the state of the soils on old fields at the Blaauwberg Nature Reserve (BBNR) as no natural recovery of CFSF was observed following cessation of agricultural activities or alien plant removal. To determine if these factors have adversely affected the nutrient status of these soils and their ability to support the establishment of natural CFSF, soil samples were collected, a chemical analysis and visual assessment of the old field study site at BBNR was done. The objectives of the study were therefore to test the soil conditions at the BBNR to develop practical and effective repair strategies. Parameters that were investigated include; hydrology (infiltration and runoff), nutrient content, pH, and erodibility (ability to endure erosive forces).

### 2.2.1 Geology of the site

The Blaauwberg Nature Reserve falls within the Malmesbury suite of rocks, some of the oldest sediments in the Cape, these were originally deposited as marine mud and muddy sands, 1000 million years ago, in the Precambrian (Proterozoic) Era (Theron, 1983; Harland et al., 1990; Compton, 2004). The Malmesbury group consists of a range of various sediments from clay to conglomerates, intruded by granites from the Cape Granite Suite. Erosion of these layers resulted in a level plain predominantly clay based which released exchangeable cations of calcium (Ca), potassium (K), magnesium (Mg) and sodium(Na), important elements in soil formation and plant nutrient cycling (Stock and Allsopp, 1992). The lower slopes of Blaauwberg Hill consist of deep soils and wind-blown sands (Compton, 2004), these are derived from sediments that accumulated in the Cape basin as near-shore sandy soils of the Table Mountain Group in the Palaeozoic era. These medium to coarse sands are typical of the nutrient poor soils and low pH levels of the ground water in the south-western cape region. The mid to lower slopes of Blaauwberg Hill were farmed from 1953 until 1968. Analysis of historical aerial photographs found that an agricultural crop (possibly wheat) was farmed for 15 years. Between 1968 and 1988 records from the area indicate that the site below Blaauwberg Hill was left fallow and used for pasturage for dairy cattle. The area was then gradually overgrown with invasive alien Acacia species until clearing was done in 1998 and the site left to recover. Factors such as parent material, rainfall, and type of vegetation are key in determining the properties of soils. Under cultivation, however, organic acids from plant roots, repeated use of fertilizers, plant removal, and replacement of nutrients by cattle dung eventually alters the composition of topsoil (Boyle et al., 1989; Piessens et al., 2006).

As agricultural activity and alien plant infestation may have altered the state of the soils at the site, a composite sample made up of subsamples of topsoil was collected from each selected site, to determine the condition of the soils and their suitability to support fynbos growth. A visual and chemical assessment was done of the study site at BBNR.

## 2.3 Methods and Materials

### 2.3.1 Chemical Soil Analysis

15 sub samples of soil were randomly taken from across each of the 5 replicate plots with the aid of a clean metal spade. The samples for each plot were taken from the soil surface to a depth of 20 cm; each sub sample was then placed in a clean plastic packet for transport. The sub samples for each plot were placed in a plastic bucket and thoroughly mixed to form composite samples and labelled for each plot. The composite samples were air dried at room temperature and a representative sample of 1 kilogram of soil was then sent for analysis of the pH levels, electrical conductivity measure, macro and micro nutrients, organic matter content and particle size analysis.

The organic carbon content was determined by Walkley-Black method. Total organic matter was calculated by multiplying the organic carbon by a factor of 1.72 as described by Walkey and Black (1934). The pH level was determined using the methods prescribed by the The Electrical Conductivity (EC) was diluted in a potassium chloride solution (approx. 0.001M), as prescribed by the Soil and Plant analysis Council of South Africa, to obtain the EC reading. The N content of the soil samples was determined by the micro-Kjeldahl method (Bremner, 1965). The Bray II procedure (Bray and Kurtz, 1945) was used to extract the available P in the samples. The cation exchange capacity (CEC) was determined by the ammonium saturation method (Chapman, 1965). Na, K, CA and Mg, the exchangeable bases were determined by atomic extraction with Potassium chloride and separated by titration. The available metallic micronutrients, of Cu, Zn, Fe, and Mn, were extracted using 5 mol mP3 DTPA (diethylenetriamine pentaacetate) at pH 7.3 and determined by atomic absorption spectrophotometry.

### 2.3.2 Visual analysis of soil surface conditions

The Tongway (1994) approach to assessing soil surface conditions was adopted using the eleven soil surface attributes developed to gauge damage to ecological processes of soil. Table 2.1 lists all the attributes measured in order to classify the soil at BBNR for its resistance to erosion, infiltration versus runoff and efficiency of organic matter production. Soil cover- raindrop interception was measured as the projected cover of perennial shrub cover to 0.5 m; this includes rocks, logs, sticks and large immobile objects that protect the soil surface from raindrop impact. Woody vegetation larger than 0.5 m is not included in this assessment nor was annual vegetative cover. The percentage cover of each shrub was calculated and assigned a class according to Table 2.1. Soil cover-overland flow obstruction is the projected cover of long-lived objects that obstruct wind flow rate, reduces loss and catches resources from across the landscape. Velocity of winds moving across the soils was measured on an open land and on the leeward side of both depressions in the soil surface and obstacles on the surface and their position in relation to the prevailing wind direction.

The average reduction in wind velocity (%) was given a class from Table 2.1. Soil crust flexibility is a good indicator of the resistance of the soil to erosion, soils with a smooth crust that conforms to gentle contours on the surface, erode less and allow water infiltration. Hard brittle crusts or broken fragmented crusts have lower infiltration rates and organic matter content (Tongway, 1994; Tongway, 1995). Visual test of crust flexibility, brittleness and coherence were done on the BBNR soils, by lightly pressing down on the soils and observing their reaction. The percentage of microbiotic crust cover was calculated for the site, by measuring identified microbiotic crusts in the 1ha test site and classed according to the table below. Soil surface fragments were immersed in a beaker of rain water and their reaction monitored over time, the resulting condition of the fragment indicates the susceptibility of the soil to erosive forces, once timed the slake test was assigned a class value from Table 3.1. A visible sign of erosion such as rills, channels, gullies and pedestalled plants were physically measured, recorded, and the type of materials eroded. This included unconsolidated depositions of sand, silt and gravel but excluded organic litter. Litter cover was measured as the percentage of local material covering the site that has been deposited or transported from nearby areas. The roughness of the soil surface known as microtopography was identified as depressions and undulations on the soil surface (furrows, burrows, hoof prints etc), this is an indicator of the ability of the soil to drain water and reduce runoff. Finally, the texture of the soil was obtained from the results of test samples submitted to Bemlab for soil particle size measurements.

**Table 2.1:** Surface attributes of soils and associated class (adapted from Tongway, 1994)

| | Class | | | | | |
|---|---|---|---|---|---|---|
| Assessment characteristic | 1 | 2 | 3 | 4 | 5 | 6 |
| Soil cover-raindrop interception | <2 % | 1-2 % | 2-5 % | 5-15 % | 15-50 % | >50 % |
| Soil cover- overland flow obstruction | 0 % | <2 % | 2-5 % | 5-15 % | 15-5 0% | >50 % |
| Crust brokenness | extensively broken | Moderately broken | Slightly broken | Intact | | |
| Microbiotic crust cover | <1 % | 1-10 % | 10-50 % | 2>50 % | | |
| Erosion features | extensive | moderate | slight | Nil | | |
| Eroded materials | extensive | moderate | slight | Nil | | |
| Litter cover | <1 % | 1-10 % | 10-25 % | 25-50 % | 50-100 % | 100 % & more |
| Soil microtopography | Smooth <3 mm deep | Few shallow depressions 308 mm | Deeper depressions 8 - 15 mm | Dee, extensive 15 - 25mm | Sink holes >25 mm | |
| Surface nature | Loos-sandy, over noncoherent sand | Crust is easily broken with finger pressure, and is brittle. Subcrust is noncoherenmt | Crust is moderately hard (needs plastic or metal tool to break, but brittle, breaking into amorphous fragments or powder. Subcrust in coherent. | Crust is very hard (needs metal tool to break surface), but is brittle, breaking into amorphous fragments or powder. Subcrust is hard and coherent. | Crust shows some flexibility when pressed with pen or finger pressure, or surface is self-mulching clay. Subcrust is coherent or strong crumb structure. | |
| Slake test | Very unstable. Fragment collapses in<2 seconds with a myriad of air bubbles into shapeless mass. | Unstable. Fragment substantially collapses over about 5 seconds, a thin surface crust, but >50 % of the subcrust material slumps to an amorphous mass | Moderately stable. Surface crust remains intact, some slumping of subcrust material, but <50 % of the subcrust slumps to an amorphous mass | Stable. Whole fragments remains intact over periods of 1 hour or more | | |
| Soil texture | Silty clay to heavy clay | Sandy clay loam to sandy clay | Sandy loam to silt loam | Sandy to clayey sand | | |

**Table 2.2.** Chemical analysis results of 5 composite soil samples from Blaauwberg Nature Reserve.

| | | | | mg .kg$^{-1}$ | | Exchangeable cations (cmol (+) . kg$^{-1}$) | | | | mg .kg$^{-1}$ | | | | | | cmol (+) .kg$^{-1}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample No. | pH (KCl) | Resist. (Ohm) | $H^+$ (cmol .kg$^{-1}$) | P Bray II | K | Na | K | Ca | Mg | Cu | Zn | Mn | B | Fe | C % | CEC (pH7) |
| Site A | 5.6 | 4460 | 0.35 | 7 | 24 | 0.03 | 0.06 | 1.28 | 0.18 | 0.09 | 0.3 | 4.6 | 0.09 | 40.66 | .055 | 1.38 |
| Site B | 5.5 | 4980 | 0.35 | 8 | 50 | 0.03 | 0.13 | 1.49 | 0.25 | 0.05 | 0.6 | 8.5 | 0.14 | 35.99 | 0.40 | 1.91 |
| Site C | 5.3 | 7340 | 0.40 | 5 | 45 | 0.04 | 0.12 | 1.57 | 0.24 | 0.03 | 0.4 | 7.6 | 0.11 | 38.78 | 0.70 | 1.88 |
| Site D | 5.3 | 5140 | 0.40 | 4 | 39 | .03 | 0.10 | 1.20 | 0.19 | 0.00 | 0.4 | 7.9 | 0.10 | 35.54 | 0.53 | 1.84 |
| Site E | 5.3 | 5430 | 0.45 | 5 | 41 | 0.03 | 0.10 | 1.59 | 0.24 | 0.00 | 0.6 | 10.7 | 0.11 | 52.43 | 0.64 | 2.06 |

| | mg .kg$^{-1}$ | | |
|---|---|---|---|
| Sample No. | Cl | $NO_3$-N | $NH_4$-N |
| Site A | 8.45 | 4.31 | 10.90 |
| Site B | 9.87 | 5.11 | 10.18 |
| Site C | 7.05 | 4.15 | 10.36 |
| Site D | 5.64 | 3.50 | 9.52 |
| Site E | 8.46 | 3.81 | 11.03 |

## 2.4 Results and Discussion

### 2.4.1 Chemical Analysis

#### 2.4.1.1 Total Organic Matter (OM) and Organic Carbon (OC)

Soil organic carbon (OC) ranged from 4 - 7 g/kg per soil sample tested (Table 3.2). The soil organic matter (OM) ranged from 6.88 - 12.04 g/kg a low reading, however, this is typical of sand fynbos soils (Low, 1983, Mitchell and Allsopp, 1984). The OC levels were critically low; this could lead to a low C: N ratio where soil microbes exposed to a Nitrogen-deprived environment are subjected to limited growth and their mineralization capability is greatly lowered (Bauer and Black, 1992). Soil OM, or colloidal humus, in ecosystems is regarded as an important source of soil nutrients and a determining factor in the availability of the majority of nutrients to plants (Agboola and Corey, 1973). The majority of N, P and S available to plants comes from soil OM (Sanchez et al., 2003). Soil OM increases CEC (Asadu et al., 1997), strengthens soil aggregate stability (Boyle et al., 1989), it provides a food source for soil microorganisms (Facelli and Pickett, 1991), improves water-holding capacity of the soil (Bauer and Black, 1992), soil tilth (Foth, 1990) and aeration of clayey soil. Organic matter in the soil plays a key role in the micronutrient status of the soil as it influences the concentrations of heavy metals (Zn, Cu and Mn) within the soils (Baruti, 1997). Practices that enrich soil organic content should be encouraged in unbalanced systems in order aid in the stabilisation of a natural nutrient cycle, thus encouraging the establishment of plants and increasing natural plant cover (Bengtsson et al., 2011).

#### 2.4.1.2 Soil pH

The pH of the BBNR soil samples ranged from 5.3 - 5.6 (Table 3.2). Soils with such low pH values are associated with fynbos vegetation types and are common in Sand Fynbos vegetation in particular (Slabbert, 2008). The soil pH values in this study were within the favourable pH range for most Fynbos species. Nutrient availability in relation to pH levels of soils are illustrated in Figure 2.1, low pH values of 5.3 can hinder availability of Ca, P, K and Mg. Boron (B), Copper (Cu) and Zinc (Zn) are most readily available from pH 5 - 7; and Iron (Fe) and Manganese (Mn) are abundant below pH 5, and can be toxic at these levels. Soil pH is important since it affects the ability of plant roots to absorb nutrients and can affect the severity of certain plant diseases. The acid and base levels of a soil solution are significant as microorganisms and plants are responsive to their chemical environment ,as such the low pH levels as found in the BBNR soil samples, the micro-organisms struggle to survive and breakdown the organic matter (Slabbert, 2008).

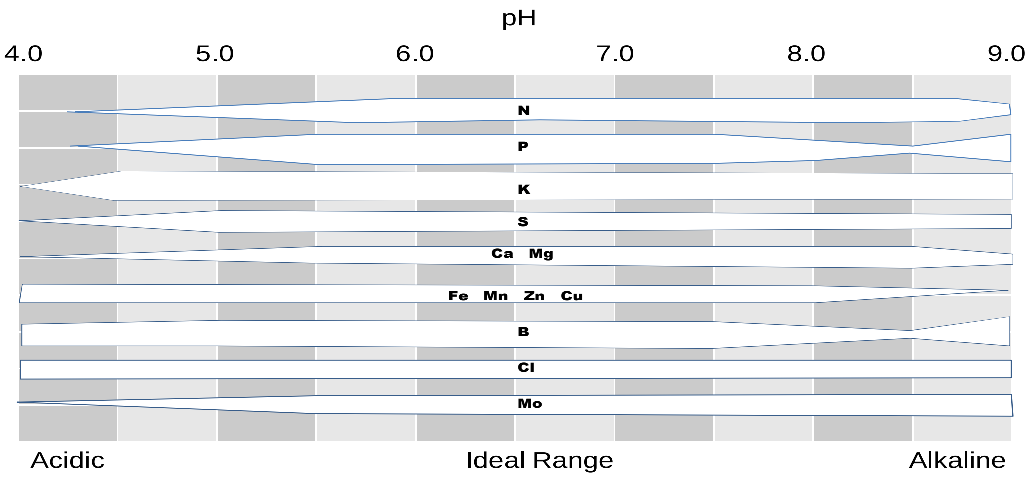


**Figure 2.1**: Nutrient availability with pH (adapted from Foth, 1990)

### 2.4.1.3 Electrical Conductivity (EC)

EC is the ability of a solution to conduct electricity and is used as an indication of the Na content of soils. The EC levels from the BBNR soil samples ranged from 3.4 - 5.6, these were very low signifying soils with low salinity. Readings of this level were expected for Sand Fynbos vegetation as it is a nutrient poor adapted vegetation type (Low and Rebelo, 1996).

### 2.4.1.4 Total Nitrogen (N)

Total N in the BBNR soil ranged from 3.50 - 5.11 $mg.kg^{-1}$ ($NO_3$-N) and 9.52 - 11.03 $mg.kg^{-1}$ ($NH_4$-N). The low N readings indicate that total N in most of the soils is not enough to support agricultural crops or microbial activities, but is sufficient for fynbos (Gaertner et al., 2007). The size of the N pool within a natural ecosystem is less important than the amount of available N relative to the total N (Skiffington and Bradshaw, 1981). Excess N can delay plant maturity, establishment of fynbos and encourage the establishment and dominance of exotic species. Nitrogen fixation by legumes is conducted through a symbiotic association between the plant root and *Rhizobium* bacteria in the soil (Heichel, 1985). Sites where exotic species dominate produce litter that was easily degraded and thus increase the amount of available N inhibiting the establishment of fynbos (Yelenik et al., 2004; Bengtsson et al., 2012). Fynbos produces litter at a slower rate that degrades gradually and therefore creates conditions that favour indigenous species. The most common sources of nitrogen for non-legumes are through the decomposition of organic matter and application of commercial nitrogen fertilizers. In reference to restoring natural processes to a previously disturbed site the application of commercial fertilisers is not viable in the long term (Bloomfield et al., 1982).

#### 2.4.1.5 Total Phosphorus (P)

The available P (Bray II) in the soils ranged from 5 - 7mg.$kg^{-1}$, the ideal level of P in a soil, for fynbos species, should be 10 mg.$kg^{-1}$ (Kotze, 2010). None of the soil samples contained sufficient levels of P; the BBNR soils are therefore highly deficient in P. This was justified as Sand Fynbos species were better able to compete with invasive alien species when P levels are lower than 30 mg.$kg^{-1}$ (Mitchell and Allsopp, 1984; Kotze, 2010). Phosphorus is necessary for the hardy growth of the plant and activity of the cells. Available P declines with a decrease in the pH value as a result of the formation of Fe and Al phosphates.

#### 2.4.1.6 Cation exchange capacity (CEC)

CEC ranged from 2.06 to 1.38 cmol (+) .$kg^{-1}$. All of the BBNR plots had CEC below 5 cmol (+) .$kg^{-1}$ this is suitable for fynbos (Table 2.2). The CEC of a soil is based on the percentage and type of clay mineral (e.g., smectites, kaolinites, & sesquioxides) and percentage organic matter, if this is very low it will affect the CEC. Soils with such low CEC values are typical of weathered soils (Thamm and Johnson, 2006) and therefore have a limited capacity to provide plants with nutrients such as Ca, K and Mg (Sanchez and Logan, 1992). Due to excessive erosion and weathering that took place at the BBNR study site, the soils that had a low CEC were prone to leaching of nutrients like K and Mg (Thamm and Johnson, 2006).

#### 2.4.1.6.1 Exchangeable Potassium (K)

Exchangeable K in the soil ranged from 0.06 - 0.13 cmol (+) .$kg^{-1}$, this is extremely low as ideal amounts of K in the soil for agricultural purposes should be approximately 70 mg.$kg^{-1}$ (Kotze, 2010). Due to the ability of fynbos to cope with low nutrient soils, these levels are acceptable (Low, 1983). Potassium is a positively charged basic metal cation whose total content in most mineral soils (it typically accounts for 2 – 8 % of the CEC) except in sandy natured soils, is greater than most of the other major nutrient elements. Soils which fix K serve as a bank which safeguards against leaching and ultimately, returns K to the exchangeable form which can be taken and utilized by plants. Soils which are predominantly sand with little or no clay have extremely low levels of natural K and are subject to severe leaching. Soils of this nature were common throughout the Cape Flats areas of the Western Cape Province in South Africa (Stock and Allsopp, 1992).

**2.4.1.6.2 Exchangeable Magnesium (Mg)**

Exchangeable Mg ranged from 0.18-0.25 cmol (+)/kg$^{-1}$. The proposed critical value in most crops is 2 cmol (+)/kg (Schwartz and Corrales, 1989). Mg was less than this critical level, suggesting that Mg supply in all the soils at BBNR were low and could limit the growth of plants (Stock and Allsopp, 1992). Deficiencies of Mg are more common on sandy soils with low CEC and organic matter content and usually accounts for 10 - 20% of the CEC (Kotze, 2010).

**2.4.1.6.3 Exchangeable Calcium (Ca)**

Exchangeable Ca ranged from 1.20 - 1.59 cmol (+) .kg$^{-1}$. The proposed critical level of Ca for a majority of plants is 5.0 cmol (+) .kg$^{-1}$ (Marx et al., 1996). All of the plots tested contained calcium levels lower than the suggested critical level; Ca was also the most dominant cation on the soil colloids (Eksteen, 1969). CEC normally has 70 - 85% Ca content.

**2.4.1.6.4 Micronutrients Copper (Cu), Zinc (Zn), Manganese (Mn), and Iron (Fe)**

Available Cu in the soil ranged from 0.00 - 0.09 mg.kg$^{-1}$. The lowest limit for Cu in soils is 0.2 mg.kg$^{-1}$, the plots at BBNR were therefore severely lacking in Cu. This was due to the severe leaching of Cu from the sandy soils at BBNR (Stock and Allsopp, 1992), although the pH level is sufficient to release Cu, there is no Cu at the site. Cu is required by plants as it activates several important enzymes.

Zn levels in the soil ranged from 0.3 - 0.6 mg.kg$^{-1}$. Levels of 0.4 - 0.6 mg.kg$^{-1}$ were considered the level at which Zn is deficient. All but one of the BBNR plots had sufficient levels of Zn (Holmes and Newton, 2004), Site A for example had a reading of 0.3 mg.kg$^{-1}$ of Zn (Table 2.2), although the pH for this site was 5.6 which is ideal for Zn availability. The resistance is similarly very low at 4460 (Ohm). Zn is an important growth regulator in plants and controls the synthesis of indoleacetic acid.

The Mn in the soil tests ranged from 4.6 - 10.7mg.kg$^{-1}$. Soils with a deficiency in Mn generally have values between 2.0 to 5.0 mg.kg$^{-1}$, only one of the plots tested had a level lower than 5.0 mg.kg. Block 5 (Appendix B). Site A had a reading of 4.6 mg.kg$^{-1}$, this was due to the lower pH reading, which will result in the non-release of Mn. The $H^+$ ions are lower for this plot than the others and will affect the low Mn reading. The remaining 4 plots had high values, due to the acidic pH readings but these levels do no warrant further intervention as they were not detrimental to Sand Fynbos (Kotze, 2010). Mn assists Fe in chlorophyll formation and serves as an activator of enzymes within the plant.

Fe in the soil ranged from 35.54 - 40.66 mg.kg$^{-1}$. All the samples tested were well above the critically deficient levels (0.3 - 10 mg.kg$^{-1}$) for available Fe in the soil (Stock and Allsopp, 1992). This was due to the low pH levels, as acidic soils release Fe and can cause Fe toxicity. Levels should however be monitored at BBNR in the future, as Fe is needed as it is an activator for respiration, is required for chlorophyll production, plays a part in photosynthesis and symbiotic nitrogen fixation in plants but in large amounts can be deleterious to fynbos (Corbineau and Come, 1995).

### 2.4.2 Visual analysis of soil surface conditions.

Each soil surface attribute was measured and assigned a class (Table 2.3) that in turn corresponds to a restoration action to improve soil conditions. Table 2.4 then identifies respective problems and potential solutions for short-term and long-term actions.

The visual analysis of the soils at BBNR indicates that the site was highly eroded by wind and that very little organic matter remained on the site. Due to low vegetative cover the compaction of the soil surface from raindrop impact was high, resulting in high runoff rates, fortunately the site had numerous microtopographic features which capture water and prevent large scale erosion. The sandy nature of the soil at BBNR was inherently unstable, however this was due to the parent materials of the soil and was a characteristic of Sand Fynbos vegetation types (Stock and Allsopp, 1992).

