An ecological approach to the reclamation and improvement of arid rangelands using adapted fodder plants

BY

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Submitted in partial fulfilment of the requirements of the degree

M.Sc.Agric (Pasture Science)

in the Department of Plant Production and Soil Science
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Die outeur wil graag sy dank betuig aan die volgende partye wat hom gedra het gedurende sy studie.

My Hemelse Vader sonder Wie se krag en genade niks moontlik is nie.

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DECLARATION

I, Daniel Barend Venter, herby declare that this dissertation for the degree M.Sc.Agric (Pasture Science) at the University of Pretoria, is my own work and has never been submitted by myself at any other university.

D.B. Venter

November 2005

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ABSTRACT

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The world we live in is changing rapidly. Ecological, economic and social aspects and understandings are all undergoing paradigm shifts. Communities, farmers and individuals in arid zones are experiencing climate changes, more so than city dwellers. A better understanding of the current thinking in range ecology and management, especially of arid environments, is critical to the management of these delicate, complex systems. Ecosystems in equilibrium or in disequilibrium react differently to management and reclamation efforts. An understanding of the basic principles and how they evolved is important in order to apply these principles correctly in the management of arid zones. The use of keystone species and simple technologies, such as water harvesting and mulching, can all be used to reclaim and manage the arid zones. Understanding the differences between systems in equilibrium and disequilibrium can be used as a guide for planning appropriate future research in the arid zones. Searching for new indigenous species to help in the reclamation of arid zones is of the utmost importance. An ecological criterion was used to identify potential plant species for reclamation of degraded arid rangelands of southern Africa. *Tripteris sinuatum* and *Sutherlandia microphylla* were identified as possible candidates. Germination studies, with seeds harvested from naturally occurring plants, were conducted for both species. Treatments were based on the natural seed dispersal mechanisms for both species. *S. microphylla* has the potential to become an important plant species for reclamation purposes in arid zones of southern Africa. Not only potential new species should be sought, but also the management of species, already in use, are of critical importance. The relative palatability and survival of 16 different *Atriplex* species and accessions were determined at two different localities in the arid Northern Cape Province of South Africa. Significant differences were found between species at both localities. It is believed that because of the variety of species in the *Atriplex* genus, relative palatability and survival should be used to determine which of the different species could be useful under specific climatic and soil conditions. The establishment and reaction of *Atriplex nummularia* and *Cassia sturtii* were tested for season of planting and the use of a stone mulch at two locations in the Northern Cape Province of South Africa. *A. nummularia* reacted the best to a moderate pruning treatments, while *Cassia sturtii* reacted best to severe pruning. These results should aid in the management of planted fodder plantations. Numerous attempts at improving natural veld have failed in the past. An examination of landscape function and the potential to harvest water in localized areas should drive veld improvement in arid zones. Seeds from two different plants species (*Tetragonia calycina* and *Tripteris sinuatum*) were used to inter-seed a bare patch in the Northern Cape Province of South Africa. The two species, with two treatments, (brush packing or not) in two different locally occurring eco-topes, were used to determine plant establishment. The water run-on eco-tope showed a significantly higher plant establishment percentage than the water run-off eco-tope. The establishment of perennial grass species was also found on the water run on eco-tope, three years after establishing the reclamation site. Such sites could form an important link in biodiversity conservation.

Chapter 1

Prepared according to the author guidelines for The Journal of Arid Environments

INTRODUCTION

General overview of the study area (biomes, vegetation, geology, soils and climatic data) and problem statement

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1. Introduction

Working in arid environments is a huge challenge. The focus and aim of this project is "An ecological approach to the reclamation and improvement of arid rangelands using adapted fodder plants". The only way to achieve this objective is to identify smaller, more defined objectives, while remembering the overall objective. This chapter is an introduction to the area concerned in South Africa, and a description of the work that has been done for this M.Sc.

2. Site descriptions

2.1. General

Four sites in the Northern Cape Province of South Africa have been identified. From east to west these site are Kenhardt, Mier, Pofadder and Kamieskroon (Figure 1). The first three sites are situated on a rainfall gradient, from a high of 200 mm per year at Mier, to a low of 80mm per year at Pofadder. The two sites in the Kamieskroon region, are the most westerly situated and are in a winter rainfall region. The Kamieskroon mountain range and the cold Atlantic ocean provides the opportunity to study the effects of a rainfall gradient of 400mm to 150mm, on plant establishment and survival within a distance of 20km.

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The study area lies in the north west of South Africa. South Africa is characterised by a rainfall gradient from a relatively high rainfall in the east, to a low in the west. The area is further divided into summer, bimodal, and winter rainfall regions. The main biomes represented in the target area are savanna, nama-karoo and succulent karoo transitional to fynbos (Tainton and Hardy, 1999). Each trial site will be discussed separately including the characteristics of the major biome in which it occurs. Detailed descriptions of the different trial sites will be discussed in following chapters, where relevant.

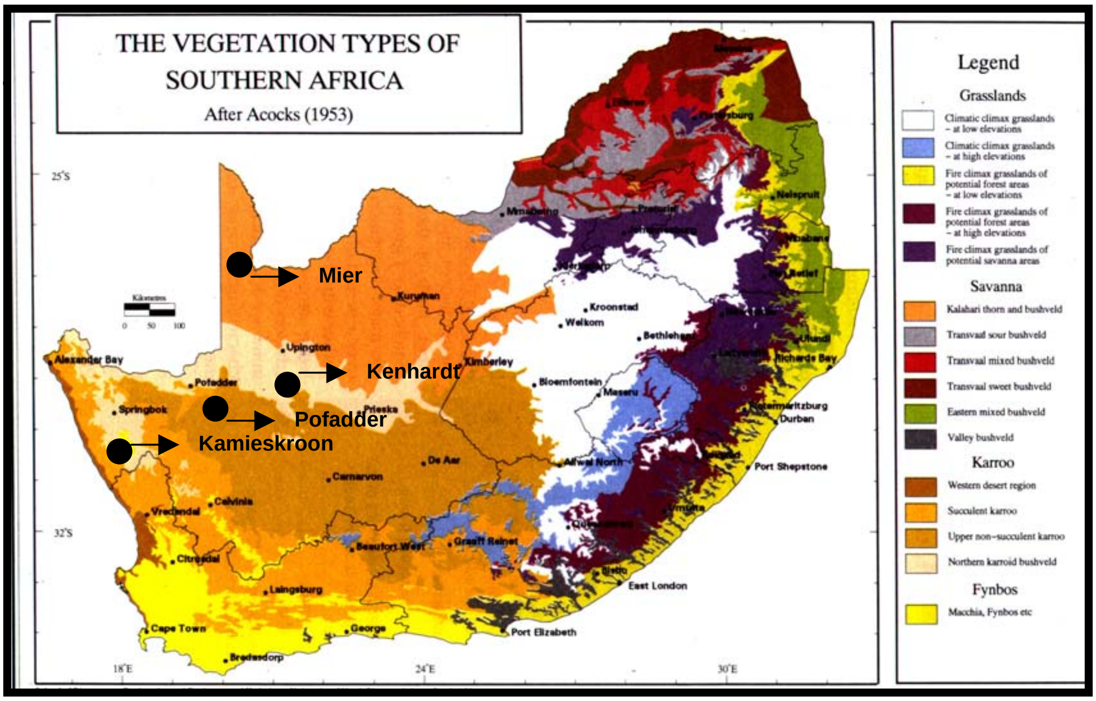

Figure 1 The vegetation types of Southern Africa (Tainton and Hardy, 1999)

2.2. Mier

The savanna Biome is the largest Biome in southern Africa, occupying over one third of the surface area of the country. South African savanna's are characterised by a grassy ground layer and a distinct upper layer of woody plants. Where the upper woody layer is close to the ground (vertical distribution) the vegetation may be referred to as Shrubveld and where it is dense as Woodland, with intermediate stages known locally as Bushveld (Low and Rebelo, 1996).

The area around Mier and Tweerivieren is known as the Shrubby Kalahari Dune Bushveld (Low and Rebelo, 1996) or the Kalahari Thornveld (Acocks, 1988). The Mier area had not been surveyed by Acocks (1988), and will be referred to as Shrubby Kalahari Dune Bushveld. This veld type covers approximately 37 434 km^2 of which 55% is transformed and 19.45 % is conserved, mostly in the Kgalagadi Transfrontier park (Low and Rebelo, 1996).

The average annual rainfall is approximately 200mm, distributed from November to April with a peak in March. The temperatures vary between –10 and 45 degrees Celsius with an average of 20 (Low and Rebelo, 1996).

A summary of the climatic data is provided in Table 1. These data were obtained from the ARC (Agricultural Research Council)[1]

The vegetation is characterised by scattered shrubs of mainly *Acacia haematoxylon* (Grey Camel Thorn) with a few individuals of *Acacia erioloba* (Camel thorn) and *Boscia albitrunca* (Shepherds tree). The shrub layer is poorly developed with some individuals of *Grewia retinervis* (Bastard roughleaf raisin) and *Rhus tenuinervis* (Kalahari currant). The grass layer in this area is well developed and often gives the impression of grassland. *Stipagrostis* species, *Eragrostis lehmanniana, Aristida meridionalis* and *Centropodia glauca* are conspicuous on the plains (Low and Rebelo, 1996). Other common species are *Rhigozum trichotomum, Grewia flava* and *Lycium hirsutum.* The grasses are tufted and entirely of the 'white type', mostly *Aristida* spp and *Eragrostis* spp with the silvery *Stipagrostis uniplumis* conspicuous (Acocks, 1988). The sparse tuftedness of the grass and the looseness of the virtually bottomless sand make this veld extremely vulnerable to grazing pressure and it is indeed fortunate that the absence of surface water has, until recently, kept it largely uninhabited (Acocks, 1988).

The soils are characterised by deep aeolion sandy soils, underlain by calcrete (Low and Rebelo, 1996). The major land type in this area is landtype Af2. This landtype is approximately 1 576 830 ha in size. The geology in this area is unconsolidated superficial deposits of tertiary to recent age (Memoirs on the Agricultural Natural Resources of South Africa No 3).[2]

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[2] Land type survey staff. 1986. Land types of the maps SE 27/20 Witdraai. Mem. Agric. Nat Resour. S. Afr. No 3

2.3. Kenhardt

Kenhardt is in the same Biome (Nama Karoo Biome) and veldtype (Orange River Nama Karoo) as Pofadder (Low and Rebelo, 1996) The Nama Karoo Biome and Orange River Nama Karoo will be discussed in the Pofadder description of veldtypes and geology.

Acocks (1988), described the region around Kenhardt as Orange River Broken Veld. The typical Orange River Broken Veld occurs on a variety of rocks e.g. banded ironstone, dolomite, quartzite and granite. Altitude ranges from 750 – 1350 m above sea level and rainfall from 150 – 350 mm per annum. Owing to its proximity to the permanent water of the Orange River, it is as a rule degraded close to the river (Acocks, 1988).

A summary of the climatic data is provided in Table 1. The data was obtained from the ARC (Agricultural Research Council)[1]

The major landtypes in the Kenhardt region are Af11, Ag2, Ah12, Ah55, Ib240 and Fc9 (Memoirs on the Agricultural Natural Resources of South Africa No 9 and No. 3).[3] The Memoir for the map 2920 Kenhardt is not available and the necessary information regarding this map was obtained from the ARC (Agricultural Research Council).[4]

2.4. Pofadder

The Nama Karoo Biome occurs on the central plateau of the western half of South Africa. This is the second largest biome in this region. The geology of this biome varies as the distribution of this biome is determined primarily by rainfall. The rainfall in this biome is extremely varied and can be as high as 520mm per annum to as low as 100mm per annum. The soils in this biome are prone to erosion and this is aggravated where over-utilisation of the veld has occurred. The dominant vegetation in this biome is a grassy, dwarf shrubland. Grasses tend to be more common in depressions or drainage lines on sandy soils. Less than 1% of the biome is protected in formal conservation areas. The major land use in this area is grazing for domestic

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[3] Land type survey staff. 1986. Land types of the maps 2920 Kenhardt. Mem. Agric. Nat Resour. S. Afr. No 3 and No 9

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animals, especially sheep and goats (Low and Rebelo, 1996). The veldtype occurring in the Pofadder region is known as Orange River Nama Karoo (Low and Rebelo, 1996) or Namaqualand Broken Veld (Acocks, 1988). The Orange River Nama Karoo veldtype is approximately 53 708 km^2 of which 1.47% is protected in formal conservation areas. The rainfall in this veldtype is low (150 to 300 mm per year), and unevenly distributed with late summer precipitation for the eastern part and late autumn for the western part.

A summary of the climatic data is provided in Table 1. The data was obtained from the ARC (Agricultural Research Council)[1]

In places, the region is very rocky and possesses a "broken" topography with *Aloe dichotoma* (Quiver Tree), *Euphorbia avasmontana* (Bushman Poison Tree) and *Euphorbia gregaria* (Aggenys Milkbush) normally associated with steep slopes of the mountains and the hills of the area. On the pediments, spike flowered *Acacia mellifera* (Black Thorn), *Rhigozum trichotomum* (Three thorns), *Boscia albitrunca* (Shepherds Tree) and *Boscia foetida* (Stink Shepherds Tree) are common, while *Stipagrostis uniplumis* (Silky Bushman's grass) often dominates the plains, especially after good rains. There are abundant thickets along the banks of the Orange River, with *Tamarix usneoides* (Wild Tamarisk), *Ziziphus mucronata* (Buffalo Thorn) and *Acacia erioloba* (Camel Thorn) along the dry riverbeds of the tributaries (Low and Rebelo, 1996). An interesting phenomenon was observed between Pofadder and the Orange River in the Kaboop Valley where extensive "forests" of *Aloe dichotoma* can be found on the granite gravel slopes below the hills. In 1948 it was observed that trees on the lower parts of the slope where dying or dead while the trees further up on the slopes were still flourishing, suggesting perhaps that, for the first time in the long life span of these trees, there was insufficient water draining from the hills, over the surface of the granite, under the gravel, to reach the lower part of the "forest" (Acocks, 1988).

The Orange River Nama Karoo occurs on soils derived from the ancient basement granites and gneisses of the Namaqualand Mobile belt on the southern edge of the Richtersveld Craton. Red yellow apedal, freely draining young soils dominate most of the area. Deep alluvial soils occur along the Orange River (Low and Rebelo, 1996).

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The major landtypes in the Pofadder Pella region are Ag25, Ag36, Ae93, Ae84, Ae96 and Ic136 (Memoirs on the Agricultural Natural Resources of South Africa No 9).[5]

2.5. Kamieskroon

The sites at Kamiekroon are transitional between the succulent karoo and the Fynbos biome. The Fynbos biome is wrongly considered by some to be synonymous with the Cape Floristic region or Cape Floral kingdom. The Fynbos biome refers only to the two key vegetation groups (Fynbos and Renosterveld). The Cape Floristic region, or Cape Floral kingdom, refers to the general geographical area and includes other vegetation types such as forest, Nama Karoo, Succulent Karoo and Thicket biomes, but excluding peripheral outliers of the Fynbos Biome such as the Kamiesberg, North-western and Escarpment Mountain Renosterveld and Grassy Fynbos east of Port Elizabeth. The Fynbos biomes vegetation is so overwhelming that the Cape Floristic Region and Cape Floral Kingdom can be considered to be essentially Fynbos. The Cape Floral Kingdom contains five biomes, of which the Fynbos biome, comprising the Fynbos and Renosterveld vegetation groups, contains most of the floral diversity. Including the Fynbos and Renosterveld vegetation to the north and east in the Cape Floral Kingdom would mean that endemicity would approach 80%, the highest level of endemicity on any subcontinent (Low and Rebelo, 1996).

The vegetation in the Kamieskroon region is classified as North-Western Mountain Renosterveld and is approximately 1 641 km^2 in size. This vegetation, which is poorly known, is largely confined to the Kamiesberg highlands around Leliefontein. The higher elevation of this region ensures sufficient rainfall to support this vegetation type. North-western Mountain Renosterveld grades with the Succulent Karoo and Fynbos at lower and higher elevations, respectively. Rainfall in this region varies from 250mm per year, with Fynbos becoming dominant at 350 to 400mm year. Granites and gneisses are the dominant geological formations in the area, giving rise to deep sandy loamy soils (Low and Rebelo, 1996). The closest weather station is situated at Springbok and the data is presented in Table 1.

[5] Land type survey staff. 1986. Land types of the maps 2918 pofadder. Mem. Agric. Nat Resour. S. Afr. No 9

3. Problem Statement

Many of the arid and semi-arid areas of South Africa are degraded to a greater or lesser extent. These areas are extremely sensitive to certain management practices, such as over-grazing. Even though these areas are mostly in disequilibrium, management has an influence, more so in the long term than in the short term. The rainfall in these areas is extremely variable and the recovery from mismanagement is usually episodic. Examples of areas which have been rested for 20 years and which have not recovered in terms of productivity, or species composition, are common place (Pers comm. Albert van Niekerk)[6].

The classical model of range succession describes vegetation at any stocking rate as being in a stable equilibrium (Westoby et al., 1989). The equilibrium is held in place by two opposing forces, grazing pressure and the tendency of the vegetation to change towards the climax (Behnke and Scoones, 1993). This model clearly does not apply to the arid and semi arid regions of South Africa (Milton and Hoffman, 1994). The state and transition model is a succession model that is a lot more applicable to arid and semi-arid regions (Laycock, 1991). This model implies that more than one locally stable state exists in terms of the plant communities. A threshold keeps the plant communities from crossing over from one state to another (Friedel, 1991). If a certain management programme is applied in combination with certain environmental factors a certain threshold can be crossed and the community will move from one state to another. The plant community will, however, not be able to cross that threshold on its own. To move a plant community back to a certain stable state certain energy inputs will be needed to cross the threshold again. These energy inputs are usually in terms of management but should also take the episodic environmental conditions into account, especially rainfall (Milton and Hoffman, 1994). The state and transition model is best understood in terms of a cup and ball analogy where the troughs are the locally stable points and the ball has to cross a threshold to reach another cup (Laycock, 1991).

The problem in these regions is to have the right environmental conditions and the correct management practices, to take some of the pressure off the natural resources.

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[6] Mr Albert Van Niekerk. "Klipkoppies" Farm, Upington.

4. Hypotheses

It is hypothesised that by using techniques such as water harvesting and stone mulching, drought tolerant fodder shrub plantations could be established in arid and semi-arid regions

It is hypothesised that the pressure on the natural veld could be alleviated through the planting of drought tolerant fodder shrubs in plantations, which could be used as fodder reserves. These plantations could be utilised after good rainfall events to give the veld a chance to recover and build up the natural seedbank in the soil.

It is further hypothesised that by establishing selected species in degraded veld it would be possible to change the community structure of the veld, thereby improving productivity.

5. Key species identification

It is an objective of this study to identify potential, useful species for these purposes. Even though a lot of work has been done on the selection and propagation of *Atriplex,* the study will include a re-examination of the establishment and palatability differences between selected *Atriplex* species.

The identification of certain indigenous species, which can be used during the reclamation of degraded rangelands, was also a critical objective. It is, furthermore, aimed to collect indigenous knowledge on the use and management of indigenous species, which will supplement existing scientific information, as the latter is very limited.

Even though the objectives are not identical to the hypotheses, the preliminary results could be used to determine whether the hypotheses are worthy of more stringent testing. The testing of the above hypotheses will also be dependant on prevailing environmental conditions, such as rainfall, which are, unfortunately, very unpredictable. One of the main objectives, therefore, is to establish plantations of drought tolerant fodder shrubs that can be used to test the hypotheses as soon as favourable environmental conditions prevail.

Table 1 Long term climatic data for three selected weather stations in the Northern Cape Province of South Africa (Agricultural Research Council)[1]

StationName	MagDist	Lat	Lon	Alt	Statistic	Stats	nYears	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
TWEE RIVIEREN	Unknown	26.466667	20.61666679	879	MaxT	Average	39.25	35.9	34.7	32.8	29	25.1	21.6	21.9	24.1	28.5	31.1	33.6	35.5	
TWEE RIVIEREN	Unknown	26.466667	20.61666679	879	MinT	Average	39.33	19.8	19.2	16.6	12	6	2	1.4	3.3	7.8	12.3	15.9	18.1	
TWEE RIVIEREN	Unknown	26.466667	20.61666679	879	Rain	Average	39.25	34.6	43.8	29.3	26.6	8.5	2.3	1.6	1.2	2.7	11	18.2	20.8	200.6
POFADDER - POL	KENHARDT	29.13333321	19.38333321	989	MaxH	Average	1.08	55.5	50.3	55.4	56	51.2	65.5	65.2	63.4	54.8	55.1	54.4	54.4	
POFADDER - POL	KENHARDT	29.13333321	19.38333321	989	MaxT	Average	34.67	33	31.3	29.9	24.6	20.6	17.3	18	19.7	23.7	26.6	30.1	32	
POFADDER - POL	KENHARDT	29.13333321	19.38333321	989	MinH	Average	1.08	23.6	21.1	24.7	25.5	21.7	31.5	26.4	23.8	20.8	22.5	20.9	21.9	
POFADDER - POL	KENHARDT	29.13333321	19.38333321	989	MinT	Average	34.67	16.5	16.6	15.5	12.1	8.2	5.5	5.1	6.1	8.7	11.1	14.1	15.5	
POFADDER - POL	KENHARDT	29.13333321	19.38333321	989	Rain	Average	35.42	8.2	19.1	22.8	19.1	5.9	6.9	5.5	2.6	4.5	4.6	4.1	9.2	112.6
KENHARDT	KENHARDT	29.36666679	21.14999962	798	MaxH	Average	12.33	41.5	48.7	56.9	60.7	62.8	68.5	66.7	55	51	48.7	43.4	43.9	
KENHARDT	KENHARDT	29.36666679	21.14999962	798	MaxT	Average	12.33	36.4	35.1	32.8	28.2	24.6	19.9	19.8	22.8	26.6	29.3	32.3	34.6	
KENHARDT	KENHARDT	29.36666679	21.14999962	798	MinH	Average	12.33	13.6	16.7	19.9	21.9	22.1	25.6	23.7	18.2	16	15.3	13.7	13.6	
KENHARDT	KENHARDT	29.36666679	21.14999962	798	MinT	Average	12.33	20	19.5	17.3	12.6	7.8	3.4	2.8	5.1	9	12.5	16.1	18.2	
KENHARDT	KENHARDT	29.36666679	21.14999962	798	Rain	Average	14.25	14.8	21.5	29.5	9.8	7.5	5	3.8	3.5	4.7	7.3	14.2	18.6	140.1
SPRINGBOK - WK	NAMAQUALAND	29.66667	17.9	1006	MaxT	Average	3.83	29.3	29.5	28.4	25	20.4	17.7	16.2	18	20.4	23.8	24.1	26.9	
SPRINGBOK - WK	NAMAQUALAND	29.66667	17.9	1006	MinT	Average	3.92	16.4	16.7	16.7	14.7	11.9	9.4	8.1	8.7	9.8	11.6	11.8	14.4	
SPRINGBOK - WK	NAMAQUALAND	29.66667	17.9	1006	Rain	Average	4.5	2	3.9	30	12.9	41.9	27.7	30.1	33.7	37.2	12.8	22.3	7.9	262.2

[1] Gert de Nysschen, ARC Institute for Soil, Climate and Water, Agromet Climate Monitoring and Information services. 600 Belvedere Street, Arcadia, PrivateBag X79, Pretoria 001, Republic of South Africa. Tel (012) 310-2660.

