POTENTIAL OF SELECTED KAROO PLANT SPECIES FOR REHABILITATION OF OLD FIELDS

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Declaration

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree

Date: ....20 August 2002........

THESIS SUMMARY

The passive recovery of old fields in the Karoo is a slow process, hampered by low and erratic rainfall, poor seed germination due to limited availability of suitable micro sites for seedling establishment, competition from existing vegetation, altered soil properties and the reduction of key soil biotic processes. The objectives of the study were to investigate the role of seed banks in the recovery of old fields, and to identify possible plant species and methods of establishing these species with the primary aim of initiating the process of succession / recovery of old fields in the Little Karoo.

The investigation of the seed bank addressed the following issues: the resemblance of the seed bank to the above-ground vegetation in an old field and the effect of disturbance on the seed bank. Furthermore, the role of propagule migration was investigated to establish possible propagule movement from undisturbed to disturbed areas was investigated. The study indicated that the perennial seed bank had a 31% similarity to the above ground vegetation in the old field. The seed bank was dominated by annual species. In the above-ground vegetation perennial canopy cover was higher compared to annual cover. The perennials with the highest densities in the soil seed bank were disturbance-adapted species with little importance for grazing animals except perhaps in the short-term. Disturbance caused annual densities to increase and perennial densities to decrease. The investigation of propagule migration compared adult canopy cover and seedling densities. The results show that perennial distribution was patchy and that propagule migration is low to non-existent. This led to the conclusion that old fields require supplemental seed additions.

A total of seven species were assessed for their restoration potential. The species used in the investigation were *Tripteris sinuata, Ruschia spinosa, Drosanthemum speciosum, Indigofera sessifolia, Pteronia incana, Ehrharta calycina* and *Chaetobromus dregeanus.* Seed viability was examined using one of two techniques ie. tetrazolium or a standard germination technique. The optimal temperature for germination was determined using the following temperature regimes: 15°C day / 10°C night, 20°C day /10°C night and 30°C day / 15°C night. The temperature range with the best performance was 20°C day / 10°C night indicating that species should be sown in autumn or early winter. This timing coincides with the onset of rains in this region.

The field trial investigated the influence that various mechanical cultivation techniques (ploughing, disking, tilling and clearing) and soil amendments (seed, seed+aquasorb and seed+straw+branches) have on the establishment of the selected species. Seed germination and seedling survival was monitored. The influence of treatments on water infiltration and soil moisture was investigated. Only four of the seven species germinated (*Tripteris sinuata, Ehrharta calycina, Chaetobromus dregeanus* and *Pteronia incana*). As far as species performance was concerned, *T. sinuata* performed best followed by *E. calycina* and *C. dregeanus*, while *P. incana* failed to persist. The cultivation treatments that yielded the best results were tilling, disking and ploughing. Emergence success in cleared and untreated plots was relatively low. As far as seedling emergence was concerned the most appropriate soil amendments were seed+aquasorb, seed and seed+straw+branches. Although soil moisture was higher on-heuweltjies than off-heuweltjies there was no significant difference in seedling emergence and survival between these localities. Even though soil moisture was higher in seed+straw+branches treatment than in seed+aquasorb and seed treatments, seedling emergence in this treatment were lower than in the two latter treatments. This clearly indicates that soil moisture is not the only factor that influences the establishment of species.

In the trial a mixture of late successional and pioneer species were sown, primarily with the aim of initiating the process of succession/ recovery of old fields. Contrary to what was expected the late successional species germinated first. This has led to the conclusion that these late successional species have no innate dormancy, further proved by the inability of species to germinate after the second season. It could thus be that these late successional species have a short live span, and that they germinate when conditions are favourable. It must also be kept in mind that the seed sown were freshly harvested, and it could be that the pioneer species needed an after-ripening period before they germinated.

TESIS OPSOMMING

Die passiewe herstel van oulande in die Karoo is 'n tydrowende proses, wat vertraag word deur wisselvallige reënval, swak ontkieming as gevolg van 'n tekort aan geskikte mikro-habitatte vir saailingvestiging, kompetisie van bestaande plantegroei, veranderende grondeienskappe en die afname in sleutel biotiese prosesse. Die doel van hierdie studie was, om die rol van saadbank in die herstel van oulande te bepaal, sowel as om moontlike plantspesies te identifiseer en metodes van vestiging van hierdie spesies te bepaal met die primêre doel om die proses van suksessie / herstel van oulande in die Klein Karoo te inisieër.

Met die saadbankstudie is die volgende punte aangespreek: die ooreenkoms tussen die meerjarige spesies in die saadbank en bogrondse plantegroei op ou lande, en die effek van versteuring op die saadbank. Verder is gekyk na die rol van voortplantings-meganisme verspreiding om moontlike beweging vanaf onversteurde na versteurde areas te ondersoek.

Die studie het aangedui dat daar 'n 31% ooreenkoms is tussen meerjarige spesies in die saadbank en die bogrondse plantegroei op ou lande areas. In die bogrondse plantegroei van die ou land was die kroonbedekking van meerjarige spesies hoër as die van eenjarige spesies. Die dominante meerjarige spesies in die saadbank was spesies wat aangepas is by versteurings, met min weidingswaarde, behalwe moontlik oor die kort termyn. Versteuring het 'n verhoging in eenjarige en 'n afname in meerjarige saailingdigthede veroorsaak. Resultate dui daarop dat meerjarige verspreiding onreëlmatig is in die versteurde area en dat die teenwoordigheid van voortplantingsmeganismes, baie laag is. Dit lei tot die gevolgtrekking dat oulande addisionele saad benodig vir hervestiging.

'n Totaal van sewe spesies is ge-evalueer vir hulle moontlike restorasie potensiaal. Die spesies wat in die ondersoek gebruik was, is *Tripteris sinuata, Ruschia spinosa, Drosanthemum speciosum, Indigofera sessifolia, Pteronia incana, Ehrharta calycina en Chaetobromus dregeanus.* Die kiemkragtigheid van die spesies is bepaal deur gebruik te maak van een van twee tegnieke nl. die tetrazolium of 'n standaard ontkiemings tegniek. Die optimale temperature vir ontkieming is bepaal deur gebruik te maak van die volgende temperatuurreekse: 15°C dag / 10°C nag, 20°C dag /10°C nag and 30°C dag / 15°C nag. Die temperatuur reeks waarop spesies die beste

presteer het, was 20°C dag /10°C nag. Dit dui daarop dat spesies tydens herfs en vroeë winter gesaai moet word. Dit is dan ook die tydperk vir die aanvangs van die reënseisoen in hierdie streek.

In die veldproef is gekyk na die invloed van verskeie meganiese bewerkings - tegnieke (ploeg, dis, ghrop en plant verwydering) en grondverbeterings behandelings (saad, saad+aquasorb en saad+strooi+takke), op die vestiging van geselekteerde spesies. Saadontkieming en saailingoorlewing is gemonitor. Die invloed van die behandelings op waterinfiltrasie en grondvog is ook ondersoek. Slegs vier van die sewe spesies het ontkiem naamlik: *Tripteris sinuata, Ehrharta calycina, Chaetobromus dregeanus* en *Pteronia incana*. Spesies wat die beste presteer het, was *T. sinuata* die gevolg deur *E. calycina* en *C. dregeanus,* terwyl *P. incana* nie oorleef het nie. Die bewerkingsbehandelings wat die beste vestiging van plante gegee het, was die ghrop en disbewerkings gevolg deur ploegbewerking. Ontkiemings sukses in areas waar plante verwyder is en onbehandelde persele was relatief laag. Die grondverbeterings behandeling wat die beste ontkieming gelewer het was saad+aquasorb gevolg deur saad en saad+strooi+takke. Alhoewel grondvog hoër was op heuweltjies as weg van heuweltjies, was daar geen betekenisvolle verskil in ontkieming en oorlewing tussen hierdie lokaliteite nie. Alhoewel grondvog hoër was in saad+strooi+takke behandelings as in saad+aquasorb en saad behandelings was ontkieming laer in hierdie behandeling as in die saad+aquasorb en saad behandelings. Dit dui dus daarop dat grondvog nie die enigste faktor is wat die vestiging van spesies beinvloed nie.

In die veldproef is 'n mengsel van pionier en klimaks spesies gesaai, met die primêre doel om die proses van suksessie/herstel van oulande te inisieër. In teenstelling met wat verwag is het die meer klimaks spesies eerste ontkiem. Dit het gelei tot die gevolgtrekking dat hierdie spesies geen dormansie het nie, en dit is verder bewys deur 'n onvermoë om te ontkiem in die tweede seisoen. Dit mag wees dat die meer klimaks spesies 'n kort lewensduur het, en dat hulle ontkiem wanneer toestande gunstig is. Dit moet ingedagte gehou word dat die saad vars geoes was, en dit kon dus wees dat die pionier spesies 'n na-rypwordings periode benodig voordat hulle ontkiem.

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CHAPTER 1: LITERATURE REVIEW: RESTORATION IN ARID ENVIRONMENTS

1.1 Introduction

The focus of the thesis was to evaluate the restoration potential of old fields in the Little Karoo, of the Succulent Karoo of South Africa. The conditions of the above-ground vegetation, the seed bank and soils were assessed. Seven indigenous species were selected to investigate their establishment techniques as a guideline for future old field restoration in the semi-arid Karoo.

The aim of the literature review is to provide insight on the concept of ecological restoration, the limits to restoration in arid environments, the status of restoration research in South Africa and the status of old field restoration. Specific literature relating to soil seed banks (Chapter 3), germination (Chapter 4) and field re-vegetation techniques (Chapter 5) is reviewed in the relevant chapters of this thesis (overview provided in chapter 2).

1.2 Restoration in general

Natural vegetation (referred to as veld in this thesis) is one of Southern Africa's major natural resources. Overexploitation has lead to a decrease in the productivity of this valuable commodity (Bradshaw & Chadwick 1980). Some examples of practices that lead to the reduction of productive land include inappropriate mining and agricultural practices as well as developments such as roads, industrial complexes and residential developments (Bradshaw & Chadwick 1980). Natural vegetation should be viewed as a complex biological system built up over long periods of time and if we are to restore it, we must have an understanding of its functioning on a biological, physical and chemical scale. Changes to the natural ecosystem either eliminate or substantially alter its ecological role, and in some cases these changes may result in the need for restoration.

Early re-vegetation depended heavily on agricultural practices and principles and attempts had a relatively low success rating (Call & Roundy 1991). Since then improved plant materials, equipment, site preparation and planting methods have allowed progress in the re-vegetation and improvement of deteriorated grazing land, cropland recreational land, and wildlife habitats. Range re-vegetation research has been dominated by empirical studies that provide some information about works under a given set of conditions, but tell us little or nothing about the underlying ecological processes (Call & Roundy 1991).

This is where the concept of restoration ecology comes in. In a simplistic way, the process of ecological restoration is defined as repairing damage caused by humans to the diversity and dynamics of indigenous ecosystems (Cairns 1988). A more complex definition of this concept as defined by the Society of Ecological Restoration (1998) implies that it is a process that assists the recovery and management of ecological integrity. This ecological integrity includes a critical range of variability in biodiversity, ecological processes and structure, regional and historical context and sustainable cultural practices. This concept gave rise to various questions relating to the extent of our knowledge of an ecological community. Bradshaw (1987) noted that communities and ecosystems, like individual organisms, have considerable ability of self-repair, so that it is possible to restore a community without really understanding some critical things about it.

A question that could be asked is what the exact goals of any restoration attempt are. The degree of degradation, the abilities and obligations of the restorers, and available resources limit the goals of restoration to some extent. The specific goals for restoration projects have been described as the most important component of any restoration project. The reason being that the goals set the expectation of the restoration attempt, drives the action plans and determines the kind and extent of post-project monitoring (Ehrenfeld 2000). Due to the complex heterogeneous lineage of restoration ecology the goals set for restoration projects are variable. Four themes have been identified. The one line centred on the restoration of individual species is derived from conservation biology. Restoration of species is predicted, based on an understanding of the autecology and habitat requirements of species under investigation (Ehrenfeld 2000). Research focus in species restoration include the genetic structure of populations and metapopulations, population biology, minimum viable population size, issues of local adaptedness, and the kinds of interspecific interactions (predators, prey, mutualists) that may be important in establishing or maintaining populations (Ehrenfeld 2000). Conservation biologists emphasize the recognition and preservation of rare or endangered communities, and goals centred on the re-establishment of such assemblages can be considered a facet of conservation-derived restoration. In this form of restoration the emphasis is placed on the need to duplicate natural conditions, as a standard of restoration success. At present the restoration of communities, particularly associations of organisms, is a primary focus of many restoration efforts (Ehrenfeld

2000). Another line within restoration ecology comes from the disciplines of geography and landscape ecology. These type of restorationists look at entire landscapes (Zonneveld 1995; Aronson & Le Floc'h 1996; Heathcote 1998; Naveh 1998). This type of goal is derived in part form the long history in Europe of landscape management. Recently, the ecosystem/landscape approach has been incorporated into the idea of ecosystem management (Grumbine 1994; Vogt *et al.* 1997). This is the most commonly cited ideal for setting restoration goals. This approach acknowledge that the viability of populations of all species, including rare and endangered species, depends on the maintenance of large-scale, as well as small-scale, ecological processes, on the presence of a characteristic mosaic of community types over a broad area, and on the movements of individuals and populations over large areas (Erhenfeld 2000). Allen (1996) points out that the ecosystem framework encourages restorationist to pay attention to both landscape-level dynamics and to attempt to integrate an understanding of these large-scale processes with the small-scale processes of soil ecology and species biology. He also indicated that the "management" part of the phrase encourages thinking about the widest possible range of interventions that affect both large- and small-scale processes. The advantage of this type of restoration attempts is that this approach encourages the integration of management goals of diverse agencies, interest groups (Ehrenfeld 2000). A third lineage is wetland restoration. This falls under the ecosystem services. Wetland restoration and creation is driven to a large extent, by legislative mandates for the repair of damage to wetlands by economic development and by agriculture. Legislation was driven by the idea that many of the ecological processes that take place in wetlands are of value to society. This type of restoration attempts is driven by human valuation (Ehrenfeld 2000). A fourth lineage is the attempt to manage extreme, often toxic, results of resource extraction. These efforts are focussed finding methods for re-establishing a functioning ecosystem on spoils, mine pits, overburdens, salinized or highly eroded soils, etc. (Lal & Steward 1992; Munshower 1994). Practitioners working on such projects often do not pretend to create replicas of the ecosystems that were originally on the site; rather the goal is to establish a functional ecosystem. From this discussion can be derived that restoration goals are diverse, and that no one paradigm can be used for setting restoration goals. Goals need to be set according to the relative scope and reasons for the restoration effort. Goals need to be realistic. Restoration attempts conducted to meet the goals of conserving species, or providing specific services or revegetating extremely damaged lands are necessary. Restorations should be seen for what they are, without pretending that they would result in a replica of the original, or that they are, by definition, superior to or inferior to community- or ecosystem-based restoration. Restorations should rather be validated on their appropriateness under certain sets of conditions.

1.3 Issues facing restoration in arid environments

Often the goal for revegetation in arid environments has been to provide forage for livestock, and not to conserve the plants and animals (Allen 1995). Historically most restoration attempts in arid and semi - arid lands have consisted of revegetation with monocultures or mixtures that consist of mainly exotic species (Johnson 1986; Pendery & Provenza 1987). This then results in a decrease of biodiversity and habitat in these areas. A great deal is known about range improvements for livestock, which entails the removal of unpalatable species such as shrubs and weeds, and as mentioned above, the planting of monocultured and mixed species, but less is known about restoration of natural vegetation in arid environments (Allen 1995). To allow nature to take its course via the process of natural succession is a time consuming process in arid environments, and cannot be achieved within human lifetimes. Thus to aid the successional process, it is necessary to understand the factors limiting succession at each point of its progress and to relieve them by cultivation, fertilisation, liming, or other specific treatments. Restoration can thus be categorised into two types: active and passive restoration. Active restoration includes the application of management techniques such as seeding and transplanting, weeding, burning, alleviation compaction, improving soil moisture, applying fertilisers and amendments, etc. Passive restoration entails the removal of stresses that caused the original degradation, such as heavy grazing, air pollution and then allowing natural succession to take place (Allen 1995). The type of restoration used is dependent on the severity of the disturbance, but most often, the two are used in combination. After various disturbance events, it would not be feasible to rely on natural succession alone to restore the ecosystem to its original state. A typical example where this would not be feasible is in overgrazed shrubland, that may be so disturbed that it may stay unsuitable for ranching for many years, simply because the component species, are long-lived and do not necessarily facilitate succession to alternative states (Milton & Dean 1995). Another aspect is that of coexistence of multiple stable states (Friedel 1991; Laycock 1991) of vegetation types after disturbance and what influence this might have on the vegetation that eventually results from succession. The possibility exists that the vegetation may return to its former state, depending upon the kind of disturbance, or the vegetation might change to another type with another disturbance regime or with exotic introductions (Allen 1988). Arid lands are especially subjected to these shifts in vegetation types due to different disturbances. In such cases, restoration seems to be the only way to restore the natural ecosystem.

1.4 Factors affecting success of restoration in arid environments

Factors that might affect the success of restoration in arid environments are (i) limited water availability, (ii) loss of biodiversity, (iii) loss of topsoil and (iv) temperature extremes (Allen 1995; Call & Roundy 1991). Precipitation in arid and semiarid ecosystems is more variable than in other ecosystems, thus plant establishment often occurs when precipitation is high. Most information pertaining to moisture requirements of plants is focused on the effects of moisture on plant productivity, but limited information exists on the minimum critical moisture requirement for the establishment of arid land plants (Allen 1995). This information could be essential to aid in the establishment of these plants in the short run, with locally adapted species then being capable to cope with shifting rainfall patterns over the long run.

Prescriptions for revegetation projects include only a few dozen species for the most. These species are the most dominant species, and the goal in choosing species is to include those that represent vegetation life forms and structural layers, where those life forms are part of the natural vegetation (Allen 1995). The problem is that there are more rare species than dominant species in a natural community. Focusing only on the dominant species somehow increases the loss of biodiversity, since no emphasis is placed on the re-establishment of rare species. Rare species have been propagated in some situations, but lack of knowledge on ways of re-introduction and lack of economic resources slows the re-introduction into natural areas (Allen 1995). For this reason, this thesis focused on dominant species only. Another aspect that also needs attention is the rate of natural plant re - colonisation into disturbed areas, since this can shed light on whether restoration efforts may in future result in vegetation with its original diversity.

Another factor that must be considered during the restoration processes is the composition of the topsoil. Disturbance causes major changes in soil and microbial spatial patterning. Soil erosion is one of the major causes of topsoil loss in arid and semi-arid regions. This degrades the physical, chemical and biological components of the soil (Whisenant 1995). Soil erosion is an irreversible process that depletes nutrients, decreases rooting volume, and reduces plant-available water reserves (Whisenant 1995). Many attempts at restoration consisted of planting late successional species into early successional soils (topsoils that were removed, eroded or compacted) (Allen 1995). The problem with this is that these soils take time to recover. So the question is: do early successional species facilitate the establishment of late successional species? The rate of soil microorganism recolonization into impacted soil is slow, and inoculation is not possible for most of them. It is thus important to look at species that are capable of coping with the minimal amount of microorganisms present (Allen 1995). In the case of mining practices, the South African National Mineral Act (Act 50 of 1991) ensures that topsoil is replaced. Even here the topsoil is a mixed dilution of the original, since this 'topsoil' is a mixture of topsoil, subsoil and parent material that is different to the undisturbed soil (Allen 1995). Mulching or incorporating organic matter can induce the development of relatively complete soil biota, and it also results in higher rates of decomposition and mineralisation (Whitford 1988).

Wind erosion is another factor that has a serious effect in arid and semi-arid regions. The rate of wind erosion is dependent on soil erodibility, surface roughness, climate, the distance travelled over a field and vegetative cover. The impact of wind erosion is the highest on the fine, nutrient-rich components of soil, such as clay, silt and organic matter. The result of this on the soil is decreased fertility of sand, gravel and other coarser material (Whisenant 1995).

Other problems associated with increased soil structure deterioration are surface crusting, accelerated erosion, salinisation, reduced macroporosity, and reduced aggregate stability (Whisenant 1995). As the process of deterioration accelerates, water infiltration is reduced and water loss from runoff and evaporation increases (Whisenant 1995). As the soil moisture content is depleted, so the vegetation production decreases and the degradation of the soil conditions increases. Thus, one of the major goals in arid and semi-arid environments must be to combat erosion loosening the soil. This would bring about changes such as, increased water infiltration, increased water availability and better root growth. This would aid in obtaining one of the main goals of restoration, which would be to establish a better vegetation cover.

1.5 Attempts towards restoration in arid and semi-arid regions in South Africa

To date many restoration programs in South Africa (particularly those on rangelands) have been conducted on a trial and error basis. The problem with this is that results are often difficult to interpret (due to a lack in proper experimental design) and difficult to obtain. Another problem is that in the past very often investigators accumulated data, submitted reports to the state or other agencies, which did not publish this information in the regularly reviewed biological literature. This makes it very difficult to find biological literature on results obtained from such investigations. This situation is due to change. A National Act, requires that sustainable development integrates social, economical and environmental factors in the planning, implementing and evaluation of decisions (the

National Environmental Management Act, no. 107 of 1998). This is to ensure that development serves both present and future generations. This will secure ecologically sustainable development and use of natural resources, while promoting justifiable economic and social development. This has led to the application of the Environmental Conservation Act of 1989 to all land-use that transforms natural vegetation. The Act provides legislation that limits environmentally damaging activities and requires that developers build costs of ecological rehabilitation into their operational budgets (Milton 2001). Thus rehabilitation programs must be of such quality that restoration be sustainable and thus ensure that there is an investment in quality research to make restoration effective.

Recently a focus to combat rangeland degradation has become a priority in large parts of South Africa (Van der Merwe & Kellner 1999). The reason for this is that South Africa is signatory to the international conventions on Biodiversity and Desertification (DEA&T 1997). The convention on Biological diversity is aimed at improving international cooperation in the quest for conservation of biological diversity and to promote sustainable use of natural resources. The Convention to Combat Desertification is aimed at combating deserfication in countries that experience serious drought and/or desertification (Hoffman & Ashwell 2001). These conventions promote acquiring knowledge on processes involved in restoration and can be used as justification for funding of research in these particular areas. This thus allows local institutions to collaborate both locally and internationally on research in these areas (Esler & Kellner 2001).

Currently the School of Environmental Science and Development at Potchefstroom University are busy compiling a data base of restoration techniques. This data base, called EcoRestore, already have more than 150 case studies that can be used as guidelines for restoration programmes in a wide range of habitats and weather conditions (Bezuidenhout 2000). At present representative sites have been selected in communal and commercially-managed districts as well as nature reserves and game farms throughout South Africa as demonstration plots for restoration techniques.