**Table 2.3**: Results of soil condition analysis at BBNR

| Assessment characteristic | *Result* | *Class* |
|---|---|---|
| **Soil cover-raindrop interception** | *15-50%* | *5* |

| | | |
|---|---|---|
| **Soil cover- overland flow obstruction** | *15-50%* | *5* |
| **Crust brokenness** | *Slightly broken* | *3* |
| **Microbiotic crust cover** | *>50%* | *4* |
| **Erosion features** | *Nil* | *4* |
| **Eroded materials** | *Nil* | *4* |
| **Litter cover** | *1-10%* | *2* |
| **Soil microtopography** | *Deeper depressions 8-15mm* | *3* |
| **Surface nature** | *Loos-sandy, over non-coherent sand* | *1* |
| **Slake test** | *Very unstable* | *1* |
| **Soil texture** | *Sandy to sandy clay* | *2* |

The particle size analysis showed that all the tested plots consisted of sand, with no significant clay or loam particles. The sand fraction in the soils is an indication that the soils are infertile and highly susceptible to wind erosion. By increasing the surface roughness of the soil and placing obstacles perpendicular to the wind path, wind speeds can be reduced and thus reduce wind erosion of the sandy soils. Pits, furrows and basins can be dug into the soil surface to increase the roughness at relatively little cost, above ground obstacles such as logs, branches (known as brush stacking), rocks, mulch and man-made erosion control (gabions) can be used simultaneously with the depressions, but costs are higher for placing above ground obstacles. Both of these methods will pool water and allow for infiltration, reduce wind speeds and trap seeds, organic debris and soil particles over time (Kennenni and Van de Maarel, 1990), they are however not ideal for sandy soils (Whisenant, 1995). On sandy soils the surface dips and obstructions should be close together to reduce the distance the finer sand particles can travel (Dixon and Peterson, 1971) and further decrease the speed that larger particles can reach which can weather structures and damage young vegetation. These measures facilitate the establishment of vegetative cover by continuing to capture and retain seeds, organic matter and soils on disturbed sites, allowing the initiation of a natural cycle of vegetation growth and regeneration.

**Table 2.4: Soil problems and potential treatments (adapted from Bradshaw, 1983)**

| Soil Attribute | Nature of problem | Class | Preliminary treatment | Long-term treatment |
|---|---|---|---|---|
| Physical | | | | |
| Structure | Too compact | 3 &4 | Rip, scarify, cultivate, incorporate organic matter or apply soil conditioner | |
| | Too open | 1 & 2 | Compact or cover with fine material | Increase vegetation, root biomass and litter |
| Stability | unstable | 1 & 2 | Soil stabilizer or mulch | Reshape slope, establish vegetation |
| Moisture | Too wet | 4 & 5 | drain | Use vegetation adapted to flooded conditions; use vegetation with high transpiration rate to lower water table |
| | Too dry | 1-3 | Organic mulch, pitting, micro catchments, contour furrowing, obstructions on soil surface to retain water and organic materials | Establish vegetation with structural and functional diversity |
| Biological | | | | |
| Soil organic matter | Low percentage | 1-3 | Organic amendments | Vegetation |
| Soil organisms | Low diversity | 1-3 | Reduce chemical and physical limitations of soil, organic matter amendments | Reduce physical and chemical limitations of soil; vegetation |
| Chemical (class not assigned to chemical attributes) | | | | |
| Macronutrients | Insufficient quantity or availability | | Fertilizer, use species adapted to infertile environments | Establish species or symbiotic associations capable of fixing nitrogen; establish vegetation with mycorrhizal infections, use woody vegetation to retain nutrients on site |
| | High levels available | | Use annual/ perennial species adapted to high nutrient levels and remove material after growing season; graze animals on site to remove nutrients | Remove abundance species with high nitrogen fixing ability; graze site for nutrient removal |
| Micronutrients | Insufficient quantity or availability | | Fertilizer, use species adapted to infertile environments | |
| pH | Too basic | | Pyritic waste or organic matter | Weathering, acidifying vegetation |
| | Too acidic | | Lime, adapted vegetation | Cation pumping vegetation |

**2.5 Conclusion**

Nutrient levels in old fields require testing and rather than focus on addition of nutrients and chemicals to alter the balance, the focus for ecological restoration should be on repairing the damaged nutrient cycling function of the ecosystem. Restoration of CFSF requires that all factors leading to its degradation are known and if they still continue to have an impact on the old fields. A number of important edaphic processes need to be assessed before restoration actions can be decided upon.

The chemical soil analysis for the nutrient status of the BBNR plots showed that the major elements of N, P and K were all within adequate levels for sand fynbos species and that the past agricultural activity of fertilizing and grazing of cattle had left little residual nutrient elements. The N levels at the study site were not adversely affected by the historic presence of alien Acacia species (Yelenik et al., 2004) and that enough time had lapsed between clearing operations and leaching of excess N from the sandy soil. All of the samples tested showed extremely low levels of organic matter and organic carbon. This has implications for the processing of nutrients within the soils and could be a limiting factor in long term persistence of fynbos establishment. Overall, the nutrient status of the soil at BBNR was suitable for fynbos establishment and growth. The future status has not been severely affected by past land use practices or alien vegetation.

Visual soil analysis found that the BBNR soil on the old fields was very sandy and highly erodible by wind. It was found that the low levels of organic matter of the soil directly affected the absorption and retention of water in the soil. In order to stabilise the sandy soil at BBNR, it is recommended that mulch, such as sterile straw, should be added on top of the soil, this will also increase the humic component. A soil conditioner or binder should be used, in the short term, to stabilise the soil for seedling and plant establishment by breaking the hydrophobic barrier on the soil surface and allowing water to percolate through. Further research is required on how best to enrich the site with the correct organic matter to encourage micro biota to return to the soils and ensure its presence and availability to CFSF.

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# CHAPTER THREE
# SITE PREPARATION TO OPTIMISE SEEDLING ESTABLISHMENT IN SAND FYNBOS

## 3.1 Abstract

The critical first step to restoring a functioning ecosystem is to halt the degradation of the existing site and activities that prevent recovery. At the Blaauwberg Nature Reserve two main drivers of degradation were identified and methods chosen to halt each. Firstly, problem animals at the site are the fossorial mammals that eat the seeds and uproot young seedlings. Control methods included erecting a fence around the site, owl nesting boxes, raptor perches and a knockdown of the population using chemical pellets. These methods proved successful in reducing fossorial mammals' numbers in the initial stages of seeding and seedling establishment, however small mammal control is not a once off procedure and must be continued until natural unassisted regeneration of plants species occurs. Secondly, the control of alien plant species at the site was done by manual cutting and application of herbicide. A prescribed fire was conducted to remove all alien plant biomass and to encourage indigenous seeds in the soil to germinate. The site was burnt at the ideal time of year for a fynbos fire, however there was little fuel and the burn was uneven across the study site. Post-fire weed control included spraying of herbaceous weeds and the local pioneer grass, *Cynodon dactylon*. Weed control was successful using a combination of manual cutting, fire and herbicide and reduced competition with indigenous seedlings. Prescribed burning on old fields has the challenge of low fuel loads for an appropriate quick and hot fire required by fynbos. Cutting and spreading of alien plant biomass is one method that may be a solution, however, the material must be evenly spread across the site and not stacked into piles which can cause excessively hot fires and scorching of the soil.

## 3.2 Introduction

### 3.2.1 Problem animal control

There are a total of 42 mammal species at the Blaauwberg Nature Reserve (BNR) site, this includes marine species such as whales, dolphins and seals. Twenty-eight reptile species and 5 amphibian species have been listed at the BNR and 140 bird species, including the Layard's Titbabbler (*Parisoma layardi*) a rare species only found at the BNR. Other rare species only occurring at the BNR are the Aardvark (*Orycteropus afer*) and the White-tailed mouse (*Mystromys albicaudatus*) (Raubenheimer, 2009). It has been found that the population numbers of the Cape Gerbil (*Tatea afra*) dramatically increase following alien *Acacia cyclops* clearing and establishment of the indigenous grass *Cynodon dactylon* (Holmes, 2008). The identification of fossorial mammals such as the Common molerat (*Cryptomys hottentotus*) and Cape molerat (*Xerorchus capensis*) as major obstacles that could hinder the establishment of seeds in the soil has been done by Holmes (2008). The removal of these fossorial mammals in the initial stages of seed germination and seedling establishment is vital, as these rodents uproot and graze on the plants, and displace the soil resulting in mass seedling mortality (Breytenbach, 1984; Auld and Denham, 2001).

### 3.2.2 Problem plant control

Humans have been the biggest invaders of the Fynbos Biome; the "human invasion" began 2500 years ago with the San and Khoi-Khoi peoples burning vegetation for hunting and grazing needs (Smith, 1986). Europeans arrived in the seventeenth century (Deacon, 1992) and they satisfied their needs for food and shelter by using alien plants and animals to replace indigenous species. They introduced many of the current invaders to the fynbos such as: Rooikrans (*Acacia Cyclops*), Long-leafed and Golden Wattle (*Acacia longifolia* and *Acacia pycnantha,* respectively*)*, Black Wattle (*Acacia mearnsii*) and Port Jackson (*Acacia saligna)* (Richardson et al., 1992). Many of these Invasive Alien Species (IAS) remain at BNR and alien clearing was begun on the old fields at BNR in the late 1980s and took place annually thereafter. The indigenous grass *Cynodon dactylon* or Kweek has been found to rapidly colonise old field sites resulting in the proliferation of molerats and the hindrance of seedling establishment (Holmes, 2001; Holmes, 2002). Herbaceous weeds are a major problem with regards to clearing of old fields and establishment of indigenous plant cover (Krug and Krug, 2004; Midoko-Iponga et al., 2005).

### 3.2.3 Prescribed burning

Fire is a key process in shaping the fynbos. Sand Fynbos is an ancient fire-driven vegetation type, many of the species occurring within CFSF have evolved several fire related reproductive traits such as post-fire seed release, fire-stimulated seed germination and flowering (Le Maitre and Midgley, 1992). Fire clears old senescent vegetation and increases the availability of nutrients in a nutrient-poor system (Stock and Allsopp, 1992; Bond and Keeley, 2005). Extensive research in the 1980s and 1990s provided guidelines for the optimal use of fire in fynbos to promote diversity (Van Wilgen et al., 1992) and control alien invasive species (Holmes and Marais, 2000). Prescribed burning in the western Fynbos Biome should be done in the late summer to early autumn prior to the first rains of the season and when biomass is sufficiently dry for the fire intensity to be high and the severity to be moderate (Forsyth and Van Wilgen, 2008). Alternate regimes are recommended for the southern Fynbos Biome (Heelmann et al., 2008). To manage a system for diversity, the fire intervals for CFSF should be between 10 and 15 years (Van Wilgen et al., 1992; Bond and Keeley, 2005; Van Wilgen et al., 2011).

In areas where alien species have dominated the vegetation for longer than 40 years, the indigenous seed banks are depleted (Holmes and Foden, 2001) and fire may be used to stimulate Acacia germination in order to deplete the alien seed bank prior to active restoration treatments. Empirical evidence has shown that fire can be used as a tool in alien clearing operations, the seed of alien acacia species is stimulated to germinate by fire and once germinated can be removed from the site to allow indigenous seedlings to establish (Holmes and Foden, 2001).

The objectives of this study were to test the use of pesticides, herbicides, bird perches and nesting boxes, and fire as tools to remove disruptive drivers of fynbos establishment for restoration purposes.

## 3.3 Methods and Materials

### 3.3.1 Problem animal control

For a functioning ecosystem to establish, a critical first step is to halt the degradation of the existing site and activities that prevent recovery (Hobbs and Norton, 1996). At old field sites the number of individual fossorial mammals has been found to greatly outnumber the predator population and the impact this has on the little remaining vegetation can be catastrophic (Breytenbach, 1984.) The result of this on restoration practices is the disturbance of the soils and eating of young plants that prevents establishment of pioneer vegetation. For this reason it has been found that a mass knock down of the population of rodents is necessary (Avery et al., 2005). This is done using chloroform or an aluminium phosphate derived poison (Phostoxin). The ethical implications of this temporary, localized control of fossorial mammals is permissible over a short-time frame (one year), given the importance of testing restoration of a critically endangered vegetation type. There is currently no ethics policy on this matter held by CapeNature, the South African National Biodiversity Institute (SANBI) or the City of Cape Town Biodiversity Management Branch. These conservation organisations approve the action provided that it does not adversely affect other non-target species. The return of the molerats and gerbils was expected to take place once the control treatments had ceased, and it was anticipated that their impact on the restoration process would be reduced as the vegetation would have had time to establish (Holmes, 2008). In order to control the mammal population at the site, Phostoxin, a household poison used for mole control, was utilised (Dickson, 2008). Four to six pellets were placed in the burrows of the mammals and then sealed, following the alien plant clearing and first herbicide application to the stoloniferous grass *Cynodon dactylon*. This allowed some of the mammals to escape the area as they were scared off by the brush cutting and weed control operations. Once this process had been followed a fence (diamond mesh 1.5 m high) was erected around the perimeter of the study site. The fence was buried 300 mm into the soil to prevent animals such as porcupine and gerbils from digging under the fence and to keep browsing antelope (such as Grysbok) off the restoration study plots.


**Figure 3.1:** Fencing around Blauuwberg Nature Reserve study site, with gate and notice of research

Environmentally sensitive solutions that work in the agricultural industry were employed (Scott, 2009). These included the placing of raptor perches around the site which replicated tree branches and encouraged hunting birds to return to the site and prey on the rodents (Snow, 2009). These were placed at the test site to allow the hunting birds to be accustomed to the perches and to use the perches as a hunting platform. The erection of owl nesting boxes was done around the perimeter of the study area and further away within the reserve, to encourage Barn owls (*Tyto alba*) back to the area to prey on the gerbils (Potter, 2004). Further, by establishing and maintaining buffer zones around the test area, natural predators such as mole snakes (*Pseudaspis cana), Honey Badger (Mellovora capensis), Cape* foxes (*Vulpes chama)* and Caracal (*Felis caracal*) were encouraged to prey on the molerats and gerbils (Saunders et al., 1991).

**a)**

**b)**

**Figure 3.2:** Raptor perch at Blauuwberg Nature Reserve; a) Newly erected raptor perch at study site; b) Raptor scat at base of perch

### 3.3.2 Problem plant control

Invasive vegetation at the site is dominated by *Acacia saligna*, which was removed manually by cutting the plants at the base and applying herbicide within 30 seconds after the cut, as described by the Working for Water Programme (Lieuw-Kie-Song, 2009). The removal of alien plant species that hinder the establishment of natural vegetation is best done on old fields with herbicide (Ashby, 1997; Musil et al., 2005). To reduce the herbaceous weed and weedy grasses on old previously cultivated fields the use of a biodegradable systemic herbicides sprayed in spring and autumn, has proven effective (Holmes, 2002).

Treatment of herbaceous perennial weeds and grasses was done by lightly brush-cutting the weeds and burning the site in late summer. Back pack sprayers (25 litres) were then used to apply a general herbicide (Round-up®) to the emergent weeds in the early autumn, as well as the resprouting *Cynodon dactylon* grasses, which is a prolific pioneer species and can swamp and out-compete young seedlings. A follow up application of herbicide was completed two weeks later, before seed sowing of the restoration species took place (Montalvo et al., 2002; Pretorius et al., 2008). The percentage cover of herbaceous weeds and *Cynodon dactylon* in each block was recorded at each survey in September 2010, April 2011 and September 2011.

### 3.3.3 Prescribed burning

On the 2$^{nd}$ February 2010 a prescribed burn was undertaken at the restoration research site at BNR. A ten-person fire team from the City of Cape Town undertook the burn and a 5 m fire break was established (Fig 4.3a) around the perimeter of the site by brush cutting the vegetation. The temperature on the day was 29°C with a relative humidity of 25% and the wind was 9 knots from the South East, the Fire Danger Index was yellow (45) indicating that prescribed burns can be undertaken with extreme care. The fire was lit from the south eastern corner of the site and allowed to burn as a continuous fire line across the site (Fig 4.3b). Due to the low fuel load on the site (slashed *A. saligna* saplings and annual and perennial grasses), the fire was not uniform and extra fuel in the form of a mixture of 50% diesel/50% petrol was added. The fire was started at 10:00 and took 2 hours to fully burn and a team was stationed at the site for a further 12 hours to monitor and prevent any potential flare-ups.

a)

b)

c)

**Figure 3.3:** Prescribed burn at Blauuwberg Nature Reserve study site. (a) Site preparation fuel load spreading and fire break clearing; (b) Fire front line of prescribed burn at BNR; (c) BNR study site 1 day post-fire, light fuels have been consumed

## 3.4 Results and Discussion

### 3.4.1 Problem animal control

The bird scat around the base of the raptor perches (Fig 4.2b) and owl nesting boxes was monitored by conservation students at BBNR to assess species identity and to assess whether the owls and raptors were using the perches. Evidence of both molerat and gerbils skulls and bones were found and it was concluded that the perches were used. Inspection of the horizontal perches had signs of scraping by the raptors talons. The burrow activity around the perches and boxes was reduced (personal observation) over the period of the study and a second knockdown of the fossorial mammals using Phostoxin was therefore not carried out. It cannot be accurately stated that the perches or Phostoxin treatment or a combination of both had an effect on the reduction in fossorial mammal activity at the site. Observations of activity at the site over the study period provide platform for future in-depth studies to determine the exact impact of these on fossorial mammal population reduction at restoration sites. Evidence, in the form of scat and spoor, of the return of the mammal predators was found and there was a visual sighting of a Honey Badger climbing over the perimeter fence and hunting the gerbils at night (personal observation).

### 3.4.2 Problem plant control

Alien *Acacia saligna* recruitment was very little due to the effective clearing protocols followed by the BNR alien clearing teams. Post-fire recruitment of the Port Jackson seedlings may have been reduced as a result of the bio-control rust fungus, *Uromycladium tepperianum* found in the surrounding populations of *A. saligna* at BNR and the annual clearing undertaken by the BNR teams. Predation of seeds by the fossorial mammals on both indigenous and alien seeds was suspected to have had an impact on the number of alien seeds in the soil seed bank at the test site (Ferreira and Van Aarde, 2000). Post-fire germination of the herbaceous weeds was prolific; the majority (80 % across the site) of these were killed with the first application of herbicide. The re-sprouting grasses were knocked down by the application of herbicide and visual observations found that they did not affect the growth of sown seedlings by smothering the seedlings.

### 3.4.3 Prescribed burning

The fire cleared the site of most old grass debris and senescent vegetation; large unburnt fuels were removed by hand to aid further clearing the site for sowing techniques. Post-fire germination of alien species was monitored in September 2010, April and September 2011, at the same time as the sown seed germination monitoring. Results from the 2010 post-fire monitoring showed some *Acacia saligna* seedlings had germinated after the fire. The winter of 2010 had a very low average rainfall (32 mm recorded, 140 mm average), however many of the acacia seedlings succumbed to the drought and those that did not were removed by hand in April 2011. Annual and perennial weeds germinated vigorously after the burn and were sprayed with herbicide in April 2010 simultaneously with the *Cynodon dactylon*. The April 2011 survey revealed that very few of these survived the hot fire and the herbaceous weeds were no longer in evidence at the site. This indicates that the adults were killed by the herbicide and remaining seed in the soils were killed by the fire. In areas where the fire didn't burn uniformly a patchy mosaic pattern developed (Fig 4.3c) and *Cynodon dactylon* re-sprouted in these areas along with the germination of herbaceous weeds, these were killed with the application of herbicide.

## 3.5 Conclusion

The different site preparation treatments used illustrate the complexity of CFSF restoration and that to restore an ecosystem, the biotic and abiotic elements as well as their interaction must be considered. When used on its own, each treatment fails to have the desired effect and that each is in fact related and dependent on the other. The control of fossorial mammals is of vital importance to active restoration treatments of sowing and plant establishment and environmentally sound methods can be used to control these mammals. The use of raptor perches and owl boxes are not a once-off treatment and can be left to encourage the predatory birds to remain at the site and contribute to the ecosystem functioning. Alien clearance is integral to restoration and a commitment to regular follow-up clearing is a necessity for the persistence of indigenous flora at a restoration site. In order for restoration of a fynbos vegetation type to be 'jump started' and remain viable, fire must be incorporated into the restoration and management of the veld. Prescribed burning conducted in the correct ecological fire season, February to March, yield positive results in the form of germination across the fundamental guilds and removal of alien species. Following the steps out lined above, the preparation of a CFSF site for restoration must be a combination of weed control and problem animal control, utilising environmentally sound methods and natural processes such as fire.

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# CHAPTER FOUR

# SEED VIABILITY AND GERMINATION TESTING OF 23 SPECIES USED FOR CAPE FLATS SAND FYNBOS RESTORATION

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## 4.1 Abstract

Re-introduction of a plant species by planting of vegetative specimens may ensure the successful establishment of that species. However, it is neither the most ecologically ideal solution nor the cheapest by an order of magnitude. The use of seed offers the potential for restoring greater biodiversity than by planting. A critical step in the use of seed for restoration is determining the viability of the seed to be used and which pre-germination treatments are required for the various species. This study investigated the viability and germination cues of 23 Cape Flats Sand Fynbos species required for rehabilitation of old fields at the Blaauwberg Nature Reserve to maximise the germination of indigenous seed for use in ecological restoration. All species were collected from natural fragments of Cape Flats Sand Fynbos, processed and germinated at 10°C minimum and 25°C maximum, and 16/8 hours light/dark, respectively. Seeds were x-rayed for viability and it was found that 52% of all the seed collected were either empty or parasitized. The low viability of wild collected seeds requires that when undertaking any restoration exercise, seed harvesters be trained properly and supervised by an expert botanist or horticulturalist whilst collecting, processing and storing seed. Pre-germination methods encompassed soaking in smoked water extract and seed coat scarification with coarse sand and grit. Seed of three species exhibited moderate germination when treated with smoke. Germination of seeds for four species increased substantially with scarification. It was found that although smoke water treatment did have positive germination results in some species the scarification treatment had a larger overall germination success. It may be that germination is related to temperatures during a fire that result in seed coat splitting, this study recommends that further investigation using more species across the Sand Fynbos vegetation be conducted on pre-germination effects of heat and scarification.

**Key words:** Seed collection; storage; smoke water; scarification; fire; Blaauwberg Nature Reserve.

### 4.2 Introduction

Sowing of seeds is necessary when undertaking restoration that replaces species that do not store their seed in the topsoil but in the canopy (Fisher et al., 2009) as with many serotinous fynbos species (Holmes and Newton, 2004). There are many factors affecting the success of sowing seeds including the depth of seed placement (Rokich and Dixon, 2007), seed predation (Ord, 2007), timing of the sowing (Holmes, 2008), wind activity (Ord, 2007) and soil moisture. It is therefore essential to ensure that viable seeds are collected and that dormancy mechanisms are overcome prior to sowing as unknown germination requirements can limit the success of the seed sowing. Seed is the perfect vessel that contains all the genetic variation of a species (Baskin and Baskin, 1998). Fertile seeds are dormant embryonic plants. The dormancy of seed falls into two categories; internal (morpho-physiological) and external or physical dormancy. Internal dormancy is a consequence of the unfinished conversion of proteins and fats in the seed (Smith, 1986). External dormancy results from a hard seed testa that inhibits the movement of oxygen and water into the seed coat and initiation of germination.

The germination of seed starts with the uptake of water and finishes with the emergence of the radicle (Brewley and Black, 1994). The major elements affecting germination are water (Figure 4.1), oxygen, temperature, light and germination stimulants such as smoke. Each plant species has a unique combination of these germination requirements and fynbos is no exception (Table 4.1). There is a general increase in oxygen concentrations in fynbos soils after a fire (Brits and Van Niekerk, 1986), as a consequence of the reduced vegetation and organisms in the soil, and this subsequently acts as a germination cue for soil-stored seed. In order to break both physiological and morphological dormancy, it has been found that seeds of fynbos species be placed on a substrate moistened with fynbos smoke-infused water and sown when the temperatures fluctuate between 10°C (nocturnal) and 25°C (diurnal) (Pierce and Moll, 1994). Light treatments can mitigate mechanical dormancy by enzymatic action which weakens the tissues around the embryo (Welbaum et al., 1998). This is a major characteristic of a post-fire environment and may stimulate germination due to the clearing of vegetation and exposure of the soil to direct sunlight (Keeley, 1987; Cowling and Holmes, 1992; Le Maitre and Midgley, 1992; Bond and Van Wilgen, 1996) . Successful germination response of smoke on chaparral seeds (Wicklow, 1977) and fynbos seeds (De Lange and Boucher, 1990), indicate that certain seeds are stimulated by chemical changes in the environment and extracts of smoke (aqueous smoke) improved germination of fynbos species (Brown, 1993; Baxter et al., 1994).