It is expected to find differences in the production, relative palatability and establishment of different *Atriplex* species. It is further expected to identify indigenous species, which could be established, to produce seed for reseeding. Potential species include *Boscia albitrunca, Tripteris sinuatum, Salsola tuberculatum, Eriocephalus africanus, Sutherlandia frutescens, Sutherlandia microphylla* and *Tetragonia calycina*. The criteria, which were used to identify these possible species, are presented in Chapter 3.

6. Study Methodology to be used

Existing plantations of *Atriplex* species, at the Pofadder and Mier sites, will be used to evaluate production and relative palatability. The relative palatability will be measured by using sheep.

Sites to determine the potential of micro-habitat modifications (water harvesting) will be identified, and the use of locally harvested seeds will be used to reseed these sites.

Further plantings will be done at the Pofadder, Kenhard and Kamieskroon sites. These plantations will be used to evaluate the establishment and adaptation of different species under different soil and climatic conditions.

On the farm “Lovedale”, in the Pofadder region, several different trials were conducted. These included relative palatability of *Atriplex* species, reclamation of bare patches and the influence of time of planting on plant establishment.

On the Mier site an existing plantation of *Atriplex* species was used to determine relative palatability. This site was also used to assess the survival of *Cassia sturtii* under extreme environmental conditions (aridity and salinity).

A plantation similar to the one at the Pofadder site was also established at the Kenhardt site to study the influence of the time of planting on plant survival.

Two trial sites were identified in the Kamieskroon area. These two sites are situated within 20km of each other and have a 250mm difference in rainfall per annum. Plantings at the two sites consisted of, two species, *Atriplex nummelaria* and *Cassia sturtii*

7. Conclusion

Work in arid environments must be long term. Many of the sites that were planted will only start to produce results under favourable climatic conditions. It is, therefore, critical that the work on these sites should continue and expand as our understanding of these areas increases. There is no “quick fix” for reclaiming degraded areas in arid environments. Most of Southern Africa consists of arid regions, which can be used sustainably as rangelands, but not for crop production. It is, therefore, vital to continue this work for extended periods.

Different strategies are needed to ensure success. Work in these areas should be done within the constraints of the natural environment. The identification of the limiting factors is of the utmost importance. Water availability is the major limiting factor in arid areas. The available water should thus be used in an optimal manner. This can be done by using adapted species, by increasing water infiltration and by improving the water holding capacity of the soils.

One of the limitations of working in the arid areas of South Africa is the lack of an easy and reliable method to determine the veld condition. Developing such a technique should receive more attention especially for the western areas of South Africa. These areas are dominated by woody shrubs and not by grasses. Reaction to management is usually slower and more permanent in arid eco-systems than in the higher rainfall areas.

A different way of looking at the problem could be to change the way that these area are utilised. Diversification of production systems might be the key to sustainable utilisation of these areas. The growing market for natural pharmaceutical products could be a solution. Production of medicinal plants as a cash crop might be one way to diversify production system in these arid environments.

Using keystone species to increase the fertility of the soils and to promote autogenic succession should also be considered. These species are usually leguminous and have the ability to increase the nitrogen content of the topsoil, thereby increasing the fertility of the soils.

Different incentives to protect the natural environment should also be examined. One possible approach is to give primary production (vegetation production) a monetary value. This could create the incentive for farmers to do reclamation work by giving an immediate return on the money spent on reclamation. The pressure on the natural veld could also be relieved because the farmer would not be solely dependent on livestock (capital) to obtain loans from banks. The farmer with the best veld would thus be awarded and his property will also be worth more than the surrounding properties. The price, or value, of the property should then be determined by the condition of the veld and not only by market related prices.

Caution should be used in choice of species. Certain species has been declared as invaders and *A. numularia* is classed as a category 2 species and can only be grown in a controlled environment with the relevant permission and permits of the authorities in South Africa.

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Chapter 2

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A review: Old and new approaches to arid zone ecology as a basis for reclamation and management of arid ecosystems

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Abstract

Ecosystems in equilibrium or in disequilibrium react differently to management and reclamation efforts. An understanding of the basic principles and how they evolved or developed is important, so as to apply these principles correctly in the management of arid zones. Arid zones do not behave or respond to the classical range succession model and are presently better described as systems in disequilibrium (state and transition model). The use of keystone species and simple technologies, such as water harvesting and mulching, can all be used to reclaim and manage the arid zones. The use of such practices all fit in with the ecological disequilibrium model and are practical applications of an ecological model. Understanding the differences between systems in equilibrium or disequilibrium can be used as a guide for planning appropriate future research in the arid zones.

Keywords: Arid ecology, degradation, disequilibrium, equilibrium, reclamation.

Introduction

The world is changing with global climate change, increasing pressure on natural resources, poverty and an unprecedented increase in human populations. In a changing environment our thoughts on, and understanding of, the impacts of these pressing issues should evolve, if we are to remain on the earth on a sustainable basis.

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Knowledge, of our natural environments, is busy changing as our understanding of these systems improve. Our knowledge and understanding of the reaction to management, and the environment, in arid ecosystems, are undergoing a paradigm shift. The accepted successional models of the past, on which management decisions were based, seem to be flawed. New thinking and new successional models are paving the way for sustainable utilisation of our arid environments. Holding on to the old ideas, successional concepts and models will impede restoration and reclamation efforts in our arid environments. “Flaws in theory feed flaws in practice which produce disappointing results” (Tyson, 1995).

“The last few years have seen a major rethink of some of the hallowed assumptions of range ecology and range management practice. What were once the hallmarks of the discipline are now being questioned. Terms and concepts such as ’vegetation succession’, ‘carrying capacity’ and ‘degradation’ are being reassessed, particularly in the dry rangelands where system dynamics are dominated by highly variable rainfall and episodic, chance events such as drought “(Scoones, 1995).

Desertification and land degradation are terms used extensively, but how well are these terms understood? Desertification is a term that was first used in the early 1940’s to describe degradation in tropical Africa. Currently this term refers only to land degradation in dryland areas. This type of degradation may be aggravated by drought but is caused primarily by poor land management (Hoffman and Ashwell, 2001).

The term desertification usually conjures up images of invading sand dunes, resulting in an area that looks like a great sand desert. In reality, however, desertification usually occurs in patches across a landscape. These patches will increase in size over time, until the productivity of the whole area has declined to such an extent that it may be compared to a desert (Hoffman and Ashwell, 2001).

…“desertification means land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities”….(UNCCD, 1995).

…”land degradation means the reduction, or loss, in arid, semi-arid and dry sub humid areas, of the biological or economic productivity and complexity of rain-fed cropland, irrigated cropland, or range, pasture, forest and woodland, resulting from land uses, or from a process or combination of processes, including processes arising from human activities and habitat patterns such as:

(i) soil erosion caused by wind/or water

(ii) deterioration of the physical, chemical and biological or economic properties of soil; and

(iii) long-term loss of natural vegetation"

(UNCCD, 1995)

The growing interest and concern in the degradation of arid areas can be justified by the mere magnitude of the problem and uncertainty of the additional effect that global climate change might have in these regions. The area occupied by dry-lands not only justifies the increased interest in these areas but should prompt a closer look at what factors drive these systems.

Dry-lands occupy one third of the land area of the Earth. In Africa 70% of the continent can be classified as dry-lands. A shocking 62% of all rangelands worldwide have already been affected by desertification (Verstraete and Schwartz, 1991). According to Hoffman and Ashwell (2001), 99% of South Africa can be classified as dry-land according to the definition of dry-land by the UNCCD (1995).

Global climate change will probably further impact South Africa's ecological systems. This is a worldwide phenomenon affecting metabolism, physiology, and the distribution of plants and animals and their interactions (Garcia and Jurado, 2003)

Increased CO_2 levels, increased variability of rainfall and increasing temperatures will affect primary production (quantity, quality and availability), secondary production and species diversity and composition worldwide (Campbell and Stafford Smith, 2000). Campbell and Stafford Smith (2000) explored the probable effects of increasing CO_2 levels, increasing temperature and reduction, or increase, in rainfall. The authors found that it was difficult to predict what the effect of global climate change would be in many arid ecosystems, because of an uncertainty of what global climate change would entail in terms of temperatures and rainfall in these areas. The authors, however, sketch certain scenarios, which do not bode well for the future, in terms of economic and ecological production, of these arid areas.

"In warmer, dry areas, and where rainfall changes do not compensate for temperature increases, or where seasonality of rainfall shifts unfavourably, there is the likelihood of increased drought problems. These will be of great concern to grazing managers, since it is often the extreme events that drive enterprises out of business, or subsistence people into famine" (Campbell and Stafford Smith, 2000)

Extreme events, such as low and variable rainfall, not only in occurrence but also volume, are already, and have been, a characteristic of many of our arid areas in South Africa. The management of such areas has in the past been based on experience and knowledge of ecological systems in equilibrium.

It was believed that systems in equilibrium had one climax state and that animal numbers had a huge impact on the vegetation. Thus a negative feedback system was responsible for determining animal numbers. Animal numbers impacted on the vegetation, which in turn impacted on the animal numbers. Reducing animal numbers would then increase the amount of available vegetation, and excluding animals from such a system would give the vegetation the opportunity to return to the climax state. Conservative stocking rates were applied to keep these systems in a healthy productive state (Behnke and Scoones, 1993). The climax stage of vegetation was assumed to be resilient and that the vegetation could return towards the climax in a series of successional sequences (Heshmatti and Squires, 1997). Under high grazing pressures the vegetation of rangelands is often altered. Reducing the grazing pressure, or removing the grazing animals does not, however, result in the reverse in the vegetation status, as the equilibrium successional model would predict (Westoby, 1980).

The determination of the potential to sustain herbivore numbers in equilibrium systems is based on the plant species composition and their reaction to grazing, namely increasers, decreasers and invaders (Van Rooyen et al., 1996). Such an approach is based on the tendency of the vegetation to change in a specific series of successional stages in response to grazing pressure (Behnke and Scoones, 1993).

Systems in disequilibrium do not, however, react in the same way to different grazing pressures. In disequilibrium the vegetation is more dependent on rainfall. Thus reaction to management should also include the variable rainfall. The main driving force in such systems is climatic and these systems can be seen as event driven rather than as management driven. Determining stocking rates in these areas, based on a theoretical equilibrium system, is thus flawed (Behnke and Scoones, 1993).

The difference between systems in equilibrium and disequilibrium are not clear-cut. Some areas may have tendencies or characteristics of both systems depending on the prevailing environmental conditions. Systems that are normally in equilibrium can react like systems in disequilibrium during severe and prolonged drought. In disequilibrium systems, certain areas such as wetter bottomlands, where moisture infiltration and retention are higher, can have equilibrium characteristics (Scoones, 1995). Ellis et al. (1993) reported on work done in New South Wales, Australia, in an arid area receiving less than 250 mm annual rainfall, and concluded that the performance of such a system was better characterised in terms of its variability than by measures of mean values. Ellis et al. (1993) suggested that if the coefficient of variation (CV) for the long-term annual rainfall exceeded 30%, the area should be characterised in terms of variability and not in terms of mean values.

It is thus clear that the management of systems in disequilibrium, or non-equilibrium systems, should be based on the variability of the system and not on average conditions. Reclamation should also take these aspects into consideration. If these systems respond to climatic events, reclamation efforts should be timed to coincide with such events. Depending on the objectives of any person, group, or organisation it should be decided to restore, reclaim or rehabilitate an area. “The realisation that biodiversity has been lost in many arid lands because of grazing, agriculture and mining has promoted an interest in restoration which has conservation goals” (Allen, 1995).

To define restoration, rehabilitation and reclamation it is necessary to define or describe the objective of each. Restoration attempts to replicate the structure and functioning of the original system, or nearly so. Reclamation still requires a high level of functioning, but is structurally less complex. A reclaimed site may, through natural succession, approximate the original ecosystem, depending on species and treatments used. A rehabilitated ecosystem may differ from the original ecosystem in structure and / or functioning but places emphasis on productivity (Allen, 1995).

Allen (1995) proposed two approaches to the restoration of an ecosystem, namely active and passive restoration. Passive restoration implies the removal of the stresses that caused the degradation. These stresses can be grazing pressure, pollution etc. From the previously discussed section on systems in disequilibrium, or non-equilibrium, a passive approach does not seem to be a viable option in many arid regions. Active restoration would involve a number of management techniques such as the introduction of propagules, weeding, burning, alleviating compaction, improving soil moisture, nutrients or organic material, etc. An active approach should be more appropriate in non-equilibrium systems, if timed to coincide with variable climatic conditions. Such an approach would be consistent with the ideas proposed in the state and transition model, domain of attraction and Russian hill analogy, where active energy inputs are needed to cross certain thresholds (Laycock, 1991). These concepts will be discussed in more detail later.

If one assumes that the original vegetation, mentioned earlier, means the same as the natural vegetation, an interesting argument on what the natural vegetation is arises. Allen (1995) stated that even the best efforts to restore biodiversity have only been able to reintroduce a fraction of the natural plant species richness. In disequilibrium systems, however, the concept of natural vegetation becomes difficult to define. The reason being that the vegetation in any one area would not be stable over long periods of time even without man's influence. Because of this, in any one area there might be several different vegetation communities that could be the natural vegetation for any given site at any given time (Sprugel, 1991).

The protection of biodiversity should form an integral part of any management programme, despite the academic arguments on what could be regarded as natural vegetation. Areas of biodiversity should be identified and protected or managed for biodiversity. One such area is the succulent Karoo in South Africa. "The Succulent Karoo Hotspot is a truly extraordinary biodiversity treasure. With over 6000 plant species, 250 species of birds, 78 species of mammals, 132 species of reptiles and amphibians and an unknown number of insects, it is the world's most diverse arid environment. Most impressive, however, is that over 40% of these species are found nowhere else on earth!" (SKEP, 2003). Restoration is not a substitute for conservation and remaining areas with high biodiversity should be managed for sustainable utilisation and protected against degradation (Allen, 1995).

Land degradation and desertification have, however, affected arid and semi-arid areas worldwide. It is usually arid areas that are the most susceptible to degradation, based on ecological, social and economic parameters (Brown, 2003), and the correct methods of utilisation, management and reclamation should be sought.

According to Whisenant (1995) reclamation and restoration efforts in arid systems should attempt to minimise management intervention (and expense) by stimulating natural successional processes to develop stable structural and functional dynamics. Whisenant (1995) proposed the use of keystone species in reclamation efforts. These are species, which are believed to be essential to ecosystem structure and function. Their inclusion may facilitate the restoration of disturbed ecosystems. Whisenant (1995) consider woody legumes to be keystone species in disturbed arid and semi-arid ecosystems and these should be among the first species re-established during restoration efforts.

The use of key resources or “keystone areas” should also be considered when keystone species are being used in reclamation of arid environments. Key resources have been described by Scoones (1995) as areas that are characterised by more equilibrium environments (often water run-on sites with more available soil moisture and nutrients). The identification and use of such areas to create a fodder bank of drought adapted fodder shrubs could prove valuable in the reclamation of these environments and as a method to produce drought fodder (Scoones, 1995). The use of exotics, such as *Atriplex nummularia* (Old Man Saltbush), in these keystone areas could prove very effective in a holistic reclamation programme. The use of exotics can be justified if they have the ability to establish and produce more readily than indigenous species and they do not have the potential to invade the surrounding area. This may sound like a contradiction for a species to be able to establish readily without the potential to invade. If one considers relative palatability of species in the natural environment, the most palatable species usually get utilised first. So if the exotic is very palatable, grazing could be used as a preventative measure against encroachment. Palatability studies on *Atriplex* should, therefore, not only increase animal utilisation of the species, but should also be seen as a method to safeguard our natural environment against encroachment.

A. nummularia was introduced to South Africa about a 100 years ago and many regard this species as having the potential to help in the fight against desertification (Le Houerou, 1994).

These fodder banks should not only be seen as a reserve for drought years. Strategic withdrawal of animals from the natural veld when the natural vegetation flowers and produces seed, can for instance, be used as a strategy to increase the natural seedbank of an area. The animals can then be kept in the keystone resource areas. Milton and Hoffman (1994) stated that germination was a function of available seed and rainfall. Variability is part of systems in disequilibrium and it is, therefore, difficult to predict when environmental conditions will be suitable for germination. By making sure that a viable seedbank exists in the soil, variability in the environment can be exploited to increase germination of seed.

Palatable indigenous species, which germinate readily, establish easily, and produce sufficient dry material, should also be considered for planting as drought resistant fodder shrubs. Some of these species also have medicinal properties and may also be used in diversification of agricultural systems. Diversification has the potential of spreading risks and supporting food security in resource poor farming systems (Tengberg et al., 1998). These species can then be used as fodder for animals and/or as potential cash crops. Further research on potential indigenous species is still needed. This research should concentrate on germination rates, ease of establishment, palatability, and adaptation to different environments, production potential and medicinal value.

It is not only the reclamation of degraded areas in an arid environment that is of importance but also the prevention of degradation. Prevention will be directly correlated to how we manage these systems. Scoones (1995) proposed that "tracking" could be used effectively in the utilisation and management of a system in disequilibrium. "Tracking" entails certain strategies that can be used during droughts and after droughts. During a drought the following actions can be considered;

- Long-distance transport of animals to feed-surplus areas (trekking, truck transport etc.)
- Feed supplementation (lopping, haymaking, concentrate purchases, etc.)
- Cereal stores to prevent needless distress sales of livestock
- Animal health care (e.g. dosing with anti-helminthics), recognising that animals die more often of disease than starvation in drought
- Diversification or switching of species composition within the family herd
- Herd and family splitting
- Supplementing or diversifying income from other livelihood sources apart from animals.

After the drought the following actions can be taken;

- Investment/re-investment of surplus from other activities in livestock (especially small stock with high reproductive rates)
- Transfers of animals within social networks (whether with kinship basis, or with stock associates etc.) on which individuals have legitimate claims

It is felt that "tracking" might work in South Africa if it is tailor made to fit the specific economic and social environment of the country. The participation of local, provincial and national governments in South Africa would be essential for this principle to work. "Tracking" should not, however, be seen as the only solution, and using a system as proposed by Scoones (1995) would necessitate changes in some of the social systems in South Africa. This approach is, however, already being used by transhumant farmers, who have more than one farm. Trekking with herds of animals to the best grazing is also a way of life for many local communities (nomadic pastoralists) in the arid Richtersveldt area of South Africa as well as some commercial farmers in Bushmanland and Namaqualand.

An alternative rangeland management strategy is a non-selective grazing system, which is based on a multi-camp high utilisation grazing approach. Beukes et al. (2002) modelled this approach using not only the ecology as a basis but also economics. This is not a new approach to commercial farming in arid areas and was also proposed by Savory and Butterfield (1999). Beukes et al. (2002) found that such an approach is only economically justified in areas receiving more that 200 mm annual rainfall. The model was run for a 7000 ha farm and it was found that 60 – 80 camps provided the highest economic returns (250 mm annual rainfall).

Management in disequilibrium systems, however, remains a challenge. The major limiting factors for management seems to be social and economic and not necessarily ecological. If the area and access to other areas were large enough to allow for "tracking", it would probably be the best approach to management in arid environments. This is, however, often not the case, and the challenge now is to find a management system to reduce risk, improve quality of life in an ecologically, economically and socially sustainable way. Taking ideas and merging them to find new innovative management system incorporating new markets such as tourism, medicinal plants, etc., is the challenge, which must now be faced.

The foregoing discussion has concentrated on some of the major limitations when working in systems, which are not in equilibrium. A brief look on how our ecological knowledge and understanding of these systems have changed will follow, looking at how we currently determine the veld condition, succession, phenology and some new approaches to managing arid environments

Current approach to veld condition assessments

The current basis, for the determination of veld condition, is ecological in nature. Aspects of succession, phenology and plant species dynamics are incorporated into determining the veld condition and the grazing capacity of an area. This discussion aims to highlight the major concepts and approaches to current veld condition assessments. While this approach is not always supported the need to identify the faults and shortcomings especially in the way that equilibrium successional models are used, in systems that are not in equilibrium, needs to be emphasized.

Management does not have a homogenous impact over a whole area. Certain localities on a farm, or in an area, will react differently to management. The identification of these localities should form an integral part in the determination of the veld condition. These localities can be differentiated from each other by the determination of the plant species composition. The building blocks of vegetation are individual plants. Individuals of one species growing together are known as a species population. A group of different species populations growing together in a local area is known as a plant community (Kent and Coker, 1996). Similar plant communities will have the same plant species composition, structure, palatability, production potential, grazing capacity, browsing capacity and, therefore, the same management requirements (Van Rooyen and Theron, 1996). The identification of different plant communities is thus considered necessary for proper veld management practices (Brown and Bredenkamp, 1994). The same plant community can occur in different localities in an area. Different plant communities are usually the result of different environmental factors. The same or homogenous plant communities will occur in areas with the same environmental factors such as clay content of the soils, slope, aspect etc. Homogenous plant communities should react similarly to management, and an understanding of the environmental-plant interactions should enable a manager to predict and manipulate the reaction of such a plant community to management practices.

An ecological management plan (applied veld management) must also consider the seasonality of plants. Plant growth occurs in seasonal phases called phenophases. Different plants will have different phenophases and this will influence the availability of food for animals during certain times of the year. The identification of different plant species is thus important in determining the availability of food for the animals during certain times of the year (Bothma, 1996a, 1996b). Because a homogenous plant community will have a certain species composition the availability of food during the year can be determined for each homogenous plant community. This information can then be used to determine the browsing and grazing capacity (ecological capacity) for each homogenous unit.

The identification of homogenous plant communities also aids in implementing a monitoring program. This will enable the manager to see if the current management plan is adequate in reaching the management objectives. If the objectives are not reached the management plan must be changed and monitoring forms the basis for an active adaptive management plan (Stuart-Hill, 1989).

