

**COST-EFFECTIVE, POST-MINING
ENVIRONMENTAL RESTORATION OF
AN OPEN-CAST PHOSPHATE MINE
AT LANGEBAANWEG, SOUTH AFRICA**

A thesis submitted in fulfilment of the

requirements for the degree of

MASTER of SCIENCE

at

RHODES UNIVERSITY

by

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December 2010

ABSTRACT

Approaching the ecological rehabilitation of an open-cast phosphate mine in the West Coast of South Africa during the post-operational phase presented some challenges. The area was extensively modified during the mining operations. Soils from different layers were mixed with topsoil being covered by subsoil, overburden dumps and tailing dams being constructed resulting in extensive cross-zoned soils. Large areas of subsoil areas were exposed on the mine floor with localized and small scale salinity being evident. The modified topography as well as the complex new surface material posed a challenge in terms of identifying suitable local species that could be used to rehabilitate the post-mining environment. The mine area was heavily infested with woody alien invasive plants, such as *Acacia cyclops*, established in an attempt to reduce the dust and little natural vegetation cover was present.

In the arid west coast environment, the four-month-long winter growing season is followed by hot and windy dry summers (Chapter 2) presenting a challenge re-establishing local vegetation in modified soils. Moreover, little was known about the local vegetation in terms of their propagation and use in stabilization techniques as an alternative to exotic vegetation such as the *A. cyclops*, which had been more often used in revegetation projects.

A study was conducted to determine the most efficient and cost-effective methods of vegetative rehabilitation of the Chemfos site (Chapter 1). A review of the literature available at the time as well as approaches that were successfully implemented in other Western Cape rehabilitation projects such as the Du Toitskloof Pass and the Sishen–Saldanha railway line (Chapter 3), were considered. Previous studies on the west coast dunes at Blaauwberg had shown using Marram grass as a dune stabilizer was most successful. Marram grass was tested in trials alongside local grasses, such as *Chaetobromus dregeanus* and *Ehrharta villosa*, that showed potential but had not been formally evaluated.

The environmental context of Chemfos (Chapter 2) as well as the Conceptual Rehabilitation Plan that considered the modified environment, soils and closure objectives of the mine, were reviewed to determine the most pressing rehabilitation-related questions that required answers. This led to the final experimental design that was implemented mid-winter in 1996 (Chapter 5). The trials were implemented in the areas perceived to be the most difficult to rehabilitate, namely the mobile sands in the

tailings dam and the exposed subsoil or mine floor areas. The use of brushwood together with specific plants and seeds appropriate for the use in either sandy soil or subsoil were evaluated in a variety of combinations and application densities to determine the most effective treatment combination at the minimum effective density. The best initial cover of the tailings dam were recorded in the *Ammophila arenaria* trials but the use of the local grass species *Ehrharta villosa*, performed better from year two onwards and was much cheaper to establish. On the subsoil, the trials where a cover of topsoil was used performed better than the combination trials. This indicated that topsoil placement on post-operational phase shaped subsoils during the mining operation to be the most desirable treatment.

Initial results of the trials were used as a basis for developing the rehabilitation techniques that were rolled out across the Chemfos landscape. The approaches were refined as indications of trial responses became evident. Lessons learned were incorporated in the adaptive management approach that was followed and the rehabilitation techniques (Chapter 6) were continually re-evaluated and adjusted. This resulted in a significant step towards achieving the overall research objective of finding cost-effective approaches to rehabilitation.

Components such as refinement of the seed collection and processing techniques (Chapter 7) where the post-harvest processing cost was significantly reduced by introducing specially designed drying racks. Processing techniques were adjusted to suit the different species, and a variety of mechanical processing options were explored. The scale of the Chemfos project led to the development of new techniques of manufacturing a smoke-derived germination stimulant (Chapter 8) since commercial availability of these products was very limited. The development of FireGrow assisted in the overall aim of reducing cost by increasing germination of seed in the rehabilitation sites using a very cost-effective smoke concentrate.

Socio-economical aspects were considered during the implementation as well as the post-closure phases of the rehabilitation and BHPBilliton invested through the agency of the SAMANCOR Trust. This led to the development of livelihoods of the staff that remained in the area and that lived in the mine village. The demography of the population has changed over time in the Green Village as well as the skills that the inhabitants have developed. Thus, the new economic opportunities that were pursued have brought a new lease on life beyond the lifespan of the mine (Chapter 9) once the closure certificate had been issued.

DEDICATION

Dedicated to:

Those who inspired

Those who endured

Those who toiled

Those who funded

Those who believe that a difference can be made

ACKNOWLEDGEMENTS

- BHPBilliton and the SAMANCOR Foundation for the vision to fund a sustainable post mining land use option.
- Dr Ted Avis and Prof. Roy Lubke of Coastal Environmental Services for the mentorship.
- Kobie Truter for her invaluable local knowledge, enthusiasm and support through the thirteen cycles of the four seasons.
- Pippa Haarhoff from IZIKO for the support and encouragement.
- The Staff of Vula Environmental Services who implemented the rehabilitation.
- Mannis Stenvert for enduring.

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CHAPTER 1. INTRODUCTION

Successful mine closure is a complex and multi-faceted process, particularly in the case of older mines that have been in operation for several decades without the benefit of a closure plan that integrates mining activities with closure goals and requirements. Some of these older mining operations were thus not designed with the rehabilitation of the site in mind, resulting in inadequate financial provisions for mine closure requirements.

At Chemfos, a disused phosphate mine situated approximately 15 km east of Saldanha Bay on the Cape West Coast of South Africa (Figure 1.1), the need to ensure minimum compliance with legislation in providing an appropriate, sustainable post-mining use of the mine, lead to the search for suitable techniques of rehabilitating the disturbed environment. A rehabilitation plan was partly formulated as a component of the exit strategy put forward by BHP Billiton. This mining company acquired the specific mining operations as a unit within the business of SAMANCOR (Pty) Ltd, a company that they acquired shortly prior to the decision to cease mining operations at Langebaanweg.

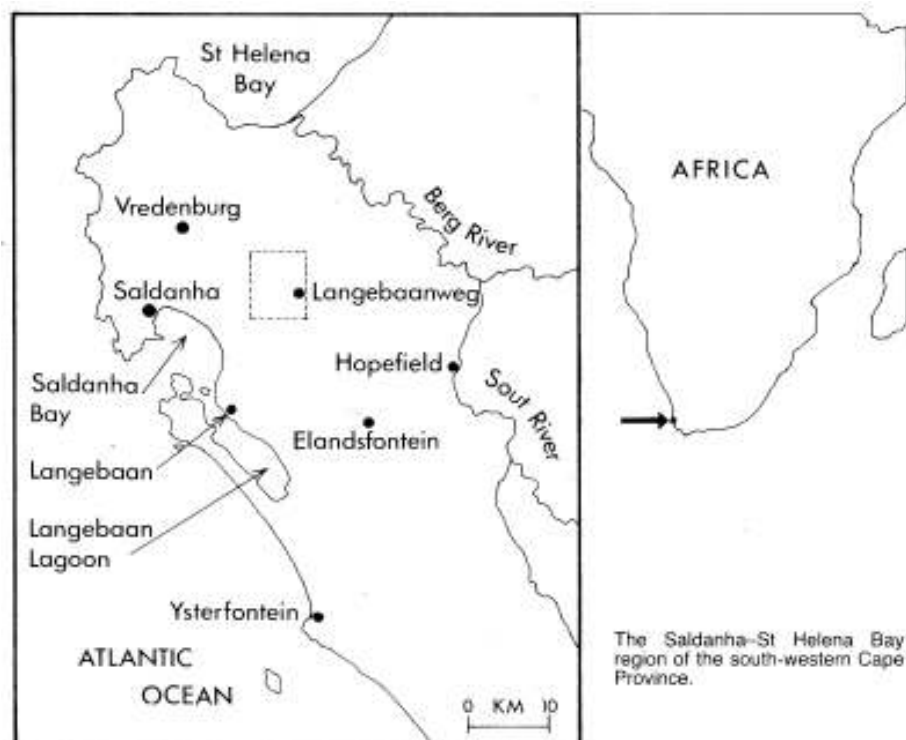


Figure 1.1: The Saldanha-St Helena Bay region of the Western Cape, showing the position of the Chemfos mine site (from Hendey, 1982).

The Chemfos Mine is located in a semi-arid environment with a long-term average rainfall of only 250 mm per annum, which poses specific challenges to vegetation rehabilitation. Furthermore, this harsh environment has supported a succession of land uses, as various layers of natural capital (Aronson *et al* 2007) found at Anyskop were exploited over the ages. The current, post-mining topography reflects the approximate paleo-topography of the early Pliocene. Phosphate deposits were formed in a marine environment when the sea levels were approximately 26 m higher than today (Hendey, 1981). Subsequent changes in sea levels and climate patterns have moulded the land, which has supported different fauna and flora at different stages in its evolution. Large-scale open-cast mining consumed the rich phosphate deposits, leaving the most dramatic evidence of natural capital consumption. The present-day Strandveld vegetation of the region has been destroyed by mining at Chemfos, and on adjacent properties, agriculture has reduced the pristine vegetation to a fragmented mosaic of degraded Strandveld and patches of thicket.

The rehabilitation plan for mine closure required the development of innovative techniques and a re-visit of proven approaches to ensure success in the restoration of this modified environment under the semi-arid conditions. This study aims to document and evaluate these techniques.

1.1 RESEARCH QUESTION

Large-scale post-mining rehabilitation in semi-arid parts of the Western Cape is not well documented. Significant successes in rehabilitating vegetation cover on mines and road reserves have, however, been obtained in higher rainfall areas (Chenik 1960, James 1966) as well as in forest regeneration in tropical areas (Parrotta *et al*, 1997). These successes cannot, however, be directly interpreted in the low rainfall areas.

How can the best practices recorded in other areas be adapted for use to rehabilitate the old mining area in a cost-effective way in order to aid mine closure and provide a long-term sustainable environment?

1.2 AIM

This study will determine the most efficient and cost-effective methods of vegetative rehabilitation on a commercial scale, in a semi-arid environment.

1.3 OBJECTIVES

1.3.1 Objective 1

Evaluate available literature and conduct interviews with rehabilitation practitioners to determine the best practices used in restoring natural environments in the western part of the winter rainfall area of South Africa.

1.3.2 Objective 2

Adapt the best practice for use under semi-arid conditions and evaluate the success of these in a variety of trials. Evaluate the cost-effectiveness of these approaches.

1.3.3 Objective 3

Using the Chemfos Conceptual Rehabilitation Plan (CES, 1996) as a base, interpret the trial results, formulate a detailed rehabilitation plan for the old mine and implement the processes on the 650 ha site. A costing model as well as a monitoring and evaluation system will be developed.

1.4 PURPOSE

The Western Cape is developing rapidly. Great pressure is placed increasingly on natural environments by developments due to man's increasing need for re-creation, agriculture and living space. The combined effect of these impacts is that most veld types (*sensu* Acocks, 1953) have become critically rare.

At the Chemfos mine site, a large portion of devastated, alien vegetation-infested land surrounded a significant fossil deposit. Aesthetically re-integrating the land back into the landscape would make the environment suitable as a tourist and education destination and would ensure continuation to a self-sustaining environment where once was a mine. Mine closure, resulting from the implementation of an appropriate rehabilitation programme, would relieve the mining company of the risks and burdens associated with dysfunctional mines.

1.5 METHODOLOGY

The most successful techniques employed in rehabilitation of a variety of disturbed vegetation types in the Western Cape will be determined by means of a literature review

and personal interviews with practitioners in the field who may not have published their findings.

The guidelines in the Chemfos Conceptual Rehabilitation Plan will be considered together with other available information to develop trial designs based on best-known practices for the restoration of the veld in different soil types and conditions.

Field trials were implemented. Cost and effectiveness will be monitored throughout the implementation phase by means of detailed record-keeping of inputs required.

Results of the field trials will be used to determine an implementation plan for the large-scale rehabilitation of the mine.

Additional research in various technical aspects was conducted as required to inform the adaptive management process.

CHAPTER 2. STUDY AREA

2.1 LOCALITY

The study was conducted at the Chemfos mine site at Langebaanweg, situated on the Cape West Coast of South Africa, approximately 15 km east of Saldanha Bay (S 32.58.0° E 018.07.0°).

2.2 CLIMATE

Situated in a winter rainfall area where most of the precipitation is associated with seasonal cold fronts, the mean average rainfall for Langebaanweg is 250 mm with the West Coast regional average being 300 mm. The annual fluctuation in rainfall is, however, substantial. The local patterns in rainfall recorded at Chemfos also reflect a significant local variation in rainfall.

Table 2.1 reflects the rainfall during the crucial first 6 years of rehabilitation as recorded by a Davies Automated Weather Station II, erected on the Chemfos site. (On-site figures for 1996 were incomplete and were replaced by data recorded at Air Force Base Langebaanweg, which lies 3.5 km to the east). During this period, the mean annual rainfall was 221 mm with only 1999 reflecting the average patterns of the general area and three years namely 1997, 1998 and 2000 reflecting less than 150 mm rainfall for the period. In contrast, 1996 and 2001 were exceptional years, with 370 and 340 mm rainfall recorded (Table 2.1). On average, more than 10 mm of rain is only recorded between May and September. This is significant, since less than 10 mm of rain is in our experience generally inadequate to support germination or active growth in all but established plants. Consequently, rehabilitation of vegetation without irrigation is only possible in the winter period, between May and September.

Table 2.1: Rainfall measured on the Chemfos site from 1997 till 2001

YEAR	MONTH												TOTAL mm
	Jan	Feb	March	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	
1996*	3.1	30.1	13.2	24.1	43.8	61.9	38	47.8	60.1	17.1	17	13.8	370.0
1997	4.0	1.4	8.6	13.2	28.4	37.6	8.2	16.6	6.0	2.4	11.0	1.6	139.0
1998	3.8	0.2	1.2	9.4	33.8	25.2	27.4	27.6	6.6	0.6	5.6	1.6	143.0
1999	0.4	0.4	0.4	15.4	26.0	21.0	33.4	48.6	44.2	1.4	9.2	5.8	206.2
2000	3.4	0.0	0.4	3.8	10.0	10.0	28.8	20.0	41.6	4.0	2.4	0.6	125.0
2001	8.4	2.0	2.4	8.0	50.0	28.6	119.6	69.2	27.8	23.2	2.8	0.8	342.8
AVG	3.85	5.68	4.37	12.32	32.00	30.72	42.57	38.30	31.05	8.12	8.00	4.03	221.00

*Data for 1996 from Air Force Base Langebaanweg

The drier months are also the warmest, with January and February having a recorded maximum of 36.5 °C. Mean temperatures for the summer months as measured in January 1997 till 2002 are 27.5 °C during the day and 14.9 °C at night. Strong south-easterly winds are also typical in the summer months and the combination of high temperatures and strong winds has a drying influence on exposed soils. Although these summer conditions are harsh, most of the established natural vegetation is dormant at that time of the year and suffers little permanent damage. The influence of unusual events such as “berg winds” is, however, very significant. During September 1997 the berg wind dried out the surface soil rapidly and caused the loss of several thousands of cuttings and seedlings in the site nursery.

The winter mean temperatures measured in July are 18.4 °C during the day with the night-time temperatures falling to 7.1 °C. Whilst south-easterly winds are typical of the summer months, northerly winds are more frequent in winter, especially between May and August. No significant frost was recorded on the site during the period under review, although it has been recorded elsewhere in the region, further from the coast.

From the recorded climatic data on the site it is clear that the relatively long hot, dry summer season, coupled with a relatively short wet season with limited rainfall, poses challenges to establishing new vegetation on the site.

2.3 GEOLOGY AND SOILS

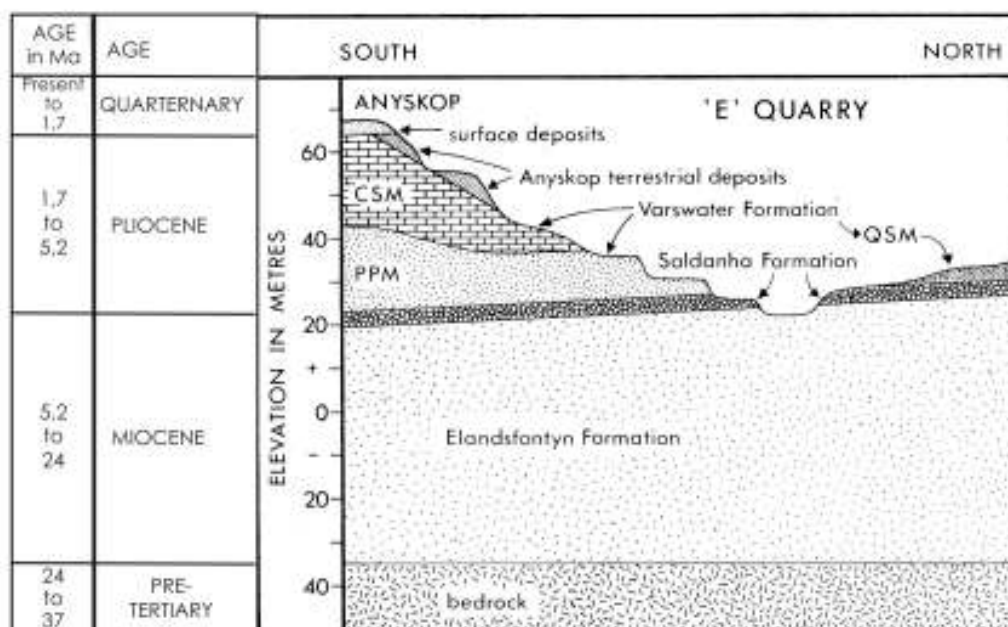
The vegetation of the site during 1996 reflected the underlying soils, which have been formed and influenced by complex geological developments due to climate change since the Miocene epoch, as well as subsequent mining activities on the site, which have disturbed and exposed these underlying geological formations.

Most of the deposits overlying bedrock in this region date from the Miocene and Pliocene epochs (late tertiary period of geological time between 24 and 1.7 million years ago). The Pliocene epoch in particular is responsible for geological elements containing the phosphate ore bodies that attracted mining to the area, as well as one of South Africa's most significant fossil deposits.

The most important factor influencing the deposition of tertiary sediments in the area was the significant changes in sea level that were experienced over this time period. The rise and fall of sea levels led to the Langebaanweg Succession, which is a sequence of sedimentary rock formations laid down at various stages of the ocean's encroachment and retreat. Hendey (1982) studied the fossil fauna of the site and recorded the geological succession (Figure 2.1). He showed that the Langebaanweg succession comprises 4 successive layers, namely the Elandsfontyn formation, the Saldanha formation, the Varswater formation (which comprises 3 distinct members) and the Bredasdorp formation.

The **Elandsfontyn formation** was deposited during the early to middle Miocene transgression, 20 to 12 million years ago (Ma), and consists of marine and terrestrial deposits with pollen fossils indicating the presence of forest and marsh vegetation.

The **Saldanha formation** was deposited on top of the Elandsfontyn complex and was the result of the erosion of the phosphoric rock that was formed during the middle to late Miocene. The eroded gravel material from this thin layer combined with other deposits to form the Saldanha Formation that dates back to between 9.8 and 6.6 Ma when the sea levels were 30 metres above current levels. The period of lower sea levels following the formation of the Saldanha formation saw a substantial drop in sea levels and thus a period on no deposition in the region. This phase lasted till around 5.2 Ma, when the phosphoric Varswater formation was deposited following the melting of part of the Antarctic ice cap.



The geological succession at 'E' Quarry, Langebaanweg. The Varswater Formation is divided into the Quartzose Sand Member (QSM), the Pelletal Phosphorite Member (PPM), and the Calcareous Sand Member (CSM).

Figure 2.1: Geological succession of the Chemfos mine area as depicted by Hendey (1982).

The **Varswater formation** consists of three main sedimentary members with specific origins.

The *Quartzose Sand Member* (QSM) includes deposits formed during the early Pliocene epoch on the flood plains, salt marsh and tidal flats that existed between the isolated high ground around Saldanha, Vredenburg and Anyskop. During this phase of sea-level increases due to the melting of the ice caps, the proto-Berg River mouthed into the channel formed when the low-lying areas were flooded.

The *Pelletal Phosphorite Member* (PPM) consists of relatively fine grained deposits of phosphate-rich sediments that were formed in the protected environment of the shallow marine environment that existed between Saldanha and St Helena Bay. Large numbers of marine fossils are found in this member together with terrestrial mammal fossils that were formed after being washed down the proto Berg River into the protected estuary. The conditions for the formation of phosphate deposits were favourable along the edges of the Saldanha–St Helena channel and formed a substantial deposit that was extensively eroded during the following phase of lower sea levels. Part of this remnant of

the deposit forms the core deposit around which Chemfos was developed. The mining process removed subsequent aeolian deposits on top of the PPM to expose the phospholitic material for processing. The resulting landscape represents in part the ancient topography during the deposition phase of the mid-Pliocene epoch.

The *Calcareous Sand Member (CSM)* contains microscopic marine fossil material.

The **Bredasdorp formation** was laid down during a time of regression of sea level in the mid-Pliocene epoch and is represented by the Anyskop deposits which show an abundance of land snail and tortoise fossils and the quaternary deposits which show evidence of human activity, e.g. stone-age tools probably left by *Homo erectus*.

The natural soil type of the site maybe described as xerosamments or sandy entisols (USDA Forest Service 1982,1999). No developed horizons are evident other than a slightly darker shallow upper layer which contains more organic material due to the decomposition of the overlying Strandveld vegetation. Disturbed soils on site are remnants of the mining operation and consist of overburden, slimes and exposed sedimentary substrate. The overburden is similar to the natural soil type, but with less organic material content in the top horizon, the slimes dams consist of unconsolidated sand remnants of phosphate extraction and the exposed substrate is calcareous, stark white with visible marine deposits, because mining was focused on the calcareous PPM and CSM of the Varswater formation.

Soil sampling was undertaken by CES during November 1995 (CES 1996) at 23 positions on the site at varying depths in order to inform the rehabilitation plan (Table 2.2). Percentage moisture and organic content was calculated for each sample and soil pH, conductivity, sodium, magnesium, manganese, iron, potassium and calcium levels were measured. Due to the complexity and cost of measuring soil nitrogen and the rapid changes that occur in the N-levels over time, it was not measured since it was unlikely to be meaningful at the envisaged planting time between one and three years later particularly once soils have been worked.

Similar soils were grouped together as they were likely to require similar treatment regimes. Although groups 8 and 9 have elevated Na levels, their isolated location, relative small size and the presence of *Sarcocornia perennis*, on the peripherals of these areas indicated probable successful vegetation regimes could be introduced.

Table 2.2: Mean soil characteristics of groups of vegetation communities as found on site during 1996 (after CES 1996)

MEAN SOIL CHARACTERISTICS OF GROUPS OF VEGETATION COMMUNITIES											
Group	Na (mg/l)	Mg (mg/l)	Mn (mg/l)	Fe (mg/l)	K (mg/l)	Ca (mg/l)	Pas P ₂ O ₅ (%) (m/m)	Soil (pH)	Cond- uctivity (ms)	Moisture (%)	Organic Matter (%)
Group 1: Recently rehabilitated (Sites No. 4,6 & 27)	1.5	8.6	6.5	5	6.8	24.2	0.45	8	0.21	8.13	1.24
Group 2 : Strandveld (Sites No: 7,15,19 & 21)	1.1	4	6.8	9.8	1.7	5	0.19	7.8	0.43	1.89	1.37
Group 3: Rehabilitated overburden dumps (Sites No.s 22.23 & 24)	1.5	5.8	3	3	2	22.7	0.23	7.8	0.16	2.77	0.53
Group 4: Rehabilitated overburden dumps (Sites No.s 2 & 3)	0.9	3.5	3	8	1.7	15.5	0.03	8.4	0.17	4.65	0.59
Group 5: Rehabilitated overburden dump and slimes dam with alien trees (Site No. s 1 , 9 & 11)	1	2.8	4.3	5.3	1.6	13	0.76	8.2	0.15	3.66	0.94
Group 6: Rehabilitated slimes dam walls & overburden dumps high in calcrete (Site No.s 8, 14, 25, & 26)	0.9	5.7	4.7	3.3	1.4	42	0.43	8.1	0.16	3.52	0.72
Group 7: Sparsely vegetated rehabilitation sites (No.s 5,10,13,16, 17 & 20)	1.5	2.1	1.3	5	1.3	2.9	0.59	7.9	0.12	4.41	0.83
Group 8: Saline floor of mine (Site No 18)	95	15	2	2	2.9	35	1.17	7.6	3.83	10.79	0.96
Group 9: Clay floor of dam (Site no. 12)	18	71	27	<1.0	14	18.4	1.54	7.7	0.48	23.36	6.88

Soil analysis results showed that generally there was some variation in these variables between the soils of the natural Strandveld vegetation and those of disturbed sites to be

rehabilitated, but nothing onward that not be corrected or ameliorated. The mine soils were not toxic, merely low in nutrients and moisture. Soil moisture was generally very low (3 - 4% of mass) which is concurrent with the low water retention capacity of sandy soils. (Groups 1-7) A surface layer of clay is present in a few sites and here soil moisture was higher (24% of mass, Group 9). pH is high with an average of 7.9. These basic conditions negate the uptake of phosphate by plants (Schachtman *et al.*, 1998) Conductivity is generally low across the site (0.086 – 0.241 milliSiemens) which indicates a low availability of ions for plant growth and is seen as less than ideal for growing conditions. Trace element levels did not indicate any specific problems for plant growth – sodium levels were generally low, thus salts are unlikely to inhibit growth, manganese and magnesium levels are low, but sufficient for plant growth, potassium is generally low, but normal for Strandveld soils and calcium is high where there is an abundance of calcrete, e.g. overburden dumps, but is not so high as to be restrictive to plant growth. Phosphate levels (0.016 – 1.54%) have no significant consequence to plant growth. Thus little was deemed to be needed to ameliorate soil conditions to support a Strandveld vegetation cover over time.

2.4 TOPOGRAPHY

The general topography of the site is rather flat with Anyskop (“A” in Figure 2.2), being the highest point in the region. Induced erosion during the mining era has resulted in a blow-out that revealed the underlying calcareous hardpan. The overlying quaternary sands and limestone are referred to as overburden by miners as they are necessary to remove to obtain access to the ore body or phosphate-bearing material in this mine.

During the early phases of mining, the ore consisted mostly of rock phosphate that appeared closer to the surface due to localized erosion. The mining took place on a small scale with processing off-site in Bellville and the impact was restricted.

With the construction of the processing plant at Chemfos, commencement of the larger-scale exploration took place. In order to expose adequate quantities of phosphate-bearing material, vast volumes of overburden had to be removed. Sandy material was of no use and was dumped in the old diggings and in a centralized overburden dump in the north-eastern corner of the mine (“B” in Figure 2.2). The calcareous material was used to construct the core of the slimes dams in the south-western corner of the property (“C” in Figure 2.2). Various other coffer dams were also constructed as required by the mining and processing process (“D” in Figure 2.2).



LEGEND:			
A	Anyskop	E	Mine Floor
B	Overburden dump	F	Backfill
C	Slimes dam	G	Cut face
D	Coffer dam		

Figure 2.2: Aerial photograph depicting significant topographical features of the post-mining environment.

The ore layer that varied in thickness from one to five metres was removed to expose the underling mine floor, a layer of cemented sediments with non-viable concentrations of phosphate ("E" in Figure 2.2).

In order to ease access between the processing plant and the mining area, the mine pit was gradually filled from the north in the later years of mining ("F" in Figure 2.2). This process recreated the previous land form and provided a significant dump site for overburden, including most of the topsoil that was removed prior to mining.

The mine path was developed based on the exploration information provided by core sampling. The ore layer was uninterrupted and was covered in a thin layer of overburden in the north that gradually increased in thickness to the south, where it increased to approximately 20 metres thick. This resulted in relatively steep final slopes in the post-mining mine environment with a range of soil types exposed ("G" in Figure 2.2).

During the site evaluations, it was considered to re-profile the mine pit in order to re-integrate the land form to represent the old pre-mining topography. However, cost considerations prevented this line of thinking very early on. Very limited re-shaping of very steep slopes was, however, approved and six slopes were adjusted by bulldozing the top edge to the toe position of the slope, thus decreasing the slope from 1:1 to close to 1:2.

These slopes were still prone to erosion as the material is of mixed origins and varies throughout. The sandy slopes that were more prone to support vegetation generally showed less signs of erosion when compared to the calcareous slopes where vegetation generally did not establish without repeated follow-up plantings.

Slope orientation in the general natural surrounding area is not significant due to the lack of variation in topography. In the post mining environment, acute changes in levels resulted in sharply contrasting micro-climatic conditions that, in turn, influenced the vegetation regimes.

The overburden dumps recover naturally by spontaneous invasion of plants from surrounding areas by seeding and growth of new plants. Due to the high percentage of topsoil that was mixed inadvertently in the substrate at the time of removal and dumping, the plants easily became established. The warmer west-facing slopes of the dumps mainly support the succulent and annual components of the vegetation, whereas the east-facing slopes are covered in woody climax species and mosses. This natural variation of the vegetation, due to the micro-climate and topography derived from a single-seed source, indicates the importance and need to apply selection criteria in the rehabilitation programme for the mine site.

Horizontal shifts in vegetation patterns can also be observed in high topsoil mounds. The top of the slope is generally drier due to percolation and the vegetation cover is sparse and the plant growth restricted when compared to the lower slopes.



Figure 2.3: August 2010 photograph depicting spoil dump B (Figure 2.2).

Established shrubs are visible on the crown band with lower cover in the dry top half of the slope.



Figure 2.4: (January 1997): Slope 32 as viewed from slope 31 (Figure 6.4) after the removal of the *A. cyclops* and at the commencement of earthworks to integrate the slope.



Figure 2.5: (August 2007): Slope 32 as viewed from slope 31 (Figure 6.4) was cleared of alien vegetation in 1996 and sloped in early 1997. Seeding and planting was conducted in 1997.



Figure 2.6: (August 1997): Slope 31 on the left and slope 32 on the right after initial planting as viewed from area 45 (Figure 6.4).



Figure 2.7: Dump slopes (August 2010) indicating natural growth from topsoil (p13)

In Figure 2.7 the slope of soil dump 52 (left) is facing north west. Spoil dump 53 on the right faces south east (see also Figure 6.4). Both dumps are of similar age (about 30 years old) and consist of similar cross-zoned soils, including topsoil. Vegetative composition is influenced by slope orientation.



Figure 2.8: Landscape view across the main open-cast mine area as seen from the preserved high wall (Area 37 in Figure 6.4) looking across area 19, the bottom of the open-cast mine, towards area 16, the in-situ calcareous overburden.

2.5 VEGETATION

2.5.1 Vegetation Map of South Africa: Saldanha Flats Strandveld

Mucina & Rutherford (2006) describe the original vegetation of the site as Saldanha Flats Strandveld (FS3). This vegetation type is distributed in extensive coastal flats from St Helena Bay and the southern banks of the Great Berg River near to its mouth in the north to the coast near Yzerfontein and Rietduin in the south at altitudes between 0 and 120 metres above sea level.

The vegetation is further described as “sclerophyllous shrub lands consisting of a sparse emergent and moderately tall shrub layer, with open succulent shrub layer forming the undergrowth”. Conspicuous displays of geophytes and annual herbaceous flora are observed in spring.

Mucina & Rutherford (2006) list the following important taxa for the vegetation type:

- **Tall shrubs:** *Euclea racemosa* subsp. *racemosa* (d = dominant), *Nylandtia spinosa*, *Rhus glauca*.
- **Low shrubs:** *Aspalathus lotoides* subsp. *lagopus*, *Clutia daphnoides*, *Euryops linifolius*, *Exomis microphylla*, *Hermannia pinata*, *Lebeckia sericea*, *Leysera gnaphalodes*, *Nexax hirta* subsp. *calciphila*, *Pterocelastrus tricuspidatus*, *Pteronia divaricata*, *P. ovalifolia*, *P. uncinata*. Succulent shrubs: *Euphorbia mauritanica*, *Ruschia macowanni*, *Tetragonia decumbens*, *T. fruticosa*, *Zygophyllum cordifolium*, *Z. morgsana*.
- **Herbs:** *Dimorphotheca pluvialis* (d), *Oncosiphon suffruticosum* (d), *Arctotheca calendula*, *Foveolina tenella*, *Hebenstretia repens*, *Helichrysum litorale*, *Nemesia versicolor*, *Senecio arenarius*, *Ursinia anthemoides* susp. *anthemoides*.
- **Geophytic herbs:** *Trachyandra ciliata*, *T. divaricata*.
- **Succulent Herbs:** *Dorotheanthus bellidiformis* (d), *Cornicosia pugioniformis* subs. *pugioniformis*, *Mesembryanthemum guerichianum*, *Senecio littoreus*.
- **Graminoids:** *Bromus pectinatus* (d) *Erharta calycina*, *E. villosa* var. *villosa*, *Schismus barbatu*, *Tribolium echinatum*.

Biogeographically important localized and wide-spread west coast endemic taxa are:

- **Low shrub:** *Afrolimon capense* (d).
- **Succulent shrub:** *Prenia pallens* subsp. *pallens*.
- **Herbs:** *Amellus asteroides*, *Grielum grandiflorum*.

- **Graminoides:** *Cladoraphis cyperoides*, *Thamnocortus spicigerus*.

Saldanha Flats Strandveld is generally found on shallow calcereous sands over a fossil-rich Pleistocene limestone hardpan layer. Fire plays a lesser role in Strandveld communities than fynbos or renosterveld and fire frequency is relatively low.

This vegetation type is listed as endangered with a conservation target of 24%, of which only 11% had been statutorily conserved by 2006 in the West Coast National Park and Yzerfontein Nature Reserve and a small portion in private nature reserves. More than half of the remaining vegetation has been transformed by cultivation, infrastructure and urban development as well as alien plant infestation (Mucina & Rutherford (2006). Moreover, the establishment of the Saldanha Bay Industrial Development Zone to the west of Chemfos that will concentrate development in previous agricultural as well as undisturbed areas, makes a strong case for conservation and rehabilitation of the vegetation in this region.

2.5.2 Post-mining Vegetation

Open-cast mining activities at Chemfos has led to the destruction of almost all the original natural vegetation on the 650 ha site, and on the adjacent properties agriculture has reduced the prevalence of pristine thicket to a fragmented mosaic (degraded Strandveld).

CES (1996) sampled 27 sites in the Chemfos mines region and recorded plant species, cover abundance as well as the physical characteristics of the site. Two major groups were sampled, i.e. natural Strandveld areas and predominantly disturbed or rehabilitated sites. Natural Strandveld communities on site showed high percentage cover (more than 70%) and dominant species recorded included *Wildenowia incurvata*, *Pteronia divaricata*, *Erharta villosa*, *E. calycina* and *Cornicosia pugioniformis*. Some communities contained over 50 different species. Overburden dumps showed a generally high species richness (14 - 22 species) and good vegetation cover (30 – 75%). Some areas were covered in alien trees (*Acacia cyclops* and *A. saligna*). Dominant species varied between dumps, but included *Acacia cyclops*, *A. saligna*, *Bromus diandrus*, *Ehrharta villosa*, *Amellus asteroides*, *Felicia tenella*, *Euphorbia* sp. and *Metalasia muricata*. Some of the overburden dumps showed good restoration progress towards a natural community. The walls of the slimes dams on site (4 dams in total) were covered in calcrete overburden and show good species richness (12 -16) and cover (25 – 40%).

Dominant species included *Metalasia muricata*, *Amellus asteroides* and unidentified mosses. The centre of the slimes dams showed good cover of alien trees (mainly *Acacia cyclops*) in the wetter areas and species richness was low (7 -13). Dominant herbaceous/grass species included *Ehrharta villosa*, *Conyza canadensis*, *Sonchus oleraceus*, *Bromus diandrus* and mosses. In the dry mobile sand areas of the slimes dams cover of less than 10% was recorded and few species were present, including *Amellus asteroides*, *Ehrharta villosa*, *Myrica cordifolia*, *Senecio burchelli* and *S. elegans*. The mine floor area in the centre of the mine site contained some saline pools and showed an average 30% vegetation cover and a great number of halophytic and freshwater species. Dominant species included *Sarcocornia* sp., *Bromus diandrus* and *Crassula natans*.