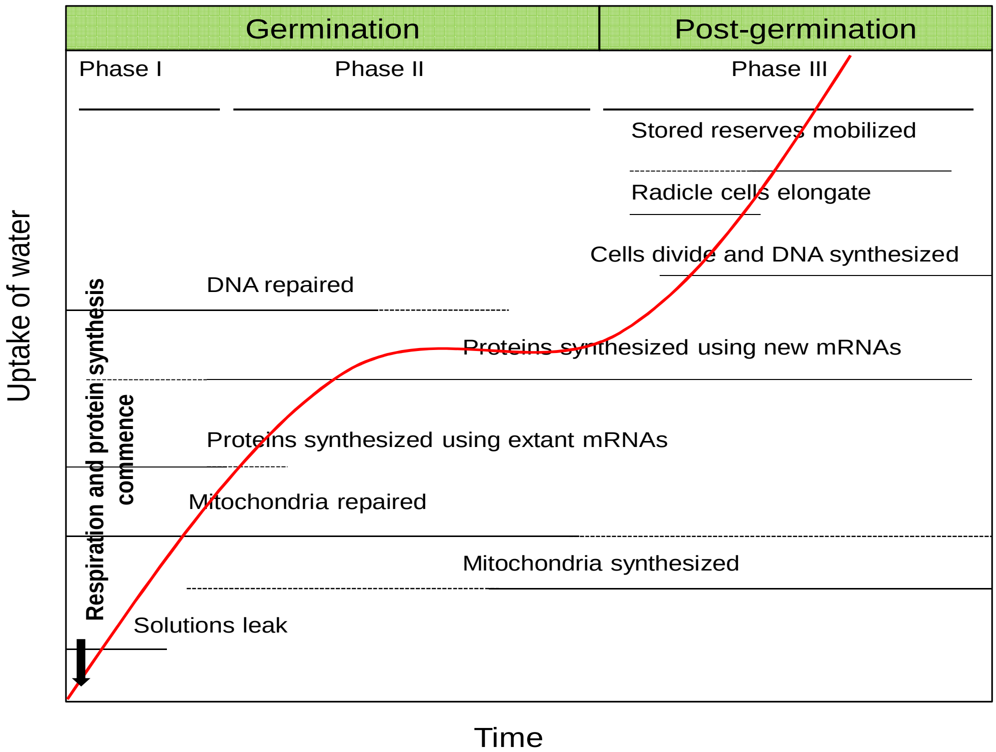



**Figure 4.1:** Time course of major events associated with uptake of water and germination and subsequent post-germinative growth. (adapted from Brewley, 1997)

**Table 4.1:** Temperature and light requirements for germination in the main fynbos floral families

| Family | **Temperature (Brits et al., 1993, Brown and Botha, 1997)** | | **Light (Pierce and Moll, 1994)** | |
|---|---|---|---|---|
| | Min | Max | Day | Night |
| Asteraceae | 10°C | 20°C | 8 hrs | 16 hrs |
| Ericaceae | 10°C | 15-25°C | 8 hrs | 16 hrs |
| Proteaceae | 8-9°C | 24°C | 8 hrs | 16 hrs |
| Restionaceae | 8°C | 28°C | 8 hrs | 16 hrs |

Seed is a living biological product and its behaviour cannot be predicted with certainty. One of the greatest hazards in restoration using seed is sowing large quantities of seeds that do not have the capacity to produce an abundant crop to cover a restoration area. Seed testing methods have been developed based on scientific knowledge to minimise the risk of poor germination by assessing the quality of seed before it is sown (Van De Venter et al., 1986; Brown, 1993; Pierce and Moll, 1994; Baskin and Baskin, 1998; Welbaum et al., 1998). Testing wild harvested Cape Flats Sand Fynbos (CFSF) species for viability will aid in the determination of effort to harvest and quantities needed for maximum germination and coverage of restoration areas. Due to low seed numbers collected from wild plant populations (Smith et al., 2004), a non-invasive and more accurate test such as x-ray was used compared with tetrazolium or cut testing the seed samples. 23 species were selected as representative of seven major families within the CFSF and contained both pioneer and threatened species. The objective of this study was to investigate the viability and the pre-germination treatments of the 23 wild collected species to determine the best germination response for economically viable restoration on old fields at BBNR. For each species we determined seed viability, and germination response to germination treatments of smoke water and scarification. To answer the main question of which pre-germination treatment will be most effective for the majority of species, the germination results of each individual species will be combined for each treatment. Large scale restoration is not a cheap exercise and hence the establishment of a pre-germination treatment that will benefit the majority of CFSF species and reduce treatment time is required.

## 4.3 Methods and Materials

### 4.3.1 Seed collection

Species were selected from the four major guilds found in sand fynbos, the Forbs (Herbaceous perennials), Ericoids (fine leafed shrubs), Proteoids (larger shrubs of the Proteaceae family) and Restioids (reed-like shrubs from the Restionaceae family). Although many of the chosen species were listed as Least Concern (IUCN Red List), these form the backbone of the ecosystem and are associated species of the more endangered flora. Seed collections were made in the BBNR area between January and October 2009. Once the timing of maturity had been established for each species (Newton et al., 2002) and a locality found that was sufficiently close to the BBNR study site (McKay et al., 2005), seeds were harvested according to standards set by the Millennium Seed Bank Project (MSBP) (Smith et al., 2004). Training was provide to unqualified staff of Vula Environmental Services in the correct methods of seed harvesting to ensure that existing vegetation from which the seed was collected was not damaged (Hay and Smith, 2004). Collection methods used included; cutting the branches of shrubs and perennials, shaking culms of restios, plucking the ripe fruit of shrubs and bagging seed heads of species that release their seed via ballistic methods. Due to lack of capacity it was not possible for MSBP staff to supervise Vula staff while harvesting in-field and standards could not be assured. A recommended rate of 50 kg of dried, un-cleaned seed per hectare (Holmes, 2002) was the target amount for collection. Once seeds were harvested, it was recommended that they were placed in a cool dry room at 15°C and 16% relative humidity, to prevent premature ageing of species, for drying, cleaning and storage for later use (Buitink and Hoekstra, 2004).

A total of 24 seed collections were received from Vula Environmental services, from the target list of 42 species supplied. Of the remaining 24 collections, 1 collection (*Staberoha distachyos)* was found to be of male flowers and not female seed. This was completely excluded from the trials as it could not be recollected in time. Other species which had low collection numbers included: *Leucadendron salignum, Leucospermum hypophyllocarpodendron subsp. hypophyllocarpodendron, Protea repens, Protea scolymocephala and Diosma oppositifolia.* Additional collections of all species were made by horticulturalists from the Millennium Seed Bank Project at Kirstenbosch National Botanic Garden (Smith and Wyk, 2004) at an additional cost of R400 per species collected to supplement the seed collected by Vula in order to attain the 50 kg $.ha^{-1}$ target at the end of 2009. Harvesting methods used by the MSBP staff were according to the standards set by MSBP Kew (Hay and Smith, 2004) and seeds were placed in the Kirstenbosch seed drying room post-harvest, which was run according to standards for storage from the MSBP (Smith et al., 2004). The total amount invoiced for the collection of 23 CFSF species from Vula was R18 863.07. Costs were divided into 3 categories: Pioneer /grass & easy germinating bulk seed @R550 $.kg^{-1}$, intermediately complex seed to collect @R850 $.kg^{-1}$ and the ericoid and similar hard to collect species @R1250 $.kg^{-1}$. All collections were weighed on delivery and Table 4. 2 shows the total weight (in grams) per species collected by Vula and the MSBP teams respectively.

Following the x-ray viability results, an investigation into the timing of collection of seed was undertaken using the Vula staff pay role time sheets for dates when harvesting for this particular project. On investigating the storage conditions at Vula it was discovered that the storage room had no temperature or humidity control and that temperature fluctuations during the post-harvest summer months were extreme (Buitink and Hoekstra, 2004). This therefore resulted in damaging many of the seeds in temperatures that were too high and others were succumbing to infections by fungi and bacteria in moist conditions (Smith et al., 2004).

The cost of seed was higher than expected and only a small quantity of seed was supplied for each species. This was attributed to the specialised list of species required for the restoration of CFSF and the effort needed to collect the seed. In addition, there was a lack of sufficient populations close to the restoration site from which to collect large quantities of seed without harming the *in situ* population within the given harvesting period.

**Table 4.2:** Weight of seed collected by Vula Environmental Services and the Millennium Seed Bank

| Family | Species | Weight of Vula Seed (g) | Weight of MSBP Seed (g) |
|---|---|---|---|
| **ASTERACEAE** | *Dimorphotheca pluvialis* | 100 | 2850 |
| **ASTERACEAE** | *Eriocephalus africanus* | 1610 | 3000 |
| **ASTERACEAE** | *Metalasia muricata* | 1185 | 2210 |
| **ASTERACEAE** | *Senecio elegans* | 124 | 1240 |
| **ASTERACEAE** | *Stoebe capitata* | 152 | 1670 |
| **ASTERACEAE** | *Stoebe cinerea* | 50 | 870 |
| **ASTERACEAE** | *Trichogyne repens* | 250 | 1320 |
| **ASTERACEAE** | *Ursinia anthemoides* | 150 | 356 |
| **ERICAEAE** | *Erica mammosa* | 1000 | 1000 |
| **GERANIACEAE** | *Pelargonium capitatum* | 70 | 2140 |
| **IRIDACEAE** | *Ferraria crispa* | 0 | 12 |
| **IRIDACEAE** | *Sparaxis grandiflora* | 430 | 1220 |
| **PROTEACEAE** | *Leucadendron salignum* | 140 | 2310 |
| **PROTEACEAE** | *Protea scolymocephala* | 70 | 2890 |
| **PROTEACEAE** | *Protea repens* | 210 | 3440 |
| **PROTEACEAE** | *Serruria fasciflora* | 430 | 1810 |
| **PROTEACEAE** | *Leucospermum hypophyllocarpodendron* | 30 | 40 |
| **RESTIONACEAE** | *Thamnochortus punctatus* | 2093 | 4720 |
| **RESTIONACEAE** | *Willdenowia incurvata* | 2495 | 0 |
| **RUTACEAE** | *Agathosma capensis* | 560 | 0 |
| **RUTACEAE** | *Diosma aspalathoides* | 70 | 890 |
| **RUTACEAE** | *Diosma oppositifolia* | 70 | 1430 |
| **THYMELACEAE** | *Passerina corymbosa* | 0 | 3610 |

### 4.3.2 Seed sampling

Seed lots were cleaned by sieving the seeds and removing as much chaff and debris as possible using a Zig-zag Aspirator (Selecta Industries Netherlands). Once a relatively uniform seed lot was obtained, a composite sample was taken by taking primary samples from different positions in the whole seed lot and then combining them. The composite samples were then reduced to more manageable sub-samples. Sub-samples were used as the working samples for the viability and germination tests. Seed lots were counted out to 100 seeds per test method (x-ray viability testing and germination), and 100 seeds for the control. Each set was then divided into 5 lots of 20 seeds each. Each container was labelled with the plant species name and the test method to be used. Each lot was given a unique identification number. Samples were then stored in a seed dry room at 15°C and 16% relative humidity, the seeds were kept in sealed plastic containers according to the International Seed Testing Association Rules (ISTA) guidelines.

### 4.3.3 Viability test

Samples were sent to Wakehurst Place, Sussex in the United Kingdom, where the Millennium Seed Bank is housed. The samples were digitally x-rayed and a percentage of viable/non-viable seed was obtained by examining the x-rays for full, empty or partially full seed. Seed samples were x-rayed using a Faxitron digital X-ray machine. 20 seeds were laid out into plastic grids, replicated 5 times, with machine-punched holes set in a regular pattern or Petri dishes. The seeds were sorted according to the size of the seed and thickness of the seed coat to determine the level of magnification needed. The x-ray provided a look into the internal morphology of the seeds and seed that may appear good on the outside may be identified as ‘empty’ or contain insect larvae via x-ray. The seeds were x-rayed under voltages substantially lower than medical x-rays to minimise genetic damage to the seeds.

### 4.3.4 Seed treatments, growing medium and test conditions

Testing under field conditions is believed to be inadequate as the results cannot be accurately repeated. Laboratory methods were used in which external conditions could be controlled and a regular result of the germination potential of the species obtained. From the above germination requirements (Table 4.3), mechanical scarification and chemical treatment with smoked water were selected, as the two most economical treatments for large scale restoration. Other treatments of chipping and acid scarification of individual seeds were too time consuming and thus costly for large scale restoration. Although the dormancy breaking treatments for fynbos families have been identified, there was no published information on the methods of mechanical scarification or smoked water on the species selected for this study. A control was conducted on all seeds. Mechanical scarification was tested by churning seed with grit and coarse gravel in a metal drum. For the purposes of this study, the seeds of the selected species were soaked in "Kirstenbosch Smoke-Plus" seed primer for 24 hours before sowing. This was done by placing 50 ml prepared smoke water in a petri dish and placing the seeds in the petri dish.

Seeds were removed from dry room conditions 48 hours prior to sowing to allow the respiration cycle to begin naturally. The three treatments namely: control, scarification and smoked water were tested on agar plates placed in a germination room at the Kirstenbosch Research Centre. A night/day germination temperature of 10°C / 25°C (Pierce and Moll, 1994), respectively and a light regime of 16 hours dark and 8 hours light was used. The pH of the agar was regulated to 7.0 and made with filtered distilled water, free of all impurities. The salinity of the agar was monitored to be lower than 40 ds .$m^{-1}$. The agar plates were kept clean and made in sterile laboratory conditions to prevent contamination of the plates by fungi, bacteria and toxic substances which could possibly infect the seeds. The germination test was run for 4 consecutive weeks with the first count taking place after the first 7 days. Weekly analysis of the plates was done to observe for any germination of the seed. The emergence of the radical was taken as the final stage in the germination tests and seeds were removed from the plates once the radical had emerged.

**Table 4.3:** A list of the main Cape Flats Sand Fynbos (CFSF) families with internal and external dormancy and the types of treatments used to break dormancy

| | Internal Dormancy (Physiological) | Internal Dormancy (Morphological) | External Dormancy (Physical) |
|---|---|---|---|
| **Families** | Asteraceae, Boraginaceae, Brassicaceae, Lamiaceae, Poaceae | Ericaceae, Orchidaceae, Apiaceae, Iridaceae | Proteaceae, Restionaceae, Fabaceae, Rhamnaceae, Aizoaceae, Malvaceae |
| **Treatments** | Warm & Cold stratification (Baskin and Baskin, 1998), increase in oxygen and ethylene (Corbineau and Come, 1995, Sutcliff and Whitehead, 1995) | | Acid scarification (Baskin and Baskin, 1998), soaking in hot water and mechanical by drilling, chipping or rubbing the seed coat (Pierce and Moll, 1994) |
| **Study Species in CFSF restoration trials with little or no published germination results** | *Dimorphotheca pluvialis, Eriocephalus africanus, Metalasia muricata, Senecio elegans, Stoebe capitata, Stoebe cinerea, Trichogyne repens, Ursinia anthemoides, Passerina corymbosa, Serruria fasciflora, Leucadendron salignum* | *Erica mammosa, Ferraria crispa, Sparaxis grandiflora* | *Pelargonium capitatum, Protea scolymocephala, Protea repens, Leucospermum hypophyllocarpodendron subsp. hypophyllocarpodendron, Willdenowia incurvata, Thamnochortus punctatus Agathosma capensis, Diosma aspalathoides,* |

a)

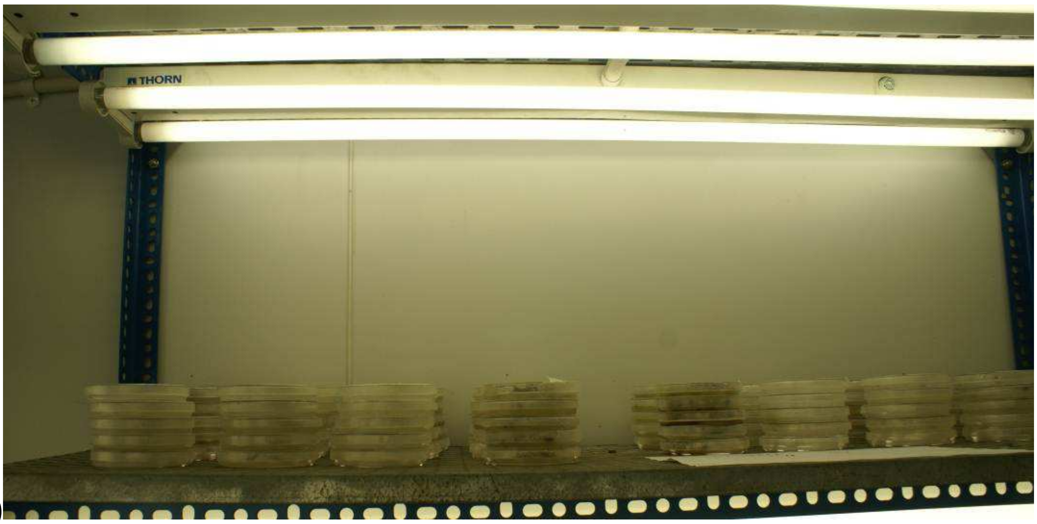

b)



**Figure 4.2:** Petri dishes in growth room. a) Petri dishes with labelling, top-down view; b) Agar levels of Petri dishes and lighting in growth room

### 4.3.5 Statistical analysis

Germination percentages were arcsine transformed prior to statistical analysis. Germination for each species (percentage germination, total time to final germination) was analysed by one-way analysis of variances (ANOVAs) using SPSS for Windows Version 19, Release Version 11.0.1. (SPSS Inc., 2001. Chicago, IL, www.spss.com). Factors in the ANOVAs were the three germination treatments used. Results were combined in order to establish which pre-germination treatment was significant for the majority of species as this was the main objective of the study for large scale restoration.

## 4.4 Results

### 4.4.1 Seed Collection

It was found that the seeds harvested by Vula were too young and the *Willdenowia incurvata* and *Thamnochortus punctatus* seeds in particular failed to mature post-harvest (Newton et al., 2002). Remaining seed collections were not stored under correct conditions (Buitink and Hoekstra, 2004) and many seeds perished prior to sowing (Gold, 2004).

### 4.4.2 Seed Sampling: X-Ray analysis of seed samples

Results from the x-ray of the BBNR seed sample showed that the majority (52%) of the seeds were empty.

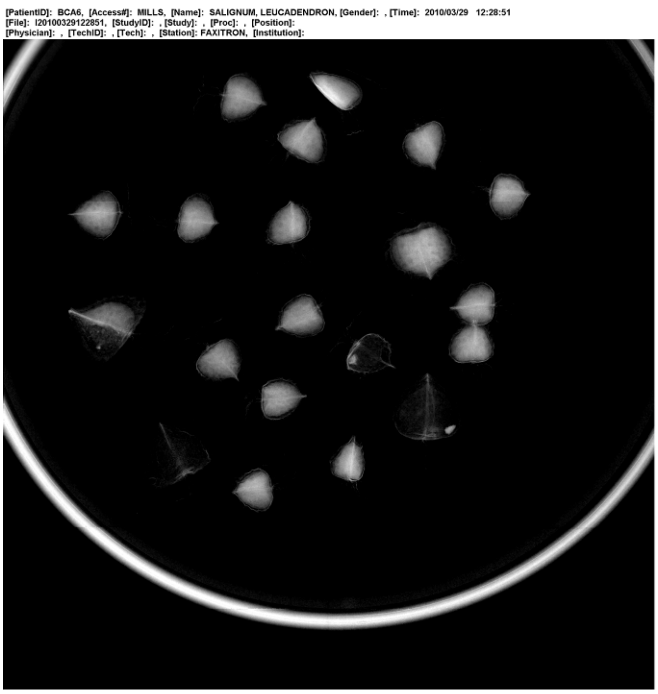



**Figure 4.3:** X-Ray plate of *Leucadendron salignum* seed, healthy seeds are white

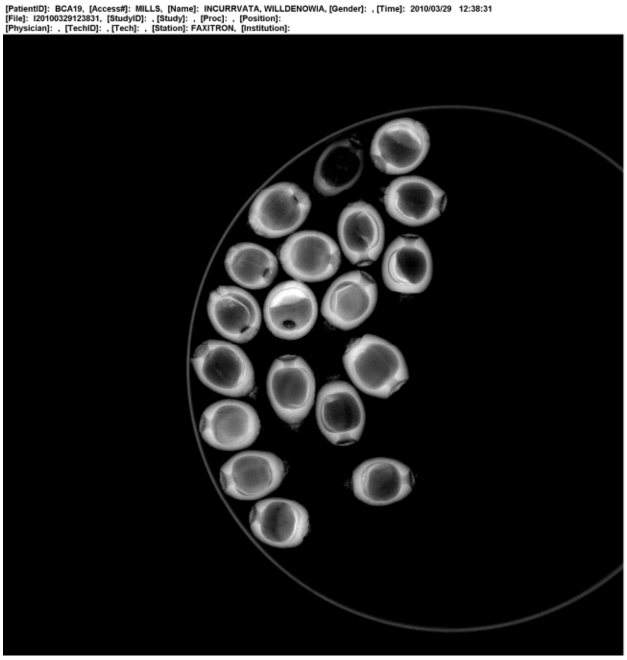



**Figure 4.4:** X-Ray plate of *Willdenowia incurvata* seed showing all empty seeds, with thick seed coats a deeper white

The x-rays showed that the seeds of *Willdenowia incurvata* were all empty (Appendix C) and only 28% of the *Thamnochortus punctatus* seeds were viable. Both restio species later failed to germinate in the growth room. The Asteraceae (*Dimorphotheca pluvialis, Metalasia muricata, Stoebe capitata, Stoebe cinerea and Ursinia anthemoides*) had an average of 51% viable seeds under x-ray, which is expected of this group (Van De Venter et al., 1986). The pioneer species of *Pelargonium capitatum* showed 84% of the seed x-rayed were viable. *Protea scolymocephala* had the highest infested seed with 85 of the 100 seeds x-rayed infected and/or eaten by insects.

### 4.4.3 Germination Results

Results from the laboratory germination tests varied greatly between species as was expected due to the physiology of each species and seed morphology (Newton et al., 2002). *Dimphotheca pluvialis, Metalasia muricata* and *Trichogyne repens* all failed to germinate under all the treatments. Re-sprouting species had higher germination percentages under control conditions, *Erica mammosa* and *Leucadendron salignum,* each had a germination percentage of 81% and 94% under control respectively. *Leucadendron salignum* had 91%

germination with scarification, indicating that the seeds respond well to disturbance of the seed coat. *Sparaxis grandiflora* had in excess of 80% germination for both control and scarification treatments and 68% for smoke. Germination of *Leucospermum hypophyllocarpodendron sub species hypophyllocarpodendron* was very low for the smoke (4%) and scarification (5%) and 0% for the control.

The Rutaceae tested showed a preference for scarification with an average germination of 50% compared with 22% (smoke) and 23% (control). *Passerina corymbosa*, a post fire pioneer species in the fynbos, had a 25% germination percentage for scarification treatment and only 2% for the control and 5% for smoke treatment. Lastly the Restionaceae, had nil germination, although a keystone group with the CFSF, their harvesting and germination requirements are very challenging (Holmes and Newton, 2004). Overall the scarification treatment yielded the highest germination percentage across the 23 species tested (Figure 4.5).