Researchers and agricultural extension officers supervise the trials. A study conducted by Visser (2001) on the rehabilitation of bare patches showed that mechanical cultivation and brush packing hastened the establishment of sown species. A survey by Van der Merwe and Kellner (1999) based on results obtained by farmers/rangeland managers showed that mechanical cultivation enables better water infiltration and increases water availability that enhances seed germination, seedling establishment and improves root growth (Griffith *et al.,* 1984 & Davies *et al.* 1982). Due to the increase in cost of using mechanical techniques, more biological options are investigated. An example of such an approach is the use of organic blocks made from cattle dung, super phosphate, grass cuttings and seed and water as microhabitats for germination and promotion of seedling growth after rain (Bezuidenhout 2000).

1.6 Attempts by the Department of agriculture

The Department of Agriculture is committed to the National Grazing Strategy of 1985, which promotes the use, development and management of natural and cultivated pastures in South Africa in such a way that it may yield the greatest sustainable benefit to present generations, while maintaining its potential to meet the needs and aspirations of future generations (Du Toit *et al.* 1991). One aspect that features in this strategy is the use of indigenous species for rehabilitation and re-enforcement of natural veld. Most of the studies done by the Department were focused on production, propagation and cultivation of species. Only a few of the studies focussed on veld reinforcement. Van Breda (1939) evaluated a method of improving sowing of grass and karoo shrub seed in fields. The results indicated that mud coating improved seed germination in the field. A study done by Joubert and Van Breda (1976) on the re- establishment of the indigenous perennial *Osteospermum sinuatum* (now *Tripteris sinuata*) by means of different soil manipulations did show potential. This study indicated that sowing without disturbing the soil is not a recipe for success. Cultivation has an important role in aiding the establishment of seeded species. The Department of Agriculture committed by law (referring to Act 43 of 1983, "The conservation of agricultural resources"), must prescribe control measures to "restore and reclaim eroded land or land that has been disturbed or denuded". Although at least 20 veld revegetation trials were carried out by the Department of Agriculture in the arid parts of the winter rainfall region between 1947 and 1982 (Milton 1994), there is no published account of their effects on the composition of Karoo shrublands. At present the Department of Agriculture in collaboration with the School of Environmental Science and Development headed by Dr. Klaus Kellner at Potchefstroom University are busy with research on restoration trials around the country.

1.7 Restoration of Old lands

Awareness of the process and consequences of desertification has lead to an increase in the focus on revegetation of arid and semi-arid sites disturbed by agriculture, mining, livestock grazing, or recreation (Grantz *et al.* 1998). Focussing on abandoned farmland, these particular areas are subjected to change from the removal of natural vegetation for the creation of farmlands, to the abandonment by ceasing cultivation of crops (Gelt 1993). Agriculture brings about changes in soils, plants and wildlife. In the case of the soil, cultivation causes mixing of distinct soil horizons and this alters the dynamics of water infiltration and availability. Levelling of areas leads to the disappearance of hills and hollows that provides safe sites for wild seedlings. Cultivation also decreases the probability of finding animals and micro - organisms that disperse seeds and develop soil.

Environmental problems that are encountered with abandonment of farmland, include: (i) increased wind and soil erosion (due to limited vegetation cover), (ii) increased weed encroachment that leads to weed dominance, resulting in plant exclusion and (iii) habitat fragmentation due to interspersing of cultivated with uncultivated, natural areas (causes species isolation and restricts plant movement, causing decreasing plant and wildlife diversity.)

Abandoned farmland is not subjected to the same amount of environmental regulation as are road cuts, mine spoils, and disrupted wetlands (Grantz *et al.* 1998). The reason for this is that it was always assumed that farmland could recover without intervention (Jackson *et al.* 1991). In more humid areas this could be possible, but in arid and semiarid regions recovery is severely challenged. One of the major challenges is the availability of water that is considered the single most limiting resource in plant growth (Boyer 1985).

1.8 Conclusion

Based on the literature it is evident that goal determination is an important aspect of restoration attempts, and that factors such as the degree of degradation, the abilities and obligations of the restorers and available resources limit these goals. The complexity of restoration ecology makes goal setting in restoration projects variable. Four themes in restoration have been identified. These are restoration based on (i) individual species, (ii) ecosystem/landscape level (iii) wetlands and (iv) the management of areas as a result of resource extraction. Since the goals of these various approaches are diverse, the restoration approach needs to be set according to the relative scope and reasons for the restoration effort. Finally, goals need to be realistic.

With a focus on restoration in arid environments, one needs to be aware that active intervention is likely to be required, since natural succession is a time consuming process in these areas. A combination of active (ie. management by applying techniques such as seeding, transplanting, weeding, etc.) and passive (removal of stresses that cause degradation such as heavy grazing, air pollution etc.) restoration techniques are required to restore these areas. Factors that have been identified that could affect the success of restoration attempts in arid environments were; (i) limited water availability, (ii) loss of biodiversity, (iii) loss of topsoil and (iv) temperature extremes. These factors very often determine the goals of restoration in arid environments. Some of the goals identified in arid land restoration have been the identification of species that are able to cope with limited micro organism availability in the soil and species that could tolerate low rainfall conditions. Other goals include ways of reducing wind erosion, surface crusting, soil erosion and finding ways to increase water infiltration.

With emphasis on restoration programs in South Africa, particularly in arid regions, very often the goals have been to identify forage species for livestock. Many of these projects were done on a trial and error basis and the data obtained is difficult to interpret, due to a lack in proper experimental design. Very often trial results were written in reports and never publicised in biological publications. Recently there has been a shift to the conduct of quality research in restoration in this area. One such project is the establishment of demonstration plots for restoration in both communal and commercially managed districts (e.g. Esler & Kellner, 2001). The trials are supervised by researchers and agricultural extension officers and focus on evaluating both mechanical and biological options for rehabilitation of these areas.

The Department of Agriculture has taken the lead in research involving rangeland improvement. One aspect of their research involves the evaluation of indigenous species for rehabilitation of natural vegetation (veld). Most of their studies however have focussed on the production, propagation and cultivation of species. Although at least 20 veld revegetation trials have been conducted by the Department of Agriculture there is no published information of their effect on the composition of Karoo shrubland.

On a global scale much emphasis has been placed on rangeland restoration, but little on the restoration of old fields. The motivation for the neglect has been ascribed to the assumption that old fields are capable of recovery without intervention. This is said to be true in the case of humid areas but not so in arid and semiarid regions, since recovery is challenged by different factors, of which water availability is one of the major factors.

Restoration efforts on old fields need to address the following: the evaluation of the restoration potential of different indigenous species and the development of appropriate methods for establishment of these species on old fields. Another aspect that could be investigated is the potential of old field recovery based on potential external seed movement into these areas.

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CHAPTER 2: GENERAL INTRODUCTION TO THE STUDY ON POTENTIAL USE OF SELECTED SPECIES FOR OLD FIELD RESTORATION

2.1 Motivation For Thesis

The mismatch of agricultural practices with the production potential of land has been linked to the spread of desertification in arid and semi-arid South Africa (Milton *et al.* 1994; Badenhorst 1995). In the past many farmers in the Karoo region focused on small grain production, because of high grain prices. This practice has become uneconomical due to unpredictable rainfall, low grain yield and vulnerability of the areas to wind erosion (Barnard 1986). Another consequence of this practice could be reduced soil fertility, since most of the farmers do not add fertilizer under dry land conditions (Jan Theron pers. comm.). Under these conditions there is a tendency for many farmers to move away from this practice, and the idea is to return old fields to more productive land. It is assumed that if no active attempt is made to rehabilitate old fields, re-establishment of plant species could take decades.

Focusing on the little Karoo region, approximately 90 000 ha consists of old fields that are underutilized (Jan Theron pers. comm.). Plant cover of the little Karoo is approximately 37% with 12% palatable and 25% unpalatable plant species (Barnard 1986). In the past many farmers were only concerned with the production of enough forage for their animals at the cost of the natural environment. A consequence of this is decreased abundance of palatable species and decreased productivity of land (Milton 1992; Milton *et al.* 1994). Previously old man saltbush (*Atriplex nummularia*) was recommended for rehabilitation of old fields in the little Karoo region. This shrub is classified as a category 2 invader, according to Notice 2485 of the Conservation of agricultural resources act (Act 43 of 1983). According to the regulations of the act, planting of this species must occur in demarcated areas and only under controlled conditions. In addition to this limitation, farmers are moving towards conservation farming (Hannes Botha pers. comm.) and it is no longer viable to recommend exotic species for rehabilitation.

Future restoration efforts will rely on an evaluation of the restoration potential of different indigenous species, and on the development of appropriate methods for establishing them on old fields. Early attempts to improve karoo vegetation by sowing seed directly into the vegetation, have failed because of an insufficient understanding of the dynamics of the vegetation (Esler 1993). Limited success could possibly be ascribed to low and erratic rainfall (Doneen & McGillivray 1943; Uhvits 1946; McGinnies 1960; Milton 1994), poor seed germination due to a lack in availability of suitable microsites for seedling establishment (Milton 1994; Van Breda 1939), predation of seed by granivores and competition from existing vegetation (Milton 1994). Improper soil conditions such as lack of organic matter with its store of available nutrients, such as nitrogen, can influence success of seedling establishment.

Other factors limiting the recovery of old field vegetation could be, the absence of propagules that restrict the immigration of species into these areas, the physical hostility of the area and the lack of essential resources (Chapter 1, section 1.7). The problem here is that only certain species would be able to tolerate these extreme conditions and this would result in a delay in ecosystem development, with tolerant species persisting for long periods. It is thus essential to aid the immigration of species into these areas, and it is eventually these species that would bring about changes in the soil structure and fertility. It is therefore important to determine what conditions are adequate for plant species to become established. This would not only provide vegetation cover for these areas, but also improve the soil conditions.

This study focuses on an area where the soils have been severely degraded, ie. where continuous agricultural practices have led to changes in soil conditions (decreased organic carbon and nitrogen content) and vegetation composition. In this study the following issues were investigated, i) the importance of the soil stored seed bank in the restoration of old fields, ii) the role of propagule migration in species composition of these disturbed areas, iii) the requirements for species establishment and (iv) the effect of different revegetation techniques on species establishment.

2.1.1 Study Area

The study area, Worcester Veld Reserve, is situated in the Worcester-Robertson Karoo, Western Cape, South Africa. The Worcester Veld Reserve is situated on a ridge of Malmesbury shale in the Breede River Valley, and is surrounded by quartzite mountains of the Table Mountain Group. The study was conducted in the Worcester

Veld Reserve (33°39'S, 19°26'E). The long term mean annual rainfall (1935-1998 years) is 242.7 mm and falls mainly in June and August. The lowest mean monthly minimum temperature of 7.4°C occurs in July, and the highest monthly maximum temperature of 30.8°C occurs in January. Rain in this area occurs mainly as winter frontal storms.

Vegetation of this area is classified as a succulent form of Karroid Broken Veld (Acocks 1953). Vegetation of the area is typically sparse dwarf shrubland and is included in the Succulent Karoo Biome, as defined by Rutherford and Westfall (1994). A characteristic of this area and the rest of the arid winter rainfall region of southern Africa are the presence of Mima-like mounds (heuweltjies). Heuweltjies are disturbed patches of relatively nutrient–rich soil (Knight *et al.* 1989). These "heuweltjies" are physically and floristically distinct from the surrounding vegetation, and have a regular distribution in the landscape (Boshoff 1989).

The soils from this area are skeletal and derived from Malmesbury shale, but soils on the heuweltjies are richer, more moist and alkaline (Stokes 1994). Soils are poorly drained, shallow (less than 50 cm) and weakly developed. Soils can however attain a depth of two metres or more in valley bottoms and alluvial plains (Scott & Van Breda 1938).

The study area was selected on the criteria that it was accessible and that it represented a situation for which this type of restoration would be applicable to in future. This particular area was utilised in the past for introduction studies, to test species that would be suitable for use for veld reinforcement in the Little Karoo region (Plate 2.1). Studies were initiated, but never completed due to frequent resignations by responsible officers. The study area has been an old field for ± 15 years, and during this period the area was periodically brush cut for no other reason than to keep it tidy.

Plate 2.1 Photograph of the area where the restoration trial was conducted at Worcester Veld reserve.

2.2 Selected Study Species

Seven species indigenous to the Succulent Karoo were investigated for their potential in the restoration of old fields.

2.2.1 Tripteris sinuata

Tripteris sinuata is in the family Asteraceae and is commonly known as Bietou. The plant occurs in the Winter Rainfall Region from Cape Point in the south western Cape to the Richtersveld in the north western Cape. It is fairly common in the Ceres Karoo and in the Little Karoo it occurs as far as Uniondale.

T. sinuata is a indigenous perennial dwarf shrub that can reach a height of 500 mm and a diameter of about 1 m. Both the ray florets and the disc flowers are yellow. They are borne in heads with a diameter of about 25 mm at the tips of the stems. The leaves are arranged oppositely on the stem and are about 30 mm long and 8 mm wide. The ripe fruitlets are pale brown and winged. *T. sinuata* have a very well developed root system and lateral roots can spread as far as 5 m around the plant (Van Breda & Barnard 1991).

T. sinuata is a highly palatable shrub and is preferentially grazed by domestic livestock and wild mammals, most probably because of its high protein content and low concentrations of secondary compounds (Milton 1992).

2.2.2 *Ruschia spinosa*

Ruschia spinosa belongs to the family Aizoaceae and is commonly known as steekvygie/doringvygie. This species occurs widely in the dry areas of southern Africa on hard and bare plains and ridges (Le Roux *et al.* 1994, Shearing & Van Heerden 1994)

R. spinosa is a leaf – succulent shrub 400 m tall and 250 – 300 mm in diameter. The stems are glossy mahogany – brown, with long sharp spines in groups of 3. Leaves are in opposite pairs, 5-20 × 1-3 mm and green. The flowers are arranged in groups at the branched tips, is 8-16 mm in diameter, each with many petals and stamens. The fruit is a pale dark grey capsule 3-6 × 3-5 mm and contains brown seeds just over 0.5mm long (Le Roux *et al.* 1994).

2.2.3 *Drosanthemum speciosum*

Drosanthemum speciosum belongs to the family Aizoaceae, and occurs in the Swellendam and Robertson district. It is a shrubby succulent that reaches a height of 40 to 60 cm. The terminal, solitary and long pedicellate, orange-red flowers with green in the centre, have a diameter of about 4 to 5 cm (Barkhuizen 1978).

2.2.4 *Indigofera sessifolia*

Indigofera sessifolia belongs to the family Leguminosae and is commonly known as boontjiekaroo.

I. sessifolia is a twiggy shrublet 150–300 mm tall and 75-400 mm in diameter, with a grey to maroon bark. Leaves are grey-green, alternate or in clusters on short shoots, composed of 3 leaflets. The leaflets are narrowly egg-shaped, and is widest at the apex, 4-8 × 1-3 mm, with fine white hairs. Flowers are pea-like, and pink. The fruit are small brown and pods are curved and bean-like with 3-5 seeds per pod (Le Roux *et al.* 1994).

This species occur on ridges and hills, but prefers gravelly soils. *Indigofera sessifolia* is a palatable plant with highly nutritious pods (Le Roux *et al.* 1994).

2.2.5 *Ehrharta calycina*

Ehrhata calycina belongs to the family Poaceae and is commonly known as rooisaadgras, because the inflorescence is sometimes reddish – brown. This species is endemic to South Africa and occurs in a wide range of habitat types, but generally prefers disturbed areas and sandy soils. It occurs in the succulent Karoo, Fynbos and Savanna biomes (Van Oudtshoorn *et al.* 1991, Gibbs Russel *et al.* 1990).

E. calycina is a very variable perennial, often rhizomatous; 300 – 700 (1800) mm tall (Gibbs Russel *et al.* 1990). Leaves are sometimes folded, sometimes flat, about 3 – 7mm wide, dark green with hairs where the leaf sheath and the leaf attach at the ligule. Leaf length varies considerably. Its inflorescence is typical with sprays of florets that are sometimes reddish- brown, borne on long flower stalks and which usually droop from the tips of the stalks (Van Breda & Barnard 1991). Flowering time is from July to June, (Gibbs Russel *et al.* 1990)

E. calycina is one of the few good grazing grasses in the Winter Rainfall region. The occurrence of this species in the veld is regarded as indicative of good veld management (Van Oudtshoorn *et al.* 1991).

2.2.6 *Chaetobromus dregeanus*

Chaetobromus dregeanus belongs to the family Poaceae and is commonly known as hartbeesgras. This grass is endemic to South Africa and occurs in sandy areas and rocky hillsides (Gibbs Russel *et al.* 1990). *C. dregeanus* occurs mainly along the West Coast as far as the Orange River, in Namaqualand and along the Cedarberg Mountains. It is suspected that it previously occurred as far south as Bloubergstrand near Cape Town and that is was formerly much more common, especially in the drier parts of the Winter Rainfall Region (Van Breda & Barnard 1991).

C. dregeanus is an erect, tufted perennial grass with culms up to 500 mm long. The leaves of the grass reach a length of 260 mm and are 5 mm wide. The leaf is hairy on the upper side. The inflorescence is usually 100 to 140 mm long and before the florets open, the entire inflorescence has an attractive red – brown colour caused by the colour of the glumes. When the spikelets open the colour of the entire inflorescence changes to pale green. Each spikelet is 10 to 16mm long and flowering time is from September to October with a peak in October (Van Breda & Barnard 1991).

Roots of *C. dregeanus* are well developed and originate from the culm nodes, and can reach a length of 1 m around the tuft and a depth of 3m. This species is also highly palatable (Van Breda & Barnard 1991, Gibbs Russel *et al.* 1990).

2.2.7 *Pteronia incana*

Pteronia incana belongs to the family Asteraceae and is found in Namaqualand, from Garies to Steinkopf, in rocky places and also in dry habitats eastwards to Port Elizabeth (Le Roux & Schelpe 1988).

P. incana is a tangled woody shrub growing up to 1 m high with a dark bark. The leaves are 1 cm long and 2 mm broad. The flower-heads are about 4 mm in diameter, about 1 cm long and have only yellow disc – florets. Bracts are in 4–10 rows, the inner ones progressively larger. This plant can either be palatable or unpalatable (Le Roux & Schelpe 1988).

2.2.8 *Criteria for species selection*

Tripteris sinuata, Ehrharta calycina and *Chaetobromus dregeanus* were selected based on the species agricultural value (i.t.o grazing and palatability). *Ruschia spinosa* and *Drosanthemum speciosum* were selected as they may act as possible nurse plants for the other species. *Indigofera sessifolia* was selected for potential nitrogen deposition to soil. *Pteronia incana* is one of the common species in the adjacent natural vegetation included to establish its potential for recruitment on disturbed soils.

2.3 Overall Objectives

The aim of the thesis was to identify possible species for rangeland revegetation in the little Karoo region. More specifically, the objectives were:

1) To establish the importance of soil stored seed bank for revegetation in the winter rainfall region of the semi- arid Karoo, and in doing so, address the question of whether old fields would recover without active restoration attempts.

2) To evaluate the effect of fluctuating temperatures on the germination of species under investigation, primarily to establish possible temperature preferences of the different species.
3) To assess the influence of mechanical cultivation and addition of soil amendments on establishment of species under investigation.

2.4 Key Questions and Chapter content

The section below briefly describes the content of each data chapter as well as key questions addressed.

CHAPTER 3:

This chapter focuses on evaluating the importance of soil seed banks in the restoration of old fields, primarily for conservation and field improvement purpose. The following key questions were addressed:

- How important is the soil stored seed bank for restoration? Ie. if old fields were allowed to restore passively, would the seed bank be sufficient to allow this?
- Is there a resemblance between the seed bank and the above-ground vegetation?
- Does disturbance influence the availability of seeds in the seed bank?
- Does propagule migration play a role in species composition in disturbed areas? ie. an old field was adjacent to natural vegetation, would propagule migration from natural vegetation into the disturbed area be sufficient for restoration?

CHAPTER 4:

The effect of different temperature regimes on the germination rate and germination percentages of seven Succulent Karoo species with potential for use in restoration trials is reported on in this chapter. The following key questions were addressed:

- How do different temperature regimes influence the rate of germination of the selected species?
- Are there optimal temperatures for germination that can be recommended for the purposes of timing of restoration attempts?

CHAPTER 5:

In a field study conducted on an old field in the Worcester Veld Reserve, the effect of different cultivation methods with addition of either an organic mulch (straw & branches) or a moisture absorbant gel (aquasorb), on seedling emergence was evaluated. The following key questions were addressed:

- What types of treatments would aid active restoration attempts, (including seeding in of selected species).
- Does cultivation affect the rate of water infiltration into soils?
- How is species abundance influenced by different soil amendments?
- How does soil moisture influence the establishment of seedlings in different treatments (main plot treatments = plough, disk, till, cleared, untreated and subplot treatments = seed, seed+aquasorb and seed+straw+branches?
- Does seedling survival rate differ between different treatments?

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CHAPTER 3: IMPORTANCE OF SEED BANK FOR RESTORATION OF OLD FIELDS IN THE LITTLE KAROO REGION

3.1 Abstract:

The study focused on evaluating the importance of soil seed banks in the restoration of old fields, primarily for conservation and field improvement purposes. The objectives of the study were to compare existing above-ground perennial canopy cover to that of the soil seed bank, to determine the influence of disturbance on perennial and annual seedling densities in the soil seed bank and to determine if propagule migration have an influence on the species composition on old fields. In the comparison of the above-ground vegetation and the soil seed bank, the vegetation survey data was presented as percentage canopy cover. The results indicated that similarity between above-ground perennial vegetation and seed banks was ± 30%. In general the perennial species dominating the above-ground vegetation and the soil seed bank were species that were common in disturbed areas, and that have little agricultural value. The study showed that disturbance decreased perennial seedling densities and increased annual seedling densities. Vegetation surveys done determining seedling: adult ratios, with data represented as total canopy cover indicated that the reproductive potential of species was low. Perennials found on old fields, present in the natural undisturbed vegetation, had a patchy distribution. The study implies that the available soil seed bank is of little importance when considering improvement, and that an exogenous seed source is required to improve the situation on old fields.

3.2 Introduction

Seeds are a crucial and integral part of semi-arid ecosystems. For annuals, they are the prevalent life stage, and for most species, seeds represent a means of dispersal into new areas. In most habitats occupied by higher plants the number of individuals present as seeds, exceeds the number of individuals present as growing plants in the above ground vegetation. The soil seed reserve and seeds appearing on the surface thereof is termed the soil seed bank. Reproductive events (seed rain) add to the seed bank, and events such as seed predation, seed loss through decay and senescence and due to germination by viable seeds, depletes the seed numbers in the soil (Bell 1988). Soil seed banks may be affected by disturbances on old fields by a reduction in the number of seeds or by changes in relative frequencies of species represented in the seed bank.