2.6 MINE CHARACTERISTICS

2.6.1 Infrastructure

Mine infrastructure was established around access to the following important components:

- **Roads:** adjacent to the R45, the old main access road from Malmesbury to Vredenburg and Saldanha. This was used for personal access.
- **Railway line:** a specially constructed siding was built off the main Malmesbury-Saldanha line and was used as the main product distribution network.
- **Water:** approximately 20 km water supply line was constructed from the Berg River to provide the mine with water to be used for processing.
- **Processing plant:** including a pilot plant, crushers, cyclonic concentrators, reservoirs as well as drying, processing and packaging plants.
- **Administration complex and support:** included laboratories, glasshouses, offices and workshops.
- **Tailings management network:** included several pump stations to pump waste slurry to the tailings dam.
- **On-site workshops:** established near the mine operations to service and support the mining equipment.

- **Mine Village:** included single quarters and houses for most of the workers. Management were housed in the nearby town of Vredenburg.

2.6.2 Mining area

This consisted of the entire terrain measuring approximately 650 ha. Key landscape features in 1996 included:

- Limited fragments of undisturbed areas that were off the mine product reserve area
- Overburden dumps
- Tailings dams
- Evaporation ponds
- Mine floor areas exposed after ore removal
- Mine path cut face where the operations stopped in the south near Anyskop
- Backfill areas where some overburden was being deposited on top of mined-out areas
- Exploration trenches

The infrastructure placement and the mining operations resulted in a modified environment. At the time when mining commenced, little importance was given to the environmental legacy or consequence of activities. The primary driver was cost and this resulted in all overburden being dumped off reserve as close to the point of origin. The result was the cross-zoning or mixing of soils that originated from different layers where they were formed during the preceding 5 million years.

2.7 SOCIO-ECONOMIC ENVIRONMENT

2.7.1 Exploitation of Natural Capital

Traditionally hunter-gatherers moved through and used natural resources from the land within the Anyskop area, as is evident from the variety of stone tools found on site (Conard, 2003). In 1825 the first farms in the area were sold to settlers as grazing and in 1907 the large farms were subdivided into the 32 modern day farms (du Preez, 1988).

Since then the Loubser family of Anyskop farm planted grain and grazed their livestock there (Dirk Loubser, pers. comm). The grazing potential of the natural vegetation in the area is relatively low, with a dry biomass of 486,31 kg/ha/year being determined for the nearby Postberg reserve (Craven, 1994), and intensive grain and pasture farming led to the destruction of natural capital on the site. In 1941 the most consumptive use of natural capital began in the form of phosphate mining. Phosphate production accelerated during the 1960s when the mine was taken over by SAMANCOR, but peak production was limited to 130 000 tons per annum (CES, 1996a). Mining operations were scarcely viable and after ceasing operation several times during the 1970s, operations were finally suspended in 1993 due to economic factors. These same economic constraints had lead to mining practices that favoured a minimum handling of material and much injudicious dumping of topsoil and overburden which severely hampered natural revegetation from seed reserves in the topsoil of the site. This, together with infestation of invasive alien plant species, many of which were introduced to stabilize the disturbed soils of the site, resulted in the near degradation of almost 650 ha of vegetation. As no provision had been made in the mine's operating budget for post-mining rehabilitation, SAMANCOR were left with a considerable challenge to rehabilitate the site sufficiently in order to obtain a closure certificate from the Department of Minerals and Energy Affairs.

Furthermore, the Chemfos site had been identified as a valuable fossil site and had attracted the interest of many foreign and local researchers, as well as being declared a National Heritage site in 1996. Restoration of the site also facilitated future research on the site and created a greater vision than just meeting the minimum DME requirements (CES, 2001).

A rehabilitation plan was thus put together to address the decommissioning of the plant and associated buildings, upgrading of useful infrastructure at the mine and mining village that could be incorporated into a tourist and administration facility for Iziko Museums and the restoration of natural vegetation on the site. Wherever possible, local people and ex-mining staff members were employed for rehabilitation operations. Demolition of infrastructure and the selling off of scrap material and unsold phosphate provided employment for 6 months for 10 local workers. Although only generating about 4% return on the cost of eradicating alien invasive plants on the site, providing local wood sellers with access to fire wood through managed wood lots supported approximately 15 families for 2 years (van Eeden *et al* 2007). Assets and 50 ha of land were transferred to a newly formed management company comprising residents and

representatives of the mining company and Fossil Park and state subsidies assisted with the upgrading of facilities.

Restoration of vegetation cost in the region of R6 000 000 over a period of 10 years (1996 – 2005) and supported 20 people annually. The local horticultural skills base that had been built up and seed collected and plants propagated from site could be used in a wider area on other projects to cross-subsidize rehabilitation costs and provide more sustainable employment outside of the main restoration season on the site.

The West Coast Fossil Park, which allows members of the public access to view the fossils and provides further employment opportunities for local people, logged an initial shortfall between income generated and operating costs, which was carried by the mining company until such time as the enterprise could be self-funding.

2.7.2 Economics and Employment

During the life-span of the mine, both employment figures as well as production varied greatly. Shortly prior to closure in 1993, Chemfos employed a total of 164 staff (Calitz, 1993). This figure included 37 staff off site in Driemanskap where the blending of some the fertilizers was done prior to final sales. The Engineering staff accounted for 19 posts and administration for a further 23 with 16 staff being responsible for marketing. Production was managed by 69 staff members.

2.8 LEGISLATIVE REQUIREMENTS FOR REHABILITATION

The passing into force of the Minerals Act (Act 50 of 1991) marked a dramatic change in environmental enforcement in the South African minerals sector. This Act greatly increased environmental management requirements on mines, with section 38 requiring the rehabilitation of disturbed surfaces to the satisfaction of the Directorate.

Section 40 of the Act further dictates that once the exploitation of any mineral which was authorized finally ceases, the person who was the holder of such permit or authorization immediately prior to such termination, shall demolish all buildings, structures or any other thing which was erected or constructed in connection with mining operations on the surface of the land concerned (except where the owner wishes to retain structures and this has been approved by the Directorate) and shall remove all debris as well as any other object which the Directorate may require and, as far as is practicable, restore any

such surface to its natural state to the satisfaction of and within a period determined by the Director: Mineral Development.

SAMANCOR thus needed to initiate a rehabilitation programme in order to obtain a closure certificate from the Department of Mineral and Energy Affairs.

Further to this, the National Environmental Management Act (Act 107 of 1998) ("NEMA") which overarches South African environmental legislation contains requirements with respect to duty of care and places obligations on company directors and managers in terms of environmental performance of their companies and remediation of environmental damage. Section 2 of NEMA sets out the principles for environmental management and section 2.4 (p) states that the costs of remedying environmental degradation must be paid for by those responsible for harming the environment. Section 28 establishes a general "duty of care" on every person who causes, has caused or may cause significant pollution or degradation of the environment to take reasonable measures to prevent such pollution or degradation from occurring, continuing or recurring, or, in so far as such harm to the environment is authorized by law or cannot reasonably be avoided or stopped, to minimize and rectify such pollution or degradation of the environment.

The discovery of significant fossil deposits on the Chemfos site and the development of the West Coast Fossil Park on the site as part of the closure strategy for the mine reflects the NEMA section 2 principles that are demonstrated in 2.4 (o), which states that "The environment is held in public trust for the people. The beneficial use of environmental resources must serve the public interest and the environment must be protected as the people's common heritage", and in 2.4 (h) "Community wellbeing and empowerment must be promoted through environmental education, the raising of environmental awareness, the sharing of knowledge and experience and other appropriate means."

CHAPTER 3. HISTORY OF REHABILITATION ON THE WEST COAST AND THE INFLUENCE ON MINE CLOSURE

This Chapter explores the lessons learned on other rehabilitation projects in the area to assist in the formulation of the best strategies to be used at Chemfos.

3.1 INTRODUCTION

Historically, rehabilitation of degraded environments on the West Coast was primarily undertaken if the degraded state represented a perceived threat to infrastructure or livelihoods. This was the case along some sections of the Sishen-Saldanha railway line near Eland's Bay, where sand accumulation on the railway lines could lead to derailments.

Occasionally aesthetical considerations such as the preservation of desirable views were strong additional drivers in attempts to find management strategies to support the development of a site. Such was the situation in Milnerton for housing development along the Blaauwberg dunes. The construction of homes with sea views was very desirable during the 1980s and the development required special techniques to maintain the desirable status quo in a dynamic dune environment.

A more responsible attitude towards the preservation and rehabilitation of the environment was also developing and these new projects were leading the way, not only complying with the enforceable laws, but also leading to sustainable land use following disturbance. Thus at Chemfos, SAMANCOR was striving towards a higher order, acknowledging custodianship and taking responsibility and implementing mitigating measures beyond the levels dictated by laws.

In attempting to find the most effective and appropriate techniques for rehabilitation at Chemfos, the most successful directions were explored using experience from a number of case studies. These case studies were amongst the information considered in compiling the Chemfos rehabilitation trials.

This chapter deals with evaluating the best practices used in other case studies in order to develop site-specific trials at Chemfos. Having been involved in all of these projects on the West Coast I am able to evaluate the techniques for further use and expansion in the large-scale rehabilitation of the open-cast mine at Chemfos, Langebaanweg.

3.2 SISHEN-SALDANHA RAILWAY LINE

The development of the Sishen-Saldanha project during the late 1970s aimed to provide easy rail access to the Port of Saldanha from the Northern Cape town of Sishen 861 km away. This dedicated railway line was designed to carry ultra-long trains, initially consisting of 216 wagons, in order to ease the management of the train scheduling. To minimize the variation in the vertical profile of the line, areas of relatively flat gradients were sought and this positioned the line on the coast for between Eland's Bay and Lambert's Bay on the West Coast. Closer to Saldanha, deep cuttings were constructed, resulting in steep cut slopes in places.

These sections of the line were vulnerable to the elements of wind and rain erosion. The railway line in the coastal section was prone to being covered by windblown sands and the cuttings were eroded by rains, with the resulting loose sand clogging the ballast stone, thus reducing the shock-absorption ability of this stone layer on which the rails are laid.

3.2.1 Research Problem, Questions and Objectives

Sections of the railway line were constructed in close proximity of the coast, particularly north of Eland's Bay. The setting out of the railway line within a primary dune system required stabilization of these dunes. This poses the question:

Can mobile sand be stabilized and thus be prevented from clogging up the ballast stone, reducing shock-absorbing properties and subsequent covering the railway line?

The aim and objectives of the study were, therefore, to:

- establish effective techniques to stabilize mobile sands;
- reduce the unconsolidated mobile sand in the vicinity of the railway line;
- and thus reduce expensive maintenance and prevent damage to rolling stock.

3.2.2 Mobile Sands

3.2.2.1 The outcome of mobile sand movement on the railway line

The proximity of the railway tracks to the shoreline in the Cape Seashore Vegetation (*sensu* Mucina, *et al*, 2006 - vegetation type AZd3) resulted in the destabilization of the fragile vegetation cover. This has resulted as follows: Strong onshore winds from the south-east during summer exacerbated the problem and created local "blow outs". This is the result of fast-moving winds that develop laminar flow characteristics in areas of no

vegetation and that then pick up sand particles that may also be covered in salts from evaporated sea water deposited as sea spray. These particles are rich in kinetic energy and move in the clear air flow just above the surface of the sand. The energy is discharged at the point where obstacles are met. The result on plants is that abrasion occurs as the particles damage the cuticle and epidermal leaf layers (Gilbert, 2007). Heavier sand particles may also be deposited at this point and this may cover smaller and low-growing plants. Sea spray will further impact on the vegetation now exposed to the direct winds without the benefit of the buffering effect of the tidal debris or front line pioneer plant species on the foredunes. Die-back of the plants is often a consequence under these extreme conditions, with the process rolling across the landscape.

When obstacles such as a north-south running railway line are encountered, the disturbance of the smooth air flow results in the particles falling out. The resulting accumulated sand on the edge of the railway line gradually forms a ramp and eventually the entire windward side of the barrier (rail track) is buried under sand.

3.2.2.2 Wind-induced sand movement

Individual sand grains are moved under the force of the wind by saltation and surface creep. The primary method of sand movement is saltation. As wind moves over a sand deposit, it is able to pick up grains from the surface and give them a forward momentum, but the weight of the sand grains soon bring the grains back to the surface. If the surface is composed of coarse, immobile particles, such as pebbles, the sand grains will bounce directly off the hard surface and back into the air, where the wind will once again provide a forward momentum. These bouncing grains can move downwind at about half the speed of the wind. If the surface is composed of finer sand grains, however, a saltating sand grain will not bounce off the surface; rather, it will strike the sandy surface and bury itself. The impact will eject a second grain into the air to be blown downwind. This "splashing" form of saltation results in a slower rate of downwind movement than the bouncing motion on hard surfaces. Either process falls under the definition of saltation (Bagnold, 1941).

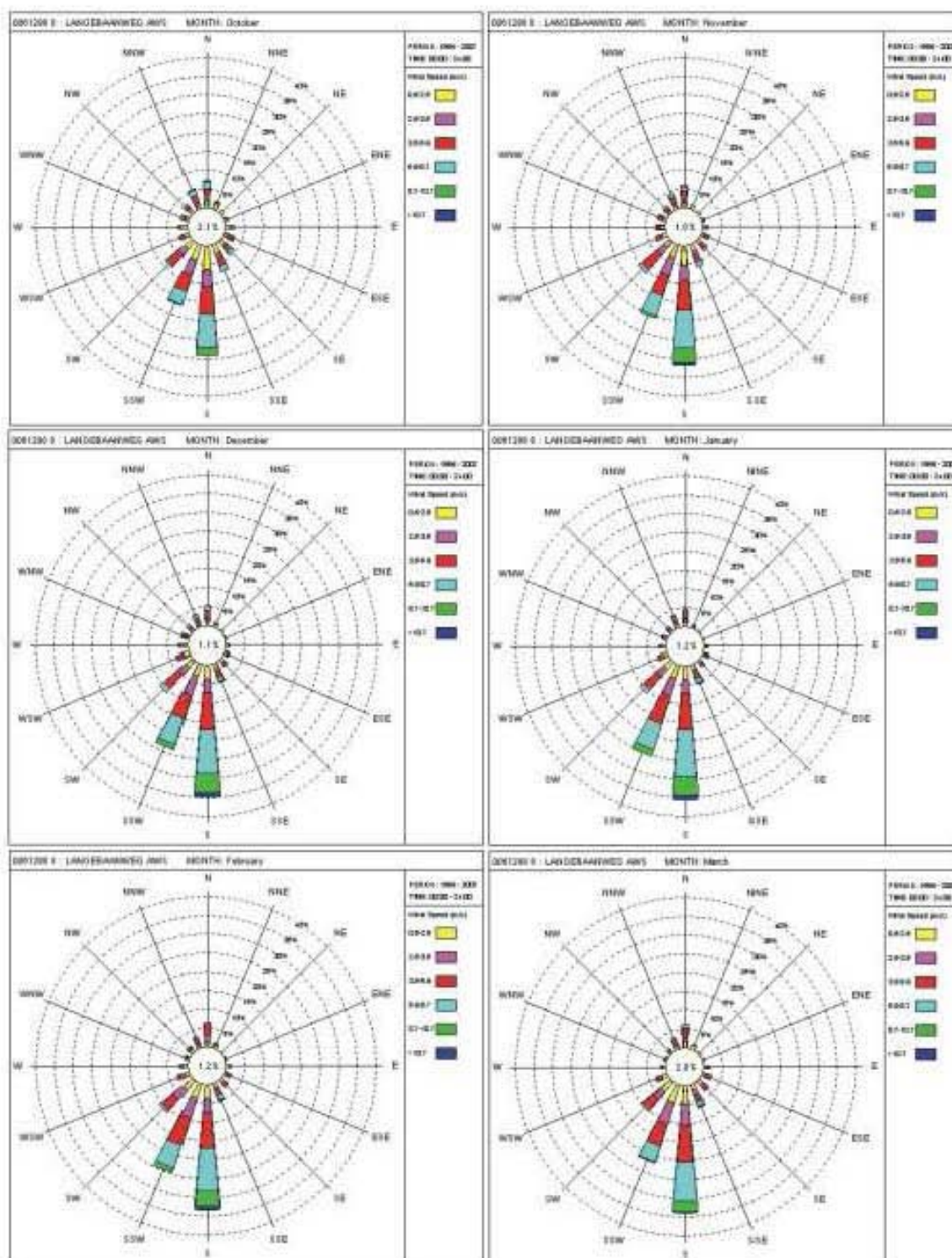
Saltation of sand grains along the surface accounts for about 75% of all sand movement by wind. However, due to the fact that sand grains average about two thousand times the weight of the atmosphere, not all winds will move sand. Wind speeds must reach what Bagnold (1941) calls a "fluid threshold", defined as the wind speed necessary for sand to start saltating under the direct pressure of the wind. The fluid threshold varies in

direct proportion to the predominant grain size of the sand surface, generally ranging from 10 to 36 km/h (Bagnold, 1941; Sharp, 1963).

The prevailing summer winds in the Eland's Bay area averages 40 km/h during the daily peaks resulting in daily saltation events. At Chemfos, southerly winds exceeding 10.5 m/s were recorded between November and February (Figure 3.1). Southerly and southwesterly winds dominate between September and April. This also corresponds with the dry period (Table 2.1). Northerly winds that are associated with rainfall in the area, never dominate, but are more prevalent between April and August (Figures 3.1 and 3.2).

After sand grains start moving under direct wind pressure, wind speeds lower than the fluid threshold can maintain sand movement. Once saltation has begun, direct wind pressure is no longer necessary to lift sand grains into the air. The impact of saltating grains provides enough energy to knock new grains into the air (assuming a sandy surface); thus, the wind need provide only enough energy to move the airborne grains downwind. The wind speed necessary to maintain saltation once it has begun is termed the "impact threshold" and defined by Bagnold (1941, p.32) as the velocity at which "the energy received by the average saltating grains becomes equal to that lost (by impact), so that motion is sustained." Like the fluid threshold, the impact threshold increases with increasing grain size.

Saltating sand grains usually stay close to the surface. In his wind-tunnel experiments, Bagnold (1941) found the average height of windblown sand to be about ten centimetres, although both height and speed of saltating grains increased with wind speed. At Kelso dunes, a fifteen-year study indicated that 90% of saltating grains moved within sixty-four centimetres of the surface, with maximum sand-blast effect at twenty-three centimetres (Sharp and Saunders, 1978).



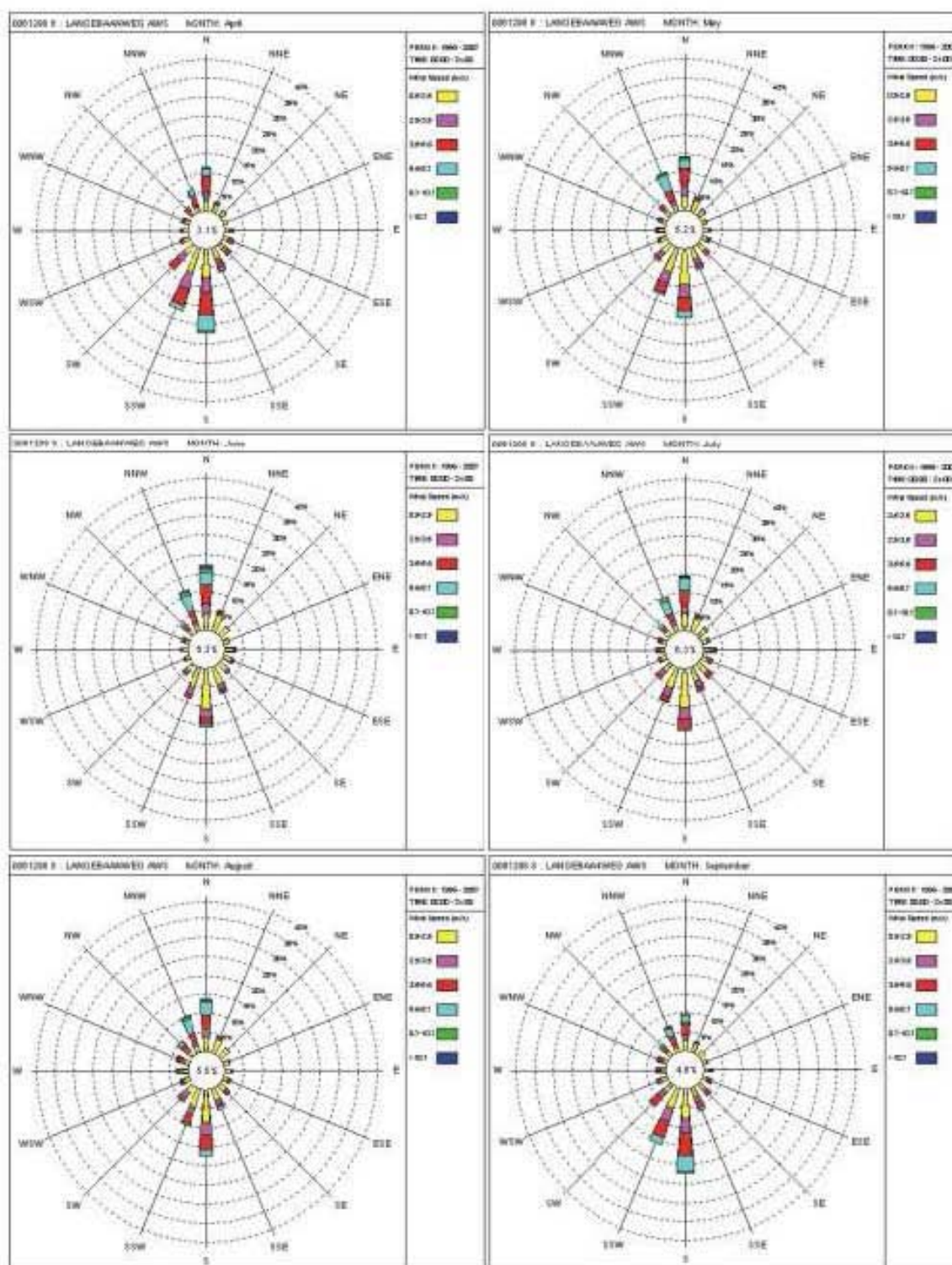


Figure 3.2: Wind-rose for the West Coast region – winter months (SA Weather Bureau).

Due to an increased fluid threshold, heavier sand grains are rarely moved directly by wind pressure. Only intense storm winds can lift the heavier grains off the surface.

Grains larger than one millimetre in diameter are generally moved by a second process called surface creep (Bagnold, 1941; Sharp, 1966). When saltating sand grains strike these heavy grains on the surface, they do not have enough energy to knock them into the air, but they do impart to the heavy grains a slight forward momentum along the surface. In this way, heavy sand grains up to two hundred times the mass of the saltating grains can be slowly moved downwind. Up to 25% of all wind-transported sand is moved by surface creep (Bagnold, 1941).

3.2.2.3 Sand Accumulation

Two primary factors are necessary for the accumulation of sand into sand sheets and dunes: 1) an adequate supply of sand; and 2) winds strong enough and persistent enough to move the sand (McKee, 1979). If these two conditions are met, large quantities of sand can be transported hundreds and even thousands of kilometres (Fryberger and Ahlbrandt, 1979).

Sand sometimes accumulates into piles rather than spread out evenly over an area. In general, sand will tend to accumulate any place "where a sufficient reduction of wind energy exists along the direction of sand drift in an active extensive system" (Fryberger and Ahlbrandt, 1979). Any obstacle, such as a rock outcrop or a stand of vegetation, can force sand accumulation by lowering wind speeds and creating a "sand shadow" to the lee of the obstacle. Any small depression or gentle dip in an otherwise flat surface can fill with sand due to lower wind velocity within the depression (Cooke and Warren, 1973). Large areas of persistent wind deceleration, such as a basin or the base of a plateau, can spawn the creation of large ergs.

Saltation over a coarse surface generally takes the form of repeated bouncing of individual grains. In such cases, most of the wind-imparted momentum is conserved and grains move rapidly downwind. In saltation over a sandy surface, however, sand grains impact into the surface, transferring some energy to the surface (via surface creep) and some energy to dislodging other grains into the air. This process produces a slower downwind movement of sand (Bagnold, 1941).

This saltation, however, ends abruptly when obstacles such as the ballast banks supporting the railway lines, brushwood fences (Figure 3.2) or shade-net curtains are encountered.

Even low brushwood fences may disrupt the momentum and air flow sufficiently to cause abrupt deposition and accumulation of the sand particles. Sand will continue to accumulate until conditions have been re-established that are conducive for saltation. This occurs when the cavities amongst the ballast rock have been saturated with accumulated sand particles, or when a ramp has formed on the downward side of a shade-cloth curtain or brushwood fence.

In Figure 3.3 the ridges formed by sand being deposited against brushwood fences are clearly visible and they remain evident years later. Once sand has built up against these fences, the sand movement continues as before.



Figure 3.3: Clearly visible ridges formed by sand being deposited against brushwood fences inside a section of the tailings dam.

3.2.2.4 Small-Scale Sand Accumulation Features

Once sand grains have accumulated into relatively large sandy patches, small-scale geomorphic features will often result, of which surface rippling is the most common. Rippling tends to develop on sandy surfaces that are in a state of relative equilibrium or slow deposition. Surfaces experiencing either marked erosion or vigorous deposition generally do not display rippling (Sharp, 1963).

Even an apparently completely flat sand sheet is inherently unstable. Due to variations in grain size a small but significant surface roughness exists, allowing for wind to pick up particles. Because larger grains saltate more slowly than smaller grains, they tend to accumulate into "jams", creating more surface roughness. Also, chance unevenness on the sand surface will always be present (Sharp, 1963).

Any unevenness, either random or saltation-induced, will tend to perpetuate itself due to the sensitivity of saltating sand to slight variations in the angle at which grains impact the surface (angle of incidence). What Bagnold refers to as the "characteristic flight path" of saltating sand grains is normally at a very low angle. Since, in most natural sand surfaces, one grain size predominates with a normal distribution around the peak size, saltating sand grains are striking the surface at a relatively uniform angle (approximately ten degrees for the average grain).

When surface unevenness occurs and a small hollow is created, less saltation impacts will occur on the upwind side of the hollow than on the downwind slope (Figure 3.4). As a result, surface creep along slope AB is considerably greater than creep along slope CA, as slope CA resides in a "saltation shadow." Consequently, sand is removed from point A and deposited at point B, creating a ripple. This, in turn, produces a second hollow downwind of the newly-created ripple and the process repeats itself with numerous parallel ridges forming at right angles to the wind direction. The coarser sand grains will tend to collect at the crest of the ripples since they are not moved as easily by the wind and there is little surface creep down the lee side of the ripples (Bagnold, 1941; Sharp, 1963).

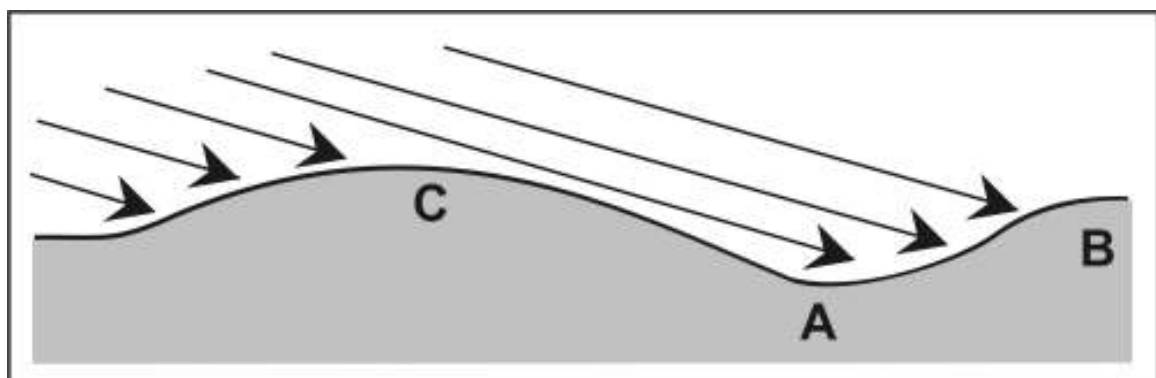


Figure 3.4: Parallel ridges forming at right angles to wind direction.

As a rule, the "wavelength" of the ripples (the distance between crests of successive ripples) increases with increasing wind speed and reflects the increasing height of ripples and the resultant lengthening saltation shadow (Sharp, 1963). In extremely heavy winds, however, ripples flatten out completely because all grain sizes are easily moved by the wind and the differential saltation and creep rates needed for ripple formation decline (Bagnold, 1941; Sharp, 1963).

The height of an individual ripple is a function of grain sorting. The more uniform the sand surface the shallower the ripples, because of the reduced amount of differential saltation and surface creep. Due to the interference of wind speeds by the growing ripples, a maximum height limit exists. As ripples increase in height, they move into levels of higher wind speeds, causing heavier grains to be blown from the ripple crests and into the troughs, filling them in (Cooke and Warren, 1973). Bagnold (1941) claims that the ripple height is generally no more than one-tenth the wavelength of the ripples. In the Kelso dune field, Sharp (1963) found a maximum wavelength of nineteen centimetres and a maximum height of one centimetre, with an average wavelength/height ratio of 18. However, Sharp notes that no satisfactory universal qualification of this height-wavelength relationship has been obtained.

In his studies of the Kelso dunes, Sharp (1963; 1966) also found that ripples move downwind at relatively fast rates. At a threshold velocity of 18 km/h, ripples advanced downwind at a rate of 0.9 cm per minute, with the rate increasing to 8 cm per minute during the strongest winds. Consequently, Sharp concluded the "adjustment in size, shape and spacing can presumably occur rapidly in response to differences in velocity" (1963, p. 631). From an initially flat surface, ripples can form a complete pattern in ten minutes (in a 48 km/h wind) and can flatten out, reform or change direction as quickly. This rapid formation and movement of sand ripples also contributes to a large volume of sand movement. At one test plot, Sharp discovered that, in one hour's time, 48 km/h winds could move 6 000 pounds of sand across a 32-metre line.

In areas where the sand surface has a relatively large number of coarse sand grains (greater than 1 mm in diameter), a second type of small-scale feature occurs, called a "ridge" by Bagnold and a "granule ripple" by Sharp. Granule ripples generally form in sands with a bimodal distribution of grain size - one fine and one coarse - where winds are moderate to strong but not strong enough to pick up coarser grains (Bagnold, 1941; Sharp, 1963).

Bagnold claimed that, like ripples, granule ripples resulted from finer saltating grains pushing coarser grains (via surface creep) into jams. Unlike sand rippling, however, these concentrated ripples of coarser grains are rarely, if ever, moved by direct wind pressure. Consequently, they are more stable and can grow to larger dimensions than sand ripples. As more and more coarse grains arrive from upwind, the granule ripple can grow quite high and the resultant saltation shadow prevents movement of large grains from the crest into the lee-side trough. In contrast to sand ripples, growth and movement of granule ripples is very slow, and individual granule ripples can exist for decades and even centuries, allowing for much greater heights and wavelengths than can develop on ephemeral sand ripples (Bagnold, 1941).

Sharp (1963) tested Bagnold's theories in the Kelso dune field. Sharp found that granule ripples were generally located in deflation hollows between dunes, where winds had removed the finer material and produced a coarse-grained surface. The granule ripples at Kelso dune field were more irregular than the sand ripples, often forming wavy chains resembling miniature barchan-like ridges. As Bagnold predicted, Sharp found that granule ripples indeed adjusted very slowly to changing wind velocities and directions. Sharp found granule ripples that were at least several months old and measured up to 12,5 cm high and over two metres in wavelength. (Bagnold reported granule ripples in Africa 60 cm in height and 6 m in wavelength.) Sharp also states that he found no gradations between sand ripples and granule ripples; rather, he found them to be distinct features even when occurring side by side, "with a sharp line of demarcation" (1963, p. 632).

3.2.3 Methods of Sand Stabilization

The traditional methods of dealing with the problem included the following:

- The construction of shade-cloth fences and the placement of brushwood barriers. This interrupted the smooth air flow and modified the deposition patterns. Saltation is thus halted and the more complex micro-topography provides a greater measure of protection in the form of localized areas of wind shadow.
- Shade-cloth fences measured 500 mm in height and were several metres long. They were installed perpendicular to the prevailing winds and were slung between timber or steel droppers. The positioning was linear on the seaward and landward side of the tracks in areas where construction activities caused disturbance.

- Brushwood was used in a similar fashion when and where available. The material was sourced from invasive *Acacia cyclops* and *Acacia longifolia*. The nature of the low-growing local vegetation precluded it from use.

Both the net and brush windbreaks were effective in initially slowing down the winds and forcing the deposition of the mobile sands resulting in wind rows of sand burying all the structures with the erosion persisting beyond the interventions.

It was realized that the only way to resolve the problem would be through stabilising the sands before they become mobile. This was done by:

- laying shade-cloth and other forms of net (old anchovy nets from the fishing boats) flat on the ground. This process was only effective for a short period of time, as explained above, because the surface soon became suitable for saltation to continue.
- curtain netting, which yielded quick results and could be used at any time of the year, but did not provide a long-term answer.

Revegetation was the only permanent alternative. In order to revegetate the area suitable seed and plant material had to be sourced.

- Seed of the local vegetation was not commercially available and a variety of agricultural seeds were considered and used to varying degrees of success.
- Seed of *Acacia cyclops* and *Acacia longifolia* was hand harvested from the region, partially cleaned and hand broadcasted in the disturbed and other exposed sandy areas. (D Cloete, pers. comm.)

3.2.4 Methodology Evaluated as Part of the Establishment of Best Practices

3.2.4.1 Brushwood packing

- Initially, the relative availability of mature woody vegetation such as *Acacia cyclops* (rooikrans) close to the coastal dunes provided an obvious short-term solution to the problem of mobile sands.
- The Acacias grew in dense stands west of the coast, some 100 to 200 meters inland from the primary dunes and provided useful brush close to the railway line.
- The brush was harvested and branches were half buried in wind rows directly across the path of the prevailing winds.

- The length of the wind rows was dictated by the space available and the distance between parallel rows varied, but generally exceeded 10 metres.
- Due to the configuration of brushwood wind rows used, the sand deposition was abrupt. This was due to the high density placement of the brushwood that resulted in the suspended material dropping out at the point of contact. On the lee side of the fences, the rotor that formed behind the screens caused the formulation of erosion gullies parallel to the brushwood fences. The sand removed from these areas were carried forward in the wind and deposited in the same fashion at the next windbreak.
- Although the use of brushwood can be seen as utilizing a renewable resource, *Acacia cyclops* does not re-sprout once cut severely and regeneration is from the germinating seeds contained in the seed bed. This regeneration takes five to seven years to the point of the next harvest, making the process not commercially acceptable.



Figure 3.5: The use of brushwood in the Chemfos trials.

3.2.4.2 Shade-cloth net barriers

- Seeking an alternative to brushwood lead to the use of shade netting to restrict the free movement of the sand from source across infrastructure to the inland dune fields.

- The shade-cloth thickness and hole size (or percentage shade factor) did not play a significant role in the amount of sand caught. This implies that even the 30% shade net presented enough of a barrier to the sand-laden wind to facilitate deposition of the particles due to the disruption of the airflow.



Figure 3.6: The use of single rows of nets near Alexander Bay.

3.2.4.3 Seeding

- Seed of commercial agricultural sources are the cheapest to obtain, but are predominantly of annual species with relatively high water requirements. The other environmental requirements of these commercial seeds are also not met under the prevailing conditions along the railway line, thus limiting the use of this inexpensive seed.
- Locally harvested seed would have been more suitable, but low yields, irregular timing in seed set and low viability made the seed collection process expensive.
- The preferred species for stabilization was thus *Acacia cyclops* (rooikrans) since the seed was relatively freely available and easy to collect, easy to establish and fast to grow into effective cover vegetation. The disadvantage of the Acacias is the undesirability of this invasive woody weedy species.

3.2.4.4 Plant propagation and transplanting into hedges

- This was primarily done to expedite the growth and effectiveness of the hedges.
- The species selection was based on the hardiest plants with the best chances of survival and consisted of Tamarisk, *Acacia cyclops*, *Myoporum* spp and *Atriplex* spp.
- None of these species were appropriate for the rehabilitation of the Chemfos mine as the use of these invasive exotic species would be against the aims of establishing a natural self-sustaining environment.

Installing single rows of net that results in abrupt deposition of sand against the nets was practiced near Eland's Bay. This causes build-up of sand that will proceed to move on once the net capacity to hold sand back has been reached.

Eskom, who were managing the Sishen-Saldanha project initially as they were the supplier of the electricity infrastructure; and later SA Transport Services as the operators, investigated Australian methods of harvesting local seeds. Natural vegetation, containing a high percentage of ripe seeds, was cut with tractor-drawn mowers and the resulting mulch was spread over the areas. In retrospect, the partial success of the process may have been due to the harvesting from areas that did not contain the correct species mix for the pioneer stands to be established, but these areas were accessible for the equipment used.