A prerequisite for the development of an effective veld management plan is a comprehensive assessment of the condition of the veld upon which realistic veld management practices can be formulated (Trollope, 1990a). Veld condition refers to the condition of the vegetation in relation to some functional characteristic, normally sustained forage production and resistance to soil erosion (Trollope, 1990b). Tainton (1981) as cited by Hurt and Bosch (1991), have also defined range condition, or veld condition, as the “state of health” of the vegetation.

Changes in environmental factors such as rainfall gives rise to changes in the vegetation. Succession is the ability of plant populations to change their habitat and to “evolve” into more productive and diverse plant communities. Pioneer species are the first plant species that will inhabit bare patches of soil. The establishment of pioneer plants will enrich the soil and create a microclimate, which will be more suitable for other plant species. These plant species in turn will be able to compete with the pioneers and will dominate the next plant community. This process of succession will continue until a climax plant population is reached. The climax plant population will be more or less stable and the kind of climax population that forms is dependent on the regional and local environmental factors. This above-mentioned form of succession is known as primary progressive succession (Tainton, 1981). This form of succession, however, does not normally apply to systems in disequilibrium.

Many plant communities reach an intermediate stage of succession because of external factors such as fire, grazing pressure or soil fertility. The African savannah is an example of a fire climax vegetation type. The regular burning of savannah areas prevents the succession of the area into woodland or forest. Grazing pressure can also prevent the vegetation from developing to the next stage of succession. Such vegetation types are known as biotic climax vegetation (Tainton, 1981).

Plant succession can be divided into four main stages (Van Rooyen et al., 1996) namely pioneer, transitional, sub-climax and climax stages. Each of these stages is characterized by a certain plant species composition. A plant species, which is most prevalent in the pioneer stage, can then be classified as a pioneer species. Similarly species, that are most prevalent or abundant in a different stage, can then be classified as being a transitional, sub-climax or climax species.

The species composition of an area can thus provide information on the successional status of that particular area. Progressive succession leads to veld improvement while retrogressive succession leads to veld deterioration. Retrogressive succession can be the result of mismanagement such as overgrazing. Veld condition assessment, at appropriate intervals, can provide information on the direction and rate at which succession is taking place (Tainton et al., 1980). Because of this tendency of the vegetation to react to management or external factors, it is assumed that removal or the increase of such a factor can drive the successional sequence and direction of the vegetation change.

The best grazing quality for a specific animal is not necessarily found in the climax stage of succession (Bothma, 1996a). Animals such as *Hippotragus equinus* (Roan) and *Hippotragus niger* (Sable antelope) require tall climax grassveld while animals such as *Connochaetes taurinus* (Blue wildebeest) and *Damaliscus dorcas phillipsi* (Blesbok) require a short intermediate grassveld. A good management plan should, therefore, ensure that the veld is in the right successional stage for a particular animal. The veld can be kept in an intermediate stage of succession through burning and the right grazing pressure.

Plant Phenology

Phenology is a scientific study, which exists on the borderline between floristic ecology and meteorology. The concept and understanding of phenology continues to undergo a metamorphosis with time as new applications and techniques are developed (Lieth, 1970).

Various definitions of phenology exist. Lieth (1970) described phenology as the art of observing life cycle phases, or activities, of plants and animals in their temporal occurrence throughout the year. "Phenology is the study of the timing of recurring biological events, the causes of their timing with regard to biotic forces, and the interrelation among phases of the same or different species", is one proposed definition of phenology (Lieth, 1974).

One would usually associate the changes in plants with different seasons. It is common to think that plants blossom in spring and lose their leaves in winter. Seasonality, however, often becomes blurred in areas where no definite seasons exist, such as in the tropics. For this reason the term seasonality must also be defined.

Lieth (1974) defined seasonality as follows: "Seasonality is the occurrence of certain obvious biotic and abiotic events, or groups of events, within a definite limited period or periods of the astronomic (solar, calendar) year."

Van Rooyen et al. (1986) suggested that phenological data could be used to identify indicator species, which could be used to indicate the start and the length of seasons. In a study of the Roodeplaat Dam Nature reserve, for example, the emergence of flowering buds in *Acacia robusta* and *Dombeya rotundifolia* indicated the beginning of spring (Van Rooyen et al., 1986).

The different stages of development in an organism are called the phenophases. Germination, vegetative growth, flowering, fruiting and seed dispersal are a few of the phenophases that occur in plants. The way in which the entire sequence of phenophases occurs throughout the year is called the "phenodynamic" (Lieth, 1970).

Most classical phenological studies or observations were basically qualitative. More recently a quantitative approach has been emphasised. This latter approach is called phenometry, the quantitative changes within one phenophase (e.g., size or weight). In phenometric studies, total dry matter is often divided into various categories (e.g., leaves, stems, roots, flowers and fruits), which often coincide with plant parts by which we distinguish phenophases (Lieth, 1970).

Phenometry can also be defined as the quantitative analysis of the life cycle of an organism, or certain specific phenophases and their correlation with environmental influences (Lieth, 1970). Phenometry searches for environmental relationships, using plant growth as a microclimatic indicator.

In most ecosystems, the analysis of the productivity of that system is compounded by the inherent variability in growth rates of different species. Each species exhibits potentially different growth habits, and responses to changing environmental conditions (Lieth, 1970).

A holistic approach to veld management is not only concerned with when certain plant species produce available material, which can be used as food for animals, but also on the amount and quality of available material that is produced. In simplified terms we want to know when and how much food is being produced for our animals. This will allow us to adapt animal numbers to the times when the least amount of food is available. A phenological spectrum for each plant community on a farm can give valuable information in determining when plant matter is available for animals. Coupled with this, if the amount of available material was known, it could prove of more value in determining the number of animals, which could be kept on a certain farm.

The different species in a community each have their own phenology. When one examines the phenodynamics of each species, and the different phenophases of each species over a year, and presents this in a table, a phenological spectrum is obtained (Lieth, 1970).

The availability of forage is considered to be the most important factor influencing habitat selection by large herbivores. The total and seasonal availability of edible material varies between different vegetation types, and can be considered to be important in the distribution of large herbivores (Dekker and Smit, 1996).

A study on giraffes in the Serengeti found that the movement of these animals was regulated by seasonal changes in the biomass and distribution of their food resources. The animals responded in local, small-scale movements and not to large-scale migrations. The giraffes in the Serengeti are adapted to these conditions and the presence of young animals throughout the year suggest that the female giraffe in this area have developed a feeding strategy, which enables them to get enough energy from their food throughout the year to be able to meet their energy requirements even during the driest months (Pellew, 1983).

The chemical composition of leaves of trees also differs during the seasons (Sauer et al., 1982). For certain species such as *Combretum apiculatum* the percentage of the leaves that was utilised by giraffe was significantly correlated with changes in the chemical composition of the leaves. The amount of a preferred species that is utilised depends on its availability, chemical composition and the availability of alternative food source species (Sauer et al., 1982).

Classical succession

Tansley (1920), cited by Mueller-Dombois and Ellenberg (1974), defined succession as follows: “The gradual changes which occur in vegetation of a given area of the earth’s surface on which one population succeeds the other”. Barbour et al. (1987) gives another definition of plant succession as a directional, cumulative change in the species that occupy a given area, over time. Succession describes the process by which the vegetation changes over time, a process, which occurs with or without human interference (Tainton and Hardy, 1999).

Plant communities follow each other in a certain pattern. Each community can be seen as a stage in succession. These plant communities are known as successional or seral communities. Seral communities will replace each other until a climax community is reached. The entire progression of the different seral communities from the first to the climax community is called a succession or a sere (Barbour et al., 1987). Succession is driven from simple ecosystems towards more complex ecosystems with more trophic levels and greater diversity of species and life forms. The modern view of vegetation change emphasises the importance of repeated, relatively frequent disturbances and accepts continuous change in vegetation as the norm (Glenn-Lewin et al., 1992).

The first community to establish in an area is known as the pioneer plant community. The species in the pioneer community are usually adapted to severe conditions. This gives them the opportunity to establish themselves (Tainton and Hardy, 1999). If no significant change in species composition occurs in a plant community over a certain time span (1-500 years) the community is said to be a mature or climax community (Barbour et al., 1987).

A climax community is not, however, static and changes do occur. Random small changes in plant numbers, or even in the flora, result in fluctuations about some long-term mean. This is a state of dynamic equilibrium (Barbour et al., 1987). A comparison between plant types found in pioneer and climax communities is given in Table 1.

In a climax community the species composition should remain the same over a long period of time. Because of evolution a constantly perpetuating, stable species composition is strictly speaking not possible (Mueller-Dombois and Ellenberg, 1974).

Table 1 Comparison between pioneer and climax plant types (Tainton and Hardy, 1999)

Pioneers	Climax
• High reproductive output	• More energy invested in growth than in reproduction
• Many small seeds, adapted to wide dispersal	• Fewer, large seeds
• Seeds with high longevity	• Seeds shorter lived
• Dormancy mechanisms allow for germination at favourable times	• Dormancy not well developed
• Generally annuals	• Predominantly perennials
• Small stature	• Variable size
• Fast growing	• Slower growing
• Short lived	• Long lived
• Plastic physiology	• Highly specialised

Primary plant succession is initiated on bare areas such as rock surfaces, or in a newly formed pond of water, where no vegetation has grown before (Tainton and Hardy, 1999). If the pioneer community becomes established on a wet substrate, such as a gradually filling bog or swamp, then the invasion is a hydrarch (wet) primary succession. If the pioneer community becomes established on a dry substrate, such as exposed granite, then the invasion is a xerarch (dry) primary succession. In either case the progression of succession is usually toward the most mesic (moderate) site and the most mesophytic community possible, given the limitations of regional climate, topography, and soil parent material (Barbour et al., 1987).

Secondary succession occurs wherever a plant community has been disturbed and is no longer in equilibrium with its environment, but where, at least, some residual effect of previous occupation of plants remain (Tainton and Hardy, 1999). The disturbance can be natural, or induced by man. Secondary succession often proceeds five to ten times faster than primary succession. This is because the conditions on the surface on which the plants have to establish are not as severe as is the case in primary succession. Usually a lot of the soil remains and many plant propagules can also be found in the soil (Barbour et al., 1987).

Change in the habitat that is brought on by the plants themselves is called the biotic reaction (Tainton and Hardy, 1999). This reaction is one of the driving forces behind succession (Barbour et al., 1987). If the change in the environment is caused by a biotic reaction, and succession follows because of this, it is known as autogenic (biotic) succession (Barbour et al., 1987). Allogenic succession, however, is due to major environmental changes beyond the control of the indigenous organisms. Some likely causes of permanent changes of this sort are shifts in climatic conditions, or the introduction of grazing animals and diseases to which the original plants are not accustomed to (Burrows, 1990). Progressive succession leads to communities with greater and greater complexity. The habitat also tends to become more mesic (moderate) (Barbour et al., 1987). Retrogression is a reversing of developmental trends, towards earlier more simple stages (Glenn-Lewin et al., 1992). The communities, which form during retrogressive succession, will also have fewer species and the habitat will tend to be more hydric (wet) or xeric (dry) (Barbour et al., 1987).

The succession discussed thus far is characterised by an accumulation of changes that lead to community-wide changes. This is known as directional succession. Cyclic succession deals with changes on a very local scale. These changes occur because of the life span of the plants and their disappearance and re-appearance in the vegetation (Barbour et al., 1987).

There are different methods to study succession or vegetation change. These methods can be divided in two categories namely a) studies on the same area and b) side by side comparisons (Mueller-Dombois and Ellenberg, 1974). When conducting studies on the same area the following techniques can be used: a) permanent plots, b) studies of enclosures, c) aerial photos taken at different times d) historical and file records and e) evidence of changes found in the present community. Most studies have been done using the side-by-side method. The reason for this being that few investigators have the opportunity to follow the changes occurring on the same habitat for any length of time (Mueller-Dombois and Ellenberg, 1974). This method is based on observations of nearby plots of different successional ages. All the other environmental variables on these plots must be the same (slope, aspect, parent material and macroclimate). The time, which the different plots were exposed to succession, must be known. The plots in different successional stage can then be compared with each other (Barbour et al., 1987).

Certain people have had a great impact on the way succession is interpreted today. Glenn-Lewin et al. (1992) described that Clements viewed succession as a highly orderly and predictable process in which vegetation change represented the life history of a plant community that assumed organism-like attributes. The start of the succession was determined by the environment and proceeds towards a climax community, the characteristics of which were controlled solely by the regional climate. According to Clements the climax was a condition of great stability in which the vegetation had reached equilibrium with the present climate (Glenn-Lewin et al., 1992). For this reason his ideas were known as the mono-climax theory (Kent and Coker, 1996). Clements developed a scheme of processes, which drive succession.

- Nudation, which is the creation of a bare area or partially bare area by the disturbance which initiates succession
- Migration, arrival of organism at the open site
- Ecesis, the establishment of organism at the site
- Competition, the interaction of the organisms at the site
- Reaction, the modification of the site by the organism thereby changing the relative abilities of species to establish and survive
- Stabilisation, the development of a stable climax

Glenn-Lewin et al. (1992) described how Gleason challenged Clements' assertion that plant communities were highly integrated organic entities and stressed the unique, individualistic behaviour of plant species and the role of change events. Gleason viewed plant communities as the fortuitous overlap of distributions of species with similar environmental tolerances (Glenn-Lewin et al., 1992).

Glenn-Lewin et al. (1992) further described how Tansley criticised Clements' assumptions on the mono-climax theory. Tansley disagreed that all the vegetation in a particular region would converge towards the same type of climax. Tansley argued, that local factors, such as rock type and topographic position result in climax vegetation types that differ from that associated with the regional climate (Glenn-Lewin et al., 1992). Tansley proposed the poly-climax theory, whereby within a given region communities could be in relatively stable equilibrium with any one, or combination of, factors. These factors could be edaphic (soil), geomorphic (topographic) and biotic (human and animals) (Kent and Coker, 1996). Glenn-Lewin et al. (1992) describes how Whittaker merged the views of Gleason and Tansley to describe climax vegetation as varying continuously across a continuously varying landscape.

One of the major problems in developing any universal model of succession is the lack of consistent generalisations, which enable any compact overview. The result has been a great divergence of views, which range between the integrated views of such ecologists as Clements and Tansley on the one hand, and the more individualistic views of such ecologists as Gleason on the other (Tainton and Hardy, 1999).

New Successional models

Modern forest and range production depends on the ability to predict consequences of management activities. Modelling expresses processes, in this case processes of vegetation change. Ecological modelling continues to increase in importance, due largely to the exponential increase in the power of computers, their usefulness for ecological systems, and the need for ecological forecasting and management (Glenn-Lewin et al., 1992).

A model is any representation, or abstraction, of a system, or process. Models are built to:

- Define problems;
- Organise thoughts;
- Understand data;
- Communicate and test that understanding, and
- Make predictions (Starfield and Bleloch, 1986).

The basic idea of succession has been discussed and a few alternative succession models must also be mentioned.

In Tainton and Hardy (1999) three alternative models of succession are mentioned. Clements' view, that succession is well ordered, was followed by that of Conell and Slayter (1977), as cited by Tainton and Hardy (1999), who proposed models, which describe how early colonist (pioneer) species could react. The early colonist species could either:

- Facilitate later higher successional species (through biotic reaction): the facilitation model;
- Have no effect on them: the tolerance model; or
- Inhibit them, through the production of alleopathic substances: the inhibition model.

The “facilitation model” is essentially a model, which follows Clements’ succession model and Tansley’s autogenic succession model. This model implies that biotic reactions play a role in facilitating the invasion of higher successional species at the expense of the species already occupying a site (Tainton and Hardy, 1999).

Savannahs have been considered to be stable ecosystems, the dynamics of which consist of fluctuations around one or more steady states or points of equilibrium, to which they return after disturbances. Equilibrium condition is highly scale-dependant. On a small scale, in space or time, all ecosystems are unstable and transient, and small-scale short-term disequilibrium may promote large-scale long term dynamic equilibrium or persistence. Whether savannahs can be said to be stable, or in equilibrium or disequilibrium, depends on the scale of observation, but also on the kind and degree of disturbance (Skarpe, 1992).

Savannahs are believed to owe their existence more to the impact of fire and large herbivores than to climate. Savannahs are highly dynamic on all temporal and spatial scales, and vary with changes in e.g. climate, primary rainfall, soil nutrient content, fire regime and herbivory (Skarpe, 1992).

A cause of vegetation change is the change in an environmental factor beyond the influence of the observed system. A distinction between dependent and independent environmental factors can be made. This distinction is scale dependent. For a particular tuft of grass, a particular grass fire, may be a disturbance, on which the grass, and its associated insect and micro-organism fauna, has no influence. On a larger scale, the fire is part of the savannah system, influenced by the amount of grass produced and left un-grazed and influencing vegetation, fauna, soil nutrients and physiognomy (Skarpe, 1992).

On all scales ecosystem dynamics depend on the relationships between constraints/disturbances and the interactive mechanism. What is an external constraint on one scale may be an interactive component of the ecosystem on a larger scale (Skarpe, 1992).

Frank Egler (1954), cited by Barbour et al. (1987), concluded that the progression of seral communities was neither fixed nor predictable. Egler concluded that the path of succession (at least in the early stages) is driven by chance and the differential longevity of plants. Chance determines which propagules are in the soil or will reach the site at the time succession begins. Egler referred to this collection of starting propagules as the initial floristic composition of the site. The final species composition of the site is based on the initial floristic composition and the longevity of the different species (Barbour et al., 1987).

The state and transition model, cup and ball analogy and basin or basin of attraction will be discussed in the next section.

Range succession: New approaches, theories and models on vegetation changes in semi- arid rangeland

The classical model of range succession regards vegetation, at any stocking rate, as being in a stable equilibrium, held in place by the balance of two steadily-applied opposing forces, grazing pressure and the tendency of the vegetation to change towards the climax (Westoby, 1980). This is known as the range succession model (Westoby et al., 1989). Excessive grazing is perceived to lead to retrogression or decline in range condition and it is assumed that the reduction in, or removal of, grazing pressure allows successional processes to restore the range to what it was, essentially by reversing the path taken by retrogression (Friedel, 1991). The grazing pressure can, therefore, be made equal and in the opposite direction to the successional tendency, producing an equilibrium in the vegetation at a certain stocking rate (Westoby et al., 1989)

The range condition model assumes that:

- A given vegetation type, or range site, has only one stable state (climax);
- Retrogressive changes caused by improper grazing result in unstable states which can be reversed by manipulation, reduction or elimination of grazing, and
- the pathway of vegetation change as rangeland improves (secondary succession) is identical to, but the reverse of, that followed in retrogression (Laycock, 1991).

In this model all the possible states of vegetation can be arrayed on a single, near linear, continuum from heavily grazed or early successional communities in poor condition to ungrazed, climax communities in excellent condition, and all changes (degradation or improvement) occur continuously and are reversible along this continuum (Laycock, 1991).

However, the forces of intrinsic change and of grazing pressure in arid areas do not operate steadily, and not necessarily in opposing directions. Changing the grazing pressure often cannot reverse change in one direction. A given grazing pressure may have no significant impact on the vegetation much of the time, but in conjunction with a particular weather event, may quickly produce radical changes. Range managers have handled these problems by continuing to set equilibrium stocking rates, but making them conservative. This approach to stocking is ill adapted to arid vegetation. Changes in the vegetation are often responses to exceptional events, rather than to average conditions (Westoby, 1980).

The concept of threshold of environmental change appears to provide a reasonable alternative, in some circumstances, to the concept of gradual retrogressive and secondary succession, which is currently accepted (range succession model) (Friedel, 1991). This model is of range in a series of short-lived states under different combinations of seasons, grazing, fire and local variables. Most of these states do not preclude a shift to other short-lived states. However, certain combinations may push the system into a new state that is not easily reversed, e.g. an eroded surface can develop following heavy grazing coupled with torrential rain, in which case the system has crossed a threshold (Friedel, 1991).

A threshold has these characteristics:

- It is the boundary in space and time between two states, e.g. grassland and shrub-invaded grassland;
- The initial shift across the boundary is not reversible on a practical time scale without substantial intervention by the range manager, e.g. with herbicides, heavy machinery, or fire.

This concept is compatible with the state and transition model of Westoby (1989) as cited by Friedel (1991).

Archer (1989) explained the concept of a threshold as a function of grazing pressure. Archer's (1989) conceptual model illustrates how grazing might cause a shift from grassland or savannah to shrub land or woodland at a particular site. Grasses are able to survive some degree of grazing pressure before retrogressing to new assemblages of herbaceous species. As grazing pressure increases, however, community structure is altered and the composition of herbaceous species shifts. Within the grassland domain, grazers alter the composition and the productivity of herbaceous species, while decreasing fire frequency and intensity, thereby increasing the probability of woody-plant establishment. If grazing pressure is reduced before some critical threshold, succession towards higher-condition grassland will occur. However, if sufficient numbers of woody-plants become established, shrub-driven successional processes begin to predominate and the site moves towards a new steady-state configuration. Once in the shrub-land or woodland domain, the site will not return to grassland after grazing has ceased, especially if the displaced grasses had originally established under a different climatic regime. Anthropogenic manipulation can alter grass-shrub mixtures, but subsequent succession may result in a rapid return to a community dominated by woody plants (Archer, 1989).

A steady state/threshold concept can provide the framework for a new approach in understanding how rangeland communities behave. We need to:

- Determine which vegetation types have relatively stable successional states;
- Develop criteria and methods to identify these states;
- Identify the thresholds which prevents the system from moving out of these states;
- Identify the fluctuations in composition which may occur in these stable states caused by weather or other factors;
- Develop a better understanding of what forces or perturbations, either natural or man-caused, cause a system to cross a threshold and move towards another state; and
- Adopt or develop conceptual models to organise and put this information into perspective (Laycock, 1991).

One potentially useful concept depicts a community as a ball or marble in a cup or trough. This “cup and ball” analogy is helpful in describing the concept of stability and the force necessary to disturb that stability (Laycock, 1991). Gordon and Forman (1983) and Forman and Gordon (1986), cited by Laycock (1991), described a “Russian hills” model using troughs and a marble to describe stability of a physical system. The depth of the trough represents the range of environmental conditions under which that community is stable. Only intense energy input or environmental change (Fig. 1.) can force a marble from one trough to another. Fig 1 (a) represents a community that is both locally and globally stable because after all disturbances or perturbations, it will return to the original configuration. This model adequately represents the successional range condition concept (Laycock, 1991). Fig. 1 (b) represents a community, which has multiple stable points, only three of which are shown. It is locally stable at configuration I. If this configuration represents "excellent" rangeland condition, minor disturbances such as grazing may change the composition of the community, but once these disturbances are lessened or stopped, the community returns to its original state. However if the community is perturbed beyond a certain critical range, it will cross threshold A and move to a new locally stable state. The depth of the trough represents the strength or energy of disturbance required to force the community across a threshold and into another trough (stable state) (Laycock, 1991).