Soil seed bank composition and its dynamics have been identified as important determinants of floristic and structural changes in old field succession (Egler 1954; Connell & Slatyer 1977; Numata 1982; Luken 1990). Species ability to re-appear could be dependent on its ability to persist in the soil seed bank (Bakker *et al.* 1996). Usually on abandoned fields weedy species are the most effective at dispersing seeds and developing a soil seed bank (Harper 1977; Thompson 1992). Some of the soil seed banks may be large and could influence vegetation development on agricultural sites. This influence can be noted in the emergence of numerous seedlings from seeds buried in the soil immediately after abandonment. In other plant communities however seed banks may be small or lacking. The availability of diaspores therefore influences the vegetation dynamics in recolonization processes of open spaces (gaps). During succession, shifts in vegetation types may occur, and as this takes place, soil seed banks often decline in their densities and show little correlation with the existing vegetation (Cook 1980; Thompson 1992). Agricultural clearances remove former vegetation and many opportunistic species quickly re–invade abandoned lands (Pickett & White 1985). The vegetation dynamics in recolonization processes of open spaces (gaps) after disturbance events is, besides vegetative processes, mainly influenced by available diaspores. In the case of succulent karoo, there appears to be a lack in correlation between soil stored seed densities and the densities of adult plants of perennial species (Esler 1993). Research done by Jones (2000) on a degradation gradient indicated that on the more degraded sites the more desirable species are absent from the soil seed bank and that weedy species (annual, only coming up after rains) dominated. Based on this a prediction can be made that the soil seed banks would have a minimal contribution in the revegetation of abandoned old fields in the Little Karoo region. To test this hypothesis, soil seed bank composition was compared with that of the existing above-ground vegetation on the old lands receiving restoration treatments. Other objectives of the study were to determine the influence of disturbance on seed availability in the seed bank, and to determine if propagule migration has an influence on species composition in disturbed areas ie. If an old field were adjacent to natural vegetation, would propagule migration from natural vegetation into the disturbed area be sufficient for restoration? The primary reason for this study was to interpret the restoration trial results (chapter 5), ie. influence of ploughing and other soil amendments.

3.3 Materials and Methods

3.3.1 Study site

The study was conducted in the Worcester Veld Reserve (33°39' S, 19°26' E). The long term mean annual rainfall (1935-1998) is 242.7 mm and falls mainly in June and August. The lowest mean monthly minimum temperature of 7.4°C occurs in July, and the highest monthly maximum temperature of 30.8°C occurs in January. During the study period from June 2000 to July 2001 was 300 mm compared with a 66-year average of 611 mm over the same seasonal period. Rainfall in October 2000, November 2000, December 2000, February 2001 and March 2001 was below average, while January 2001 rainfall was 10.13 mm above average (see figure 5.2). Mima-like mounds or "heuweltjies" are characteristic of the area. These heuweltjies are physiognomically and floristically distinct from the surrounding vegetation (Darlington 1985; Midgley & Musil 1990) and have a regular distribution in the landscape (Lovegrove & Siegfried 1986).

3.3.2 Methods

Soil samples, selected to represent the soil seed bank, were taken over the entire area of the restoration trial in a disturbed area. A 15 m × 25 m plot, subdivided into 5 main plots (15 m × 5 m), further subdivided into 5 subplots (3 m × 5 m) was replicated 7 times over the study area. In each of the 15 m × 25 m plots, the disturbance treatments were randomly allocated to the 5 main plots (Figure 3.1). A detailed description of the establishment and findings of the restoration plot is presented in chapter 5. Two of the replicates were located on- heuweltjies and 5 replicates were located off-heuweltjies. For each main plot, one of the following treatments was allocated at random: a control treatment, cleared treatment, ploughed, disked or tilled. For each of the subplots one of the following treatments was allocated: (i) a control treatment, (ii) mulched (straw and branches), (iii) seeded, (iv) seeded with straw and branches or (v) seeded with aquasorb. The total number of subplots was 175. The plot was established in June 1999, but treatments were allocated in June 2000.

Rep 1

P	C	U	T	D
None	SsB	S	sB	S
SA	sB	SsB	S	SsB
S	S	none	none	SA
SsB	SA	sB	SsB	sB
sB	None	SA	SA	none

Rep 2

D	U	C	T	P
SA	SsB	none	SsB	S
sB	SA	SA	S	SA
none	S	SsB	none	none
SsB	none	sB	sB	SsB
S	sB	S	SA	sB

Rep 3

U	P	D	C	T
SsB	none	none	SA	sB
SA	SsB	sB	SsB	SsB
S	SsB	SsB	none	SA
none	SA	S	S	none
sB	sB	SA	sB	S

Rep 4

D	U	C	P	T
SA	SA	SA	SA	S
S	none	sB	SsB	sB
SsB	SsB	SsB	none	SsB
none	S	S	sB	none
sB	sB	none	S	SA

Rep 5

U	C	P	D	T
S	none	sB	none	S
SsB	S	SsB	S	none
none	SsB	SA	SsB	SsB
SA	SA	S	SA	SA
sB	sB	none	sB	sB

Rep 6 / Rep 7

P	C	D	T	U	D	U	C	T	P
SsB	SsB	SsB	SA	none	S	SA	none	sB	SA
none	none	S	SsB	SsB	none	SsB	SsB	S	S
S	S	SA	S	SsB	sB	none	SA	SsB	none
sB	SA	none	SA	SA	SsB	sB	S	SA	SsB
SA	sB	sB	sB	sB	SA	S	sB	none	sB

N

Figure 3.1: Schematic representation of trial layout. With main plot treatment, Ploughed = P, Disked = D, Tilled = T, Cleared = C, Untreated = U and subplot treatments: None = control, sB = Straw and branches, S = Seed, SA = Seed & Aquasorb and SsB = Straw, seed and branches.

A vegetation survey was conducted in May 1999 (ie. 1 month prior to plot establishment) estimating the percentage canopy cover of species in each of the subplots. Percentage canopy cover of individual perennial species was estimated, while the cover of all annual species was combined into the same category. In addition, the percentage bare ground cover was recorded.

To analyse soil seed bank populations, two random soil samples were collected in soil cylinders, 10 cm in diameter and 5 cm in depth on each subplot in May 1999, prior to cultivation. In June 1999 the soil was mechanically disturbed, but due to a limited seed supply the sowing trial was postponed until June 2000. During this time soils were mechanically cultivated and soil sampling was repeated in April 2000, when 105 of the 175 subplots were randomly selected and sampled. Soil samples collected in May 1999 and April 2000 were stored in plastic bags in a store room at room temperature and were air dried.

The two soil samples collected in each of the subplots at each of the sample times were bulked and sieved through a 2 mm sieve. Soil samples were spread evenly (1.5 cm) in seed trays, over a 2 cm base of moistened, sterilised subsoil. Samples were placed on benches in an open greenhouse during June 2000 (Plate 3.1). Batches were kept separate within the greenhouse and trays were orientated at random (and moved frequently at random) within each of the batches. An automatic irrigation system was used to water the trays three times daily. Emerging seedlings were identified every two weeks. After identification, seedlings were removed. Those seedlings that could not be identified were transplanted into separate pots and grown to maturity (flowered), to enable identification.

Plate 3.1 In the seed bank study, soil cores were collected from the study site and placed in seed trays in a greenhouse at Worcester Veld Reserve, where they were monitored over the entire seasonal range. This photograph shows the experimental set-up.

To determine whether the undisturbed vegetation functioned as a source for seed, seedlings (< 5 mm basal diameter) and established plants were counted in 400 quadrats in June 2001. These 1 m^2 quadrats were arranged in 50 m long transects (n = 8) running parallel to a road situated between the cultivated and the adjacent natural vegetation (Figure 3.1). Three sample transects (each comprising of 50 quadrats), were placed at distances of 5, 10 and 20 m into the undisturbed vegetation, and five parallel sets of transects were set out on the cultivated area (old field), at distances of 5, 10, 15, 20 and 25 m into the disturbed area. Transects placed in the disturbed area were directly north of, and at a slightly higher elevation, than the old field used for the restoration trial. The old field was previously used for the introduction of *Chaetobromus dregeanus* and was established ± 15 years ago. Analysis of variance was used to compare seedling and adult densities at various distances within cultivated (old field) and undisturbed areas. Seedling:adult ratios were assumed to indicate the reproductive success of established plants under cultivation and undisturbed vegetation.

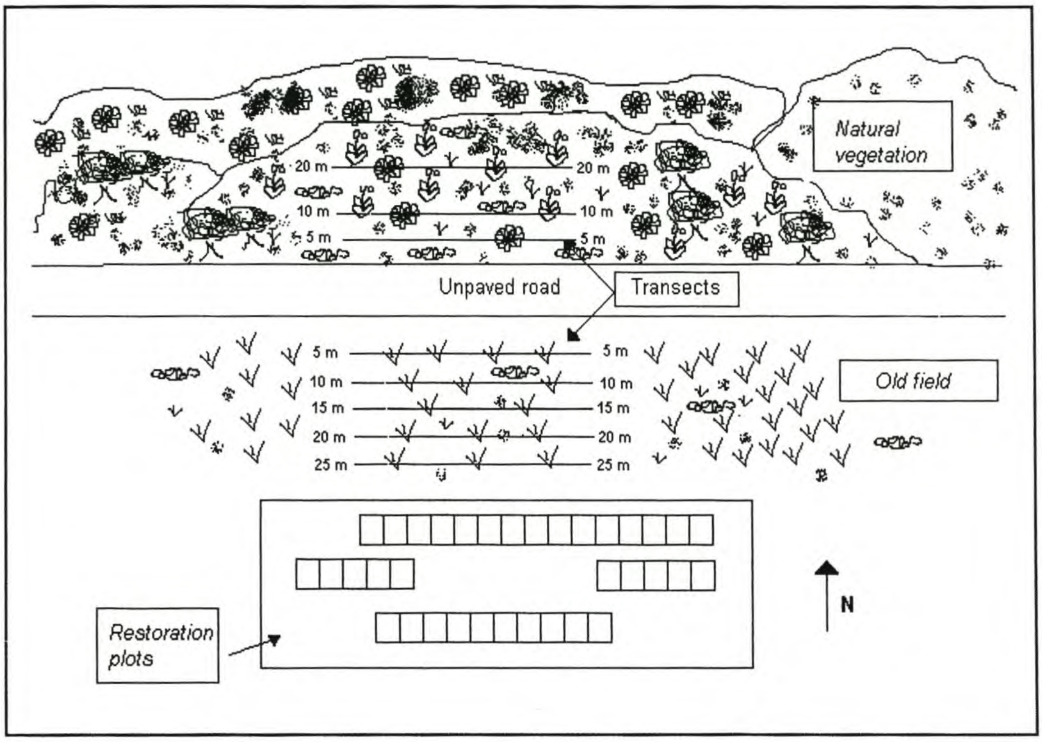

Figure 3.2 Schematic representation of transects (transect length = 50 m) surveyed to compare seedling and adult densities in cultivated and adjacent undisturbed vegetation at the Worcester Veld Reserve.

3.4 Results

3.4.1 Vegetation cover prior to treatment

In order to establish if a difference existed in the above ground vegetation prior to the plot preparation (method allocation), a vegetation survey was conducted in May 1999. Results of the vegetation survey showed that the following perennial species were significantly different at a level of $P < 0.05$; that is *Atriplex semibacatta* (Chenopodiaceae), *Atriplex suberecta* (Chenopodiaceae), *Prenia pallens* (Mesemembryanthemaceae) and *Sutera uncinata* (Scrophulariaceae) (Table 3.1). Percentage canopy cover of "Opslag" (herbaceous species that appear after rain and live for less than a year) was significantly different in the different treatment plots. Overall canopy cover was low across the study area, and total cover ranged from 21-31%. The species with the highest percentage canopy cover was *Athanasia trifurca*

(Asteraceae). The comparison of localities indicated that *Atriplex suberecta* and "Opslag" were significantly different at P < 0.05. In both cases canopy cover on-heuweltjies was significantly (P < 0.05) higher than off-heuweltjies. Although analyses showed no significant differences, *Athanasia trifurca* canopy cover was higher off- than on-heuweltjies. Percentage canopy cover of *Atriplex semibacatta* was higher on- than off-heuweltjies. Average total canopy cover on-heuweltjies was 24% and 27% off-heuweltjies (Table 3.1). In the areas marked for different cultivation allocations, canopy cover for the following species were significantly different at P < 0.05: *Atriplex semibacatta, A. suberecta, Prenia pallens, Sutera uncinata* and "Opslag". The average total percentage canopy cover in the marked plots prior to method application was as follows: 23.40% for ploughing plots, 26.34% for tilling plots, 32.06% for disking plots, 20.86% for clearing plots and 30.65% for untreated plots.

3.4.2 Seed bank study prior to and after disturbance

Results of ANOVA for seedling density (used as an estimator of the soil seed bank) demonstrated that for variable representing the position in the landscape (locality), the seedling densities of species that were significantly different at P < 0.05 prior to disturbance were *Atriplex suberecta*, *Cotula coronopifolia* (Asteraceae) and *Lolium multiflorum* (Poaceae) (Table 3.2). After disturbance the seedling densities that were significant at P < 0.05 were *Oxalis pes-caprae* (Oxalidaceae) and *Sisybrium orientale (Brassiceae)*. Prior to disturbance, annual and perennial seedling densities were higher on–heuweltjies than off-heuweltjies. The dominating perennial in the soil seed bank on-heuweltjies prior to disturbance was *Atriplex suberecta*, while *Ruschia multiflora* (Mesembryanthemaceae) dominated off-heuweltjies. Although the seedling density of *Atriplex suberecta* decreased, this species remained the dominant perennial in the soil seed bank on-heuweltjies, while off-heuweltjies *Athanasia trifurca* was the dominant perennial after disturbance. Annual seedling densities were higher in both localities after disturbance than before. *Oxalis pes-caprae* was the only species that differed significantly (P < 0.05) before and after disturbance and showed an increase in seed (or possibly bulb) densities over all of the treatments. *Oxalis pes-caprae* increased 13 fold on–heuweltjies and 9 fold off-heuweltjies after disturbance. Perennial cover was higher off-heuweltjies after disturbance while on-heuweltjies perennial seedling densities decreased. The perennial to annual species ratios for the different localities before and after disturbance were as follows: 0.20 for on-heuweltjies and 0.25 off-heuweltjies prior to disturbance and 0.25 on-heuweltjies and

0.33 off-heuweltjies after disturbance. Seedling density ratios prior to disturbance were 0.50 for both localities, and remained the same off-heuweltjies, while the ratio changed to 0.09 on–heuweltjies after disturbance (Table 3.2).

Results of ANOVA for seedling density demonstrated that for the variable representing the method of cultivation the seedling densities that were significantly different prior to disturbance were *Amaranthus* sp. (Amaranthaceae), *Atriplex suberecta, Athanasia trifurca, Chenopodium album (Chenopodiaceae), Melica* sp. *Stellaria media (Caryophyllaceae), Poa annua (Poaceae), Polygenum aviculare (Polygonaceae), Ruschia caroli (Mesembryanthemaceae), Ruschia multiflora (Mesembryanthemaceae)* and *Sisybrium orientale* (Table 3.3). With disturbance, seedling densities that were significant at $P < 0.05$ were *Cotula coronopifolia, Crassula sieberana, Juncus articulatus (Juncaceae), Melilotus alba (Fabaceae), Stellaria media, Oxalis pes-caprae, Poa annua, Prenia pallens* and *Psilocaulon utile (Mesembryanthemaceae)*. Although data were not significantly different ($P > 0.05$) the perennial species that increased over all of the methods were *Athanasia trifurca, Crassula sieberana (Crassulaceae), Prenia pallens, Ruschia caroli* and *Sutera uncinata*. Overall disturbance caused a decrease in perennial seedling densities with the greatest decline occurring in ploughed areas, followed by disked and tilled treatments, while densities increased in cleared and untreated treatments. Annual densities increased over all the treatments, with the highest density increase in tilled plots, followed by untreated, disked, ploughed and cleared plots (Table 3.3). Apart from *Drosanthemum speciosum (Mesembryanthemaceae),* none of the target species, selected for the field trial in Chapter 5 were present in the soil seed bank.

3.4.3 Comparison of vegetation cover and soil seed bank data

Prior to disturbance, perennial species that were present in both the soil seed bank and above-ground vegetation included: *Atriplex suberecta, Athanasia trifurca, Prenia pallens, Ruschia caroli, Ruschia multiflora* and *Sutera uncinata*. Species absent in the above – ground vegetation but present in the soil seed bank prior to disturbance were: *Panicum maximum, Crassula colorata* (Crassulaceae) and *Psilocaulon sp.* Perennial species that appeared in the soil seed bank after disturbance were *Elytropappus rhinocerotis* (Asteraceae) and *Crassula sieberana*. Based on perennial species similarity in above -ground vegetation and seed bank, approximately 31% of the species in the above – ground vegetation were present in the soil seed bank.

3.4.4 Above-ground presence/absence of perennial species in disturbed and adjacent undisturbed natural vegetation: adult cover and seedling densities.

Results from the two vegetation surveys, ie. the survey prior to disturbance (Table 3.1) and the one comparing vegetation of cultivated and adjacent undisturbed natural vegetation (Table 3.4) showed the following species are restricted to disturbed vegetation: *Aspalathus* sp., *Athanasia trifurca, Atriplex semibacatta, Atriplex suberecta, Cadaba aphylla* (Capparaceae), *Chrysocoma ciliata* (Asteraceae), *Chaetobromus dregeanus* (Poaceae), *Cynodon dactylon* (Poaceae), *Delosperma* sp. (Mesembryanthemaceae), *Dodonaea thunderbergiana, Elytropappus rhinocerotis, Felicia filifolia* (Asteraceae), *Galenia africana, Helichrysum* sp. (Aizoaceae), *Lightfootia nodosa, Manoclamys albicans* (Chenopodiaceae), *Prenia pallens, Prismatocarpus* sp., *Ruschia cymosa* (Mesembryanthemaceae), *Ruschia multiflora, Salsola kali* (Chenopodiaceae), *Sanderia hispida, Sutera uncinata* and *Sutherlandia microphylla* (Fabaceae). Of these species the following were present in the soil seed bank: *Athanasia trifurca, Atriplex suberecta, Elytropappus rhinocerotis, Prenia pallens* and *Sutera uncinata.* Alien species that were present were *Atriplex semibacatta* and *Salsola kali.* Species that did however cross the boundary (ie. occurred in both the disturbed and undisturbed areas) were: *Tylecodon paniculatus, Drosanthemum speciosum, Ehrharta calycina* (Poaceae), *Euphorbia burmanii* (Euphorbiaceae), *Indigofera sessifolia* (Fabaceae), *Pteronia incana* (Asteraceae), *Pteronia paniculata* (Asteraceae), *Ruschia caroli, Tetragonia fruticosa* (Aizoaceae) and *Tetragonia hirsuta* (Aizoaceae). Species restricted to undisturbed vegetation were *Aloe microstigma* (Asphodelaceae), *Cissampelos capensis* (Menispermaceae), *Crassula lycopodioides* (Crassulaceae), *Crassula* sp. (Crassulaceae), *Euphorbia* sp. (Euphorbiaceae), *Haworthia pumila, Rhus* sp. (Anacardiaceae), *Senecio* sp. (Asteraceae) and *Senecio radicans* (Asteraceae). Of these species only *Drosanthemum speciosum* and *Ruschia caroli* were present in the soil seed bank.

During the time of the survey there were no seedlings present in the disturbed area. The only species for which seedling densities were significantly different between the natural vegetation and the cultivated area ($P < 0.05$) was *Pteronia paniculata.* In general the reproductive potential for the majority of the species was low to non-existent when measured according to the seedling:adult ratios. The total monthly rainfall at the time the survey was conducted was 10.8 mm. The soil had more time to dry out, if any seeds germinated the seedlings had little chance of surviving.

Table 3.1: Comparison of percentage canopy cover of individual species and cover of bare ground in the study area prior to treatment allocation within variables representing the position in the landscape (locality) and method of cultivation (restoration method). Significant values are indicated in bold. n = 22.