In order to augment the limited successes of the windbreaks, a nursery was established on the farm Kleinberg, adjacent to the farm Anyskop directly south of Chemfos. The emphasis of the nursery was propagating *Atriplex numilaria* and *Tamarisk hispida* to use in establishing vegetative windbreaks (D Cloete, pers. comm.. 1996). Remnants of these exotic windbreaks are still growing in the areas north of Eland's Bay and on the land bridge between Saldanha and Marcus Island.

3.2.5 Lessons Learned and Applied to Chemfos

Revisiting the railway line section during May 1996 prior to designing the Chemfos rehabilitation trials, it was apparent that some of the efforts employed in trying to deal with the mobile sands did not have the desired long-term results.

Netting was covered by sand with the tips of the poles protruding and the rest of the landscape in these plumes was essentially no different from what it was 15 years previously. The sand had accumulated against the nets and moved as in the past.

Brushwood hedges could still be seen in places as a result of the dry climate. Their functionality was, however, not much better than the nets.

It was obvious that employing linear netting with wide spacing between rows would not be appropriate for Chemfos.

The persistence of agricultural weeds and crops as well as *Acacia cyclops* also indicated that it would be a potential problem should these be used at Chemfos, where the objective was more than stability and where a stable, appropriate functional ecosystem was our objective.

3.3 BLAAUWBERG DUNES

The post-1980 residential development of the rural coastal area north of Milnerton brought people and infrastructure into an area that was previously mostly used for recreation. The low-key road to the village of Blaauwberg followed the coastline from the Rietvlei. The road was constructed well above the high-water mark, but still within the dune system, resulting in frequent sand accumulation on the road surface during summer.

The sand movement is the result of the now fragmented cyclic process driven by the climatic change caused by the cooler prevailing conditions that formed when Antarctica froze over. The resulting higher wind speeds and the drier conditions result in sand being transported. The prevailing south-easterly winds are the main driver in relocating sand from the beaches that originated as a result of erosion, back to the land.

The coastline between Milnerton and Blaauwberg runs in an approximately northerly direction and the wave action is characterized by a south-westerly swell. The net result of the coastal orientation, the wind direction and the swell is that sand migrates in a northerly direction along the coast (Compton 2004).

Windblown sand, when moved across the land, is generally trapped by vegetation in the fore dunes, a very dynamic system that through seasonal condition changes may at times release sand to be moved further inland.

Contracting linear disturbances such as roads in the path of natural sand progression leads to sand accumulation in areas undesirable to development and, in this instance,

sand build-up on and adjacent to the road surface created a safety risk and resulted in expensive continual removal of sand from the area throughout summer.

The CSIR was tasked to investigate the problem and the solution entailed retaining the deposited sand in the scour zone, where the spring high tides would be able to erode it back to sea in winter (refer to CSIR Report, 1994).

3.3.1 Dune Stabilization

In searching for a suit of species to catch the mobile sand directly above the high-water mark but below the sea level during leap tide in winter storm conditions, a whole range of local and some exotic species were evaluated. The successful species had to be summer active in order to thrive during the period of sand build-up, had to be able to withstand salt spray and sea water and had to grow vigorously so as not to be covered by the accumulated sands.

The indigenous species evaluated included *Cladoraphis cyperoides*, *Ehrharta villosa* (pypgras), *Tetragonia fruticosa*, *Arctotheca populifolia* (sea pumpkin) and *Agropyron distichum* (sea wheat). *Ammophila arenaria* (Marram grass), an introduced species from Europe, was found to have the most desirable characteristics.

The plants have been used in dune rehabilitation for decades and, although not indigenous, have a very dense tufted nature, a very well developed, deep-penetrating root system and a very rapid growth rate and have proved very successful in stabilization of dune sands.

Although the primary dune system at Blaauwberg does not compare well to the tailings dam situation at Chemfos, it did demonstrate the effectiveness of the Marram grass in stabilising mobile sands in a short growing season. The most promising finding was that the Marram would die back after 3 to 5 years should the critical growing requirements not be met, thus allowing for the recolonization of the area by other species in the protection of nurse plant material.



Figure 3.7: Typical stand of Marram grass after two growing seasons.

3.3.2 Methodology

- a. Re-shaping of primary dune profile
- b. Introduction of exotic vegetation to trap sand directly above the normal high-tide mark
- c. Establishment of an erodable front dune profile
- d. Stabilization of slope and dune outside of the scour zone
- e. Gradual replacement of exotic vegetation with local coastal species such as *Cladoraphis cyperoides*, *Ehrharta villosa* and *Agropyron distichum* (sea wheat) in the frontal areas and *Metalasia densa*, *Chrysanthemoides monolifera* on the high-lying back dunes.

3.3.3 Management of the Artificial Dune System

The alternative dune profile that was introduced, primarily captures the sand during the summer months in a narrow band from where it is removed back to sea during spring high tide storm events. During the removal phase, the frontal dune profile usually suffers significant damage as the sand and vegetation is removed by wave action. The damage must be repaired by re-planting the Marram in spring. If this is not done, the sand will accumulate beyond the point where the next winter storms can remove it, resulting in erosion of the toe of the dune and a building up of the dune directly behind this. If the

accumulated sands are not stabilized, the dune will become mobile in summer and will result in the same problems experienced before.

3.3.4 Lessons Learned and Applied to Chemfos

The Blaauwberg project taught that catching sand is best done with vegetation and specifically grasses. A 100-metre long length of shade net measuring 75 cm high can resist approximately 110 m³ of sand before it spills over and continues beyond the nets. This sand must then be removed for the net to be functional again.

If a 100-metre-long grass field is planted measuring 10 metres wide, the same amount of sand can be caught, resulting in less than a 10 cm layer. Some grasses, such as *Ammophila arenaria* (Marram grass), if irrigated and fertilized, can grow fast enough not to be covered by this accumulation.

This observation led to the inclusion of *Ammophila arenaria* in the stabilization trials.

3.4 DU TOITSKLOOF PASS

The Environmental Impact Assessment (1989) recognized that Du Toitskloof was aesthetically sensitive and biologically diverse and fragile. These factors were considered during the initial and subsequent redesign of the road alignment and construction methods:

- The road alignment integrated into the landscape wherever possible and the construction methods and materials were selected to blend with the surrounding areas.
- The gradual changes in the vertical alignment did, however, result in various cut-and-fill slopes being created. These slopes had to be revegetated.

Prior to this project, the standard specifications adopted by the South African Road Agencies on most roads entailed seeding a mixture of grasses from the Dry and Mesic Grassland Biome species such as *Eragrostis curvula*, *Chloris gayana*, *Cenchrus ciliaris*, *Digitaria* spp and *Cynodon dactylon* and commercial agricultural legume seed such as Clover, Vetch and Medicago to provide rapid cover and stability.

The Environmental Management Team that was formed to guide the construction process suggested, however, that no vegetation other than annual grass species that originated outside the system be used (Boucher & Anderson 1994).

3.4.1 Rehabilitation

3.4.1.1 Cut and fill slopes

The proximity of the road to the Moolenaars River and the unique scenic beauty of this rugged environment resulted in a road design where the aim was to mimic the irregular finishes of the natural alluvial plains and the weathered sandstone and granite mountain sides. The construction methodologies were adjusted and typical smooth slopes often associated with road sides were replaced by irregular and landscaped slopes with natural-looking micro-topography.

Although the aspect of micro-topography was not identified or monitored in any formal manner, it was observed that this aspect could play a major contributing role in the successful initial establishment of diverse vegetation in a functional ecosystem in a relatively short period of time.

3.4.1.2 Variation in Vegetation along route

The N1 travels through the Du Toitskloof from Rawsonville to the eastern portal for the Du Toitskloof tunnel. In the distance of just under 9 km, it meanders through a variety of vegetation types that were poorly defined in 1994 during the planning phases of the project. In order to retain the integrity of the vegetation, all plants and seed collected during search and rescue prior to construction, were grouped according to position of origin and habitat such as north-facing slope, drainage channel, rocky outcrop, et cetera. The vision and practice was to reinstate vegetation in similar areas to those from which they were rescued. Even vegetative matter removed from the site prior to earthworks were chipped and saved in bags in the areas of origin to be reintroduced into the planting medium later.

This fine-scale planning was one of the major contributors to the success of the rehabilitation of the site, as the species used in rehabilitation were mostly appropriate to the new post-construction environment.

3.4.2 Research Problem, Questions and Objectives

Constructing a dual carriageway through a narrow valley required considerable engineering skills and a substantial amount of blasting & cutting into the mountain side and filling-in of lower-lying areas. Integrating these man-made structures into the environment necessitated the rehabilitation of the environment. This leads to the **research question**:

Can local plant species be used to stabilize and revegetate the road verges and associated disturbance?

The objectives were to:

- visually integrate the road into the landscape and ensure ecosystem integrity,
- ensure functionality of a mountain reserve area.

3.4.3 Methodology and Lessons Learned

Various standard revegetation techniques were used during the construction of the road, but these were modified to enhance the establishment of suitable vegetation that reflects the pre-construction regime.

The most significant variations in approach included the following:

- Minimizing the impact of construction on vegetation that fall outside the construction footprint by installation of exclusion fencing and enforcement of the rule.
- The establishment of an on-site nursery that handled whole plant collection, seed collection and propagation of plant material for the rehabilitation phase.
- Harvesting of the thin layer of topsoil that occurred on the slopes prior to construction and the placement of these material containing propagules on top of the post-construction slopes in the same area. Soil storage times were also limited to reduce damage to propagules and the rehabilitation followed swiftly upon the completion of earthworks.
- The establishment of a varying natural topography along the route visually integrated with the surrounding environment. Slope angles were varied along particularly long slopes and, where possible, boulders were left or positioned to create a natural effect.
- The blasting methodology was also changed from pre-split blasting, which results in very uniform finishes, to pocket blasting, which results in a rough and irregular finish.

This aided vegetation establishment as it provided pockets where topsoil and water accumulate to support growth.

- Removal of all alien vegetation within the road reserve was also undertaken to reduce competition and a secondary seed reservoir establishment.
- The major decision not to import any vegetation from outside the valley resulted in the retention of the genetic integrity of the vegetation along the road.
- The presence of a full-time Landscape Technician on site to assist engineers with the horticultural and aesthetical aspects of unforeseen situations in real-time has resulted in a process more holistic in execution than previously possible.



Figure 3.8: (2010): Cut slope and median integrated with original vegetation at Du Toitskloof Pass near Molenaars River Bridge.



Figure 3.9: (2010): Worst cut slope with direct transplants and some recruitment south of the westbound carriageway, east of Trout Farm, Du Toitskloof Pass.

3.4.4 Selected Results

The specifications provided by the Engineers called for 60% crown cover. Due to the environment and the particular nature of the soils in the area, rock was also classed as cover when encountered during a descending point survey, since it precluded plant establishment.

Initial revegetation commenced during 1994, with the last major revegetation taking place during 1996. Monitoring commenced during January 1996 and ended in February 1998.

Twenty-five slopes were monitored eight times during this period using the descending-point method. During the process, a steel grid measuring 1 000 mm by 1 000 mm was used and placed at predetermined intervals. The grid contained set points and the status at each point was recorded and the results interpreted.

A variety of data were recorded and the output reflected the slope cover composition in terms of the percentage split between weeds, grasses, fynbos, bare areas and rock areas.

At the end of the monitoring cycle, twenty-one of the twenty-five slopes had a recorded cover significantly higher than 60%.

The grass component (the commercial pioneer species Teff, *Eragrostis tef* and Italian rye grass, *Lolium multiflora*) had significantly reduced to near-zero in most of the slopes. The annual grasses (rye grass & Teff) did, however, act as a rapidly establishing pioneer and nurse plant for the fynbos species whose numbers only became significant two years after seeding.

3.4.5 Lessons Learned and Applied to Chemfos

The use of properly harvested and stored local topsoil, even if applied thinly, proved to be of great value. With this in mind, the use of stockpiled topsoil at Chemfos was investigated. The topsoil available at Chemfos was, however, in very short supply and it was decided not to harvest topsoil from undisturbed areas

Planting propagated and rescued plants expedited the establishment of a mature appearance of the seeded area. The greatest value of using plants in conjunction with seeding was that specific plants associated with specific microhabitats could be introduced. The species of plants that could be introduced by seeding was limited to free-seeding plants. Species that were not practical to introduce by seeding were propagated or relocated after harvesting them to the on-site nursery prior to the occurrence of the disturbance.

During the development of the Chemfos trial design, it was clear that we could not evaluate the use of larger propagated plants, as there were no plants commercially available. Direct transplants were not considered after small-scale informal tests indicated a potential for high mortality. We did not have good knowledge of the local plants at the start of the project and decided to harvest seedlings of pioneer and early succession species from disturbed areas that were planted up in seedling trays. These plants were allowed to establish in the nursery before they were transplanted. This resulted in a near 100% successful planting phase where the plants survived until at least the end of winter.

CHAPTER 4. EARLY STUDIES AT CHEMFOS AND MOVES TOWARDS CLOSURE

4.1 INTRODUCTION

In 1995 SAMANCOR approached Coastal & Environmental Services (CES) to compile a rehabilitation strategy that would result in the issue of a Mine Closure certificate in terms of Section 40 of the Minerals Act (Act 50 of 1991). In order to compile the strategy the following systematic steps were followed:

- A description of dominant plant communities.
- An evaluation of the post-mining topography and vegetation cover to determine rehabilitation required.
- Sampling of the vegetation on site in order to determine a possible vegetation change model and the maximum slope that can sustain vegetation.
- Determine invasive vegetation strategy.
- Determine the relationship between soils and vegetation on the different sites such as the slimes dams, overburden dumps and mine floor areas.
- Review the knowledge base and incorporate all the information into a rehabilitation plan.
- Consult with interested and affected parties on the utilization of the area as a research and educational centre for Palaeontology.

4.2 VEGETATION AND SOIL SAMPLING ANALYSIS

4.2.1 Vegetation

During 1996, twenty-seven sites were sampled throughout the Chemfos mine region (Figure 4.1), where the physical characteristics of the site were recorded as well as all of the plant species. Cover abundance was recorded according to the Braun-Blanquet scale. Plant specimens were collected and identified in the field. Specimens were identified at Stellenbosch (STE) and at the Selmar Schönland Herbarium (GRA) where the specimens are housed. One hundred and thirty-eight species were identified as listed in Appendix A. Data from the field were captured in WordPerfect, converted using the “Cornell Conversion Programme” and analysed using TWINSpan, DECORANA and CANOCO programmes.

4.2.2 Soil

Samples were taken with a 10 cm diameter soil auger at 23 sites, coincident with vegetation sample sites, throughout the project area (Figure 4.1). Two samples were obtained from each core, the first from the surface to a depth of 15 cm and the second from a depth of 30 to 45 cm.

The field-moist soil samples were weighed and dried in an oven set at 70 °C for 24 hours and then weighed again. The percentage moisture in each sample was calculated as the percentage loss of weight on drying. To determine the organic carbon content, the dry soils were then placed in a combustion oven set at 450 °C for 12 hours and then weighed again. The estimated organic carbon content was calculated as the percentage loss of weight on ignition.

Soil pH was measured in distilled water using a standardized Sentron pH meter.

Quantities of Sodium, Magnesium, Manganese, Iron, Potassium and Calcium concentrations were determined in each sample using an atomic absorption (AA) spectrophotometer. The quantities of phosphorus in the surface samples were determined using a Molybdenum Blue extraction technique and measuring concentrations with an AA spectrophotometer (CES, 1996).

4.3 CLASSIFICATION AND INTERPRETATION OF VEGETATION

The results of the TWINSpan analysis (Figure 4.1) indicate a division of the relevés or samples into two major groups: those which are predominantly natural areas or contain a large number of species from the natural region (Groups 1-4); and those which are predominantly disturbed or rehabilitated sites (Groups 5-9). Within the first group there are two major divisions, forming groups of relevés that contain a large number of the Strandveld species (Group 2), relevés which have been rehabilitated (Groups 3 & 4) and relevés rehabilitated recently containing a fair number of succulent species (Group 1). The larger group formed at division 3 consists of the Strandveld and undisturbed areas as well as a number of the overburden dumps which have become well vegetated (Groups 2-4). The undisturbed Strandveld community is identified as a single group (Group 2). The relevés of the overburden dumps are a group which can be separated into those near the plant (Group 3), and those older dumps which are adjacent to the road (Group 4).

The other large group of disturbed sites and some of the slimes dams overburden dumps are not that easily interpreted. In some of these releves, the cover is either very low (Group 7) or, in some cases, has a high cover of invasive species, such as *Acacia cyclops* (Group 5). Where there is a higher concentration of calcrete a natural group is formed (Group 6), as is the case when the soils are saline (Group 8) or high in clay (Group 9) (Figure 4.1).

The DECORANA programme plot of axes 1 and 2 shows the distribution of the samples along the various gradients (Figure 4.1). On the first axis, releves 6 and 27 are well separated as these are recent rehabilitation sites, which contain a large amount of the annual mesem (*Mesembryanthem crystallinum*). They are grouped with the natural sites on the dendrogram (Figure 4.1, Groups 1-4) as they also contain a fair number of other species as well. The undisturbed strandveld areas (releves 7, 15, 21 and 19) are distributed mainly along the second axis (Group 2 in Figure 4.1). The main body of releves is clustered in the lower left of the figure, which includes the majority of the restoration sites, viz. Groups 3 and 4, the Strandveld community (Figure 4.1). Groups 5 and 6, being rehabilitated sites with alien trees and sites high in calcrete respectively, are most dissimilar to the natural Strandveld (Group 2), as is Group 9.

Thus, these results do not show a gradient from younger to older rehabilitation sites, but they do at least indicate some of the natural communities and clearly show that some of the overburden dumps have become well vegetated with indigenous species and are well on the way to the restoration of a natural vegetation cover.

4.3.1 Description of the Plant Communities

4.3.1.1 Strandveld

(Relevé numbers 7, 15, 19 and 21).

These releves are grouped on the dendrogram and are natural Strandveld communities within the mine site, although some (19 and 21) have been disturbed due to grazing or other human activities. The structure of the community is characteristically Strandveld with a large restioid element in most cases. These communities were in all cases found on fairly flat, open regions.

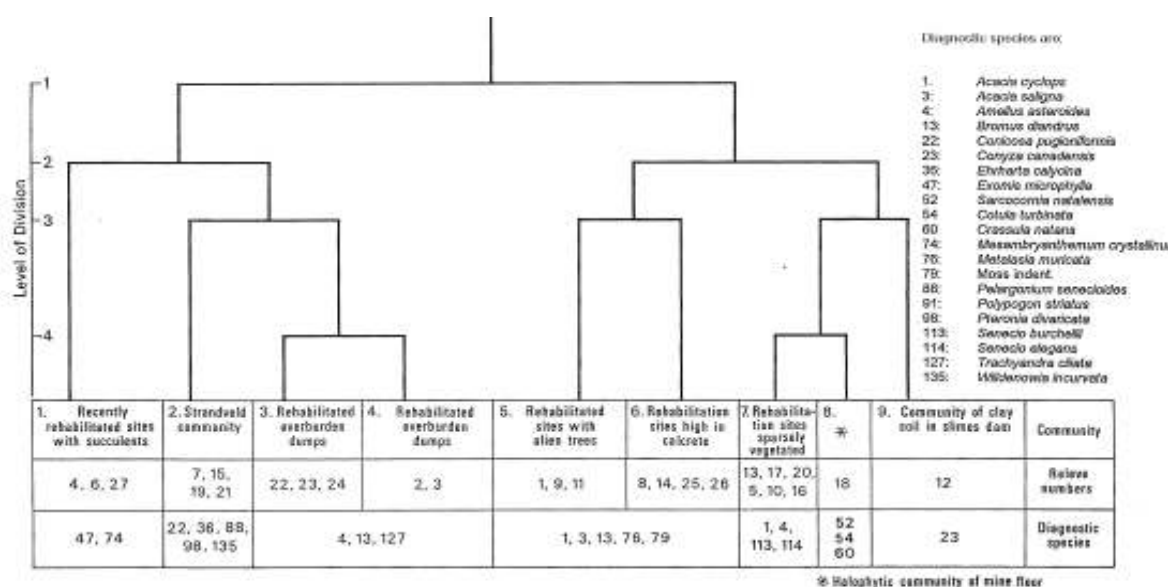


Figure 4.1: Dendrogram Produced by TWINSpan Classification of the 27 Relevés or Sample Sites into 8 Groups.

Percentage cover is generally high, with cover of greater than 70%. Restio/grass height ranges from 60 cm to 1.2 m and shrubs (5-60% cover) are 1-1.5 m high. Dominant species include *Wildenowia incurvata*, *Pteronia divaricata*, *Ehrharta villosa*, *E. calycina*, and *Conichosia pugioniformis* among others. Species-rich communities with over 50 species were recorded in some areas.

4.3.1.2 Overburden dumps

(Relevé numbers 1, 2, 3, 22, 23, 24, 25 and 26)

The large overburden dumps (Figure 4.1: Groups 3, 4 and in part 5 and 6) generally have a fairly high species richness (14-22 species) and good vegetation cover (30-75% cover). Some are covered with alien trees (*Acacia cyclops* and *A. saligna*) up to 2.5 m tall, but in others these aliens have been removed. Shrubs (mainly *Metolalia muricata*) make up to 30% of cover (up to 1.5 m tall) on some dumps and grass/herbaceous cover (30-40 cm tall) is between 30 and 75%.

Dominant species vary between dumps, but include *Acacia saligna*, *A. cyclops*, *Bromus diandrus*, *Ehrharta villosa*, *Amellus tenuifolius*, *Felicia tenella*, *Euphorbia sp.* and *Metolalia muricata*. Some of these overburden dumps are well on the way to restored natural communities.

4.3.1.3 Slimes dams

(Relevé numbers 8, 9, 10,11,12,13 and 14).

The walls of the slimes dams (Figure 4.1: Group 6) are covered with calcrete overburden and these have a good complement of 12 - 16 species and cover of 25 - 40%. Dominant species include *Metlasia muricata*, *Amellus tenuifolius*, (*A. tenuifolius*) and a cover of unidentified mosses.

The centre of the slimes dams (Figure 4.1: Groups 5 &7) have a good cover (60-80%) in the wetter areas although much of the cover is alien trees (mainly *Acacia cyclops*) and species richness is low (7-13 species). Dominant herbaceous/grass species include *Ehrharta villosa*, *Conyza canadensis*, *Sonchus oleraceus*, *Bromus diandrus*, and mosses.

In the dry mobile sand areas of the slimes dams (Figure 4.1: Groups 5 & 7) there is a low cover of less than 10% and only 4 to 8 species present. These include *Amellus asteroides*, *Ehrharta villosa*, *Myrica cordifolia*, *Senecio burchelli* and *S. elegans* .

4.3.1.4 Rehabilitation sites

(Relevé numbers 4, 5, 6, 16, 17, 20, and 27)

In rehabilitation sites (Figure 4.1: Group 7) where the surface has only been ripped, cover is low (10-20%) with 14-18 species, but many of these are only occasional isolated plants. Common species include *Senecio elegans*, *Helichrysum mycopoides*, *Amellus tenuifolius*, and *Senecio burchellii*.

4.3.1.5 Sites rehabilitated by mine management during early 1990s

These sites (Figure 4.1: Group 1) have been covered with straw and manure and have a good cover of 40 - 50%, but this is mainly *Mesembryanthem crystallinum*. In areas where this annual species has died off, the cover is low with only *Tetragonia fruticosa*, being present. In other areas there may be up to 22 species, but in low number and many of these are introduced weeds.

4.3.1.6 Mine floor area

(Releve number 18)

Refer to Figure 4.1: Group 8. In the centre of the mine site (Plate 4.6b) there are some saline pools and a higher cover of vegetation (30%) and a great number of halophytic and freshwater species. Dominant species include *Sarcocornia sp.*, *Bromus diandrus*, and *Crassula natans*.

4.4 PLANT/SOIL INTERACTIONS

The nine plant communities identified by TWINSpan (Figure 4.1) show some soil characteristics which differ between groups (Table 2.2). Although there is not much variation in soil pH, lower pH values are found in those groups which are natural strandveld (Group 2), well-rehabilitated overburden dumps (Group 3) and mine and slime dam sites high in salts (Groups 8 & 9). The latter two groups have the highest conductivity and concentration of sodium and potassium cations. The strandveld community (Group 2) also has a higher conductivity and concentration of some trace elements.

In general, the rehabilitation sites (Groups 1 and 4-7) have pH values of greater than 8.0 and low values of the trace elements. An exception is the concentration of calcium which may be higher, especially on areas where calcrete has been deposited. The phosphorus concentration is also higher in some of these areas and may be three times the amount of the natural Strandveld. Potassium is higher in the rehabilitation sites which have been treated with manure and mulching (Group 1). These areas also have higher soil moisture and organic matter contents. Soil moisture is generally higher in the rehabilitation sites (Groups 3 - 6) than the natural Strandveld (Group 2) and well-rehabilitated overburden dumps (Group 3). However, because of the low cover of vegetation there is little organic matter and soil conductivity in these areas is very low.

4.5 CONCEPTUAL REHABILITATION PLAN: FINDING WAYS OF RESTORING STOCKS TO RENEW FLOWS

- A conceptual rehabilitation plan was prepared (CES, 1996a) and followed by a detailed work plan with various revegetation strategies (CES, 1996b; see Chapter 5).
- The restoration of Chemfos required action on a broad front that included decommissioning plant and buildings, upgrading remaining buildings and infrastructure and upgrading of the mine village (Figure 4.2; see Chapter 9).
- The restoration of natural vegetation and the assistance with the establishment of the new land use function as a Fossil Park provided a major focus in the region (BCD 2000, CES 2001; see Chapter 9).
- The early study concluded that some of the slopes would not be able to support a natural self-sustaining vegetation regime and that these were to be adjusted to a more suitable slope as soon as possible. This work commenced in the summer of 1996 (see Chapter 6).
- An alien vegetation programme was recommended and physical removal of aliens commenced during 1996 (see Chapter 6).
- Revegetation was proposed to commence during 1997 in areas previously cleared of alien vegetation (see Chapter 6).
- It was recommended to set up trials to evaluate the best techniques for the rehabilitation of the drift sands. These experiments were later expanded to include the mine floor and partially vegetated areas as well (see Chapter 5).

CHAPTER 5. CHEMFOS MINE TRIAL DESIGN

This Chapter explores the adaptation of the best practises used on similar projects to the complex, Chemfos post-mining environment. Evaluation took the form of a series of replicated trials in two distinct environments: processed tailings and in-situ soils.

5.1 INTRODUCTION

Rehabilitation of the degraded environments of the mine site was necessary to make the mine site safe and also in order for the mining company to de-register as an active mine and to obtain a closure certificate in terms of Section 40 of the Minerals Act (Act 50 of 1991). The guidelines in the conceptual rehabilitation plan (CES, 1996) were considered together with other available information in order to affect successful rehabilitation of the mine site. Trial designs were, therefore, formulated based on best-known practices for the restoration of the different soil types and conditions of the site.

The aim of this chapter is to discuss the design of these field trials, assess the success or failure of the different trials that were implemented and, in terms of their cost, assess their effectiveness, when monitored over a ten-year period.

5.2 BACKGROUND

Many successful rehabilitation projects have been documented in the past, but examples of successful rehabilitation of open-cast mines are rare. Open-cast mines in the Western Cape are mostly restricted to sand mines and rock and gravel quarries and are generally limited in size. Their rehabilitation has largely been neglected till the mid-1990s.

Larger operations such as the PPC (Pretoria Portland Cement) dolomite mines in Piketberg and Riebeek West, which are situated in shale Renosterveld, are particular examples of inadequate rehabilitation of such mines. Further north, just north of Hondeklipbaai, there are a number of coastal diamond mines, many of which are larger in extent than the 650 ha Chemfos mine, which have had little or no rehabilitation at all. There has been very limited, if any, successful rehabilitation undertaken on these mine sites, as they are in particularly remote locations, in very arid climates and on the tailing soils on which it is extremely difficult to establish plants.. Because of the combination of relatively slack older laws and difficult environmental conditions, little has been done to understand effective rehabilitation of open-cast mines in these areas. Moreover, the

enormous cost associated with post-mining rehabilitation is one of the biggest contributing factors resulting in many inadequately restored or revegetated mines.

The integration of the mining operation and rehabilitation, including the design of the mine path and processes in line with restoration aims, is a fairly modern concept. The mining operations at Brand se Baai, some 200 km north of Chemfos, benefited from this thinking when Grindley and Bardour proposed in 1990 that the mined-out areas should have a long-term rehabilitation goal of resembling the original field conditions. (Blood, 2006) This approach influenced the design of the mining operations as well as the continued rehabilitation attempts.

Where the mining operations were driven by short-term considerations, such as production goals without concern for the land form left behind, the post-mining rehabilitation invariably resulted in the need for the double handling of waste material after the mining process ceased. Mining was driven by the economic goals and shareholder interests, rather than the rehabilitation of the site after closure. In the case of economically marginal mines such as Chemfos, especially during the latter years of its productive life, early mistakes were not rectified due to the cost constraints. Management priorities focused on product refinement, marketing, product transport and processing plant maintenance.

At Chemfos, the practice of separating the overburden layers into fine and course material was followed by default in order to construct a new tailings dam next to the operational tailings dam. The calcareous layer was used for dam-wall formation and the topsoil and sandy material was used to backfill behind the mine path, resulting in partial re-landscaping of the mine area. The older areas were, however, unaffected by this process and the overburden stockpiles were left unmoved.

5.3 POST-MINING LAND FORM

A conceptual rehabilitation approach was formulated and rehabilitation trials were designed to determine the best approach for a variety of soil types and scenarios. In order to plan and manage the rehabilitation, a reference plan was generated. Mining survey maps were used to generate a digital elevation model, which was simplified to produce a line drawing demarcating the post-mining environment. Classification of soil types, slopes, and all other useful information were incorporated into the diagram that served as the basis for all future rehabilitation (Figure 5.1). This was based on a 2000 aerial photograph (Figure 5.2).

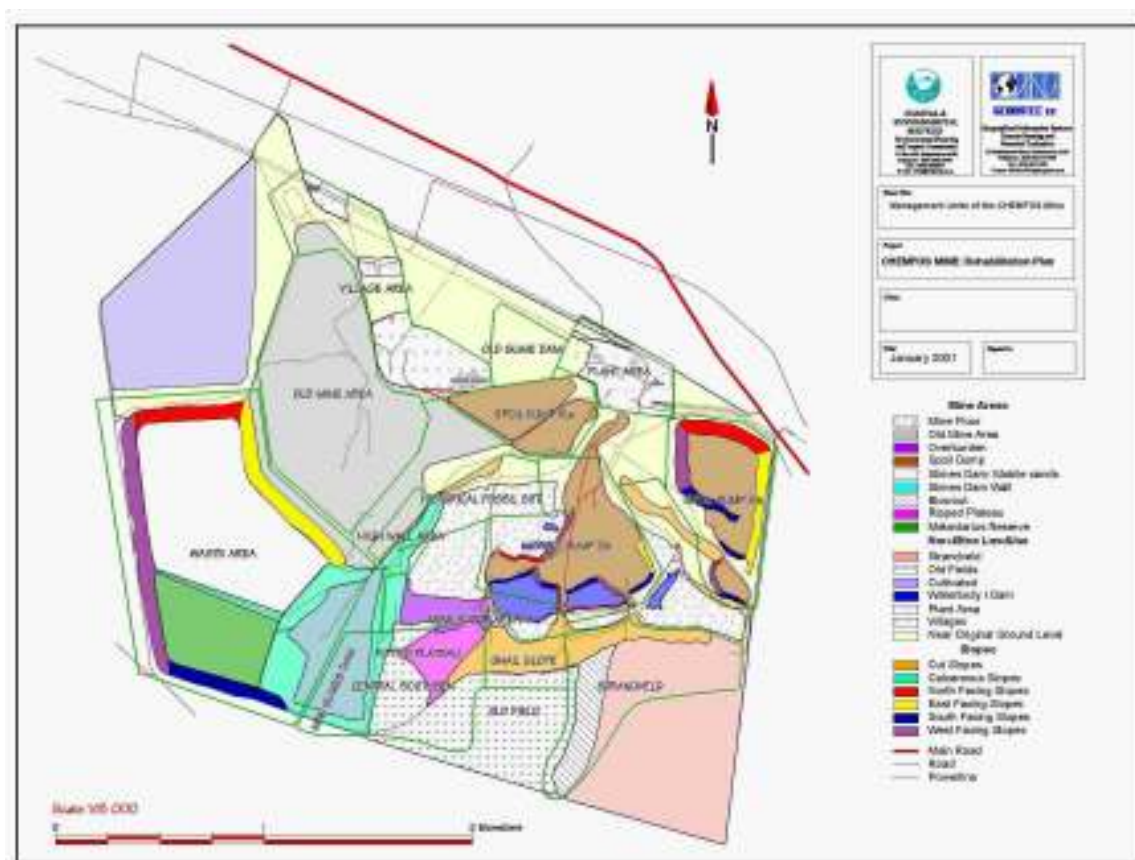


Figure 5.1: The Chemfos mine plan that was used as reference for the rehabilitation trials.



Figure 5.2: March 2000 aerial photograph showing the land form that gave rise to the classification of the land for rehabilitation.

5.4 PURPOSE OF THE TRIALS

During the early studies undertaken by CES, it became apparent that the site varied considerably in topography, soils and vegetative cover (Chapter 4). It was also evident that none of the methodologies used on any of the other Western Cape rehabilitation sites referred to in Chapter 3, offered any ready-made solutions for the rehabilitation of Chemfos. In order to approach the substantial task of rehabilitating the old mine successfully, it was decided to implement a series of trials utilizing a range of the best techniques used elsewhere, but to modify them to provide site-specific information.

The site posed two major challenges in terms of soil conditions, viz. mobile sands that consisted of processed homogenous tailings found in the tailings dam and hard pan that included the material of the palatal phosphate mine floor as well as the exposed calcareous materials. It was reasoned that if we conducted trials in the mobile sands of

the tailings dams (stabilization trials) and on the in-situ mine floor areas (revegetation trials), we would have results that could be interpreted for the remainder of the site. Due to the contrasting conditions of the two sites chosen and the relatively natural conditions that prevailed in areas previously topsoiled, it was decided to expand the trials and to implement another set of trials that would provide minimum inputs that may be required to restore species richness (reinforcement trials).

Three more sets of trials were also designed to test the response of methodologies on slopes and on calcareous hard pan. Since the trials were programmed to be implemented in the following year (1997), the provisional unquantified results of the 1996 trials had provided adequate information to suggest that the trials would not provide any new information and the trials were thus abandoned in favour of rehabilitation that included aspects of the initial trials.

5.5 ESTABLISHMENT AND SAMPLING OF THE TRIALS

The trials were all established during the first winter at Chemfos, shortly after site establishment on 3 June 1996. Detail design of the trials and preparation for the implementation commenced immediately. Planting and seeding of the trial areas were undertaken between 10 July 1996 and 30 July 1996. In all the localities discussed below the various replicated treatments were laid out as permanent plots that could be sampled at intervals over the years. The trials were established as experimental plots of sufficient size (25 m x 25 m) to allow sampling of the vegetation that could become established over the period of the experiment. The plants in all the treatment plots were not watered or cared for, nor managed in any way throughout the course of the study. It was initially decided to use these trials as an indicator of the techniques to be applied to the different sites of the Chemfos Mine, but later it became apparent that the results of these trials could be extended to the long-term assessment of the most favourable treatments to be applied in the rehabilitation of such an arid area following large-scale disturbance.

The cost of implementing the trials were calculated by determining a base price per trial that included the overhead and management cost as well as general non specific costs. Thus there was a basic cost even to the control plots where no treatments were applied. Each measurable activity was recorded per trial and the cost associated was tabulated in a MS Excel spreadsheet.

Sampling was carried out to estimate the cover and species richness in each of the treatment sites. Sampling was carried out using the point sampling method for an estimation of percentage cover and sampling was done by surveying a 100 random points per treatment plot (Arneria Heydenrych – née Craven, pers. comm.). All species of plants were recorded in all the trial plots, not only the species that were planted.