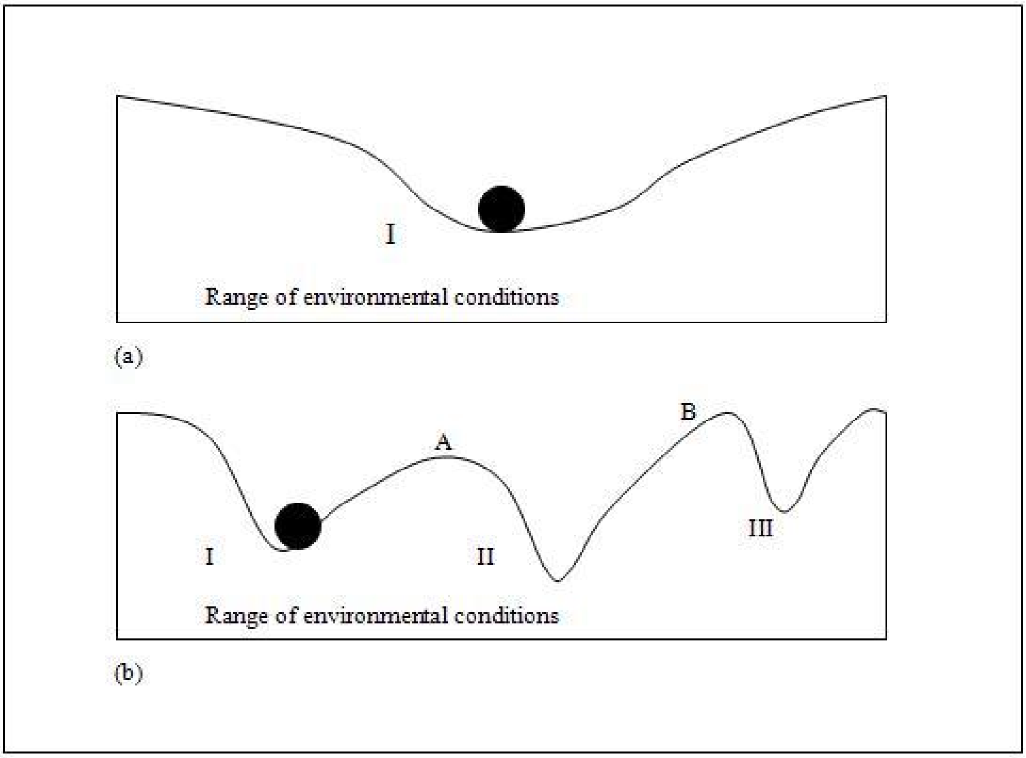

Figure. 1 *Diagram illustrating the ball and cup, or trough, analogy to illustrate global and local stability concepts. The community is represented as a black ball on a topographic surface (cup or trough), which represents the range of environmental conditions under which the community is stable. In (a) the community is both locally and globally stable because, after all the disturbances, it will return to configuration I. In (b) the community is locally stable, but if disturbed beyond a certain critical range, it will cross threshold A and move to a new locally stable configuration II (Laycock, 1991).*

The state and transitional model was used in the Karoo (Milton and Hoffman, 1994) to describe the vegetation changes that occur in that region. Two conceptual models based on the state and transitional model of vegetation change were proposed for the southern Karoo shrubveld and the eastern Karoo shrublands. These models were a lot more applicable in this arid environment than the previously used range succession models. State and transition models are more flexible and incorporate cyclic and succession processes as well as stochastic responses of vegetation to climate or biotic disturbances. Since these models predict which vegetation states can be manipulated by livestock withdrawal and which, could be altered only by active management, the models may be used to guide management decisions relating to conservation of biological diversity, or livestock management in the Karoo (Milton and Hoffman, 1994).

Conclusion

The classical model of range succession clearly does not apply to the arid and semi-arid regions of South Africa. The state and transition model is a succession model that is a lot more applicable to arid and semi-arid regions. If a certain management programme is applied with the addition of certain environmental factors, a certain threshold can be crossed and the community will move from one state to another (degradation, or improvement). The plant community will, however, not be able to cross that threshold by itself. To move a plant community back to a certain stable state, certain energy inputs are needed to cross the threshold. These energy inputs are usually in terms of management but must also take episodic environmental conditions into account, especially rainfall.

As knowledge of the natural ecosystems increases, relevant technologies to reclaim degraded areas can be used in a more efficient way. A wealth of knowledge exists on the reclamation of degraded areas in arid and semi-arid regions.

Many reclamation techniques are very costly and are unlikely to be offset by short-term benefits. The partial clearing of vegetation to alter water and nutrient availability, or reseeding to establish indigenous species, could possibly increase carrying capacity or the nature conservation value of such shrublands. The further use of micro-catchments to establish selected key species can also be used to initiate autogenic restoration in degraded areas. These key species and micro-catchments can be used to concentrate nutrients, organic matter and water to form “fertile islands" in a degraded area. The benefits of water harvesting techniques have usually been short term and unsustainable in arid areas when the sole objective was the production of herbaceous crops and fodder. When the aim is restoration and woody shrubs (keystone species) are used to change the micro-environmental conditions by harvesting wind blown soil and seeds, it might have the possibility of being a sustainable option. Keystone species are species believed essential to ecosystem structure and function, and their inclusion in a restoration programme may facilitate restoration of degraded ecosystems.

Improved grazing management, such as decreasing stocking rates, must form part of any long-term management plan. It is highly unlikely that decreasing stocking rates alone will have the desired effect on severely degraded areas. Several limiting factors such as resources (water, nutrients, soil organic matter and propagules), harsh micro-environment and the impact of animals, have an influence on the successful establishment of plants in arid environments. The most limiting of these is water. Strategies to increase water infiltration, such as water harvesting, can have a strong influence on plant establishment. Only a holistic approach to land reclamation in arid areas will prove to be successful in the long term. Certain strategies should be followed as part of a holistic restoration programme in degraded areas to increase natural resources. These strategies should include:

- Reduction or elimination of the cause of degradation;
- Addressing soil degradation and initiate soil improving processes;
- Establishment of vegetation that addresses micro-site availability, soil improvement and nutrient cycling problems; and
- the arrangement of landscape components to reduce detrimental landscape interactions.

The realisation that desertification and land degradation is a problem that affects every-one of us, directly or indirectly, has prompted an action programme. Because of the extent of damage in certain areas, restoration to simulate the natural ecosystems before degradation has limitations without any intervention in terms of management. The impact of degradation is extremely severe on the soils, water and vegetation of the arid zones. One of the main causes of degradation is social in nature and this also needs immediate attention.

A better understanding of ecological processes is needed to make a real difference on a global scale. New and innovative use of technologies is needed in the war against degradation. The effects of global climate change on degradation and desertification are not known as yet and need further research. A holistic multi-disciplinary approach is needed if the problem of degradation is to be solved. No "quick fix" will be able to solve the problem and the fight against land degradation must be an ongoing process.

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Chapter 3

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Can ecological criteria be used as a tool to choose species for reclamation in arid rangelands? The use of germination percentages of *Tripteris sinuatum* and *Sutherlandia microphylla* as an example.

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Abstract

An ecological criterion was used to identify potential plant species for reclamation of degraded arid rangelands of southern Africa. *Tripteris sinuatum* and *Sutherlandia microphylla* were identified as possible species. Germination studies, with seeds harvested from naturally occurring plants, were conducted for both species. Treatments were based on the natural seed dispersal mechanisms of both species. Scarification, leaching and a control with two different light exposures were tested with *S. microphylla* and seed wing removal for *T. sinuatum*. Significant differences were found between the leaching and the control and between scarification and the control treatments for *S. microphylla*. No significant differences were found for any of the treatments for *T. sinuatum. S. microphylla* has the potential to become an important plant species for reclamation purposes in arid zones of southern Africa.

Keywords: Germination, Reclamation, *Sutherlandia microphylla*, *Tripteris sinuatum*,

1. Introduction

If there is a need for restoration, or reclamation, it is self evident that a degree of degradation or disturbance has occurred. This would mean a shift in productivity of a system, usually from a high to a lower productivity. In arid environments, or systems in disequilibrium, the change back to a higher level of productivity once a threshold has been crossed cannot occur through the natural process of succession without an

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additional energy input if the state and transition successional model is accepted to be true for these areas (Behnke and Scoones, 1993). The disturbance, that degraded or changed, the area from one productivity status to another can be anything from overgrazing to opencast mining or even local climate change because of global climate changes.

Reclamation, restoration or rehabilitation has defined objectives with the future land use in mind (Allen, 1995). This land use should be realistic and within the constraints of the local climate and environment. To use an over simplified example it would not be reasonable to expect an eight ton maize yield on shallow soils, in an area with a low or unreliable annual rainfall. The economic constraints should also be considered when the future land use is decided on. Again, to use a simplified example, to produce sugar in an area where there are no sugar mills would not be economically viable due to the cost involved in transporting the product to the closest mill.

The purpose of this explanation is to emphasize that all the natural, social and economic resources should be considered when defining objectives for land use. The same approach (in reverse) should be followed in the choice of plant species for use in reclamation of arid environments. Which plant species occurs naturally in an area, and what are the objectives (land use possibilities) for this area? Arid lands have been used in a sustainable manner through natural systems of grazing by wild ungulates for millennia (Shearing and Van Heerden, 1994). Man, however, no longer lives in an unrestricted system, with no fences or economic constraints, to eke out a living in “peace and harmony with nature”. Natural processes, which have been in operation for millennia may, however, be simulated to achieve desired land use objectives.

The question arises, how did certain desirable plant species survive in the past, under what is now referred to as natural systems? Apart from a “natural” grazing system, each species developed specific survival mechanisms. This was especially true in arid environments. Some species had thorns and spikes as protection, which in turn provided protection for young seedlings establishing under their protective canopies. Others were extremely unpalatable, or poisonous, or excreted allelopathic chemicals to kill off the competition for scarce resources, such as water. Yet others were prolific seeders, producing thousands of seeds, which were either wind blown or dispersed by water. Some seeds contain chemical germination inhibitors, or salts that have to be leached, and only germinate when conditions are favourable in terms of soil moisture. Other plants have impermeable seed coats and only germinate over a period of several seasons, to spread the risk of germination under unfavourable conditions. Rhizomes and tubers, which ensure survival of plants under extreme conditions, are other forms of drought tolerant adaptations. Thus, it can be seen that plants have numerous survival adaptations in arid areas (Le Roux and Schelpe, 1997; Le Roux et al., 1994; Manning and Goldblatt, 2000; Shearing and Van Heerden, 1997; Van Rooyen, 2001).

Which of these characteristics will be beneficial in an ecological approach to reclaim degraded arid rangelands? What is needed in plant species to be used for reclamation in arid environments? What properties would the desired plant need to germinate, establish, survive and proliferate under such unfavourable conditions?

2. Ecological criteria for plant species used in reclamation of arid environments.

Arid systems or systems that are not in equilibrium (disequilibrium), are climatic event driven and not necessarily management driven (Behnke and Scoones, 1993). This does not mean that good management is not required in areas that are in disequilibrium. The opposite is true for most of these arid areas. Well-managed areas in these arid eco-systems will, however, only react to management when favourable climatic conditions prevail.

Different plants have different strategies to survive under harsh conditions. Most often they use underground storage organs or they survive in the form of a dormant seed banks. The seeds will germinate, or plants will shoot only under favourable conditions. The conditions required for seed germination will be different for most species, under arid conditions, but a general assumption for germination would be that enough moisture is available for germination and establishment. Different seed dispersal strategies also influence breaking the dormancy of seeds. Certain seeds have to be ingested, move through the digestion tract of an animal, before germination will take place. Some plant species are so specialized that their seed has to travel through the digestion tract of a specific class of animal, such as a ruminant or a bird species. A classical example of such a plant species is the mistletoe of which four different species, in two families, occur in the arid areas of South Africa. Interestingly enough, these plants are not only adapted with respect to their dispersal but are also host plant specific (environmental growing conditions).

Viscum continuum only occurs on *Acacia* species while *Viscum rotundifolium* occurs on *Gymnosporia*, *Carissa* and *Lycium* species (Shearing and Van Heerden, 1997). These are extreme examples of parasitic plants, but the same principles can be used in non-parasitic plants to determine what is needed to break the seed dormancy, such as acid treatments and scarification. Examining the plant species, in question, and how their seeds are dispersed, when they germinate (under what conditions) and where they grow (medium) are questions that need to be asked before the commencement of germination trials. Hopefully this will reduce the amount of random guesswork and make for more successful germination.

The arid areas of South Africa are characterised by a wealth of plant species, many of which are endemic and occur nowhere else in the world. For example the succulent Karoo hotspot has over 6000 plant species, 250 species of birds, 78 species of mammals, 132 species of reptiles and amphibians and an unknown number of insect species (SKEP 2003). With such a wealth of species the choice of plant species should be relatively easy. Criteria for the choice of indigenous plant species to be used in reclamation should be identified. The following possible criteria may be used. It should be noted that many other factors can be included and that this is only used to identify possible species.

- Distribution of species, which will give an indication of the broad climatic adaptation of species.
- Palatability and nutritive value of the plant species. Many of the plant species in the arid areas of South Africa have not been characterized in terms of palatability, or nutritive value, for domestic stock (future studies should concentrate on this). The use of indigenous knowledge in this regard is of the utmost importance. Many farmers know which species livestock prefer. These species are usually abundant in road reserves where no grazing takes place. Exotic species, that are highly palatable, could also be considered, as such plant species will probably be grazed to such an extent that encroachment would not be a problem.
- Availability of seed. Some plant species have been identified as potential fodder shrubs and seeds are commercially available in limited quantities. It is advisable to harvest seeds in road reserves as these plants will be adapted, not only to broad climatic conditions but also, to local environmental and climatic conditions.
- The quantity of viable seed produced by the plants. This has not been determined for many of the plant species in question. A holistic approach to rehabilitation in disequilibrium systems is needed and plants that will increase their seeds in the

natural seed bank should be given preference. A plantation could then be used, not only as fodder but also, to harvest seeds and as a nucleus from which seeds could disperse through natural mechanisms. Because systems in disequilibrium are event driven, and not necessarily management driven, the possibility of favourable climatic conditions for seed germination and establishment cannot be pre-determined.

- Added value of the plant species. Some of the species occurring in arid areas also have medicinal value. With the current trend in searching for treatments for HIV, cancer and other diseases the possibility for producing not only livestock but also medicinal cash crops is increasing. Diversification of production systems in arid areas is not always possible because of the low and infrequent rainfall in these areas. If the possibility exists to diversify production systems it should be utilised and investigated to the full.

Several species were subjected to the above-mentioned criteria. Two species were chosen according to these criteria for germination studies. These species are, *Sutherlandia microphylla* and *Tripteris sinuatum,* formerly know as *Osteospermum sinuatum*. A summary of how the two species measure up against the given criteria is presented in Table 1.

Table 1 Assessment of *Sutherlandia microphylla* and *Tripteris sinuatum* based on given criteria.

	Species	
Criteria	*Sutherlandia microphylla*	*Tripteris sinuatum*
Distribution	Broadly distributed (Well adapted)	Broadly distributed (Well adapted)
Palatability & nutritive value	Palatable & nutritious (grazed extensively in natural veld)	Palatable & nutritious (Grazed extensively in natural veld)
Seed availability	Not commercially available	Commercially available
Quantity of seed produced	High	High
Added value	Medicinal properties (high potential)	No known medicinal or commercial value

3. Plant species description

3.1 Sutherlandia microphylla

S. microphylla is wide spread in southern Africa (Le Roux and Schelpe, 1997; Le Roux et al., 1994; Manning and Goldblatt, 2000; Shearing and Van Heerden, 1997; Van Rooyen, 2001;). The genus is restricted to southern Africa and occurs in South Africa, Botswana and Namibia (Van Wyk et al., 2000). It is an attractive shrub growing up to 1.3 m in height with branches, which are shallowly fluted, with minute stiff hairs. The leaves are divided into 17-21 narrow oblong leaflets, which are 5 – 19mm long and hairy below. It has red flowers up to 3.7 cm long and clustered in groups of 2 – 8. The mature fruits are inflated and are 2.5 – 4 times as long as they are broad (Le Roux and Schelpe, 1997). The pods are wind dispersed and contain about 20 lens shaped, blackish seeds per pod and flowering occurs from late winter to spring (Van Rooyen, 2001). It grows practically everywhere but prefers disturbed and gravely soils. *S. microphylla* is highly palatable, despite a strong taste, and has a high nutritional value and good production (Le Roux et al., 1994). When the plants are grazed in large quantities it does tend to give the milk of grazing animals a bitter taste (Shearing and Van Heerden, 1997). *S. microphylla* is not long lived (Le Roux et al., 1994). This indicates that this species is more of a “pioneer” or ephemeral species than a “climax” or perennial species, according to the criteria suggested by Tainton and Hardy (1999).

S. microphylla is commonly known as “cancer bush” and has traditionally been used to cure and treat various ailments such as colds, influenza, chicken pox, diabetes, varicose veins, piles, inflammation, liver problems, backache and rheumatism. The seeds contain canavine and it is possible that this, or some other amino acid is responsible for the reported benefits in treating cancer. The presence of pinitol explains the traditional anti-diabetic use of the plant (Van Wyk et al., 2000). *Sutherlandia* is a palatable legume and has the potential to be used extensively in such a role. This species is a prolific seed producer, and has the potential to be used as a cash crop for the pharmaceutical industry. The anti-cancer, anti-oxidant and anti-tumour promoting properties of *Sutherlandia frutescens* have been validated (Chinkwo, 2005; Fernandes, et al., 2004; Kundu et al., 2005). Further work is needed in this field including investigating potential markets for this species.

S. microphylla meets most of the criteria for use in the reclamation of degraded rangelands and has the potential not only to provide fodder for animals but also to diversify production systems and rehabilitate degraded areas.

3.2 Tripteris sinuatum

T. sinuatum, is a palatable perennial shrub of great interest to stock farmers (Esler and Phillips, 1994). This plant species is widespread in southern Africa and occurs almost everywhere in arid areas in southern Africa and often forms colonies. Specimens have even been collected in the higher rainfall areas of the southern Free State Province and in the eastern and southern parts of Lesotho (Le Roux et al., 1994). Shearing and Van Heerden (1997) described *T. sinuatum* as one of the positive indicators in the Karoo region, being a palatable plant, and an indicator of how well an area has been managed. *T. sinuatum* is also being used in the winter rainfall areas of southern Africa to reinforce the veld (Le Roux et al., 1994). Plants grow to a height of 10 – 50 cm, and when protected from grazing can reach heights of up to 80 cm.

It is a woody shrub with pale to purplish grey bark. The leaves are lanceolate in shape, opposite, and widest beyond the middle and have a few irregular teeth or lobes on the margins (Le Roux et al., 1994). The flowers are borne on short stalks and the ray and disc florets are yellow. The fruits are three winged and mainly wind borne (Le Roux and Schelpe, 1997).

T. sinuatum has seeds that are readily dispersed by wind and consequently seed densities are higher under nurse plants such as mound-forming mesembryanthema and in litter (Yeaton and Esler, 1993), where the seeds are trapped after dispersal. It has being stated that this species grows best in the shade and protection of larger shrubs because of its palatability (Shearing and Van Heerden, 1997). This species is highly palatable with a high production, which reacts promptly to rain after droughts (Le Roux et al., 1994).

4. Materials and Methods

The *T. sinuatum* and the *S. microphylla* seeds used in this investigation were harvested on the farm “Lovedale” in the Kenhardt district. The farm is situated approximately 40 km southeast of Pofadder in the Northen Cape Province of South Africa. The germination studies were conducted in a growth chamber on the Hatfield Experimental Farm of the University of Pretoria.

4.1. Sutherlandia microphylla

Three basic treatments (control, scarification and leaching), which were split for light, and no light with four replications each were used to determine germination in *S. microphyllum.* A summary of the different treatments is represented in Table 2.

Table 2 Different treatments used for germination in *Sutherlandia microphylla*

Treatment	Light	Replications
Control	Exposed	4
Control	Not exposed	4
Leached	Exposed	4
Leached	Not exposed	4
Scarification	Exposed	4
Scarification	Not exposed	4

The petri-dishes were prepared by putting filter paper (Whatman Filter paper, Ashless, 9.0cm) in the bottom of each. The paper was wetted with distilled water. For every treatment twenty-five seeds of *S. microphylla* were randomly selected out of each batch of treated seeds and placed, approximately 8mm apart, in a petri-dish. For the leaching treatment, randomly selected seeds where leached for 15 hours in distilled water prior to placement in the petri-dishes, while for the scarification treatment randomly selected seeds were scratched three times on sandpaper (P120) before being places in the petri-dishes.

The petri-dishes for each treatment were randomly numbered from one to eight and sealed with parafilm. Numbers one to four of each treatment were exposed to 18 hours of fluorescent light and six hours of darkness per day in a growth chamber kept at 26 degrees Celsius. Numbers five to eight were covered with a black polyethylene sheet and kept under similar conditions as the light exposed petri-dishes. All dishes were inspected three times per week to determine germination and to ensure that the seeds stayed moist for the twenty-one day period of the experiment.

4.2. Tripteris sinuatum

Two basic treatments (seed-wings intact, seed-wings removed), which were split for light, and no light with five replications each were used to determine germination in *T. sinuatum*. A summary of the different treatments is represented in Table 3.

Table 3 Different treatments used for germination in *Tripteris sinuatum*

Treatment	Light	Replications
Seed-wings intact	Exposed	5
Seed-wings intact	Not exposed	5
Seed-wings removed	Exposed	5
Seed-wings removed	Not exposed	5

The petri-dishes were prepared in a similar fashion as described for the *S. microphylla* study. For every treatment twenty seeds of *T. sinuatum* were randomly selected out of each batch of treated seeds and placed in a petri-dish. The seed-wings of randomly selected seeds were removed by hand prior to placement in the petri-dishes.

The petri-dishes for each treatment were randomly numbered from one to ten and sealed with parafilm. Numbers one to five of each treatment were exposed to 18 hours of fluorescent light and six hours of darkness per day in a growth chamber kept at 26 degrees Celsius. Numbers six to ten were covered with a black polyethylene sheet and kept under similar conditions as the light exposed petri-dishes. All the dishes were inspected three times per week to determine germination and to ensure that the seeds stayed moist for the twenty-one day experimental period.

4.3 Data analyses

An analysis of variance with the Proc GLM model (Statistical Analysis System, 2001) was used to determine the statistical significance of difference between different treatments and light effects for these data. Means and standard deviations (SD) were also calculated. Significance of difference (5%) between means was determined by the Fischer test (Samuels, 1989).