	Locality		Restoration Method				
Species	Heuw.	Off-heuweltjie	Ploughed	Tilled	Disked	Cleared	Untreated
Allium sp.	0.00^{a}	0.08^{a}	0.04^{a}	0.4^{a}	0.01^{a}	0.08^{a}	0.11^{a}
Annual grass	0.00^{a}	0.06^{a}	0.01^{a}	0.10^{a}	0.08^{a}	0.04^{a}	0.00^{a}
Athanasia trifurca	0.31^{a}	15.92^{a}	9.52^{a}	10.15^{a}	13.01^{a}	11.08^{a}	13.36^{a}
Atriplex semibacatta	7.44^{a}	4.07^{a}	**4.21^{ab}**	**9.40^{a}**	**5.65^{ab}**	**1.42^{b}**	**4.93^{ab}**
Atriplex suberecta	**4.22^{a}**	**0.10^{b}**	**1.14^{ab}**	**0.34^{b}**	**3.06^{a}**	**0.82^{ab}**	**1.12^{ab}**
Chaetobromus dregeanus	0.02^{a}	0.31^{a}	0.21^{a}	0.16^{a}	0.10^{a}	0.16^{a}	0.48^{a}
Cynodon dactylon	0.00^{a}	1.23^{a}	0.11^{a}	0.24^{a}	0.05^{a}	0.18^{a}	3.75^{a}
Dodonaea thunbergiana	0.00^{a}	0.01^{a}	0.02^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}
Drosanthemum speciosum	0.00^{a}	0.03^{a}	0.04^{a}	0.03^{a}	0.00^{a}	0.01^{a}	0.04^{a}
Elytropappus rhinocerotis	0.00^{a}	0.40^{a}	0.36^{a}	0.29^{a}	0.29^{a}	0.31^{a}	0.20^{a}
Elytropappus scaber	0.00^{a}	0.02^{a}	0.00^{a}	0.00^{a}	0.04^{a}	0.03^{a}	0.00^{a}
Ehrharta calycina	0.00^{a}	0.00^{a}	0.01^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}
Galenia africana	0.00^{a}	0.05^{a}	0.02^{a}	0.02^{a}	0.03^{a}	0.07^{a}	0.04^{a}
Helichrysum sp.	0.00^{a}	0.57^{a}	0.77^{a}	0.14^{a}	0.40^{a}	0.34^{a}	0.36^{a}
Opslag	**11.60^{a}**	**0.39^{b}**	**2.15^{b}**	**2.30^{b}**	**8.14^{a}**	**2.71^{b}**	**3.01^{b}**
Tripteris sinuata	0.00^{a}	0.01^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.03^{a}	0.00^{a}
Lightfootia nodosa	0.00^{a}	0.01^{a}	0.02^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.02^{a}
Monoclamys albicans	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.01^{a}	0.00^{a}	0.00^{a}
*Prenia pallens**	0.16^{a}	0.14^{a}	**0.08^{b}**	**0.09^{b}**	**0.13^{b}**	**0.30^{a}**	**0.13^{b}**
Prismatocarpus sp.	0.63^{a}	0.00^{a}	0.02^{a}	0.03^{a}	0.01^{a}	0.57^{a}	0.26^{a}
Pteronia pinaculata	0.00^{a}	0.02^{a}	0.00^{a}	0.00^{a}	0.01^{a}	0.04^{a}	0.00^{a}
Pteronia incana	0.00^{a}	0.01^{a}	0.04^{a}	0.00^{a}	0.01^{a}	0.00^{a}	0.00^{a}
Ruschia caroli	0.00^{a}	1.07^{a}	1.26^{a}	1.95^{a}	0.00^{a}	0.35^{a}	0.27^{a}
Ruschia multiflora	0.00^{a}	0.52^{a}	0.02^{a}	0.08^{a}	0.62^{a}	0.15^{a}	0.99^{a}
Sanderia hispida	0.00^{a}	0.01^{a}	0.00^{a}	0.01^{a}	0.01^{a}	0.01^{a}	0.00^{a}
Sutera uncinata	0.02^{a}	2.50^{a}	**3.33^{a}**	**0.96^{b}**	**0.41^{b}**	**2.17^{ab}**	**1.91^{ab}**
Tetragonia hirsuta	0.00^{a}	0.01^{a}	0.01^{a}	0.03^{a}	0.00^{a}	0.00^{a}	0.00^{a}
Tetragonia fruticosa	0.00^{a}	0.01^{a}	0.01^{a}	0.00^{a}	0.00^{a}	0.02^{a}	0.00^{a}
% Bare ground cover	75.60^{a}	72.56^{a}	**76.60^{ab}**	**73.66^{ab}**	**67.94^{b}**	**79.14^{a}**	**69.35^{b}**

Within row superscripts that are the same do not differ at $P < 0.05$

Table 3.2 Seedbank composition at different localities (on and off – heuweltjies) before and after cultivation. Data given as mean density of germinated seedlings (m^2). Significant values are indicated in bold. ([1,2 & 3]) Within rows superscripts that are the same do not differ at $P < 0.05$. (*) indicates perennial species.

Species	[1]Before Heuweltjie	Off –heuw	[2]After Heuweltjie	Off-heuw.	[3]Difference Heuweltjie	Off-heuw
Amaranthus sp.	8.80[a]	0.96[a]	7.20[a]	4.48[a]	-1.60[a]	3.52[a]
Anagallis arvensis	1.60[a]	9.28[a]	7.20[a]	15.68[a]	5.60[a]	6.40[a]
Arthotheca sp.	0.79[a]	0.64[a]	1.60[a]	0.00[a]	0.81[a]	-0.64[a]
*Atriplex suberecta**	**696**[a]	**68.81**[b]	215.21[a]	196.49[a]	-480.79[b]	127.68[a]
*Athanasia trifurca.**	0.00[a]	9.92[a]	16.80[a]	253.13[a]	16.80[a]	243.21[a]
Bulbostylis hispidula	0.79[a]	25.60[a]	0.00[a]	15.04[a]	-0.79[a]	-10.56[a]
Capsella bursa-pastoris	0.00[a]	0.00[a]	0.00[a]	0.64[a]	0.00[a]	0.64[a]
Cardamine hirsuta	16.00[a]	19.84[a]	3.19[a]	3.19[a]	-12.81[a]	-16.65[a]
Cerastium capense	4.00[a]	2.24[a]	4.80[a]	6.08[a]	0.80[a]	3.84[a]
Chenopodium album	3.19[a]	1.28[a]	0.79[a]	2.88[a]	-2.40[a]	1.60[a]
Cladoraphis cyperoides	4.01[a]	26.23[a]	5.59[a]	41.93[a]	1.58[a]	15.70[a]
Cotula coronopifolia	**2.40**[a]	**0.32**[b]	0.00[a]	4.48[a]	-2.40[a]	4.16[a]
Cotula sp.	0.00[a]	1.60[a]	0.00[a]	5.76[a]	0.00[a]	4.16[a]
*Crassula colorata**	7.99[a]	10.88[a]	0.79[a]	5.12[a]	-7.20[a]	-5.76[a]
*Crassula sieberana**	0.00[a]	0.00[a]	7.20[a]	1.60[a]	7.20[a]	1.60[a]
*Drosanthemum speciousum**	0.00[a]	0.00[a]	0.00[a]	1.28[a]	0.00[a]	1.28[a]
Echium planagineum	0.00[a]	1.92[a]	0.79[a]	3.84[a]	0.79[a]	1.92[a]
*Elytropappus rhinocerotis**	0.00[a]	0.00[a]	0.00[a]	0.96[a]	0.00[a]	0.96[a]
Galinsonga parviflora	0.00[a]	0.32[a]	0.00[a]	0.31[a]	0.00[a]	-0.01[a]
Isolepis incomtula	1.61[a]	38.40[a]	0.79[a]	7.68[a]	-0.82[a]	-30.72b
Juncus articulatus	7.20[a]	35.21[a]	6.40[a]	27.52[a]	-0.80[a]	-7.69[a]
Juncus bufonius	0.00[a]	0.96[a]	0.00[a]	0.64[a]	0.00[a]	-0.32[a]
Lepidium bonariense	1.60[a]	0.00[a]	0.00[a]	0.32[a]	-1.60b	0.32[a]
Linaria sp.	0.00[a]	0.00[a]	0.79[a]	0.00[a]	0.79[a]	0.00[a]
Logfia sp.	0.00[a]	7.04[a]	0.79b	16.96[a]	0.79[a]	9.92[a]
Lolium sp.	**66.4**[a]	**16.00**[b]	39.19[a]	16.96[a]	-27.21[a]	0.96[a]
Malva parviflora *	1.60[a]	0.00[a]	1.60[a]	0.32[a]	0.00[a]	0.32[a]
Matricaria sp.	7.20[a]	43.20[a]	4.01[a]	51.53[a]	-3.19[a]	8.33[a]
Medicago polymorpha	0.00[a]	0.00[a]	1.60[a]	1.28[a]	1.60[a]	1.28[a]
Melica sp.	0.00[a]	7.36[a]	0.00[a]	6.72[a]	0.00[a]	-0.64[a]
Melilotus alba	0.00[a]	0.32[a]	0.79[a]	1.60[a]	0.79[a]	1.28[a]
Mesembryanthemum crystallinum	0.00[a]	0.00[a]	5.59[a]	0.64[a]	5.59[a]	0.64[a]
Osteospermum cladestinum	0.79[a]	0.00[a]	1.60[a]	13.44[a]	0.81[a]	13.44[a]
Oxalis pes-caprae.	**216.00**[a]	**51.19**[b]	**2922.48**[a]	**472.32**[b]	2706.48[a]	421.13[b]
*Panicum maximum**	0.00[a]	0.32[a]	0.00[a]	1.92[a]	0.00[a]	1.60[a]
Paspalum sp.	35.21[a]	28.15[a]	3.19[a]	6.08[a]	-32.02[a]	-22.07[a]
Picris echoiodes	0.00[a]	0.32[a]	0.79[a]	0.96[a]	0.79[a]	0.64[a]
Plantago lanceolata	0.00[a]	0.00[a]	0.79[a]	2.24[a]	0.79[a]	2.24[a]
Poa annua	177.60[a]	122.57[a]	108.79[a]	78.41[a]	-68.81[a]	-44.16[a]
Polygonum aviculare	595.92[a]	237.36[a]	91.99[a]	197.45[a]	-503.93[b]	-39.91[a]
*Prenia pallens**	8.80[a]	10.88[a]	30.41[a]	72.00[a]	21.61[a]	61.12[a]
Pseudo gnaphalium luteo-album	110.40[a]	78.72[a]	26.40[a]	39.68[a]	-84.00[a]	-39.04[a]
*Psilocaulon sp.**	0.00[a]	0.32[a]	0.00[a]	9.28[a]	0.00[a]	8.94[a]
Raphanus raphanistrum	0.00[a]	0.00[a]	0.79[a]	0.00[a]	0.79[a]	0.00[a]
Reseda lutea	19.20[a]	44.16[a]	27.19[a]	57.60[a]	7.99[a]	13.44[a]
*Ruschia caroli**	0.00[a]	1.28[a]	2.40[a]	5.76[a]	2.40[a]	4.48[a]
*Ruschia multiflora**	11.21[a]	312.65[a]	23.20[a]	37.76[a]	11.99[a]	-274.89[a]
Salvia reflexa	**35.20**[b]	**52.48**[a]	31.99[a]	23.36[a]	**-3.21**[a]	**-29.12**[b]
Schismus sp.	0.00[a]	3.52[a]	0.79[a]	1.92[a]	0.79[a]	-1.60[a]
Setaria sp.	0.00[a]	29.76[a]	3.19[a]	31.04[a]	3.19[a]	1.28[a]
Sisybrium orientale	97.61[a]	17.93[a]	**229.61**[a]	**22.39**[b]	132.00[a]	4.46[b]
Sonchus sp.	18.40[a]	15.36[a]	14.40[a]	19.20[a]	-4.00[a]	3.84[a]
Stellaria media	0.00[a]	11.20[a]	0.79[a]	25.28[a]	0.79[a]	14.08[a]
*Sutera uncinata**	5.59[a]	7.36[a]	5.59[a]	53.76[a]	0.00[a]	46.40[a]
Total perennials	747.17	433.30	304.78	575.38	-442.39	142.08
Total annuals	1431.92	931.44	3555.89	1229.77	2123.97	298.33

Table 3.4 Total and mean numbers of seedlings and adult plants of perennial species and seedling: to adult
-20) inside undisturbed natural vegetation adjacent to restoration plot and 5, 50 m × 1 m transects, in an old
means with the same superscripts do not differ significantly at P < 0.05 (one way ANOVA). Shading = data f
LSD's (Fisher's least significant difference) for shaded areas are different to that of non - shaded areas.

Seedlings Distance	Mean Total 50m^2	Adults per transect	Mean Total 50m^2	Seedling: per transect	adult ratio
Atriplex semibacatta					
-20	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
-10	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
-5	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
5	0.00^{a}	0.00^{a}	4.00^{b}	0.08^{b}	0.00
10	0.00^{a}	0.00^{a}	9.00^{b}	0.18^{b}	0.00
15	0.00^{a}	0.00^{a}	34.00^{a}	0.68^{a}	0.00
20	0.00^{a}	0.00^{a}	12.00^{b}	0.24^{b}	0.00
25	0.00^{a}	0.00^{a}	4.00^{b}	0.04^{b}	0.00
Aloe microstigma					
-20	0.00^{a}	0.00^{a}	6.00^{a}	0.12^{a}	0.00
-10	1.00^{a}	0.02^{a}	4.00^{a}	0.08^{a}	0.25
-5	0.00^{a}	0.00^{a}	3.00^{a}	0.06^{a}	0.00
5	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
10	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
15	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
20	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
25	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
Aspalathus sp.					
-20	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
-10	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
-5	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
5	0.00^{a}	0.00^{a}	0.00^{b}	0.00^{b}	0.00
10	0.00^{a}	0.00^{a}	3.00^{ab}	0.06^{ab}	0.00
15	0.00^{a}	0.00^{a}	0.00^{b}	0.00^{b}	0.00
20	0.00^{a}	0.00^{a}	0.00^{b}	0.00^{b}	0.00
25	0.00^{a}	0.00^{a}	5.00^{a}	0.10^{a}	0.00
Athanasia trifurca					
-20	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
-10	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
-5	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
5	0.00^{a}	0.00^{a}	4.00^{c}	0.08^{c}	0.00
10	0.00^{a}	0.00^{a}	29.00^{bc}	0.58^{bc}	0.00
15	0.00^{a}	0.00^{a}	52.00^{bac}	1.04^{bac}	0.00
20	0.00^{a}	0.00^{a}	99.00^{a}	1.98^{a}	0.00
25	0.00^{a}	0.00^{a}	68.0^{ba}	1.36^{ba}	0.00
Cadaba aphylla					
-20	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
-10	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
-5	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
5	0.00^{a}	0.00^{a}	2.00^{b}	0.04^{b}	0.00
10	0.00^{a}	0.00^{a}	16.00^{a}	0.32^{a}	0.00
15	0.00^{a}	0.00^{a}	0.00^{b}	0.00^{b}	0.00
20	0.00^{a}	0.00^{a}	6.00^{b}	0.12^{b}	0.00
25	0.00^{a}	0.00^{a}	1.00^{b}	0.02^{b}	0.00
Chaetobromus dregeanus					
-20	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
-10	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
-5	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
5	0.00^{a}	0.00^{a}	413.00^{ba}	8.26^{ba}	0.00
10	0.00^{a}	0.00^{a}	423.00^{a}	8.46^{a}	0.00
15	0.00^{a}	0.00^{a}	365.00^{bc}	7.30^{bc}	0.00
20	0.00^{a}	0.00^{a}	318.00^{c}	6.36^{c}	0.00
25	0.00^{a}	0.00^{a}	246.00^{d}	4.92^{d}	0.00
Chrysocoma ciliata					
-20	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
-10	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
-5	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
5	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
10	0.00^{a}	0.00^{a}	2.00^{a}	0.04^{a}	0.00
15	0.00^{a}	0.00^{a}	3.00^{a}	0.06^{a}	0.00
20	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
25	0.00^{a}	0.00^{a}	4.00^{a}	0.08^{a}	0.00
Cissampelos capensis					
-20	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
-10	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
-5	0.00^{a}	0.00^{a}	6.00^{a}	0.12^{a}	0.00
5	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
10	000^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
15	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
20	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
25	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
Euphorbia sp.					
-20	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
-10	0.00^{a}	0.00^{a}	2.00^{a}	0.04^{a}	0.00
-5	0.00^{a}	0.00^{a}	1.00^{a}	0.02^{a}	0.00
5	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
10	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
15	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
20	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
25	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
Felicia filifolia					
-20	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
-10	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
-5	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
5	0.00^{a}	0.00^{a}	0.00^{b}	0.00^{b}	0.00
10	0.00^{a}	0.00^{a}	0.00^{b}	0.00^{b}	0.00
15	0.00^{a}	0.00^{a}	3.00^{a}	0.06^{a}	0.00
20	0.00^{a}	0.00^{a}	0.00^{b}	0.00^{b}	0.00

Seedlings Distance	Mean Total 50m^2	Adults per transect	Mean Total 50m^2	Seedling: per transect	adult ratio
Crassula lycopodioides					
-20	0.00^{a}	0.00^{a}	7.00^{c}	0.14^{c}	0.00
-10	0.00^{a}	0.00^{a}	24.00^{a}	0.48^{a}	0.00
-5	1.00^{a}	0.02^{a}	16.00^{ba}	0.32^{ba}	0.06
5	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
10	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
15	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
20	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
25	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
Crassula sp.					
20	0.00^{a}	0.00^{a}	222.00^{ba}	4.44^{ba}	0.00
-10	0.00^{a}	0.00^{a}	301.00^{a}	6.02^{a}	0.00
5	6.00^{a}	0.12^{a}	93.00^{c}	1.86^{c}	0.06
5	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
10	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
15	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
20	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
25	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
Delosperma sp.					
-20	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
-10	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
-5	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
5	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
10	0.00^{a}	0.00^{a}	2.00^{a}	0.04^{a}	0.00
15	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
20	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
25	0.00^{a}	0.00^{a}	2.00^{a}	0.04^{a}	0.00
Drosanthemum speciosum					
-20	0.00^{a}	0.00^{a}	14.00^{a}	0.28^{a}	0.00
-10	0.00^{a}	0.00^{a}	18.00^{a}	0.36^{a}	0.00
-5	0.00^{a}	0.00^{a}	0.00^{b}	0.00^{b}	0.00
5	0.00^{a}	0.00^{a}	43.00^{a}	0.86^{a}	0.00
10	0.00^{a}	0.00^{a}	18.00^{b}	0.36^{b}	0.00
15	0.00^{a}	0.00^{a}	1.00^{b}	0.02^{b}	0.00
20	0.00^{a}	0.00^{a}	0.00^{b}	0.00^{b}	0.00
25	0.00^{a}	0.00^{a}	0.00^{b}	0.00^{b}	0.00
Elytropappus rhinocerotis					
-20	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
-10	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
-5	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
5	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
10	0.00^{a}	0.00^{a}	6.00^{a}	0.12^{a}	0.00
15	0.00^{a}	0.00^{a}	4.00^{a}	0.08^{a}	0.00
20	0.00^{a}	0.00^{a}	6.00^{a}	0.12^{a}	0.00
25	0.00^{a}	0.00^{a}	5.00^{a}	0.10^{a}	0.00
Ehrharta calycina					
-20	0.00^{a}	0.00^{a}	15.00^{b}	0.30^{b}	0.00
-10	0.00^{a}	0.00^{a}	21.00^{b}	0.42^{b}	0.00
-5	0.00^{a}	0.00^{a}	118.00^{a}	2.36^{a}	0.00
5	0.00^{a}	0.00^{a}	0.00^{b}	0.00^{b}	0.00
10	0.00^{a}	0.00^{a}	0.00^{b}	0.00^{b}	0.00
15	0.00^{a}	0.00^{a}	0.00^{b}	0.00^{b}	0.00
20	0.00^{a}	0.00^{a}	1.00^{b}	0.02^{b}	0.00
25	0.00^{a}	0.00^{a}	12.00^{a}	0.24^{a}	0.00
Euphorbia burmanni					
-20	0.00^{a}	0.00^{a}	8.00^{cd}	0.16^{cd}	0.00
-10	0.00^{a}	0.00^{a}	28.00^{a}	0.56^{a}	0.00
-5	0.00^{a}	0.00^{a}	22.00^{ba}	0.44^{ba}	0.00
5	0.00^{a}	0.00^{a}	28.00^{a}	0.56^{a}	0.00
10	0.00^{a}	0.00^{a}	11.00^{b}	0.22^{b}	0.00
15	0.00^{a}	0.00^{a}	0.00^{c}	0.00^{c}	0.00
20	0.00^{a}	0.00^{a}	0.00^{c}	0.00^{c}	0.00
25	0.00^{a}	0.00^{a}	0.00^{c}	0.00^{c}	0.00
Pteronia incana					
-20	0.00^{a}	0.00^{a}	3.00^{b}	0.02^{b}	0.00
-10	0.00^{a}	0.00^{a}	2.00^{b}	0.04^{b}	0.00
-5	0.00^{a}	0.00^{a}	11.00^{a}	0.22^{a}	0.00
5	0.00^{a}	0.00^{a}	15.00^{a}	0.30^{a}	0.00
10	0.00^{a}	0.00^{a}	3.00^{ba}	0.06^{ba}	0.00
15	0.00^{a}	0.00^{a}	2.00^{ba}	0.04^{ba}	0.00
20	0.00^{a}	0.00^{a}	1.00^{ba}	0.02^{ba}	0.00
25	0.00^{a}	0.00^{a}	0.00^{b}	0.00^{b}	0.00
Pteronia paniculata					
-20	3.00^{b}	0.06^{b}	139.00^{ba}	2.78^{ba}	0.02
-10	152.00^{a}	3.04^{a}	136.00^{ba}	2.72^{ba}	1.12
-5	85.00^{a}	1.70^{a}	112.00^{b}	2.24^{b}	0.76
5	0.00^{a}	0.00^{a}	1.00^{ba}	0.02^{ba}	0.00
10	0.00^{a}	0.00^{a}	5.00^{a}	0.10^{a}	0.00
15	0.00^{a}	0.00^{a}	3.00^{ba}	0.06^{ba}	0.00
20	0.00^{a}	0.00^{a}	5.00^{a}	0.10^{a}	0.00
25	0.00^{a}	0.00^{a}	0.00^{b}	0.00^{b}	0.00
Rhus sp					
-20	0.00^{a}	0.00^{a}	0.00^{b}	0.00^{b}	0.00
-10	0.00^{a}	0.00^{a}	0.00^{b}	0.00^{b}	0.00
-5	0.00^{a}	0.00^{a}	8.00^{a}	0.16^{a}	0.00
5	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
10	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
15	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00
20	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00

Table 3.3 Composition of soil seed bank before and after cultivation, data given as number of seedlings per m^2. Within rows superscripts that are the same do not differ at P < 0.05.