The trials were established in June and July 1996 and then sampled at intervals, initially every year (1997 to 1999) and then sporadically, roughly every four years. The important dates with respect to trial establishment and sampling were as follows:

Establishment of trials were completed by 30 July 1996. Sampling was conducted during the following periods:

August 1997 (Heydenrych & Lombaard)
September 1998 (Heydenrych & Lombaard)
September 1999 (Heydenrych & Lombaard)
September 2004 (Heydenrych & Lombaard)
September 2008 (University of Cape Town Ecol. Hons. students & Pienaar & **van Eeden**)

5.6 STABILIZATION TRIALS ON THE TAILINGS DAM

5.6.1 The Design of the Trials

The tailings dam is situated in the south-western corner of the mine and was constructed by creating an outer wall consisting of mainly calcareous material and overburden. The dam wall measured nearly 20 m high above the lowest point and covered an area of approximately 53 ha. The tailings were the result of the processing of the Palletal Phosphate Member (PPM) in order to concentrate the naturally occurring phosphates. The process of crushing, milling and homogenizing the PPM resulted in particles very uniform in appearance and rounded in form. This contributed greatly to the mobility of the sands. The tailings were deposited in the tailings dam via a network of pipelines that flanked the outer perimeter of the dam. From a series of points along this perimeter, the water-borne tailings were pumped into the dam to settle, allowing the water to evaporate. The beach sand-like deposition pattern was stable when wet, but the sands became mobile once they had dried out. The trials designed to be implemented in this area focused primarily on determining means of stabilising the sands by vegetative means with or without the aid of brushwood barriers.

The trials designed for this area were aimed at providing answers to the following question: “What is the best technique for stabilizing drift sands in the tailings dam area”. In order to answer this question, the information gathered from various sites on the West Coast was considered and three main approaches were formulated. The approaches were further refined and implemented in randomly placed replicated sites that measuring 25 x 25 m (625 m²).

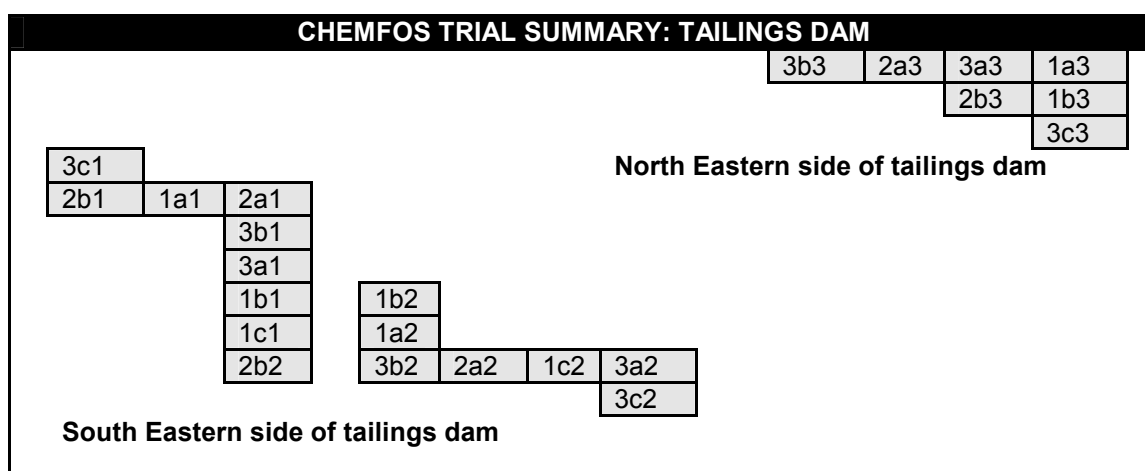
The trial blocks were demarcated using 10-mm round-bar steel droppers on the corners of each plot and the trial names were welded on the surface of mild steel plates on metal spikes resembling nursery markers (Figure 5.3).



Figure 5.3: The trial block corner droppers and markers.



Figure 5.4: Google image indicating the position of the tailings dam and the site where the stabilization trials were established in June 1996.



NOTE: The trials are numbered 1a through to 3c with the second number, i.e. 1a3, indicating replication

Figure 5.5: Graphic Depiction of the Relative Position of the Stabilization Trials.

Table 5.1 summarizes the materials used per trial block. Each of the trials was replicated three times.

Table 5.1: Summary of materials used in implementing the tailings dam trials.

Trial No	Treatment	Material requirement	Unit	Quantity /replicate
1	Establish grasses only			
1a	Marram @ 4/m ² - plants	Marram tufts	no	2500
1b	Ehrharta sp. @ 6/m ² - plants	Ehrharta plugs	no	3750
1c	C. dregeanus 20 kg/ha seed Pack brushwood	C. dregeanus seed Brushwood	kg m ³	1.25 40
2	Establish grasses and brushwood in rows and overseed / plant rows = 5 m, plots are 30 x 30 m			
2a	Seed strips with annual grass Seed strips with Pioneer mixture Pack brushwood Plant Marram @ 4/m ²	Italian Rye "Midmar" Local seed mixture Brushwood Marram	kg kg m ³ no	0.9 0.9 40 1800
2b	Seed strips with Pioneer mixture Pack brushwood Plant Marram @ 4/m ²	Local seed mixture Brushwood Marram	kg m ³ no	1.8 40 1800
2c	Interplant with pioneers 1/m ² Pack brushwood Plant Marram @ 4/m ²	Plugs - mixed Brushwood Marram	no m ³ no	900 40 1800
3	Pack brushwood, over-seed and plant			
3a	Seed annual grass & Pioneers Pack brushwood	Italian Rye "Midmar" Local seed mixture Brushwood	kg kg m ³	1.25 1.25 40
3b	Seed with Pioneer mixture Pack brushwood	Local seed mixture Brushwood	kg m ³	1.25 40
3c	Interplant with pioneers 1/m ² Seed with local seed Pack brushwood	Plugs - mixed Local seed mixture Brushwood	no kg m ³	625 1.25 40

5.6.2 The Evaluation of the Grass Trials

Three main grass species were used in these experiments. They were selected because of relative availability and their known or perceived effectiveness in binding mobile sands.

5.6.2.1 Trial 1a, *Ammophila arenaria* (Marram grass)

- *Ammophila arenaria*, an exotic rhizomatous grass from the Mediterranean regions, is a salt-tolerant, xerophytic grass with known properties to rapidly stabilize mobile sands ([http://en.wikipedia.org/wiki/Ammophila_\(Poaceae\)](http://en.wikipedia.org/wiki/Ammophila_(Poaceae))).
- Vegetative propagation: “Splits” or tufts of divided clumps of grass were harvested from well-established communities of Marram grass in Koeberg Nature Reserve. The harvested tufts were planted directly into the trial areas using Stockosorb gel (this is a synthetic sodium-based co-polymer with the ability to absorb 200 times its own volume in water for later release to plants).

Main attributes:

- A reasonable supply of material was available for harvest from Koeberg Nature Reserve.
- Marram has a known ability to bind mobile soils under extreme conditions on coastal dune sands when irrigated and fertilized.
- It is fast growing and it has the ability to outgrow sand accumulations caused by forced deposition due to the effectiveness of the grass to disrupt smooth air flow.

Application:

Marram was planted in rows at a planting density of 4 tufts per m². Commercial planting is specified at 6 tufts per m², but the cost is relatively high and competition seemed to be problematic at the higher density.



Figure 5.6: *Ammophila arenaria* tufts, harvested from Koeberg, were established in the trials in combination with seeding, planting local plant material and brushwood packing.

5.6.2.2 Trial 1b, *Ehrharta villosa* (Pypgras)

- *Ehrharta villosa*, a rhizomes grass primarily found in sandy environments along the West Coast
- Vegetative propagation: rooted cuttings of rhizomes were used. Early indications on the site confirmed previous trial results of a very low rate of establishment by direct transplants. Various factors may have contributed to this including the low air humidity, fine hair roots and the very specific mycorrhizal associations. Plant material was harvested from the veld during the early morning at first light, dipped in gel and transported to the nursery facility. Rhizome cuttings were made of vigorously sprouting plants. The ideal cuttings contained at least two nodes, strong roots and a sprouting shoot. The cuttings were planted in 78 cavity seedling trays in a commercial compost-based growing mix and grown under small tent structures to retain the heat at night.

Main attributes:

- A reasonable supply of material was available for harvest from natural sites.
- Pypgras is known to bind mobile soils on the coast and inland even under semi-arid conditions. .
- The grass is able to establish spreading colonies that allow other plants to colonize once the areas have become stable.

Application:

Planting were done in rows in combination with seeding and or brushwood packing. A planting density of six rooted & sprouted plugs per m² was used throughout.



Figure 5.7: *Ehrharta villosa* was harvested locally, split and established in the nursery prior to planting in combination treatments in the trials.

5.6.2.3 Trial 1c, *Chaetobromus dregeanus* (Hartebeesgras)

- *Chaetobromus dregeanus*, a tufted grass that occurs in a range of habitats
- Grasses were selected as it was observed that their ability to grow in coastal and mobile sands and to withstand sand build-up was promising.
- Seed obtained from the Department of Agriculture, Worcester.

Main attributes:

- The seed was readily available and the grass naturally occurs in areas on the West Coast. Subsequent discovery of two populations close to the mine enabled us to collect the local West Coast form instead of the Karoo form that was obtained from the Department of Agriculture.
- Hartebeesgras has a known ability to bind mobile soils.
- It is a palatable species and it is known to spread under favourable conditions. It has a medium seed set, but good viability.

Application

Seeded at 40 kg/ha with brushwood cover.

5.6.2.4 Results of the grass trials

The results for all the trials were expressed in Excel spread-sheets. For individual trials the percentage cover was extracted for each year and the results expressed in histograms. For these grass trials the percentage covers of the three different grass species are shown over the 11-year period (Figure 5.8). For each species there was an initial increase up until 2004, and then the percentage cover decreased.

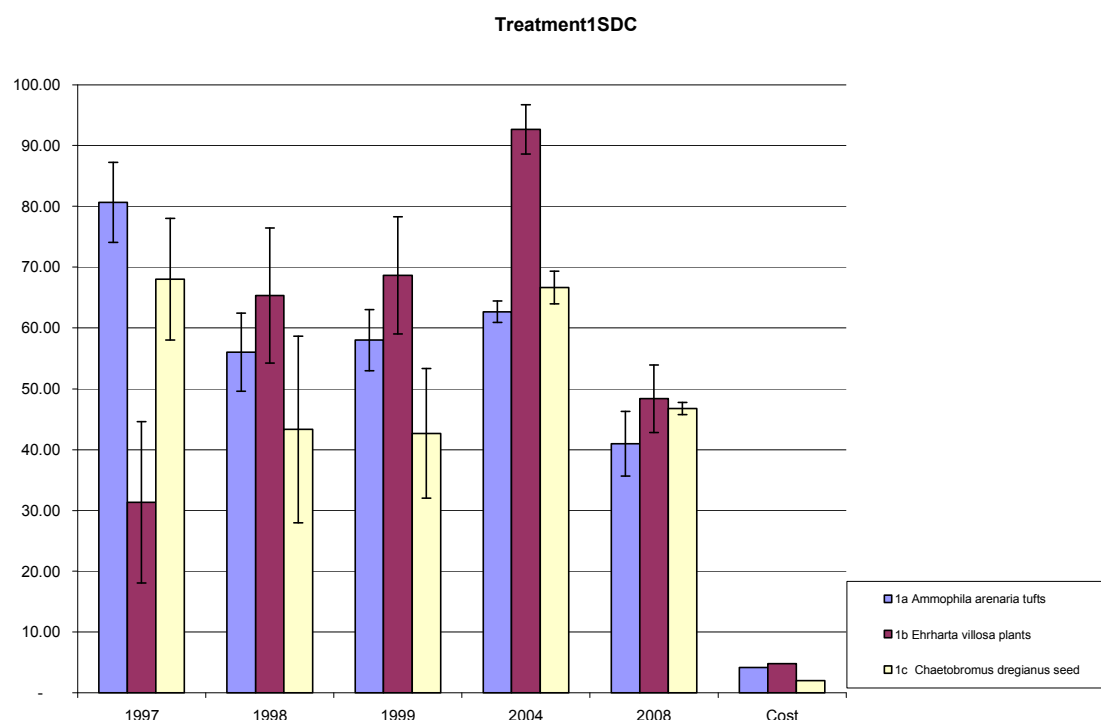


Figure 5.8: Histograms showing the percentage cover of the three grass species in the trials (Nos 1a to 1c) over an 11-year period (Cost is indicated in R/m²).

Discussion

These treatments vary from the vegetative propagated tufted exotic grass, *A. arenaria* (Marram grass), with a known ability to stabilize sands rapidly, to seeded local grasses, *E. villosa* (pypgras) and *C. dregianus* (Hartebeesgras), that have not been tested before as being suitable as a monoculture with sand-binding properties. The use of the *E. villosa* in a vegetatively propagated form has also not previously been tested on a large scale. It was used as vegetative clumps, as no seed of the grass was available when the trials were implemented.

Initial casual observations during the summer of 1996 caused great concern when the *C. dregianus* and *E. villosa* (Figure 5.10) apparently both died back, resulting in very limited improvement of the stability of the area. They initially appeared not to be ideal for use where rapid results are required. The 1997 wet season did, however, improve the situation and saw the resurgence of both species (Figure 5.9).



Figure 5.9: *Ehrharta villosa* die-back observed in the 1996/7 summer.

Increase in cover of the *E. villosa* over time was very good, but it was the worst performer during 1996 and 1997 and it can be contributed to the slow rate of initial growth (Figure 5.8 – histogram above). Cover of this species peaked at 90% in 2004 and that contributed to the initial low species richness as it restricted other species from establishing in the area. This was followed by a decline as the population matured to less than 50% of the maximum cover and represents a state where other species can become established in the area.

A. arenaria provided initial stability whilst all the species effectively stabilized the sand 12 months after introduction. The rapid growth makes the grass ideal for use in high wind environments to stabilize mobile sands. The grass does become moribund in time and the drop in cover to 40% is reflective of this. Unlike the local grasses, *A. arenaria* did not spread outside the planted areas. The drop of cover to around 40% for all the grasses in the long term indicated a stable vegetative state with little difference between the treatments in terms of cover and reflects the soil potential to support the stable state of cover.

Evaluating the cost, it is clear that for long-term interventions seeding of *C. dregeanus* is the obvious choice at less than half the price of *A. arenaria*. Vegetative production of *E. villosa* is not recommended due to cost. Subsequent seeding of *E. villosa* @ 5 kg/ha, however, resulted in similar long-term cover as the vegetative trials at a cost of R0.65/m² making it even more cost-effective than the *C. dregeanus*. Seeding of *E. villosa* was not evaluated in the trial phase due to the unavailability of seed during the winter of 1996.

The use of either of the two local grasses as part of a stabilization regime is recommended from a cost-effective angle. The use of *A. arenaria*, on the other hand, is recommended as part of a regime to yield rapid short-term results.

Neither the local grasses nor the *A. arenaria* can be used in isolation if the objective is to introduce a quick and sustainable regime for stabilising mobile sands. The short-term objective of stabilization and the longer-term objective of diversity at the lowest price is thus best met by a phased approach that includes the use of vegetatively produced *A. arenaria* overseeded with local grasses and followed by the introduction of more diverse vegetation in the second or third year once stability has been achieved.

Although the prevalence of agricultural weeds was not specifically studied, it is possible to review the impact of invasion of the trials by foreign species such as *Bromus diandrus*, as all plants were recorded in the surveys.

During 1997, *B. diandrus* was only recorded once in the control plot. During 2004 it was, however, recorded 82 times in 12 plots. During 2008, *B. diandrus* was completely absent from the sampling. This indicates the opportunistic nature of the species to establish in disturbed environments that are in transition towards a stable state. Once the stability has been achieved, *B. diandrus* is suppressed. The informal fertilization experiments where manure was added (see chapter 6) do, however, have *B. diandrus* as a major component of the species composition in the fertilized areas. This replaced the initially dominant *Oncosiphon suffroticosum*.

In comparison to the control sites where the cover ranged from 26% to 37% in 2009, it is clear that the interventions all yielded positive long-term results. The rate of establishment of cover on the control sites was, however, not monitored regularly so the comparison between trials and controls in this regard cannot be made. This was an oversight, since it was not envisaged initially to monitor the development of the trials for so long. The zero percentage cover departure point and the progress to the 2008 status

thus indicate total but not progressive development. The proximity of the control sites within the confines of the tailings dam also affected the recruitment within the controls. It can be speculated that the stability brought about by the implementation of the stabilization practices employed in the tailings dam had a significant influence on the cover of the control sites.

5.6.3 The Evaluation of *Ammophila arenaria* and Brushwood Trials

In this trial the aim was to determine if a combination of grass planting and brushwood packing would be more efficient and/or cost-effective in comparison to monoculture planting. The brushwood sections were seeded with local and annual commercial grass seed in trial “a” and inter-planted in trial “b” using local species.

5.6.3.1 Trial 2a: *Ammophila arenaria* in 5 m strips with annual grass and local species seeded brushwood strips

- Vegetative state used: *A. arenaria* “splits” or tufts of divided clumps of harvested grass were used. Tufts were planted directly into the trial areas using Stockosorb gel.
- The brushwood originated from *Acacia cyclops* (rooikrans). In order to prevent further infestation of this weed, seeds were hand-removed from the brushwood prior to use.
- Commercial seed of *Lolium multiflora* (Italian rye grass) was used (Agrihilton).
- Locally collected seed was used in combination with some seed bought in from Worcester field reserve. Since we arrived on site during June, it was not possible to collect adequate quantities of local seed and thus commercial seed was initially obtained.

Main attributes:

- A reasonable supply of *A. arenaria* was available for harvest from Koeberg Nature Reserve.
- Brushwood was an abundant resource since more than 60% of the surface area of the old mine was covered in *A. cyclops*. Brushwood has previously been used in the reference areas to temporarily stop the movement of sand.
- Grass and local seed effectively bind sand if the growth is adequate. The brushwood protection would provide initial protection. Using commercial Italian rye grass seed reduced the cost of the treatment.

Application:

- Planted in 5 m wide rows in combination with seeding and or brushwood packing at a planting density of 4 tufts per m².
- Brushwood was packed in 5 meter wide rows with the branch ends facing into the prevailing winter winds, in a single layer. Branch ends were covered, placed in a shallow trench and covered to secure the position.
- Seeding took place prior to brush-packing in hand-tilled soil. This was done in order to prepare a seed bed.

5.6.3.2 Trial 2b: *Ammophila arenaria* in 5 m strips with brushwood strips seeded with local species

- Vegetative state used: *A. arenaria* “splits” or tufts of divided clumps of grass harvested were used. Tufts were planted directly into the trial areas using Stockosorb gel.
- The brushwood originated from *A. cyclops*. In order to prevent further infestation of this weed, seeds were hand-removed from the brush-wood prior to use.
- Seed of local species were seeded in the brushwood strips.

Main attributes:

- Reasonable supply of *A. arenaria* was available for harvest from Koeberg nature reserve.
- Brushwood was an abundant resource since more than 60% of the surface area of the old mine was covered in *A. cyclops*. Brushwood has previously been used in the reference areas to temporarily stop the movement of sand.
- In order to evaluate the effectiveness of the locally available species to grow in the homogenized sand, seedlings were collected and grown on for a month in the nursery in bags and in seedling trays. They were introduced as understory planting to simulate the colonization process.

Application:

- Planted in 5 m wide rows in combination with seeding and or brushwood packing at a planting density of 4 tufts per m².

- Brushwood was packed in 5 m wide rows with the branch ends facing into the prevailing winter winds, in a single layer. Branch ends were covered, placed in a shallow trench and covered to secure the position.
- Planting of the plants at a rate of one plant per 4 m² using polymer gel took place prior to the placement of the brushwood

5.6.3.3 Results of the *A. arenaria* and brushwood trials

The results for these trials were expressed in Excel spread-sheets and the percentage cover of all species are shown over the 11-year period (Figure 5.10). There was an initial increase up until 2004 and then the percentage cover decreased.

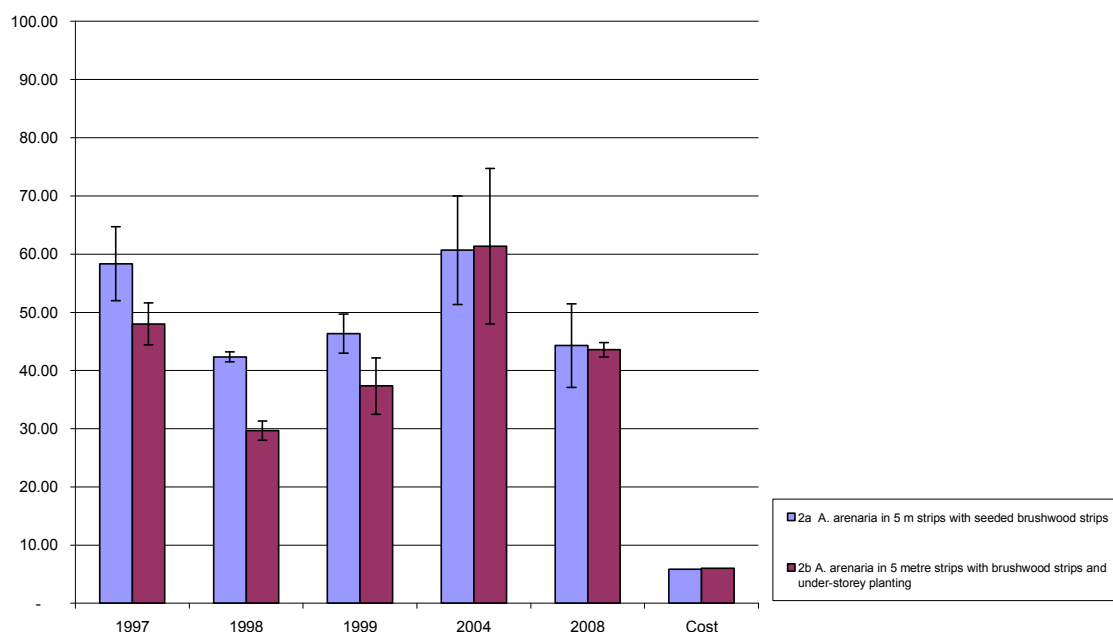


Figure 5.10: Histograms showing the percentage cover of *A. arenaria* in association with brushwood and associated seeding and understory planting trials (Nos 2a to 2b) over an 11-year period (Cost is indicated in R/m²).

Discussion

In order to find cost-effective ways of increasing diversity in association with the effectiveness of the *A. arenaria* within the use of brushwood as a protective layer, seeding and planting was evaluated. The initial differences between the best performing combination (2a) and the worst performer (2b) was 10.3%. This increased during 1998 to

12.6% which was the maximum difference achieved. From 1999 the difference between the best and worst performer was 8.17% in reverse order. The insignificant 0.72% difference observed during 2008 indicates that over time, in a relatively stable environment, initial impacts and differences become obscure.

The cost difference between the most expensive (2b) and best initial performer (2a) was, however, significant. The cost associated with 2a was recorded at R1.99/m². In comparison, 2b was 0.5% more expensive than 2a, but consistently under-performed in terms of cover.



Figure 5.11: (August 2010): *A. arenaria* in association with brushwood and associated seeding and understory planting.

5.6.4 The Evaluation of Brushwood Packing Trials

Since brushwood was in good supply, the trial aimed at determining if brushwood in combination with understory seeding or planting would be able to address the problem of mobile sands in the long term. Pure stands of brushwood packing without any introduction of seed or vegetation was not evaluated, since the tailings were processed and thus contained no propagules. The shape and size of the area in question (nearly 60 ha), the 30 m raised elevation and the disturbed nature of the surrounding vegetation,

made it unlikely that natural seed spread would enable the establishment of vegetation in the brushwood areas.

During the operational phase of the mine, brushwood was used to limit the impact of the sand being blown about and at the time of designing the trials (more than 3 years after the placement) there was hardly any evidence of colonization in the sand deposits around the brushwood.

5.6.4.1 Trial 3a: brushwood packing on mixed seeding

- The brushwood originated from *A. cyclops*. In order to prevent further infestation of this weed, seeds were hand-removed from the brushwood prior to use.
- Commercial seed of *Lolium multiflora* (Italian rye grass) was used (Agrihilton).
- Locally collected seed was used in combination with some seed bought in from Worcester field reserve. This was done since we arrived on site during June and it was not possible to collect adequate quantities of local seed.

Main attributes:

- Brushwood was an abundant resource since more than 60% of the surface area of the old mine was covered in *A. cyclops*. Brushwood has previously been used in the reference areas to temporarily stop the movement of sand.
- Grass and local seed effectively bind sand if the growth is adequate. The brushwood protection would provide initial protection.

Application:

- Brushwood was packed with the branch ends facing into the prevailing winter winds, in a single layer. Branch ends were covered, placed in a shallow trench and covered to secure the position.
- Seeding took place prior to brush-packing in hand-tilled soil. This was done in order to prepare a seed bed.
- Commercial *Lolium multiflora* (Italian rye grass) was seeded at 10 kg per ha in order to see if the considerably cheaper seed may have the same initial effect and if it can be used as nurse plants.
- Local seed was seeded at 10 kg per ha.

5.6.4.2 Trial 3b: Brushwood packing on seeding using local seeds

- The brushwood originated from *A. cyclops*. In order to prevent further infestation of this weed, seeds were hand-removed from the brushwood prior to use.
- Locally collected seed was used in combination with some seed bought in from Worcester field reserve. This was done since we arrived on site during June and it was not possible to collect adequate quantities of local seed.

Main attributes:

- Brushwood was an abundant resource since more than 60% of the surface area of the old mine was covered in *A. cyclops*. Brushwood has previously been used in the reference areas to temporarily stop the movement of sand.
- Grass and local seed effectively bind sand if the growth is adequate. The brushwood protection would provide initial protection.

Application:

- Brushwood was packed with the branch ends facing into the prevailing winter winds, in a single layer. Branch ends were covered, placed in a shallow trench and covered to secure the position.
- Seeding took place prior to brush-packing in hand-tilled soil. This was done in order to prepare a seed bed.
- Local seed was seeded at 20 kg per ha. This costs much more than the treatment in 3b, but may deliver better long-term results.

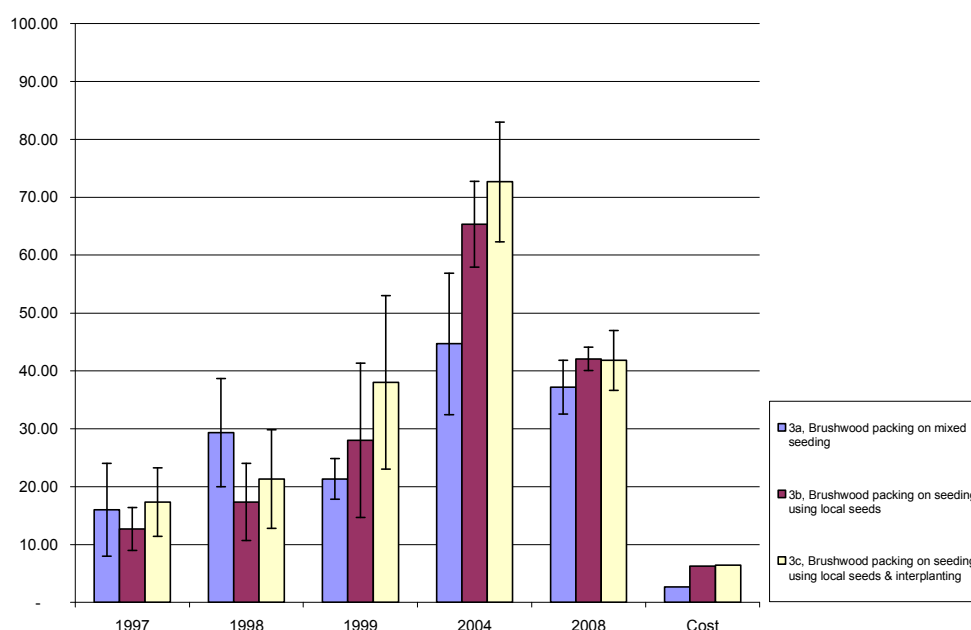


Figure 5.12: Histograms showing the percentage cover of seeding and planting in association with brushwood (Nos 3a to 3c) over an 11-year period (Cost is indicated in R/m²).

5.6.4.3 Results and Discussion

The rate of establishment of cover on all three trials was initially very similar with no significant difference evident 12 months after establishment. During the following 12 months, Trial 3c achieved a 5 percentage point increase in cover over the worst performer (3b). This lead was increased in year three to a 40% improvement over trial 3a that can be seen as significant, although the performance this long after the establishment of the trials becomes less meaningful as the stabilization of the area soon after intervention is critical and this was achieved at 41% of the basic seed mix used in 3a.

5.6.5 Results of the Diversity of Plant Species in All Trials

The results for all the trials were expressed in Excel spread-sheets and then for all the individual trials discussed above, the plant diversity (species richness) was extracted for each year and the results expressed in histograms. For all the trials established on the slimes (tailings) dam the species richness are shown over the 11-year period (Figure 5.13).

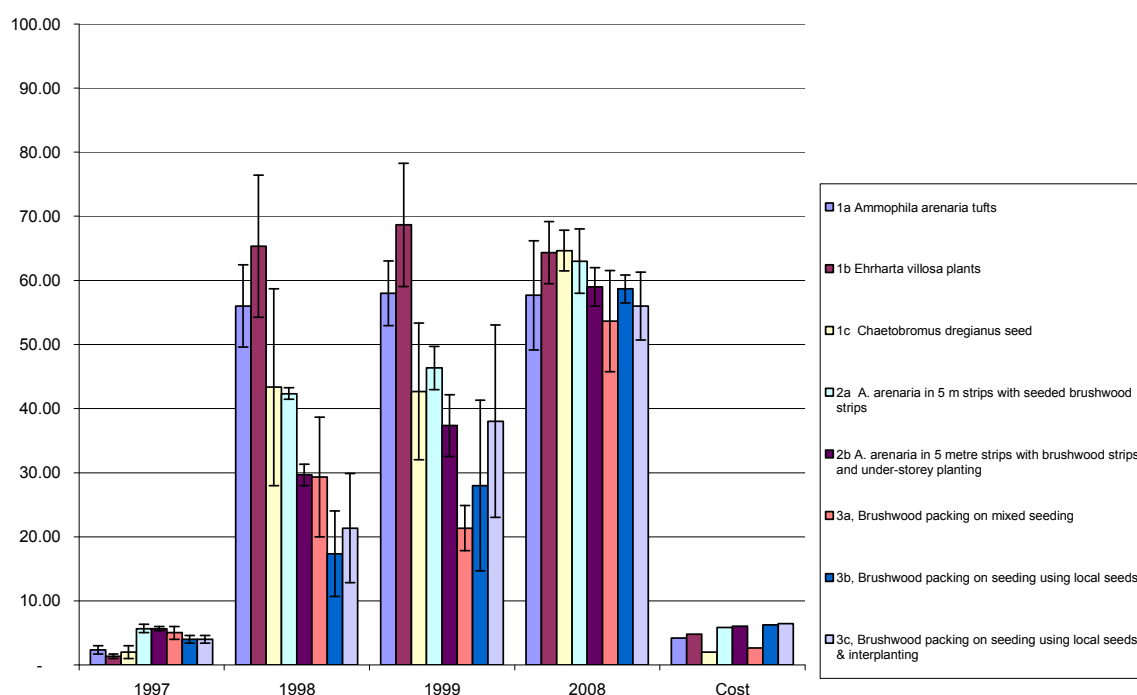


Figure 5.13: Histograms showing the number of species in the trials (Nos 1a to 3c) over an 11-year period (Cost is indicated in R/m²).

Initial species richness in all the trials is very low. One year after the initial establishment of the trials, all the plots recorded similar species richness with no more than six species counted.

A significant increase in species richness was, however, achieved in the following year with Trial 3b only recording 17 species (lowest number) and 1b recorded 65 species.

This pattern persisted in 1999. With the resampling of the trials in 2008, the difference between treatments has all but been lost indicating the importance of a suitable recruitment environment for the increase in species richness.

5.7 REVEGETATION TRIALS ON THE SUBSOIL SURFACE OF THE MINE FLOOR

5.7.1 The Design of the Trials

The trails designed for this area were aimed at providing answers to the following question “*What is the best technique for reintroducing desirable vegetation into the in-situ subsoils exposed during the mining operation?*” The trials were established on the

Palatal Phosphate beds, exposed and ready for mining. The area where the trials were established represents the last area of active mining. It is similar in substrate and composition to much of the mined-out areas since the mining methods employed left a thin layer of the PPM behind. Determining the most suitable rehabilitation strategy in what is arguably the worst-case scenario, would point the direction for the expansion of the rehabilitation in other areas as well.



Figure 5.14: Location of revegetation trials on the subsoil of the old mine site.

Chemfos Trial Summary

Subsoil plots

East of water body

5b3	7g3	7h3	
5a3	7f3	6a2	7g2
4c3	7e3	6b2	
4b3	6c3	6a3	
4a3	6b2	6b3	
7d3	7c2		

7c3	7b3	7a3
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4a2	5a2	4b2	5b2	4c2	7f2	7h2	7e2		
7b2	6c2	7a1	6c1	7c2	7d1	7f1	7g1	7h1	
7a2	7a1	6c1	6b1	6a1	5b1	5a1	4c1	4b1	4a1

South of water body

NOTE: The trials are numbered 4a to through to 7h with the second number i.e. 6a1, indicating replication

Figure 5.15: Graphic depiction the relative position of the revegetation trials.

Table 5.2 summarizes the materials used per trial block. Each of the trials were replicated.

Table 5.2: Summary of materials used in implementing the mine floor trials.

Trial No	Treatment	Material requirement	Unit	Quantity /replicate
4	Pack brushwood, over-seed and plant			
4a	Seed with Pioneer mixture	Local seed mixture	kg	1.25
	Pack brushwood	Brushwood	m ³	40
4b	Plant with pioneers @ 1/4 m ²	Plugs - mixed	no	156
	Pack brushwood	Brushwood	m ³	40
4c	Plant with pioneers @ 1/9 m ²	Plugs - mixed	no	70
	Pack brushwood	Brushwood	m ³	40
5	Pack brushwood in 2 m strips with 2 m spaces & over-seed / interplant			
5a	Seed with Pioneer mixture	Local seed mixture	kg	1.25
	Pack brushwood	Brushwood	m ³	40
5b	Plant with pioneers @ 1/4 m ²	Plugs - mixed	no	156
	Pack brushwood	Brushwood	m ³	40
6	Seed & plant only			
6a	Seed @ 20 kg/ha, local seed	Local seed mixture	kg	1.25
6b	Plant with pioneers @ 1/4 m ²	Plugs - mixed	no	156
6c	Plant with pioneers @ 1/9 m ²	Plugs - mixed	no	70
7	Place Topsoil or chips on subsoil seed all plots and fertilize some			
7a	Place topsoil 75 mm thick	Top soil	m ³	46
	Seed with Pioneer mixture	Local seed mixture	kg	1.25
	Fertilize 14 days after germination	6:1:1 (14) @ 400 kg/ha	kg	25
7b	Place topsoil 75 mm thick	Top soil	m ³	46
7c	Place chips @ 300 m ³ /ha	Chips	m ³	18
	Seed with Pioneer mixture	Local seed mixture	kg	1.25
	Fertilize 14 days after germination	6:1:1 (14) @ 400 kg/ha	kg	25
7d	Place chips @ 300 m ³ /ha	Chips	m ³	18
	Seed with Pioneer mixture	Local seed mixture	kg	1.25
7e	Seed with Pioneer mixture	Local seed mixture	kg	1.25
7f	Fertilize only	6:1:1 (14) @ 400 kg/ha	kg	25
7g	Control			

5.7.2 The Evaluation of the Use of Brushwood Packing and Seedling Densities

Since brushwood was in good supply, the trial aimed at determining if brushwood in combination with under-storey seeding or planting would increase the survival rate of plants by seeding and planting. Brushwood would form a protective micro-environment.

Pure stands of brushwood packing without any introduction of seed or vegetation was not evaluated since the in-situ subsoils contained no propagules.

The areas were, however, used as part of an ad-hoc evaluation to determine if the seeds contained on the branches of *A. cyclops* would release naturally within a suitable period of time. This proved not to be the case, since the seeds within the pods remained on the brush for more than 30 days. Instead of using the brush that was stockpiled 1.5 m high, new brush was cut for use on the trial blocks, as the wet branches were easier to work with. The brush that was left was colonized by rodents and visited by birds.

5.7.2.1 Trial 4a: Brushwood packing on mixed seeding

- The brushwood originated from *A. cyclops*. In order to prevent further infestation of this weed, seeds were hand-removed from the brushwood prior to use.
- Commercial seed of *Lolium multiflora* (Italian rye grass) was used (Agrihilton).
- Locally collected seed was used in combination with some seed bought in from Worcester field reserve. This was done since we arrived on site during June and it was not possible to collect adequate quantities of local seed.