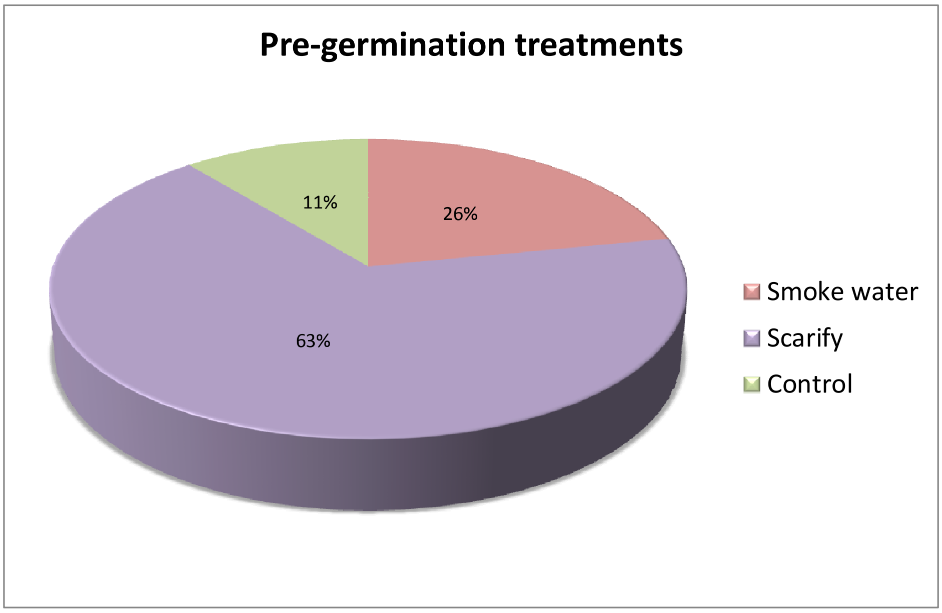



**Figure 4.5:** Combined species germination results of pre-germination treatments for Smoke water (26%), Scarification (63%) and control (11%) for all 23 species tested (n=100)

**4.5 Discussion**

The overall results of the x-ray and seed germination treatment trials indicate that seed harvesting times and storage methods must be accurate and of a high standard when dealing with seed on a large scale for restoration. When undertaking a large and expensive restoration exercise, it is recommended that the seed harvesters be trained properly and supervised by an expert botanist or horticulturalist whilst collecting. The amount of seed collected was very low as the collecting area was limited to natural remnants around the restoration site. Although only 20% of the available seed was collected at any one time, a higher percentage of seed harvested would have a negative impact on the natural recruitment of species (Gold, 2004). It is suggested that a larger area be selected for harvesting for future restoration similar to the BBNR study as research has shown that pioneer species may be collected further away from the restoration site (McKay et al., 2005, Turner, 2007). Planning of a restoration project must include sufficient time to harvest enough seed over a number of flowering seasons.

The smaller seeded asteraceous species, both the annual and perennial species were damaged by the scarification process and germination was poor, it is recommended that hot and cold stratification (Table 4.3) be used where required and that to minimise costs seed from this family be sown untreated at the correct time of year. It was found that fungal growth heavily affected the germination of the asteraceous and geophytic species and this directly affected their germination by inhibiting sufficient light to the seed for germination (Bewley and Black, 1994), consuming the oxygen available for the seedling growth (Patil et al., 2012) and causing deterioration of the seed coat in general. Under natural conditions in the field this would not occur to such a large extent as the seed would be further apart and the conditions drier (Ries and Hoffman, 1996). Another species that was affected by fungal growth on the plates was *Eriocephalus africanus.* The fruits of this species are covered with long woolly hairs, with the seeds housed within, extraction of the seeds from the woolly fruits, causes unacceptable damage to the seeds and they are best left within the fruits (Smith et al., 2004, Terry and Bertenshaw, 2008). To prevent the loss of seeds and seedlings to fungal and bacterial attack, the seeds must be washed before treatment in a weak bleach solution and sand or grit used for the scarification should be sterilised prior to use on the seeds. Any additional costs accrued in doing this will be nullified by the prevention of loss of seeds and the need to re-harvest and sow again. Laboratory germination results for these species were negatively affected by the lack of surface sterilisation of the seeds and therefore requires further testing to obtain accurate results.

Depending on the morphological requirements of species, pre-germination treatments varied in their results. Overall, the smoke water treatment was not successful for CFSF species. This illustrates the need for a hot fire to encourage prolific germination after veld fires. The Cape Floral Region (CFR) is a unique vegetation type which is characterised by summer drought, poor soils and frequent fires (Van Wilgen et al., 1992, Cowling and Holmes, 1992, Le Maitre and Midgley, 1992). The frequency of fires ranges between 5 to 40 years (Brown and Botha, 1997, Van Wilgen et al., 1992, Bond and Keeley, 2005) and many of the fynbos species are adapted to respond to fire germination cues (Bond and Keeley, 2005, de Lange and Boucher, 1993a, De Lange and Boucher, 1993b) . It must be noted that there is a minority of species which are independent of fire-cues. These species occur mainly in moist ravines and are woody species; very few of these species are found in CFSF. Those species that do occur in CFSF vegetation resprout after a fire, the majority of fynbos species found in the CFSF have a fire dependent germination cue. Similar fire germination cues have been found in plants in the Californian chaparral (Keeley, 1991, Keeley and Fotheringham, 1998), the Australian west coast shrublands (Bell et al., 1993, Hughes and Westoby, 1992, Dixon et al., 1995) and in the Mediterranean shrublands (Roy and Sonie, 1992, Keeley and Fotheringham, 1998).

The approach to seed dormancy involves the selection of seed treatments that mimic the natural environmental conditions that would result in germination. Scarification mimics the heat effects of fire within the fynbos. This causes the seed coat to crack or fracture, which allows water and gases to penetrate the seed coat. It has been found that scarification improved the germination of Leucadendron and Leucospermum species (Brown and Van Staden, 1973, Brits et al., 1993) this study confirms these results for scarification.

*Protea repens* and *Protea scolymocephala* germination was relatively poor, however this is a trait of the Protea genus as they provide vast numbers of seed, yet few are viable and/or germinate (Smith et al., 2004). They had 15% and 14% viable seed from the x-ray analysis. These proteas are obligate reseeding species, mother plants are killed by fire, seeds are retained on the plant and released when fire passes through the veld (Rebelo, 1995, Heelmann et al., 2008). Both species had higher germination rates under scarification treatment than smoke, indicating that germination may be affected more by temperature and cracking of the seed coat than chemicals within the smoke. The pincushion (*Leucospermum hypophyllocarpodendron ssp. hypophyllocarpodendron*) is known to respond to desiccation treatment prior to sowing and to lactic acid treatments (Pierce and Moll, 1994). It was previously unknown whether scarification via coarse sand was a viable treatment, moderate germination of this species indicates that desiccation and acid scarification remain the best methods. Majority of fynbos seed is dispersed via ballistic methods, wind or insects (Goldblatt and Manning, 2000) and naturally the seeds are exposed to the elements causing the testa to crack allowing oxygen and moisture to initiate germination. Therefore scarification was the best method for the majority of the 23 CFSF species tested (Figure 4.5).

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# CHAPTER FIVE

# SEEDBED PREPARATION FOR BROADCAST SEEDING TO RESTORE CAPE FLATS SAND FYNBOS ON OLD FIELDS

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## 5.1 Abstract

Cape Flats Sand Fynbos is one of the most threatened and poorly conserved vegetation types in the Cape Floristic Region, with >85% of land transformed by developments and most of the remaining vegetation degraded as a result of invasion by alien plants. The two most important management interventions, both within current conservation areas and in any future land areas acquired for conservation; are alien plant clearance and fynbos restoration. At old field sites; where indigenous soil seed banks have been lost, it is essential to re-introduce the longer-lived fynbos components that contribute to vegetation structure, either by sowing or planting propagated material, in order to facilitate restoration. Without intervention, a grassy herbland develops both on fallow fields and following the clearance of dense alien acacia stands. This vegetation forms an “alternative stable state” to fynbos, causing protracted or non-existent recovery of fynbos. The appropriate seedbed preparation techniques and associated broadcast sowing for economic and ecological restoration of Cape Flats Sand Fynbos species were investigated. Four different seedbed preparation and sowing techniques were applied during April 2010 for broadcast seeding. This included broadcast onto untilled soils, tilled soils, tilled soils and plank embed and hydro seed onto tilled soils. Results from the study found that the most successful methods for sowing seeds were the ‘hydro-seeding’ and ‘broadcast and embed’. These methods may have provided better contact between the soil and seeds and better protection from predation and wind. Economically

the 'broadcast and embed' was better as machinery was more efficient and effective than commercial hydro seeding.

**Keywords:** Plough; rehabilitation; seed; mechanical; hydro seeding; embed

## 5.2 Introduction

Re-introduction of indigenous species by seeds maybe cheaper in an order of magnitude and possibly offers the potential for restoring greater biodiversity than by planting (Gaertner et al., 2007). Preparation of soils to receive sown seeds has been a human practice for hundreds of years (Deacon, 1992). It was established by early agricultural settlements that a correctly prepared seedbed is a powerful tool to ensure that precious seed germinates and seedlings survive. Restoration of systems and processes in an ecosystem require that some form of manipulation be applied to achieve the best results for plant establishment. Although the best option is to allow a disturbed site to recover naturally, it was found on old fields at the Blaauwberg Nature Reserve (BBNR), 25 km north of Cape Town, South Africa, that after more than 20 years after disturbances had been removed no natural recovery had taken place. This was as a result of insufficient immigration of desired seeds (Whisenant, 1995) due to the large distance (>5 km) between the old fields and a natural CFSF fragment at BBNR. Low dispersal distances among fynbos species (Holmes, 2002; Holmes and Newton, 2004), excessive damage to pioneer species by fossorial mammals (Holmes, 2008; Mugabe, 2008) and dominance of the site by non-fynbos species such as grasses and perennial weeds also led to little natural recovery at the site. Natural recovery is very slow if the disturbed area is far from undisturbed natural areas and is exacerbated in unfertile environments, it was also found that in weed-dominated sites, manipulative management actions were required to accelerate the recovery of the system (Yates et al., 2000; Krug and Krug, 2007). Wind and water eroded sands such as at BBNR (Chapter Two) may bury or expose seeds and damage or kill young plants.

The creation of a rough surface by ploughing furrows or placing depressions in the seedbed surface reduces wind velocity across these surfaces (Whisenant, 1995; Coetzee, 2005) and seedling survival is highest in the bottom of these depressions (Hull, 1972). Disking and ploughing soils to create furrows and ridges facilitates precipitation use by pooling the water to slowly seep into the soils rather than running off down slopes. General guidelines for furrow depth and width in sandy soils are between 100 mm-150 mm deep and 450 mm apart (Ward et al., 1996; Visser et al., 2010). This improves water penetration, reduces wind erosion and prevents excessive competition between planted species (Barnett and Baker, 1991). Ensuring that seeds are covered with soil and have good seed-to-soil contact can be achieved by gently compacting the soil once seed has been sown and has been shown to greatly benefit restoration efforts in arid and semi-arid environments (Whisenant, 1995; Visser et al., 2010).This is done by dragging a pole, plank or chain across the soil surface to lightly fill in the furrows and stabilize the soils (Whisenant, 1993) and is most effective on freshly ploughed and sown seedbeds (Vallentine, 1989).

The use of polyacrylamides (PAM), which are soil conditioners that increase water infiltration, binding soil particles to other soil particles, organic matter and seeds, has been known to improve seedling emergence (Newquist, 2009). Sowing techniques such as broadcast, aerial, rill and hydro seeding have all shown positive results in field trials in different vegetation types (Whisenant, 1995; Midoko-Iponga et al., 2005; Pretorius et al., 2008).

Timing of seeding is a key factor in the success of the survival of the plants. Germination and seedling establishment require sufficient soil moisture and ideal temperatures; the best time to sow seeds in the Western Cape is just prior to the winter rains in March and April. This allows the seeds the maximum period of favourable conditions to establish before the harsh drier summer conditions.

Direct seeding has many advantages over transplanting as seeds are more readily collected and are easier and cheaper to store and maintain than living plants, they are easier to transport and require less time to plant (Barnett and Baker, 1991). As a key step in restoring fynbos in the lowlands, we investigated which different seedbed preparation treatments were optimal for indigenous species re-introduction and were realistic economically and therefore could be used for large scale restoration on old fields.

### 5.3 Materials and Methods

#### 5.3.1 Experiment layout

The test site for this study was on the south eastern side of Blaauwberg Hill in the BBNR. A random split-plot replicate block design was used to investigate the treatments. The trial site covered an area of 118 m x 56 m and comprised of five replicate blocks (Appendix B).

Each block was subdivided into four 20 x 10 m plots with 5 m buffers around the perimeter of the site and 2 m buffers between plots. Plot treatments were completely randomized within each replicate block. The dimensions of the site layout were chosen to obtain results applicable to large scale restoration.

### 5.3.2 Seedbed preparation

Four different seedbed preparation treatments for broadcast sowing were investigated. These included; ploughing to a depth of 100 mm for 3 of the 4 treatments, then leaving the furrows open (Broadcast & disk), dragging a heavy wooden plank across the surface of the soil to embed the seeds (Broadcast & embed) and hydro seeding (Hydro seed) using a modified 'bakkie sakkie' fire suppression sprayer to apply the seed to the soil surface in a mixture of seed, Hydro Pam L55 and water. The product was applied at a rate of 0.1 $l.m^{-2}$ and mixed at 15 parts to 1 part water. The fourth treatment did not include manipulative ploughing but only broadcasting the seeds directly onto the soil surface (Broadcast & control). All seed was broadcast by hand as fynbos seed varies in size and shape. Thus mechanical broadcast sowing using agricultural equipment was not suited. A 4 x 4 tractor and plough with rotational disks was used, as the site was inaccessible for conventional tractors. A total of 54 kg of uncleaned seed was sown across the whole site, seed numbers were calculated according to the calculations from the Seed Information Database (SID) of the MSBP which provides a mean 1000 seed weight in grams for each species (Table 5.1). Site visits for 2 years (2008 and 2009) prior to sowing of seeds found no parent plants of any of the 23 sown species at the site (Chapter One) and it was thought that there was little to no remaining soil seed bank of the selected species.

An area adjacent to the study site was also used as a reference site where no seed was sown. Rainfall data were obtained for the duration of the trial period from the BBNR weather station at Melkbosstrand.

**Table 5.1:** Total weight of species sown and number of seeds as per the Seed Information Database of the Royal Botanical Gardens Kew.

| Family | Species | Total Weight (g) | Mean 1000 Seed Weight (g) | Number of seeds sown | Number of seeds sown per treatment |
|---|---|---|---|---|---|
| ASTERACEAE | *Dimorphotheca pluvialis* | 2 950 | 2.8 | 1 053 571 | 263 392 |
| ASTERACEAE | *Eriocephalus africanus* | 461 | 21.59 | 21 352 | 5 338 |
| ASTERACEAE | *Metalasia muricata* | 3 395 | 0.34 | 9 985 294 | 2 496 323 |
| ASTERACEAE | *Senecio elegans* | 1 364 | 0.4 | 3 410 000 | 852 500 |
| ASTERACEAE | *Stoebe capitata* | 3 222 | 0.15 | 21 480 000 | 5 370 000 |
| ASTERACEAE | *Stoebe cinerea* | 920 | 0.12 | 7 666 666 | 1 916 666 |
| ASTERACEAE | *Trichogyne repens* | 1 570 | 1.16 | 1 353 448 | 338 362 |
| ASTERACEAE | *Ursinia anthemoides* | 506 | 29.8 | 16 980 | 4 245 |
| ERICAEAE | *Erica mammosa* | 2 000 | 0.11 | 18 181 818 | 4 545 454 |
| GERANIACEAE | *Pelargonium capitatum* | 2 210 | 3.91 | 565 217 | 141 304 |
| IRIDACEAE | *Ferraria crispa* | 12 | 7.63 | 1 573 | 393 |
| IRIDACEAE | *Sparaxis grandiflora* | 1 650 | 5.57 | 296 299 | 74 074 |
| PROTEACEAE | *Leucadendron salignum* | 2 450 | 8.3 | 295 180 | 73 795 |
| PROTEACEAE | *Protea scolymocephala* | 2 960 | 8.37 | 353 643 | 88 410 |
| PROTEACEAE | *Protea repens* | 3 650 | 67.9 | 53 755 | 13 438 |
| PROTEACEAE | *Serruria fasciflora* | 2 240 | 2.7 | 829 629 | 207 407 |
| PROTEACEAE | *Leucospermum hypophyllocarpodendron* | 70 | 2.02 | 34 653 | 8 663 |
| RESTIONACEAE | *Thamnochortus punctatus* | 6 813 | 4.42 | 1 541 402 | 385 350 |
| RESTIONACEAE | *Willdenowia incurvata* | 2 495 | 122 | 20 450 | 5 112 |
| RUTACEAE | *Agathosma capensis* | 560 | 1.33 | 421 052 | 105 263 |
| RUTACEAE | *Diosma aspalathoides* | 960 | 10.9 | 88 073 | 22 018 |
| RUTACEAE | *Diosma oppositifolia* | 1 500 | 13.29 | 112 866 | 28 216 |
| THYMELACEAE | *Passerina corymbosa* | 3 610 | 0.51 | 7 078 431 | 1 769 307 |

### 5.3.3 Costs

The cost for each seedbed preparation and sowing technique; was recorded and is illustrated in Table 5.4. The rate for man hours (R176/day) was taken from the Expanded Public Works Programme of South Africa (Lieuw-Kie-Song, 2009) which facilitates such programmes as the Working for Water, Working on Fire and Working for Wildlife and Environment Programmes. The cost of renting ploughing and hydro seeding equipment was obtained from the Agricultural

Research Council of South Africa. The cost of each technique was then compared with the germination success of the seedbed preparation treatments to obtain a cost/germination score.

### 5.3.4 Statistical Analysis

Indigenous seedlings were counted in four 1 X 1-m permanent quadrats per plot, identification of sown seed was done using photographs of laboratory germinations and knowledge of the researcher as a seed conservation biologist. Three data sets were collected: (1) early spring (September 2010), (2) at the end of summer (April 2011) and (3) at the end of spring (September 2011), at each survey the number of seedlings in each quadrate were counted, both sown seed and weeds, percentage over of overall sown seedlings was recorded and the percentage cover of *Cynodon dactylon*. Only alien Acacia seedlings, herbaceous weeds and the indigenous *Hermannia althaefolia* were counted in the reference site on each of the 3 surveys and no seedlings of the 23 sown species were found. Data was subjected to: Analysis of Variance using SPSS for Windows Version 19, Release Version 11.0.1. (SPSS Inc., 2001. Chicago, IL, www.spss.com), to see whether the seedbed preparation treatments had a significant effect on the growth of the 23 plant species. A Univariate Analysis of Variance was done which included all the factors together, to see which of the factors had a significant effect on the growth of each of the plants. Descriptive statistics were needed to see the average growth and the standard deviation of the growth of each plant as well. All costs were recorded for the field sowing, under the following headings; labour, capital costs, and operational costs.

## 5.4 Results

### 5.4.1 Seedbed preparation and sowing techniques

Comparison of the germination results in random split-plot blocks found neither significant same treatment variation nor significant effects from minor topographic changes at the site (Table 5.2). Results were therefore combined for each individual treatment and further comparisons made between treatments.

**Table 5.2:** Tests of Within-Subjects Effects (Sowing Method*Block)

| Survey Time | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| September 2010 | 772.178 | 3.815 | 202.381 | .463 | .754 |
| April 2011 | 613.237 | 3 | 204.412 | .408 | .748 |
| September 2011 | 158.941 | 3 | 52.980 | .979 | .402 |

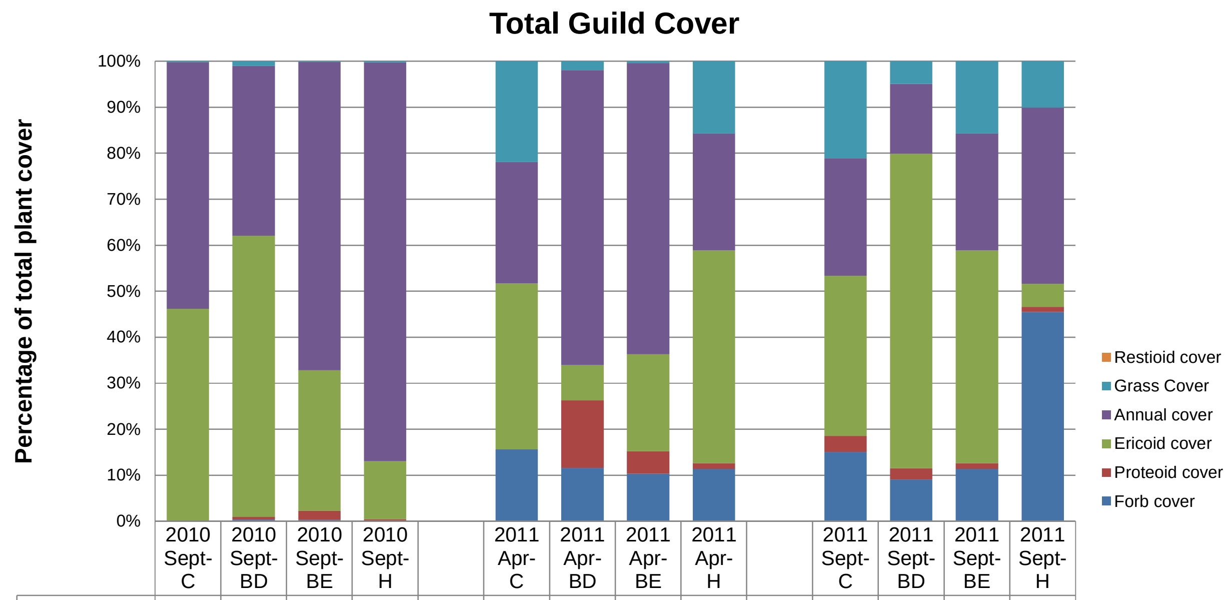
Results from the seedbed preparation tests conducted in field show that hydro seeding was the most successful (P=0.036, S.E=3) but also the most expensive. The 'broadcast and embed' technique was also successful (P=0.021, S.E=3) and was slightly less expensive since it did not require skilled labour or numerous return trips to the site. Whilst all of the techniques used showed positive results for 83% of the species, there was no germination in four of the sown species (*Stoebe cinerea, Thamnochortus punctatus, Trichogyne repens* and *Willdenowia incurvata).* The x-ray results from the Millennium Seed Bank Project showed that 81% of Stoebe cinerea seeds were empty, 72% for *Thamnochortus punctatus*, 80% for *Trichogyne repens* and 100% for *Willdenowia incurvata (n=100)* (Chapter Four). The control technique of broadcasting seed onto an unploughed soil surface; showed fair germination among the majority of species after the initial sowing in 2010 (Table 5.3). The overall percentage of species that germinated under control was 0.005%, decreasing to only 0.0015% survival after the final survey. This result had the greatest loss of species over the study period with a mean loss of 65% of the germinated species. Species sown with the broadcast and disk technique showed varied results with only 29% of all species sown germinating, mainly in the first spring season of 2010. Guild cover for this technique found that as with the other techniques the proteoid and forb guilds had low germination in the first season but did improve in the following 2 surveys. The grass cover was low on all techniques following the first survey of September 2010, but did increase mainly in the control and hydro seeding technique. The hydro seeding technique had the highest number of seedlings observed for the forb guild. Hydro seeding had the most reduction in ericoid cover of all the techniques in the final survey , yet the highest increase in forb cover. A total of 0.009% of the seed sown with the hydro seeding technique germinated in the first spring, 0.0016% and 0.0029% grew in the autumn and spring of 2011 respectively. The greatest mortality occurred in the April 2011 survey after the first summer season.

Germination of species was excellent for the broadcast and embed technique, the best performing species were the Proteaceae and Rutaceae, within the proteoid and ericoid guilds respectively and this is illustrated in Figure 5.1 which shows the recorded percentage live cover of each technique. The broadcast and embed technique also had the lowest cover for grasses than any of the other techniques as it had very little *Cynodon dactylon* regrowth and competition with seedlings. Individual species that yielded high germination results for this method were *Eriocephalus africanus* and *Ferraria crispa*. *Passerina corymbosa* had very high germination count on the spring 2010 survey for this method, however numbers decreased in the following two surveys with only an average of 1 plant per plot surviving in spring 2011. Conversely, *Stoebe capitata*, a forb, had very low cover initially with this method and improved over time (Figure 5.1). The broadcast and embed method had the least species loss over the survey period and the best overall cover for ericoids.

Rainfall data for the period January 2010 until December 2011, show that less rain was received during the study period than the expected monthly rainfall for Cape Town and Melkbosstrand area. During the month of August 2012 no precipitation fell at BBNR (Figure 5.2).