	[1]Before					[2]After				
Species	Ploughed	Disked	Tilled	Cleared	Untreated	Ploughed	Disked	Tilled	Cleared	Untreated
Amaranthus sp.	**6.86^{a}**	**1.14^{ab}**	**2.28^{ab}**	**3.43^{ab}**	**2.28^{ab}**	10.29^{a}	6.86^{a}	4.57^{a}	3.43^{a}	1.14^{a}
Anagallis arvensis	16.00^{a}	0.00^{a}	4.57^{a}	13.71^{a}	1.14^{a}	6.86^{a}	10.29^{a}	1.14^{a}	18.29^{a}	29.71^{a}
Arthotheca sp.	0.00^{a}	1.14^{a}	1.14^{a}	0.00^{a}	1.14^{a}	0.00^{a}	0.00^{a}	0.00^{a}	1.14^{a}	1.14^{a}
*Atriplex suberecta**	**109.70^{b}**	**323.42^{ab}**	**58.30^{b}**	**110.86^{a}**	**637.68^{a}**	171.43^{a}	141.72^{a}	93.72^{a}	125.71^{a}	476.56^{a}
*Athanasia trifurca**	**16.01^{a}**	**4.57^{ab}**	**9.14^{ab}**	**4.57^{ab}**	**1.14^{b}**	126.96^{a}	216.00^{a}	256.01^{a}	118.85^{a}	208.86^{a}
Bulbostylis hispidula	17.14^{a}	13.71^{a}	18.28^{a}	37.71^{a}	5.71^{a}	0.00^{a}	44,57a	0.00^{a}	1.15^{a}	7.99^{a}
Capsella bursa-pastoris	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	1.14^{a}	1.14^{a}	0.00^{a}
Cardamine hirsuta	16.00^{a}	27.43^{a}	20.57^{a}	12.57^{a}	17.14^{a}	2.28^{a}	4.57^{a}	0.00^{a}	1.14^{a}	7.99^{a}
Cerastium capense	7.99^{a}	2.28^{a}	2.28^{a}	1.14^{a}	0.00^{a}	5.71^{a}	2.28^{a}	9.14^{a}	7.99^{a}	3.43^{a}
Chenopodium album	**2.29^{ab}**	**0.00^{b}**	**0.00^{b}**	**2.29^{ab}**	**4.57^{a}**	0.00^{a}	4.57^{a}	1.14^{a}	4.57^{a}	1.14^{a}
Cladoraphis cyperoides	22.85^{a}	3.43^{a}	44.57^{a}	27.43^{a}	1.15^{a}	24.00^{a}	19.44^{a}	22.85^{a}	45.72^{a}	45.72^{a}
Cotula coronopifolia	0.00^{a}	1.14^{a}	1.14^{a}	1.14^{a}	1.14^{a}	**0.00^{b}**	**3.43^{ab}**	**4.57^{ab}**	**2.28^{ab}**	**5.71^{a}**
Cotula sp.	2.29^{a}	1.14^{a}	0.00^{a}	2.29^{a}	0.00^{a}	3.43^{a}	2.28^{a}	1.14^{a}	11.43^{a}	2.28^{a}
*Crassula colorata**	26.28^{a}	6.86^{a}	5.71^{a}	5.71^{a}	5.71^{a}	6.86^{a}	2.28^{a}	5.71^{a}	2.28^{a}	2.28^{a}
*Crassula sieberana**	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	**1.14^{b}**	**10.29^{a}**	**2.28^{b}**	**1.14^{b}**	**1.14^{b}**
*Drosanthemum speciousum**	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	1.14^{a}	0.00^{a}	3.43^{a}
Echium planagineum	1.14^{a}	0.00^{a}	1.14^{a}	4.57^{a}	0.00^{a}	11.43^{a}	1.14^{a}	0.00^{a}	1.14^{a}	1.14^{a}
*Elytropappus rhinocerotis**	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	2.28^{a}	0.00^{a}	1.14^{a}	0.00^{a}
Galinsonga parviflora	0.00^{a}	0.00^{a}	1.14^{a}	0.00^{a}	0.00^{a}	0.00^{a}	1.14^{a}	0.00^{a}	0.00^{a}	0.00^{a}
Isolepis incomtula	55.99^{a}	16.01^{a}	54.86^{a}	7.99^{a}	4.56^{a}	9.14^{a}	14.86^{a}	2.28^{a}	2.28^{a}	0.00^{a}
Juncus articulatus	28.57^{a}	18.29^{a}	11.43^{a}	41.14^{a}	36.57^{a}	**9.14^{b}**	**38.86^{a}**	**14.86^{ab}**	**18.29^{ab}**	**26.28^{ab}**
Juncus bufonius	2.29^{a}	1.14^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	1.14^{a}	0.00^{a}	1.14^{a}	0.00^{a}
Lepidium bonariense	0.00^{a}	2.29^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	1.14^{a}
Linaria sp.	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	1.14^{a}
Logfia sp.	2.28^{a}	18.29^{a}	1.14^{a}	3.43^{a}	0.00^{a}	9.14^{a}	7.99^{a}	6.86^{a}	19.43^{a}	18.29^{a}
Lolium sp.	49.15^{a}	27.43^{a}	45.72^{a}	9.14a	20.57^{a}	17.14^{a}	26.28^{a}	12.57^{a}	33.14^{a}	27.43^{a}
*Malva parviflora **	0.00^{a}	2.29^{a}	0.00^{a}	0.00^{a}	0.00^{a}	1.14^{a}	1.14a	0.00a	1.14^{a}	0.00^{a}
Matricaria sp.	31.99^{a}	36.58^{a}	17.14^{a}	74.28^{a}	4.56^{a}	7.99^{a}	16.01^{a}	69.14^{a}	60.58^{a}	7.99^{a}
Medicago polymorpha	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	2.29^{a}	2.29^{a}	2.29^{a}	0.00^{a}	0.00^{a}
Melica sp.	**13.71^{a}**	**5.71^{ab}**	**1.14^{b}**	**4.57^{ab}**	**1.14^{b}**	6.86^{a}	7.99^{a}	1.14^{a}	4.57^{a}	3.43^{a}
Melilotus alba	0.00^{a}	1.14^{a}	0.00^{a}	0.00^{a}	0.00^{a}	**1.14^{ab}**	**3.43^{a}**	**2.29^{ab}**	**0.00^{b}**	**0.00^{b}**
Mesembryanthemum crystallinum	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	2.29^{a}	0.00^{a}	2.29^{a}	2.29^{a}	3.43^{a}
*Oxalis pes-caprae **	169.15^{a}	88.01^{a}	85.70^{a}	83.42^{a}	65.14^{a}	**784.08^{b}**	**1356.48^{ab}**	**2003.52^{a}**	**837.60^{b}**	**880.08^{b}**
Osteospermum cladestinum	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	1.14^{a}	4.57^{a}	4.57^{a}	9.14^{a}	29.71^{a}	2.29^{a}
*Panicum maximum**	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	1.14^{a}	0.00^{a}	0.00^{a}	2.29^{a}	1.14^{a}	3.43^{a}
Paspalum sp.	9.14^{a}	25.15^{a}	11.42^{a}	105.14^{a}	0.00^{a}	5.71^{a}	2.28^{a}	1.14^{a}	10.29^{a}	6.86^{a}
Picris echoiodes	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	1.14^{a}	0.00^{a}	2.29^{a}	1.14^{a}	0.00^{a}	1.14^{a}
Plantago lanceolata	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	4.57^{a}	1.14^{a}	0.00^{a}	2.28^{a}	1.14^{a}
Poa annua	**116.57^{ab}**	**142.85^{ab}**	**120.00^{ab}**	**298.30^{a}**	**13.70^{b}**	**302.86^{a}**	**46.85^{b}**	**7.99^{b}**	**34.30^{b}**	**43.44^{b}**
Polygonum aviculare	**494.86^{a}**	**493.70^{a}**	**216.00^{b}**	**245.86^{ab}**	**240.00^{b}**	100.56^{a}	154.30^{a}	216.00^{a}	84.58^{a}	281.14^{a}
*Prenia pallens**	7.99^{a}	9.14^{a}	18.29^{a}	11.43^{a}	4.57^{a}	**22.85^{b}**	**64.01^{ab}**	**52.56^{ab}**	**89.14^{a}**	**72.00^{ab}**
Pseudo gnaphalium luteo-album	84.57^{a}	99.43^{a}	78.86^{a}	96.00^{a}	79.99^{a}	41.14^{a}	59.42^{a}	17.14^{a}	25.15^{a}	36.58^{a}
*Psilocaulon sp.**	0.00^{a}	1.14^{a}	0.00^{a}	0.00^{a}	0.00^{a}	**1.14^{b}**	**0.00^{b}**	**0.00^{b}**	**0.00^{b}**	**31.99^{a}**
Raphanus raphanistrum	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	1.14^{a}	0.00^{a}
Reseda lutea	29.71^{a}	40.00^{a}	31.99^{a}	49.14^{a}	34.29^{a}	62.86^{a}	36.58^{a}	36.58^{a}	31.99^{a}	76.56^{a}
*Ruschia caroli**	**3.43^{a}**	**0.00^{b}**	**0.00^{b}**	**0.00^{b}**	**1.14^{ab}**	5.71^{a}	5.71^{a}	5.71^{a}	4.57^{a}	2.28^{a}
*Ruschia multiflora**	**308.57^{ab}**	**188.57^{ab}**	**420.58^{a}**	**109.70^{b}**	**105.14^{b}**	26.28^{a}	43.43^{a}	27.43^{a}	48.00^{a}	22.86^{a}
Salvia reflexa	41.14^{a}	51.43^{a}	33.14^{a}	57.14^{a}	54.86^{a}	28.57^{a}	16.00^{a}	28.57^{a}	33.14^{a}	22.86^{a}
Schismus sp.	2.28^{a}	4.57^{a}	0.00^{a}	4.57^{a}	1.14^{a}	2.29^{a}	1.14a	3.43^{a}	0.00^{a}	1.14^{a}
Setaria sp.	38.86^{a}	10.29^{a}	21.71^{a}	2.28^{a}	33.14^{a}	21.71^{a}	21.71^{a}	11.43^{a}	36.57^{a}	24.00^{a}
Stellaria media	**19.43^{a}**	**5.71^{b}**	**2.29^{b}**	**6.86^{ab}**	**5.71^{b}**	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

3.5 Discussion:

Total canopy cover was low across the restoration plot prior to disturbance. The dominating species in the above – ground vegetation were *Atriplex semibacatta, Atriplex suberecta* and *Athanasia trifurca.* In general the species that dominated the old field were species that seldom occur in undisturbed areas. In the restoration area, species cover–abundance and plant form diversity was lower on–heuweltjies than off–heuweltjies. In the natural vegetation, heuweltjies have a higher plant form diversity and cover–abundance (Boshoff 1989). Data collected on soil status indicated overall that there were more similarities than differences between on-heuweltjie and off-heuweltjie soils (Appendix 3.1). Continuous cultivation could have led to changes in the soil profile of heuweltjies. This could have led to the reduction in the nutrient status noted on heuweltjies in comparison with off-heuweltjies. Another factor that could have affected plant form diversity is competition by established plants. The species most commonly found on the heuweltjies were *Atriplex semibacatta* and *Atriplex suberecta.* These species produce large amounts of seedlings that could inhibit the emergence of seedlings from other species, by out competing them. An observation that was made during the study was that temperatures on-heuweltjies were higher than off-heuweltjies. This could also have affected seedling emergence.

The soil seed bank in the old field was dominated by species commonly found in areas of high disturbance ie. *Atriplex suberecta*, *Athanasia trifurca* and *Ruschia multiflora.* These were also the species that dominated the above–ground vegetation. Before disturbance of the old field, the soil seed bank data showed higher densities of annual species than perennials. Key elements of annual community dynamics are disturbances at spatio–temporal scales (Van Rooyen 1999). Small-scale disturbances created by burrowing rodents, porcupines, aardvarks or foxes or through antelope activity, provide patches that are favourable for colonization by annual plants. These patches often have increased nutrient status (Milton & Dean 1991). This ties in with the life-history of annual species. Results show higher soil seed bank densities of annual species on-heuweltjies. Heuweltjies are disturbance driven systems with higher nutrient and moisture levels than, off–heuweltjie areas. Annuals are out-competed by perennials when perennial cover is dense, thus disturbance is required that will reduce perennial cover and provide an opportunity for annual recruitment.

Annual species mainly occur in sites where disturbance and physical stress inhibits the formation of a dense community of perennials (Dean & Milton 1991, 1995; Milton & Dean

1991, 1992; Yeaton *et al.* 1993). The results indicated that disturbance reduced perennial seed densities and increased annual soil seed bank densities.

Data shows that the majority of seeds in the old field soil seed bank are annual species, despite the dominance of shrubs in the above–ground vegetation. Species with a plant cover of less than 1% had a better representation in the soil seed bank than some of the more abundant species. Data indicate that the presence of a soil seed bank cannot be relied on, when considering old field restoration in the Succulent Karoo. The data showed that disturbance actually increases the number of annual species by bringing seeds to the soil surface. This potentially causes competitive problems.

Although some species crossed over the natural vegetation boundary ie. occurred in both the disturbed and natural vegetation, their cover abundance was low in the disturbed area. Some of the species with low cover abundance were absent from the soil seed bank. From the seedling:adult ratios it can be deducted that most of the species have little chance of moving from the natural vegetation to the cultivated areas certainly in the short-term (<12yrs). Further evidence of the lack in movement is the low density of species in the disturbed areas, in some cases only one individual per species.

3.6 Conclusion:

Due to low perennial cover, the chance of weed dominance with cultivation is high considering the dominance of annuals in the soil seed bank. The data showed that disturbance increased annual seedling densities while it decreased perennial densities. Perennial soil seed bank diversity is low and the perennial soil seed bank is dominated by disturbance-adapted perennials. Most of the species found in the soil seed bank can only provide short-term relief for livestock. From these data it is apparent that for the successful return from a disturbance adaptive vegetation to a more productive state, high levels of shrub and grass species seed supplementation is required. A further suggestion is the planting of clumps of perennial species to "kick-start" succession, which would otherwise take a long time.

The lack of propagule movement over a distance reduces the chance of propagule migration from the natural to the cultivated area; this is further motivation for propagule supplementation.

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APPENDIX 3.1 Comparison of soil elemental concentrations between on (n=10) and off- heuweltjie (n=25) sites. Data are presented as means ± standard deviations. Significant values are indicated in bold.

	Locality			
Soil Property	**Heuweltjie^b**		**Off -heuweltjie^a**	
pH	**7.15^a**	**± 0.16**	**4.65^b**	**± 0.29**
Resistance	875.80^a	± 70.99	1022.00^a	± 211.84
P (mmol/kg)	0.94^a	± 0.17	0.99^a	± 0.76
K (mmol/kg)	**10.25^a**	**± 3.47**	**3.62^b**	**± 0.34**
Na (mmol/kg)	3.64^a	± 0.63	3.77^a	± 0.76
Ca (mmol/kg)	**123.94^a**	**± 24.04**	**18.22^b**	**± 2.95**
Mg (mmol/kg)	35.72^a	± 2.83	13.63^b	± 1.14
C (mmol/kg)	972.02^a	± 215.84	962.10 ^{a}	± 40.06
N (mmol/kg)	59.82^a	± 14.14	52.65^a	± 2.58
% Sand	**68.80^a**	**± 1.98**	**74.92^b**	**± 1.91**
%Clay	**16.80^a**	**± 1.13**	**13.36^b**	**± 0.61**
% Silt	14.30^a	± 0.99	11.72^a	± 1.45

Within rows subscripts that is the same do not differ at $P < 0.05$

CHAPTER 4: GERMINATION OF SPECIES USED IN THE RESTORATION TRIALS

4.1 Abstract

The effect of different temperature regimes on the germination rate and germination percentages of seven Succulent Karoo species was investigated. Species used in the investigation were, *Tripteris sinuata, Ruschia spinosa, Drosanthemum speciosum, Indigofera sessifolia, Pteronia incana, Ehrharta calycina* and *Chaetobromus dregeanus.* Germination rate and percentages were investigated under the following temperature regimes: 15°C day / 10°C night, 20°C day / 10°C night and 30°C day /15°C night. According to the results, the majority of species would perform better at lower temperatures ie. 15°C day / 10°C night and 20°C day / 10°C night, with the exception of *Chaetobromus dregeanus.* Based on the germination results the species with the best performance at lower temperatures is *R. spinosa,* while *C. dregeanus* was the species with the best performance at the highest temperature regime. Based on the results it can also be predicted that *C. dregeanus,* would be the species that would be able to perform well under summer and winter rainfall conditions, while the other species have potential for restoration of old fields in winter rainfall regions with lower or similar temperatures. Based on the results, the best time for restoration attempts on old fields in the succulent karoo is during autumn and early winter when temperatures are suitable and soil moisture conditions are optimal.

4.2 Introduction

Germination and recruitment are said to be the critical stages in the life cycles of most plants (Esler & Phillips 1994). The ability of seeds to germinate has a limiting influence on the geographical distribution of plants. To ensure maximal survival, germination must occur when environmental conditions are favourable. For a seed to do this, adequate moisture, oxygen and an optimal temperature are required (Pollock *et al.* 1969; Ibrahim & Roberts 1983; Kelly 1985).

Plants that grow in semi–arid conditions very often have to cope with temperatures that are higher than optimum as well as unsuitable soil water potential in the soil. In the Karoo, a large semi-arid rangeland covering approximately 30% of South Africa's land surface (Rutherford & Westfall 1986), summer drought is a common phenomenon. Soil and/or canopy stored seed-banks of perennials are limited in these areas (Esler & Phillips 1994; Esler *et al.* 1992), and recruitment would only occur if rainfall is sufficient, provided seeds are available (Esler 1993; Esler & Phillips 1994). It is thus expected that seeding would fail in years of low and/or poorly distributed rainfall. Increased moisture stress delays germination and reduces germination rate (Doneen & Mcgillivray 1943; Uhvits 1946; McGinnies 1960). Another factor influencing the success of germination is temperature. The temperature requirements for germination are different for each species. Temperature seems to have some degree of control in preventing seed germination during extreme summer months in the Karoo region. The tendency in most of these studies is that germination percentages tend to be higher under regimes that simulate spring/autumn conditions (10°C night/ 20°C day) when the probability of rain is higher (Esler 1999; Esler & Cowling 1995; Esler *et al.* 1992; Henrici 1935; Theron 1964). Even though seeds of several plant species could germinate at a wide temperature range, fluctuating daily temperatures could break seed dormancy induced by the hard testa, and facilitate germination (Olea *et al.* 1989; Lodge *et al.* 1990).

Since seeds are an important component of the life-history of most karoo-species, relative to other vegetation types, gaining insight into the factors that govern the germination and consequent recruitment of the species has great implication for the selection of species for reintroduction into disturbed vegetation.

Recovery of vegetation cover in these arid areas is an extremely slow process (Abu-irmaileh 1994). Limited by soil moisture, arid ranges cannot economically support intensive and costly revegetation practices. Re - seeding is a potential tool for range improvement (Miles 1974). In order for re – seeding to be effective it is thus important to have an understanding of what is required for germination to be successful.

The aim of the study was to evaluate the suitability of selected species for old field restoration in the semi - arid areas of the Karoo, by evaluating the effect of temperature fluctuations on their germination rates. In addition these experiments were conducted in order to interpret species responses in the field trial (chapter 5).

4.3 Materials And Methods

4.3.1 Study species

Seven species occurring in the Little Karoo region were selected for this study: *Tripteris sinuata*, (Asteraceae), *Pteronia incana* (Asteraceae), *Indigofera sessifolia* (Leguminosae), *Ruschia spinosa* (Mesembryanthemaceae), *Drosanthemum speciosum* (Mesembryanthemaceae), *Chaetobromus dregeanus* (Poaceae) and *Ehrharta calycina* (Poaceae). These species were used in the field trials to investigate the effect of revegetation techniques on species establishment (Chapter 5). An overall description of their characteristics is given in chapter 2.

4.3.2 Viability tests

Four replicates of 20 seeds each were examined. Seeds for the viability tests were selected at random. Viability percentage was determined using the tetrazolium technique (Grabe 1970). Seeds were imbibed for 24 hours in water, pierced with a needle under a dissecting microscope without damaging the embryo, and soaked in colourless 2,3,5 – tetraphenyltetrazolium chloride (TTC) solution for 16 h at 25°C in the dark. Seeds were washed with distilled water after staining, and evaluated under a dissecting microscope. Seeds were categorised according to the following 2 groups, namely (i) completely stained and thus viable seeds; (ii) completely unstained and presumably non-viable seeds.

Seed size of *Ruschia spinosa* and *Drosanthemum speciosum* were too small to apply tetrazolium test. These species were placed in a germination cabinet at 21 °C in the dark for 26 days. The germination of four replicates of 25 seeds was monitored.

4.3.3 Laboratory seed germination experiments

Twenty-five seeds were sown in each of four Petri dishes (diameter, 9 mm) containing two layers of filtech filter paper saturated with a 2 $g.l^{-1}$ solution of Captan fungicide (to prevent fungal infection). Petri dishes were then placed in controlled environmental conditions within electrocool growth cabinets. The cabinets were set at alternating temperature/light cycles designed to simulate average seasonal day and night temperatures. Different temperature treatments were, 30°C, 16 h light period and

15°C, 8 h dark period; 20°C, 16 h light period and 10°C, 8 h dark period and 15°C, 16 h light period and 10°C, 8 h dark period. These treatments correspond to those frequently used in Karoo seed germination literature, and are designed to simulate summer and spring/autumn temperature conditions respectively Seeds were considered germinated when the radicle had emerged and elongated to 2 mm. Numbers of germinated seeds were recorded at two–day intervals for a month after the initiation of the germination trials.

Data were subjected to analyses of variance (ANOVA). Fisher's least significant differences (LSD) were used at a 5 % significance level.

4.4 Results And Discussion

The viability of the seed lot as determined by the tetrazolium test was as follows: *Tripteris sinuata* (85%), *Chaetobromus dregeanus* (81%), *Ehrharta calycina* (11%), *Pteronia incana* (57%), and *Indigofera sessifolia* (79 %). The viability of species tested by germination was as follows: *Drosanthemum speciosum* (51%) and *Ruschia spinosa* (92%).

Results of ANOVA for percentage germination demonstrated that variances from species, temperature and species × temperature were significant at $P < 0.05$ (Table 4.1). There were no significant differences at $P < 0.05$ for variances, replicates and species × replicates.

Germination of seeds were significantly higher at temperature ranges of 20°C day, 10°C night and 15°C day, 10°C night than at 30°C day, 15°C night temperatures. There was however no significant difference in germination between 20°C day, 10°C night and 15°C day, 10°C night temperatures.

Germination percentages of each species at each temperature were converted to a ranked value to make comparisons easier (Table 4.2). The data indicated that high temperatures (30°C day, 15°C night) have a slowing effect on most of the germination percentages of species. It did not however inhibit germination totally, but in general germination was the lowest at these temperatures. Germination was poorest for *D. speciosum* and *E. calycina* with germination being lower than 20%, while germination for *T. sinuata* and *P. incana* ranged between 20 and 39% and for *I. sessifolia* and *R.*

spinosa it ranged between 40 and 59%. *C. dregeanus* was the only species that yielded 70 % germination at 30°C day, 15°C night temperature. Skinner (1964) found that temperature optima for perennial grasses from the Winter- rainfall region, peaks at 20°C, however the results obtained for *C. dregeanus* suggest that this species might be able to perform well under summer-rainfall conditions, where germination peak at 30°C (Roux 1960).

At 20°C day and 10°C night temperature regimes, germination for *R. spinosa* and *T. sinuata* were optimal, while the 15°C day, 10°C night temperature regime yielded the highest germination percentages for *D. speciosum* and *E. calycina.*

Overall *R. spinosa* performed the best over the temperature ranges, and should thus be successful in adapting to similar natural conditions.

Table 4.1: Analyses of variance for percentage germination for selected species under different temperature regimes (10°C, 10h night/15°C, 14h day; 10°C, 10h, night/20°C, 14h day and 15°C, 10h night/30°C, 14h day). Significant values are indicated in bold.