Main attributes:

- Brushwood was an abundant resource since more than 60% of the surface area of the old mine was covered in *A. cyclops*. Brushwood has previously been used in the reference areas to temporarily stop the movement of sand. In the very exposed areas consisting of subsoils with no vegetative cover on it, the brushwood was used to determine the effect of a protective environment.

Application:

- Brushwood was packed with the branch ends facing into the prevailing winter winds; in a single layer. The brushwood was not secured.
- Seeding took place prior to brush-packing in hand-tilled soil. This was done in order to prepare a seed bed.
- Commercial *Lolium multiflora* was seeded at 10 kg per ha in order to see if the considerably cheaper seed may have the same initial effect and if it can be used as nurse plants.
- Local seed was seeded at 10 kg per ha.

5.7.2.2 Trial 4b: Brushwood packing on area planted with 1 plant/4 m²

- The brushwood originated from *A. cyclops*. In order to prevent further infestation of this weed, seeds were hand-removed from the brushwood prior to use.
- Locally harvested and grown on seedlings were used to evaluate the survival and colonization rate of plants versus seeding. The motivation behind the trial was to assess the response difference between seed and plants during the short growing season and to determine the minimum planting density should planting perform better than seeding.

Main attributes:

- Brushwood was an abundant resource since more than 60% of the surface area of the old mine was covered in *A. cyclops*. Brushwood has previously been used in the reference areas to temporarily stop the movement of sand. In the very exposed areas consisting of subsoils with no vegetative cover on it, the brushwood was used to determine the effect of a protective environment on plants.

Application:

- Brushwood was packed with the branch ends facing into the prevailing winter winds; in a single layer. The brushwood was not secured.
- Plants were planted from 128-cavity trays in between the brush.



Figure 5.16: (Aug 2010) Trial 4c1 to the left and 4b1 to the right.

5.7.2.3 Trial 4c, Brushwood packing on area planted with 1 plant/9 m²

- The brushwood originated from *A. cyclops*. In order to prevent further infestation of this weed, seeds were hand removed from the brushwood prior to use.
- Locally harvested and grown on seedlings were used to evaluate the survival and colonization rate of plants versus seeding (Table 6.3). The motivation behind the trial was to assess the response difference between seed and plants during the short growing season and to determine the minimum planting density, should planting perform better than seeding.

Main attributes:

Brushwood was an abundant resource since more than 60% of the surface area of the old mine was covered in *A. cyclops*. Brushwood has previously been used in the reference areas to temporarily stop the movement of sand. In the very exposed areas consisting of subsoils with no vegetative cover on it, the brushwood was used to determine the effect of a protective environment on plants.

Application:

- Brushwood was packed with the branch ends facing into the prevailing winter winds; in a single layer. The brushwood was not secured.
- Plants were planted from 128-cavity trays in between the brush.

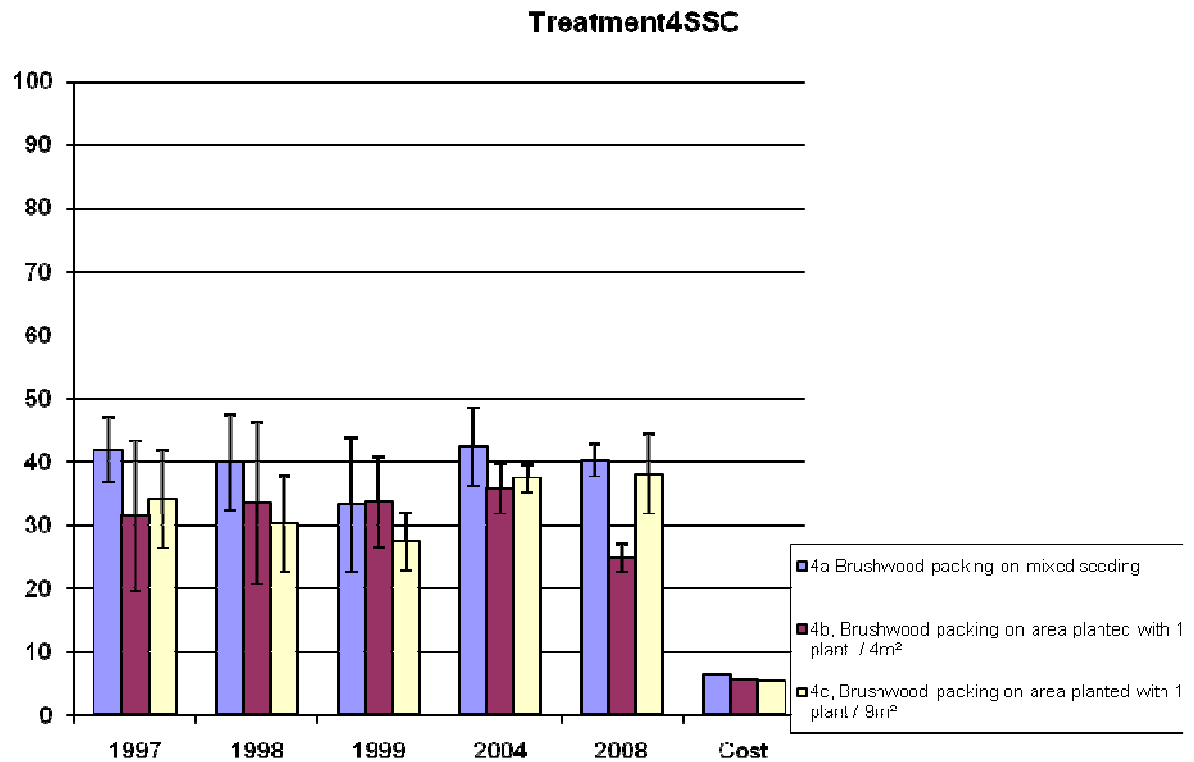


Figure 5.17: Histograms showing the % cover (No's 4a to 4c) over an 11-year period (Cost is indicated in R/m²).

5.7.3 The Evaluation of the Use of Brushwood Packing Alone

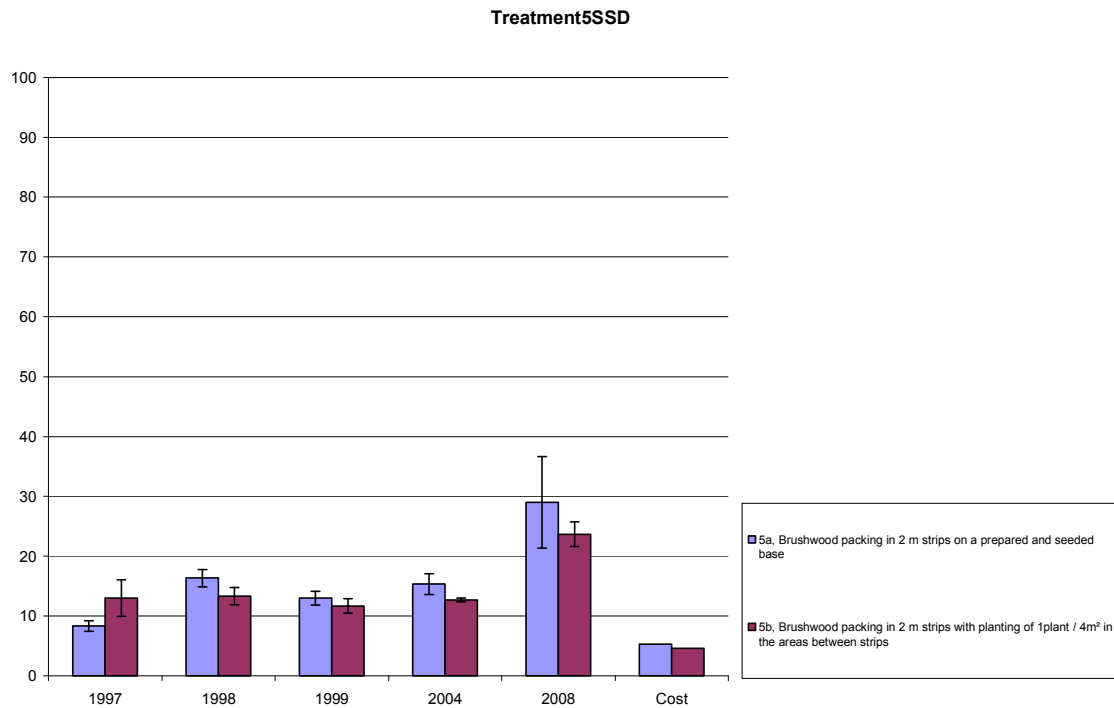


Figure 5.18: Histograms showing the number of species in the trials (No's 5a to 5b) over an 11-year period (Cost is indicated in R/m²).

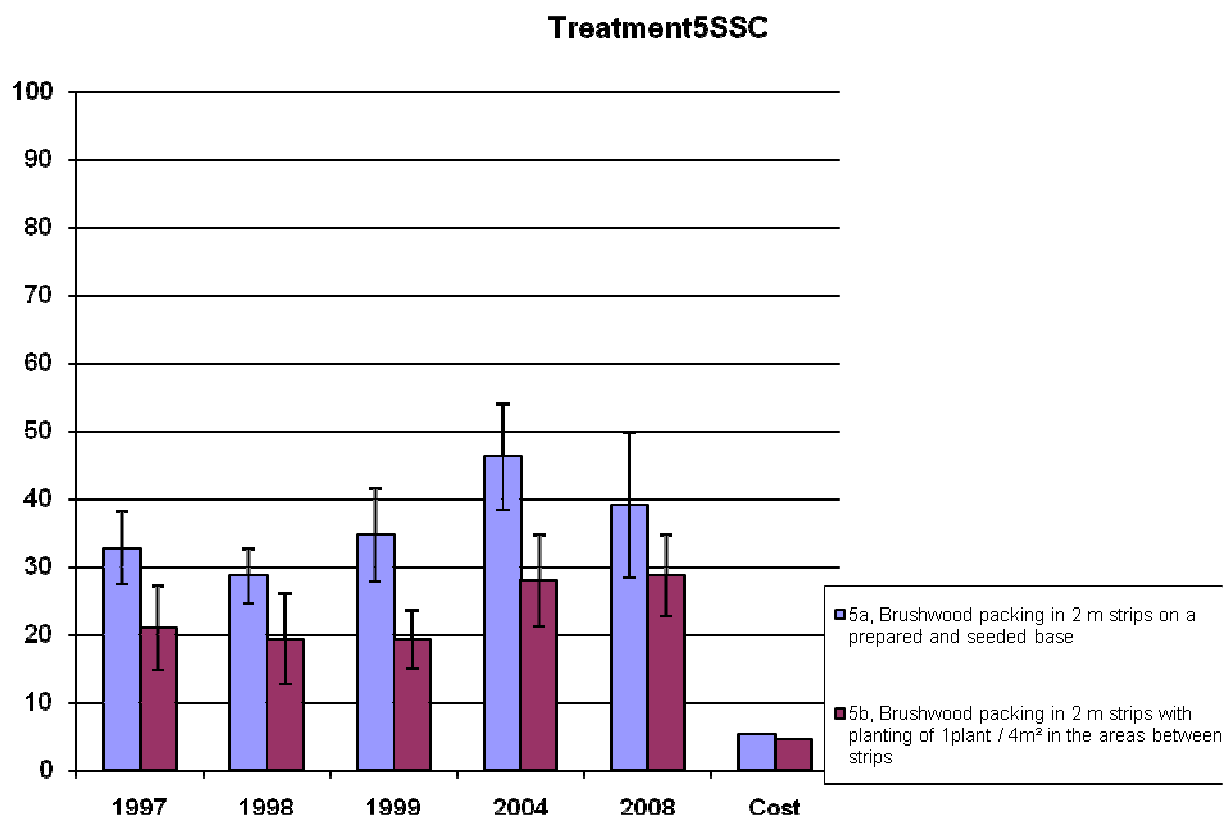


Figure 5.19: Histograms showing the % cover in the trials (No's 5a to 5b) over an 11-year period (Cost is indicated in R/m²).

5.7.3.1 Trial 5a: Brushwood packing in 2 m strips on a prepared and seeded base

- The brushwood originated from *A. cyclops*. In order to prevent further infestation of this weed, seeds were hand-removed from the brushwood prior to use.
- The use of brushwood in strips aimed to evaluate the effectiveness of reduced brushwood quantity on the germination and survival of seeded areas.

Main attributes:

- Although brushwood was abundantly available, the cost of harvesting, collection, de-seeding and placement was substantial. If the 40% reduction in cost of using strips still resulted in good protection of seedlings, the method would be more desirable to use than the full cover placement of brushwood.

Application:

- Brushwood was packed with the branch ends facing into the prevailing winter winds; in a single layer. Brushwood was not secured. Brushwood strips of 2 m wide were placed with 2 m wide gaps in-between.
- The entire area was prepared and preseeded with 20 kg of seed/ha.

5.7.3.2 Trial 5b: Brushwood packing in 2 m strips with planting of 1 plant/4 m² in the areas between strips

The brushwood originated from *A. cyclops*. The use of brushwood in strips aimed to evaluate the effectiveness of reduced brushwood quantity on the establishment and survival of the introduced plants.

Main attributes:

The placement of the brushwood strips perpendicular to the prevailing winds forms protective pockets from where the introduced plants can establish and spread.

Application:

- Brushwood was packed with the branch ends facing into the prevailing winter winds; in a single layer. The brushwood was not secured. Brushwood strips of 2 m wide were placed with 2 m wide gaps in between.
- The entire area was prepared and preseeded with 20 kg of seed/ha.

Discussion

Initial establishment was very similar (round 30% cover) for all the trials except for 5b that only achieved 21% cover. This trend was maintained until 2008, although the differences became less noticeable in later years.

In terms of performance, none of the trials stand out as a clear answer. The final best performing trial by a small margin, was also the most expensive to implement and the cheapest trial (5b) delivered the worst results throughout, achieving only 58% of the cover (4a) in 2008.

The cost of 4a was 14% higher than that of the next best performer (4c) and resulted in a 22% better cover in 2004, that reduced to only 7% by 2008.

Compared to the worst performer (5b), the cost was 26% more, but yielded 30% better results. There is thus a direct correlation between cost and results when comparing the best and worst results in this case. The very marginal results of the worst performer during 2008 and 2009 makes the use of the cheaper option too risky on large implementation.

5.7.4 The Evaluation of the Seeding or Seedlings Only without Brushwood

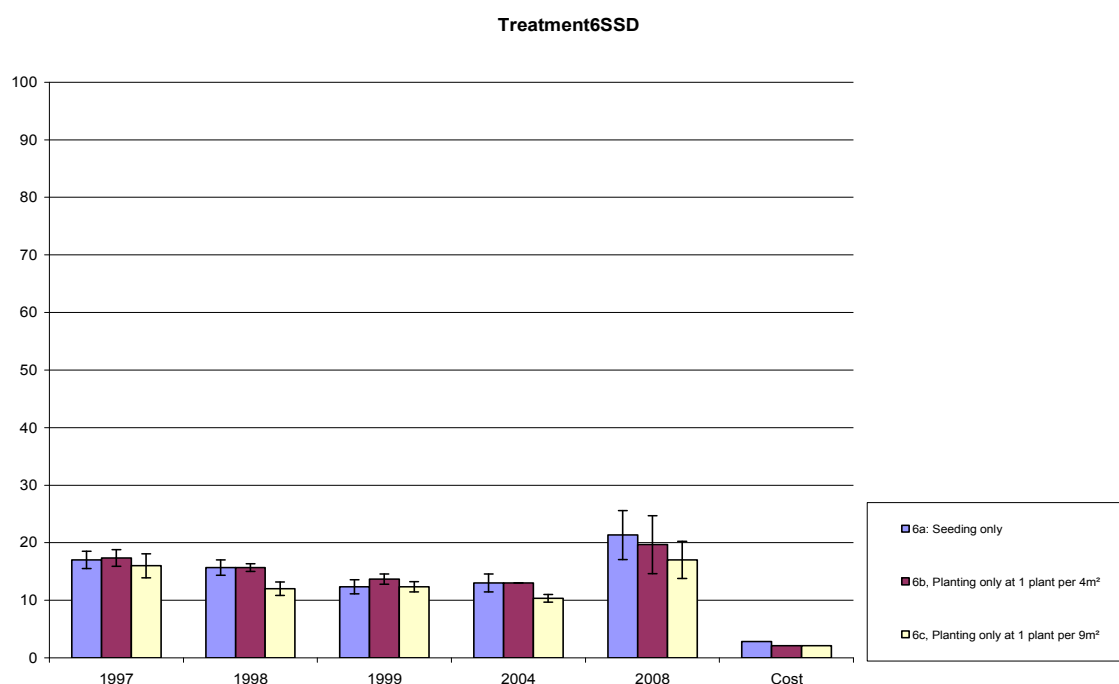


Figure 5.20: Histograms showing the number of species in the trials (No's 6a to 6c) over an 11-year period (Cost is indicated in R/m²).

5.7.4.1 Trial 6a: Seeding only

Seeding only without the aid of protecting microtopography provided by brushwood packing.

Main attributes:

This treatment represented the lowest input cost other than the control plots. The introduction of seed directly into the post-mining environment would indicate establishment and survival and the potential for natural recovery.

Application:

- The soil surface was disturbed in order to provide a suitable seed bed. This was done by hand to produce grooves measuring about 300 mm long 20-40 mm deep and 50 mm wide. Seed was then hand-broadcasted across the entire area and wind and water accumulated the seed in the hollows.
- The entire area was seeded with 20 kg of seed/ha.

5.7.4.2 Trial 6b: Planting only at 1 plant per 4 m²

This trial entailed planting only without the aid of protecting micro-topography provided by brushwood packing.

Main attributes:

This treatment represented relatively low input cost. The introduction of mixed species of plants directly into the post-mining environment would indicate establishment and survival of plants that may have a survival advantage over seed introduction in this short growing season area.

Application:

- Individual hollows were created for each plant. The hollows were created by hand using spades. The holes were over-excavated to allow for the deep planting of the plants that were then left with a water-harvesting cavity around them. The deeper planting also initially provided a measure of wind protection.
- The plants were planted at a rate of 1 plant per 4 m².

5.7.4.3 Trial 6c: Planting only at 1 plant per 9 m²

This trial entailed planting only without the aid of protecting micro-topography provided by brushwood packing.

Main attributes:

This treatment represented lower input cost in comparison to 6b. The introduction of mixed species of plants directly into the post-mining environment would indicate establishment and survival of plants that may have a survival advantage over seed

introduction in this short growing season area. The lower density of planting was evaluated to determine if there was a critical mass associated with planting plants into this environment (when compared to 6a).

Application:

- Individual hollows were created for each plant. The hollows were created by hand using spades. The holes were over-excavated to allow for the deep planting of the plants that were then left with a water-harvesting cavity around them. The deeper planting also initially provided a measure of wind protection.
- The plants were planted at a rate of 1 plant per 9 m².

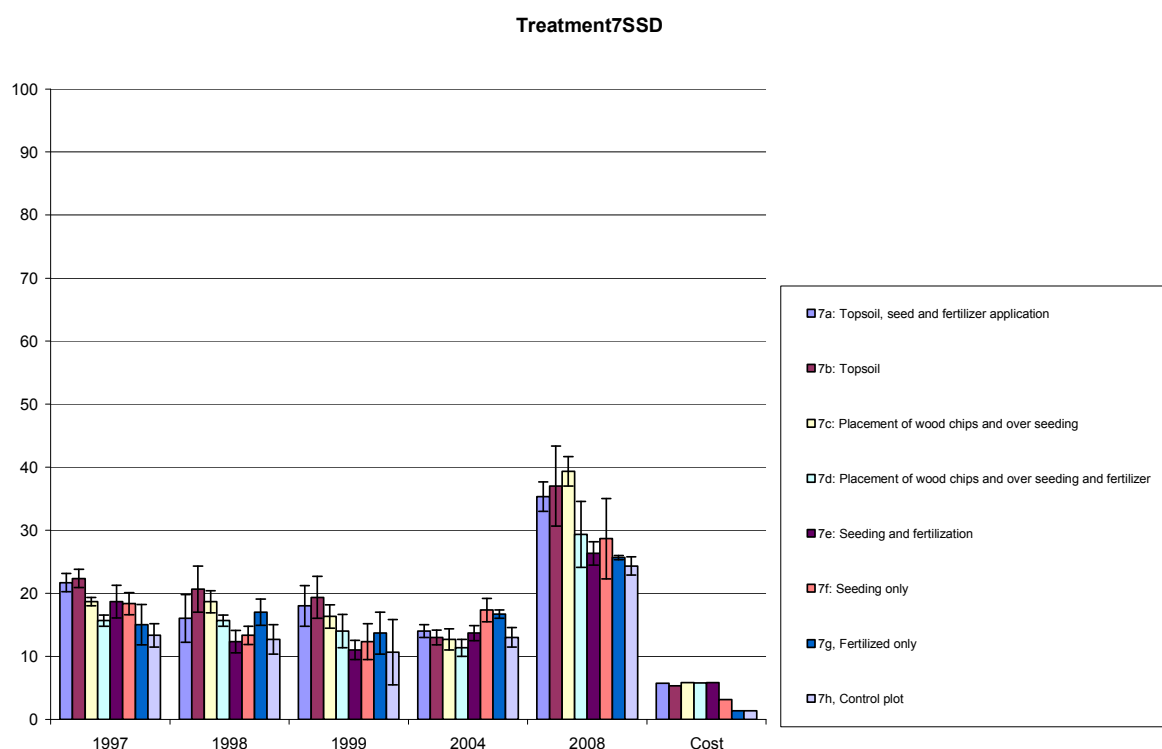


Figure 5.21: Histograms showing the number of species in the trials (Nos 7a to 7h) over an 11-year period (Cost is indicated in R/m²).

Discussion

The results of this trial are inconsistent with the predictions. During the first 8 years, the cheapest and least intensive rehabilitation technique yielded better results than the other

two. Fine-scale soil fertility testing has not been done and the anomaly can probably be linked to this, as all the other factors were uniform.

Long-term monitoring has, however, seen an increase in both species richness and cover in the seeded areas (6a) in comparison to 6b & 6c, which were planted.

The most significant observation, though, was made when Prof Tim Hoffmann's students surveyed the excess brushwood stockpile areas on the edge of the prepared trial areas during 2008 following field observations. These areas were used as an initial experiment to see if *A. cyclops* seeds that persisted on the branches would be removed by mice and birds. This did not happen within the available time frame of 30 days and branches were left and fresh seed-free branches were used in the trials. During preparation for a re-evaluation survey conducted during 2008 by students of UCT, it was observed that the protective habitat provided by the brushwood and the faunal diversity lured, resulted in a marked increase of species that developed within the brushwood area. It was thus decided to demarcate three trial blocks within the brushwood areas and to survey them to determine the effect of providing long-term thicker brushwood protection.

During 1996, the *A. cyclops* branches were packed in rows of approximately 3 m wide and 1.5 m high and left. Initial observations were that seeds were removed from the branches, but that not all seeds were removed, rendering the approach useless as the double-handling required to position the branches to have some seeds removed, followed by a hand-stripping to ensure that all persistent seeds were removed, was too expensive. This experimental site was thus not monitored again until 2008 when it was monitored and assigned the reference 10a.

The advantage of dense brush cover is quite apparent. Nesting sites for birds and small mammals lured a host of inhabitants to the site and with them came the seeds that germinated under favourable conditions.

The result is a higher percentage cover and higher species richness than even the benchmark site.

Since the cost of all the activities was recorded, a retrospective cost evaluation of the brush stockpiling was assessed to be R8/m³ or R12/m² making it the most expensive of all the trials, but yielding the best results in terms of cover (almost 94%) and species richness (15.64 vs the benchmark (BM1) of 26.17). Trial 10a (see discussion above), at

almost double the cost of the next most expensive trial, is not considered a practical alternative. It is also unlikely that adequate quantities of material will always be available. It does, however, highlight the importance of early reestablishment of a faunal component to assist with seed dispersal and the establishment of a functional ecosystem.

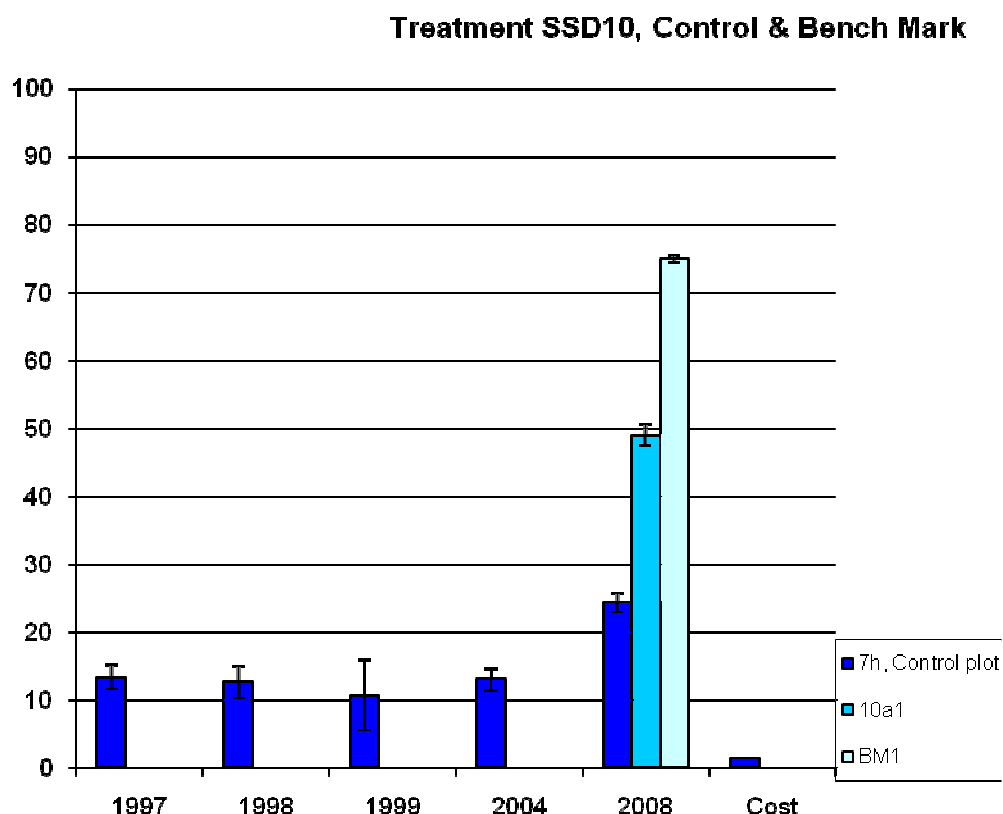


Figure 5.22: Histograms showing the number of species in the control plot (7h) as well as the newly sampled benchmark and 10a brushwood stockpile (Cost is indicated in R/m²).

5.7.5 The Evaluation of Topsoil or Wood Chips and Seeding

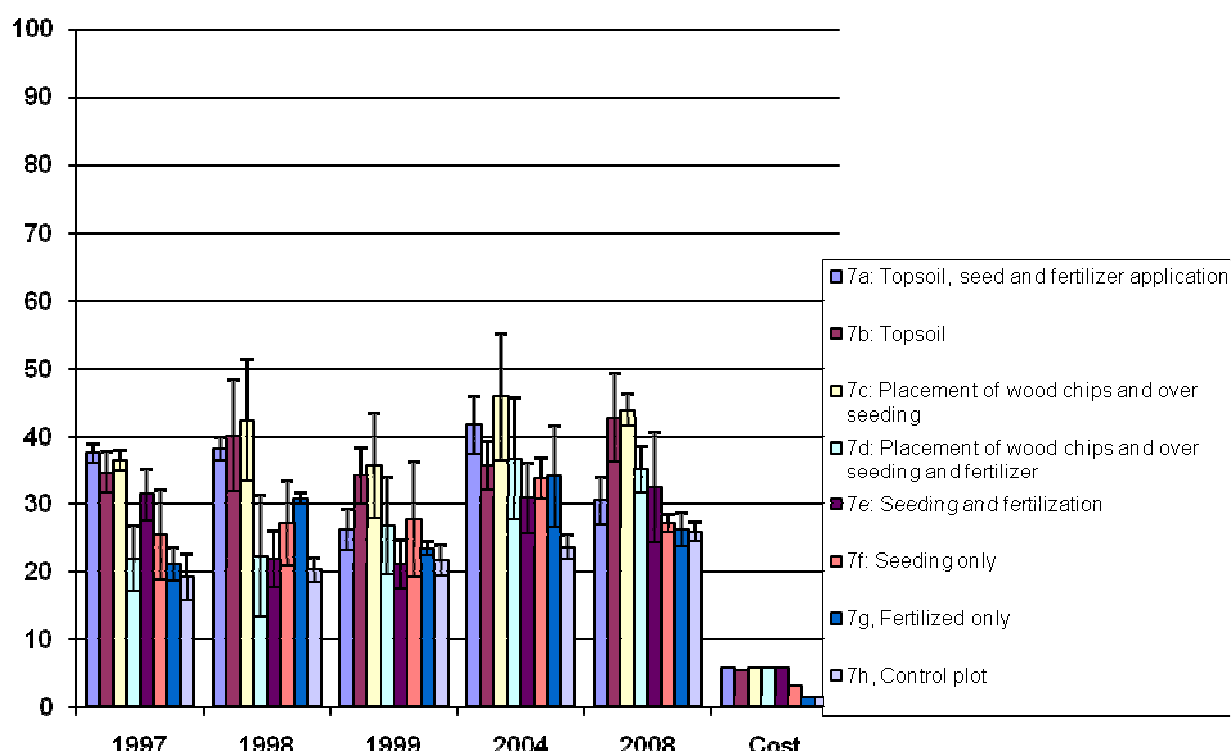


Figure 5.23: Histograms showing the percentage cover of seeding, planting and fertilizing in association with the use of wood chips (No's 7a to 7g) over an 11-year period (Cost is indicated in R/m²).

5.7.5.1 Trial 7a: Topsoil, seed and fertilizer application

This treatment aimed to evaluate the benefit of the use of scarce topsoil on the establishment of seedlings from seed and the benefit of limited application of fertilizer.

Main attributes:

Topsoil from uncertain age and unknown exact location (although believed to be from the mine path last opened) was used.

Application:

- All trial areas were denuded so they were free of vegetation. Topsoil was placed from stockpiles to the trial blocks in a 75 mm layer by mechanical means and then hand-leveling.
- The area was prepared for seeding and hand-seeded.
- 6:1:1 (14), a chicken-manure-based fertilizer was hand-applied 14 days after germination at a rate of 400 kg/ha.

5.7.5.2 Trial 7b: Topsoil

This treatment aimed to evaluate the benefit of the use of scarce topsoil on the establishment of seedlings from the topsoil only.

Main attributes:

Topsoil from uncertain age and unknown exact location (although believed to be from the mine path last opened) was used. The duration of the storage of the topsoil was uncertain but believed to have been at least 3 years. The storage conditions were not ideal as the soils were stockpiled in heaps more than 2 m high.

Application:

All trial areas were denuded so they were free of vegetation. Topsoil was placed from stockpiles to the trial blocks in a 75 mm layer by mechanical means and then hand-leveled.

5.7.5.3 Trial 7c: Placement of wood chips and over-seeding

This treatment aimed to evaluate the use of wood chips as a substitute for topsoil. Seed was introduced.

Main attributes:

Since *A. cyclops* was abundantly available, the use of chips to augment or replace topsoil was considered.

Application:

- All trial areas were denuded so they were free of vegetation. Chips obtained from de-seeded *A. cyclops* branches were used at a rate of 300 m³ per ha.
- A seed bed was prepared, seed broadcasted and the chips were placed by hand.

5.7.5.4 Trial 7d: Placement of wood chips and over-seeding and fertilizer

This treatment aimed to evaluate the use of wood chips as a substitute for topsoil. Seed was introduced.

Main attributes:

Since *A. cyclops* was abundantly available, the use of chips to augment or replace topsoil was considered.

Application:

- All trial areas were denuded free of vegetation. Chips obtained from de-seeded *A. cyclops* branches were used at a rate of 300 m³ per ha.
- A seed bed was prepared, seed broadcasted and the chips were placed by hand.
- 6:1:1 (14), a chicken-manure-based fertilizer was hand-applied 14 days after germination at a rate of 400 kg/ha.

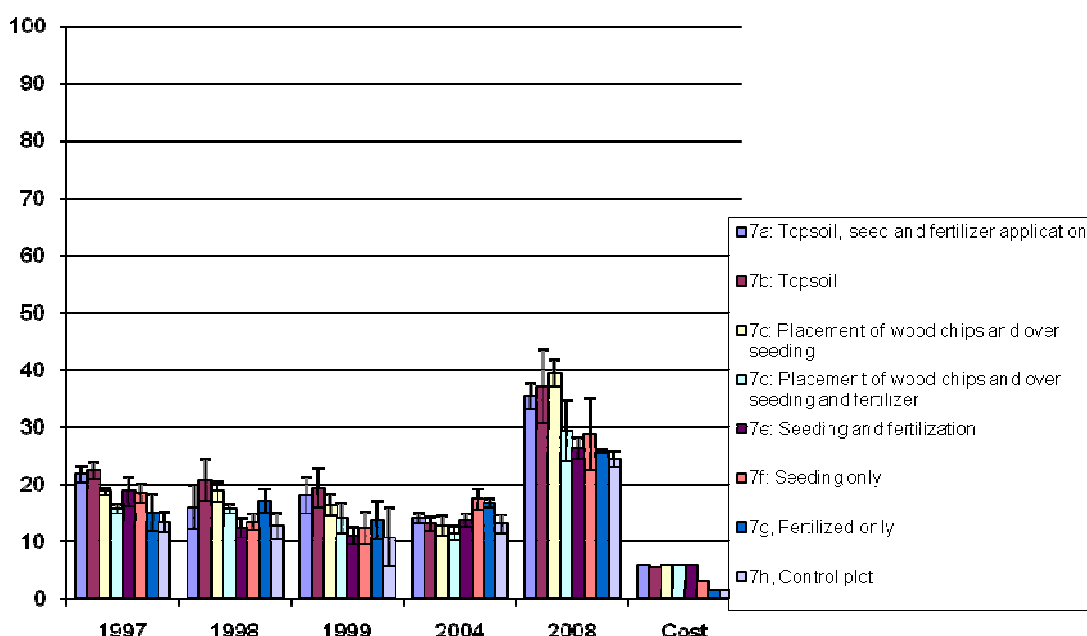


Figure 5.24: Histograms showing the number of species in the trials (Nos 7a to 7h) over an 11-year period (Cost is indicated in R/m²).

Discussion

The use of topsoil replacements as part of the rehabilitation process is the obvious choice if cost and availability is not a factor. Short supply of either or both more often than not is, however, the reality on most mines and particularly on mines that require rehabilitation after the operational phase.

Evaluating the cost and benefits of using topsoil was a key factor in determining the approach that was followed at Chemfos as the post-mining environment was indeed extremely barren and consisted mostly of cross-zoned soils stockpiled in dumps and mine-floor environments.

The positioning of the trials on the alkaline phosphate-rich subsoils aimed to determine the extent of rehabilitation possible on these soils in a natural or ameliorated state.

The trials evaluated the use of the different components in combination to assess the most effective minimum level of intervention required to establish suitable vegetation to the mining area.

Initial results for the seeded and topsoiled areas reflected slightly better results (2.8% points) in comparison to the topsoiled-only trials. In comparison, seeding on the in-situ soils yielded an 8.5% point better result. Germination from the seed contained in the topsoil thus contributed toward the improved results.

The results of the next ten years do not reflect linear development of the vegetation and are inconclusive on a fine scale. In broader terms, the topsoiled sites did perform better than the sites treated with wood chips.

The 1997 results reflect that the topsoiled and seeded topsoil area was 22% more expensive to install, but it yielded a 75% better result when compared to the worst performer, 7d. The reason why the fertilized trial did not perform better than the unfertilized trials in this case cannot be explained and probably relates to localized soil conditions, as the trend persisted until 2008.

The four trials that had topsoil or wood chips added did, however, achieve cover above 64% with the topsoil trial (7b) achieving almost 80% and with 7c exceeding 83%; this compares well with the benchmark at just below 75%.

The final cover in the control site was recorded at 50%, although it is suspected that the proximity of the seed-bearing plants in the other trial sites contributed towards this. It took six years for the control to exceed 20% cover, a level of cover that all the other treatments exceeded within 12 months after being first established.

5.7.5.5 Trial 7e: Seeding and fertilization

This trial was designed to evaluate the ability of seeds to colonize the in-situ substrate with the aid of limited fertilization.