5. Results and Discussion

5.1. Germination of *Sutherlandia microphylla*

Significant differences ($P<0.05$) were found between the control and the scarification and leaching treatments for *S. microphylla.* No significant differences ($P>0.05$) were found between the two different light exposures. The germination data are presented in Table 4. The *S. microphylla* seeds are wind dispersed. The tiny black seeds are carried in a bladder like structure and are then released. Treatment of the seeds by, scarification or leaching, both improved the germination of the seeds significantly ($P<0.05$).

Table 4 Effect of leaching, scarification and light exposure on percentage germination of *Sutherlandia microphylla*

Treatments	Exposed to light Germination %	Not exposed to light Germination %
Control	37.0 (13.2)* $_1^a$	45.0 (6.8) $_1^a$
Scarification	79.0 (11.5) $_1^b$	83.0 (6.8) $_1^b$
Leaching	76.0 (3.3) $_1^b$	75.0 (3.8) $_1^b$

[a], Column means with the same superscript do not differ (P>0.05) significantly

[1, 2] Row means with the same subscript do not differ (P > 0.05) significantly

* Standard deviations

The data is graphically illustrated in Figure 1. Considering the dispersal method of this species, both these mechanisms could play a role in nature, where seeds would remain relatively dormant after dispersal if not scarified (rubbing effects of sand grains) or leached.

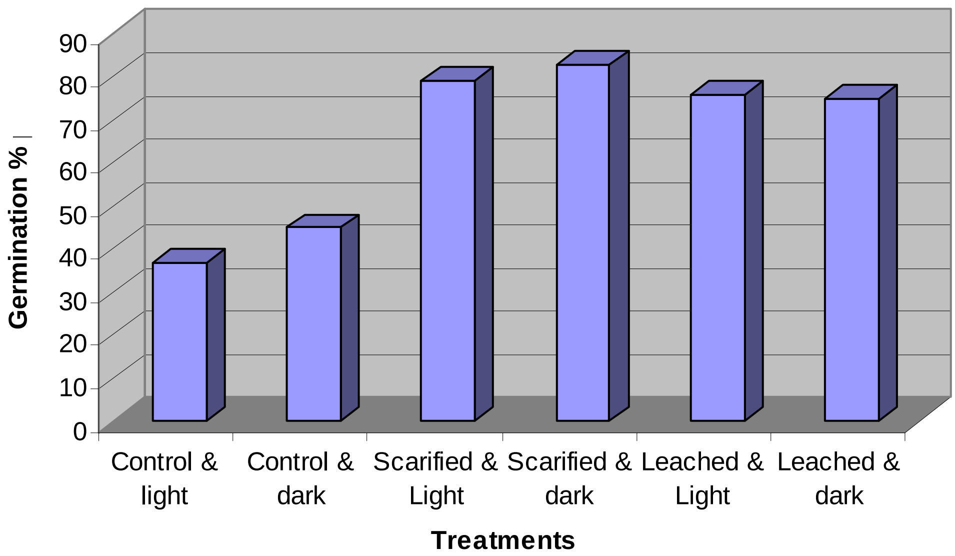

Figure 1 The effect of scarification, leaching and different light treatments on the germination of *Sutherlandia microphylla* after 21 days

5.2. Germination of *Tripteris sinuatum*

T. sinuatum seeds are mainly wind dispersed and have attached seed wings. The differences in germination for seeds, with seed wings removed, and under different light exposures, were tested. The seed wings were removed, by hand, to increase contact between the exposed surface area of the seed and a moist growth medium. The ecological approach being, that by increasing the area exposed to moisture (which is the limiting factor in arid environments), the germination of seeds would be improved. The seeds being mainly wind borne, (being deposited on the soil surface) the effect of different light treatments, were also investigated. The choice of treatments was based on the natural seed dispersal process of *T. sinuatum*. Fungus contamination had developed in all the petri-dishes after three days. It is not certain if this was a seed borne contamination, or if it was contamination from the laboratory. The contamination was uniform across all of the treatments and it is assumed that it had no effect on the comparisons between treatments. Fungal contamination might, however, have resulted in an underestimation of the average germination percentage of the seeds and caution should be shown in extrapolating the data from this experiment for other seed batches of this species. The percentage germination of the different treatments is presented in Table 5.

Table 5 Effect of seed wing removal and light exposure to germination percentages of *Tripteris sinuatum*

Treatments	Exposed to light Germination %	Not exposed to light Germination %
Seed wings intact	20.0 (7.9)* $_1^a$	16.0 (14.3) $_1^a$
Seed wings removed	24.0 (8.9) $_1^a$	19.0 (8.9) $_1^a$

[a], Column means with the same superscript do not differ (P>0.05) significantly

[1, 2] Row means with the same subscript do not differ (P > 0.05) significantly

* Standard deviations

The highest germination percentage (24 %) was recorded when the seed wings were removed and the seed was exposed to light, even though it was not statistically significant (P>0.05). This species is naturally wind dispersed which could lead to the conclusion that the seed would remain on the soils surface, either under a shrub or in some kind of depression. This could be the explanation of why both treatments, exposed to light, even though not statistically significant, had a better percentage germination than those treatments without light exposure. This is graphically illustrated in Figure 2.

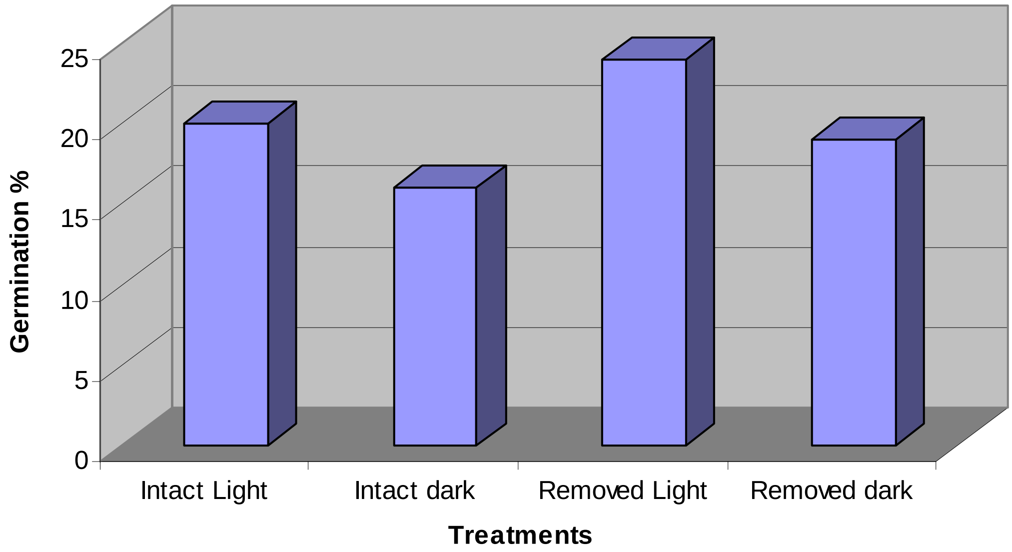

Figure 2 The effect of seed wing removal and light treatment on the germination of *Tripteris sinuatum* after 21 days

6. Conclusion

With a wealth of naturally occurring species, to choose from, criteria are needed to choose the most desirable species for reclamation. The criteria should not only consider the ecological adaptations, but also economic aspects. Is it possible to not only reclaim, but also to diversify production systems? Criteria to narrow down the choice of species were used and *S. microphylla* and *T. sinuatum* were chosen as two possible candidates for reclamation purposes. The next logical step would be to produce seedlings for plantations, reseed with the chosen species and to determine if the species in question would be able to reproduce naturally from core or nucleus areas. To determine this the germination percentages of seeds produced in nature were tested. It is advisable to aim to simulate natural conditions during germination to break the dormancy, if there is any. It is believed that this approach to germination trials should improve the success of germination.

Using this approach it was found that *S. microphylla* showed a significantly ($P<0.05$) higher germination with scarification (83%) and leaching (75%) treatments than the control (45%). No significant differences ($P>0.05$) were found between the different light treatments.

No significant differences (P>0.05) in germination were found between the two treatments and light exposures for *T. sinuatum*. The overall germination percentages, for all the treatments, for this species were disappointing. *T. sinuatum* has successfully been used in the past to improve and reclaim degraded areas in the Karoo region of South Africa. The fungal contamination could, however, have influenced the germination results negatively.

It is concluded that a criteria is needed before choosing any species for reclamation. Using, and aiming to simulate, natural dispersal mechanisms is necessary in treating seeds to ensure better germination, especially for *S. microphylla,* and that *Sutherlandia* species should be tested further for reclamation purposes. A crucial step is the ongoing research into its medicinal value and creating a market for this product. This would not only meet the ecological criteria but also the economic criteria to reduce some of the pressure on the natural environment, by diversifying production systems in an otherwise grazing production dependant area. Increasing and providing a more secure economic income should also have added social benefits. Thus a holistic approach is needed to reclamation incorporating ecological, social and economic considerations.

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Chapter 4

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Relative palatability and long-term survival of different *Atriplex* species, at two different localities, in the arid Northern Cape Province of South Africa.

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Abstract

The relative palatability and survival of 16 different *Atriplex* species and accessions were determined at two different localities in the arid Northern Cape Province of South Africa. The two localities were analysed separately because of marked environmental differences. Significant differences were found between species at both localities. It is believed that because of the variety of species in the *Atriplex* genus, relative palatability and survival should be used to determine which of the different species could be useful under specific climatic and soil conditions. It is concluded from this study, that further investigation is needed concentrating especially on *A. nummularia, A. breweri, and A. lentiformes,* which were the most palatable at the Pofadder site, and *A. canescens* (FR1) and *A. breweri,* which were the most palatable at the Mier site.

Keywords: Arid environments, *Atriplex*, Palatability, Survival

1. Introduction

Chenopods are well adapted and occur in disturbed habitats of the temperate and subtropical climates of both the northern and southern hemispheres. There are approximately 1250 species, in about 100 genera, worldwide in the Chenopodiaceae family, of which *Atriplex* is one (Kadereit et al., 2005). It appears that, because of the adaptability of these species, the chenopods not only survived in these harsh

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environments, but also evolved to increase the range of tolerance, under which these species can grow. The centre of diversity of the Chenopodiaceae is in the Old World desert belt from the Canary Islands across North Africa to Central Asia, where all the tribes and nearly two thirds (approximately 60%) of the genera are present. The second centre is Australia, followed by North America, South America and South Africa (Kadereit et al., 2005).

The question arises that with such a wealth of species, and wide range of adaptations, which would be the best suited for fodder and livestock production in particular arid areas. Considerable work has been done on *Atriplex* species, but the suitability of different species in certain areas and certain production systems is still questionable.

The aim of this study was to test the relative palatability and long term survival of several *Atriplex* species (Table 3) at two different locations in South Africa. Both sites are in the arid zone but are in two different climatic regions and in different biomes. P. J. Malan established the sites in 1995 as part of a MSc. study (Malan 2000).

The potential of fodder shrubs, as part of integrated management systems, is being realized in many parts of the world, especially in arid areas, or areas that have been disturbed (Ben Salem et al., 2002). In arid areas shrubs have the potential not only to be used as an alternative feed source, but also as an stabilizing agent, economically, ecologically and socially. Shrubs are considered to be a cost effective fodder resource for ruminants in many countries (Ben Salem et al., 2005). Ecologically speaking the shrubs can create microhabitats for other plants to become established, apart from the soil stabilizing and erosion control advantages (Abou El Nasr et al., 1996, Andreu et al., 1998). Economically shrubs can be used to buffer the effects of droughts, and have the potential to increase livestock production (Chriyaa et al., 1997a, Chriyaa et al., 1997b). The economic effect then has a direct influence on the social aspects, by providing a more sustained income. Such fodder sources can also alleviate the effects of droughts in arid areas where droughts are the norm and not the exception, due to the varied probability in rainfall events.

Concentrate feeds are often in a limited or seasonal supply and are often very costly in arid or marginal areas. The use of fodder shrubs to supplement animals, as an alternative to costly concentrates, should therefore be considered for such marginal areas (Ben Salem et al., 2004). Production from these shrubs may be considered for own use and/or an alternative source of income. The shrubs can be used in part to diversify the production system currently in use and as an alternative source of income. Abou El Nasr et al. (1996) found that silage made from *Acacia* and *Atriplex* provided sufficient digestible nutrients to meet energy and protein requirements for maintenance requirements of sheep.

Many areas are characterised by saline water. This is especially so in arid areas with high evaporation rates. If saline water can be used to produce halophytic fodder shrubs, such as *Atriplex*, these plants can be become an important feed resource for small ruminants in these areas (Swingle et al., 1996).

According to the model of Guevara et al. (2003) *A. nummularia* can be used economically for goat production on the plains of Argentina with a mean annual rainfall of 175 mm. It should be noted that the production in these area is based on a saline water table of approximately 5 to 10 m deep. It does, however, show that fodder shrubs can be used economically as a feed source to improve livestock production. It is suggested that similar models be tested for other areas where the use of fodder shrubs can be economically and ecologically beneficial. The highest input cost for the model of Guevara et al. (2003) was fencing of the saltbush plantations. This could be reduced, or eliminated, where camps are already in use. By using an existing camp and positioning the plantation in the corner of a fenced camp / paddock it is also possible to halve the cost of fencing due to the use of the existing fence.

A concern in the use of halophytes in livestock production is animal health and carcass quality. Alazzeh and Abu-Zanat (2004) found that lactating Awassi ewes had differences in blood mineral levels on a saltbush diet compared to the control diet. The mineral levels, especially selenium, were high but not high enough to show any toxicological symptoms, but care should be taken when feeding lactating Awassi ewe's saltbush for prolonged periods. Abu-Zanat and Tabbaa (2005) found that feeding *Atriplex* browse (*A. nummularia* and *A. halimus*) with concentrate rations to lactating Awassi ewes did not produce any negative effect on the milk yield of ewes or the growth rates of lambs.

Hopkins and Nicholson (1999) found that there were no differences in the carcass quality and acceptability to consumers for lambs fed on an *A. nummularia* supplemented diet. It should be noted that no reference to the meat quality of lambs on diets of other *Atriplex* species could be found.

Valderrdbano et al. (1996) found that *A. halimus* was tolerant of high grazing pressure in autumn, in the Ebro valley in Spain. The animals utilised the re-growth of the previous season. Goats in northern Mexico were found to utilise shrubs more often than grasses, even when the animals had severely worn incisors. One of the shrubs utilised in this case was *A. canescens* (Mellado et al., 2005). Mellado et al. (1991) found that 80 % of the diet of goats in this region consisted of browse with the highest preference *for A. canescens, Bouteloua scordioides* and *Sphaeralcea angustifolia*.

Many questions, arising on the use of *Atriplex* species as a suitable fodder shrub, have been investigated all over the world. Using the information and making informed decisions based on this should be the next step in the work towards using this species as a tool for sustainable production in arid environments.

Because of the species richness in this genus, the adaptability and palatability should be tested for as many species as possible under different climatic conditions. This should be done in areas of need and should be site specific. The plantations planted by Malan (2000) in two different climatic zones were used to assess the relative palatability of different *Atriplex* species.

2. Materials and Methods

2.1 Study site description

The two experimental sites were both situated in the Northern Cape Province of South Africa (Mier and Pofadder) (Fig 1).

Mier is situated in the savanna Biome, which is the largest Biome in southern Africa, occupying over one third of the surface area of the country. A grassy ground layer and a distinct upper layer of woody plants characterize South African savannas. Where the upper woody layer is close to the ground (vertical distribution) the vegetation may be referred to as Shrubveld and where it is dense as Woodland with intermediate stages locally known as Bushveld (Low and Rebelo, 1998).

The area around Mier and Tweerivieren is known as the Shrubby Kalahari Dune Bushveld (Low and Rebelo, 1998) or the Kalahari Thornveld (Acocks, 1988). The

Mier area was not surveyed by Acocks (1988) and will be referred to as Shrubby Kalahari Dune Bushveld. This veldtype covers approximately 37 434 km^2 of which 55% is transformed and 19.45 % is conserved, mostly in the Kgalagadi Transfrontier Park (Low and Rebelo, 1998).

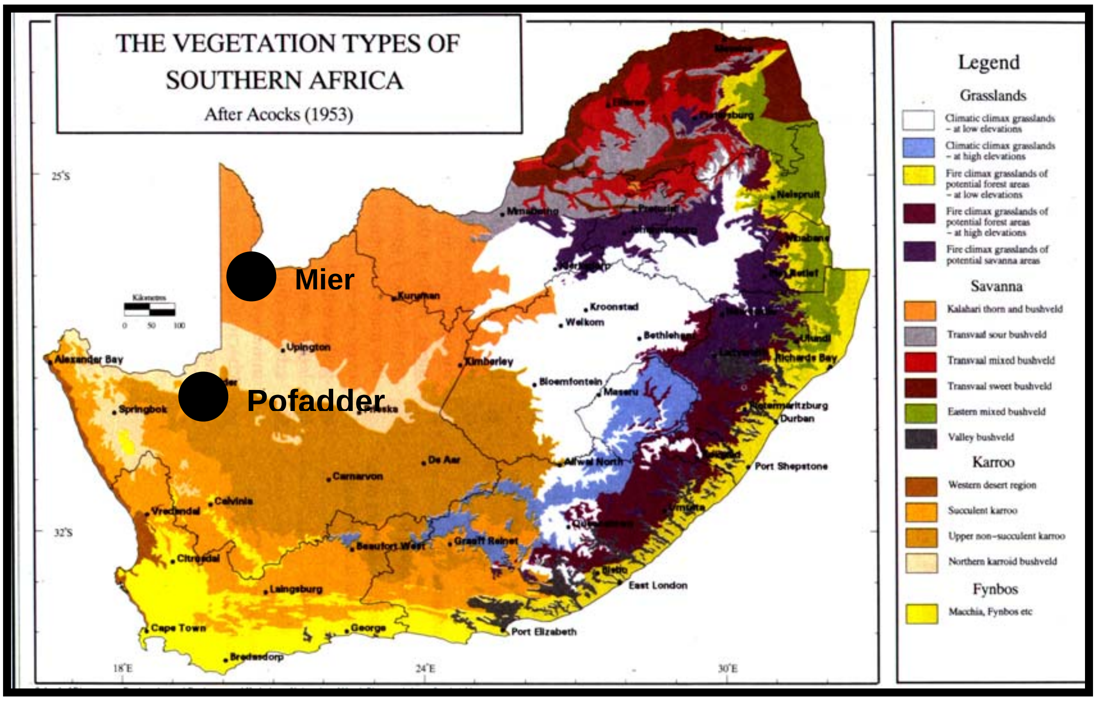

Figure 1 The vegetation types of Southern Africa (Tainton and Hardy, 1999)

The average annual rainfall is approximately 200mm, distributed from November to April with a peak in March. The temperatures vary between –10 and 45 degrees Celsius with an average of 20 °C (Low and Rebelo, 1998).

Pofadder is situated in the Nama Karoo Biome, which occurs on the central plateau of the western half of South Africa. This is the second largest biome after the savanna biome in South Africa. The geology of this biome varies as the distribution of this biome is determined primarily by rainfall. The soils in this biome are prone to erosion and this is aggravated where over-utilisation of the veld has occurred. The dominant vegetation in this biome is a grassy, dwarf shrub land. Grasses tend to be more common in depressions or drainage lines on sandy soils. Less than 1% of the biome is protected in formal conservation areas. The major land use in this area is grazing for domestic animals, especially sheep and goats (Low and Rebelo, 1998). The veldtype occurring in the Pofadder region is known as Orange River Nama Karoo (Low and Rebelo, 1998) or Namaqualand Broken Veld (Acocks, 1988). The

Orange River Nama Karoo veldtype is approximately 53 708 km^2 of which 1.47% is protected in formal conservation areas. The rainfall in this veldtype is low (150 to 300 mm per year), and unevenly distributed with late summer precipitation for the eastern part and late autumn for the western part.

There is an 110m difference in altitude between the two sites with Mier situated at 879 m and Pofadder at 989m above sea level.

The two sites differ considerably in terms of mean annual rainfall and rainfall distribution. Mier is in a summer rainfall area while the site at Pofadder is a borderline winter rainfall area with a weak bimodal rainfall distribution pattern. The climatic parameters for the different sites, as reported by Malan (2000), are presented in Table 1.

Table 1 Climatic parameters for each site (Malan 2000)

	Average (n = 30)	Average (n = 30) Temperature	
Site	Rainfall (mm)	Min	Max
Mier	213	11	29.4
Pofadder	117	11.4	25.8

The chemical and physical properties of the soils for the sites, as determined by Malan (2000), are presented in Table 2. The soils at Pofadder are more alkaline than the sandy soils at Mier. The Mier soils were much lower in nutrient content than the soils at Pofadder.

Table 2 Chemical and physical soil properties of the two different sites (Malan 2000)

Site	Clay (%)	pH ($h_2 0$)	Ca (ppm)	Mg (ppm)	P (Bl) (ppm)	K (ppm)	Na (ppm)
Mier	<5	6.3	188	71	11	95	5
Pofadder	<10	8.6	2213	291	70	1300	672

2.2. Establishment of sites

Malan (2000) established both sites in 1995. Both sites were planted with seedlings produced on the Hatfield Experimental Farm of the University of Pretoria. A minimum of two replicates of each species was planted at each location with spacing of 1.5m in the rows and 5m between the rows (1333 plant per hectare).

2.3 Determining survival and relative palatability

The survival rates at the two sites were determined in 1996 (Malan, 2000) and again in 2001. A comparison between the 1996 and 2001 survival rates is presented in Table 3. The long-term survival rate is important as it give a better indication of species adaptability to the different climatic conditions.

The relative palatability at the two sites was determined. It is important to note that the data for the two sites was interpreted separately. The reason for the separate analysis is the differences in the climate and soils of the two different sites.

Relative palatability of the different *Atriplex* species was determined in August 2001 at Pofadder using 43 Dorper ewes and 35 lambs. Monitoring was done 24 hours and 48 hours after introduction of the animals into the plantation. The plants were evaluated using a subjective scale of 0 to 3 with 0.5 increments where 0 = no utilisation and 3 = severe utilisation. Two independent observers were used for the observations. The animals had free access to three water troughs that were randomly placed in the camp. All the ephemerals and grasses in the camp were removed by hand before the sheep were allowed access to the saltbushes.

A similar number of sheep were used in March 2002 to determine the relative palatability of different *Atriplex* species in the established Mier plantation. A similar process with the same subjective scale of 0 – 3 with 0.5 increments as the one used at Pofadder was used to determine the relative palatability at Mier. Three independent observers made the observations 24 and 48 hours after introduction of the animals in the plantation. The animals had free access to three water troughs that were randomly placed in the camp. All the ephemerals and grasses in the camp were removed by hand before the sheep were allowed access to the saltbushes.