Source	DF	Mean square	Pr >F
Replicate	3	139.65	0.2417
Species	6	6628.33	**0.0001**
Species×Replicate	18	72.18	0.7350
Temperature	2	2331.11	**0.0001**
Species×Temperature	12	1559.21	**0.0001**
Error	42	96.27	

Table 4.2 Average percentage germination and ranking of percentages of the following species: *Tripteris sinuata, Pteronia incana, Indigofera sessifolia, Ruschia spinosa, Drosanthemum speciosum, Chaetobromus dregeanus* and *Ehrharta calycina* at two temperature regimes: 10°C, 10h night/ 15°C, 14h day; 10°C, 10h, night/20°C, 14h day and 15°C, 10h night/30°C, 14h day. Germination was recorded after 32 days, N = 100 seeds. Ranking order (5=100–80%; 4=79–60%; 3=59–40%; 2=39–20%; 1=19–0%)

Species	**Percentage germination**			**Ranking**		
	10°C /15°C	**10°C / 20°C**	**15°C / 30°C**	**10°C / 15°C**	**15°C / 20°C**	**10°C / 30°C**
T. sinuata	83	88	39	5	5	2

table 4.2 contd.

Species	**Percentage germination**			**Ranking**		
	10°C /10°C / 15°C	**15°C / 20°C**	**10°C / 30°C**	**10°C / 15°C**	**15°C / 20°C**	**30°C**
P. incana	33	36	38	2	2	2
I. sessifolia	38	29	48	2	2	3
R. spinosa	90	98	49	5	5	3
D.speciosum	68	64	8	4	4	1
C.dregeanus	29	65	71	2	4	4
E. calycina	7	5	3	1	1	1

Species were also evaluated with regard to individual germination rates. Germination rate is important in arid and semi-arid areas, since favorable germination conditions are sporadic and establishment of seedlings must occur rapidly. Germination rate can be converted to a value (Maguire 1962), that can be used to compare and separate different germination performances. This value is calculated by dividing the number of germinated seeds at every count, by the number of days it took for germination to occur and then by adding the fractions to get a single value. A high value indicates rapid germination in a short period.

Table 4.3: Germination values (t) (Maguire 1962) and germination percentages (%) of the different species at different temperatures.

Species	15°C,10°C		20°C,10°C		30°C, 15°C	
	%	t	%	t	%	t
T. sinuata	83	2.38	88	3.36	39	2.19
P. incana	33	0.72	36	1.30	38	0.54
I. sessifolia	38	1.03	29	2.37	48	2.14
R. spinosa	90	2.96	98	5.67	49	4.39
D.speciosum	68	1.54	64	2.53	8	0.32
C.dregeanus	29	0.57	65	2.73	71	4.01
E. calycina	7	0.13	5	0.12	3	0.14

From table 4.3 can be deduced that 20°C/10°C is the best temperature range for the germination of most species, since the best performance in the shortest period occurred here. This is supported further by the occurrence of the highest germination value. The results correlate with findings of other research in the karoo that found germination percentages to be highest under regimes that simulate spring/autumn conditions (Esler & Cowling 1995; Esler *et al.* 1992; Hartmann & Dehn 1987; Henrici 1935; Theron 1964). The germination value for 15°C/10°C was less than 1 for *P. incana*, *C. dregeanus* and *E calycina* and germination and thus proceeded very slowly. *I. sessifolia* and *D. speciosum* had germination values between 1 and 2, and the species that performed best were *T. sinuata* (2.38) and *R. spinosa* (2.96). Germination for the majority of species started in the first 7 days after initiation, but the time taken to reach the optimal value varied. *R. spinosa* reached the optimal germination value in 7 days while *E. calycina* took 21 days.

Based on the results the species that would be able to perform well both under summer and winter rainfall conditions is *C. dregeanus,* while the other species have potential for restoration of old fields in winter rainfall regions. An assumption that can be made based on the results is that the best time to attempt old field restoration in the Succulent Karoo would be during autumn and early winter when temperatures are suitable and soil moisture are optimal.

An interpretation of the restoration trial in the light of these results is presented in chapter 6.

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CHAPTER 5: AN ASSESSMENT OF INFLUENCE OF REVEGETATION TECHNIQUES ON THE ESTABLISHMENT OF SELECTED SUCCULENT KAROO SPECIES

5.1 Abstract

Little emphasis has been placed on researching restoration possibilities on old fields in the Succulent Karoo of South Africa. In a field study conducted on an old field in the Worcester Veld Reserve, the effect of different cultivation methods with addition of either an organic mulch (straw & branches) or a moisture absorbent gel (aquasorb), on seedling emergence was evaluated. The following treatments were applied: (I) plough, (ii) disk, (iii) till (iv) cleared and (v) untreated. Seven indigenous plant species were sown *Chaetobromus dregeanus, Ehrharta calycina*, *Tripteris sinuata, Indigofera sessifolia, Ruschia spinosa, Pteronia incana* and *Drosanthemum speciosum.* The soil amendment treatments were as follows: seed, seed with organic mulch and seed with aquasorb. Only four of the seven species germinated, that is *T. sinuata, C. dregeanus, E. calycina* and *P. incana.* Species with the highest germination rates were *T. sinuata*, followed by *P. incana, E. calycina* and *C. dregeanus.* Ranked according to highest percentage germination in a treatment species performance were as follows highest germination by *C. dregeanus,* followed by *T. sinuata, E. calycina* and *P. incana.* Treatment preferences varied between species, and although there were no significant differences between cultivation techniques, the overall trend indicated that disturbance had a higher priority rating than undisturbed treatments. Based on frequency of cultivation preference it could be concluded that most species preferred a tilling treatment. Based on results, when a comparison is made on which of the amendment treatments were the most effective the results indicated that, seedling emergence was higher in areas where seed and aquasorb were sown, followed by seed treatment and then treatments containing organic mulch. Results from species performance indicated that as far as the species persistence is concerned, *T. sinuata performed* best followed by *Ehrharta calycina* and *C. dregeanus,* while *P. incana* failed to persist.

5.2 Introduction

Approximately 25 % of the world's population live in arid zones, which cover about 47% of the earth's surface. Poor land use, coupled with changing climatic conditions have led to the deterioration of an estimated 75% of the productive portions of these drylands (Esler & Kellner, 2001). An increased awareness of the process and consequences of desertification have led to increased focus on revegetation of arid and semi-arid sites disturbed by agriculture, mining and livestock grazing on a global scale (Grantz *et al.* 1998). Policymakers over the globe are searching for ways of combating deterioration. In South Africa restoration research has generally focused on ways to combat livestock and mining impacts (Mentis 1999; Van der Merwe & Kellner 1999; Beukes 1999; Schmidt *et al.* 2000). Globally, little emphasis has been placed on researching restoration possibilities on old fields as it has been assumed that old fields are capable of recovery without intervention (Grantz *et al.* 1998; Jackson *et al.* 1991). Horn (1974) showed that this is the case in humid environments, but in arid and semiarid regions this is less likely to be the case due to environmental limitations. Limited water availability and spatial distribution of nutrients makes recovery challenging in these areas. Other factors that might influence the recovery period are availability of seed supplies, suitable microsites for establishment, altered soil properties and a reduction of key soil biotic processes (Milton & Hoffman 1994; Stokes 1994; Beukes 1999).

The Little Karoo is part of southern Africa's winter rainfall succulent karoo biome (Milton *et al.* 1997). The plant cover of the little Karoo is approximately 37% consisting of 12% palatable and 25% unpalatable plant species (Barnard 1986). Approximately 90 000 ha of the little Karoo consists of old fields. Until the early 90's old man saltbush (*Atriplex nummularia)* was recommended by the Department of Agriculture for the rehabilitation of old fields. *Atriplex nummularia* is classified as a category 2 invader, according to Notice 2485 of 1999 of the Conservation of Agricultural Resources Act 1983, (Act 43 of 1983). According to this act the planting of this species must occur in demarcated areas and only under controlled conditions. Currently many farmers are moving towards conservation farming. Many want to create wildlife habitats, and increase recreation opportunities. A need exists for the investigation of restoration potential of plants indigenous to the area, as well as methods of establishing these species. Plants would thus be selected on criteria of palatability and aesthetics.

During the 1970's the Department of Agriculture initiated studies to investigate possible ways of increasing the palatable species, as well as pin - pointing cost-effective establishment methods. Oversowing was suggested as an effective way of establishing species, under the condition that soils must be disturbed (Joubert & van Breda 1976), however their results were not that spectacular. Since then a variety of mechanical treatments have been applied by rangeland managers and farmers to combat the spread and development of bare patches. Machinery used for this purpose, was either manufactured by the rangeland managers themselves or by using implements that are usually used for cultivation purposes in the agricultural sector (Van der Merwe & Kellner 1999). Most of these studies have been done on trial and error basis. Here we investigate the possibility of aiding the restoration process by disturbing the area with different implements, providing a seed source and by treating soil surface with an organic mulch and/or moisture supplementing gel (Hydrogel). The hydrogel is said to absorb and retain large quantities of water and nutrients, and to optimise plant growth with minimal losses of water and nutrients through leaching and evaporation. The gel also increases water reserves of soils for several years and provides plants with a regular moisture supply. Cultivation and mulching enhances water infiltration (Van Merwe & Kellner 1999; Beukes 1999; Tongway & Ludwig 1996) and increases the frequency of favourable microsites (Beukes 1999; Milton 1995; Abusuwar 1995) and seed germination and the establishment of seedlings (Van der Merwe & Kellner 1999).

The study was aimed at selecting and evaluating species and techniques for establishing species for use in the revegetation of old fields in the little Karoo region. Differences in emergence and seedling survival were evaluated to see whether these could be used as criteria for selecting adapted species for old fields.

5.3 Materials And Methods

5.3.1 Field trial

In 1999 a site was selected for the establishment of a restoration trial in the Worcester Veld Reserve. This reserve, which falls within of the Worcester-Robertson karoo, is characterized by mima-like mounds (heuweltjies) (Stokes 1994). The vegetation of the area, forming part of the Succulent Karoo Biome, is dominated by chamaephytes many of which are succulent (Midgley & Musil 1990). The Biome is characterised by a high species diversity and there are a considerable number of rare and endangered species. Many species are endemics or near endemics (Hall *et al*. 1980; Werger 1978). The study site was previously used by the Department of Agriculture for the cultivation of species suitable for veld reinforcement in the Little Karoo region. Approximately 15 years ago experiments were terminated and since then the area has been periodically brush cut and disked to prevent overgrowing.

A 15 m × 25 m plot, subdivided into 5 main plots (15 m × 5 m), and further subdivided into 5 subplots (3 m × 5 m) was replicated 7 times over the study area (Figure 5.1). Two of the replicates were located on heuweltjies. For each main plot, one of the following treatments was allocated at random: a control treatment, cleared treatment, ploughed, disked or tilled. For each of the subplots one of the following treatments was allocated: (I) a control treatment, (ii) mulched (straw and branches), (iii) seeded, (iv) seeded with straw and branches or (v) seeded with aquasorb (Figure 5.1). Considering depth of cultivation and effect on vegetation cultivation, implements differed as follows: the plough implement worked to a depth of 30 cm and caused mixing of soil layers and the removal of above ground vegetation; disking had a similar effect to ploughing but disturbance was less drastic and depth of cultivation was to a depth of 10 cm, while tilling broke the surface crust, creating furrows, with limited vegetation removal. The corners of the plots were clearly marked with steel pegs. Approximately 1800 seeds of *Tripteris sinuata* (ca. 85 % viable), 1800 *Chaetobromus dregeanus* (ca. 81 % viable), 1800 *Ehrharta calycina* (ca. 11 % viable), 1800 *Pteronia incana,* (ca. 57 % viable), 1800 *Drosanthemum speciosum* (ca. 51 % viable), 1170 *Ruschia spinosa* (ca. 92 % viable) and 30 seeds of *Indigofera sessifolia* (ca. 79 % viable) were mixed and broadcast over each of the subplots using steel quadrats to ensure even distribution of seeds on June the 8th and 9th 2000. An organic mulch in the form of wheat straw was spread on designated blocks. Branches of *Acacia karoo* were stacked on top of the straw to minimize relocation by wind. Straw was used as mulch since this is the most readily available organic mulch for farmers.

Most of the species were chosen due to their agricultural potential (Chapter 2). *Tripteris sinuata* is a palatable indigenous perennial shrub with winged, wind–dispersed seed that favours more sheltered microsites (Milton 1995). *Ruschia spinosa* is a pioneer, mound-forming shrub that, establishes in open microsites (Yeaton & Esler 1990). *Drosanthemum speciosum* like *Ruschia spinosa* is a succulent shrub that is able to establish in open microsites. *Indigofera sessifolia* is a palatable shrublet with highly nutritious pods, which prefers gravely soils. This is also a legume, which releases valuable nitrogen into the soil (Le Roux *et al.* 1994). *Chaetobromus dregeanus* is a palatable perennial grass and *Ehrhartha calycina* is a perennial grass that is considered as one of the few good grazing grasses in the Little karoo (Van Breda & Barnard 1991). *Pteronia incana* can occur in dry and rocky areas and can be palatable or unpalatable (Le Roux & Schelpe 1988).

In July 2000, one month after the treatments were applied, monitoring of seed germination was initiated. Permanent steel quadrats of 1 m × 1 m were placed in each of the subplots for this purpose. Seed germination within these 1 × 1 m quadrats was recorded 2 weeks after each rainfall event of 10 mm. Seed germination was monitored a total of 3 times between July 2000 and July 2001. During every monitoring event all the individual seedlings were counted including those counted previously. Monitoring of seed germination was terminated in September 2000.

Rep 1

P	C	U	T	D
None	SsB	S	sB	S
SA	sB	SsB	S	SsB
S	S	none	none	SA
SsB	SA	sB	SsB	sB
sB	None	SA	SA	none

Rep 2

D	U	C	T	P
SA	SsB	none	SsB	S
sB	SA	SA	S	SA
none	S	SsB	none	none
SsB	none	sB	sB	SsB
S	sB	S	SA	sB

Rep 3

U	P	D	C	T
SsB	none	none	SA	sB
SA	SsB	sB	SsB	SsB
S	SsB	SsB	none	SA
none	SA	S	S	none
sB	sB	SA	sB	S

Rep 4

D	U	C	P	T
SA	SA	SA	SA	S
S	none	sB	SsB	sB
SsB	SsB	SsB	none	SsB
none	S	S	sB	none
sB	sB	none	S	SA

Rep 5

U	C	P	D	T
S	none	sB	none	S
SsB	S	SsB	S	none
none	SsB	SA	SsB	SsB
SA	SA	S	SA	SA
sB	sB	none	sB	sB

Rep 6

P	C	D	T	U
SsB	SsB	SsB	SA	none
none	none	S	SsB	SsB
S	S	SA	S	SsB
sB	SA	none	SA	SA
SA	sB	sB	sB	sB

Rep 7

D	U	C	T	P
S	SA	none	sB	SA
none	SsB	SsB	S	S
sB	none	SA	SsB	none
SsB	sB	S	SA	SsB
SA	S	sB	none	sB

N

Figure 5.1: Schematic representation of trial layout. With main plot treatment, Ploughed = P, Disked = D, Tilled = T, Cleared = C, Untreated = U and subplot treatments: None = control, sB = Straw and branches, S = Seed, SA = Seed & Aquasorb and SsB = Straw, seed and branches.

In October 2000, seedlings were marked to track seedling survival over the dry period. Due to limited number of seedlings available per treatment, a maximum of 7 seedlings per species were tagged per subplot treatment. Seedling survival was monitored on a monthly basis until June 2001.

Soil moisture content was determined from soil cores sampled weekly; at a depth of 5 cm. Five soil core samples were collected on off-heuweltjie areas for each method and treatment, while 2 soil core samples per method and treatment were collected on-heuweltjies. Soil cores were sealed in pre-weighed airtight vials, weighed, dried at a constant temperature of 60 °C for three days and reweighed. Gravimetric soil water content was expressed as a percentage of oven-dried soil (Black 1965).

Soil infiltrability was measured using a standard 425 g can, 75 mm in diameter and open at both ends. The can was placed on the soil and lightly tapped into the soil to prevent leakage, and 50 ml of water was poured into the can. The time taken for the water to soak into the soil was measured with a stopwatch. This was converted to give infiltration rate in m/hr.

5.3.2 Statistical analysis

Data were subjected to analysis of variance (ANOVA). Fisher's least significant differences (LSD) were used at a 5% significance level. Recording dates for seedling emergence were analysed separately. Cumulative soil moisture counts over the study period was analysed for the different treatments.

5.4 Results

5.4.1 Climatic data

The distribution of rainfall during the study period was similar to long-term records (1935 –1999) (Figure 5.2). However the total amount of rainfall during the study period from June 2000 to July 2001 was 300 mm compared with a 66-year average of 611 mm over the same seasonal period. Rainfall in October 2000, November 2000, December 2000, February 2001 and March 2001 was below average, while in January 2001 rainfall was 10.13 mm above average (Figure 5.2).

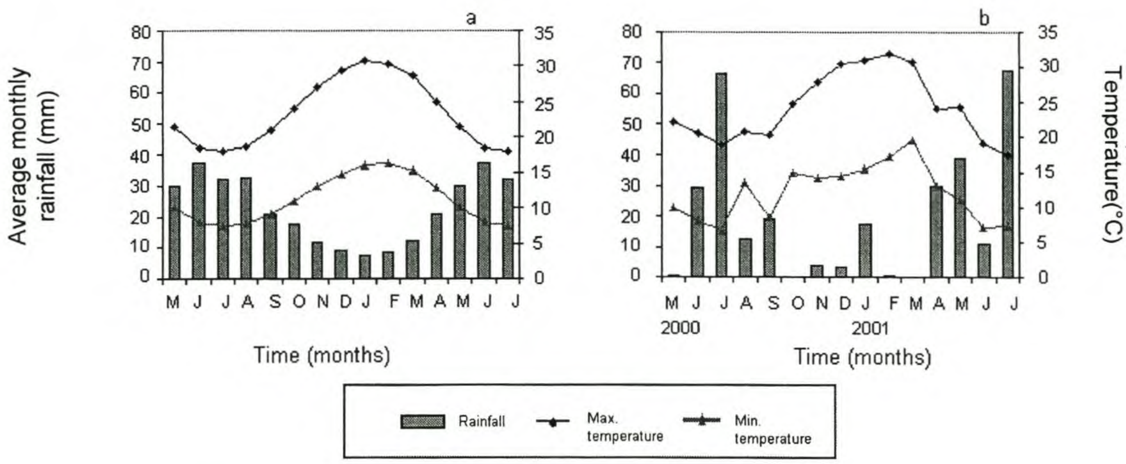

Figure 5.2: Average monthly rainfall, maximum and minimum temperatures for (a) 66 years and (b) June 2000 to July 2001 at Worcester Veld Reserve. Data obtained from Worcester Veld Reserve weather station (Botha pers. com.).

5.4.2 Soil moisture and water infiltration data

Cumulative measurements of soil moisture content showed that the moisture content of heuweltjie soils was significantly ($P < 0.05$) higher than off–heuweltjie soils. Soil moisture content of seed+straw+branches treatment was significantly ($P < 0.05$) higher than seeded and seed+aquasorb treatments. The ploughed treatment was the only method that differed significantly ($P < 0.05$) from other methods (Table 5.1)

Soil moisture on heuweltjie plots constantly remained higher than off–heuweltjie (Figure 5.3). During the rainy season, soil moisture on–heuweltjies and off–heuweltjies was higher in the seed+straw+branches treatment than in the other treatments (seed and seed+aquasorb treatments). In the drier season, no significant differences were observed in the soil moisture content of the three different treatments (Table 5.1)

Results for water infiltration demonstrated no significant ($P > 0.05$) differences, for variances locality, method and treatment (Table 5.1). Initial moisture on heuweltjies was significantly ($P < 0.05$) higher than that of off- heuweltjies ($P < 0.05$).

Table 5.1: Cumulative soil moisture content and water infiltration capacity (m/hr), for variables treatments and cultivation methods. Data indicated is mean percentage soil moisture content over the study period.

Factor	*Locality*		*Treatment*[1]			*Method*[2]				
	Heuw	Off-heuw	S	SA	SsB	P	C	U	T	D
[3]Moist.	241.17^a	163.07^b	173.23^b	180.29^b	201.21^a	160.00^b	195.05^a	187.29^a	191.91^a	195.71^a
[4]Infiltr.	1.27^a	0.84^a	0.95^a	1.09^a	0.86^a	0.91^a	0.80^a	0.97^a	1.16^a	1.01^a
[5]In. moist.	2.08^a	1.48^b	1.61^a	1.69^a	1.67^a	1.63^a	1.83^a	1.53^a	1.61^a	1.67^a

Within variables in rows superscripts that is the same do not differ at $P < 0.05$,[1] S = seed, SA = seed & aquasorb, SsB = seed, straw & branches; [2] P = ploughed, C = cleared, U = untreated, T = tilled, D = disked; [3]Moist.= cumulative soil moisture content, [4]Infilt. = infiltration capacity, [5]In moist. = initial soil moisture content.

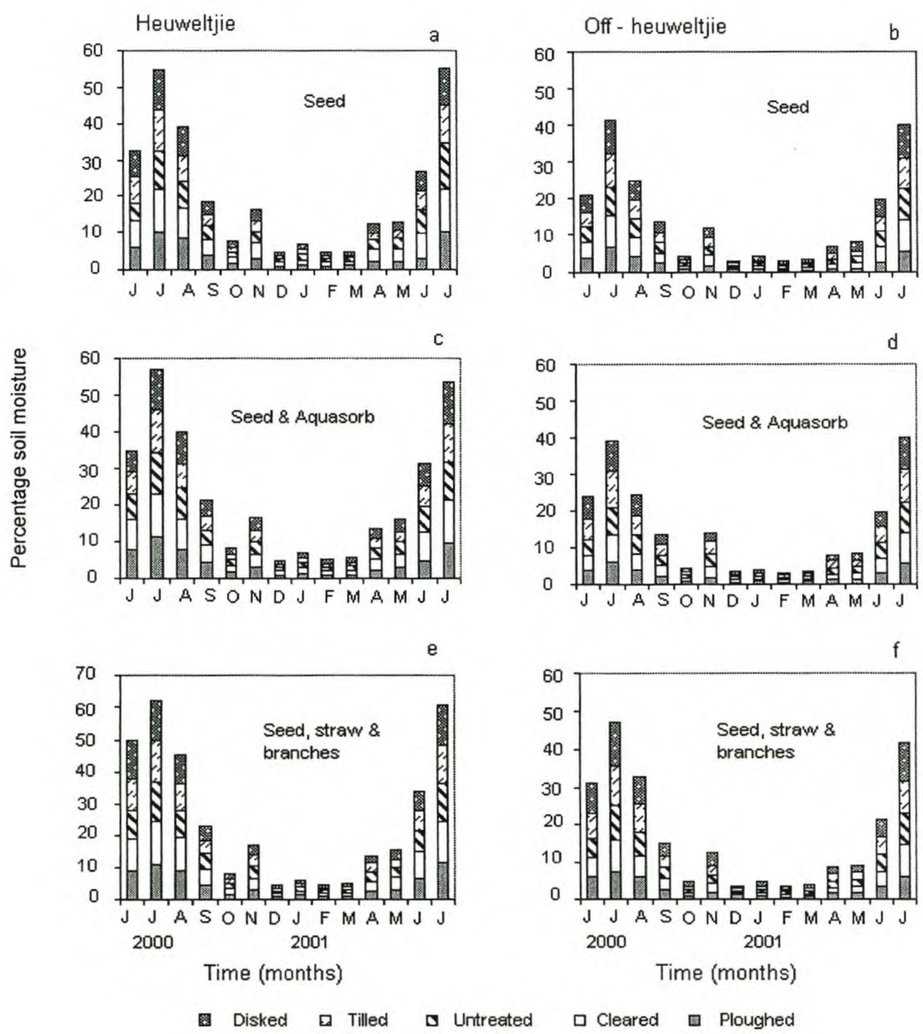

Figure 5.3: Cumulative percentage soil moisture per month in different plot treatments on heuweltjies (a, c & e) and off-heuweltjies (b, d & f), monitored from June 2000 to July 2001.