**Table 5.3:** Total number of seeds germinated per sowing technique for each block count and combined block counts for each sowing technique.

| Control | | | | |
|---|---|---|---|---|
| **Block** | **September 2010** | **April 2011** | **September 2011** | **Total** |
| **1** | 117 | 32 | 22 | 171 |
| **2** | 96 | 38 | 39 | 173 |
| **3** | 115 | 19 | 72 | 206 |
| **4** | 94 | 21 | 66 | 181 |
| **5** | 93 | 42 | 84 | 219 |
| | | | | |
| **Broadcast & disk** | | | | |
| **Block** | **September 2010** | **April 2011** | **September 2011** | **Total** |
| **1** | 177 | 45 | 100 | 322 |
| **2** | 139 | 31 | 98 | 268 |
| **3** | 143 | 51 | 136 | 330 |
| **4** | 103 | 73 | 84 | 260 |
| **5** | 123 | 36 | 150 | 309 |
| | | | | |
| **Broadcast & embed** | | | | |
| **Block** | **September 2010** | **April 2011** | **September 2011** | **Total** |
| **1** | 108 | 73 | 115 | 296 |
| **2** | 136 | 99 | 121 | 356 |
| **3** | 152 | 67 | 118 | 337 |
| **4** | 213 | 103 | 157 | 473 |
| **5** | 151 | 86 | 171 | 408 |
| | | | | |
| **Hydro seed** | | | | |
| **Block** | **September 2010** | **April 2011** | **September 2011** | **Total** |
| **1** | 132 | 63 | 145 | 340 |
| **2** | 141 | 42 | 104 | 287 |
| **3** | 133 | 83 | 13 | 229 |
| **4** | 270 | 51 | 114 | 435 |
| **5** | 212 | 61 | 169 | 442 |
| | | | | |
| | | | | |
| | **Control** | **Broadcast & disk** | **Broadcast & embed** | **Hydro Seed** |
| **September 2010** | 515 | 685 | 760 | 888 |
| **April 2011** | 152 | 236 | 428 | 300 |
| **September 2011** | 283 | 568 | 682 | 545 |
| **Total** | **950** | **1489** | **1870** | **1733** |




| | 2010 Sept-C | 2010 Sept-BD | 2010 Sept-BE | 2010 Sept-H | 2011 Apr-C | 2011 Apr-BD | 2011 Apr-BE | 2011 Apr-H | 2011 Sept-C | 2011 Sept-BD | 2011 Sept-BE | 2011 Sept-H |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Restioid cover | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Grass Cover | 0.1 | 1.1 | 0.1 | 0.3 | 9.1 | 1.0 | 0.2 | 10.2 | 9.1 | 5.1 | 10.2 | 9.1 |
| Annual cover | 35.0 | 39.5 | 50.5 | 96.2 | 11.0 | 33.2 | 30.0 | 16.5 | 11.0 | 15.5 | 16.5 | 34.5 |
| Ericoid cover | 30.0 | 65.4 | 23.0 | 14.0 | 15.0 | 4.0 | 10.0 | 30.0 | 15.0 | 70.0 | 30.0 | 4.5 |
| Proteoid cover | 0.0 | 0.6 | 1.5 | 0.3 | 0.0 | 7.6 | 2.3 | 0.8 | 1.5 | 2.5 | 0.8 | 1.0 |
| Forb cover | 0.1 | 0.4 | 0.2 | 0.2 | 6.5 | 6.0 | 4.9 | 7.4 | 6.5 | 9.3 | 7.4 | 41.0 |

**Figure 5.1:** Total cover for all guilds recorded at the Blaauwberg Nature Reserve study site for the period September 2010, April 2011 and September 2011 and the techniques broadcast and disk (BD), broadcast and embed (BE), hydro seed (H) and the control (C).

### 5.4.2 Costs

The highest costing technique was the hydro seeding method. The cost of broadcast seeding remained the same for both the disking and embedding methods, with the only extra cost for embedding for the purchase of the plank that was dragged behind the tractor. All costs listed in Table 5.4 have been extrapolated to reflect the cost of each method on a 1 hectare piece of land. Figure 5.3 illustrates the cost-germination score.

**Table 5.4.** Costs for seedbed preparation and sowing techniques for 23 CFSF species on old fields.* including Hydro Pam product and operator for hydro seeding equipment

| Treatment type | Costs (including labour) for 2010 | Total Cost |
|---|---|---|
| **Control** | Burning R32 000/ha<br>Herbicide & pesticide R44 000/ha<br>Seed sowing R5280/ha | R81 280 |
| **Broadcast and disk** | Burning R32 000/ha<br>Herbicide & pesticide R44 000/ha<br>Seed sowing R5280/ha<br>Ploughing R5750/ha | R87 030 |
| **Broadcast and embed** | Burning R32 000/ha<br>Herbicide & pesticide R44 000/ha<br>Seed sowing R5280/ha<br>Ploughing R5870/ha | R87 150 |
| **Hydro seed** | Burning R32 000/ha<br>Herbicide & pesticide R44 000/ha<br>Hydro seeding R18 504/ha* | R94 504 |

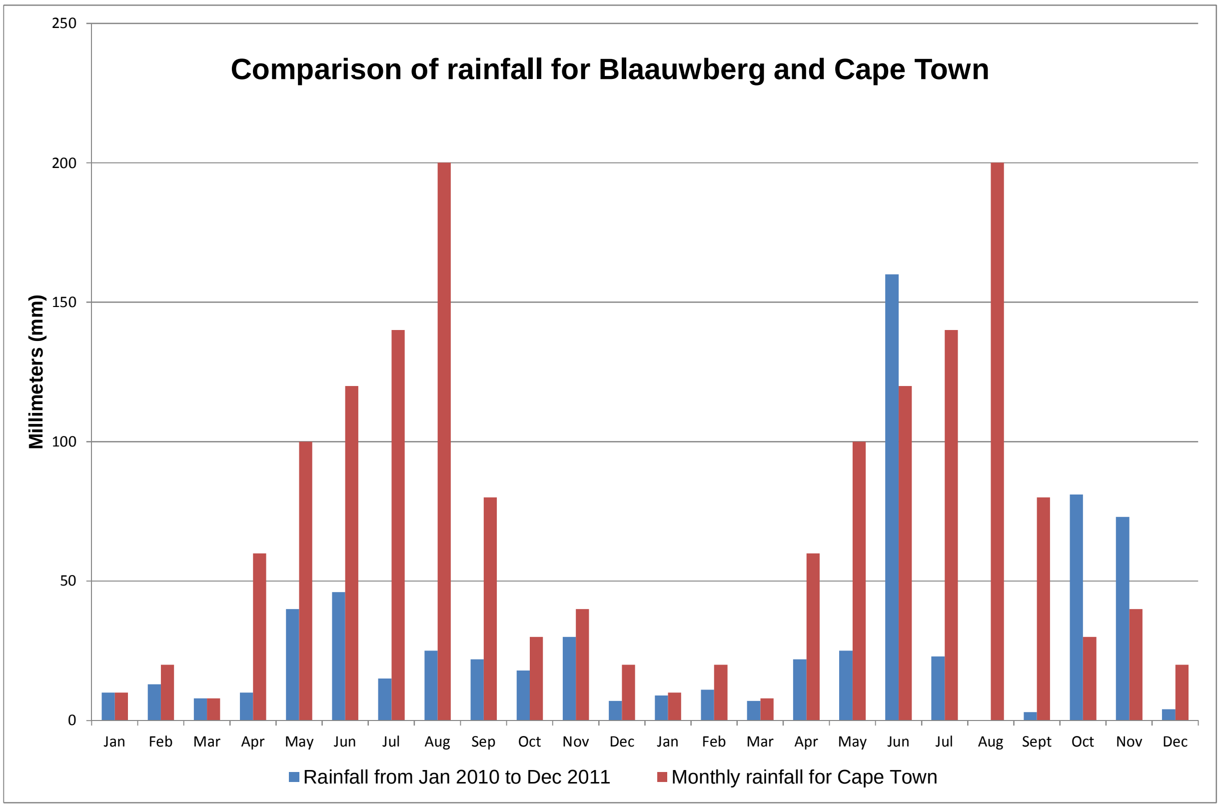



**Figure 5.2:** Rainfall figures from BBNR for January 2010 to December 2011 compared to average monthly rainfall for Cape Town

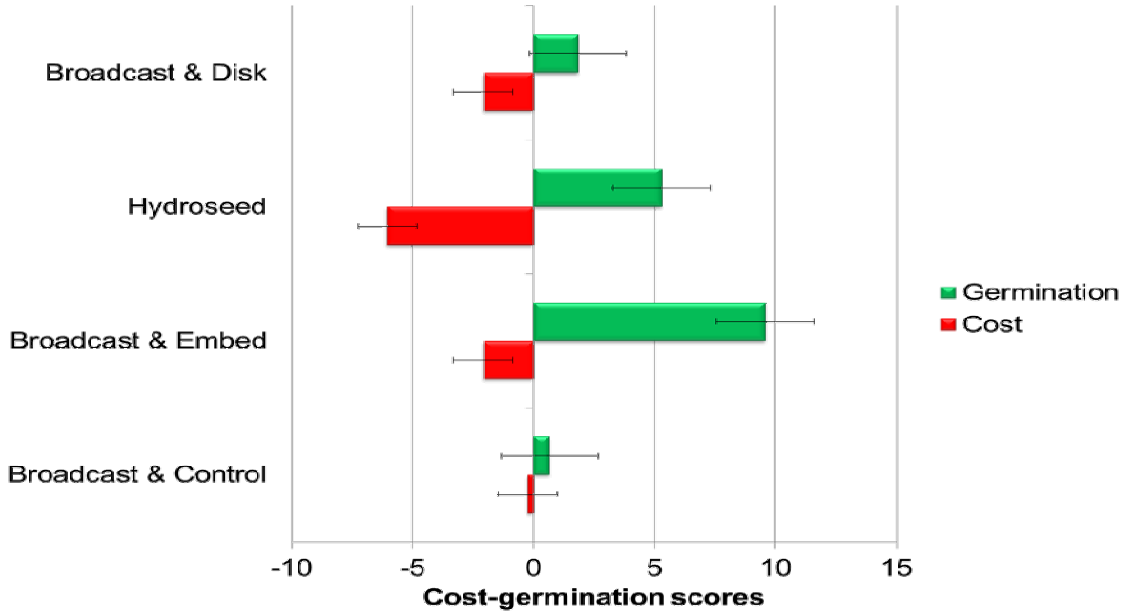



**Figure 5.3:** The cost/benefit graph illustrating the high cost of the hydro seeding technique and lower germination and long term survival of indigenous species when compared to the lower costs of broadcast and embed method and much greater germination and long term survival of the seedlings

## 5.5 Discussion

Correct seedbed preparation often determines the success or failure of a restoration project. It is one of the most labour intensive activities and is critical for the long-term establishment of target restoration species, as it provides them with optimal germination environments, allowing them to germinate earlier than existing weed species at the site and thus have an advantage over their competitors (White and Harper, 1970). Both the hydro seeding method and broadcast and embed methods were successful in aiding seedling establishment. Hydro seeding provided seeds with the best initial germination boost from the application with water and a soil stabliser, and had the maximum germination in the first and second survey period, however seedling survival decreased in the third survey and it is concluded that continued monitoring of this may show a downwards trend in overall survival for this technique. The broadcast and embed method was better for protecting seeds from the elements and predation and for longer term survival of seedlings. The majority of species that responded to being buried by the plank embedding technique had seed diameters that ranged from 47-180 mm and smaller seeded species did not germinate as positively included *Erica mammosa*, *Dimorphotheca pluvialis*, *Metalasia muricata*, *Senecio elegans*, *Pelargonium capitatum* and *Ursinia anthemoides*. The depth of the disk furrows and embedding may have been too deep for these species to germinate and reach the surface of the soil, however many did show improved germination over time and broadcast and embed had the highest percentage count in the September 2011 survey. Long term survival of species using this technique may be better than that of other techniques tested. It is recommended that these two methods be combined and tested again in the field, to obtain the benefits of both and outweigh the negatives of each.

Mechanical preparation of the seedbeds using the tractor and disk plough was efficient and effective at roughening the soil surface, removing and killing existing weeds and aiding the sowing process on a large scale in a small amount of time, it is however, difficult to use on steep, sandy and rocky slopes. In South Africa, agricultural equipment is readily available for rent for once-off restoration projects. Manual labour is also willingly available in South Africa where job creation is at a premium and many organizations provide funding for man hours on projects, where jobs are created (Lieuw-Kie-Song, 2009). Manual labour is time consuming and does not produce a uniform result, and also costly in terms of man hours needed to achieve what machinery can do in a shorter time. Due to the nature of wild plant seed used for restoration manual labour has a role to play in the broadcasting of the seed into ploughed furrows, as commercial seeding machines cannot accommodate partially clean seed of all shapes and sizes at once.

Hydro seeding required specialized equipment, additional products and extra time on site to complete the sowing. There were additional ‘skilled’ labour costs as an expert in the use of hydro seeding was required as compared with the general ploughing and broadcast seeding where general labourers could be used. To maintain the correct application rate of the seeding mixture, the tank had to be refilled regularly and the water source was far from the study site this resulted in additional time spent driving and extra fuel costs for the bakkie to travel to the water source and back. Costs could be reduced in this regard for hydro seeding, by supplying a mobile water carrier or tank at the site for refilling the tank and also training an on-staff operator thereby not paying the additional ‘skilled’ labour costs and enhancing the capacity of existing staff.

The results for the broadcast and disk technique indicate that the ideal germination environment was not established for seedlings as they were exposed to wind, sun and easy access for fossorial mammals, over half of the seedlings were lost by the spring of 2011. The lack of rain in the winter of 2010 and 2011 (Figure 5.2) may have been a cause of the failure of this technique, as the principle behind this method is for the seeds to lay in the bottom of the disked furrows and be covered with sand when the rain washes the sand down the sides of the furrows (Whisenant, 1995; Coetzee, 2005; Visser et al., 2010). The similar results to the control method illustrates that exposure of the seeds to the environmental conditions and predation in the autumn by rodents including fossorial mammals which are highly active before the cooler winter season (Lefroy et al., 1991) play a major role in the loss of restoration seed and seedling survival on CFSF(Holmes, 2008). On old sandy fields, activity of burrowing animals makes the site unsafe for large tractors and other machinery with a risk of becoming mired in the soft sand. It is therefore recommended that seedbeds be prepared and seed sown after the first heavy rains in the autumn and once the foraging activity of the fossorial mammals has ceased, prior to winter burrowing activities.

There was no germination in the field trials for the restios species, (*Willdenowia incurvata* and *Thamnochortus punctatus*) and asteraceous species (*Trichogyne repens* and *Stoebe cinerea),* although there was germination in laboratory germination tests *(*Cowell*. in prep).* The failure to germinate in field poses questions about the seeds morphology, collection timing and methods and storage requirements and even attraction to small mammals on a species specific level, these topics require further investigation.

Restoration in seasonally dry areas around the globe and the Mediterranean-type climate of the Cape Town lowlands can be a trying practice, owing to a number of factors such as high winds and short bursts of heavy rainfall that can blow seed away and result in soil erosion at the exposed site (Midoko-Iponga et al., 2005; Holmes, 2008). Seed germination and seedling survival may also be limited by low rainfall (Glenn et al., 2001; Snyman, 2003). The first two can be overcome through the seedbed preparation techniques discussed above, however the availability of water where rainfall amounts are variable and timing is unpredictable can adversely affect seedling establishment. Although Glenn et al. (2001) found that irrigation of direct seeded plots in the USA did not increase plant cover and the installation of irrigation was costly, compared to the costs and loss of species in this study it is suggested that the use of irrigation to supplement rainfall in CFSF vegetation be investigated.

Lastly, while organic matter was not used in this study, hindsight has shown that the addition of organic matter to the soil surface increases water penetration and reduces wind erosion effects on the soil. Organic matter directly affects water infiltration and evaporation by soils. Long-term loss of organic matter can have negative consequences on the soils ability to retain water. Using organic matter prior to sowing of seeds for restoration should be tested in the future, as it will aid in the retention of soil moisture and micro nutrients aiding seedling survival during dry periods.

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# CHAPTER SIX

# GENERAL CONCLUSION AND DISCUSSION

## 6.1 Introduction

The first chapter introduced the Blaauwberg Nature Reserve (BBNR) and established why it is a core conservation area. Home to 47 Red List threatened plant species and three threatened vegetation types: Cape Flats Dune Strandveld (endangered), Swartland Shale Renosterveld (critically endangered), and Cape Flats Sand Fynbos (critically endangered). BBNR is a conservation priority for the City of Cape Town as custodian of the BBNR. The BBNR is being proclaimed a Provincial Nature Reserve, however areas around Blaauwberg Hill have been proclaimed since the 1980's. Used for wheat farming and grazing of cattle in its recent history, the BBNR also has a rich cultural history dating back to the Khoi-Khoi and San peoples 2500 years ago, the Battle of Blaauwberg Hill between the Dutch and the British in 1806 and with remaining military lookout posts from the Boer and World Wars. Thus the BBNR is both a heritage and conservation priority in Cape Town and although the main aim of the study was the restoration of old fields back to Cape Flats Sand Fynbos (CFSF) vegetation, it illustrated the value of this conservation area from many other aspects. Chapter 1 also provided the history of disturbance of the site and the perimeters that the research would have to work within to obtain realistic results for restoration of CFSF. These challenges included the Mediterranean climatic conditions along the west coast of the Cape, the old sandy soils at the study site and anthropogenic disturbances. The BBNR is one of the largest remaining lowland conservation areas close to the City of Cape Town and future studies should be aimed at the conservation of the various aspects of this site; Cape Flats Dune Strandveld, Swartland Shale Renosterveld, their plant and animal communities, ecological prowness and threatened species. The primary objective of the research was to identify the optimal seeding techniques to restore CFSF on old fields on a large scale and that would be cost effective. This reference study illustrated that restoration of a particular vegetation type is a unique and specialised practise (Hobbs, 2007). The challenges to restoration on old fields at BBNR were explored; the main drivers of disturbance remaining at the site post-agriculture were alien invasive plant species and an imbalance of the ecosystem with an excessively large population of fossorial mammals. Investigation into data and literature on fynbos species germination protocols revealed very little published information is available on CFSF species. However, much work has been done on species from other fynbos ecozones (Brown et al., 1999) that behave in similar ways. Reviews of seedbed preparation and sowing techniques, found that although many techniques are available, they are restricted by the soil type and availability of the correct machinery. It was found that a thorough soil analysis should be done before beginning with restoration on old fields. It was also found that few studies have reported the overall outcome of restoration efforts and that reporting negative results and causes is also important to future restoration efforts.

**6.2 Site management for restoration of Cape Flats Sand Fynbos.**

Chapters 2 and 3 undertook an analysis of the soil condition and nutrient contents at the BBNR study site and how to prepare the site for the application of seeds for restoration. The aim of this study was to gather data which could inform necessary soil improvement techniques required for the sowing of CFSF for establishment on old fields. In order to gather information on the hydrologic, stability and nutrient cycling processes of the soil an assessment of the surface soil conditions was done, using the Tongway model (Tongway, 1994). Soil samples taken randomly across the site were tested for nutrient content from farming at the site; macro and micro nutrient, salt content, pH and carbon composition were recorded. Results from the analysis confirmed a soil deficiency in copper, magnesium and calcium. Investigation into accepted norms for fynbos soils found that these levels were acceptable for CFSF as the sandy soil structure is unable to absorb these micro nutrients due to the low clay particle content in the sands. The tested soils all had extremely low levels of organic matter or humus. The implication of this is the development of a hydrophobic layer on the soil surface and the inability of water to filter into the soil. It also has implications for nutrient processing and the presence of micro biota in the soil. This could be a limiting factor in fynbos establishment and research needs to be done on the organic carbon content of the soils and how best to enrich the site with the correct organic matter for restoration and establishment of CFSF. The experience of poor rainfall over the study period illustrated the need for organic matter in the soil to retain what little moisture may be available to aid seedling establishment and survival. The question of soil biota was first crossed in the literature review and later on in-depth analysis of the soils, it was found that this is a new avenue of information required in restoration of fynbos and that future research is required on the soil biota for CFSF, which species are on old fields present and their relationships with the floral species found in CFSF.

Two drivers of disturbance were identified and management methods were employed to reduce the negative impact of these at the site. These were the seed predation and soil disturbance activities of fossorial mammals (molerats and Cape Gerbil), and the competition from grasses (*Cynodon dactylon*), herbaceous weeds and invasive shrub species (*Acacia saligna*) which were most important in preventing establishment of indigenous species.

Intense molerat activity prevented the establishment of fynbos shrub species in previous studies and this impact was highest where *Cynodon dactylon* was present. Methods to control the molerat and gerbil numbers included the construction of raptor perches to encourage Jackal Buzzards and other birds of prey to hunt at the site. Owl boxes were placed around the study area to encourage Barn Owls to roost and hunt at BBNR. Remains of small mammals were monitored by conservation staff at BBNR and it was established that the raptor perches and owl boxes were having an impact on the populations at the site. A fence was placed around the entire 1 hectare study site to keep browsing ungulates and other small mammals out. This was found to be effective, however camera traps and accurate records of animal activities are required to make improved decisions about the management actions taken for mammals control for restoration and illustrated the need to control all disturbances on a new restoration site. It was decided that the fence should remain for a period of at least three years in order for the young plants to establish. The use of chemicals to control the fossorial mammals was successful at reducing numbers initially as a knockdown technique; however it is not environmentally sound, neither is it an economically viable method and its continued use after one application is not recommended. The use of herbicide is the best application to remove herbaceous weeds and grasses, however, if treatments are applied only once-off, success is limited and follow-up applications need to be made, particularly in the control of *Cynodon dactylon*. Continual alien clearing was seen to be necessary for the successful establishment and continuation of indigenous species at the site. The use of prescribed fire to remove grass and weed cover to expose bare soil was a success where the fire burnt hot and even across the landscape. The lack of sufficient fuel for the entire site to burn evenly was an unforseen obstacle and it is recommended that further research is needed into bulking up the fuel content across a site for a prescribed burn, without jeopardising the soil structure with too high a fuel load and scorching of the soil.

### 6.3 Application of seed for restoration on old fields.

The fourth chapter identified the best pre-germination treatments of 23 CFSF species aimed at preventing establishment failure from seed, using scarification and smoke water treatments respectively. It was found that there was limited literature on the pre-germination treatments of the selected 23 species and after interrogating what there was, the most successful methods used on a wide range of fynbos species were scarification and smoke water pre-germination treatments used to break dormancy. The study therefore focussed on establishing which of these 2 treatments was optimal for the majority of CFSF species and compared this with costs for each treatment, to determine the most economic method. Seed was collected from wild plant populations close to the study site to ensure genetic integrity of the restored plants. An external contractor was employed to harvest sufficient seed for a rate of 50 $kg.ha^{-1}$, this however was not achieved, as described below, and further harvesting had to be done to supplement the contractor's seed lot. The first step undertaken was to test the viability of the wild collected seed. This was achieved by sending seed samples to the Millennium Seed Bank Project in the United Kingdom for x-ray testing. The x-ray analysis found that 52 % of all the seed sampled was empty and non-viable. Examination of the cause of this found that seed harvested by the contractor had been harvested prematurely, the prescribed storage conditions were not adhered to and that the conditions in which the seeds were kept had high relative humidity and extreme temperatures, some of the seed even being dried in the sun. The conclusion drawn from this experience is that seed harvesting form wild plants is a very skilled and specialised practice and is not suitable for general unskilled labourers who have not been given sufficient training and understanding of the concepts behind seed development and conservation of viability. Commercial seed harvesting from seed orchards and annual plant species can tolerate incorrect methods of harvesting and storage. However wild fynbos species cannot and this resulted in the entire study being delayed for 12 months to accommodate extra harvesting by professionals from the MSBP. The costs associated with the contractors seed harvesting were not in line with the quality delivered and lessons learned from this experience are that for restoration using seed stand a chance of success skilled dedicated personnel need to be used and that the seed harvesting is not a money making exercise.

The pre-germination treatments in the laboratory found that although smoke water treatment did have positive germination results in some species, the majority of the guild species selected had no reaction to the smoke treatment. The scarification treatment had a larger overall germination success and this signifies that the actual chemicals in smoke may have very little effect on CFSF species. It may rather be that germination is related to a combination of cues, including temperatures during the fire that result in seed coat splitting and the gaseous exchanges that take place during fire events. The costs of pre-germination treatments were relatively low, once capital outlay was deducted as a once off cost to restoration.

The study found that due to the rarity of seed of Red List threatened species and the low germination of these seeds under laboratory conditions, seed-collection and sowing efforts should focus on species that are readily available in and around the restoration site and that germinate easily. It is further recommended that for species on the Red List or with challenging and unique germination requirements, they are sown and grown as seedlings or vegetatively in a nursery and planted at the restoration site. Successful establishment of these species outweighs the costs involved when planting as apposed to total failure when using seed.