Main attributes:

The ability to allow the establishment of vegetation of the subsoils and the impact of fertilization was evaluated.

Application:

- A seed bed was prepared, seed broadcasted.
- 6:1:1 (14), a chicken-manure-based fertilizer was hand-applied 14 days after germination at a rate of 400 kg/ha

5.7.5.6 Trial 7f: Seeding only

This trial was designed to evaluate the ability of seeds to colonize the in-situ substrate without the aid of any amelioration.

Main attributes:

The ability to allow the establishment of vegetation of the subsoils was evaluated.

Application:

A seed bed was prepared and seed broadcasted.

5.8 CONTROL

5.8.1.1 Trial 7g: Fertilizer only

Fertilizer was added to the control plots.

Main attributes:

The establishment of vegetation in this area by external drivers would be evaluated and the response of these to fertilizers could be compared to the unfertilized and untreated control.

Application:

Other than the unifying initial clearing of the site, as part of the overall preparation, nothing was done to these trial blocks

5.8.1.2 Trial 7h: Control plot

No material was added to the control plots.

Main attributes:

The establishment of vegetation in this area by external drivers would be evaluated.

Application:

Other than the unifying initial clearing of the site, there was no intervention on this site.

Discussion

Trials in this group were significantly cheaper to install than the topsoiled trials as they represent minimal levels of intervention that included preparation, seeding and fertilizing. The poor performance of the control, particularly during the first eight years, highlights the importance of rehabilitation of disturbed environments on this scale.

Although trial 7g (fertilizing only) reflects similar later results as the seeding trials, it is doubtful that without the addition of seed to the general environment, these results would have been attained. To establish this, exclusion plots would be required and this was not part of our experimental design.

Initial results of seed and fertilizing were 36% below that of the same treatment on topsoil but the cost was only 21% of the cost of the topsoiled trials.

After 12 years, the difference was reduced to 12% with 11% less species richness being recorded in the non-topsoiled trials

Since the trials were not monitored for plant vigour, it is not possible to say if the lack of topsoil would in the longer term have a detrimental effect. The trends, however, suggest that this may not be the case and that the soil profile will improve in time.

The most significant finding was the effect that cover, in combination with small mammals and birds, had. Trial 10a was not formally monitored, as it was an interim experimental site set up to determine how long it will take birds, rodents as well as

natural seed drop to render the branches of *A. cyclops*, collected in full seed, useful in trials without the need of manual and expensive seed stripping.

The initial indications proved that it will require longer than three months, thus rendering the material usable when it was no longer required. The brush was thus left in the wind rows and formed an ideal protected and undisturbed nesting and perch site, luring birds and small mammals that aided to seed dispersal into the area. The result was monitored in 2008 and the site recorded a 93.7% cover and 30% greater species richness than any of the trials, whilst being 60% of that of the benchmark.

This is significant, but the cost and the volume of material, as well as the obstruction of the dense brush and the associated fire risk, make this very attractive option non-viable.

5.9 GENERAL DISCUSSION

Evaluating the effectiveness of achieving cover and species richness by the different treatments was done by monitoring the trial areas five times over a period of eleven years.

The graphs are presented representing cover and species richness as it was monitored over time for the two main areas, i.e. the slimes dams and the subsoil (phosphate bed) areas.

In all the cases, the sampling was undertaken in all three replicates of the trials.

The recorded values were plotted in Excel, indicating standard deviation and error bars.

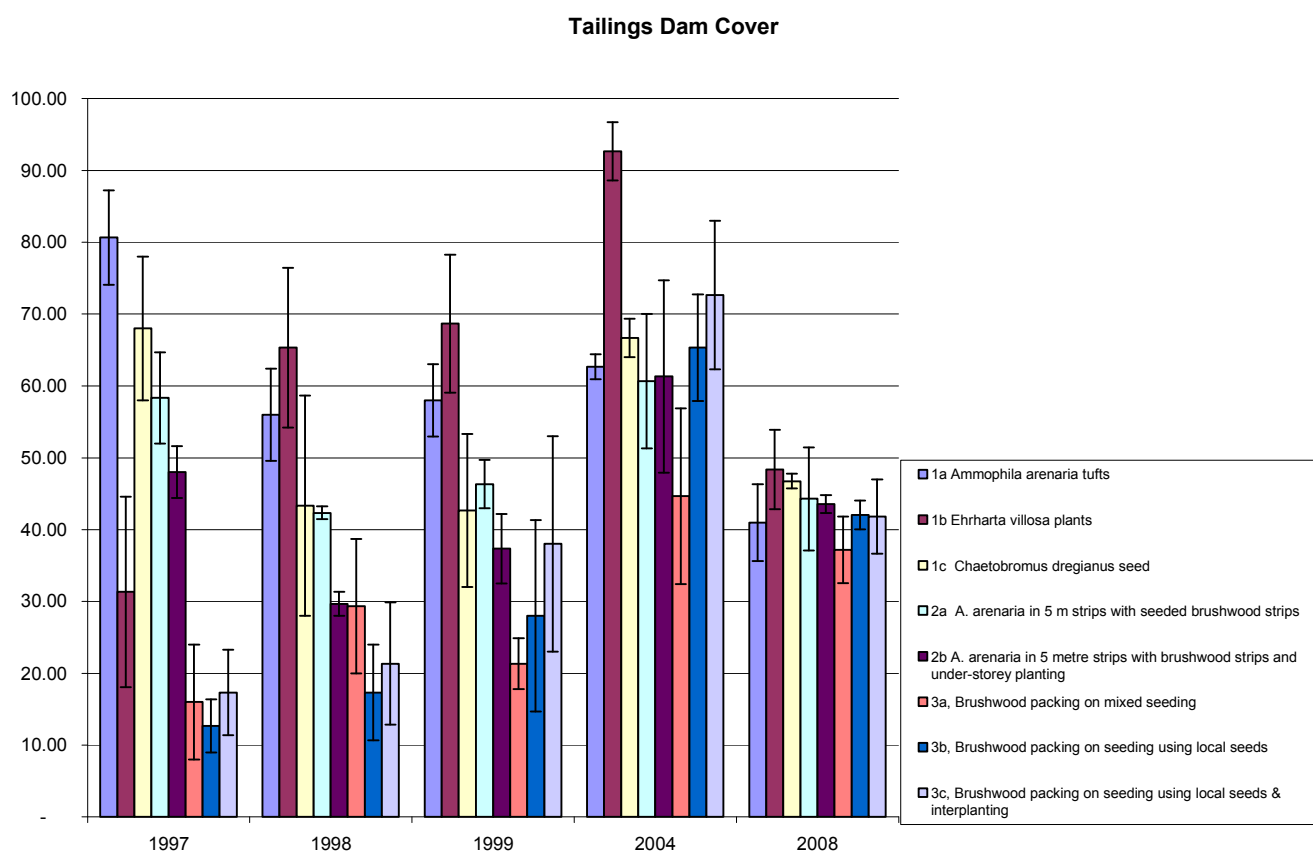


Figure 5.25: Histograms showing the development of cover in the trials (No's 1a to 3c) over an 11-year period.

The planting of *Ammophila arenaria* tufts at 4 plants per square metre achieved the best overall cover after the first year. This response was similar to the plantings along the coastal dunes and proved that the Marram could grow in areas of lower rainfall (139 mm during 1996).

The long-term average rainfall for the Chemfos area is 250 mm per year and the average between 1996 and 2001 is 221 mm. From Table 2.1 it can be seen that the rainfall is erratic in periodicity as well as amount. February is the driest month with an average rainfall of below 1 mm. July is the wettest month, with an average of almost 44 mm of rainfall recorded during the rehabilitation period.

The distinctive wet season is from May until September if the overall records are reviewed. During 1997, only May and June were significantly wet months, followed by below-average rainfall until the following May. This erratic rainfall pattern is also reflected

when the annual rainfall figures are viewed, where the very wet 1996 season recorded 296% more rain than the dry 2000 season.

The challenge was to find a local indigenous grass and other plant species that could be used to initially stabilize the area, as the objective was to establish a functional natural ecosystem in modified soils in this area of erratic rainfall. None of the native grasses were ever grown or propagated on any significant scale in this area and direct transplants were not an option, as inadequate source material and lack of uniformity would hamper implementation of trials in this manner.

We thus embarked on propagating *E. villosa* plants from cuttings made from nearby disturbed areas. The plants were planted at six plugs per square metre. The low cover recorded for this treatment during 1997 was not encouraging, with cover ranging between 8% and 54%. This is in contrast with cover in excess of 86% recorded in 2004 for this treatment.

Seeding with *C. dregeanus* yielded good initial results with cover exceeding 60% on average. It was, however, the cheapest treatment. The cost of R1,99/m² is the overall third lowest of all treatments with fertilizing only and the control plot in the subsoils being the only cheaper option. It is also less than half the price for the *Ammophila arenaria* tufts (R4,19/m²) and the *E. villosa* plants (R4,79/m²)

All the brushwood combination trials (2a, 2b, 3a, 3b & 3c) initially yielded very low cover. The brushwood seeding combination trials (3a-3c) did the worst at less than 20% cover in 1997. They were also the most expensive trials (R5,34/m² to R6,44/m²) due to the amount of labour required to source and prepare the brushwood. Their cover remained low beyond 1999 and the cover values in 2008 was not significantly different from the other treatments.

Changes in cover over time

The summary below points out that:

- *A. arenaria* provided the highest initial vegetation cover
- In all the following years *Ehrharta villosa* provided the best cover
- Brushwood packing in conjunction with local grasses did the worst till 1998

- Thereafter, brushwood in combination with annual commercial grass seeds remained the worst in terms of cover.

5.10 ASSESSING THE PREFERABLE TREATMENTS WITH RESPECT TO PERFORMANCE AND COST

The cheapest overall treatment (1c), seeding with *C. dregeanus*, did reasonably well in terms of initial cover provided as well as long-term cover (Table 5.2).

The second most cost-effective trial in the first year, (1a) Marram planting was significantly better, but over time lost its dominance due to the species dying back, allowing native species to colonize the area.

The most expensive trials, that include the use of brushwood, were not initially effective to establish vegetative cover, but did develop over 12 years to be very similar in terms of cover when compared to the cheaper treatments.

All the treatments were able to stabilize the homogenized mobile sands. The inter-relationship between the various trials and the large scale of the trials contributed that there were less sand available in the slimes dam to be moved around by winds. This certainly benefited the trials that were less effective initially.

The overall cover peaked in 2004 and then declined. This can be attributed to the ecosystem maturing and more longer-lived species persisting, allowing fewer annual species to germinate seasonally.

Table 5.3: Summary of the cost of the trial per m² in 1996 and percentage cover as assessed during the surveys

COVER PERCENTAGE PER TREATMENT INDICATING COST IN RANDS								
Cost in Rands	4.19	4.79	1.99	5.85	6.04	5.34	6.24	6.44
Treatment	1a	1b	1c	2a	2b	3a	3b	3c
1997	80.67	31.33	68.00	58.33	48.00	16.00	12.67	17.33
1998	56.00	65.33	43.33	42.33	29.67	29.33	17.33	21.33
1999	58.00	68.67	42.67	46.33	37.33	21.33	28.00	38.00
2004	62.67	92.67	66.67	60.67	61.33	44.67	65.33	72.67
2008	40.98	48.37	46.75	44.28	43.57	37.17	42.07	41.82

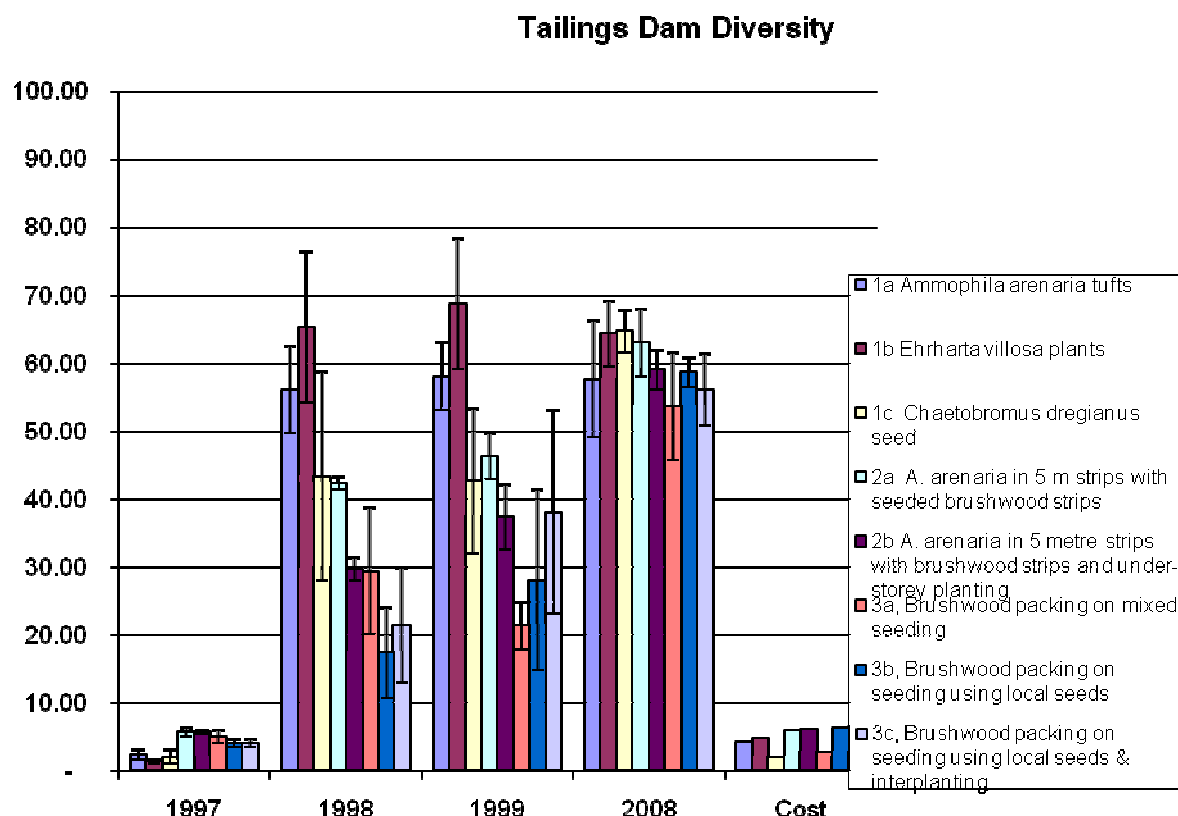


Figure 5.26: Histograms showing the development of species richness in the trials (Nos 1a to 3c) over an 11-year period.

5.10.1 Species Richness as an Estimation of Success

Initial species richness observed in the trials was very low. This was due to the trials being implemented in modified and processed soils that contained no organic matter, no stored seeds, in a tailings dam inside a twenty-metre-high surrounding wall. The wall was vegetated with *A. cyclops* during the mining phase in order to reduce the impact of the summer winds. The tailings were pumped around the perimeter of the slimes dam in a slurry and discharged into the tailings dam at a number of points that were managed in order to obtain the best settlement profile. The wet tailings were stable and in the lower lying areas, *Phragmites australis* and *A. cyclops* and a variety of agricultural weeds persisted.

The seed stores for these were clearly from outside of the confines of the tailings dam and the species that established were then able to find a niche in the working tailings dam environment.

Once the pumping of tailings was discontinued, the upper inside slopes of the dams dried out and no vegetation could establish there, resulting in the sands becoming mobile. Gradual accumulation of the sand blown from the south was observed to accumulate against the southern face of the northern wall and bridging already occurred by 1995, with processed tailings blowing out of the tailings dam creating a potential threat to the adjacent mine areas that were gradually recovering after having been abandoned after mining ceased during the 1950s.

During winter storms a reversal of the sand movement was observed. The abrasion of seedling by sand-laden wind during winter and summer was suspected to have a significant influence on the inability of windblown seed that were caught in the tailings dam system to establish.

The trial design had in mind to stop sand movement effectively close to the ground and to provide suitable habitat for seedlings to establish.

The theory we had was that seedlings can tolerate wind, but not sand carried in the wind. It was observed that by interrupting the air flow sufficiently for the wind not to be able to pick up sand or to move it forward by saltation (as described by Fryberger and Ahlbrandt, 1979), seedlings would not be haemorrhaged and should be able to survive the critical first few weeks after germination. The brushwood trials did indicate that some of the seed that was introduced survived.

Table 5.4: Summary of the number of species per treatment in 1996 and cost

NUMBER OF SPECIES PER TREATMENT IN 1996 AND COST IN RANDS								
Cost in Rands	4.19	4.79	1.99	5.85	6.04	5.34	6.24	6.44
Treatment	1a	1b	1c	2a	2b	3a	3b	3c
1997	2.33	1.33	2.00	5.67	5.67	5.00	4.00	4.00
1998	56.00	65.33	43.33	42.33	29.67	29.33	17.33	21.33
1999	58.00	68.67	42.67	46.33	37.33	21.33	28.00	38.00
2004	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2008	57.67	64.33	64.67	63.00	59.00	53.67	58.67	56.00

The initial number of species observed in the slimes dam trials was very low, with the lowest average number of species found in 1b. The *Ehrharta* was a pure stand and an almost complete monoculture.

Trials 2a and 2b contained six species during 1997. This indicated poor germination of most the species introduced. Reasons for this are complex to explain and it can probably

be contributed to a combination of factors rather than one single factor. Amongst these, is the timing of the seeding process; since seeding was the primary means of introducing diversity of species, any failure in germination would be reflected.

The trials were conducted at the end of June and early in July of 1996. It was later found that areas that were seeded at the end of April showed improved germination as well as improved survival of the seedlings.

The low number of plants (1 small plant/m²) that were introduced by planting them in some of the trials (2b and 3c) had a low probability of them being included in a random sample survey. The mortality of these introduced plants was not specifically monitored.

There was a significant increase in the species richness after the second rainy season following introduction (Table 5.5).

Table 5.5: Summary of the species richness per trial

Year	Trials with most Spp		Trials with least Spp		Least spp / Most spp
	Trial no	Number of species	Trial no	Number of species	
1997	1b	6	2b	1	17%
1998	1b	65	3b	17	26%
1999	1b	68	3a	21	31%
2008	1c	65	3a	54	83%

Trial 1b (*E. villosa* plants) remained the trial with the most number of species until the final 2008 survey (Table 5.5).

Although the 2004 trial samplings were conducted and cover data recorded, the data set for species richness for the tailings dam was lost. It is not suspected that there was a significant change in the development trends in these areas.

Significant though, is the narrowing of the gap between the least species-rich and the most species-rich trials. This would suggest that the specifics of the methods of intervention in stabilizing mobile sands are less important than actually successfully stabilizing them.

When compared to the interventions on the mobile sand dunes north of Eland's Bay (Chapter 3), the difference in the results achieved by the approaches are evident. The positioning of the trials in the tailings dam at Chemfos in a matrix across the mobile area

as well as the subsequent seeding of the entire area with *E. villosa* and a selection of local species (refer to the Species list in Appendix A), resulted in the stabilization of the sands over a large area, allowing vegetation to establish that could withstand minor sand movements.

Abrupt interventions such as nets and brushwood that are spaced at more than 5-metre intervals allow sands to become mobile in strong winds. Nets and brushwood both have limited life-spans and areas that have been temporarily stabilized will require the establishment of long-lived vegetation.

The Chemfos trials have shown that, should a system be stable and should an adequate seed source be present downwind, the ability to recover is greatly increased if the movement of sand in the wind can be restricted. The species richness purely achieved in this way (without the introduction of harvested seed), as well as the maximum distance from seed source, required additional studies.

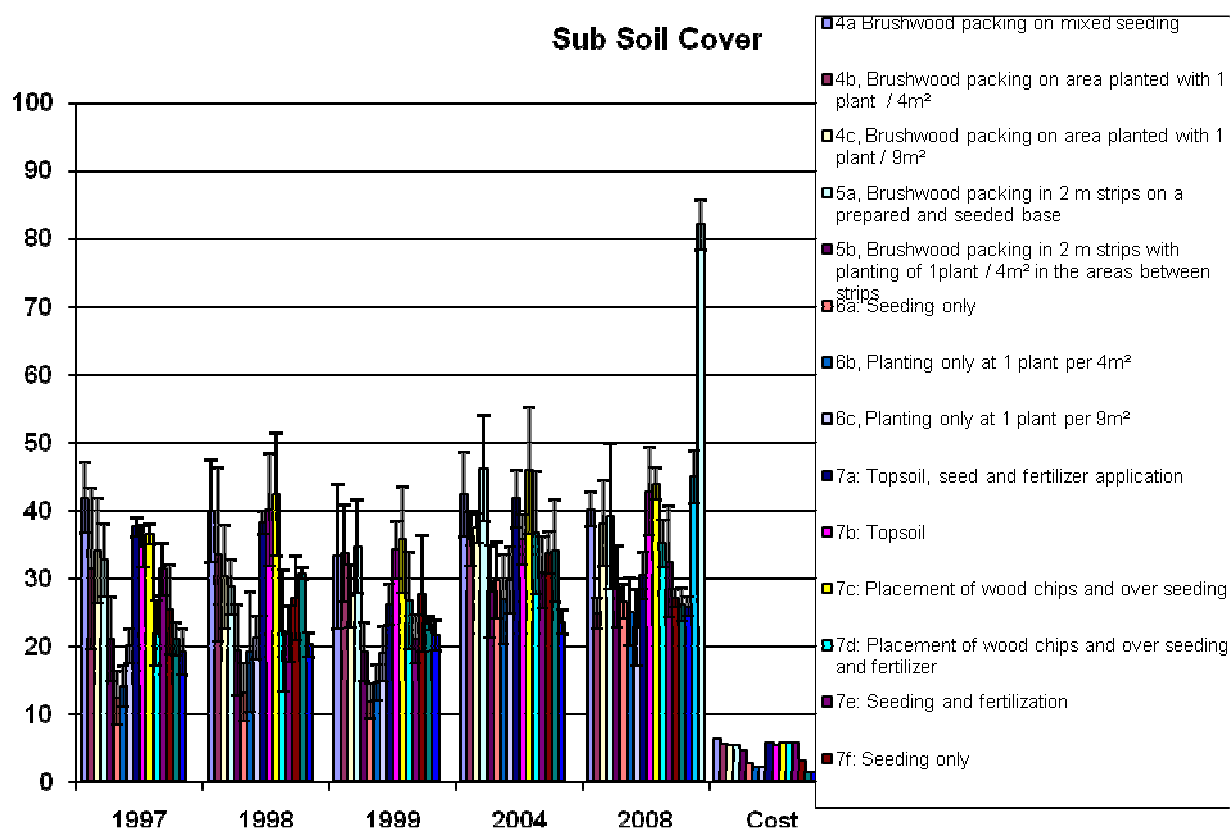


Figure 5.27: Histograms showing the development of cover in the trials (Nos 4a to 6c) over an 11-year period. (Cost is indicated in R/m²).

5.10.2 Evaluation of the Subsoil Trials

Initial results from the 1997 surveys showed the advantage of topsoil placement. The 35% cover recorded from the topsoiled site is marginally lower than the 37.5% of the site that was also seeded and fertilized, but more than double the 16% cover of the control site. The cover benefit remains significant until 2004 and becomes less significant in 2008. This can be attributed to the fact that the trial site has overall benefited from the additional growth brought about by the trials. The close proximity of seed-bearing plants to all the plots, including the control site, and the presence of insects, rodents and birds acting as dispersal and propagating agents, were also beneficial. Initial significant advantage, however, persisted for at least eight years. When compared to seeding-only plots, the topsoiled, seeded and fertilized sites achieved 67% better cover in the first year in comparison to the non-topsoiled and seeded areas. This is significant and emphasizes the importance of judicious salvage and reuse of topsoil during mining operations. The significance of time becomes apparent when the 2008 results are compared. The advantage of the best initial treatment is reduced to 27% after 11 years. It is, however, possible that complete exclusion of all indirect benefits of the surrounding trials and the associated ecological functioning from the reference site would have seen the reference site remain in a more static state.

Seeding-only trials and the planting of 1 plant per 4 m² resulted in similar cover and species richness over time on the phosphate beds. Topsoil placement, seeding with topsoil and seeding with wood chip cover yielded similar patterns of cover and species richness development over time; this being markedly better than the seeding- and planting-only trials.

The control plot had the lowest percentage cover and the lowest species richness, except in 1997 and 2008 when it was similar to the seeding- and planting-only trials. These trials, however, yielded much better results in year 2, 3 and 4 when the rainfall was very low.

The use of brushwood packing in strips in combination with other treatments is not as meaningful in the phosphate bed areas, where the results are similar to those treatments that did not receive the strip treatments. The relative stability of the soils and low-particle loading of the winds probably account for this.

The situation is, however, completely different for the brushwood stockpile area. Although not intended as a trial initially, some ad-hoc experiments were done to determine for how long the seeds of the *A. cyclops* would remain on the freshly harvested branches from trees that were in full seed. The branches were de-seeded by hand for the trials, contributing to the expense. Brushwood was loosely packed 1,2 metres high in an area adjacent to the formal trial areas. This section was also pre-prepared and thus uniform to the trial areas.

The seed drop that was recorded took too long for the brushwood to be used in the trials and after two weeks the trials were all covered with hand de-seeded branches and the stockpile was left intact. Since it was not part of the formal trials, the area was not sampled. In 2008 the area appeared to have remarkable cover and was thus sampled. This trial (10a) displayed a near 100% vegetation cover. It can be ascribed to the high level of physical protection against predators for rodents and it is an excellent perch site for birds that deposited seeds of fruit-bearing plants such as *Chrysanthemoides incana* in the area where it germinated. The rodent population brought more seeds from and to their burrows and the entrapment of windblown seeds also seem to be of significance. This trial has higher cover, but lower species richness when compared to the benchmark site.



Figure 5.28: (2010): Trial 10a. The area of stockpiled brushwood that was monitored in 2008 and displayed significant cover.

The correlation between cover and species richness in the subsoil trials is not constant throughout. The increase in species richness is steady and peaks in 2004 in the majority of the trials. The maximum species richness for 7c achieved in 2008 is 52% of the species richness of the benchmark site.

Species richness does not develop over time following single interventions. A plateau of cover and species richness is established following once-off interventions that are stable, but not dynamic in the medium term. Continued monitoring of the site may indicate trends towards increased species richness with the development of the habitat for birds and small mammals that can act as seed-dispersing agents.

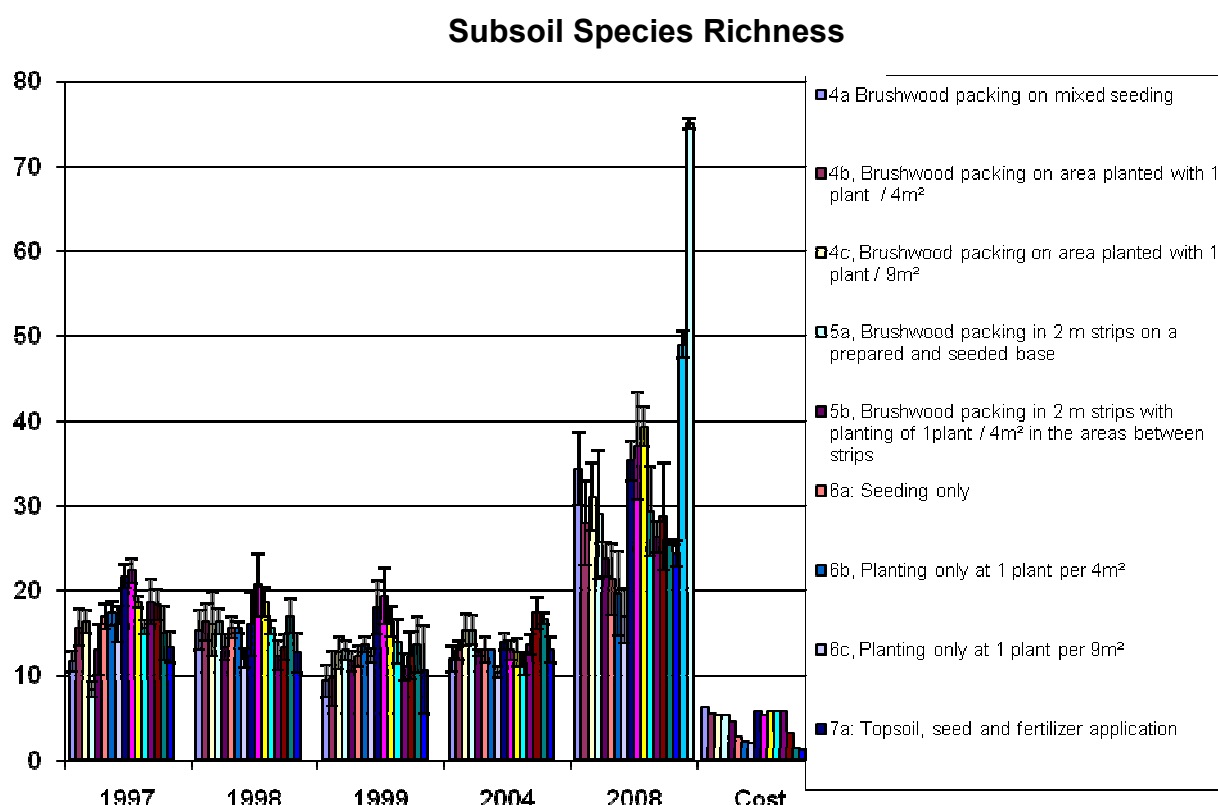


Figure 5.29: Histograms showing subsoil species richness during the trials. (Cost is indicated in R/m²).

The influence of topsoil is noticeable, but the quality of the topsoil was compromised by storage practices and would probably yield better results when used fresh. No trials were done to determine the critical thickness of the topsoil layer. Since minimal topsoil was used (100-mm layer), the addition of seed and fertilizer in various combinations did not indicate significant advantages of these practices in the long term. In the short term,

however, topsoil with the addition of seed yielded the best results, indicating the advantage of additional nutrients and seed availability. Nutrient influence appears to be significant in the medium term, increasing cover and species richness. Nutrient levels applied were, however, very low (27 kg N/ha) and informal trials have indicated that excessive nutrient application results in the dominance of annual species, thus outcompeting more desirable diversity.

CHAPTER 6. REHABILITATION TECHNIQUES

6.1 INTRODUCTION: THE EARLIER MINING PROCEDURE

Post-operational rehabilitation of mines is undesirable when compared to concurrent rehabilitation which is the norm today. In most cases, mining is a systematic process following a predetermined and ordered path that is the result of comprehensive planning management. Today rehabilitation is part of mine planning. In comparison, the archaic approach meant that one was left with a post-mining environment that was typically dysfunctional, especially in the event of unplanned closure such as Chemfos.

A typical environment of past practices could be seen at Langebaanweg, where economic factors had forced the closure of the mine. The mining operations were halted mid-stream and the site was left with little access to the knowledge base that would have existed when the mine staff members were involved with operations, including some aspects of rehabilitation, such as the physical modification of the slopes or topography.

The time frames given to the consultants to develop the mine-closing scenarios were also very short. The briefing was given during the early part of 1995, resulting in a report and recommendations being produced after initial field work of CES in November 1995 (CES, 1996a). The conceptual rehabilitation plan was circulated for pricing during April 1996 (CES, 1996a) and the contract was negotiated and a contractor appointed during May 1996, with work commencing on 15 June 1996.

These aspects reflect the ad hoc approach that followed the unplanned closure. Longer time frames and a more systematic approach may have yielded better results and might have contributed to a more synergistic approach between mining and rehabilitation. This was not the case. However, the single biggest advantage of this post-mining rehabilitation was the almost complete freedom of operations during the rehabilitation process. Unrestricted by normal mining operations and the impact of these on the rehabilitation programme allowed freedom of movement and did create an ideal environment for experimentation.

The aim of this chapter is to:

- a. Describe the legacy of the Chemfos Langebaanweg site
- b. Discuss the initial environmental assessment and the importance of the fossil site
- c. Outline the general rehabilitation approach that included :
 - Removing alien vegetation,
 - Transforming the land shape where required,
 - Introducing desirable pioneer and sub-climax vegetation,
 - Diversification of the vegetation initially introduced,
 - Maintaining the vegetation to ensure establishment,
 - Continued alien vegetation control, and
 - Monitoring and evaluation of the processes.

6.2 THE CHEMFOS LEGACY

During the earlier phase of mining at Chemfos there were no mining regulations forcing the mine company to prescribe to a rehabilitation plan; the major factor in governing the mining process was simply economic, which resulted in mining practices that favoured minimum handling of tailing materials. Consequently, at Chemfos:

- The positioning of overburden dumps was determined mainly by the material processing and handling of work flows.
- Dumps were created in mined-out areas or in areas where the mineral reserves were low and not viable to extract.

Little consideration was given to the resulting landform or the separation and repositioning of materials according to the origin of the layers. Topsoil (or the top 200-300 mm of soil) was mixed with the underlying aeolian sands and calcareous material from deeper down, resulting in a completely modified environment.

All these factors have hampered the natural restoration that potentially may have taken place from propagules within the topsoil, had it been separated and used to cover the overburden. Near total degradation of almost 650 ha of vegetation occurred because of this approach.

Furthermore, at Chemfos, as in other similar mine sites:

- Practical considerations such as dust suppression and land stabilization, lead to the introduction of alien plants, such as *Acacia cyclops*, *A. saligna* and *Eucalyptus spp* to stabilize and recolonize mobile sands (Figure 6.1).
- Seed-bearing branches of the woody alien plants were packed on the stockpiles, spoil heaps and on mine-floor areas.
- This resulted in a high level of alien plant infestation that significantly reduced the dust during windy periods, but hampered recovery of the natural vegetation.

No provision was made during the active life-span of the mine for a budget to rehabilitate the post-mining environment and the limited backfilling of portions of the large open-cast mine was due to operational requirements and the construction of haul roads. The backfill was done in order to raise the road between the cut face where the mining operations were conducted (Area 16 on Figure 6.2) to the point where the material was dumped in the Grizzly crusher at the start of the ore processing (the northern-most point of area 36 on Figure 6.2).

Thus, rehabilitation was limited to packing *Acacia* brushwood at closure of operations, and SAMANCOR was left with a legacy of a mining programme that required much strategic planning for a closure certificate to be granted by the Department of Mineral and Energy Affairs (DMEA) (CES 2001).

To complicate the issue of the rehabilitation further, the mine ownership had changed during the years. From a small mining company initially taken over by AMCOR, which consolidated activities, it was taken over by SAMANCOR, which initiated closure. In 1998 Billiton acquired SAMANCOR and, with that, the Chemfos Mine in closure and the responsibilities for restoration. The merger with BHP resulted in the formation of BHP Billiton, who now funds the process of restoring natural capital, although they have no direct benefit from the restoration of the mine.



Figure 6.1: *Acacia cyclops* was introduced to stabilize the area and reduce dust pollution during summer (from the 1970s).

6.3 INITIAL ENVIRONMENTAL STUDIES AND THE IMPORTANCE OF THE FOSSIL SITE

In 1995 SAMANCOR approached Coastal & Environmental Services (CES) to compile a conceptual rehabilitation plan that would result in a post-mining landscape that is self-supporting and aesthetically compatible to the surrounding area (CES, 1996a). Although this was the initial brief, it soon became obvious that in restoring natural capital to the area, cognizance of the extremely valuable fossil site was a major priority (Hendey, 1982). These fossils have attracted the interest of leading overseas and local researchers and they have generated over seventy publications. Important discoveries include *Agriotherium africanum*, the first bear ever found in Africa south from the Sahara; *Homiphoca capensis*, an extinct true seal and four extinct species of penguins (Hendey, 1981).

The fossil region of the mine was declared a National Heritage Site in 1996. Thus, restoration would need to provide for future research on the fossils and create a new and continued use for the site by the Iziko Museum group. The formulation of an exit strategy following the cessation of operations was driven by a greater vision for a post-mining

mine use rather than the mere meeting of minimum requirements by DMEA (CES 2001). The use of the land as a regional landfill site or for industry was initially investigated. This idea was not pursued as the proximity to the fossil deposit and declared Natural Heritage site would have lead to conflict of land use.

6.4 GENERAL REHABILITATION APPROACH

The rehabilitation approach was based the information gathered in reviewing the best practices as well as the continued information stream generated by the trials implemented during 1996. These replicated trials were monitored to give an indication of the most suitable methods to be used on the larger areas (Lubke *et al*, 1998). The provisional indications, arrived at during monitoring and evaluation, were adapted and implemented on a large scale, monitored and the approach refined for further implementation in new areas (CES, 1997). The information on the restoration techniques, applied to different management units on the whole site, was recorded on GIS for future reference (CES, 1997 & 1999).