2.4. Data processing

The data for both sites were subjected to similar data analyses, but interpreted separately, because of the environmental differences and the different observation times at the sites. Relative palatability was only determined for species with a survival rate of 60% or higher. This was done to include the adaptability (survival percentage) of the species in the analysis. This would also eliminate a skewed result, where fewer plants would be utilised more heavily, due to the limited number of plants per species on offer for utilisation, relative to other species.

The data was analysed with the Proc GLM repeated measure of analysis variance model (Statistical Analysis System, 2001) to determine the LSmean value of each species (according to the subjective scale used to score each plant) and to test for significant differences between the LSmean values of species and for differences between 24 and 48 hours.

The resulting data were then sorted in a descending order according to the LSmean values of each species to get an indication of which species was more likely to be utilised, relative to the other species on offer.

3. Results and Discussion

The different survival rates and a comparison between the survival rates found by Malan (2000) and this study are given in Table 3. The sorted LSmean values for Pofadder and Mier indicating the relative palatability of each species compared to the other species on offer at each site are presented in Tables 4 and 5 with the assumption that the more likely a species is to be utilised, the more palatable it is relative to the other species on offer.

Twelve of the sixteen species planted at Pofadder in 1995 survived the first growing season (Malan, 2000). All of these species had a 60% survival rate or higher in 1996. All twelve species survived until 2001, but only nine of the remaining twelve species had a 60% or higher survival (Table 3). These nine species were used to determine the relative palatability probabilities for the Pofadder site (Table 4). During a field visit in 2005 it was found that none of the *A. glauca*, *A. semibacata, A. undulate* and *A. halimus* survived. *A. glauca* was the only one of these four species that was included in the initial palatability trial in 2001 and it was found that is was the most palatable of the species on offer (Table 4), however, it did not survive until 2005. It is assumed that it is either not well adapted or that rodents grazed it, until it died off.

Table 3 Names, origin and survival rate of *Atriplex* species planted at Mier and Pofadder for 1996 and 2001 (Malan 2000)

		Survival (%) at different sites			
		Mier	Pofadder	Mier	Pofadder
Accessions	Origin	1996		2001	
A. amnicola	Western Australia	90	0	40	0
A. breweri	Australia	100	80	90	60
A. canescens (Aus)	North America	100	90	80	90
A. canescens (FR1)	North America	100	100	90	80
A. canescens (FR2)	North America	Dnp	90	Dnp	90
A. canescens (Rin)	North America	100	90	50	90
A. canescens (SR)	North America	100	100	90	100
A. cinerea	Australia	40	0	10	0
A. glauca	Mediterranean	100	100	0	100
A. halimus	Mediterranean	100	90	40	20
A. lentiformis	North America	100	100	90	100
A. nummularia	Australia	100	100	100	100
A. paludosa	Australia	10	0	0	0
A. rhagadioides	Australia	100	0	0	0
A. semibaccata	Americas	100	80	0	20
A. undulate	South America	70	80	10	20

Dnp Did not plant

Of the fifteen species initially planted at Mier, fifteen survived the first growing season with thirteen of the fifteen achieving a 60% or higher survival. Good management by the farmer at this locality contributed to the initial high survival percentages for the first growing season (Malan, 2000). However, only eleven species survived until 2001, of which only six had a 60% or higher survival (Table 3). These six species were used to determine the relative palatability for the Mier site (Table 5). It is assumed that, of the fifteen species initially planted, these six species are best adapted to this locality (Table 3).

A significant difference was found in utilisation of all species between 24 and 48 hours ($Pr>0.0001$) and the relative palatability of the different species ($Pr > 0.0001$). If the assumption that utilisation is indicative of palatability, is correct, the species in Table 4 can be grouped into classes from the most palatable to the least palatable.

At 24 hours *A. glauca* was the most palatable with no significant difference (P>0.05) between *A. nummularia, A. breweri, and A. lentiformes* being the second most palatable group of plants. The third most palatable group consisted of *A.canescens* (Rin*), A. canescens* (SR) and *A. canescens* (FR1) with *A. canescens* (Aus) intermediate between these two groups not differing significantly (P>0.05) between either. The least palatable species for both 24 and 48 hours was *A. canescens* (FR2).

Table 4 Relative palatability (LSmean) of *Atriplex* species / accessions at Pofadder after 24 and 48 hours of utilisation

	LSmean (SE)	
	24 Hours	48 Hours
A. glauca	3.00 (0.119)[a]	3.00 (0.144)[a]
A. nummularia	1.00 (0.119)[b]	1.78 (0.144)[b]
A. breweri	0.92 (0.153)[b]	1.67 (0.185)[b]
A. lentiformes	0.88 (0.119)[b]	1.40 (0.144)[bc]
A. canescens (Aus)	0.75 (0.125)[bc]	1.00 (0.151)[cd]
A. canescens (Rin)	0.50 (0.119)[cd]	1.18 (0.144)[cd]
A. canescens (SR)	0.48 (0.119)[cd]	1.05 (0.144)[cd]
A. canescens (FR1)	0.44 (0.133)[cd]	0.97 (0.161)[d]
A. canescens (FR2)	0.25 (0.125)[d]	0.36 (0.151)[e]

[a - e,] Column LSmeans with the same superscript do not differ (P>0.05) significantly

The general order of species according to their relative palatability did not change after 48 hours. However, the grouping of plants in different palatability groups did (Table 4). *A. glauca* was still the most palatable after 48 hours with no significant difference (P>0.05) between *A. nummularia* and *A. breweri* being the second most palatable group. The third most palatable group consisted of *A. canescens* (Aus), *A. canescens* (Rin), *A. canescens* (SR) and *A. canescens* (FR1) with *A. lentiformes* intermediate between the two groups not differing from either, except from *A. canescens* (FR1) in the second group. The two groups differed significantly (P>0.05) from each other. *A. canescens* (FR2) was still the least palatable after 48hours.

It is, however, interesting to note that at 48 hours all the species was more likely to have been utilised than at 24 hours. This indicates that there is a difference in and between species over time and that the less palatable species are more likely to be utilised over a longer time period if no other species are available.

Table 5 Relative palatability (LSmean) of *Atriplex* species / accessions at Mier after 24 and 48 hours of utilisation

	LSmean (SE)	
	24 Hours	48 Hours
A. canescens (FR1)	2.48 (0.147)[a]	3.00 (0.130)[a]
A. breweri	2.30 (0.147)[a]	2.87 (0.130)[a]
A. lentiformes	1.63 (0.147)[b]	2.19 (0.130)[b]
A. canescens (Aus)	0.67 (0.156)[c]	1.02 (0.138)[c]
A. nummularia	0.53 (0.140)[c]	1.00 (0.124)[c]
A. canescens (SR)	0.52 (0.147)[c]	0.87 (0.130)[c]

[a - c], Column LSmeans with the same superscript do not differ (P>0.05) significantly

Both species (Pr > 0.0001) and observation times (Pr > 0.0001) differed significantly when the Mier data was subjected to analyses. Three distinct groups of palatability were observed in the Mier area (Table 5). With *A. canescens* (FR1) and *A. breweri* being in the most palatable group, *A. canescens* (Aus), *A. nummularia* and *A. canescens* (SR) in the least palatable group and A. lentiformes in a grouping intermediate between these. Neither the grouping nor the order changed between 24 and 48 hours, but the LSmean values changed significantly (P<0.05) indicating better utilisation over a longer time period. This again indicates that the least palatable species would be well utilised over a longer period of time if no other species were available.

4. Conclusion

The large variety of species in the Chenopodiaceae family and especially the different species in the *Atriplex* genus, which have evolved and adapted to a wide range of environmental conditions, makes it difficult to determine which species are best suited for a particular purpose in a certain area.

Testing different species for long-term survival and relative palatability in specific locations, should reduce some of the random guesswork usually associated with choosing a suitable species. This includes the local environmental conditions and the specific utilisation regime to be used in that area.

It is concluded from this study, that further investigation is needed, concentrating especially on *A. nummularia, A. breweri, and A. lentiformes,* which were the most palatable at the Pofadder site, and *A. canescens* (FR1) and *A. breweri,* which were the most palatable at the Mier site. Further work is needed to investigate why there was a marked difference in relative palatability between the two sites and it is suggested that water qualities, which differ significantly between the two areas, be investigated.

Production studies of the different species in each palatability class for each site could be used as the next criteria to determine which of the species in the class would be best suited to an area. This might seem trivial, but because there was a marked difference between the two different utilisation times, the species, which are relatively less palatable, might have a better production. The higher production might outweigh the fact that the species are less palatable, and they would still be utilised if the period of utilisation were lengthened, or if the animals had no choice in a mono-specific stand. It is believed that *A. nummularia* would be one such species, and that its production would offset the fact that it was found to fall in a palatable class at Pofadder and the least palatable class at Mier.

Because the trend in relative palatability between the two sites differed one could not extrapolate these findings to other locations. Studies over longer time spans and at lower grazing pressures should also be undertaken to validate the above-mentioned results.

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Chapter 5

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Linking conservation and reclamation: The use of a small localized water run-on site on a bare patch for plant establishment in the arid Northern Cape Province of South Africa as an example.

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Abstract

Seeds from two plants species (*Tetragonia calycina* and *Tripteris sinuatum*) were used to overseed a bare patch in the Northern Cape Province of South Africa. The two species with two treatments, (brush packing or not) in two different locally occurring eco-topes were used to assess plant establishment. No significant differences were found between the treatments and no significant interaction between the treatments and the different eco-topes were found. A significant difference was, however, found between the two eco-topes occurring on the bare patch. The water run-on eco-tope showed a significantly higher plant establishment than the water run-off eco-tope. The establishment of perennial grass species was also found on the water run-on eco-tope, three years after establishing the reclamation site. It is concluded that the use of local water run-on eco-topes should be part of the basis in site selection for reclamation of arid areas. These sites could form an important link in conservation.

Keywords: Bare patches, Conservation, Reclamation, *Tripteris sinuatum, Tetragonia calycina*

1. Introduction

Ecological restoration has many different definitions, but all seem to have a common objective, to increase, or restore diversity, and to repair damaged or altered ecosystems. Choi (2004) cited authors and their definitions for reclamation. Jordan et

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al. (1987), as sited by Choi (2004), define ecological restoration as “the recreation of entire communities of organisms, closely modelled on those occurring naturally”. The National Research Council (1992), as cited by Choi (2004), defines restoration as “the return of an ecosystem to a close approximation of its condition prior to disturbance”. Jackson et al. (1995), as cited by Choi (2004), describe it a “process of repairing the damage caused by humans to the diversity and dynamics of indigenous ecosystems”.

Regularly occurring bare patches in vegetation are not an uncommon phenomenon and have been observed in vegetation types in various arid zones of the world (Couteron and LeJeune, 2001). Sparse cover and patchiness often characterize vegetation in arid areas, which could be due to differences in microhabitats (Burke and Mannheimer, 2003). Hoffman and Ashwell (2001) have described desertification / degradation as occurring in patches across a landscape with the productivity of the whole area declining and the patches increasing in size. The regularity and distribution of the bare patches in a landscape can be used to determine if their occurrence is a natural phenomenon or not. Couteron and Le Jeune (2001) used the propagation and inhibition model to verify this phenomenon, from aerial photography, in vegetation types in the arid zones of Africa. The bare patches occurring in Bushmanland, where this study was conducted, have not, however, been subjected to any kind of modelling and verification and their occurrence cannot be explained as man-made or as naturally occurring phenomena.

Even though there are different plausible explanations for the occurrence of the bare patches in the Bushmanland region (man made, natural, cyclic, etc.), no one cause can be given for their occurrence at present and further studies are needed. That farms and areas in this region have been overgrazed and degraded cannot, however, be denied (Anderson et al., 2003). In a study investigating biodiversity between protected areas and commercial and communal rangelands marked differences were found (Fabricius et al., 2003). Even though the study was not conducted in Bushmanland, it is symptomatic of degradation and the influence of different land use practices in arid areas. The non-equilibrium behaviour of arid areas, however, makes it extremely difficult to determine if the vegetation is degrading, stable or improving or just reacting to short-term favourable climatic conditions (Pickup et al., 1998).

The mere exclusion of grazing animals does not seem to be the answer to increasing biodiversity and improving rangeland condition in arid areas, due to their non-equilibrium behaviour. Oba et al. (2001) used the hump back response model and found that long-term exclusion of grazing negatively impacts on species richness in arid zones. Heavy grazing pressures can also adversely affect the biodiversity as found by Riginos and Hoffman (2003) in the succulent Karoo of South Africa.

Didham et al. (2005) makes an interesting argument for alternative stable states in environments, which are under high environmental stress. It was concluded by Didham et al. (2005) that it is important to enhance the resilience of critical focal processes to future disturbances. Didham et al. (2005) conclusion also validates the method of Pickup et al. (1998) in determining trends in vegetation change for arid zones of Australia.

It is believed that high biodiversity in an ecosystem increases its resistance to change. In a harsh environment the range of tolerance for many species is very small and overlapping. The species, which dominate in a previously disturbed area, could be because of the propagules present after disturbance. Because of the overlapping range of tolerance in these harsh environments, the first species arriving and establishing could exclude other species establishing (Didham et al., 2005). Such an approach would justify the use of overseeding with desirable species in disturbed arid zones. The opposite is true for the extremely diverse succulent Karoo, with it high diversity and endemism, where many species are site specific (Cowling et al., 1999).

Global climate change does have the potential to adversely impact on the biodiversity of the arid zones in South Africa, especially with respect to some of the national parks and their conservation value in this region (Rutherford et al., 1999). Long distance migration of plant species is associated with limited and occasional rare climatic events, and the rapid change in the global climate, might exclude the possibilities of such events occurring in a reasonable timescale to prevent extinction of the species (Rutherford et al., 1999). Grazing also severely impacts on the flower production and fruit set of plants, especially in the succulent Karoo, which would further impair the migration of plants through natural seed dispersal (Riginos and Hoffman, 2003). Cowling et al. (1999) proposed a system of determining conservation areas in the succulent Karoo of southern Africa. This system included the major ecosystem driving forces and climatic and edaphic variables, which could be responsible for the high species diversity in this region. Cowling et al. (1999) stated the importance of “on” and “off” reserve conservation. The importance of sufficient grassveld in the Bushmanland region, Nama Karoo biome, is also considered as valuable in conservation of the succulent Karoo, as it used to provide summer grazing for large mammals, which used to move in mass migrations to the succulent karoo during the winter months. This is believed to have been one of the main driving forces in the evolution and succession of the succulent Karoo (Cowling et al., 1999).

Bushmanland is situated to the east of the succulent Karoo and forms part of the Nama-Karoo. The major form of land use in this region is livestock grazing, with the occasional game farm. Due to its geographical position it could form an essential link for conservation. This could take on the form of many small areas with a relatively good vegetation cover and species composition, situated close enough to each other to allow for migration of plant species. Using localized bare patches as the key to promoting plant species establishment and creating favourable growing conditions could not only aid in conservation, but could form the link to a more ecologically friendly land use of the area. The establishment of palatable high producing fodder species also has the potential to alleviate some of the pressure on the natural surroundings, which in turn would have a positive affect on species migration. Even though this might seem similar to gardening with indigenous species in a wild mosaic, the imminent change in global climate justifies efforts of such a nature if it is used as a tool to link ecosystems. The potential value of such efforts should be seen on a landscape level and not as a single attempt in plant establishment.

Van den Berg and Kellner (2005) found that the best results in the reclamation of bare patches in a semi-arid area of South Africa were obtained with restoration treatments that included a combination of ripping, over-sowing, brush packing and added organic material. These results were obtained in an area with a long term mean annual rainfall of 314 mm, which is significantly higher than the 80 mm mean annual rainfall of the area concerned in this paper. Van den Berg and Kellner (2005) obtained better results with perennial grass seeds from a commercial producer than with seeds harvested in the surrounding area.

This paper is concerned with the establishment of plants in the arid Northern Cape Province of South Africa, using bare patches not as an indicator of degradation but as an opportunity to achieve plant establishment. The reasoning being that bare patches can act as a water harvesting area to increase moisture infiltration in specified sites was tested. Over-sowing treatments with locally harvested seeds of palatable long-lived shrubs, to further create suitable microhabitats for plant establishment in these areas, were also tested.

2. Material and Methods

2.1 Study site description

The restoration plots are situated on the farm Lovedale in the Nama Karoo Biome in the Northen Cape Province of South Africa approximately 40 km south east of the small town of Pofadder (Figure 1).

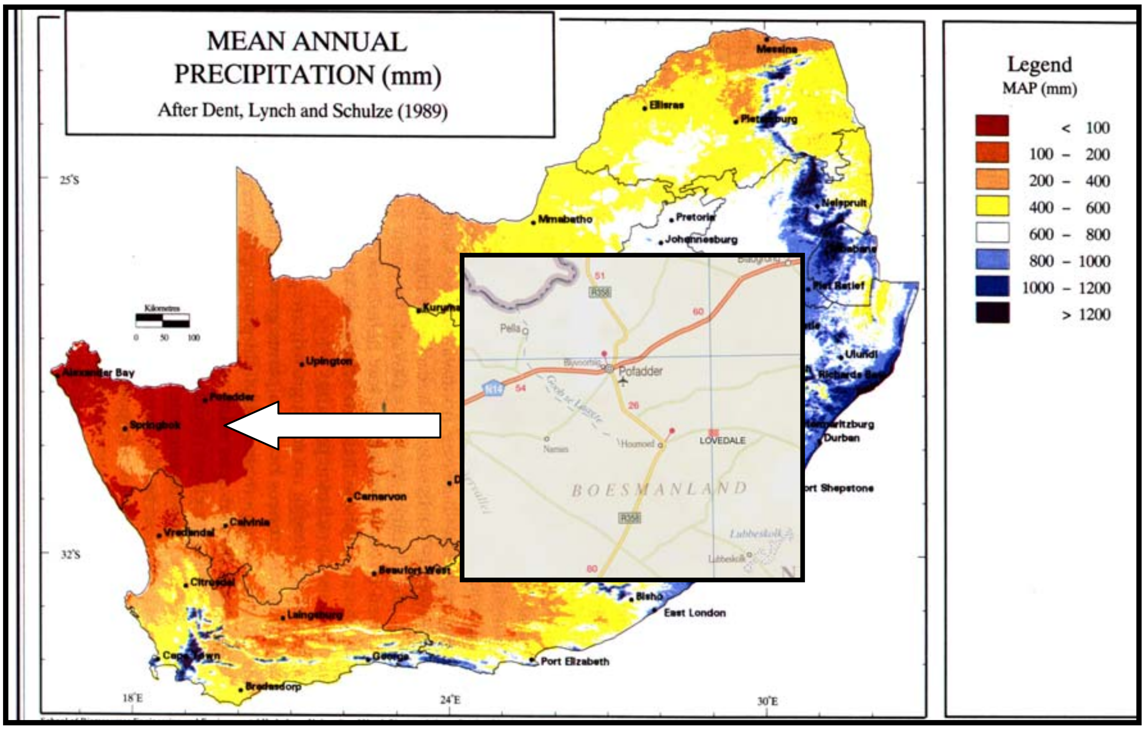

Figure 1 The mean annual precipitation of South Africa (Tainton and Hardy, 1999)

The Nama Karoo Biome occurs on the central plateau of the western half of South Africa. This is the second largest biome in this region. The geology of this biome varies as the distribution of this biome is determined primarily by rainfall. The rainfall in this biome is extremely varied and can be as high as 520mm per annum to as low as 100mm per annum. The soils in this biome are prone to erosion and this is aggravated where over-utilization of the veld has occurred. The dominant vegetation in this biome is a grassy, dwarf shrub land. Grasses tend to be more common in depressions or drainage lines on sandy soils. Less than 1% of the biome is protected in formal conservation areas. The major land use in this area is grazing for domestic animals, especially sheep and goats (Low and Rebelo, 1998). The veld type occurring in the Pofadder region is known as Orange River Nama Karoo (Low and Rebelo, 1998) or Namaqualand Broken Veld (Acocks, 1988). The Orange River

Nama Karoo veldtype is approximately 53 708 km^2 of which 1.47% is protected in formal conservation areas. The rainfall in this veld type is low, and unevenly distributed with late summer precipitation for the eastern part and late autumn for the western part.The Orange River Nama Karoo occurs on soils derived from the ancient basement granites and gneisses of the Namaqualand Mobile belt on the southern edge of the Richtersveld Craton. Red yellow apedal, freely draining young soils dominate most of the area. Deep alluvial soils occur along the Orange River (Low and Rebelo, 1998).

2.2. Establishment of reclamation site

A bare patch of approximately 120 m by 60 m was chosen as the experimental site (Fig 2). Four discreet eco-topes were identified in and around the bare patch. Two eco-topes in the bare patch itself consisted of water run-on and water run-off areas. No vegetation occurred on these areas and a hard soil crust characterized both. A gentle slope from west to east occurred across the whole of the bare patch as it was situated in a natural drainage line.

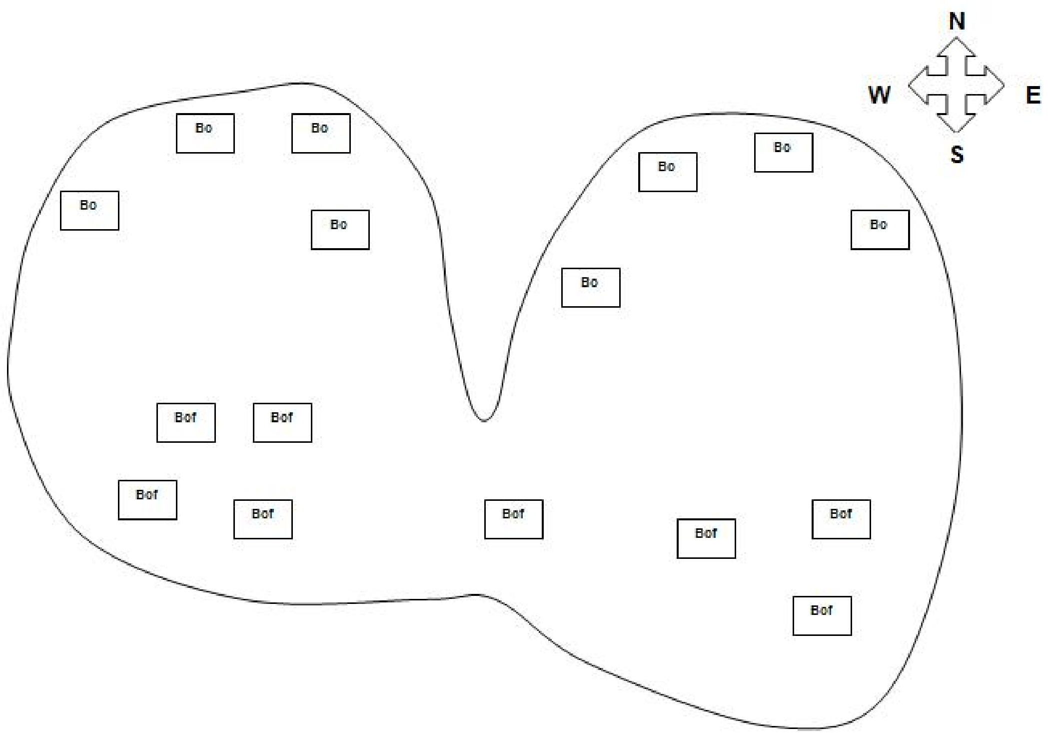

Figure 2 Graphic illustration of the bare patch and location of plots in the water run-on (Bo) and run-off (Bof) eco-topes. Not drawn to scale

Perennial grasses on very shallow soils underlain by calcrete dominated the northern boundary of the patch, while perennial grasses on deep sand dominated the southern boundary. The grasses on the southern boundary were denser and the tufts appeared larger. The eastern and western boundaries were dominated by *Rhigozum trichotomum* (Three thorn) with a few grasses interspersed between individual plants. A lone *Aloe dicotoma* stood on the western boundary of the site.