In chapter 5 the methods to improve seed germination and seedling survival on site were tested. Seedbed preparation and sowing techniques of ‘Broadcast onto unploughed soils’, ‘Broadcast onto tilled soils’, ‘Broadcast onto tilled soils and plank embed’ and ‘Hydro seed onto tilled soils’ were all tested using seed of 23 CFSF species collected locally. Seeds were sown in April prior to expected winter rains in the Cape at a rate of 54 $kg.ha^{-1}$ or 18 715 030 mixed seeds of the 23 species tested. Many of the species sown did not establish in significant numbers. This was probably a combination of seed predation (a population of granivores still present), lack of seed viability and failure to germinate owing to unusually low winter rainfall. What little germination results from both cover and counts could be analysed from the surveys of the seedbed preparation and sowing techniques showed that the most successful methods for sowing the seeds were the ‘hydro-seeding’ and ‘broadcast and embed’. These methods may have provided better contact between the soil and seeds and better protection from predation and wind. Economically, the ‘broadcast and embed’ was better as machinery was easily used and required no additional expertise. Hydro seeding was the most expensive technique owing to the use of water, a soil stabiliser and extra fuel costs and skilled labour. It had a higher initial density of plants per plot but it did not have positive results in the long-term. Hydro seeding did provide the seed with water and good seed-to-soil contact initially; did not provide long term protection for the seed from the climate or predation by granivores. This study shows that the overall benefits of seedling establishment from the use of ploughing and both the hydro seeding and broadcast and embed methods by far out weigh the costs involved in manipulating the system. The broadcast and embed method was better for protecting seeds from the elements and predation and for longer term survival of seedlings.

This study did not replicate techniques from a previous study but embarked on tests to provide new scientific information on the appropriate seedbed preparation techniques for the establishment of CFSF species on old fields, taking into account lessons learnt from a previous study by Dr P Holmes in 2008 (Holmes, 2008). The challenges of conducting scientific research in the natural environment were quickly encountered and it must be stated that the desired objectives were not met due to uncontrollable elements such as weather patters and movements of uncontrolled animals. However, in order to obtain results applicable to practical restoration in the field, trials had to be undertaken in situ and not in laboratory conditions. The lack of positive results for the seedbed preparation and sowing techniques was not a complete loss as lessons can be taken from any results positive or negative. The recommendation to use either embedding or a combination of hydro seeding and embedding is therefore made by this study; the former is cost effective and ensures that seeds received good seed-to-soil contact and protection by embedding; the latter additionally provides benefits of early favourable conditions for germination.

## 6.4 Conclusion

To conclude this study the following suggestions are; that before any restoration is undertaken at a site, a full study of all past and current disturbances is done. This will provide for a list of possible actions to mitigate the drivers of disturbance and a time frame before actual sowing or planting can be done. This study found no alteration to the nutrient content of the soils from agricultural activity or alien plant invasion on the old field soils. However, old field histories differ from site to site and a soil analysis should be done of both the physical soil surface and the chemical components of the soil, should they be altered by previous activities. Here again measures can be put in place to restore the soils before adding plants and seeds to the restoration site. It is further recommended that on old fields where organic matter has been removed or is in low quantities that a supplement be added before restoration is undertaken and the system allowed a period to assimilate to a more stable level with organic matter, as wholesale compost is often very rich and raw in nutrients. Questions relating to the micro biota in CFSF soils should be addressed in future research projects, including establishing which species occur in CFSF and which are required by CFSF species to establish and then how to inoculate the soils to achieve this.

It is recommended that all pre-germination and dormancy breaking tests be conducted within a laboratory, as this study found it impossible to accurately establish individual species germination under field conditions without photographs of sown species in early germination stage or without expert knowledge and aid. The study found that herbicide applied twice, pre and post-fire had a good effect on reducing weed cover of herbaceous weeds and *Cynodon dactylon* and a follow-up of mostly invasive alien species control should be done as indigenous species establish. Ploughing to a depth of 100 mm was suitable for most CFSF species. However, the smaller seeded Asteraceae and Ericaceae species should be sown at a shallower depth for good germination. Restoring a site by sowing indigenous seeds after alien clearing and burning will increase diversity by improving species presence at the site. However, when testing in the natural environment there may be variable that are not controllable such as the poor climatic conditions for the rainy seasons of both 2010 and 2011, it is recommended that irrigation be planned for should a drought be experienced or expected, additional sowing should also be considered. Finally, it is recommended that a combination of seeding and planting be researched for restoration of CFSF on old fields. Planting propagated material of rare and Red List species may help ensure that they establish and the costs will be balanced by the costs of collecting, losing and recollecting a near extinct species. Planted islands may provide better cover and micro climates for seed of pioneer, annual and less threatened species.

## 6.5 References

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# APPENDIX A

FLORAL LIST FOR BLAAUWBERG NATURE RESERVE

| Family | Genus & Species | Red Data List Status | Phenology |
|---|---|---|---|
| AIZOACEAE | Aizoon sarmentosum | | Jun-Oct |
| AIZOACEAE | Antimima mucronata | VU | Apr-Jun |
| AIZOACEAE | Carpanthea pomeridiana | | Sep-Nov |
| AIZOACEAE | Carpobrotus acinaciformis | | Aug-Dec |
| AIZOACEAE | Carpobrotus edulis | | Aug-Oct |
| AIZOACEAE | Carpobrotus quadrifidus | | |
| AIZOACEAE | Conicosia pugioniformis subsp. pugioniformis | | Sep-Nov |
| AIZOACEAE | Dorotheanthus bellidiformis subsp. bellidiformis | | Aug-Sept |
| AIZOACEAE | Drosanthemum candens | | Oct-Jan |
| AIZOACEAE | Drosanthemum floribundum | | Sep-Dec |
| AIZOACEAE | Drosanthemum intermedium | | Aug-Sept |
| AIZOACEAE | Galenia africana | | Oct-Dec |
| AIZOACEAE | Jordaaniella dubia | | May-Sep |
| AIZOACEAE | Lampranthus aduncus | | May-Aug |
| AIZOACEAE | Lampranthus amoenus | EN | Jul-Oct |
| AIZOACEAE | Lampranthus aureus | EN | Aug |
| AIZOACEAE | Lampranthus emarginatus | | Sep-Dec |
| AIZOACEAE | Lampranthus filicaulis | VU | Jun-Jul |
| AIZOACEAE | Lampranthus reptans | EN | Aug-Oct |
| AIZOACEAE | Lampranthus sociorum | VU | Oct |
| AIZOACEAE | Lampranthus spiniformis | | May-Jun |
| AIZOACEAE | Mesembryanthemum crystallinum | | Nov-Dec |
| AIZOACEAE | Phyllobolus canaliculatus | | Nov |
| AIZOACEAE | Prenia pallens | | Sep-Dec |
| AIZOACEAE | Ruschia caroli | | Mar-Apr |
| AIZOACEAE | Ruschia diversifolia | | May-Jun |
| AIZOACEAE | Ruschia geminiflora | VU | Sep-Oct |
| AIZOACEAE | Ruschia indecora | EN | Sep-Oct |
| AIZOACEAE | Ruschia macowanii | | Aug-Sept |
| AIZOACEAE | Ruschia tecta | EN | Sep-Oct |
| AIZOACEAE | Ruschia umbellata | | |
| AIZOACEAE | Skiatophytum tripolium | VU | Sep |
| AIZOACEAE | Tetragonia decumbens | | Aug-Nov |
| AIZOACEAE | Tetragonia fruticosa | | Sep-Nov |
| AIZOACEAE | Tetragonia nigrescens | | Jul-Oct |
| ALLIACEAE | Tulbaghia capensis | | Apr-Oct |
| AMARANTHACEAE | Bassia diffusa | | |
| AMARANTHACEAE | Exomis microphylla | | |
| AMARANTHACEAE | Manochlamys albicans | | Sep-Jan |
| AMARANTHACEAE | Sarcocornia perennis | | Jan-Jun |
| AMARYLLIDACEAE | Amaryllis belladonna | | Feb-Apr |
| AMARYLLIDACEAE | Brunsvigia orientalis | | Feb-Apr |
| AMARYLLIDACEAE | Cybistetes longifolia | | Dec-Apr |

FLORAL LIST FOR BLAAUWBERG NATURE RESERVE

| | | | |
|---|---|---|---|
| AMARYLLIDACEAE | Gethyllis afra | | Dec-Jan |
| AMARYLLIDACEAE | Gethyllis cilliaris | NT | Dec-Feb |
| AMARYLLIDACEAE | Haemanthus coccineus | | Feb-Apr |
| AMARYLLIDACEAE | Haemanthus pubescens subsp. pubescens | | Feb-Apr |
| AMARYLLIDACEAE | Haemanthus sanguineus | | Jan-Apr |
| ANACARDIACEAE | Searsia crenata | | Apr |
| ANACARDIACEAE | Searsia dissecta | | Jul |
| ANACARDIACEAE | Searsia glauca | | Jun-Sep |
| ANACARDIACEAE | Searsia incisa | | Jun |
| ANACARDIACEAE | Searsia laevigata | | Oct-Dec |
| ANACARDIACEAE | Searsia lucida | | Aug-Oct |
| ANTHERICACEAE | Chlorophytum triflorum | | Jul-Oct |
| ANTHERICACEAE | Chlorophytum undulatum | | Jul-Oct |
| APIACEAE | Annesorhiza nuda | | Dec-Apr |
| APIACEAE | Annessorhiza macrocarpa | | Aug-Jan |
| APIACEAE | Arctopus echinatus | | May-Jul |
| APIACEAE | Dasispermum suffruticosum | | Aug-Nov |
| APIACEAE | Glia prolifera | | Dec-Mar |
| APIACEAE | Lichtensteinia obscura | | Nov-Jan |
| APOCYNACEAE | Asclepias crispa | | Nov-May |
| APOCYNACEAE | Cynanchum africanum | | Jun-Dec |
| APOCYNACEAE | Cynanchum obtusifolium | | Jun-Dec |
| APOCYNACEAE | Eustegia minuta | | Jul-Feb |
| APOCYNACEAE | Gomphocarpus cancellatus | | Mar-Dec |
| APOCYNACEAE | Microloma sagittatum | | Jun-Oct |
| ARACEAE | Zantedeschia aethiopica | | Jun-Dec |
| ARALIACEAE | Centella villosa | | Sep-Dec |
| ASPARAGACEAE | Asparagus aethiopicus | | Jan-Jun |
| ASPARAGACEAE | Asparagus asparagoides | | Jul-Sep |
| ASPARAGACEAE | Asparagus capensis | | Apr-Aug |
| ASPARAGACEAE | Asparagus declinatus | | Jun-Oct |
| ASPARAGACEAE | Asparagus exuvialis | | Oct-Apr |
| ASPARAGACEAE | Asparagus fasciculatus | | Mar-Jun |
| ASPARAGACEAE | Asparagus lignosus | | Oct-May |
| ASPARAGACEAE | Asparagus retrofractus | | Apr-Jun |
| ASPARAGACEAE | Asparagus rubicundus | | Mar-Jun |
| ASPARAGACEAE | Asparagus undulatus | | Jul-Oct |
| ASPHODELACEAE | Aloe mitriformis | | Dec-Feb |
| ASPHODELACEAE | Bulbine aethiopica | | |
| ASPHODELACEAE | Bulbine lagopus | | Jul-Dec |
| ASPHODELACEAE | Bulbinella triquetra | | Sep-Nov |
| ASPHODELACEAE | Trachyandra brachypoda | | Nov-Apr |
| ASPHODELACEAE | Trachyandra ciliata | | Jun-Sep |
| ASPHODELACEAE | Trachyandra divaricata | | Jul-Sep |
| ASPHODELACEAE | Trachyandra hispida | | Jun-Sep |
| ASPHODELACEAE | Trachyandra muricata | | Jul-Oct |
| ASPHODELACEAE | Trachyandra revoluta | | Aug-Nov |

| | | | |
|---|---|---|---|
| ASTERACEAE | Amellus asteroides subsp. asteroides | | Oct-Jan |
| ASTERACEAE | Arctotheca calendula | | Jul-Nov |
| ASTERACEAE | Arctotheca populifolia | | Jan-Dec |
| ASTERACEAE | Arctotis acaulos | | Aug-Oct |
| ASTERACEAE | Arctotis hirsuta | | Aug-Oct |
| ASTERACEAE | Arctotis stoechadifolia | | Sep-Dec |
| ASTERACEAE | Athanasia trifurcata | | Oct-Nov |
| ASTERACEAE | Berkheya armata | | Sep-Nov |
| ASTERACEAE | Berkheya rigida | | Sep-Jan |
| ASTERACEAE | Osteospermum incana | | Dec-May |
| ASTERACEAE | Osteospermum monilifera | | Mar-Jul |
| ASTERACEAE | Chrysocoma ciliata | | Oct-Jan |
| ASTERACEAE | Cineraria geifolia | | Aug-Nov |
| ASTERACEAE | Cotula turbinata | | Jul-Oct |
| ASTERACEAE | Didelta carnosa | | Jul-Nov |
| ASTERACEAE | Didelta carnosa var. tomentosa | | |
| ASTERACEAE | Dimorphotheca pluvialis | | Aug-Oct |
| ASTERACEAE | Dimorphotheca sinuata | | Aug-Oct |
| ASTERACEAE | Disparago anomala | | Dec-Apr |
| ASTERACEAE | Elytropappus rhinocerotis | | Feb-Apr |
| ASTERACEAE | Eriocephalus africanus | | Jan-June |
| ASTERACEAE | Eriocephalus racemosus | | Jul-Sep |
| ASTERACEAE | Euryops tenuissimus | | Aug-Oct |
| ASTERACEAE | Euryops thunbergii | | Sep-Oct |
| ASTERACEAE | Felicia tenella | | Aug-Nov |
| ASTERACEAE | Gazania krebsiana | | Sep-Jan |
| ASTERACEAE | Gazania pectinata | | Aug-Nov |
| ASTERACEAE | Gymnodiscus capillaris | | Jul-Oct |
| ASTERACEAE | Helichrysum cochleariforme | NT | Sep-Dec |
| ASTERACEAE | Helichrysum cymosum | | Sep-Apr |
| ASTERACEAE | Helichrysum dasyanthum | | Sep-Nov |
| ASTERACEAE | Helichrysum litorale | | Sep-Dec |
| ASTERACEAE | Helichrysum niveum | | Dec-Feb |
| ASTERACEAE | Helichrysum patulum | | Dec-Jan |
| ASTERACEAE | Helichrysum revolutum | | Jul-Oct |
| ASTERACEAE | Helichrysum teretifolium | | Jul-Nov |
| ASTERACEAE | Helichrysum tricostatum | NT | Sep-Dec |
| ASTERACEAE | Leysera gnaphalodes | | Sep-Nov |
| ASTERACEAE | Leysera tenella | | Aug-Oct |
| ASTERACEAE | Metalasia densa | | Jun-Oct |
| ASTERACEAE | Metalasia muricata | | May-Sept |
| ASTERACEAE | Oncosiphon suffruticosum | | Sep-Dec |
| ASTERACEAE | Osteospermum spinosum var. spinosum | | May-Oct |
| ASTERACEAE | Othonna arborescens | | May-Sept |
| ASTERACEAE | Othonna coronopifolia | | Jul-Nov |
| ASTERACEAE | Othonna cylindrica | | Jul-Oct |
| ASTERACEAE | Othonna filicaulis | | May-Aug |

FLORAL LIST FOR BLAAUWBERG NATURE RESERVE

| | | | |
|---|---|---|---|
| ASTERACEAE | Othonna pinnata | | Jun-Sep |
| ASTERACEAE | Othonna quercifolia | | May-Sept |
| ASTERACEAE | Pteronia divaricata | | Aug-Nov |
| ASTERACEAE | Pteronia hirsuta | | Nov-Jan |
| ASTERACEAE | Senecio arenarius | | Jul-Sep |
| ASTERACEAE | Senecio burchellii | | Apr-Jul |
| ASTERACEAE | Senecio elegans | | Sep-Nov |
| ASTERACEAE | Senecio littoreus | | Aug-Nov |
| ASTERACEAE | Senecio pinifolius | | Mar-May |
| ASTERACEAE | Senecio sarcoides | | Jul-Oct |
| ASTERACEAE | Steirodiscus tagetes | | |
| ASTERACEAE | Stoebe cinerea | | Apr-May |
| ASTERACEAE | Stoebe fusca | | Mar-May |
| ASTERACEAE | Stoebe plumosa | | Apr-Jun |
| ASTERACEAE | Trichogyne ambigua | | Apr-Nov |
| ASTERACEAE | Trichogyne repens | | Jul-Oct |
| ASTERACEAE | Tripteris clandestina | | Jul-Sep |
| ASTERACEAE | Ursinia anthemoides | | Aug-Oct |
| ASTERACEAE | Ursinia anthemoides subsp. anthemoides | | |
| BORAGINACEAE | Lobostemon fruticosus | | May-Dec |
| BORAGINACEAE | Lobostemon glaucophyllus | | Jul-Oct |
| BRASSICACEAE | Heliophila adpressa | | Sep-Oct |
| BRASSICACEAE | Heliophila africana | | Aug-Oct |
| BRASSICACEAE | Heliophila coronopifolia | | Aug-Oct |
| BRUNIACEAE | Berzelia lanuginosa | | Sep-Dec |
| BRUNIACEAE | Staavia radiata | | Sep-Dec |
| CAMPANULACEAE | Cyphia bulbosa | | Aug-Nov |
| CAMPANULACEAE | Cyphia digitata | | Jul-Oct |
| CAMPANULACEAE | Lobelia erinus | | Sep-Dec |
| CAMPANULACEAE | Monopsis simplex | | Nov-Apr |
| CAMPANULACEAE | Wahlenbergia capensis | | Sep-Dec |
| CAMPANULACEAE | Wahlenbergia tenella | | Nov-May |
| CARYOPHYLLACEAE | Dianthus albens | | Sep-Feb |
| CARYOPHYLLACEAE | Silene sp. bb29 | | |
| CELASTRACEAE | Gymnosporia buxifolia | | Jul-Apr |
| CELASTRACEAE | Pterocelastrus tricuspidatus | | Apr-Jun |
| CELASTRACEAE | Putterlickia pyracantha | | Feb-Aug |
| CELASTRACEAE | Robsonodendron maritimum | | Jun-Oct |
| COLCHICACEAE | Androcymbium capense | | Jun-Aug |
| COLCHICACEAE | Baeometra uniflora | | Aug-Oct |
| COLCHICACEAE | Ornithoglossum viride | | Jul-Oct |
| COLCHICACEAE | Wurmbea marginata | | Sep-Oct |
| COLCHICACEAE | Wurmbea spicata | | Aug-Nov |
| CONVALLARIACEAE | Eriospermum capense | | Nov-Mar |
| CONVALLARIACEAE | Eriospermum lanceifolium | | Mar-Apr |
| CONVALLARIACEAE | Eriospermum sp. 1 bberg wcr | | |
| CONVOLVULACEAE | Cuscuta nitida | | Aug-Dec |
| CRASSULACEAE | Adromischus hemisphaericus | | Nov-dec |

FLORAL LIST FOR BLAAUWBERG NATURE RESERVE

| | | | |
|---|---|---|---|
| CRASSULACEAE | Cotyledon orbiculata | | Sep-Dec |
| CRASSULACEAE | Crassula capensis | | May-Nov |
| CRASSULACEAE | Crassula ciliata | | Nov-Jan |
| CRASSULACEAE | Crassula cymosa | | Oct-Jan |
| CRASSULACEAE | Crassula dejecta | | Nov-Feb |
| CRASSULACEAE | Crassula fascicularis | | Dec-Mar |
| CRASSULACEAE | Crassula flava | | Dec-Feb |
| CRASSULACEAE | Crassula glomerata | | Aug-Nov |
| CRASSULACEAE | Crassula muscosa var. muscosa | | Oct-Feb |
| CRASSULACEAE | Crassula nudicaulis | | Sep-Dec |
| CRASSULACEAE | Crassula saxifraga | | Apr-Jun |
| CRASSULACEAE | Crassula tetragona subsp. tetragona | | Dec-May |
| CRASSULACEAE | Crassula tomentosa | | Dec-Mar |
| CRASSULACEAE | Crassula vaillantii | | Sep-Jan |
| CRASSULACEAE | Tylecodon grandiflorus | | Jan-Feb |
| CRASSULACEAE | Tylecodon paniculatus | | Nov-Jan |
| CUCURBITACEAE | Kedrostis nana | | Feb-Mar |
| CYPERACEAE | Ficinia bulbosa | | Feb-Sep |
| CYPERACEAE | Ficinia deusta | | Mar-Aug |
| CYPERACEAE | Ficinia dunensis | | Aug-Oct |
| CYPERACEAE | Ficinia indica | | Jun-Nov |
| CYPERACEAE | Ficinia oligantha | | Sep-Jan |
| CYPERACEAE | Ficinia secunda | | Mar-Oct |
| CYPERACEAE | Ficinia trichodes | | Jun-Sep |
| CYPERACEAE | Hellmuthia membranacea | | May-Oct |
| CYPERACEAE | Isolepis antarctica | | Oct-Nov |
| DIPSACACEAE | Scabiosa columbaria | | Aug-Feb |
| DROSERACEAE | Drosera cistiflora | | Aug-Sept |
| DROSERACEAE | Drosera trinervia | | Aug-Nov |
| EBENACEAE | Euclea racemosa | | Dec-Jun |
| ERICACEAE | Erica axillaris | | May-Dec |
| ERICACEAE | Erica imbricata | | Jan-Dec |
| ERICACEAE | Erica lasciva | | Feb-Aug |
| ERICACEAE | Erica mammosa | | Nov-May |
| ERICACEAE | Erica paniculata | | Jul-Oct |
| ERICACEAE | Erica plumosa | | Jun-Sep |
| ERICACEAE | Erica similis | | |
| EUPHORBIACEAE | Clutia alaternoides | | Aug-Oct |
| EUPHORBIACEAE | Clutia daphnoides | | Jun-Sep |
| EUPHORBIACEAE | Euphorbia arceuthobioides | | Jun-Nov |
| EUPHORBIACEAE | Euphorbia burmannii | | Jun-Sep |
| EUPHORBIACEAE | Euphorbia caput-medusae ssp. caput-medusae | | May-Sept |
| EUPHORBIACEAE | Euphorbia caput-medusae ssp. marlothiana | | May-Sept |
| EUPHORBIACEAE | Euphorbia mauritanica | | May-Oct |
| EUPHORBIACEAE | Euphorbia tuberosa | | Jun-Sep |
| FABACEAE | Aspalathus acanthophylla | VU | Sep-Feb |

| | | | |
|---|---|---|---|
| FABACEAE | Aspalathus acuminata | | Aug-Mar |
| FABACEAE | Aspalathus ericifolia | | Sep-Nov |
| FABACEAE | Aspalathus hispida | | Sep-Jan |
| FABACEAE | Aspalathus laricifolia subsp. canescens | | Sep-Dec |
| FABACEAE | Aspalathus puberula | | Oct |
| FABACEAE | Aspalathus spinescens subsp. spinescens | | Sep-Oct |
| FABACEAE | Aspalathus spinosa | | Aug-Mar |
| FABACEAE | Aspalathus ternata | | Sep-Nov |
| FABACEAE | Dipogon lignosus | | Jan-Dec |
| FABACEAE | Dolichos decumbens | | July-Aug |
| FABACEAE | Indigofera angustifolia | | May-Dec |
| FABACEAE | Indigofera brachystachya | | Nov-Sep |
| FABACEAE | Indigofera digitata | | Sep-Dec |
| FABACEAE | Indigofera heterophylla | | May-Feb |
| FABACEAE | Indigofera procumbens | | Jun-Oct |
| FABACEAE | Indigofera psoraloides | VU | Jun-Dec |
| FABACEAE | Indigofera sp. atlantic beach golf estate | | |
| FABACEAE | Lessertia argentea | | Sep-Oct |
| FABACEAE | Lessertia frutescens | | Jul-Dec |
| FABACEAE | Liparia vestita | | Mar-Oct |
| FABACEAE | Lotononis cf. umbellata | | May-Oct |
| FABACEAE | Melolobium sp. bct i/3 | | |
| FABACEAE | Otholobium bracteolatum | | Nov-Apr |
| FABACEAE | Otholobium hirtum | | Sep-Nov |
| FABACEAE | Otholobium virgatum | | Nov |
| FABACEAE | Podalyria sericea | NT | May-Jun |
| FABACEAE | Psoralea repens | NT | Nov-Feb |
| FABACEAE | Wiborgia obcordata | | Aug-Oct |
| FABACEAE | Xiphotheca reflexa | EN | Aug-Nov |
| FUMARIACEAE | Cysticapnos vesicaria | | Aug-Oct |
| GENTIANACEAE | Chironia baccifera | | Nov-Feb |
| GENTIANACEAE | Orphium frutescens | | Nov-Feb |
| GENTIANACEAE | Sebaea aurea | | Oct-Dec |
| GERANIACEAE | Geranium incanum | | Aug-Oct |
| GERANIACEAE | Pelargonium betulinum | | Aug-Jan |
| GERANIACEAE | Pelargonium capitatum | | Sep-Oct |
| GERANIACEAE | Pelargonium carnosum | | Mar-May |
| GERANIACEAE | Pelargonium gibbosum | | Nov-Apr |
| GERANIACEAE | Pelargonium lobatum | | Sep-Nov |
| GERANIACEAE | Pelargonium longicaule var. longicaule | | Aug-Jan |
| GERANIACEAE | Pelargonium longifolium | | Oct-Nov |
| GERANIACEAE | Pelargonium multiradiatum | | Sep-Mar |
| GERANIACEAE | Pelargonium myrrhifolium var. myrrhifolium | | Aug-Feb |
| GERANIACEAE | Pelargonium pinnatum | | Nov-Mar |
| GERANIACEAE | Pelargonium senecioides | | Sep-Nov |