5.4.3 *Soil analyses*

Heuweltjie soils had a higher proportion of silt and clay and a lower sand fraction than those off-heuweltjies (Table 5.2). Heuweltjie soils were calcareous with a high pH. Macro-elemental concentration of K, Ca and magnesium was higher on heuweltjies than away from heuweltjies. There was however no significant (P > 0.05) difference in the C, N and P status on the different localities.

Table 5.2 Comparison of soil elemental concentrations between on (n=10) and off- heuweltjie (n=25) sites. Data are presented as means. Significant values are indicated in bold.

	Locality	
Soil Property	**Heuweltjie[b]**	**Off -heuweltjie[a]**
pH	**7.15[a] ± 0.16**	**4.65[b] ± 0.29**
Resistance	875.80[a] ± 70.99	1022.00[a] ± 211.84
P (mmol/kg)	0.94[a] ± 0.17	0.99[a] ± 0.76
K (mmol/kg)	**10.25[a] ± 3.47**	**3.62[b] ± 0.34**
Na (mmol/kg)	3.64[a] ± 0.63	3.77[a] ± 0.76
Ca (mmol/kg)	**123.94[a] ± 24.04**	**18.22[b] ± 2.95**
Mg (mmol/kg)	35.72[a] ± 2.83	13.63[b] ± 1.14
C (mmol/kg)	972.02[a] ± 215.84	962.10[a] ± 40.06
N (mmol/kg)	59.82[a] ± 14.14	52.65[a] ± 2.58
% Sand	**68.80[a] ± 1.98**	**74.92[b] ± 1.91**
%Clay	**16.80[a] ± 1.13**	**13.36[b] ± 0.61**
% Silt	14.30[a] ± 0.99	11.72[a] ± 1.45

Within rows subscripts that are the same do not differ at P < 0.05

5.4.4 *Seedling emergence*

Results of ANOVA for percentage seedling emergence demonstrated that variables representing species, method and treatment were significant at P < 0.05 (Table 5.3). There was considerable variation in the seedling emergence patterns in each of the monitoring periods. Interactions that were significant at P < 0.05 on different monitoring dates were; locality x method x treatment x species (June), locality x species (July), locality x method, locality x treatment (September), method x treatment, locality x method x treatment (June & September) and treatment x species, method x treatment x species (June, July & September) (Table 5.3).

Over the monitoring period seedling emergence in disked and tilled plots remained significantly (P < 0.05) higher than that of ploughed, untreated and cleared plots

(Table 5.4). In June 2000, seedling emergence was significantly higher (P < 0.05) in plots treated with straw and branches compared to that of plots with seed and seed with aquasorb treatments. Treatment effects in July were not significant (P > 0.05). In September 2000, seedling emergence in plots with seed and seed+aquasorb was significantly higher than that of plots with seed+straw+branches. Emergence of *T. sinuata* was significantly (P < 0.05) higher than that of the other 3 emerging species over the monitoring period. In July 2000 emergence of *P. incana* was significantly (P < 0.05) higher than that of *E. calycina and C. dregeanus*. In September 2000 emergence for *E. calycina* and *C. dregeanus* was significantly (P < 0.05) higher than that of *P. incana*.

Percentage seedling emergence in tilled and disked treatments was significantly (P < 0.05) higher than for ploughed, cleared and untreated methods for *T. sinuata* (Table 5.5). In June 2000 plots treated with seed+straw+branches had a higher (P < 0.05) percentage seedling emergence than seed and seed+aquasorb treated plots. In July 2000 seedling emergence was significantly (P < 0.05) higher in seed and seed+aquasorb treatments than in plots treated with seed+straw+branches.

P. incana seedlings only started emerging in July after 66 mm rain (2^{nd} event). Percentage emergence was higher in less disturbed plots, ie. untreated, tilled and cleared plots, than in disked and ploughed treatments (Table 5.5). In September there was a decline in seedling numbers for all treatments, with the greatest decline for cleared and untreated plots, followed by tilled, disked and ploughed plots. Over the monitoring period, seedling emergence was significantly (P < 0.05) higher in seed+aquasorb and seeded treatments, compared to the seed+straw+branches treatment.

Emergence of *E. calycina* was not significant (P > 0.05) in June and July 2000. In September, emergence in tilled plots was significantly (P < 0.05) higher than that of disked and ploughed plots while emergence in cleared and untreated plots was not significant (P > 0.05). Emergence was significantly (P < 0.05) higher in seed+aquasorb treatments than that of seed and seed+straw+branches treatments.

In June and July 2000 emergence was not significant (P > 0.05) for *C. dregeanus*. In September 2000 percentage seedling emergence was significantly higher in tilled and disked plots compared to that of ploughed plots, while in cleared and untreated treatments emergence was not significant (P > 0.05). Emergence was significantly higher ($P < 0.05$) in seed+ aquasorb treatment, than seed+straw+branches treatment.

In July 2000, percentage seedling emergence was significantly ($P < 0.05$) higher in ploughed plots to that of tilled and disked plots, while no emergence occurred in cleared and untreated plots (Table 5.5). In September 2000 there was no significant ($P > 0.05$) difference in seedling emergence with various methods. Tilled plots did however have a higher percentage emergence than ploughed and disked methods.
In July and September 2000 emergence was significantly ($P < 0.05$) higher in seed and seed+aquasorb treatments, than in the seed+straw+branches treatment

5.4.5 Seedling survival

Results of ANOVAS for time until 50 % survival demonstrated that the variable representing species was significant at $P < 0.05$. Interactions that were significant at $P < 0.05$ were, method x treatment, locality x treatment, method x treatment x species, locality x species, locality x treatment x species. ANOVA for slope depicting the rate of mortality demonstrated that variance species and interaction locality x species was significant (Table 5.6).

Table 5.3: Analyses of variance for percentage seedling emergence, under different cultivation methods (ploughed, disked, tilled, cleared & untreated) and seed treatments (seed, seed+aquasorb & seed+straw branches) with two localities (on- and off-heuweltjies).

		Percentage germination					
		June		**July**		**September**	
Source[a]	**DF**	**Mean square**	**Pr < F**	**Mean square**	**Pr < F**	**Mean square**	**Pr < F**
Local	1	5.41679067	0.2327	91.07750496	0.0784	331.9067460	0.0539
Error	5	2.904451		18.703646		52.703472	
Method	4	55.4699901	**<.0001**	38.7537202	**0.0326**	320.639881	**<.0001**
Locality x method	4	4.0573537	0.0918	14.6768353	0.3276	331.906746	**0.0005**
Error	20	1.727344		11.878125		19.647483	
Treatment	3	66.4364253	**<.0001**	323.4271660	**<.0001**	610.183118	**<.0001**
Method x treatment	12	7.6938657	**0.0005**	13.1882440	0.2375	53.075397	**<.0001**
Locality x treat	3	3.1049521	0.2548	12.4892113	0.3049	41.382275	**0.0183**
Locality x method x treat	12	5.601910	**0.0079**	14.4946263	0.1727	24.467283	**0.0266**
Error	75	2.246354		10.156655		11.641088	
Species	3	442.964203	**<.0001**	1647.087880	**<.0001**	651.469494	**<.0001**
Treatment x Species	9	66.434221	**<.0001**	132.686425	**<.0001**	64.569141	**<.0001**
Method x Treatment x species	48	19.629630	**<.0001**	22.286293	**<.0001**	18.007192	**0.0025**
Locality x species	3	5.556341	0.0561	62.914145	**< .0001**	20.322751	0.1153
Locality x treatment x species	9	3.121046	0.1742	9.222236	0.3367	7.132055	0.7099
Local x method x treat x specie	48	5.220341	**<.0001**	7.165096	0.6929	5.793589	0.9905
Error	300	2.181887		8.116262		10.206597	

[a]Local = locality; Treat = treatment; Specie = species

Table 5.4: Percentage germination, time to 50 % seedling survival, slope for rate of mortality and percentage survival for variances; method, treatment and species

Variable		Percentage germination			TL 50[a] (days)	
		June	July	Sept.		
Method:	Till	1.51	3.41	5.22	93	30
	Disk	1.64	3.05	4.69	86	29
	Plough	0.95	1.87	3.21	86	27
	Untreated	0.20	2.71	1.17	71	27
	Cleared	0.14	2.44	1.29	101	22
		0.366	***0.961***	***1.236***	***41***	***19***
Treatment:	None	0.00	0.46	0.45	-	-
	Seed	0.99	3.24	4.79	92	27
	Seed & Aquasorb	0.90	3.86	4.57	98	28
	Seed, straw & branches	1.68	3.22	2.35	98	29
		0.357	***0.759***	***0.208***	***22***	***9***
Species:	*T. sinuatum*	3.56	7.43	5.22	122	41
	E. calycina	0.00	0.29	2.63	79	16
	C. dregeanus	0.01	0.04	2.06	59	7
	P. incana	0.00	3.01	1.04	56	7
		0.347	***0.670***	***0.75***	***22***	***6***

[a] Time (days) until 50 % of the seedlings were survivors

Table 5.5: Percentage seedling emergence and time until 50 % survival for *T. sinuata (T.sin), C. dregeanus (C. dreg), E.calycina (E.cal)* and *P. incana (P. inc)*, monitored on 3 different monitoring dates during the rainy season of 2000. Emergence is given as mean percentage seedlings per plot (m^2). Method + treatment + abbreviation are given in Table 5.1.

Method	PERCENTAGE GERMINATION												Time until 50% survival			
	June[a]				July[b]				September[c]							
& Treatment	T.sin	E.cal	C. dreg	P.inc	T.sin	E.cal	C. dreg	P.inc	T.sin	E.cal	C. dreg	P.inc	T.sin	E.cal	C. dreg	P.inc
Cleared	0.00	0.00	0.00	0.00	2.02	0.00	0.00	0.36	1.31	0.83	0.00	0.24	-	-	-	-
CS	0.12	0.00	0.00	0.00	9.17	0.00	0.00	4.05	6.31	0.00	0.00	1.43	118	87	71	-
CSA	0.48	0.00	0.00	0.00	9.88	0.00	0.00	5.95	6.07	0.83	1.19	0.95	129	76	62	14
CSsB	1.67	0.00	0.00	0.00	5.36	0.00	0.00	2.26	3.10	0.00	0.00	0.00	60	130	302	-
Disked	0.00	0.00	0.00	0.00	0.95	0.00	0.00	0.12	1.43	0.00	0.00	0.48	-	-	-	-
DS	7.02	0.00	0.00	0.00	11.43	1.55	0.00	2.98	13.69	6.07	9.76	1.31	124	69	36	34
DSA	6.79	0.00	0.00	0.00	13.33	0.00	0.00	4.05	10.95	6.78	6.07	4.05	120	81	50	33
DSsB	12.38	0.00	0.00	0.00	12.38	0.00	0.00	2.02	6.79	4.64	1.07	1.07	161	96	55	85
Ploughed	0.00	0.00	0.00	0.00	0.60	0.60	0.00	0.00	1.19	0.12	0.24	0.24				
PS	4.88	0.00	0.00	0.00	5.83	1.55	0.00	1.19	7.02	3.81	5.48	1.30	133	55	83	-
PSA	3.81	0.00	0.12	0.00	4.76	2.38	0.12	2.38	7.62	7.14	5.60	1.31	83	39	58	39
PSsB	6.43	0.00	0.00	0.00	9.64	0.95	0.00	2.14	7.14	5.00	0.95	1.07	161	96	55	85
Tilled	0.00	0.00	0.00	0.00	1.07	0.00	0.00	1.19	0.83	0.00	0.36	1.19				
TS	6.55	0.00	0.00	0.00	13.81	0.00	0.00	3.81	12.50	6.67	12.62	2.50	204	76	53	49
TSA	6.67	0.00	0.00	0.00	13.33	1.19	0.71	4.64	13.21	7.38	6.79	2.86	99	90	60	125
TSsB	11.07	0.00	0.00	0.00	12.38	0.00	0.00	2.38	8.81	5.83	0.95	1.07	114	77	36	125
Untreated	0.00	0.00	0.00	0.00	1.67	0.00	0.00	1.19	1.43	0.00	0.00	0.00				
US	1.19	0.00	0.00	0.00	4.76	0.00	0.00	4.76	5.60	0.00	0.00	2.38	92	-	-	14
USA	0.12	0.00	0.00	0.00	7.14	0.00	0.00	8.57	4.52	0.00	0.24	1.67	92	-	-	-
UssB	2.02	0.00	0.00	0.00	9.05	0.00	0.00	6.19	2.38	0.00	0.00	0.48	34	-	-	-

Fisher's least significant difference a = 1.554; b = 2.997; c = 3.360, d = 88.084

Table 5.6: Analyses of variance for time till 50 % survival and percentage seedling survival. Significant values are indicated in bold.

		Time till 50 % survival		Percentage survival	
Source	DF	Mean square	Pr < F	Mean square	Pr < F
Locality	1	611.6952809	0.8073	1415.204127	0.1817
Error	1	9252.0142		1415.20413	
Method	4	3228.33599	0.6667	3268.40787	**0.0235**
Locality x method	4	6645.93977	0.3321	1567.67268	0.1775
Error	17	5367.6699		876.16124	
Treat	2	11067.75739	0.0868	60.723847	0.8833
Method x treatment	8	9905.22167	**0.0393**	1070.677478	0.0528
Locality x treatment	2	28376.93784	**0.0034**	717.076604	0.2439
Locality x method x treatment	8	6046.33187	0.2175	619.795186	0.2904
Error	34	210.3426		487.36692	
Species	3	80345.8804	**<.0001**	22137.92069	**<.0001**
Treatment x Species	6	3806.7289	0.2689	493.48034	0.3772
Method x Treatment x species	25	5507.1455	**0.0187**	562.46703	0.1932
Locality x species	3	11626.0091	**0.0110**	398.66707	0.4571
Locality x treatment x species	6	6513.5088	**0.0498**	623.28709	0.2326
Local x method x treat x species	13	4884.4922	0.0857	649.11535	0.0738
Error	80	2938.6744		524.82393	

Although there were no significant differences between time until 50% survival (TL50), the overall trend was that TL50 was longer in cleared and tilled than in ploughed, disked and untreated plots (Table 5.5). No significant (P > 0.05) differences were found with treatment, but the trend was that treatments with seed+straw+branches had longer TL50s than seed and seed+aquasorb treatments. Time until 50 % survival for *T. sinuata* was significantly higher than that for the other 3 species. TL50 for *E. calycina* was significantly higher than for *P. incana*, while for C. *dregeanus* it did not differ significantly from either of the species.

TL50 for *T. sinuata* was significantly (P < 0.05) higher in tilled, disked and ploughed plots, than that of cleared and untreated plots (Table 5.5). There was no significant (P > 0.05) difference in TL50 for treatments.

There was no significant (P > 0.05) difference in the TL50 for *E. calycina* in different plots. The TL50 in the seed+straw+branches treatment was significantly (P < 0.05) higher than that for seeded and seed, aquasorb treatments.

Data indicate that TL50 in cleared plots and seed+straw+branches treatment for *C. dregeanus* was significantly ($P < 0.05$) higher than other plots and treatments (Table 5.5). This is due to inclusion of an observation, CSsB that only had one seedling present (outlier). When excluding the observation, the arrangement of preference for treatments seems to be: ploughed, tilled, disked and cleared. Arrangement of preference for treatments on exclusion was seed, seed+aquasorb and seed+straw+branches treatments. The TL50 for *P. incana* was significantly ($P < 0.05$) higher in tilled plots than that in other plots. While TL50 was significantly ($P < 0.05$) higher in disked and ploughed than that of cleared plots. TL50 was significantly ($P < 0.05$) higher in seed+straw+branches and seed+aquasorb treatments compared to that of seed treatment.

For *T. sinuata* and *C. dregeanus* TL50 was significantly ($P < 0.05$) higher on heuweltjie soils than off-heuweltjies. The TL50 for seed and seed+aquasorb treatments TL50 was significantly ($P < 0.05$) higher than mulched (seed+straw+branches) treatment for *T. sinuata* on heuweltjies, while off-heuweltjies there was no significant ($P > 0.05$) difference between treatments. For *C. dregreanus* on heuweltjies TL50 was significantly ($P < 0.05$) higher for seed treatment than for seed+aquasorb treatment, while there were no significant difference between the mulched and the former two treatments. There was no significant ($P > 0.05$) difference in TL50 for *C. dregeanus* between treatments off-heuweltjies. For *P. incana* and *E. calycina* TL50 was significantly higher ($P < 0.05$) off-heuweltjies than on heuweltjies (Table 5.7).

Table 5.7: Mean time taken to reach 50 % survival for *T. sinuata, E. calycina, C. dregeanus* and *P. incana* with different treatments in different localities (heuweltjies & off – heuweltjies).

	Time until 50% survival							
Treatment	**Heuweltjie**				**Off-heuweltjie**			
	T.sin	*E.cal*	*C.dreg.*	*P.in*	*T.sin*	*E.cal*	*C.dreg.*	*P.in*
Seed	200	52	139	44	121	73	39	37
Seed & Aquasorb	143	63	45	16	89	75	60	85
Seed, straw & branches	95	58	90	24	134	111	64	84

Fisher's least significant difference = 67.433

5.4.6 *Problems encountered during revegetation experiment*

Technical problems encountered with data logger made the use of microclimate information difficult, due to much variation. Seedling emergence was counted cumulatively from the start, without tagging individual seedlings and this could have affected the result found for total percentage germination ie. percentage germination could be higher than estimated. In straw+seed+branches treatments some seedlings sustained damage.

5.5 Discussion

The selected species were evaluated for their ability to establish in the rehabilitation environment. The most promising species were *Tripteris sinuata, Ehrhartha calycina* and *Chaetobromus dregeanus*. Potential establishment techniques were also evaluated, and the most promising methods were disk and till cultivation, followed by ploughing.

5.5.1 Seedling emergence

The overall trend was that seedling emergence was higher in disturbed than in undisturbed plots. Tilled plots in general had the highest seedling emergence, followed by disked and ploughed treatments. In general, seedling emergence was highest in the least drastic of the disturbed treatments. Cultivation by tilling and disking broke surface crust, to allow water infiltration but above ground vegetation cover removal was limited. Thus the remaining vegetation potentially could have provided micro-habitats/environments for seedling establishment. The more drastic ploughed treatment removed above ground vegetation, leaving seeds (seeds of over-sown species) exposed.

In general, the seedling emergence was higher in seed and seed+aquasorb treatments, than in the seed+straw+branches (mulch) treatments. The reason for this could be that the mulch was too densely packed, and that it had a smothering effect on the seeds. Another reason could be that the mulch did not allow enough sunlight through for germination to occur.

Rainfall in May 2000 was below average, while rainfall in June 2000 was similar to that of the long-term average (Figure 5.2). Soil was therefore very dry in May and June of 2000, and this consequently impacted seedling emergence, which was low to non-existent. After 29 mm rainfall in June 2000, *T. sinuata* started germinating, while the other species remained ungerminated. Emergence during this period was higher in mulched treatments, and this could be ascribed to higher soil moisture content (Figure

5.3) and possibly due to lower soil temperatures underneath mulch. *T. sinuata* germinated better in moderately disturbed plots than in undisturbed (cleared and untreated) and severely disturbed (ploughed) plots throughout the monitoring period. As already suggested, possible reasons for the better establishment in moderately disturbed plots could be that not all of the existing vegetation was removed thus providing extra litter or shelter that could be used as microhabitats for establishment. In addition, plots had a higher moisture content as indicated by soil moisture data (Figure 5.3). Rainfall in July 2000 was twice the long-term average. This rainfall event triggered the germination of *P. incana* and *E. calycina*. Rainfall also resulted in emergence of opportunistic weeds that dominated the study area during this period. Emergence in seed, seed+aquasorb treatments were higher than in seed+ straw+branches treatment for *P. incana, E. calycina* and *T. sinuata* (Table 5.3). It is possible that emergence in seed, straw branches treatment could have been retarded by competition with weeds, that were more abundant underneath mulch (personal observation). In addition to competition, seedlings underneath the mulch had to cope with the smothering effect of the mulch. *C. dregeanus* germinated at the end of the rainy season. Of the four species that emerged, the highest count in a single plot was 40 seedlings/120 viable seeds (33 %) for *C. dregeanus*, 30 seedlings/120 viable seeds (25 %) for *T. sinuata*, 16 seedlings/120 seeds (13.33 %) for *E. calycina* and 13 seedlings/120 seeds (10.83 %) for *P. incana*.

Species germination responses in the laboratory correlated with field performance for all of the species that germinated ie. *T. sinuata, P. incana, E. calycina* and *C. dregeanus*. The laboratory trial indicated that all of the species selected for the trial have potential for restoration in the winter rainfall regions. The species that showed potential for restoration for both summer and winter rainfall regions were *C. dregeanus*. This was also the species that germinated in late winter, in the field trial. The other species that performed well in the laboratory trial were *Ruschia spinosa, Drosanthemum speciosum* and *Indigofera sessifolia*. It could be that the mesembs (family : Mesembryanthemaceae), ie. *Ruschia spinosa* and *Drosanthemum speciosum* germinated at the beginning of the trial but that died before monitoring commenced, ie. one month after sowing. *Indigofera sessifolia* is a hardseeded species, and seeds that germinated in the laboratory had seed coat damage, therefore the seed coat restrain germination. Conditions in the field may delay the scarification process of seeds. An alternative could be to scarify seeds before sowing.

5.5.2 Seedling survival

Although there was no differences in percentage survival (due to low sample numbers) (Appendix 5.1) between different restoration methods the overall trend was as follows: higher survival in tilled, disked and ploughed treatments than cleared and untreated plots. Within treatments the trend for survival was that mulch (seed+straw+branches), had a higher survival rate than seed and seed+aquasorb treatments.