Each experimental plot consisted of four hand-dug furrows of approximately 2.5 m long. The rows were orientated in a north south direction so as to be perpendicular to the general slope of the main drainage line in which the bare patch was situated. The plots were prepared (December 2001) and a representative soil sample was taken at 10cm depth for each plot. The samples were pooled in two representative samples one for each eco-tope. The plots were sown in March 2002 (i.e. in the theoretical autumn rain period).

The soil samples were analysed for organic carbon (Walkley – Black), Ca, Mg, K, Na (Extractable Cations: Ammonium acetate (1 mol dm-3, pH 7)), extractable phosphorus (Bray – 1) and electrical resistance of the soil paste (The non-affiliated Soil Analysis Work Committee, 1990).

Figure 3 Illustration of typical experimental plot

2.3 Restoration treatments

Each row (four per plot) was regarded as a separate treatment. The plots were divided in two, to facilitate the application of brush packing treatments (Fig. 3). The treatments consisted of randomly seeding with two different species, brush packing or no brush packing and eight replications on each of the two eco-topes.

Each plot was split in two and brush packing with *R. trichotomum* was randomly allocated to two of the four rows (Fig 3). Each of the two rows was randomly seeded with approximately 50 grams of either, locally hand harvested, *Tetragonai calycina* or *Tripteris sinuatum* seeds. Each plot was replicated eight times on the water run-on, water run-off, *R. trichotomum* and grass eco-topes. Figure 2 graphically illustrates the position of the eight replications on the water run-on (Bo) en water run-off (Bof) eco-topes. The position of the plots in the other eco-topes is not illustrated as no plant establishment occurred in any of them and no data analysis was done for them.

2.3. Determining plant establishment

The germination percentage of the *T. calycina* was not tested prior to the trial. Untreated *T. sinuatum* seeds from the same locality had a germination percentage of 20% when exposed to light and 16% when it was not exposed to light (Venter and Rethman, unpublished). Van den Berg and Kellner (2005) also found that locally harvested grass seeds had a lower germination percentage than commercially available seeds. While *T. sinuatum* seeds are commercially available, *T. calycina* is not.

It was not possible to distinguish between plant species at the different seedling stages, and all plants, annuals and perennials, that germinated were counted in each of the eight rows of the plots. The plants were not identified and only the number of germinated plants was used in the data sets.

Five different observation times was used and counts were made in July 2002, August 2002, September 2002, January 2003 and March 2003 (i.e. 4, 5, 6, 10 and 12 months after seeding).

2.3 Data processing

The four different treatments (two species with brush packing or not) were grouped together; into two treatments namely brush packing and no brush packing. This was done because the species could not be identified and all the plants in the plots were counted, thus not testing for species differences. An analysis with the Proc GLM repeated measure analysis of variance model (Statistical Analysis System, 2001) was used to determine the significant difference between different localities (water run-on and water run-off), treatments (brush packing or no brush packing) and for interaction between treatments and localities for the different observation times (Samuels, 1989).

3. Results and discussion

The water run-on site had a significantly (P<0.05) higher plant establishment. No interaction between the treatments (brush packing) and the localities (water run-on and run-off) was found at any of the different observation times.

Table 1 LSMEAN values for plant establishment in two different eco-topes for five different observation times

	Plant establishment		
Locality	Water run-on	Water run-off	
	LSMEAN	LSMEAN	Pr > [t]
Observation time 1	11.59375	7.46875	0.0040
2	8.9375	6.1250	0.0063
3	10.15625	5.3125	0.0001
4	4.53125	2.84375	0.0846
5	1.96875	0.90625	0.0643

No significant differences (P>0.05) was found between the brush packing treatments at any of the observation times (Table 2)

The difference between the two eco-topes was significant (P<0.05) at the earlier observation times but not for the last two. Although these latter observations tend towards being significant and they are probably not significant due to the low counts that were observed during 2003 (Table 1).

While the water run-on and run-off sites had plant establishment the other eco-topes (data not analysed) had no plants at all. The water run-on site had a higher organic carbon percentage and a higher Ca content than the water run-off sites (Table 3).

Perennial grasses were found to have established on the water run-on plots in the 2005-growing season (pers comm. N.F.G. Rethman)[1]. The fertility of the water run-on eco-tope was higher except for the percentage carbon, Ca, Mg, and a higher resistance.

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Table 2 LSMEAN values for plant establishment for two different treatments over five different observation times

	Plant establishment		
Treatments	Brush packing	No Brush packing	
	LSMEAN	LSMEAN	Pr > [t]
Observation time 1	9.5625	9.5	0.9638
2	7.78125	7.28125	0.6153
3	7.875	7.59375	0.7407
4	3.875	3.500	0.6978
5	1.34375	1.53125	0.7402

Interestingly the Na was lower in the run-on site than in the run-off site, indicating possible leaching at this site. Due to the soil samples being taken only to a depth of 10cm, deeper layers could have had a higher salt load. This would have to be investigated further especially, if this eco-tope is going to be used as a focal point for woody pant establishment. In which case halophytic species might be preferred.

Table 3 Soil sample results for water run-on (Bo) and water run-off (Bof) eco-topes

	Water run-on (Bo)	Water run-off (Bof)
P	19.6	17.3
Ca (mg/kg)	1071	869
K (mg/kg)	297	265
Mg (mg/kg)	584	420
Na (mg/kg)	54	93
Resistance (ohm)	900	420
pH	8.8	8.4
Organic carbon (%)	0.18	0.09

It is believed that a higher water run-on and infiltration in the water run-on eco-tope is the main driving force for the better plant establishment as this is the major limiting factor for plant establishment in arid areas and the brush packing had no significant effect. The lack of any result from the brush packing treatment, which was envisaged as a protection against herbivory as well as creating a favourable micro-climate for seedling establishment, might have been due to the lack of success in anchoring the brush, with the result that no consequential treatment effect was obtained, with the dispersal of brush by the wind being a major factor. The organic carbon content of the soil could play a role in the water retention capabilities of the soil and needs further investigation.

5. Conclusion

The correct choice of microhabitat to establish plants in arid areas could play an important role in the conservation of plant species in the arid zones of South Africa. The establishment of perennial grasses in the water run-on eco-tope suggests that it is possible to shorten the time scale for perennial grass recovery in arid areas. This is contrary to the long timescale needed when livestock removal from an area is the only management input (Valone et al., 2001), and suggests that these areas are in different stable states or disequilibrium. The establishment of perennial grasses would alleviate some of the pressure on the surrounding vegetation, as it forms a major part of the diet of most grazing animals.

Vegetated mounds were found to create changes in the local microclimate and soil properties of arid environments (El-Bana et al., 2003). Further investigation of establishing desirable woody species is suggested in water run-on sites, as the attempt to establish two palatable woody species from seed was not successful in this instance. It is suggested that using seedlings could prove to be more effective in the establishment of palatable woody species on selected sites. Such established sites could then act as focal points for plant establishment similar to the vegetated mounds (El-Bana et al., 2003) creating favourable microhabitats and playing a vital role in linking sensitive environments and establishing possible plant migration routes. It is concluded that the major limiting factor for plant establishment in arid environments is water. Local sites with water run-on are more successful in the establishment of plants in arid environments.

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Chapter 6

Prepared according to the author guidelines for The Journal of Arid Environments

The reaction of *Atriplex nummularia* and *Cassia sturtii* to different planting and pruning treatments in the arid Northern Cape Province of South Africa.

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Abstract

The establishment and reaction of *Atriplex nummularia* and *Cassia sturtii* were tested for season of planting and the use of a stone mulch at two locations in the Northern Cape Province of South Africa. No significant reaction was found with the use of a stone mulch. A significant difference in the reaction of both species was, however, found between the autumn and spring planting seasons. Both species were subjected to four different pruning treatments. *A. nummularia* reacted the best to moderate pruning treatments at one of the locations and showed no reaction to pruning at the other. *Cassia sturtii* reacted best in terms of re-growth, at both locations, to heavy pruning treatments.

Keywords: Arid, *Atriplex nummularia, Cassia sturtii*, Planting treatments, Pruning treatments.

1. Introduction

Fodder shrubs have the potential to form part of integrated management systems in many parts of the world, especially in arid areas, or areas that have previously been disturbed (Ben Salem et al., 2002). Kadereit et al., (2005) reported that the chenopods, of which *Atriplex nummularia* is one, are particularly successful in dry, saline or disturbed habitats of temperate and subtropical climates in the northern and

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southern hemisphere. *Cassia sturtii* is a legume fodder shrub, originating in Australia and used in the arid zones of Africa and other areas (Ventura et al., 2004).

There are many ecological, economic and social benefits if fodder shrubs are used correctly as part of integrated holistic management programmes. The potential dangers such as the invasion of exotics, should, however be kept in mind. In arid areas shrubs have the potential not only to be used as an alternative feed source, but also as a stabilizing agent. Shrubs are considered to be a cost effective fodder resource for ruminants in many countries (Ben Salem et al., 2005). Ecologically speaking the shrubs can create microhabitats for other plants to become established, apart from the soil stabilizing and erosion control advantages (Abou El Nasr et al., 1996; Andreu et al., 1998). Both Chisci and Martinez (1993) and Chisci et al. (2001) reported on the beneficial effects of *A. halimus* on physical soils properties and the reduction of erosion on clay soils in the Mediterranean. Economically shrubs can be used to buffer the effects of droughts, and have the potential to increase livestock production (Chriyaa et al., 1997a; Chriyaa et al., 1997b). The economic effect then has a direct influence on the social aspects, by providing a more sustained income. Such fodder sources can also alleviate the effects of droughts in arid areas, where droughts are the norm and not the exception, due to the varied probability in rainfall events.

Concentrate feeds are often in a limited or seasonal supply and are often very costly in arid or marginal areas. The use of fodder shrubs to supplement animals, as an alternative to costly concentrates should, therefore, be considered for such marginal areas (Ben Salem et al., 2004). Production from these shrubs may be considered for own use and/or as an alternative source of income. The shrubs can be used in part to diversify the production system currently in use and as an alternative source of income. Abou El Nasr et al. (1996) found that silage made from *Acacia* and *Atriplex* provided sufficient digestible nutrients to meet energy and protein requirements for maintenance requirements of sheep.

Many areas are characterized by saline water. This is especially so in arid areas with high evaporation rates. If saline water can be used to produce halophytic fodder shrubs, such as *Atriplex*, these plants can be become an important feed resource for small ruminants in these areas (Swingle et al., 1996).

According to the model of Guevara et al. (2003) *A. nummularia* can be used economically for goat production on the plains of Argentina with a mean annual rainfall of 175mm. It should be noted that the production in this area is based on a saline water table at approximately 5 to 10 m deep. It does, however, show that fodder shrubs can be used economically as a feed source to improve livestock production. It is suggested that similar models be tested for other areas where the use of fodder shrubs can be economically and ecologically beneficial. The highest input cost for the model of Guevara et al. (2003) was fencing of the saltbush plantations. This could be reduced, or eliminated, where camps are already in use. By using an existing camp and positioning the plantation in the corner of a fenced camp / paddock it is also possible to halve the cost of fencing due to the use of the existing fence. Malcolm et al. (1988) indicated that it might be possible to reduce establishment costs, without sacrificing yield, by planting fewer bushes per hectare if larger species are used. Additional capital costs that need to be considered are irrigation or water harvesting structures, because when annual rainfall drops below 200 – 250 mm, additional water from runoff or irrigation is mandatory for improving production (Le Houerou, 1984). Abu-Zanat et al. (2004), however, found that the increase in production with the use of water harvesting structures justified the capital outlay of water harvesting structures.

Erosion and evaporation as well as water scarcity are limiting factors for agricultural production in arid regions (Frede et al., 1994). The use and testing of simple technologies to improve water infiltration and reduce evaporation is thus needed. Xie et al. (2005), states that a gravel mulch significantly decreased evaporation from soil surfaces. Geddes and Dunkerley (1999) found that gravity drops released from desert shrubs may provide both a erosive force beneath these plants and a means for dispersing litter from the plants into the surrounding landscape, where litter may continue to affect hydrological and erosion processes. By limiting splash from mineral particles, litter acts to limit soil splash from beneath shrubs. In this way may contribute to the persistence of plant mound micro-topography that is common in desert shrublands. Certain plant species should also benefit more from stone mulches than others. *A. canescens* and *Atriplex confertifolia* are reported to have a shallow root system (<2.5 m) and survive summer droughts while maintaining their leaf area (Hacke et. al., 2000). Plants with a deeper root system should be able to utilise deeper moisture remaining from winter recharge in the winter rainfall areas (Hacke et. al., 2000), thus the deeper rooted species would in theory benefit less from stone mulches than the shallow rooted species, even though some have the ability to survive summer droughts.

The management of fodder plantations are of the utmost importance. Optimising survival and production for a plantation is needed, especially taking the initial capital input cost into consideration. Abu-Zanat et al. (2004) reported that intensity of cutting/pruning had a highly significant effect on the potential of re-growth of *A. nummularia* and *A. halimus*, where cutting at 45cm enhanced the amount of re-growth. Different cutting intensities had no significant effect on the survival of the treated shrubs, which indicates the high tolerance of saltbushes to cutting or browsing. Cutting might also influence plants by optimising reaction to light. Jefferson and Pennacchio (2005) reported that light might be an important limiting factor in the community structure of a chenopod shrubland. When two plants are in close proximity, not only will they compete for light, they may also be competing for the available soil nutrients and moisture. A complex relationship, therefore, exist between above and belowground competition between plants. Branching, root growth and leaf production may be suppressed when light intensities are below the optimal levels required.

Many shrubs, used as fodder in arid areas, have the potential to become invasive. Zalba et al. (2000) warns that invasion by exotic plants is one of the main threats to the conservation of biodiversity. These invasive species, once established, can often be difficult to eradicate and the impact on natural communities and ecosystems can be very serious. Zalba et al. (2000) developed a model to determine the probability of *A. nummularia* establishment in Argentina and concluded that these kinds of models can aid the management of exotic species.

Huston (2004) states that many properties of plant invasions can be predicted on the basis of environmental conditions that affect both native and exotic species, and that the severity of impact vary independently over environmental gradients. The critical environmental properties for predicting invasibility are productivity, which is influenced by climate and soils and disturbance regimes. Understanding landscape variation in the probability and impact of invasion by exotic species, should allow development of more efficient monitoring programmes for exotic invasions, more effective control and better prioritisation of control programmes.

This study concentrated on the influence of different planting seasons and the use of stone mulches in establishing *A. nummularia* and *C. sturtii*. It also investigated the reaction of these species to different pruning treatments.

2. Material and Methods

2.1 Study site description

The research plots are situated on the farms “Lovedale” and “Klipkoppies” in the Nama Karoo Biome in the Northen Cape Province of South Africa. “Lovedale” is situated approximately 40 km south east of the small town of Pofadder while Klipkoppies is situated between Upington and Kenhardt (Figure 1). Kenhardt is in the same Biome (Nama Karoo Biome) and veldtype (Orange River Nama Karoo) as Pofadder (Low and Rebelo, 1998). Acocks (1988) described the region around Kenhardt as Orange River Broken Veld. The typical Orange River Broken Veld occurs on a variety of rocks e.g. banded ironstone, dolomite, quartzite and granite. Altitude ranges from 750 – 1350 m above sea level and rainfall from 150 – 350 mm per annum. Owing to its proximity to the permanent water of the Orange River, it is as a rule degraded close to the river (Acocks, 1988).

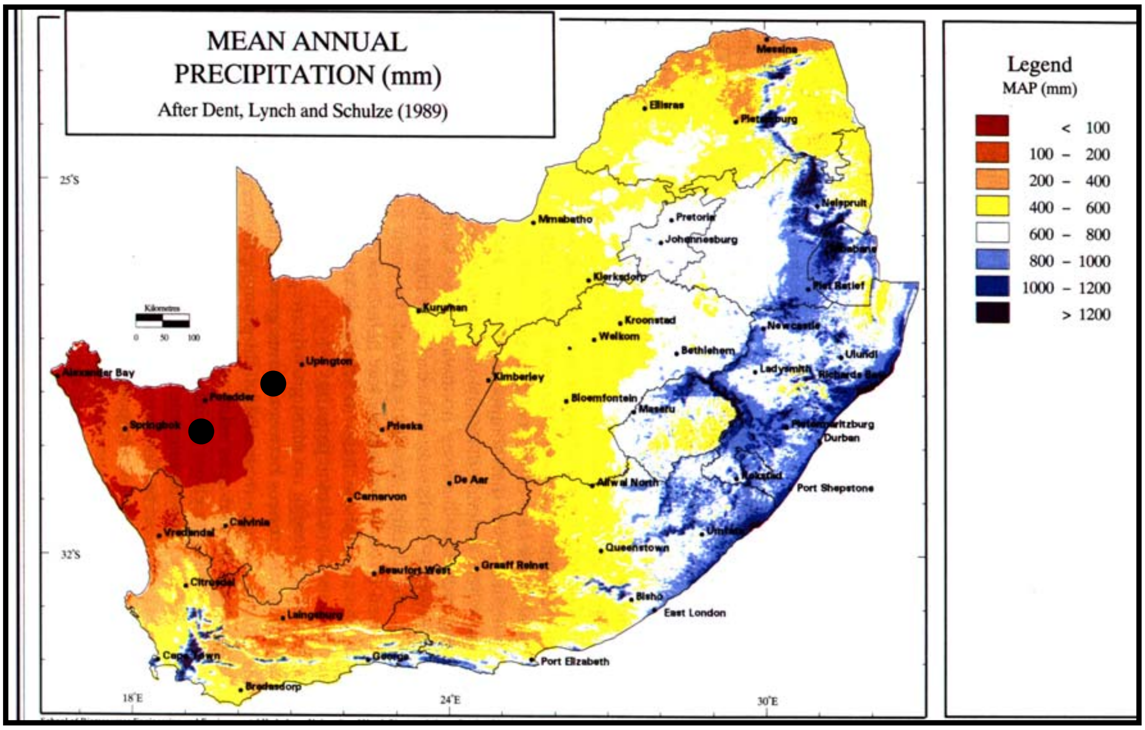

Figure 1 The mean annual precipitation of South Africa (Tainton and Hardy, 1999)

The Nama Karoo Biome occurs on the central plateau of the western half of South Africa. This is the second largest biome in this region. The geology of this biome varies as the distribution of this biome is determined primarily by rainfall. The rainfall in this biome is extremely varied and can be as high as 520mm per annum to as low as 100mm per annum. The soils in this biome are prone to erosion and this is aggravated where over-utilisation of the veld has occurred. The dominant vegetation in this biome is a grassy, dwarf shrub land. Grasses tend to be more common in depressions or drainage lines on sandy soils. Less than 1% of the biome is protected in formal conservation areas. The major land use in this area is grazing for domestic animals, especially sheep and goats (Low and Rebelo, 1998). The veld type occurring in the Pofadder region is known as Orange River Nama Karoo (Low and Rebelo, 1998) or Namaqualand Broken Veld (Acocks, 1988). The Orange River Nama Karoo veldtype is approximately 53 708 km^2 of which 1.47% is protected in formal conservation areas. The rainfall in this veld type is low, and unevenly distributed with late summer precipitation for the eastern part and late autumn for the western part. The long term climatic parameters of Pofadder (Lovedale) and Kenhardt (Klipkoppies), which are the closest towns to the two sites are given in Table 1. The Orange River Nama Karoo occurs on soils derived from the ancient basement granites and gneisses of the Namaqualand Mobile belt on the southern edge of the Richtersveld Craton. Red yellow apedal, freely draining young soils dominate most of the area. Deep alluvial soils occur along the Orange River (Low and Rebelo, 1998).

Table 1 Climatic parameters for Pofadder and Kenhardt (Agricultural Research Council)[1]

Site	Average Rainfall (mm)	Average Temperature °C	
		Min	Max
Pofadder	112.6	11.25	25.56
Kenhardt	140.1	12.02	28.53

2.2. Establishment of planting sites

Both sites were planted with seedlings produced on the Hatfield Experimental Farm of the University of Pretoria. Both sites were prepared, fenced and planted in March 2002 and again in August 2002. Twenty-four plants of both *Atriplex nummularia* and *Cassia sturtii* were planted at each planting date, which gave a total of 48 plants per species for each site. The spacing for both sites was 2m X 2m between plants and

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rows, which gives a plant density of 2500 plants per hectare. Figure 2 shows the experimental site for Kenhardt. On “Lovedale” parallel-planting furrows were prepared with a tractor and plough. An even soil depth of approximately 40 cm covered the site. Four representative soil samples were taken from this site and pooled. The planting holes were dug by hand at “Klipkoppies” and two distinct soil types occurred on this site. One half of the site was dominated by a hard limestone layer overlain by shallow sandy soils, whereas, the other half was dominated by deeper sandy soils. Two representative soil samples were taken for each soil type and pooled. The soil samples were analysed for organic carbon (Walkley – Black), Ca, Mg, K, Na (Extractable Cations: Ammonium acetate (1 mol dm-3, pH 7)), extractable phosphorus (Bray – 1) and electrical resistance of the soil paste (The non-affiliated Soil Analysis Work Committee, 1990). The soil sample results are presented in Table 2.