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|---|---|---|---|
| GERANIACEAE | Pelargonium tabulare | | Sep-Jan |
| GERANIACEAE | Pelargonium triste | | Aug-Feb |
| HAEMODORACEAE | Wachendorfia paniculata | | Aug-Nov |
| HEMEROCALLIDACEAE | Caesia contorta | | Nov-Mar |
| HYACINTHACEAE | Albuca cooperi | | Sept-Nov |
| HYACINTHACEAE | Albuca flaccida | | Aug-Oct |
| HYACINTHACEAE | Albuca maxima | | Aug-Oct |
| HYACINTHACEAE | Albuca spiralis | | Aug-Oct |
| HYACINTHACEAE | Drimia capensis | | Dec-Mar |
| HYACINTHACEAE | Drimia elata | | Dec-Apr |
| HYACINTHACEAE | Drimia sp. (Tenicroa group) | | |
| HYACINTHACEAE | Lachenalia bulbifera | | Apr-Sep |
| HYACINTHACEAE | Lachenalia hirta | | Aug-Sept |
| HYACINTHACEAE | Lachenalia pallida | Declining | Aug-Oct |
| HYACINTHACEAE | Lachenalia reflexa | | Jun-Aug |
| HYACINTHACEAE | Lachenalia rubida | | Mar-Jul |
| HYACINTHACEAE | Lachenalia unifolia | | Aug-Oct |
| HYACINTHACEAE | Ornithogalum cf. hispidum | | Aug-Dec |
| HYACINTHACEAE | Ornithogalum conicum | | Nov-dec |
| HYACINTHACEAE | Ornithogalum suaveolens | | Sept-Nov |
| HYPOXIDACEAE | Empodium plicatum | | Apr-Jun |
| HYPOXIDACEAE | Spiloxene capensis | | Jul-Nov |
| HYPOXIDACEAE | Spiloxene ovata | | Jun-Oct |
| HYPOXIDACEAE | Spiloxene serrata | | May-Oct |
| IRIDACEAE | Aristea africana | | Oct-Jan |
| IRIDACEAE | Babiana villosula | EN | May-July |
| IRIDACEAE | Babiana ambigua | | Aug-Sept |
| IRIDACEAE | Babiana odorata | | Jul-Sep |
| IRIDACEAE | Babiana tubulosa | | Sept-Oct |
| IRIDACEAE | Chasmanthe aethiopica | | Apr-Jul |
| IRIDACEAE | Chasmanthe floribunda | | July-Sep |
| IRIDACEAE | Ferraria crispa subsp. crispa | | Aug-Oct |
| IRIDACEAE | Ferraria divericata | | Aug-Nov |
| IRIDACEAE | Ferraria uncinata | | Aug-Oct |
| IRIDACEAE | Freesia viridis | | July-Sept |
| IRIDACEAE | Geissorhiza aspera | | Aug-Sept |
| IRIDACEAE | Geissorhiza exscapa | | Oct-Nov |
| IRIDACEAE | Geissorhiza tenella | | Oct-Dec |
| IRIDACEAE | Gladiolus alatus | | Aug-Sept |
| IRIDACEAE | Gladiolus carinatus | | Feb-Apr |
| IRIDACEAE | Gladiolus cunonius | | Sep-Oct |
| IRIDACEAE | Gladiolus griseus | CR | May-July |
| IRIDACEAE | Gladiolus meliusculus | VU | Sep-Oct |
| IRIDACEAE | Gladiolus priorii | | Apr-Jun |
| IRIDACEAE | Gladiolus watsonius | | Aug-Sept |
| IRIDACEAE | Ixia dubia | Declining | Oct-Dec |
| IRIDACEAE | Ixia maculata var. maculata | NT | Sep-Oct |
| IRIDACEAE | Lapeirousia anceps | | Sept-Nov |
| IRIDACEAE | Lapeirousia cf. fabricii | | Sep-Oct |

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|---|---|---|---|
| IRIDACEAE | Melasphaerula ramosa | | Jul-Sept |
| IRIDACEAE | Micranthus alopecuroides | | Oct-Dec |
| IRIDACEAE | Micranthus tubulosus | | Nov-Dec |
| IRIDACEAE | Moraea cf. elsiae | | Nov-Dec |
| IRIDACEAE | Moraea ciliata | | Jul-Sep |
| IRIDACEAE | Moraea flaccida | | Aug-Oct |
| IRIDACEAE | Moraea fugax | | Aug-Nov |
| IRIDACEAE | Moraea galaxia | | Jul-Sept |
| IRIDACEAE | Moraea gawleri | | Jul-Oct |
| IRIDACEAE | Moraea miniata | | Aug-Sept |
| IRIDACEAE | Moraea tripetala | | Aug-Sept |
| IRIDACEAE | Moraea vegeta | | Sep-Oct |
| IRIDACEAE | Romulea flava | | Jun-Sep |
| IRIDACEAE | Romulea hirsuta | | Aug-Sept |
| IRIDACEAE | Romulea rosea | | Jul-Oct |
| IRIDACEAE | Romulea tabularis | | Jul-Oct |
| IRIDACEAE | Sparaxis bulbifera | | Sep-Oct |
| IRIDACEAE | Sparaxis villosa | | Aug-Sept |
| IRIDACEAE | Watsonia meriana | | Sep-Nov |
| JUNCAGINACEAE | Triglochin bulbosa | | Jul-Nov |
| LAMIACEAE | Leonotis leonurus | | Nov-Jul |
| LAMIACEAE | Leonotis ocymifolia | | Mar-May |
| LAMIACEAE | Salvia africana-caerulea | | Jun-Jan |
| LAMIACEAE | Salvia africana-lutea | | Jun-Dec |
| LAMIACEAE | Salvia lanceolata | | Sep-Jun |
| LAMIACEAE | Stachys aethiopica | | Aug-Sept |
| LAURACEAE | Cassytha ciliolata | | Sept-Jan |
| LINACEAE | Linum quadrifolium | | Sep-Nov |
| MALVACEAE | Hermannia alnifolia | | Jul-Oct |
| MALVACEAE | Hermannia decumbens | | Aug-Oct |
| MALVACEAE | Hermannia pinnata | | Aug-Oct |
| MALVACEAE | Hermannia procumbens subsp. procumbens | CR | Sept-Oct |
| MENISPERMACEAE | Cissampelos capensis | | Feb-May |
| MOLLUGINACEAE | Adenogramma lichtensteiniana | | Aug-Dec |
| MOLLUGINACEAE | Limeum africanum | | Aug-Nov |
| MOLLUGINACEAE | Pharnaceum elongatum | | Aug-Oct |
| MOLLUGINACEAE | Pharnaceum lanatum | | Aug-Oct |
| MONTINIACEAE | Montinia caryophyllacea | | May-Oct |
| MYRICACEAE | Morella cordifolia | | May-Aug |
| MYRICACEAE | Morella quercifolia | | Aug-Oct |
| MYRSINACEAE | Myrsine africana | | All year |
| NEURADACEAE | Grielum grandiflorum | | Sep-Oct |
| OLEACEAE | Olea europaea subsp. africana | | Oct-Mar |
| OLEACEAE | Olea exasperata | | Oct-Mar |
| ORCHIDACEAE | Corycium crispum | | Sep-Oct |
| ORCHIDACEAE | Corycium orobanchoides | | Sep-Oct |
| ORCHIDACEAE | Disa bracteata | | Sep-Nov |
| ORCHIDACEAE | Disa cornuta | | Sep-Feb |
| ORCHIDACEAE | Disa draconis | EN | Oct-Nov |
| ORCHIDACEAE | Disperis villosa | | Aug-Sept |

| | | | |
|---|---|---|---|
| ORCHIDACEAE | Holothrix villosa | | Oct-Jan |
| ORCHIDACEAE | Ptergodium volucris | | Sep-Oct |
| ORCHIDACEAE | Pterygodium caffrum | | Sep-Nov |
| ORCHIDACEAE | Pterygodium catholicum | | Sep-Nov |
| ORCHIDACEAE | Satyrium coriifolium | | Aug-Oct |
| ORCHIDACEAE | Satyrium odorum | | Aug-Oct |
| OROBANCHACEAE | Harveya squamosa | | Sep-Dec |
| OROBANCHACEAE | Hyobanche sanguinea | | Aug-Oct |
| OXALIDACEAE | Oxalis caprina | | Apr-Jun |
| OXALIDACEAE | Oxalis compressa | | Jul-Sep |
| OXALIDACEAE | Oxalis eckloniana | | May-July |
| OXALIDACEAE | Oxalis flava | | May-Jun |
| OXALIDACEAE | Oxalis hirta | | Apr-Jun |
| OXALIDACEAE | Oxalis livida | | Apr-May |
| OXALIDACEAE | Oxalis luteola | | May-Jun |
| OXALIDACEAE | Oxalis obtusa | | Jun-Oct |
| OXALIDACEAE | Oxalis pes-caprae | | Jun-Oct |
| OXALIDACEAE | Oxalis polyphylla | | Mar-Jun |
| OXALIDACEAE | Oxalis purpurea | | May-Sept |
| OXALIDACEAE | Oxalis pusilla | | May-July |
| OXALIDACEAE | Oxalis tomentosa | | Apr-Jun |
| OXALIDACEAE | Oxalis versicolor | | May-Nov |
| PLUMBAGINACEAE | Limonium equisetinum | | Sep-Jan |
| PLUMBAGINACEAE | Limonium perigrinum | | Aug-Jan |
| PLUMBAGINACEAE | Limonium purpuratum | | Oct-Feb |
| POACEAE | Agrostis lachnantha var. lachnantha | | Oct-Mar |
| POACEAE | Aristida junciformis | | Nov-May |
| POACEAE | Chaetobromus dregeanus | | Sep-Nov |
| POACEAE | Cladoraphis cyperoides | | Aug-May |
| POACEAE | Cymbopogon marginatus | | Oct-May |
| POACEAE | Cynodon dactylon | | Sep-May |
| POACEAE | Ehrharta calycina | | Jul-Dec |
| POACEAE | Ehrharta villosa | | Sep-Dec |
| POACEAE | Koeleria capensis | | Nov-Feb |
| POACEAE | Pentaschistis airoides | | Aug-Oct |
| POACEAE | Pentaschistis aspera | | Sep-Dec |
| POACEAE | Pentaschistis pallida | | Sep-Oct |
| POACEAE | Sporobolus virginicus | | Oct-Apr |
| POACEAE | Stenotaphrum secundatum | | Oct-Jan |
| POACEAE | Themeda triandra | | Oct-Jul |
| POACEAE | Thinopyrum distichum | | Oct-Jan |
| POACEAE | Tribolium hispidum | | Sep-Dec |
| POACEAE | Tribolium uniolae | | Oct-Dec |
| POLYGALACEAE | Muraltia trinervia | | Aug-Nov |
| POLYGALACEAE | Nylandtia spinosa | | Jun-Jul |
| POLYGALACEAE | Polygala cf. scabra | | Jul-Oct |
| POLYGALACEAE | Polygala garcinii | | Oct-Dec |
| POLYGONACEAE | Rumex sagittatus | | Jan-Apr |
| PROTEACEAE | Leucadendron lanigerum var. lanigerum | EN | Jul-Sep |

FLORAL LIST FOR BLAAUWBERG NATURE RESERVE

| | | | |
|---|---|---|---|
| PROTEACEAE | Leucadendron levisanus | CR | Sep-Oct |
| PROTEACEAE | Leucadendron salignum | | Apr-Nov |
| PROTEACEAE | Leucadendron thymifolium | CR | Aug-Sept |
| PROTEACEAE | Leucospermum hypophyllocarpodendron subsp. hypophyllocarpodendron | VU | Aug-Jan |
| PROTEACEAE | Leucospermum hypophyllocarpodendron subsp. canaliculatum | VU | Aug-Jan |
| PROTEACEAE | Leucospermum tomentosum | VU | Jun-Nov |
| PROTEACEAE | Protea repens | | Jan-Dec |
| PROTEACEAE | Protea scolymocephala | | Aug-Oct |
| PROTEACEAE | Serruria aemula | CR | Jul-Oct |
| PROTEACEAE | Serruria decipiens | | Jul-Oct |
| PROTEACEAE | Serruria fasciflora | | May-Dec |
| PROTEACEAE | Serruria trilopha | CR | Aug-Oct |
| RESTIONACEAE | Calopsis fruticosa | | Aug-Nov |
| RESTIONACEAE | Calopsis impolita | | |
| RESTIONACEAE | Calopsis rigorata | | |
| RESTIONACEAE | Chondropetalum microcarpum | | Apr |
| RESTIONACEAE | Chondropetalum nudum | | Apr-Jun |
| RESTIONACEAE | Chondropetalum rectum | | |
| RESTIONACEAE | Chondropetalum tectorum | | |
| RESTIONACEAE | Hypodiscus willdenowia | | Jun-Aug |
| RESTIONACEAE | Ischyrolepis capensis | | Oct-Nov |
| RESTIONACEAE | Ischyrolepis eleocharis | | |
| RESTIONACEAE | Thamnochortus erectus | | Sep-Oct |
| RESTIONACEAE | Thamnochortus fruticosus | | Jul-Nov |
| RESTIONACEAE | Thamnochortus punctatus | | Mar-May |
| RESTIONACEAE | Thamnochortus spicigerus | | Apr-May |
| RESTIONACEAE | Willdenowia incurvata | | Jun |
| RESTIONACEAE | Willdenowia teres | | Sep |
| RHAMNACEAE | Phylica cephalantha | | Apr-Sep |
| RHAMNACEAE | Phylica ericoides | | Jan-Dec |
| RHAMNACEAE | Phylica plumosa | | May-Aug |
| RHAMNACEAE | Trichocephalus stipularis | | May-Sept |
| ROSACEAE | Cliffortia falcata | | Aug-Oct |
| ROSACEAE | Cliffortia juniperina | | Sep-Mar |
| ROSACEAE | Cliffortia polygonifolia | | Apr-Nov |
| RUBIACEAE | Anthospermum galioides | | Jul-Jan |
| RUBIACEAE | Anthospermum prostratum | | Aug-Oct |
| RUBIACEAE | Anthospermum spathulatum subsp. spathulatum | | Jun-Feb |
| RUBIACEAE | Galium tomentosum | | Sep-Nov |

FLORAL LIST FOR BLAAUWBERG NATURE RESERVE

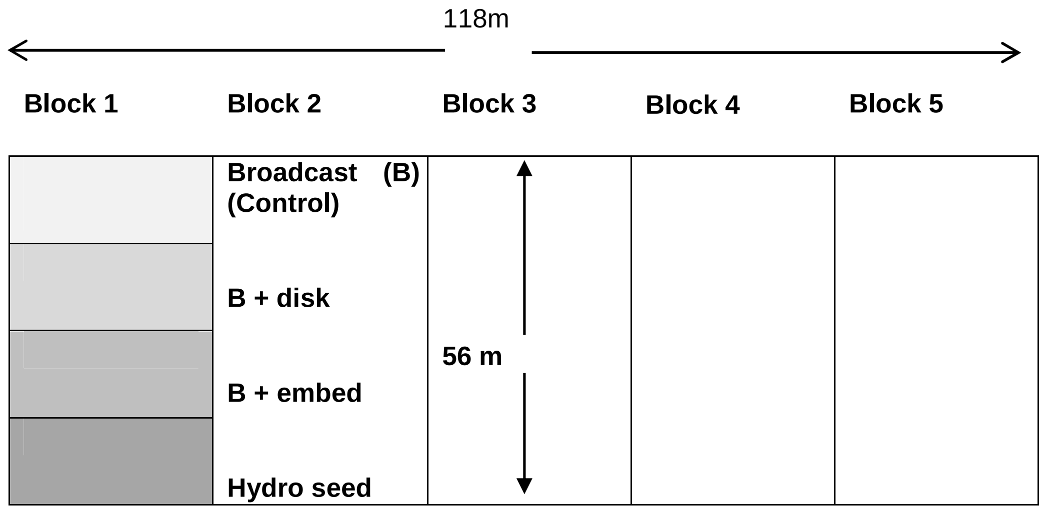
| | | | |
|---|---|---|---|
| RUTACEAE | Agathosma capensis | | Jan-Dec |
| RUTACEAE | Agathosma imbricata | | Jun-Jan |
| RUTACEAE | Agathosma serpyllacea | | May-Dec |
| RUTACEAE | Coleonema album | | Aug-Oct |
| RUTACEAE | Diosma demissa | VU | Mar-Jun |
| RUTACEAE | Diosma dichotoma | VU | Nov-Jan |
| RUTACEAE | Diosma oppositifolia | | Sep-Jan |
| SANTALACEAE | Osyris compressa | | Dec-Jun |
| SANTALACEAE | Thesidium fragile | | All year |
| SANTALACEAE | Thesium aggregatum | | Aug-Jan |
| SANTALACEAE | Thesium carinatum | | Jan-Dec |
| SANTALACEAE | Thesium pubescens | | Aug-Nov |
| SANTALACEAE | Thesium virgatum | | Aug-Feb |
| SAPOTACEAE | Sideroxylon inerme | | Dec-Jun |
| SCROPHULARIACEAE | Diascia diffusa | | Aug-Nov |
| SCROPHULARIACEAE | Diascia elongata | | Aug-Nov |
| SCROPHULARIACEAE | Dischisma arenarium | | Aug-Oct |
| SCROPHULARIACEAE | Dischisma ciliatum | | Aug-Nov |
| SCROPHULARIACEAE | Hebenstretia cordata | | Sep-Feb |
| SCROPHULARIACEAE | Hebenstretia repens | | Jul-Oct |
| SCROPHULARIACEAE | Hemimeris racemosa | | Jul-Oct |
| SCROPHULARIACEAE | Hemimeris sabulosa | | Jul-Oct |
| SCROPHULARIACEAE | Lyperia lychnidea | | Aug-Nov |
| SCROPHULARIACEAE | Lyperia tristis | | Jul-Oct |
| SCROPHULARIACEAE | Manulea cheiranthus | | Jul-Nov |
| SCROPHULARIACEAE | Manulea thyrsiflora | | Aug-Oct |
| SCROPHULARIACEAE | Manulea tomentosa | | Aug-Dec |
| SCROPHULARIACEAE | Nemesia affinis | | Aug-Nov |
| SCROPHULARIACEAE | Nemesia barbata | | Aug-Oct |
| SCROPHULARIACEAE | Nemesia bicornis | | Jul-Sep |
| SCROPHULARIACEAE | Phyllopodium phyllopodioides | | Jul-Sep |
| SCROPHULARIACEAE | Selago fruticosa | | Sep-Dec |
| SCROPHULARIACEAE | Sutera uncinata | | May-Oct |
| SCROPHULARIACEAE | Zaluzianskya capensis | | Jul-Oct |
| SCROPHULARIACEAE | Zaluzianskya villosa | | Jul-Nov |
| SOLANACEAE | Lycium afrum | | Jul-Sep |
| SOLANACEAE | Lycium ferocissimum | | Jul-Sep |
| SOLANACEAE | Solanum guineense | | Mar-Aug |
| SOLANACEAE | Solanum linnaeanum | | Jun-Sep |
| TECOPHILAEACEAE | Cyanella hyacinthoides | | Aug-Nov |
| THYMELAEACEAE | Lachnaea capitata | VU | Jun-Mar |
| THYMELAEACEAE | Lachnaea grandiflora | VU | Aug-Jun |
| THYMELAEACEAE | Passerina corymbosa (was P. vulgaris) | | Oct-Nov |
| THYMELAEACEAE | Passerina ericoides | | Oct-Nov |
| THYMELAEACEAE | Passerina paleacea | | Oct-Nov |
| THYMELAEACEAE | Passerina rigida | | Nov |
| THYMELAEACEAE | Struthiola cf. ciliata | | Jan-Dec |
| THYMELAEACEAE | Struthiola striata | | Sep-Jun |
| TYPHACEAE | Typha capensis | | Dec-Mar |
| VISCACEAE | Viscum capense | | Jul-Oct |
| VISCACEAE | Viscum rotundifolium | | Feb-May |
| ZYGOPHYLLACEAE | Zygophyllum flexuosum | | Jun-Oct |
| ZYGOPHYLLACEAE | Zygophyllum morgsana | | Apr-Oct |

| | | | |
|---|---|---|---|
| ZYGOPHYLLACEAE | Zygophyllum sessilifolium | | Jul-Sep |
| ZYGOPHYLLACEAE | Zygophyllum spinosum | | Jun-Sep |

FLORAL LIST FOR BLAAUWBERG NATURE RESERVE

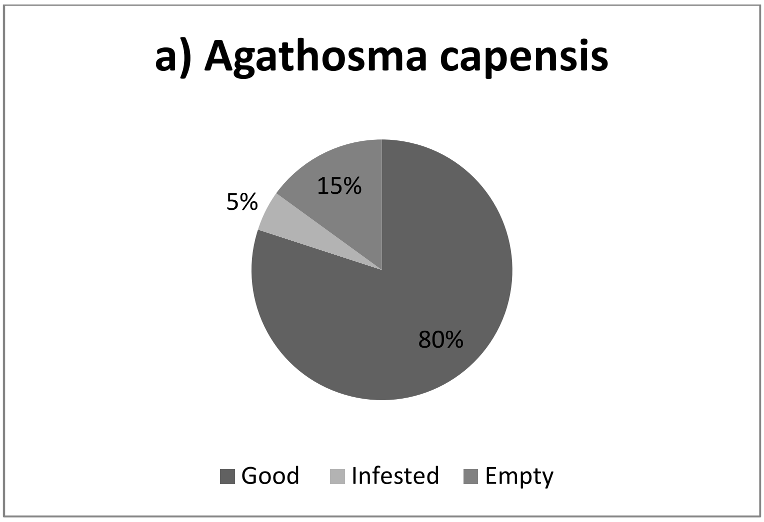
# APPENDIX B

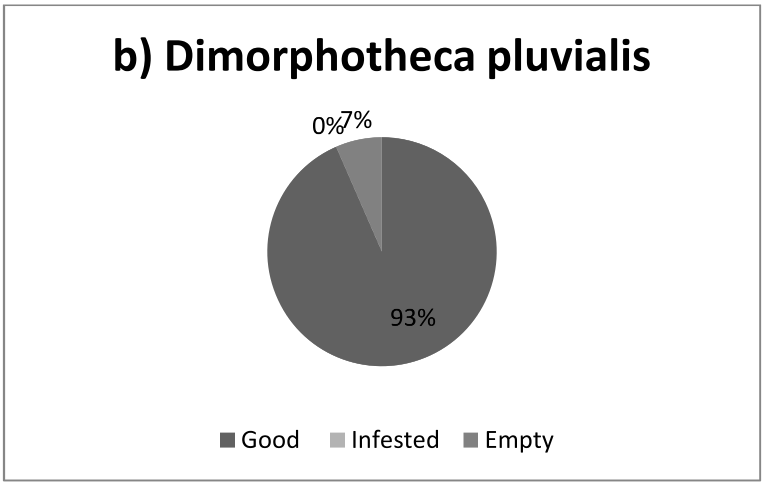
## Split-plot block design of field experiment at Blaauwberg Nature Reserve