T. sinuata was the species with the highest survival rate, followed by *E. calycina, P. incana* and *C. dregeanus*. Survival for species was in general very low. Milton (1994) found that most Karoo seedlings died within a year of emergence, because of a lack of follow-up rainfall. Highest mortality occurred from November to January, the hottest, driest months in Worcester. Rainfall was adequate during the winter period but the problem seemed to be the lack of follow up rain in spring. The study was conducted in a very dry year with a total of 300 mm rainfall during the study period compared to the long-term average of 611 mm. This seems to be the main limitation to this kind of revegetation attempt, as it is impossible to predict climatic conditions. Over this period, the mulching effect decreased due to wind action. The straw mulch was not incorporated into the soil. From November to January, water infiltration capacity did not differ between treatments as well as between localities (on and off-heuweltjies).

Although soil moisture remained higher on heuweltjies, there was no difference in seedling survival between localities ie. on and off – heuweltjies. Therefore soil moisture is not the only factor that influenced survival. Some possible factors that could have affected survival include soil temperature, competition for soil moisture, nutrients and herbivory. Midgley and Moll (1993) found that competition in the Karoo shrubland appears to be primarily for soil moisture.

5.6 Conclusion

This study showed that the cultivation techniques that disturbed the soil the least, such as tilling and disking are better for seedling emergence than the more drastic cultivation technique, ploughing. It would however only be possible to say whether establishment was successful if the surviving plants were able to reproduce themselves, because this would determine if the species would be able to persist in the natural environment. There was no significant difference in emergence between seeded and seed+aquasorb treated plots. The mulch had a higher soil moisture content, yet lower emergence, which suggested that the mulch had a smothering effect. In addition, competition from annual weeds for moisture and light could have been a factor that contributed to the lower emergence in this treatment. The mulched treatment did however have the highest percentage seedling survival.

This study was conducted over one season and during this time rainfall was below the long-term average. Restoration attempts will always be risky due to low rainfall in these areas. It would be worthwhile to continue the experiment by over - sowing species to monitor response in a year with higher rainfall. It is recommended that study be continued to evaluate surviving plants on the basis of their ability to reproduce. A further recommendation is to evaluate the success of an additional treatment - that of a combination of mulch and aquasorb.

Another avenue of investigation would be to see how acclimatized, container grown seedlings would cope under natural conditions. Looking at a combination of reseeding and transplanting could be of greater value for faster establishment of plants, and therefore restoration of old fields.

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APPENDIX 5.1 total numbers of marked seedlings per species, for the evaluation of seedling survival over time.

	Species			
Treatment	*T. sinuata*	*E. calycina*	*C. dregeanus*	*P. incana*
Ploughed + S	39	30	28	0
Ploughed +SA	39	41	27	9
Ploughed +SsB	39	42	10	10
Cleared +S	16	0	0	0
Cleared + SA	25	2	2	0
Cleared + SsB	14	0	1	0
Untreated +S	19	0	0	3
Untreated + SA	16	0	0	0
Untreated +SsB	7	0	0	0
Tilled + S	41	35	27	10
Tilled +SA	42	49	27	7
Tilled + SsB	40	37	8	6
Disked +S	44	43	29	5
Disked +SA	40	46	29	13
Disked +SsB	35	38	8	7

CHAPTER 6: GENERAL CONCLUSIONS AND RECOMMENDATIONS

This chapter summarises the main findings of the thesis. Recommendations relating to the economic implication of restoration are made. The objectives of the thesis were:

1. To determine the importance of seed banks on the restoration of old fields by:
   - Establishing the efficiency of the seed bank to allow passive restoration on old fields.
   - Comparing the species composition of the seed bank with the above-ground vegetation.
   - Evaluating the effect of disturbance on the availability of seeds in the seed-bank.
   - Determining the role of propagule migration in species composition in disturbed areas ie. if an old field were adjacent to natural vegetation, would propagule migration from the natural vegetation into the disturbed area be sufficient for restoration?

2. To evaluate species for old field restoration in the Little Karoo, by evaluating the effect of different temperature regimes on their germination rate, with the aim of determining the timing for restoration attempts.

3. To assess the influence of mechanical cultivation and soil amendments on the establishment of selected species by:
   - Evaluating different types of treatments that would aid active restoration attempts.
   - Establishing the influence of different soil amendments of species abundance.

6.1 The importance of seed banks in old field restoration (Chapter 3)

Above ground vegetation and seed bank of the old field were dominated by species that usually occur in high disturbance areas, ie. *Atriplex semibaccata, Atriplex suberecta* and *Athanasia trifurca.* These are species that seldom occur in undisturbed areas. Species cover-abundance and plant growth form diversity were lower on-heuweltjies than off-heuweltjies. In natural vegetation the situation is normally the opposite. The condition of the heuweltjie vegetation could be ascribed to the effect of continuous cultivation on the soil profile. Low plant growth form diversity on heuweltjies could be ascribed to competition by established plants. Temperature could also have had an effect on seedling emergence, since heuweltjie soil surface temperatures were higher than that of off-heuweltjie soils during the study period.

The results indicated that there is a low correlation between perennial canopy cover of old fields and the soil seed bank and that seed banks are dominated by disturbance adapted species, mostly annuals. Focussing on the agricultural value of these species, these species can only provide short-term relief for livestock foraging requirements. Though perennial species dominated the above-ground vegetation, the seed bank was dominated by annual species. The results showed that species with a plant cover of less than 1% had a better representation in the seed bank than some of the more abundant species. Results indicated that disturbance increased annual seed bank densities, while perennial seed bank densities decreased. This could lead to a potential competitive advantage of annuals over perennials. This is an indication that soil seed bank is not to be relied on when considering old field restoration.

Data showed that annual seed bank densities increase even though areas are left untreated. This could have been interannual variation, owing to seed set, since the soil batch used to determine seed bank densities before cultivation were taken ± 1 year prior to the batch taken to evaluate the influence of disturbance on seed bank densities.

Although there were similarities in species that were present in the natural vegetation and the old field, the species cover abundance was low in the disturbed area. Some of the species with the low cover abundance were absent from the soil seed bank in the disturbed area. Seedling:adult ratios indicated that species have little chance of moving from the natural vegetation to the disturbed area on the short-term (< 12 yrs). There is a low cover of species in the disturbed areas, in some cases only one individual, indicating a lack in movement from the natural vegetation to the disturbed area.

Based on the results it can be concluded that seed banks have little value on the short-term (< 12yrs) in the restoration of old fields. Data also indicated that propagule migration is very low. The results suggest that active attempts (such as selective seeding of species) must be made to increase the productivity of the land.

6.2 Evaluation of possible species for old field restoration: assessing the influence of different temperature regimes on germination of selected species. (Chapter 4)

Seven species were selected for the laboratory and field trials: *Tripteris sinuata, Drosanthemum speciosum, Ruschia spinosa, Ehrharta calycina, Pteronia incana, Chaetobromus dregeanus* and *Indigofera sessifolia. T. sinuata, E. calycina* and *C. dregeanus* were selected on the criteria of their agricultural value. *Ruschia spinosa* and *Drosanthemum speciosum* were selected as they may act as possible nurse plants for the other species although the evidence of this was precluded due to the short time span of this project. *Indigofera sessifolia* a legume was selected for potential nitrogen deposition to soil. *Pteronia incana* is one of the common species in the adjacent natural vegetation and was included to establish its potential for recruitment on disturbed soils.

Overall, most of the species performed better at a temperature of 20°C day / 10°C night. The result correlates with the findings of other research on Karoo species that found the highest germination occur under regimes that simulate spring/autumn temperature conditions (Esler & Cowling 1995; Esler *et al.* 1992; Hartmann & Dehn 1987; Henrici 1935; Theron 1964).

Only four of the seven species examined in the laboratory, germinated in the field trial. Although some of the species germinated well under laboratory conditions, they failed to appear in the in the field study. Species that failed to germinate in the field trial but that performed well in the laboratory trial were; *Ruschia spinosa, Drosanthemum speciosum* and *Indigofera sessifolia.* It is possible that the two mesembs, *Ruschia spinosa* and *Drosanthemum speciosum* germinated in the beginning of the trial, but that seedlings died prior to the commencement of germination monitoring. When monitored in the second rainy season there was still no sign of these species germinating. *Indigofera sessifolia* seeds that germinated in the laboratory trial had seed coat damage, while the rest of the seeds that failed to germinate had their seed coats intact. The seed coat thus restrained germination in the field as scarification may take longer under field conditions. Alternatively, scarification should take place prior to sowing.

A species that could be recommended for restoration trials for both winter and summer rainfall areas, similar to these of the experimental area, is *Chaetobromus dregeanus* based on laboratory and field experiment results. This species showed good responses in the laboratory at 20°C day/10°C night and 30°C day/15°C night temperatures.

Although seedling emergence of this species started late in the rainy season, this species succeeded in surviving over the warm season, with seedlings receiving the minimal moisture.

Although temperature played a role, as was evident from results obtained, other factors should be considered when determining the suitability of species for restoration. Coupled with temperature is soil moisture, and it is necessary to determine the influence of moisture stress on the germination and consequent establishment of species. Another factor to consider is seed dormancy and it is necessary to determine ways of breaking seed dormancy, as well as determining the period of dormancy. Some species that fail to germinate may have a dormancy period and when observing on a short–term basis these species may appear to be unsuccessful, when in actual fact they are not. Under natural conditions the pioneer species ie. Mesembryanthemaceae would have germinated first forming nurse plants and providing a microhabitat for the establishment of late successional species. In the trial a mixture was sown of late successional and pioneer species. The restoration treatments created microhabitats for seedling establishment and in this case the late successional species germinated. Observations in the second season showed no further germination of the late successional species, which indicate that these species have no innate dormancy. It could be that, seeds of the late successional species have a short life span, and the species germinate when conditions are favourable. Keeping in mind that the seed that were sown were freshly harvested, it could be that the pioneer species needed an after-ripening period before they germinated.

6.3 Management recommendations for old-field restoration: based on the evaluation species performance with different cultivation techniques and soil amendments (Chapter 5).

6.3.1 Seeding densities

Emergence of sown shrub and grass seed only occurred after the first substantial, cool season rainfall of 66.3 mm. No further emergence occurred during the study period except for *Chaetobromus dregeanus*. Reseeding with these indigenous species could increase plant densities on old fields. Based on the species survival monitoring data the number of surviving one year old plants per species produced by 120 seeds were determined and converted to give the number of seeds required to produce 5 000 one year old plants of each of the species on a hectare. These values were converted to seed mass by dividing the number of seeds required to yield 5 000 plants per hectare, by the number of seeds per kg of each of species, to give an indication of the seeding densities (kg) required to produce 5 000 one year old plants per species. Based on these results, under similar rainfall and temperature conditions, the average seeding densities per hectare for the different methods would be as follows: 1.75 kg of *T. sinuata*, 0.25kg of *C. dregeanus*, 0.20 kg of *E. calycina* in tilled areas, 2.75 kg of *T. sinuata*, 0.55kg of *C. dregeanus,* 0.16 kg of *E. calycina* in disked areas, 4.83 kg of *T. sinuata,* and 0.55 kg of *C. dregeanus* , 0.1 kg of *E. calycina* in ploughed areas. In cleared and vegetated (untreated) areas seeding density rates would be as follows: 5.8 kg of *T. sinuata* in cleared and vegetated areas and 0.57 kg of *E. calycina* in cleared areas (Table 6.1).

6.3.2 Economic implications of treatments

According to Wiedemann and Cross (2000) a stand of 5 plants/m^2 on rangeland indicates successful establishment. When considering the average number of surviving plants of the different species per treatment (Table 6.1) and the cost of the different mechanical treatments (Table 6.2), tilling seems to be the most cost effective of the cultivation techniques (Figures 6.1, 6.2 and 6.3). For all of the mechanical treatments re-seeding as amendment is the most cost effective of the treatments (Table 6.2 and Figures 6.1, 6.2 and 6.3). Based on the estimated average number of surviving one year old plants (Table 6.1) there appears to be no significant difference in number between the seed and seed+aquasorb. Therefore reseeding alone seems to be the best option when it comes to the amendments. If short-term advantages were the aim of the restoration attempts, attempting any of these methods would not be a viable exercise. To sell this unproductive veld would be more profitable than to restore. The average market values for veld for grazing in this region is ± R250 / hectare (Botha, pers. comm.). From a long-term perspective restoration could be viable, but it all depends on the farmer's financial status. Possible ways of reducing the cost to the farmer would be if he/she could collect seeds from local sources, for example along road and railway reserves (Esler & Kellner 2001). The dilemma is that restoration of this nature provides a long-term, albeit uncertain, benefit but the exhorbitant short-term costs make recommendations for restoration very difficult. Long-term benefits include: increased property values, increased carrying capacity for livestock and wildlife erosion control, improved veld conditions, increase in biodiversity and the possibility of reducing the rate of desertification. The issue of who should shoulder the costs of restoration should be addressed by policy and decision makers only after an in-depth ecological economics study (beyond the scope of this thesis).

6.3.3 General recommendations

Results showed that disturbance is required to aid the establishment of species. Disturbance must not be so drastic that it removes all available vegetation, as is the case in clearing and ploughing. A light cultivation method such as tilling and disk cultivation is recommended. Tilling cultivation is recommended since this is the more cost effective method based on seedling survival success and machinery cost (Table 6.2). The seed treatments that showed the best results in terms of seedling emergence were the seeded and seed+aquasorb treatments. Based on cost effectiveness as described in table 6.2, seeding is recommended as the best treatment.

6.3.4 Shortcomings of the study

Data collected for the determination of the role of propagule migration were collected once off. Data would have been more meaningful if seed dispersal were monitored over a season where seed traps are used to catch seeds and to aid in the identification of species that disperse as well as determining the agents involved in the dispersal of these seeds.

Good record keeping of microclimatic data would have been good for to identify the effect of surface temperature on seedling emergence, unfortunately this was not possible due to problems encountered with the dataloggers. Seedling emergence was counted cumulatively from the beginning without tagging individual seedlings. This affected results in terms of total percentage germination it could have been that the percentage germination were higher than estimated. The method used to sow seeds was broadcasting without covering seeds, this could have affected the results obtained. Incorporation of seeds into the soil might have given better results.

6.3.5 Future research

Although the study showed that disturbance is required to aid the establishment of species, the results showed that disturbance causes seed bank densities of annuals to increase. It is suggested that future research should be focused on restoration techniques that causes small scale disturbances, with a more patchy distribution, ie.

less uniform disturbance, that would increase the possibility of seeds landing in a more suitable microhabitat for establishment. An approach incorporating patchiness is probably a more appropriate simulation of natural conditions (Eccles *et al.* 2001; Eccles *et al.* 1999). Future research should evaluate the cost effectiveness vs. ecological 'success' (depending on aim/goal) of these contrasting re-vegetation techniques (possibly using a modelling approach). At a farming scale, this type of disturbance could be approached by land imprinting, done with an device called an "imprinter", that forms funnel-shaped seedbeds, and that simultaneously mulches the above-ground plant material, thus providing a microsite for seedling establishment (Abusuwar 1995). Other aspects that should be considered in future research are the influence of moisture stress on the germination and consequent establishment of species, the role of seed dormancy is species establishment, and determining after ripening periods for plant specie. This study focused on the physical aspect of soil, which leads to another avenue that requires investigation, that is the soil chemical status, and finding ways of increasing micro organisms in the soil. Finally, future research should test the viability of planting established adult plants to act as seed catchers or to provide microsites for species who potentially disperse into the area or who are artificially reseeded later.

Table 6.1: Estimated quantities of seed (numbers and air-dry mass) required to produce 5 000 one-year old plants of *Tripteris sinuata, Erhartha calycina* and *Chaetobromus dregeanus* on different treatments and methods (Figure 5.1) under similar rainfall conditions. Method / treatment codes described in full in figure 5.1.

Method Treatment	1 year old plants/ sown seed			Seeds per 5000 surviving plants			Seed mass (kg) per 5000 surviving plants		
	T.sin	*C.dreg.*	*E. cal.*	*T.sin*	*C.dreg.*	*E. cal.*	*T.sin*	*C.dreg.*	*E. cal.*
TS	7/120	3/120	5/120	85714	200 000	120 000	1.24	0.18	0.11
TSA	5/120	2/120	2/120	120 000	300 000	300 000	1.74	0.28	0.29
TSsB	4/120	—	3/120	150 000	—	200 000	2.17	—	0.19
DS	4/120	1/120	3/120	150 000	600 000	200 000	2.17	0.55	0.19
DSA	5/120	1/120	3/120	120 000	600 000	200 000	1.74	0.55	0.19
DSsB	2/120	—	5/120	300 000	—	120 000	4.35	—	0.11
PS	3/120	1/120	4/120	200 000	600 000	150 000	2.90	0.55	0.14
PSA	3/120	1/120	6/120	200 000	600 000	100 000	2.90	0.55	0.01
PSsB	1/120	—	4/120	600 000	—	150 000	8.70	—	0.14
US	2/120	1/120	—	300 000	600 000	—	4.35	0.55	—
USA	2/120	—	—	300 000	—	—	4.35	—	—
UssB	1/120	—	—	600 000	—	—	8.70	—	—
CS	2/120	—	—	300 000	—	—	4.35	—	—
CSA	2/120	—	1/120	300 000	—	600 000	4.35	—	0.57
CSsB	1/120	—	1/120	600 000	—	600 000	8.70	—	0.57

Table 6.2 Relative cost of treatments in Rands per hectare. Machinery cost from Müller & Archer 2001.

Treatment	Cost Considerations	Average cost (Rands/ha) *
Seed only	1– 9 kg/ha @ R50/kg average (= R150-R450/ha)	250
Seed+Aquasorb	20 kg/ha Aquasorb @ R50/kg = R1000/ha	1250
Seed + straw +branches	straw @ R2.50 per bale = R 416.67/ha Chainsaw fuel & usage = R130/ha Transport, tractor fuel and usage R3/km × 2km × 66 trips (=R396/ha) (if the brush has to be transported)	1192.67
Mouldboard plough	Tractor fuel & usage (R145.8/ha) Labour @ R40/day	185.50
Disc	Tractor fuel & usage (R90.95/ha) Labour @R40/day	130.95
Tiller	Tractor fuel & usage (R63.44/ha) Labour @R40/day	103.44
Clearing	Labour @R40/day	40.00

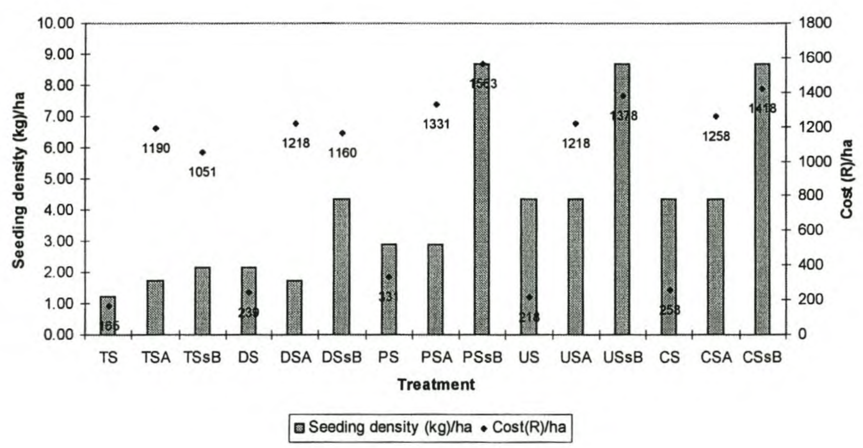

Fig. 6.1 Comparison of seeding densities (kg) and cost per hectare for *Tripteris sinuata* with different treatments. Treatment codes: main treatments, T = tilled, D = disked, P = ploughed, C = cleared, U = untreated; subplot treatments, S = seed, SA = seed+aquasorb & SsB = seed+straw+branches.

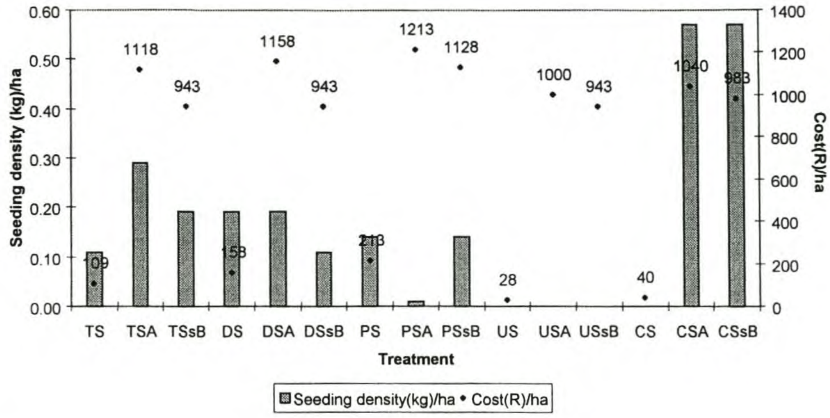

Fig. 6.2 Comparison of seeding densities (kg) and cost per hectare for *Ehrharta calycina* with different treatments. Treatment codes: main treatments, T = tilled, D = disked, P = ploughed, C = cleared, U = untreated; subplot treatments, S = seed, SA = seed+aquasorb & SsB = seed+straw+branches. Where bars are absent, no plants survived and cost indicated are treatment cost without seeding cost included.

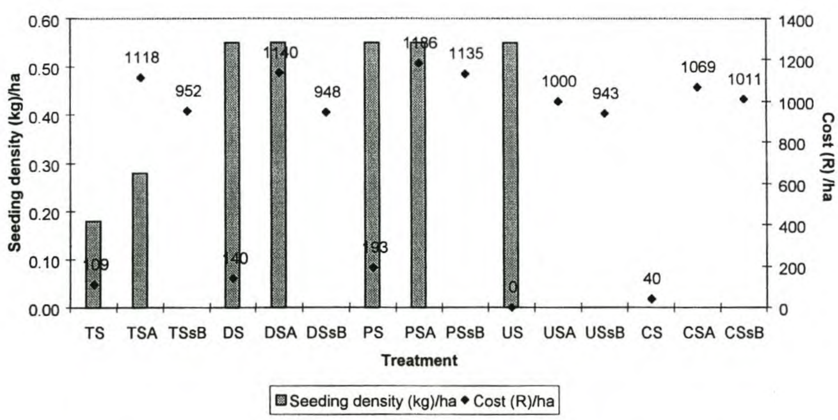

Fig. 6.3 Comparison of seeding densities (kg) and cost per hectare for *Chaetobromus dregeanus* with different treatments. Treatment codes: main treatments, T = tilled, D = disked, P = ploughed, C = cleared, U = untreated; subplot treatments, S = seed, SA = seed+aquasorb & SsB = seed+straw+branches. Where bars are absent, no plants survived and cost indicated are treatment cost without seeding cost included.

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