Table 2 Soil sample results for “Klipkoppies” and “Lovedale”

	“Klipkoppies”		“Lovedale”
	Deep soils	Shallow soils	
P (mg/kg)	66.3	76.7	20.6
Ca (mg/kg)	1471.0	1613.5	2244.3
K (mg/kg)	530.5	514.5	628.0
Mg (mg/kg)	219.5	215.0	134.7
Na (mg/kg)	97.5	102.5	200.3
Resistance (ohm)	1125.0	1100.0	930.0
pH ($H_2 0$)	9.0	9.4	9.3
Organic carbon (%)	0.2	0.3	0.1

Rocks from the surrounding area were used for the stone mulch treatment. The rocks had an average diameter of approximately 10 cm for the Kenhardt site and approximately 5cm for the Pofadder site. During the subsequent growing seasons the normally arid experimental site at “Lovedale” was characterised by several consecutive dry seasons and supplementary water was applied to the experiment at 6 – 8 week intervals in the summer and 12 – 16 week intervals in winter up until the end of the 2003/2004 growing season.

The site at Kenhardt received supplementary water every 6 – 8 weeks until January 2005 when all supplementary water was stopped. Plants were pruned in September 2004 at both locations.

Figure 2 Illustration of experimental plot at Kenhardt

2.3 Planting and Pruning treatments

Two different species *A. nummularia* and *C. sturtii* with two planting times (a spring planting (March 2002) and an autumn planting (August 2002)) were used at both sites. A stone mulch treatment was also used at both sites, with two different soil types at the Klipkoppies site. Each treatment plot consisted of three individual plants. The planting treatments with the replications for "Lovedale" are presented in Table 3. The different species were not seen as a separate treatment as the species were not compared with each other due to the large difference between the species. The plots were divided in two, each side representative of a planting date (Spring or Autumn) with the treatments completely randomized within each planting time.

Table 3 Planting treatments at "Lovedale"

Treatments			
Planting time	Mulch	Replication	Number of plants
Spring	Stone mulch	4	12
Spring	No stone mulch	4	12
Autumn	Stone mulch	4	12
Autumn	No stone mulch	4	12

Four pruning treatments were completely randomized over all the planting treatments. The effect between planting and pruning treatments was not tested for. The pruning treatments are presented in Table 4. Not only the heights of the plants, but also the diameters of the plants, were pruned to leave a plant, which closely resemble a cylinder. Each individual pruned plant was a replication for the specific treatment.

Table 4 Pruning treatments of *Atriplex nummularia* and *Cassia sturtii* at "Lovedale"

Treatment	*Atriplex nummularia*		*Cassia sturtii*	
	Height (m)	Replications	Height (m)	Replications
1	Control	12	Control	11
2	0.8	12	0.75	11
3	0.6	12	0.5	11
4	0.4	12	0.25	11

The planting treatments for "Klipkoppies" are presented in Table 5 and the four pruning treatments are presented in Table 6.

Table 5 Planting treatments at "Klipkoppies "

Treatments			Replications	Number of plants
Planting time	Stone mulch	Soil type		
Spring	Stone mulch	Deep	2	6
Spring	Stone mulch	Shallow	2	6
Spring	No stone mulch	Deep	2	6
Spring	No stone mulch	Shallow	2	6
Autumn	Stone mulch	Deep	2	6
Autumn	Stone mulch	Shallow	2	6
Autumn	No stone mulch	Deep	2	6
Autumn	No stone mulch	Shallow	2	6

As at "Lovedale" not only the height but also the diameter of the plants was pruned to resemble a cylinder. All pruning treatments were randomly allocated over the whole experimental site and all planting treatments. The effect between planting and pruning treatments was not tested for.

Table 6 Pruning treatments of *Atriplex nummularia* and *Cassia sturtii* at "Klipkoppies"

Treatment	*Atriplex nummularia*		*Cassia sturtii*	
	Height (m)	Replications	Height (m)	Replications
1	Control	12	Control	11
2	1.5	12	1.0	11
3	1.0	12	0.7	11
4	0.5	12	0.4	11

2.3. Determining plant adaptation and reaction to pruning

To compare the reaction of A. *nummularia* to the different planting treatments, the height and diameter of each plant at both sites was measured in May 2004. These measurements were used to determine the plant volumes according to the equation for a cylinder.

Volume (m^3) = $\pi r^2 * h$
π = 3.14159
r = radius (m)
h = height (m)

It was assumed that a bigger least square mean volume would be an indication of a better reaction to a planting treatment. Volume was only used as a measure to compare between the different treatments within one species. Each location was analysed separately because of the soil and climatic differences.

To compare the reaction of *C.sturtii* to the different planting treatments, the height of each plant was measured in May 2004. It was assumed that a higher least square mean height would be an indication of a better reaction to a planting treatment within this species. Results are presented in Table 7 for "Lovedale" and Table 9 for "Klipkoppies". It should be noted that the results for both species are presented in these tables, but that the species, were not compared to each other, as the one measurement is in m^3 (Volume) and the other in meters (height).

Plants at both locations were subjected to the pruning treatments in September 2004, and all plants were measured after pruning as previously described. Measurements were again taken in April 2005, and the difference between the two measurements was determined for each pruning treatment. A larger difference in volume for *A. nummularia* and height for *C. sturtii* was assumed to be an indication that the plant reacted better to a specific pruning treatment. Results are presented in Table 8 for "Lovedale" and Table 10 for "Klipkoppies" respectively. The treatments in these tables correspond to the treatments described in Table 4 and Table 6 respectively.

The volume of the *A. nummularia* and the height of the *C. sturtii* were not used to estimate production and further destructive harvesting studies are needed to validate a regression between volume and production for these two species under these environmental conditions.

2.3 Data processing

The data for each species at the two locations were analysed separately. The data for each species at a location were subjected to an analysis of variance with the Proc GLM model (Statistical Analysis System, 2001) and this was used to determine the significance between different planting treatments (height and volume differences). Means and standard deviations (SD) were also calculated. Significant differences (P>0.05) between means were determined by the Fischer test (Samuels, 1989). The difference in volume and height was used as the variable parameter and subjected to similar analyses to determine the significant differences between the pruning treatments.

3. Results and discussion

The reaction of *A. nummularia* and *C. sturtii* on the farm “Lovedale” to different planting seasons and the use of a stone mulch is presented in Table 7. The data for each of the two species was analysed separately, and should thus be interpreted independently from each other. *A. nummularia* reacted significantly (P<0.05) differently to the two planting times (Pr > 0.0063) with a definite advantage of spring planting on “Lovedale”. No significant difference (P>0.05) was found between the two planting times for *C. sturtii* (Pr > 0.0604) at this location. No significant difference (P>0.05) was found between the use of a stone mulch for *A. nummularia* (Pr > 0.9864) or for *C. sturtii* (Pr > 0.4515). This might be due to the supplementary watering.

A significant difference (P<0.05) was found for the no mulching treatment between the spring and autumn season for *A. nummularia* (Pr > 0.0052). This result is, however, of no great importance, as the spring planting date was significantly better for this species at this location as previously stated. *A. nummularia* thus only reacted significantly to planting season on “Lovedale”.

A significant difference (P<0.05) was found for the stone mulching treatment between the spring and autumn planting season (Pr > 0.0301) for *C. sturtii* on “Lovedale”. This of no real importance due to practical considerations, where planting of a site would normally only occur in either spring or autumn. Thus no reaction was exhibited, by *C. sturtii,* to either mulching or time of planting on “Lovedale”.

Table 7 The reaction of *A. nummularia* and *C. sturtii* to different planting seasons and the use of a stone mulch on the farm "Lovedale"

	VOLUME (m^3) *Atriplex nummularia*		HEIGHT (m) *Cassia sturtii*	
	Spring	Autumn	Spring	Autumn
Stone mulch	LSmean (SD)		LSmean (SD)	
No mulch	$1.58 (0.831)^{a}_{1}$	$0.83 (0.356)^{a}_{2}$	$0.89 (0.157)^{a}_{1}$	$0.91 (0.147)^{a}_{1}$
Mulch	$1.35 (0.686)^{a}_{1}$	$1.06 (0.516)^{a}_{1}$	$0.79 (0.179)^{a}_{1}$	$0.94 (0.116)^{a}_{2}$

^{ab} Column mean with the same superscript do not differ significantly (P>0.05)

$_{12}$ Row means with the same subscript do not differ significantly (P>0.05)

The results for the different pruning treatments on *A. nummularia* and *C. sturtii* at "Lovedale" are presented in Table 8. The results for the two species at this location were analysed separately, and the treatments correspond to the treatments described in Table 4.

No significance (P>0.05) was found between any of the pruning treatments for *A. nummularia* on "Lovedale". There was no significant difference between treatment 1 and 2, and between treatment 3 and 4, for *C. sturtii*, however, a significant difference (P<0.05) between these two treatment groupings was found (Table 8). *C. sturtii* thus reacted more favourably to severe pruning (0.5m – 0.25m) than to the 0.75m and control treatments on Lovedale.

Table 8 The reaction of *A. nummularia* and *C. sturtii* to different pruning treatments on the farm "Lovedale"

	VOLUME (m^3) *Atriplex nummularia*	HEIGHT (m) *Cassia sturtii*
	LSmean (SD)	LSmean (SD)
Treatment 1	$1.34 (0.952)^{a}$	$0.23 (0.086)^{a}$
Treatment 2	$2.55 (2.155)^{a}$	$0.31 (0.131)^{a}$
Treatment 3	$2.08 (1.265)^{a}$	$0.45 (0.095)^{b}$
Treatment 4	$1.95 (1.242)^{a}$	$0.55 (0.131)^{b}$

^{ab} Column mean with the same superscript do not differ significantly (P>0.05)

The reactions of *A. nummularia* and *C. sturtii* to different planting seasons, soil types and a stone mulch on the farm “Klipkoppies” are presented in Table 9. The data for each of the two species were analysed separately and should thus be interpreted independently from each other. Significant differences (P<0.05) were only found with *C.sturtii* spring planting between any of the soil or mulch treatments. A significant difference (P<0.05) was, however, found between the season of planting for both *A. nummularia* (Pr > 0.0067) and *C. sturtii* (Pr > 0.0272), both species reacting better to the spring planting season.

Table 9 The reaction of *A. nummularia* and *C. sturtii* to different planting seasons, soil types and a stone mulch on the farm “Klipkoppies”

		VOLUME (m^3)		HEIGHT (m)	
		Atriplex nummularia		*Cassia sturtii*	
		Spring	Autumn	Spring	Autumn
Soil type	Stone mulch	LSmean (SD)		LSmean (SD)	
Deep	No mulch	$12.40(4.443)^{a}_{1}$	$8.98(2.563)^{a}_{1}$	$1.53(0.116)^{a}_{1}$	$1.25(0.133)^{a}_{2}$
Deep	Mulch	$11.16(5.178)^{a}_{1}$	$10.28(2.068)^{a}_{1}$	$1.42(0.093)^{ab}_{1}$	$1.26(0.174)^{a}_{1}$
Shallow	No mulch	$14.41(5.769)^{a}_{1}$	$8.45(3.785)^{a}_{2}$	$1.24(0.162)^{b}_{1}$	$1.04(0.529)^{a}_{1}$
Shallow	Mulch	$12.32(3.543)^{a}_{1}$	$9.27(3.099)^{a}_{1}$	$1.22(0.108)^{b}_{1}$	$1.25(0.198)^{a}_{1}$

^{ab} Column mean with the same superscript do not differ significantly (P>0.05)

$_{12}$ Row means with the same subscript do not differ significantly (P>0.05)

No difference was found in the spring planting season between the use of mulch on the deep soils (Pr > 0.4196) or on the shallow soils (Pr > 0.9007) for *C. sturtii.* There was, however, a significant difference (P<0.05) between the plants on the deep soils and shallow soils, except for the mulch treatment on the deep soil, which did not differ from the shallow soils treatments. *C. sturtii* planted in autumn showed no significant difference (P>0.05) between the mulching treatments and soil types (Table 9).

The results for the reaction of *A. nummularia* and *C. sturtii* to different pruning treatments on the farm “Klipkoppies” are presented in Table 10. The results for the two species at this location were analysed separately, and the treatments correspond to the treatments described in Table 6.

There was a significant difference ($P<0.05$) between treatment 1 and 2 and between 2 and 4 for the pruning of *A. nummularia*. No significant differences ($P>0.05$) were found between treatments 2 and 3 or between treatments 3 and 4. *A. nummularia* had the best reaction to treatments 2 and 3 (1.0 – 1.5m). Interestingly enough the plants in the control (treatment 1) became smaller, indicating that no pruning was detrimental to *A. nummularia* under these conditions. *C. sturtii* reacted significantly differently ($P<0.05$) to all four pruning treatments with the best reaction to treatment 4 (0.4m) the most severe pruning treatment.

Table 10 The reaction of *A. nummularia* and *C. sturtii* to different pruning treatments on the farm "Klipkoppies"

	VOLUME (m^3) *Atriplex nummularia*	HEIGHT (m) *Cassia sturtii*
	LSmean (SD)	LSmean (SD)
Treatment 1	-1.17 (3.303)^{a}	0.10 (0.059) ^{a}
Treatment 2	5.72 (4.433)^{b}	0.19 (0.087) ^{b}
Treatment 3	3.82 (2.683)^{bc}	0.35 (0.116) ^{c}
Treatment 4	2.99 (1.774)^{c}	0.44 (0.077) ^{d}

^{ab} Column mean with the same superscript do not differ significantly ($P>0.05$)

5. Conclusion

The establishing of fodder plantations is costly, and the correct planting methods are required to ensure success, and reap the highest rewards. Correct management of fodder plantations after establishment is essential not only for survival of the plants but also to optimize fodder production. This is essential in marginal and arid areas, where these fodder plantations are a valuable fodder resource during droughts, which are the norm and not the exception. The fodder plantations can also be used to alleviate some of the pressure on the natural veld, at critical times, to improve flowering and seed production of the natural vegetation and so aid in reclamation of degraded areas.

A. nummularia and C. *sturtii* did not react to the use of a stone mulch, which could be due to the use of supplementary watering, which probably offset the benefits of the mulch, water being the limiting factor at both locations. *A. nummularia* performed best when planted in the spring season at both locations. *C. sturtii*, however, exhibited no difference in performance with either spring or autumn planting at "Lovedale". This might be due to the fact that *C. sturtii* is a temperate species and

"Lovedale" has a weak bimodal rainfall distribution. *C. sturtii* did, however, react best to the spring planting at "Klipkoppies", with is strong summer rainfall pattern.

Pruning can be used to simulate controlled utilisation. *C. sturtii* reacted favourable to severe pruning at both locations (0.5 – 0.25m at "Lovedale" and 0.4 m at "Klipkoppies"). It can thus be concluded that utilisation is beneficial to production for *C. sturtii*. It should be noted, however, that the same programme should still be tested over time. It is, therefore, important to still test how often one can utilise the plants in a production system. Further research regarding this is still needed.

A. nummularia did not show any significant reaction to any pruning treatment on "Lovedale". Interestingly enough the plants in the control treatment at "Klipkoppies" decreased in size, indicating that it should be utilised to maintain plant vigour and growth at this location. It also reacted favourably to a pruning treatment of 1.5 – 1m at "Klipkoppies". Utilisation of *A. nummularia* should also be tested over time to determine the best frequency of utilisation to optimise fodder production without reducing plant vigour.

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Chapter 7

General recommendations and conclusions

Work in arid environments must be long term. Many of the sites that were planted will only start to produce results under favourable climatic conditions. It is, therefore, critical that the work on these sites should continue and expand as our understanding of these areas increases. There is no “quick fix” for reclaiming degraded areas in arid environments. Most of Southern Africa consists of arid regions, which can be used sustainably as rangelands, but not for normal crop production. It is, therefore, vital to continue this work for extended periods.

A different way of approaching the problem could be to change the way people utilise these areas. Diversification of production systems might be the key to sustainable utilisation of these areas. The growing market for natural pharmaceutical products could be a solution. Production of medicinal plants as a cash crop might be one way to diversify a production system in these arid environments.

Using keystone species to increase the fertility of the soils and to promote autogenic succession should also be considered. These species are often leguminous which have the ability to increase the nitrogen content of the topsoil, thereby increasing the fertility of the soils.

Different incentives to protect the natural environment should also be examined. One possible approach is to give primary production (vegetation production) a monetary value. This could create the incentive for farmers to do reclamation work by giving an immediate return on the money spent on reclamation. The pressure on the natural veld could also be relieved because the farmer will not be solely dependent on livestock (capital) to obtain loans from banks. The farmer with the best veld would thus be rewarded and his property will also be worth more than the surrounding properties. The price or value of the property should then be determined by the condition of the veld and not only by market related prices.

Reclamation of the arid areas around the world should be based on a holistic approach taking environmental, economical and social factors into account. An ongoing coordinated research programme should be initiated and implemented to increase the knowledge on reclamation in these environments, including economists and social scientists.

The classical model of range succession clearly does not apply to all arid and semi-arid regions of South Africa. The state and transition model is a succession model that is a lot more applicable to arid and semi-arid regions. If a certain management programme is applied in combination with certain environmental factors, a threshold can be crossed and the community will move from one state to another (degradation, or improvement). The plant community will, however, not be able to cross that threshold by itself. To move a plant community back to a previous stable state energy inputs will be needed to cross the threshold. These energy inputs are usually in terms of management but must also take episodic environmental conditions into account, especially rainfall.

Many reclamation techniques are very costly and are unlikely to be offset by short-term benefits. The partial clearing of vegetation to alter water and nutrient availability, or reseeding to establish indigenous species, could possibly increase carrying capacity or the nature conservation value of such shrub lands. The further use of micro-catchments to establish selected key species can also be used to initiate autogenic restoration in degraded areas. These key species and micro-catchments can be used to concentrate nutrients, organic matter and water to form “fertile islands” in a degraded area. The benefits of water harvesting techniques have usually been short term and unsustainable in arid areas when the sole objective was the production of herbaceous fodder crops. When the aim is restoration and woody shrubs (keystone species) are used to change the micro-environmental conditions by harvesting wind blown soil and seeds, it might have the possibility of being a sustainable option. Keystone species are species believed to be essential to ecosystem structure and function, and their inclusion in a restoration programme may facilitate restoration of degraded ecosystems.

Strategies to increase water infiltration, such as water harvesting, can have a strong influence on plant establishment. Only a holistic approach to land reclamation in arid areas will prove to be successful in the long term. Certain strategies should be followed as part of a holistic restoration programme in degraded areas to improve natural resources. These strategies should include:

A better understanding of ecological processes is needed to make a real difference on a global scale. New and innovative use of technologies is needed in strategies degradation. The effects of global climate change on degradation and desertification are not known as yet and need further research. A holistic multi-disciplinary approach is needed if the problem of degradation is to be solved. No "quick fix" will be able to solve the problem and the fight against land degradation must be an ongoing process.

With a wealth of naturally occurring species, to choose from, criteria are needed to choose the most desirable species for reclamation. Such criteria should consider both ecological adaptations, and economic aspects. Is it possible to not only reclaim, but also to diversify production systems? Criteria to narrow down the choice of species were used and *S. microphylla* and *T. sinuatum* were chosen as two possible candidates for reclamation purposes. The next logical step would be to produce seedlings for the establishment of plantations, reseeding with the chosen species and to determine if the species in question would be able to reproduce naturally from core or nucleus areas. It is advisable to aim to simulate natural conditions during germination to break the dormancy if there is any. It is believed that this approach to germination trials should improve the success of germination.

It is concluded that criteria are needed for the choice of species for reclamation. Using and aiming to simulating natural dispersal mechanisms is necessary in treating seeds to ensure better germination, especially of *S. microphylla*, and that *Sutherlandia* species should be tested further for reclamation purposes. A crucial step is the ongoing research into its medicinal value and creating a market for such products. This would not only meet the ecological criteria but also the economic criteria to reduce some of the pressure on the natural environment, by diversifying production systems in an otherwise grazing production dependant area. Increasing and providing a more secure economic income should also have added social benefits. Thus a holistic approach is needed to reclamation, incorporating ecological, social and economic considerations.

The large variety of species in the Chenopodiaceae family and especially the different species in the *Atriplex* genus, which have evolved and adapted to a wide range of environmental conditions, makes it difficult to determine which species are best suited for a particular purpose in a certain area.

Testing different species for long-term survival and relative palatability in specific locations should reduce some of the guesswork often associated with choosing suitable species. This includes the local environmental conditions and the specific utilisation regime envisaged in that area.

It is concluded from this study that further investigations are needed concentrating especially on *A. nummularia, A. breweri, A. lentiformes* and *A. canescens* (FR1). Studies over longer time spans and at lower grazing pressures should also be undertaken to validate the results obtained in this study.

The correct choice of microhabitat to establish plants in arid areas could play an important role in the conservation of plant species in the arid zones of South Africa. The establishment of perennial grass in the water run-on eco-tope suggests that it is possible to shorten the time scale for perennial grass recovery in arid areas. This is contrary to the long timescale needed when only livestock are removed from an area and suggests that these areas are in different stable states or disequilibrium. The establishment of perennial grasses may also alleviate some of the pressure on the surrounding vegetation as they form a major part of the diet of many animals.

Further investigation onto the establishment of desirable woody species is suggested on water run-on sites, as the attempt to establish two palatable woody species from seed was not successful. It is suggested that using seedlings could prove to be more effective in establishing palatable woody species on selected sites. It is concluded that the major limiting factor for plant establishment in arid environments is water. Local sites with higher water run-on are more likely to be successful in the establishment of plants in arid environments.

Establishing fodder plantations is costly, and the correct planting methods are required to ensure success, and to reap the highest rewards. Correct management of fodder plantations after establishment is also essential for survival and optimal fodder production. This is particularly true in marginal and arid areas, where these fodder plantations are a valuable fodder resource during droughts, which are the norm rather than the exception. Such fodder plantations can also be used to alleviate some of the pressure on the natural veld, at critical times, to improve flowering and seed production of the natural vegetation and so aid in reclamation of degraded areas.

A. nummularia performed best when planted in the spring season. *C. sturtii*, however, showed no difference in performance with spring or autumn planting at “Lovedale”. This might be due to the fact that *C. sturtii* is a temperate species and “Lovedale” has a weak bimodal rainfall distribution. *C. sturtii* did, however, react best to a spring planting at “Klipkoppies” with is strong summer rainfall pattern.

C. sturtii reacted favourably to severe pruning at both “Lovedale” and “Klipkoppies”. It can thus be concluded that utilisation is beneficial to production for *C. sturtii*. It should be noted, however, that the same programme should still be tested over time. It is, therefore, important to determine how often one can utilise the plants in a production system and further research regarding this is still needed.

A. nummularia did not show any significant reaction to pruning on “Lovedale”. Interestingly enough the plants in the control treatment at “Klipkoppies” deteriorated, indicating that it should be utilised to maintain plant vigour and growth at this location. It also reacted favourably to a pruning treatment of 1.5 – 1m at “Klipkoppies”. Utilisation of *A. nummularia* should also be tested over time to determine the best frequency of utilisation to optimize fodder production without reducing plant vigour.