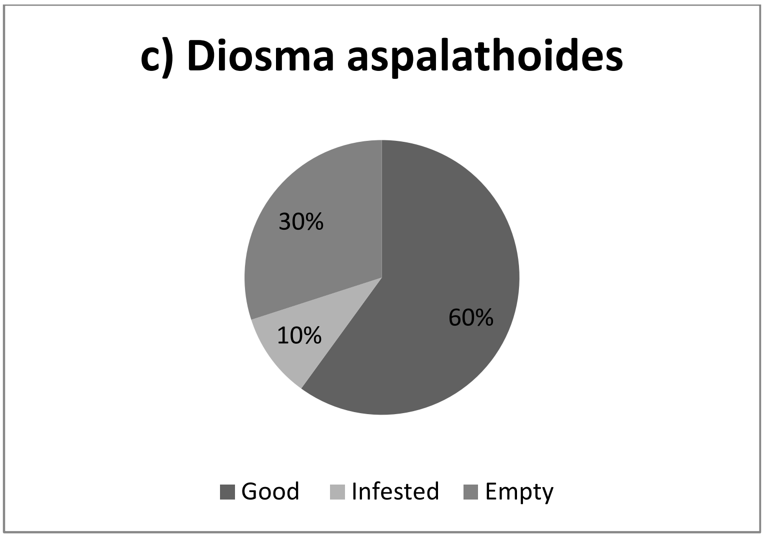


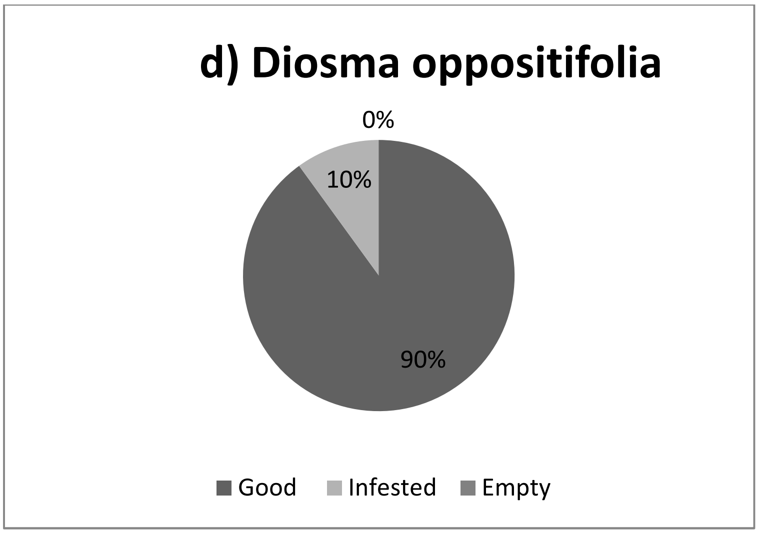
## APPENDIX C

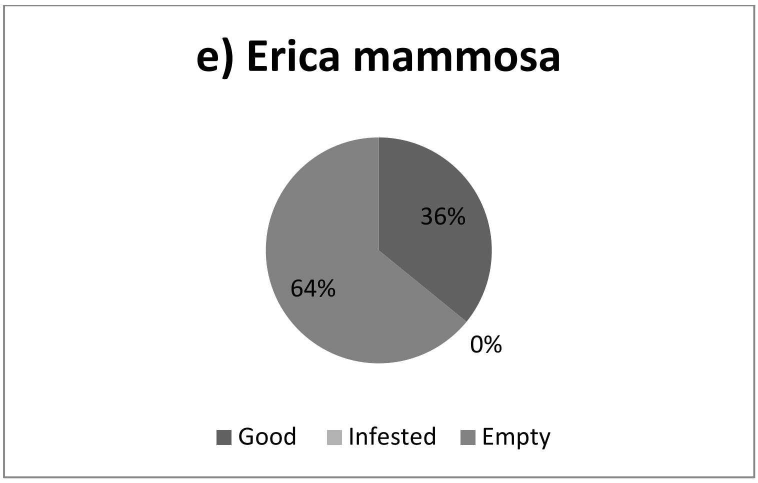
**X-ray viability results for 23 species (*n*=100, S.E=3), percentage total viable seeds shown as good, infected and empty**



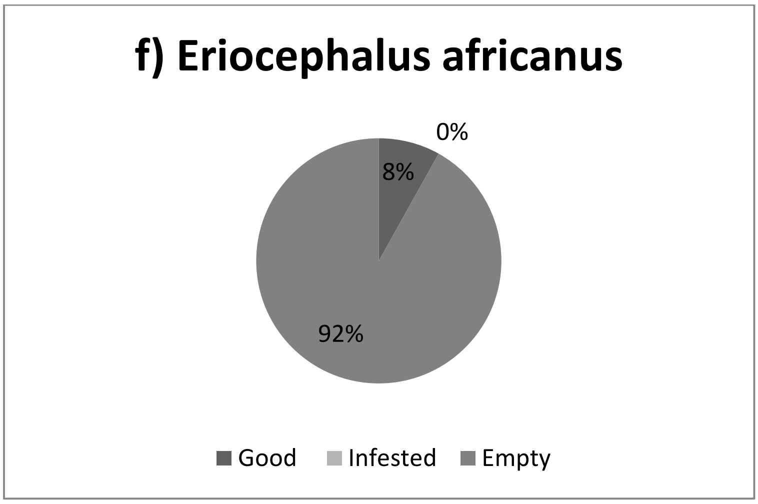



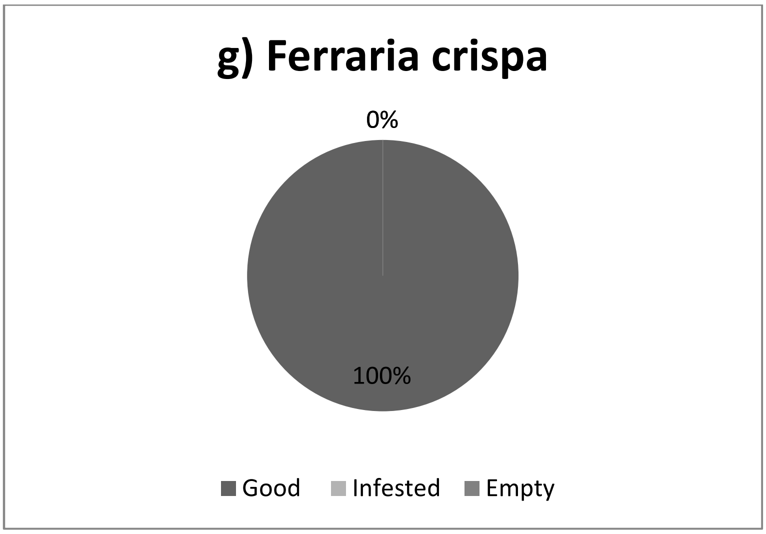

c) Diosma aspalathoides
30%
10%
60%
Good
Infested
Empty

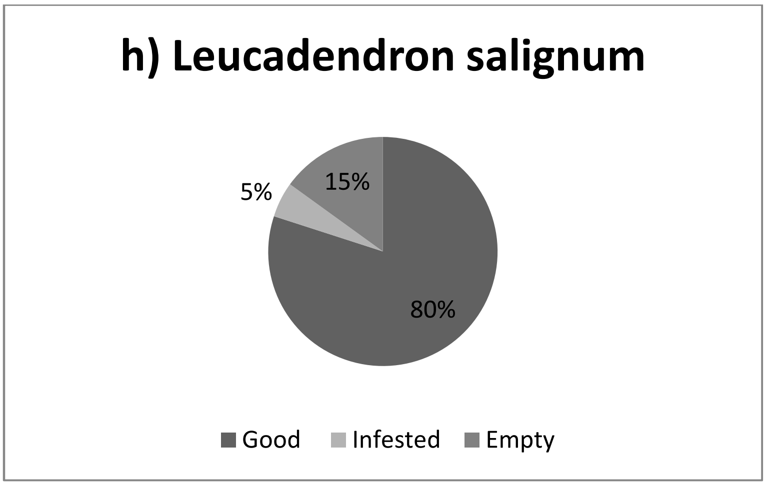

d) Diosma oppositifolia
0%
10%
90%
Good
Infested
Empty


e) Erica mammosa
36%
64%
0%
Good
Infested
Empty

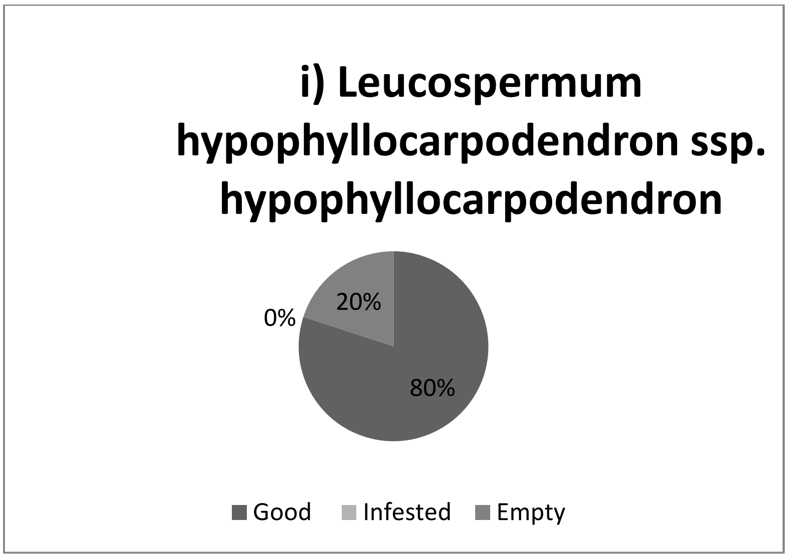
X-ray viability results for seed of 23 Cape Flats Sand Fynbos species

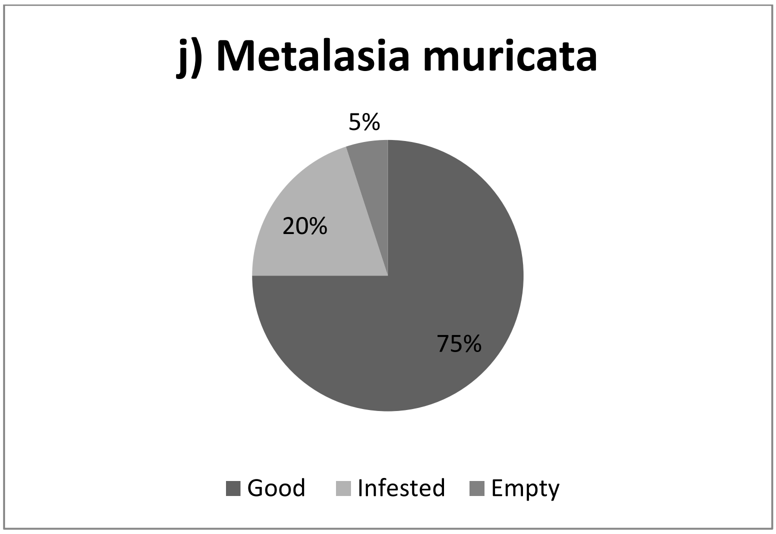


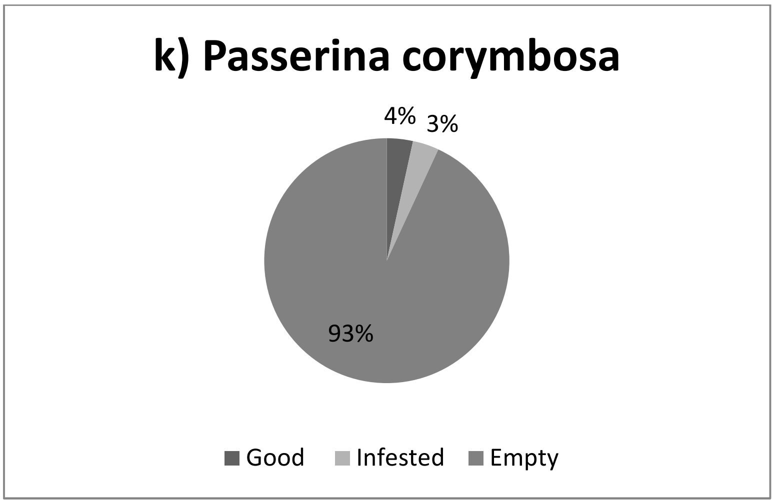



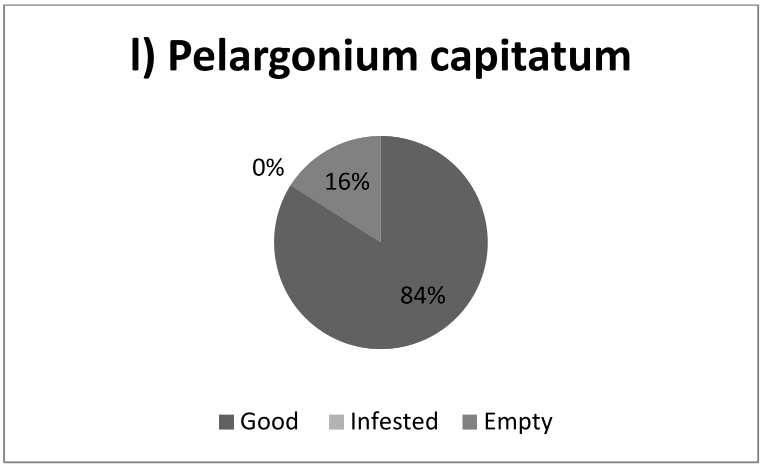
X-ray viability results for seed of 23 Cape Flats Sand Fynbos species

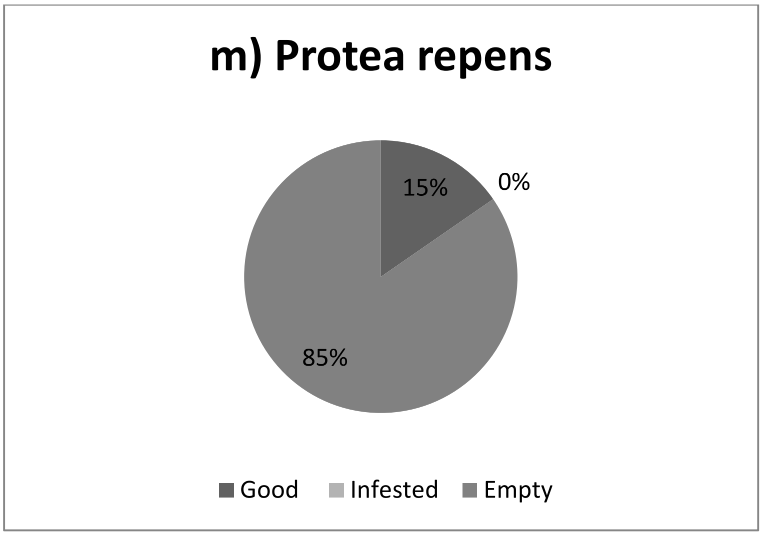


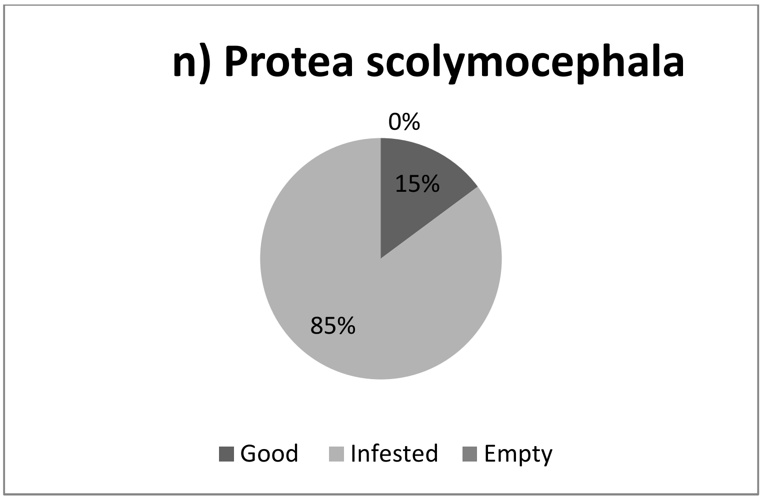



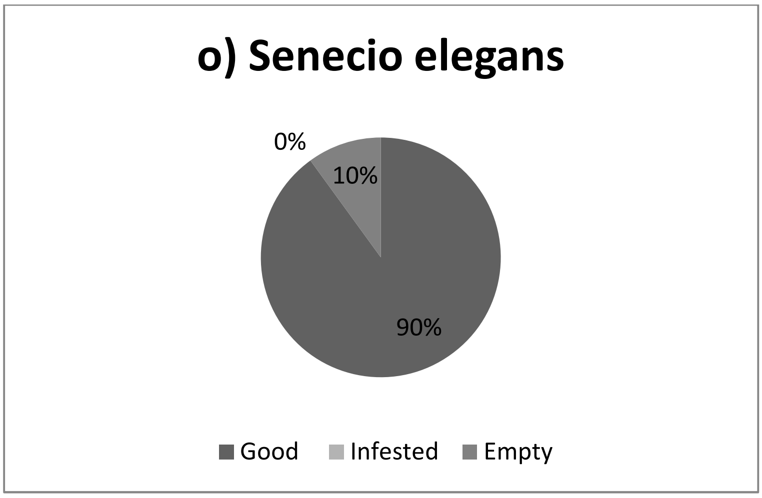



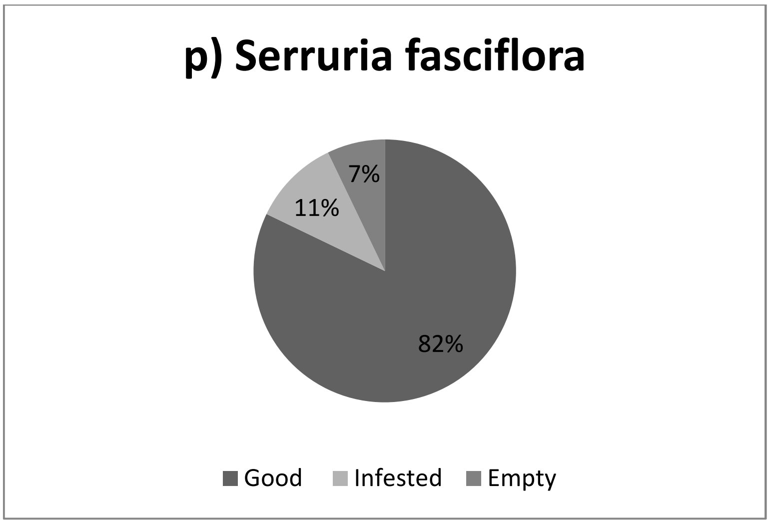
X-ray viability results for seed of 23 Cape Flats Sand Fynbos species

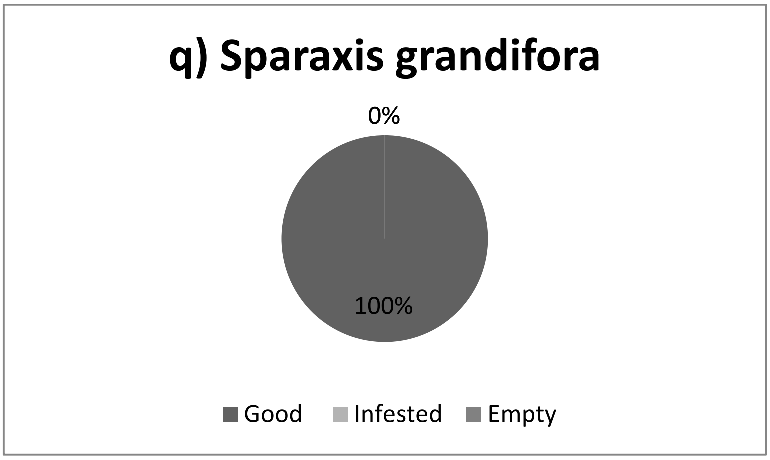


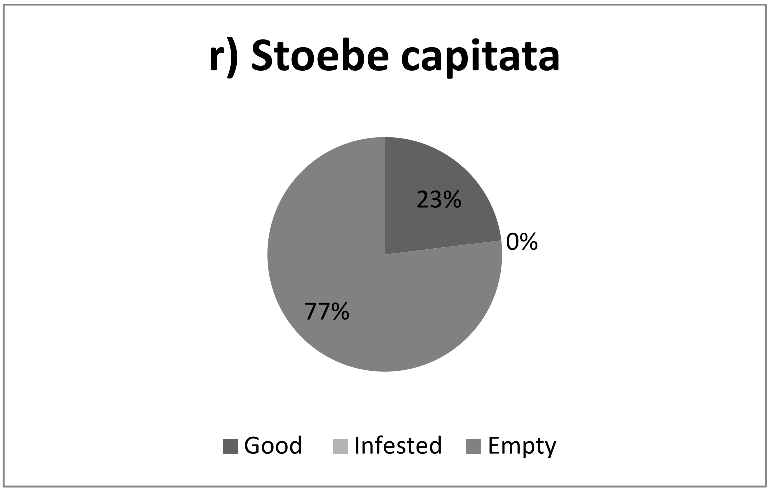



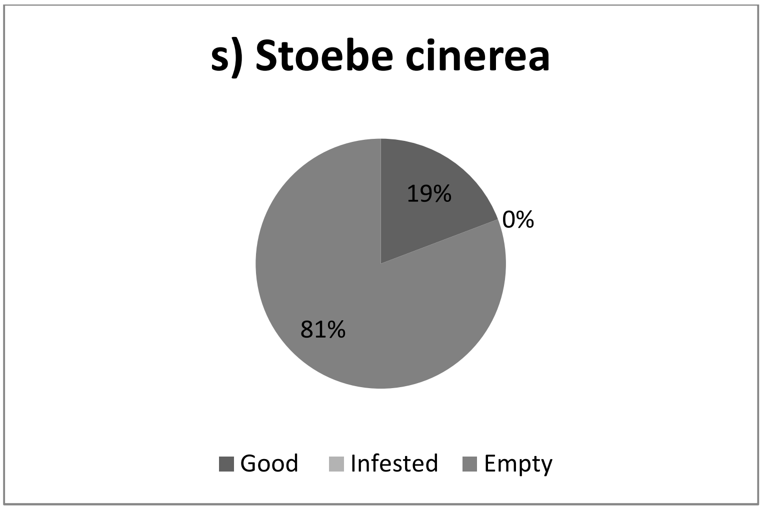

o) Senecio elegans
0%
10%
90%
Good
Infested
Empty

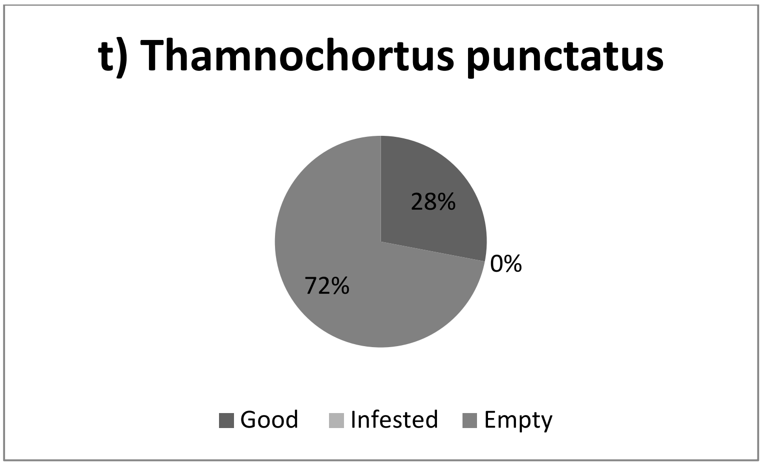

p) Serruria fasciflora
7%
11%
82%
Good
Infested
Empty


q) Sparaxis grandifora
0%
100%
Good
Infested
Empty

X-ray viability results for seed of 23 Cape Flats Sand Fynbos species



X-ray viability results for seed of 23 Cape Flats Sand Fynbos species