This chapter reviews the systematic approach followed in transforming a dysfunctional post-mining environment into a self-sustaining ecosystem that supports the post-mining land use of an ecotourism destination and fossil park.

In order to manage the process effectively and to establish the rehabilitation in the shortest possible time, all the different techniques were considered and adapted to the local conditions using, as far as possible, the easily accessible local resources. In this chapter, the general techniques adopted in the overall rehabilitation of the site are discussed. Using all the skills and expertise as discussed in other Chapters (4, 5, 7 and 8) a process of rehabilitation was developed unique to this site. During the course of the rehabilitation process in the years 1996 to 2005 we developed and perfected techniques which have now become fundamental in the rehabilitation of semi-arid areas on the south-western coast of South Africa, using local vegetation. Many of the techniques and approaches described in the chapters mentioned have been adapted for use in quarry, roadside and mine rehabilitation in areas such as Big Bay Blaauwberg, Alexkor mine rehabilitation trials and Kleinzee mine rehabilitation.

The work was contracted to Top Turf from 1996 to 1999 on a yearly renewable contract basis. Top Turf restructured the Cape operations and withdrew from the project during

July 1999 and we formed Vula Environmental Services to continue with the rehabilitation programme.

The systematic approach that was followed included:

- Removing alien vegetation
- Transforming the land shape, where required
- Introducing desirable pioneer and sub-climax vegetation
- Diversification of the vegetation initially introduced
- Maintaining the vegetation to ensure establishment
- Continued alien vegetation control
- Monitoring and evaluation of the processes

6.5 ERADICATION OF ALIEN VEGETATION

6.5.1 Introduction

Due to the high level of alien vegetation infestation on the mine, it was important to reduce the amount of alien vegetation prior to implementation of any rehabilitation plan. The logistical considerations of alien removal, the timing of operations, as well as the levels of infestation throughout the mine site were all important considerations in planning the alien removal. Contrary to the modelling approach later proposed by Higgins (2001), a systematic approach was followed of clearing the dense stands first, rather than moving from less dense stands into the densely infested areas. The primary reason for using this approach was that:

- the site was an isolated island of infestation; and
- the highest densities of aliens occurred on the steeper slopes and other modified areas that had very little natural vegetation cover; and thus
- more input was required over a longer period to clear the alien vegetation and restore these sites.

Programming the alien vegetation clearing required comprehensive knowledge of all aspects of the activities involved. Though it was easy to obtain statistics from firewood harvesting operations in this regard, the information was inappropriate for our purpose.

6.5.2 Firewood Production from Alien Vegetation

During the development of the approach of alien vegetation removal, a variety of factors were considered, including the status quo of informal firewood harvesting from parts of

the mine. Some of the dismissed mine workers resorted to subsistence firewood collection on the mine site. The traditional practice of selectively harvesting only mature trees resulted in a landscape littered with brushwood, with saplings growing through the dry debris layer resulting in a nearly impenetrable mass of litter and smaller plants. In other words, disposal of all alien biomass and the removal of the smaller plants were ignored.

We embarked on a programme of organising the informal woodcutters and wood production:

- Each small operator was assigned a specific section to work in, starting in the areas of highest plant densities.
- Parallel to this operation, we conducted training of our own staff in bush-clearing; and
- We explored the option of commercialization of the firewood removal.

6.5.3 Costs of Firewood Production

It soon became obvious that the cost associated with cutting felled trunks into short sections and splitting them for firewood was not economically sustainable if returns of 17% on invested capital were required. This norm was set by the managing company, Top Turf, during 1996 as a standard criterion for all operational units. Since the RDP woodcutters (Re-Development Programme) required less in return and were happy to work in an organized fashion, they were allowed to proceed with clearing all the commercially viable firewood, leaving the thinner material and brushwood to be cleared by the rehabilitation team. Integrating the 6 RDP teams into the strategy brought about a reduction on cost of approximately R3 000 per ha, resulting in a saving of around R210 000 for the 70 ha of the whole site partly cleared in this way.

6.5.4 Procedure of Alien Clearing

Since no standardized norms of alien clearing were available, we developed our own norms based on maximum sustainable output of staff measured during an initial month of post-training supervised activities. These norms were then set as benchmarks for planning and evaluation purposes. Alien vegetation was graded according to density, from high to medium and low, and according to site, i.e. flat, medium or very steep slopes (Table 6.1).

Table 6.1: Slope conditions, alien vegetation densities and day work norms developed for Chemfos

Activity	Slope	Density	Man-day/ha
Cut and burn	> 30°	High	12
Cut and burn	> 15° < 30°	High	10
Cut and burn	< 15°	High	9

Activity	Slope	Density	Man-day/ha
Cut and burn	> 30°	Medium	10
Cut and burn	> 15° < 30°	Medium	8
Cut and burn	< 15°	Medium	6

Activity	Slope	Density	Man-day/ha
Cut and burn	> 30°	Low	8
Cut and burn	> 15° < 30°	Low	6
Cut and burn	< 15°	Low	4

Activity	Slope	Density	Man-day/ha
Cut and burn	> 30°	Very Low	6
Cut and burn	> 15° < 30°	Very Low	4
Cut and burn	< 15°	Very Low	3

Team Composition

Operators Chain-saw	Operators Brush Cutter	Helper	Team Leader
2	2	6	2

These standardized norms were used to develop the programme of execution for all alien vegetation clearing. The same approach of determining norms for productive work

in alien clearing were used in establishing the norms as a base throughout the remainder of the rehabilitation programme.

The alien vegetation control programme (see Table 6.2) was primarily conducted during summer as seeding and planting was more appropriate in autumn and winter. The warm windy summer months hampered productivity and the teams were encouraged to start work at 05:30 instead of the traditional 07:00 and to complete the daily task and then to retire for the rest of the day. Frequently targets were reached by noon before the conditions became very trying. In this way the staff morale was kept high and the daunting task of eradicating all the alien vegetation was completed as planned by autumn 1999.

Table 6.2: Alien vegetation control - Norms for day works

Activity	Slope (°)	Density	Man-day/ha	Area/ man	Team size			Team size			Team size		
					50 m X	50 m X	50 m X	50 m X	50 m X	50 m X	50 m X	50 m X	50 m X
Cut and Burn	> 30	High	12	833	17	2499	50	4167	83	5883	118	7500	150
	> 15												
	< 30												
Cut and Burn	< 30	High	10	1000	20	3000	60	5000	100	7000	1400	9000	180
Cut and Burn	< 15	High	9	1111	22	3333	67	5556	111	7778	156	10000	200

Activity	Slope (°)	Density	Man-day/ha	Area/ man	Team size			Team size			Team size		
					50 m X	50 m X	50 m X	50 m X	50 m X	50 m X	50 m X	50 m X	50 m X
Cut and Burn	> 30	Medium	10	1000	20	3000	60	5000	100	70000	140	9000	180
	> 15												
	< 30												
Cut and Burn	< 30	Medium	8	1250	25	3750	75	6250	125	8950	179	16250	325
Cut and Burn	< 15	Medium	6	1667	33	5001	100	8333	167	11667	233	15000	300

Activity	Slope (°)	Density	Man-day/ha	Area/ man	Team size			Team size			Team size		
					50 m X	50 m X	50 m X	50 m X	50 m X	50 m X	50 m X	50 m X	50 m X
Cut and Burn	> 30	Low	8	1250	25	3750	75	6250	125	8750	175	11250	225
	> 15												
	< 30												
Cut and Burn	< 30	Low	6	1667	33	5001	100	8333	167	11667	233	15000	300
Cut and Burn	< 15	Low	4	2500	50	7500	150	12500	250	17500	350	22500	450

Activity	Slope (°)	Density	Man-day/ha	Area/ man	Team size			Team size			Team size		
					50 m X	50 m X	50 m X	50 m X	50 m X	50 m X	50 m X	50 m X	50 m X
Cut and Burn	> 30	Very Low	6	1667	33	5001	100	8333	167	11667	233	15000	300
	> 15												
	< 30												
Cut and Burn	< 30	Very Low	4	2500	50	7500	150	12500	250	17500	350	22500	450
Cut and Burn	< 15	Very Low	3	3333	67	9999	200	16665	333	23331	467	29997	600

6.5.5 Alternative Uses of Alien Biomass

In consideration of the techniques of rehabilitation as discussed in the types of trial experiments (Chapter 5), some alternative approaches for the use of the biomass of alien *Acacia* wood resulting from the eradication programme were discussed. Chipping the material and using the chips as a mulch layer and brushwood packing of de-seeded branches were two methods for using the material in the rehabilitation programme.

Before the results of these trials could be evaluated, it was noted that the cost of processing the brushwood was prohibitive. After clearing, the brushwood was packed in rows and also in other areas where brush-packing was carried out during the operational phase of the mine, and the following problems resulted:

- Sand accumulation where the brushwood was used in the slimes dams resulted in undesirable acute topography due to sand deposition patterns (see Chapter 3 - on sand and wind).
- Physical barriers to access resulted in areas where the brush was packed. They restricted access and made mechanical operations or any form of movement cumbersome.

Brushwood accumulation hampered the rehabilitation progress and this factor, as well as cost considerations, meant that other alternatives needed to be considered, the most suitable being burning.

Burning

Burning was considered the most appropriate option to eliminate the accumulated brushwood. Once tree-felling was completed, the resulting debris of branches, leaf litter, etc. was stockpiled in burning heaps.

A flexible burning programme was integrated into the rehabilitation programme. Wind direction and velocity were amongst the factors that were considered. Since there was not enough time to allow all branches to dry out completely prior to burning, the operation mainly took place on days with moderate winds to ensure complete combustion of the woody material.

Block burns were conducted into the wind to create safe fire breaks and once the target areas were adequately isolated, the remaining areas were burned downwind.

The fire was extinguished using a hydro-seeder with a synthetic sodium-based co-polymer (HydroPam) added at a rate of 3 kg per 10 kilolitres of water. HydroPam is traditionally used as an additive in hydroseeding that helps with seed adhesion and dust control. Its use in fire suppression was accidentally discovered in 1997 when a change in wind direction resulted in an unintentional fire that had to be extinguished. The hydroseeder was at hand, but loaded with polymer prior to seeding a nearby embankment and used to extinguish the fire. The resulting efficiency of the HydroPam in the water in extinguishing fires was most noticeable. This led to the standardization of the practice of using HydroPam during fire-fighting and controlled burns (<http://hydropam.com/>).

6.5.6 The Biological Control of Aliens

During 1997, the the Plant Protection Unit of the Agricultural Research Council (ARC), in Elsenburg, requested funding from BHPBilliton, then still SAMANCOR, for a research project to evaluate the effectiveness of the range of native Australian bio-control agents on *Acacia* species. The research was aimed at finding solutions on a national level for the problem of controlling the spread of the *Acacia cyclops*, rooikrans. Since Chemfos was developing into an island of natural vegetation surrounded by agricultural land with a high potential threat of re-infestation, it was considered wise to establish a nucleus of bio-control agents at Chemfos. In addition, this would buffer the site from re-infestation from adjacent populations of uncontrolled *Acacia cyclops*.

It was decided to establish a long-term monitoring research site for the ARC in the areas surrounding two water bodies. Slopes number 28 to number 30 were ideally suited for this purpose as the trees could remain intact with little chance of seed formation and distribution from these areas into the newly rehabilitated site due to the high levels of seed predation achieved. Access to trees in area 19 was easier due to a flatter terrain and this area was also set aside as an *Acacia* monitoring site. The introduction of *Melantarius servenus* to the *Acacia cyclops* trees in these sites resulted in an ideal study area to monitor the feeding patterns and breeding results of the introduced agents (Figure 6.2).

The results of the seed damaged by the various phases of feeding of *Melanterius servulus* was substantial, approaching 60% initially and peaking at 90% nine years later (Figure 6.3).

Utilizing the biological controls in rehabilitation added another dimension to the control of *Acacia cyclops* in this area. The trees are extremely capable of becoming established and growing on slopes in poor subsoil where none of the local species perform adequately in preventing erosion. Thus, although the presence of the invaders is not desirable, the ability of the *A. cyclops* to stabilize a steep slope is worthwhile in maintaining the trees of the species in such areas. In particular their use in the stabilization of the slopes above the water bodies was desirable. These reservoirs would have to be filled in to reduce the slope to a suitable angle for rehabilitation with indigenous species. Maintaining the alien species does add diversity of habitats to the site and is thus justified, providing that the biocontrol agents remain active.



Figure 6.2: Monitoring seed predation on *Acacia cyclops*. (2007).

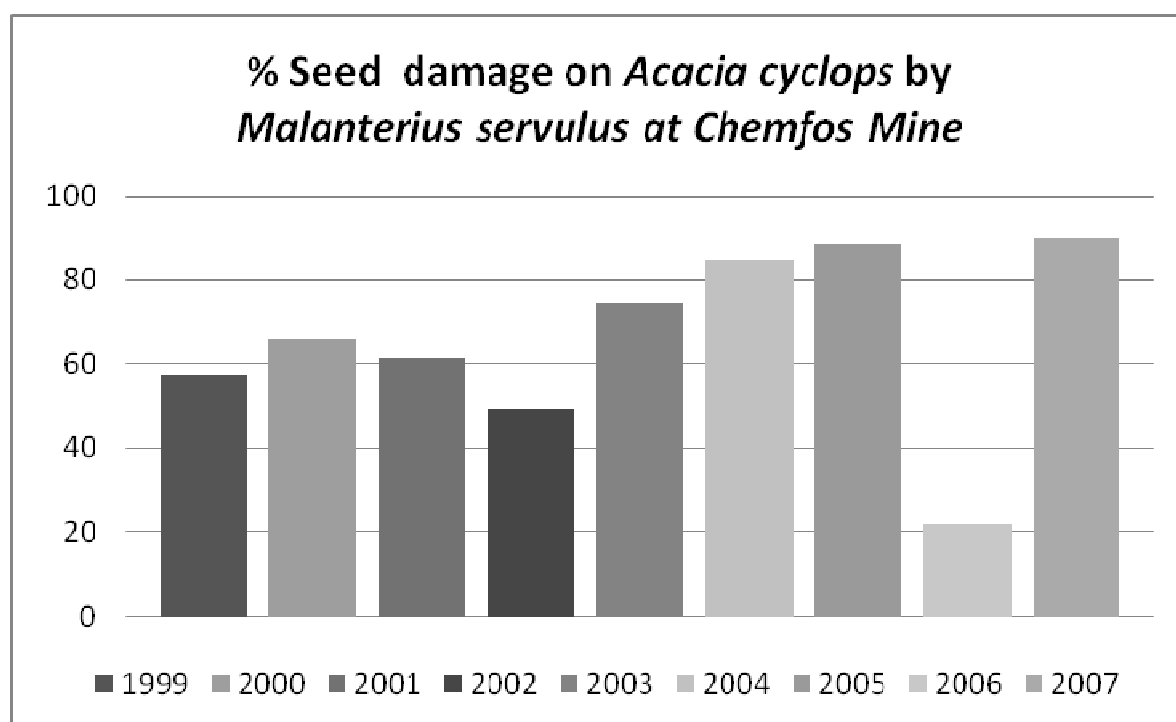
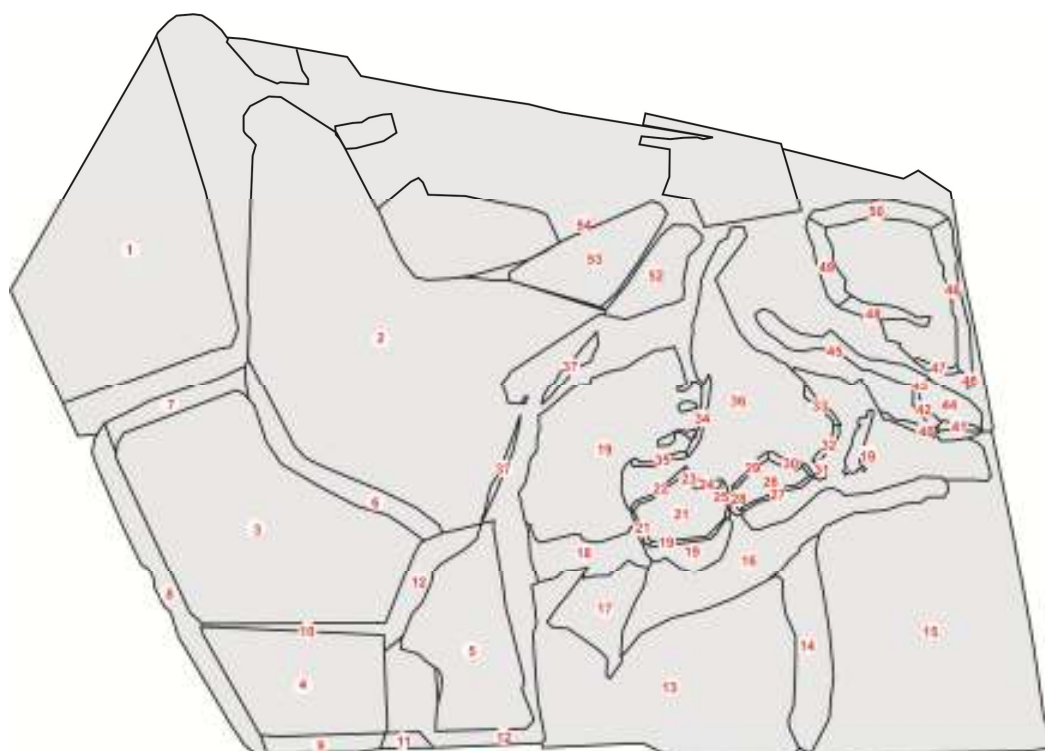


Figure 6.3: Percentage seed damage to *Acacia cyclops* by the beetle, *Melanterius servulus* at Chemfos mine (from 1999 till 2007) (Impson and Moran 2008).

6.6 LANDFORM AND SLOPE ADJUSTMENTS

Initial discussions regarding the integration of the land forms into a final nature reserve were driven by considerations for the aesthetical appearances and functionality of the land form and the prognosis for rehabilitation. Cost was a major and deciding factor and the decision was to reshape only the embankments that posed a safety risk as this was the only enforceable requirement of the Department of Mineral and Energy Affairs.

There were a number of slopes on the Chemfos site which were in need of consideration for reshaping (Figure 6.4). The steeper slopes were evaluated and areas 19 to 25 and 31 to 35 were adjusted from 1:1 slopes to 1:2.5. This slope angle was the result of pushing the steeper slope out and cutting rearwards into the level fill areas. Slopes 27 to 30 were left intact due to the potential impact on the sizable water body that is below these sites. A decision not to flatten them was made because material could easily be dozed into the confines of the open water body. Moreover, the diverse bird life was considered valuable as an additional tourist attraction to an ecologically diverse area.



See text for details of the numbers where slopes were adjusted

Figure 6.4: Rehabilitation sites of the Chemfos mine.

In order to find local vegetation that would grow under the specific site conditions, samples of all plants grown for rehabilitation was planted in sections of the slope that was cleared of alien vegetation. This was done in order to find alternative vegetation cover to the slopes. Slope 27 is a cut slope into in-situ phosphate ore (palatial phosphate bed) and has no potential to support significant vegetation. It was thus decided to fence off the near vertical slope as a safety precaution. The other slopes consist of cross-zoned heterogeneous sand and calcareous overburden.

The area was also prepared and hydro-seeded at clean seed equivalent rate of 15 kg/ha of a pioneer as well as diverse seed mixture. Initial establishment was poor and the experimental planting was repeated in 1998. The planting was watered until December 1998 in the hope to establish the native plants under these adverse conditions.

Since this attempt failed as well, it was decided to leave the *Acacia cyclops* in this area intact, since they coped remarkably well under conditions unsuitable to indigenous plants (Figure 6.5).



Figure 6.5: *Acacia cyclops* established on 1:1 subsoil slopes. Biocontrol agents limit the seed set (see Section 6.5.6 above).

6.7 PREPARATION OF THE SOIL BEDS FOR CULTIVATION OF PLANTS

Subsequent to alien vegetation clearing and burning, the areas were left fallow till days before anticipated seeding. This was done in order to minimize the wind erosion.

- **Areas without any significant vegetation cover** and that were accessible by machines, were prepared by using tractor and tine implements or in the case of compacted calcareous material, a small dozer with ripper teeth. Vegetation established readily in the microtopography created in this way (Figures 6.6 and 6.7).
- The emphasis was placed on preparing a rough surface area with microtopography that can accumulate seeds, fine soil particles and water in localized hollows. This was the result of observing the natural vegetation establishment on the old phosphate beds where the germination of seeds transported into the exposed site established in the hollows created by bulldozer tracks some three to six years prior to the rehabilitation phase commenced.
- **Areas of significant vegetation cover** where seedlings other than annual plants persisted in more than 40% of the area and areas on slopes inaccessible to the tractor and equipment were hand-prepared.

- Hand preparation was done by using strengthened hand rakes in a way that the traditional African hoe is used.
- Deep hollows 30 cm long and 3-5 cm deep were created at a density of 5 to 8 per square metre. This resulted in a suitable seed bed for most of the areas on the mine.
- Mechanical sowing was undertaken initially in an attempt to evaluate the effectiveness of reducing the cost further.
- The equipment used was developed by the Department of Agriculture and consisted of a combination seeder that created furrows into which the seeds were sown.
- The experiment was abandoned since the process that works well in softer soils on level sites could not be modified to cope with the calcareous subsoils or slopes and the heterogeneous seed mixtures.

6.8 INTRODUCTION OF A COVER OF VEGETATION

Soil stability and the establishment of a suitable vegetation cover was the prime objective of the initial seeding. The seed species selection and method of seeding (hand- or hydroseeding) was determined by the site conditions of the specific area concerned.

Seed collection was based on the anticipated needs of the next sowing season and the seed allocations were done at the end of the seed collection phase and before the seeding commenced. Since seed collected did not always match the seed requirement for the rehabilitation exactly (see seed collection and processing – Chapter 7), the seed allocation was done by proportioning a particular seed available per species to all the areas where it would be required (See Appendix A).

Hydroseeding (or hydraulic mulch seeding, hydro-mulching) is the preferred method of introducing seed into dysfunctional landscapes as the process is quick and effective. Hydroseeding is a planting process which utilizes a slurry of seed and mulch. The slurry is transported in a tank, either truck- or trailer-mounted, and sprayed over prepared ground in a uniform layer. Hydroseeding is an alternative to the traditional process of broadcasting or sowing dry seed. It promotes quick germination and inhibits soil erosion. If used, the mulch in the hydroseed mixture helps maintain the moisture level of the seed and seedlings. The slurry often has other ingredients, including fertilizer, tackifying or binding agent such as HydroPam and a smoke treatment to enhance germination, such as FireGrow.



Figure 6.6: (July 1999): Initial growth from calcareous areas that were dozer ripped and hydroseeded.



Figure 6.7 (Same site as Figure 6.6 in August 2010): Mature growth from calcareous areas that were dozer ripped and hydroseeded.

The first commercial hydroseeder was invented in the United States in the early 1950s in order to shoot seed and fertilizer efficiently over broad areas. The process is now used throughout the world (modified from "<http://en.wikipedia.org/wiki/Hydroseeding>").

Hydroseeding is, however, not suitable for all areas. Access is limited to areas where the heavy equipment can travel safely or where the extension hoses can reach (Figure 6.8). The cost of hydroseeding (roughly three times that of mechanical seeding or sowing and four times that of hand-seeding) limits the application to areas where the advantage of adding stickers, thus reducing erosion of slopes, is seen as a priority that validates the additional expense.



Figure 6.8: Hydroseeding of slopes in progress using extension hoses that allow access to areas where the equipment cannot drive.

6.9 INTRODUCTION OF A DIVERSE VEGETATION COVER

Initial trials referred to earlier aimed at evaluating planting densities. Due to the semi-arid nature of the site and the short growing season (see Chapter 2.2), it was not possible to wait for conclusive results from the trials prior to the start of the implementation of the rehabilitation programme.

During the implementation phase, it was decided to use the higher planting density of 1 plant per 9 m² or 1111 plants per ha to introduce clusters of diverse vegetation into vegetative stabilized areas.

6.10 PLANT PROPAGATION

Initial aims were to propagate plants and to plant them as plugs from vegetable growing polystyrene trays as this would represent the most cost-effective approach. The help of a commercial propagation nursery was sought to do the propagation, but most of the

species required had never been grown commercially before this time. The nurseries did not want to commit to the production of the required material and we were forced to embark on small-scale experimental propagation. The construction of propagation facilities of greenhouses and shade houses and the training of staff enabled us to operate independent of commercial growers.

- **Planting Time:** Established horticultural practices suggested that the propagation should thus commence six to eight weeks prior to the plants being required and in 1997 the production programme was developed to commence 12 weeks prior to the anticipated planting date at end of May. Propagation was set to commence during the first week in March of 1997. We did not, however, expect that the summer dormancy of the potential mother plants would result in a zero strike rate.
- In order to ensure planting success, we resorted to harvesting seedlings from the areas that were to be cleared of alien vegetation. These seedlings were stabilized in polystyrene trays in the nursery prior to being planted out. This improved the chances of survival and gave greater operational flexibility, since we could then choose only to transplant into the restoration sites prior to rainy spells.
- The approach was modified and the main propagation season was rescheduled and took place in August till October when the mother plants were in an optimal state in their natural habitat.
- Plantlet life-span in the tray was a limiting factor and some species that could not remain in the seedling trays were planted into 2-kg and 4-kg bags. This was done reluctantly and in the end only for selected species, as for the cost of introducing one plant in a 4-kg bag, at least 10 and up to 15 plugs could be planted.
- Plugs were watered throughout summer and given a single feeding of a balanced fertilizer at the start of the cooler period in May.
- Species allocation was done based on the plant material at hand and the areas to be planted at the planting rates discussed (Table 6.3).
- Initial experiments using a modified tobacco planter was abandoned since it is only suitable for level sandy soils and it only plants in rows.

- The preferred method of planting that was developed required a small team digging planting holes measuring 10 to 15 cm deep, followed by a team placing a selection of pre-mixed plantlets into the holes, followed by the final team carrying Stockosorb gel in a super saturated state in modified knapsack sprayers. The gel was applied at 250 ml per plant (Figure 6.9) and the holes were closed, leaving a water-harvesting, dish-shaped depression around the plant. This process worked well and the seedling survival rates were nearly 100%.



Figure 6.9: Stockosorb polymer gel being added to planting hole to provide slow release of water to transplanted plants.

Table 6.3: Species allocation based on plant material at hand and areas to be planted

Plant allocation 2001

Area	1200				2	3	8, 9	Wal 6	17	18	19	46 - 50	54 A	Balance
ha / Area					5	42.9	11.5	3.2	10.8	4.5	22	4.3	3.96	129.02
Plant Quantity per Area					5555.56	47666.7	12777.8	3555.56	12000	5000	24444.4	4777.78	4400	143356
It.	Genus	Qty	Descr											
1	Aloe mitrifomis	250	Open		-		-	-	-	-	-	-	-	250
2	Aloe sp.													
3	Arctotis sp. (PINK)	1200	Plugs											1200
4	Arctotis sp. (WHITE)	1000	Plugs											1000
5	Aspergus	4600	Plugs											4600
6	Botterboom	14	20 kg											14
7	Carpobrotus	2326	Open											2326
	Carpobrotus	9445	Unrooted		1500		3000		3000	2000		1500		-1555
8	Chatebromus	17600	Plugs		800		2000		1500	800				12500
9	Chrysanthemoides incanum/monolifera	8826	Plugs		800		800		1000	200		300		5726
10	Dietes	265	4 kg											265
11	Euphorbia caput-medusae													0
12	Diospyros austro africana	45	2 kg											45
13	Elandswe	500	Open											500
14	Ehretia vilosa	30	2 kg											30
	Ehretia vilosa		Plugs											0
15	Eriocephalus racemosus	15	4 kg		5		3		5	5		3		-1
	Eriocephalus racemosus	24	20 kg				4			5		5		10
16	Euphorbia	2300	Plugs		200		100		200	50		100		1650
17	Euphorbia mauritica	192	4 kg		10		20		20	10		10		122
	Euphorbia mauritica	2400	Plugs		200		400		400	100		100		1200
18	Euryops linifolius	56	2 kg		6		10		10	10		10		10
	Euryops linifolius	2400	Plugs		100		200		200	100		100		1700
19	Euryops multifidus	90	2 kg		10		10		10	10		20		30
20	Euryops virgineus	297	4 kg				30							267
21	Exomus	22800	Plugs		800		1200		2500	800		500		17000
22	Felicia hyssopifolia (PURPLE)	80	4 kg											80

Plant allocation 2001

Area	1200				2	3	8, 9	Wal 6	17	18	19	46 - 50	54 A	Balance
ha / Area					5	42.9	11.5	3.2	10.8	4.5	22	4.3	3.96	129.02
Plant Quantity per Area					5555.56	47666.7	12777.8	3555.56	12000	5000	24444.4	4777.78	4400	143356
It.	Genus	Qty	Descr											
	Felicia hyssopifolia (PURPLE)	294	Plugs		-	-	-	-	-	-	-	-	-	294
23	Flecia haminifolia	130	4 kg											130
	Flecia haminifolia	196	Plugs											196
24	Gazania pink. (YELLOW)	800	Plugs											800
25	Geranium	2200	Plugs											2200
26	Geranium	2000	Plugs											2000
27	Gymnodiscus	401	2 kg		20		40		50	10				281
	Gymnodiscus	250	4 kg				20		50	25		50		105
	Gymnodiscus	588	Plugs				100		100	50		100		238
28	Imperata cylindrica	84	4 kg											84
29	Othonna arborescens													0
30	Keurbome	7	4 kg											7
31	Klein Pers Vygie	3000	Plugs		200		400		200	200		300		1700
32	Leonotis leonorus	51	4 kg											51
33	Polypogon strictus													0
34	Limonium capense	63	2 kg		10		10			10		20		13
	Limonium capense	2352	Plugs		100		300		450	200		300		1002
35	Limonium peregrinum (Strandroos)	44	4 kg				10			10		10		14
36	Lycium ferocissimum	1120	4 kg		30		50		200	80		200		560
	Lycium ferocissimum	588	Plugs		50		100		100	100				238
37	Maram gras	20000	Open											20000
38	Manabokka	45	4 kg											45
39	Mayetenus heterophylla	102	5 kg		10		20		25	10		25		12
	Mayetenus heterophylla	2000	Plugs		200		300		300	50		100		1050
40	Mesem bryanthemum sp. Rooi	600	Plugs											600
41	Vetivaria nigritana													0
42	Mesem ryanthemum	1800	Plugs		100		150		200	20		100		1230
43	Oedera uniflora	20	4 kg											20
44	Olea	84	10 kg											84
	Olea	48	20 kg											48

Plant allocation 2001

Area				3	8, 9	Wal 6	17	18	19	46 - 50	54 A	Balance
ha / Area	1200		2	42.9	11.5	3.2	10.8	4.5	22	4.3	3.96	TOTAL
Plant Quantity per Area			5555.56	47666.7	12777.8	3555.56	12000	5000	24444.4	4777.78	4400	143356
It.	Genus	Qty	Descr									
45	Osteospermum	1200	Plugs									1200
46	Othonna cylindrica	63	4 kg		5		10	5				33
	Othonna cylindrica	588	Plugs		50		88	50				300
47	Pelargonium	15	4 kg									15
	Pelargonium	5400	Plugs									5400
48	Plectranthus neochilus	3200	Plugs									3200
49	Rhus sp.	246	4 kg		20		40	10		40		126
	Rhus sp.	102	5kg		10		20	5		10		47
50	Salvia lanceolata	456	4 kg		50		80	50		50		126
		196	Plugs		50					100		46
51	Senecio halimifolius	8000	Plugs		300			150		300		7150
52	Steekbiesie	588	Plugs									588
53	Sutherlandia	500	Plugs		50			50		50		300
54	Tecomaria capense	152	4 kg									152
55	Thamnocorthus	56	4 kg									56
	Thamnocorthus	156	5 kg									156
	Thamnocorthus	10	20 kg									10
56	Tylecton grandiflora	1274	Plugs									1274
57	Vetivar	970	4 kg									970
58	Zantedeschia aethiopica	48	4 kg									48
	Zantedeschia aethiopica	686	Plugs									686
59	Zygophyllum morskana	340	2 kg		30		60	10				210
	Zygophyllum morskana	117	5 kg		10			10		30		47
	Zygophyllum morskana	119	4 kg							30		69
	TOTAL	139854		0	9852	0	10813	5195	0	4463	0	103930

6.11 MAINTENANCE

Initial provisions were made to complete the project in five years. The programme was modified and completed over a nine-year period that included four years of maintenance and diversification. This was all completed within the original budget as the methodologies developed and the parallel income generated allowed for this (CES 1996).

- During the life-span of the rehabilitation project it became apparent that maintenance would need to form an integrated part of the approach for longer than anticipated.
- Intervention was required to ensure that rehabilitated areas remain clean of alien vegetation and those areas that failed to establish were re-seeded.
- Causes for failure related primarily to wind erosion, water erosion and unfavourable soil conditions.

6.12 PROJECT COSTS

The initial project budget was R6 728 500.

The implementation phase was completed at a cost of R5 072 105 in 5 years.

This allowed for the extension of the maintenance for a further four years until 2005 totaling a cost of R983 609 or 16% of the total budget (Figure 6.10).

Since the mine was active for more than half a century, provision for the rehabilitation cost could have been made during the operational life-span even though the ownership and management structure had changed several times.

Typically, during the 88/89 financial year, the turnover of Chemfos was close on R30 million, yielding a pretax profit of around R4 million. This profit was also achieved during 89/90 off a lower turnover base of R26 million (M Calitz, pers. comm.).

It must, however, be considered that removal of overburden was stopped in 88/89 and subsequent mining was not subject to the excessive cost that forced the closure of the mine.

The years of very profitable mining after the re-launch of operations in 1981 did, however, see higher profit margins, although we could not obtain accurate figures for this period. Had systematic backfilling commenced earlier and rehabilitation been conducted on an ongoing basis, the final rehabilitation cost would have been considerably less. The likelihood of this is, however, not great as the rehabilitation techniques were not developed and there was no

urgent pressure or perceived need to restore ecosystem functionality to marginal agricultural land as the general perception was at the time.

During 2005/6, an additional maintenance budget was prepared for consideration, but BHPBiliton referred the matter to Iziko since they were the managers of the land and the remaining project capital has been transferred to them. The quotation was not accepted and no maintenance had been done. The quotation was revised in 2008 and amounts to R172 112 representing 3% of the total budget.

Failure of maintenance does have exponential cost implications and it is expected that the trend of reducing cost of maintenance that was initially seen will reverse itself and as the cost of alien vegetation removal is directly related to the age of the infestation.

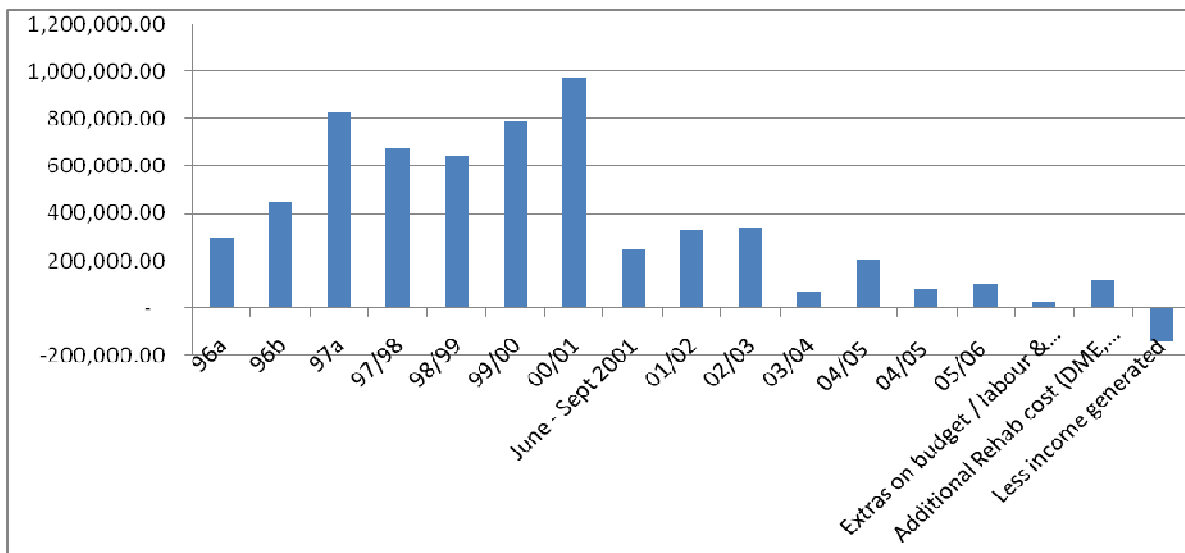


Figure 6.10: Expenditure (in Rands) of the rehabilitation of Chemfos from 1996 till 2006).

6.13 DISCUSSION

6.13.1 The Chemfos legacy

The Chemfos legacy, in no small form, shaped the development of the rehabilitation plan from the consultation to the implementation phase. The transformed, semi-arid environment challenged conventional approaches used elsewhere and a unique answer had to be found.

6.13.2 The initial assessment

The development of the conceptual rehabilitation plan followed the initial assessment and played out in a specific time frame. In retrospect, the advantage of insight now highlights that some of the approaches that were followed may very well have been adjusted for better results.

The initial time frame set for rehabilitation was inadequate and very optimistic, but was based on the expectation of the mining company to exit the scenario rather than the theoretical rehabilitation plan. The time frame of implementation should ideally be stretched initially to maximize the information gathered from any form of trials and the inclusion of this very valuable data in the planning process

Rehabilitation at Chemfos commenced in June 1996. Trial design, material procurement, staff training and implementation of the trials had to be conducted within a narrow time window as it was very late in the rainy season. During 2000 it was observed that the hydroseeding conducted in April of 1999 yielded the best ever results in some of the poorest soils on the mine. This can be contributed to the use of the refined selection of seed that was suited to the soils (based on informal observations of previous sowings since the statistical information of the implemented trials were not yet available) and primarily timing.

The seeds germinated shortly after the initial rain and were already growing at the end of May 1999, compared to 1996 when the seeds were only sown at the end of June. Although the advantage of an additional 6 or 8 weeks' worth of growth may seem insignificant, the rainy season in this region is only 20 weeks long and not utilizing the full length of the season compromises results in all probability.

Initial expectation was also to have results from the 1996 trials in hand to determine the direction of the implementation for the rehabilitation by the second season. In reality, this was not the case and meaningful results only became available during 1999. The lag time of almost three years was not planned for, but should, in similar instances, be allowed for to ensure that the correct information is available to direct the roll-out of the implementation. It is advisable to commence these trials during the feasibility or prospecting phase of a new mine of this nature as the information may influence the land shaping and even mine path resulting in optimized cost-efficiencies.

Initial expectations were that it might be possible to restore the entire site only by seeding. It did, however, become apparent that the diversification by means of introduction of small

plants added to the diversity and expedited the process. Although the use of direct transplants or harvesting of plants from the natural areas on the mine was practiced during the trials, the limited area that was still undisturbed could not yield adequate volumes of plants. Research in production techniques of the local vegetation thus commenced in August 1996 but in retrospect should have started in May that year, as this would have added a range of additional species to be used that were only found to grow during the next year.

Since the adaptive management model was followed, most of the information gathered was fed into the process of rehabilitation in short cycles; the rehabilitation implementation towards the end was near optimal.

The important fossil site has subsequently been developed into a tourist attraction and research facility. The context of the old mine has assisted in making accessible the fossils to the public and adds to the understanding of the processes that lead to the formation of the fossils. The fact that the topography now, to some extent, represents the paleo-topography brings home the picture clearly to the public.

6.13.3 The Rehabilitation Process

The continued evaluation of the success of the individual rehabilitation techniques in order to determine every next step is, in retrospect, the single most advantageous decision made in the approach formulation. Aerial photographs D.8 to D.11 (Appendix D) assisted in this regard.

The Adaptive Management Approach (Figure 6.11) that was developed for the Rehabilitation at Chemfos required recordkeeping to determining the actual cost and success of every step of the process. This enabled not only informed decision-making, but provided a costing model that can be modified and applied on other similar sites with reasonable accuracy. The models and norms developed for optimising efficiencies in alien clearing by incentivising the process is used during 2010 by the West Coast Biosphere Reserve teams to structure maintenance of the alien vegetation on site with only minor adjustments.

The major obstacles encountered during the rehabilitation relates not to the natural systems in the area but to the modifications caused by mining and the lack of integrated planning of the rehabilitation as part of the mining process.

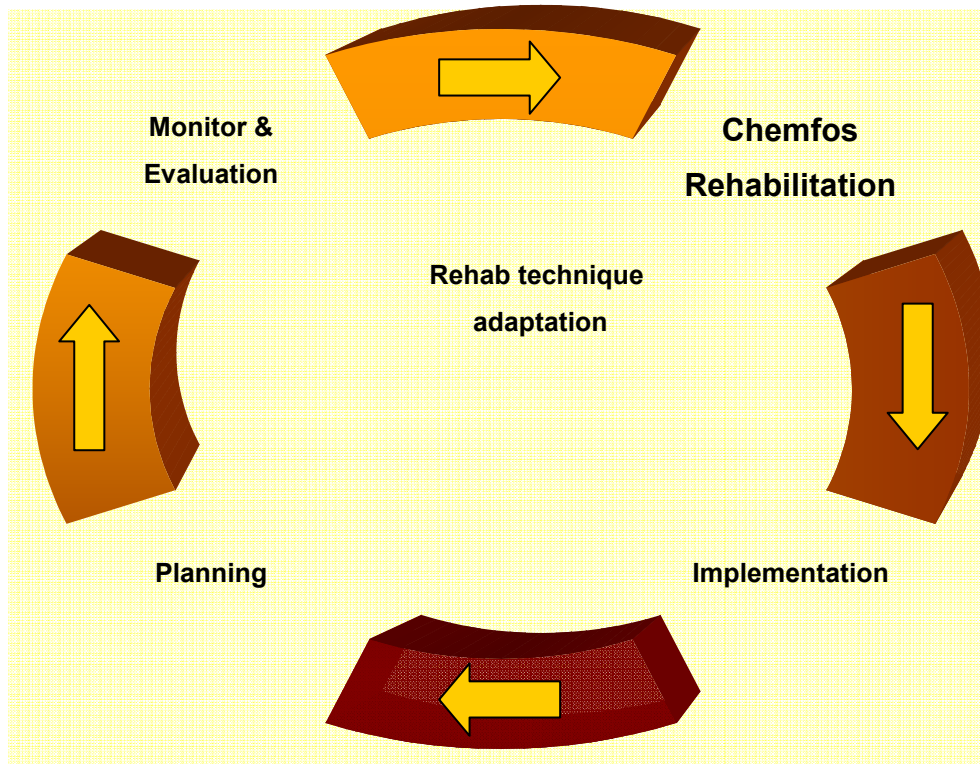


Figure 6.11: Schematic diagram depicting the Approach formulation used at Chemfos.

6.13.4 Transforming the Land Shape

Due consideration was given to the post-mining land shape. Original estimates to reverse mining operations and to backfill the mined-out areas using the spoil and overburden dumps were done by the consulting engineers, but the prohibitive nature of the cost resulted in the search for an alternative approach.

In consultation with representatives of the Department of Minerals and Energy Affairs, the consultants proposed that the unsafe embankments be addressed and that attempts should be made to address the remaining areas through rehabilitation. Reprofiling of four fill embankments commenced in November 1996 and was completed by mid-February 1997. Two unsafe embankments were not modified due to the limited potential benefit when compared to the potential negative impact. The high wall site that depicts the area's stratigraphy that was found to be very valuable to researchers of Iziko Museums and the 1:1 slope surrounding the smaller permanent water body that supports a vibrant bird population nesting in the *Acacia cyclops* was left. These areas were fenced off and marked with appropriate signage.

In addition to understanding the development of the ancient land form, the current post-mining environment in its rehabilitated state adds to the diversity of the area. The modified topography has resulted in a variety of localized ecosystems that differ from the original. The variation has been used well in creating cycle tracks, horse-riding trails as well as hiking routes and bird hides that all add to an improved visitor's experience. The diverse habitats also favours a greater than normal variety of birdlife as a range of water bodies and wetlands now persist, ranging from salt marshes to deep water.

6.13.5 Alien Vegetation

The historical practice of treating topsoil and subsoil as unwanted overburden and the injudicious placement of these assets destroyed the more cost-effective rehabilitation potential of concurrent ongoing mine rehabilitation. The lack of integrated planning resulted in a post-mining environment that did not lend itself to natural or spontaneous rehabilitation. This hostile environment thus required a range of rehabilitation techniques that were not fully developed at the time. The introduction of *Acacia cyclops* and *A. longifolia* to stabilize the exposed areas to reduce the windblown dust thus created additional challenges for the rehabilitation of the mine. Had the rehabilitation process formed part of the mining process, adjustments to the work and traffic flows could have made sequential rehabilitation a reality. The separation of the vegetation layer, topsoil and subsoils during exploration and mining and the systematic placement of these in the proper order to areas already mined would have added to the cost of mining by increasing the hauling cost (due to distance) but the advantages gained by regenerating vegetation for the topsoil in a growth-supporting medium is invaluable (Boucher and le Roux, 1981).

Costs incurred for the alien vegetation removal would have been unnecessary, since there would have been no need to remove the *Acacia spp* that was introduced for the purpose of dust suppression. If, however, the topsoil was used in direct rehabilitation and the area did later on become invaded by *Acacia spp*, as is the case with a lot of disturbed farmland in the West Coast, the cost of the collection of a broad range of seeds, including the costly climax species, and the propagation of plants would have been unnecessary if the process was limited to alien vegetation control.

In discussing targets for ecosystem repairs for the Working for Water project, Holms states that "Where indigenous propagule sources persist (in the soil seed bank) considerable recovery of natural vegetation can be expected, especially when care is taken during operations to clear invasive alien plants, even where alien stands are dense (Holms 2007).

It is conceded that the thinking that resulted in the rehabilitation of Chemfos developed over time as the best practices improved and evolved. In finding ways of managing the alien vegetation on site, the introduction of the biological control agents were done into a near perfect research site. The isolated nature of the sites that were left as part of the long-term trials made them ideal to study aspects of the control agents and the location in the now West Coast Fossil Park, where research requirements and non-interference with trials are understood, is conducive to long-term monitoring of trials, adding another dimension to the research.

In a report on developing an ecological researchers' strategy for the National Working for Water Programme (Fourie, 2002) it was proposed that protocols should be developed for the different invasive alien treatment and control process. It was proposed that the initial assessment of the site or area to be treated should take into consideration a variety of factors such as the appropriateness of clearing, site-specific considerations on where to clear and where not to clear, the use of appropriate techniques such as mechanical and chemical or biological means. In retrospect, the approach followed at Chemfos complied with all these aspirations set out by the working group. The data recorded during the process also provide good benchmarks for productivity and planning purposes of similar projects elsewhere. The approach as well as the norms and cost model was, in fact, used in successfully clearing *Acacia spp* from areas in L'Agulhas, the Cape Flats and Yzerfontein.

6.13.6 Establishing Cover Vegetation

The introduction of vegetation into the modified landscape once cleared of alien vegetation followed the traditional pattern of seedbed preparation and seeding. The methods of preparation and techniques of seeding were based on the local conditions and do not represent any major shift in practice. Significant, however, is the understanding of the importance of timing of the seeding that was developed. The selective allocation of most appropriate seed to areas where the microtopography and the local soil conditions would support growth contributed to the most economical use of resources. During the rehabilitation, a variety of preparation techniques were used that included dozing, tilling and hand-preparation using African hoes and rakes. All of these are efficient under the appropriate conditions, with hand work being favoured on slopes and inaccessible areas and mechanical means for larger-scale applications

Hand-seeding, mechanical seeding and hydroseeding were also used with hydroseeding being favoured for slopes where difficulties are experienced and additives such as stickers

(degradable polymer-based glues) were required to assist in localizing seeds till germination. It is also the most suitable for seeding larger areas when using locally harvested seeds, since these seeds once processed are not uniform and not suited to mechanical seeding. Hand-seeding is the most flexible and appropriate in fragmented areas. Mechanical seeding is appropriate for larger uniform areas not often found at Chemfos.

6.13.7 Diversification

Based on the cost of seed collection of the woody species in quantities that would likely yield significant numbers of established plants per ha in a regime where rainfall was uncertain and predation by guinea fowl was high, the diversification option that was followed favoured plan production and the introduction of established plants (Figure 6.12) at the beginning of the growing season. The establishment of nurse clusters of these plants have resulted of self-recruitment of these components within the project time frame (Figure 6.13).



Figure 6.12: Propagation of diverse vegetation for introduction in clusters in seeded environments (2000).



Figure 6.13: Initial clusters of diverse vegetation on a modified embankment that was hydroseeded (August 1998).

6.13.8 Maintenance

Subsequent lessons learned indicated that the lapse of maintenance shortly after the implementation causes exponential growth in the cost of maintenance. Initial costs proposed for maintenance of alien vegetation was R80 000 for 2005 and R45 000 for 2006. This was not implemented and at the end of 2006 a review of the situation was completed and the cost estimate for the alien vegetation removal amounted to R172 000, representing a growth in cost of nearly 382% of this period. It is, therefore proposed to have a five- to ten-year maintenance plan in place after the initial rehabilitation has been completed. The development of an Environmental Management Plan with goals set out for a further 10 years is proposed as the break in continuity between the rehabilitation implementation and subsequent management leads to costly re-learning and a loss of intellectual capital.

6.14 CONCLUSION

Various obstacles were encountered during the rehabilitation of the Chemfos mine. In most cases cost-effective and innovative solutions were developed and the closure certificate of the Chemfos mine was issued to BHP Billiton.

CHAPTER 7. SEED COLLECTION AND PROCESSING

This Chapter deals with the collection and processing of seed as one of the primary means of rehabilitation of the modified environment of the post-operational mine.

7.1 INTRODUCTION

Re-establishment of vegetation in a disturbed environment may occur naturally and the recovery is scale-dependant as observed in grasslands by Coffin & Lauenroth (1988). Recovery along linear disturbances such as pipelines has been observed to be rapid where the topsoil has been saved and replaced after the disturbance took place, as the primary propagules are seeds contained in the soils (Hoffman *et al*, 2008). In chemically or physically modified soils and subsoils, such as resulting from large areas disturbed by mining, these propagules are absent and have to be re-introduced.

The natural processes of seed production and dispersal into these barren sites are the natural driving forces of the reintroduction of invading species and this process of succession is very slow. The soils in the mined-out sites are depleted of natural propagules and have to be re-inoculated or reseeded. To speed up the process of restoration, within the time frames associated with mining and mine closure, the process of seed dispersal has to be enhanced and optimized. Fortunately, basic agricultural and horticultural techniques for seed collection and processing have been practiced since 6500 BC in the Valley of the Jordan River and modern-day Turkey and these techniques were refined by the Romans (King 2008).

The challenge that was presented on the Chemfos site was finding the appropriate species and techniques that would result in successful rehabilitation of a large site of some 650 ha, where there was little or no topsoil, and where the whole mine site had been extensively modified. There is very little indigenous seed available commercially and in order to provide the seed necessary for the restoration of the large site, seed collecting and processing techniques had to be developed. In this chapter the aim is to show how indigenous seed was collected using different techniques, how the different species were processed and then how the costs of the different techniques were analysed in order to make subsequent recommendations for future rehabilitation projects.

7.2 SEED COLLECTION

Seed collected initially during 1996 was a random process driven by the need to collect sufficient seed for field trials. Since the project commenced in June 1996, there was no time to plan and collect the broad spectrum of seeds that were to be used later. Collection of seeds of late succession and summer flowering plants was carried out. In order to obtain adequate quantities of seed for the initial field trials, commercial sources of seed were sought and some seed was obtained from the Veld Seed Reserve of the Department of Agriculture in Worcester. Initially the availability of pioneer species was low since the seeds of the pioneer plants are mainly dispersed in spring. Thus the use of commercial grass seed was explored to ensure the inclusion of quick-germinating plants to act as a cover crop. Consequently, the trials could be implemented in time, but fine-scale observations on the performance of a broad spectrum of the local species on the specific trial sites could not be included.

7.3 SEED COLLECTION TECHNIQUES

The seed collection techniques that were used were adapted from previous experience for the rehabilitation of the Outeniqua and Du Toitskloof passes. This entailed hand collection for seed from the veld once the seeds have been identified as ripe and viable, a cumbersome process with erratic yields, but often it remains the only option.

7.3.1 Hand Harvesting

This is the most basic way of collecting seed. Plants such as *Metalsia* spp., most grasses and annuals disperse the seeds from the mother plants and they must be closely monitored until approximately 30% of the seeds of a given population are about to disperse, when they are collected. In other species with seeds which are not rapidly dispersed, such as *Prenia pallens*, *Juncus krausii* and *Amellus tenuifolius*, the seeds are allowed to dry on the plant and collected when time permits. Seeds contained in fleshy fruits such as *Lycium* spp. and *Chrysanthemoides* spp. are collected as soon as the fruits are ripe so as to avoid loss of seed to fruit-eating birds.

Seed collection is best done in the mornings before the seed-dispersal mechanisms are fully functional. Wind-dispersed seeds are best collected before the heat of the day as slight disturbance of the seed heads results in seed release, thus reducing the efficiency of collection.

Collection commenced at or before 06:00 and was terminated when the insects became too bothersome with rising temperatures during the day and when the natural seeds dispersal reduced the efficiency of collecting adequate seed.

During observations conducted in the field it became apparent that seed collection is hampered by the need to hold a bag in one hand whilst collecting seed with the other. Seed collection could be speeded up by the design of a bag with a stiff edge that remained open and was fitted around the waist of the collector, thus allowing the collectors to pick seed using both hands.

Efficiency of seed collection proved to be subject to the ability of individuals and productivity amongst collectors could vary dramatically. This made it difficult to programme the periods of collection of seed and increased the risk of not obtaining adequate quantities of seed for the next season. Norms of quantities of seed collected in a given time period or session were established for each species and seed collectors were then paid according to weight of material collected. Since the inclusion of plant material other than seed would skew the results, all collected material was weighed initially and an advanced payment was made. Once the seed yields were determined, additional payments were made to each person, based on the weight of clean seed collected. Although this was a cumbersome system to administer, it ensured that the collectors could operate with a minimum of supervision.

7.3.2 Vacuum Harvesting

The Veld Reserve in Worcester grows selected species as monocultures and this enables commercial large-scale harvesting using a specialized tractor-drawn vacuum harvester developed by Mr van Breda. (<http://www.elsenburg.com/trd/farms/worcester.html>)

This mechanized harvesting of seed in cultivated stands of selected plants reduces the cost of the seed to a fraction of the cost of wild harvested seeds. Direct cost comparisons between seed harvested on the reserve and the hand-harvested seeds used on the project can, however, not be drawn since the cost of the seed from the reserve is subsidised by the Department of Agriculture, who pays all associated cost, including the overhead of the operations.

This approach of establishing plants for seed as monocultures under irrigation was considered for the Chemfos project, but due to associated time and cost constraints, it was not implemented. It could, however, be a viable alternative to collection from natural sources

under specific conditions where a long life-span of a project could make this approach viable.

Small-scale vacuum harvesting has proven to be useful on a limited range of species and can prove profitable in some years. Both Stihl and Hasqvana manufacture equipment (leaf vacuum machines) that can be adapted for use in seed collection. These hand-held devices are limited in capacity, but the mobility allows the operator to access remote areas.

The Stihl SH 85 has a straight suction action created by an impeller. The material sucked in through the tube moves over the open impeller in the suction chamber resulting in shredding (<http://www.stihl.co.za/blowers-vacuum-shredders-mistblowers/65/67-sh-85.html>). It was designed to shred leaf debris collected during garden cleanups efficiently and it proved to be very useful in the collection and partial cleaning of seeds of *Tetragonia* spp. and *Zygophyllum* spp. The husks were shredded, but this did not result in significant damage to the seeds and the resulting material was screened, yielding nearly clean seeds on the first screening.



Figure 7.1: The Stihl SH 85 used as a vacuum harvester.

The Hasqvarna BlowVac that was used is now discontinued, but is quite different in principle from the current options available (<http://www.abbeygardensales.co.uk/subprod/hasqvarna-petrol-blowers-vacs-0002606.aspx>). It worked on the principle of blowing air down a thin chamber in a thick two-chamber tube, deflecting most of it back into the primary tube resulting in suction. The volume of the small amount of air that was expelled could be

controlled and this was directed ahead of the suction area. The result was a steady, adjustable blowing force that lifted seeds and debris off the ground followed by a suction that collected the material in a bag. In order to reduce the volume of the material collected, the equipment had a fast rotating spindle and attached nylon cord that acted as a shredder through which all the material entering the collection bag had to pass. This action was very gentle and had hardly any impact on hard seed making it ideal for processing and collecting material such as *Senecio spp* and *Sutherlandia frutescens*.

The small hand vacuums both cost in the region of R5 000 each and with good maintenance they will last around two to three seasons. The equipment is ideal for sub-optimal season collection of seeds that are accumulated by termites, mice and wind.

Prolific flowering of annual species results in a healthy seed set as is the case with *Ursinia anthemoides* and *Dimorphotheca pluvialis*. Collecting seed of these species is difficult, since seeds are borne close to the ground and they are released by touch. In order to collect meaningful quantities of these seeds, the Billy Goat® was utilized. This apparatus (<http://www.billygoat.com/site/intro.aspx?pid=67>) was developed as a mechanical road sweeper using a powerful vacuum and was adapted for the collection of seeds of prolifically flowering annual species. Although the machine is self-propelled, it is not suitable for use on unpaved surfaces and very difficult in soft sand. Modifications included the addition of a draw rope to the front for a person to assist in pulling the equipment. The seed collected in this manner contained a large amount of sand that had to be screened out in the field prior to transporting the seed to the processing areas.

In order to ensure adequate seed availability for the next season, the surrounding areas were observed during winter and spring and significant populations of potential plants to be used in the reintroduction programme were marked during flowering. The population positions were recorded on a location map together with dates for anticipated seed collection.

Permits for the collection of seed from the road reserves were obtained from the Western Cape Department of Nature Conservation and collections from private land such as Anyskop (adjacent farm) and Air Force Base Langebaanweg were sanctioned by the respective owners and controlling authorities.

7.4 DRYING OF SEEDS

In order to reduce the cost of processing, seed handling was restricted to a minimum. Consequently, flowers and fruits that were collected were not cleaned as this was regarded as an unnecessary step and increased costs. The seed heads and fruits were, however, dried and only processed to a point that would allow for the release of seeds.

Seed collected while still on the flower heads contains substantial moisture at times and had to be dried to induce seed release and to prevent the formation of fungal growth. The use of a two-layered tray system was introduced to allow natural air movement and to catch the seeds that were released.

Stacking frames were constructed that could accommodate two double rows of frames. The frames were constructed using 38 mm x 38 mm SA Pine battens assembled in a jig using dry-wall screws. Frames for the rows were covered with stretched second-hand anchovy nets with 5 mm x 10 mm grids that allowed free air movement and the falling through of released seeds onto the second frame that was covered with a poly cotton fabric (Figure 7.2).

Seed such as *Metalasia* spp. were collected and placed on the racks without any further processing and would be dry for packing within two weeks depending on the air moisture. The seeds of *Metalasia* do not release readily within that period of time, so the flowers were de-stalked and packed. The subsequent handling during the mixing and seeding processes was adequate to release the seeds for germination.

Seeds of *Lycium ferocissimum* had to be processed from freshly picked succulent fruit. Ripe fruits released seeds readily when rubbed by hand on an abrasive surface. The resulting pulp is then smeared on a cloth-covered frame and allowed to dry. The resulting seed cake is easily removed and packed (Figure 7.3).



Figure 7.2: The twin-rack drying system.



Figure 7.3: Processing the dried seed pulp of *Lycium ferocissimum*.

Prenia pallens is perhaps one of the better examples of rapid cost increase for seed processing and thus the seed was used in the partially processed form. Whole plants were collected after seed ripened and these were dried under cover on a cement floor. The process took approximately three to four weeks and during that time, the material was turned daily. The dry material was fed through a hammer mill with a 10 mm screen. The resulting

material was sampled and a seed count performed to determine relative seed quantity per batch.

In order to provide seed at a 98% clean seed level on another contract, seeds had to be screened through a series of sieves and then placed in water to float off the remaining husks. The period of exposure to water was kept to a minimum, typically under one minute. The seeds were removed once the water has been drained off and the seeds were dried on cloth covered frames in the sun for one to two hours before being placed indoors prior to packing. Since the process is laborious and only small quantities of seed could be recovered at a time, the cost of the final process represented nearly 40% of the final cost of the seed.

7.5 COST OF SEED COLLECTION

No statistical information was available to serve as a guide to determine the cost of seed collection for the project when we commenced the work in 1996. The commercial suppliers that existed at the time were Worcester Veld Reserve, Kirstenbosch National Botanical Garden and Silverhill Seeds. These suppliers could not supply the seeds required or provide useful costs since they focus on providing smaller quantities of clean seeds to specialist growers or agricultural seeds primarily from the Karoo areas. Small quantities of seed from the field reserve were used during the initial trials to evaluate the methodology. Bulk local seed collection required a different approach and all aspects of the collection and processing had to be developed for the project.

Based on previous seed collection experience, the final approach used at Chemfos was formulated and adapted in order to provide the 5 000 kg of clean seed equivalent required to complete the rehabilitation of the mine.

7.5.1 General Seed Costs

The annual seed collection programme was based on the area to be seeded during the following autumn. Since collection results can only be finalised once seed has been dried and processed, broad estimates were used to determine required quantities. Relative cost of selected seed collected in bulk is represented in Table 7.1, but it excludes seeds collected in small quantities for propagation purposes. Seed collected and processed represents the production of seed during 2002. The rates are adjusted to reflect collection prices in the 2008 collection season. These rates are only relevant to large-scale projects with internal pricing structures. The model has to be adapted should commercial viability of a seed collection entity be brought into the equation. Although a 45% allowance was added to cover

overheads and profits, the seed collection and processing does not represent a viable business unit independent of other activities.

Table 7.1: Summary of details of mass of different species of seeds collected, time for the collection, final yields of seed and costs in a typical year.

Name	Month collected	Wet mass of material as collected (kg)	Man-days required for collection	Amount paid per kg material collected (R)	Amount paid for this collection (R)	Yield of partly processed and dry seed (kg)	Allocation of fixed cost for processing (R) 65 000	Cost (R)	Overhead & Profit @ 45% (R)	Cost per kg of yielded dry material (R)	Total cost of seed (R)	Total number of seeds per batch x100
<i>Amellus tenuifolius</i>	January	128.22	6.00	3.00	384.66	30.00	85.32	98.15	44.17	142.31	4,269.36	4930
<i>Athanasia crithmifolia</i>	January	77.77	4.00	7.00	544.39	10.00	85.32	139.76	62.89	202.66	2,026.57	37950
<i>Athanasia trifurcata</i>	January	50.65	4.00	6.00	303.90	20.00	85.32	100.52	45.23	145.75	2,915.06	41500
<i>Carpobrotus edulis</i>	December	48.00	2.00	6.00	288.00	24.00	85.32	97.32	43.80	141.12	3,386.88	41800
<i>Chaetobromus dregeanus</i>	October	644.14	3.50	20.00	12882.80	200.00	85.32	149.74	67.38	217.12	43,424.09	10830
<i>Chrysanthemoides incana</i>	September	35.10	10.00	45.00	1579.50	16.00	85.32	184.04	82.82	266.86	4,269.80	220
<i>Dimorphotheca pluvialis</i>	September	18.56	11.00	70.00	1299.20	15.00	85.32	171.94	77.37	249.31	3,739.64	3480
<i>Ehrlharta calycina</i>	October	61.48	8.00	15.00	922.20	22.00	85.32	127.24	57.26	184.50	4,059.03	22000
<i>Ehrlharta villosa*</i>	November	603.00	21.00	8.00	4824.00	29.00	85.32	251.67	113.25	364.92	10,582.68	11
<i>Eriosephalus racemosus</i>	September	41.37	8.00	16.00	661.92	25.00	85.32	111.80	50.31	162.11	4,052.79	660
<i>Eunyops multifidus</i>	November	12.27	5.00	10.50	128.85	1.00	85.32	214.16	96.37	310.53	310.53	990
<i>Foveolina tenella</i>	September	55.03	7.00	4.00	220.12	7.00	85.32	116.77	52.55	169.32	1,185.21	31110
<i>Juncus kraussii</i>	February	73.29	8.00	9.50	696.25	10.00	85.32	154.95	69.73	224.68	2,246.77	45900
<i>Lebeckia spinescens</i>	November	35.04	16.00	50.00	1752.00	3.99	85.32	524.42	235.99	760.41	3,034.04	2400
<i>Lessertia frutescens</i>	November	3.45	15.00	40.00	138.00	1.00	85.32	223.32	100.50	323.82	323.82	1100
<i>Leysera gnaphalodes</i>	November	9.94	4.00	30.00	298.20	0.76	85.32	477.69	214.96	692.65	526.42	36700
<i>Lycium ferocissimum</i>	July	31.07	9.00	18.00	559.26	12.00	85.32	131.93	59.37	191.30	2,295.57	5490
<i>Metalesia muricata</i>	October	95.42	12.00	6.50	620.23	35.00	85.32	103.05	46.37	149.42	5,229.54	11040
<i>Oncosiphon grandiflorum</i>	December	77.12	4.00	4.00	308.48	60.00	85.32	90.47	40.71	131.18	7,870.50	68450
<i>Oncosiphon suffruticosum</i>	October	118.99	6.00	6.00	713.94	70.00	85.32	95.52	42.99	138.51	9,695.62	75800
<i>Ornithogalum cooperi</i>	October	1.79	3.00	35.00	62.65	0.45	85.32	224.55	101.05	325.59	146.52	17450
<i>Ornithogalum thyrsoides</i>	December	96.03	4.00	8.00	768.24	20.00	85.32	123.74	55.68	179.42	3,588.35	22350
<i>Othonna cylindrica</i>	October	19.07		20.00	381.40	10.19	85.32	122.75	55.24	177.99	1,813.74	840
<i>Pelargonium capitatum</i>	October	3.76	5.00	45.00	169.20	0.95	85.32	263.43	118.54	381.97	362.87	1640
<i>Prenia pallens</i>	January	410.01	10.00	1.20	492.02	20.50	85.32	109.32	49.20	158.52	3,249.68	18220
<i>Rhus glauca</i>	October	13.66	6.00	30.00	409.80	11.74	85.32	120.23	54.10	174.33	2,046.68	870
<i>Senecio elegans</i>	November	1.17	1.00	40.00	46.80	0.47	85.32	184.90	83.20	268.10	126.01	9480

Cost-effective, post-mining environmental restoration of an open-cast phosphate mine at Langebaanweg, South Africa

Name	Month collected	Wet mass of material as collected (kg)	Man-days required for collection	Amount paid per kg material collected (R)	Amount paid for this collection (R)	Yield of partly processed and dry seed (kg)	Allocation of fixed cost for processing (R) 65 000	Cost (R)	Overhead & Profit @ 45% (R)	Cost per kg of yielded dry material (R)	Total cost of seed (R)	Total number of seeds per batch x100
<i>Senecio littoreus</i>	November	57.89	8.00	12.00	694.68	14.75	85.32	132.42	59.59	192.01	2,832.16	4940
<i>Stylapteris micranthus</i>	November	166.71	6.00	1.00	166.71	42.00	85.32	89.29	40.18	129.48	5,437.98	1250
<i>Trachyandra divaricata</i>	October	439.89	8.00	2.50	1099.725	45.00	85.32	109.76	49.39	159.16	7,162.01	1070
<i>Zygophyllum morskana</i>	October	60.33	6.00	7.50	452.475	4.00	85.32	198.44	89.30	287.74	1,150.97	14
Totals		3,490.22	220.50		33,869.58	761.80		5,243.30	2,359.49		143,360.89	

* 2009 data added

7.5.2 Cost of Seed Per Species

The cost of seed collection varies substantially between species. A selection of species was used that included seed from across the spectrum of plants found growing on these sites. *Euryops multifidus*, at R311.00 per kg, is expensive to collect but germination is good and the plants establish very well. Only small quantities of seed were required to re-introduce the species in suitable areas. The 1 kg of seed collected contained 99 000 seeds and this was adequate to re-introduce the species on more than 5 ha. In Figure 7.4, it is the most expensive of the middle range of species.

Cheaper bulk seed formed the mainstay of the introductions and included pioneer species e.g. *Oncosiphon spp*, intermediate species such as *Amellus sp*, and the very useful climax plant, *Metalasia muricata*.

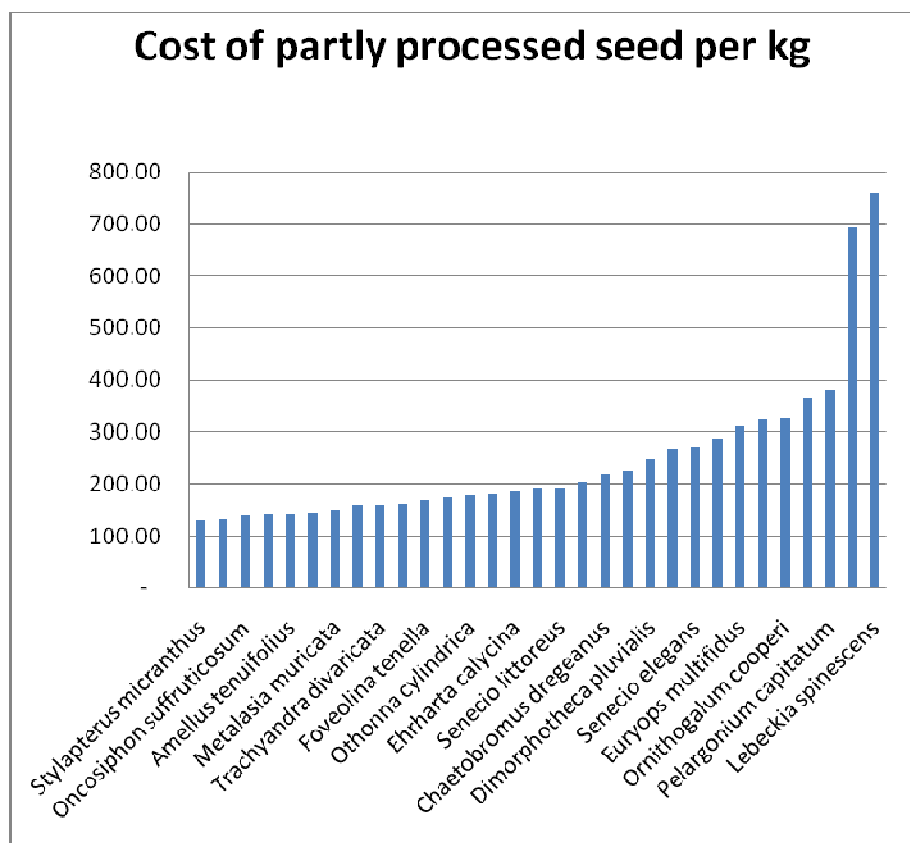


Figure 7.4: Cost in Rands per kg of partly processed seed of selected species.

Some species, e.g. *Rhus glauca*, did not germinate readily when seeded into the rehabilitated areas. This may relate to these shrubs being dispersed by birds and small mammals and these species were thus not collected in any great numbers. Due to the

collecting cost of R2 046.68 and a yield of 87000 seeds with no observed germination in the first year after seeding, seeds of species like the *Rhus glauca* were no longer collected.

The cost of seed collection varies depending on a large range of factors. Distribution, density and phenology all play a part in this. A species like *Lebeckia spinescens* only occurred in a limited area on the mine in high enough density to make collection viable. The normal pattern of occurrence is sparse. Collecting seed from sparsely occurring species in a near climax vegetation stand requires much movement looking for plants with seeds of a suitable ripeness. The yields are thus very low. A factor contributing to the low yield is response of *Lebeckia* to air moisture once ripe. The seeds ripen in the seed pods but the last phase of hardening and maturing takes place rapidly. If this phase is coupled with rainy weather, it is very difficult to monitor the plants. On the first day of dry weather, ripe seed pods rapidly dry activating the release mechanism that opens the seed pods through a differential pressure along the legume's seed pod. If the seed ready phase co-insides with other important scheduled events, it is likely that the seed collection of this particular species would fail during that specific year. Collecting *L. spinescens* was thus complex and expensive under the conditions that prevailed and was the most expensive seed by weight of collected material to collect at R760 per kg. Seeds such as *Dimorphotheca* and *Senecio spp.* are adversely affected by rain in a different way. Should rain occur during the seed release phase, the seeds drop to the ground and adhere to the soil. Once this happens, it is no longer cost-effective to collect these seeds. Species like *Amellus* have sessile seeds that remain in the seed heads for months and are released only once the seed heads dry out. The collection window for a species like *Amellus* is thus not narrow and the collection can be managed along with scheduled tasks.

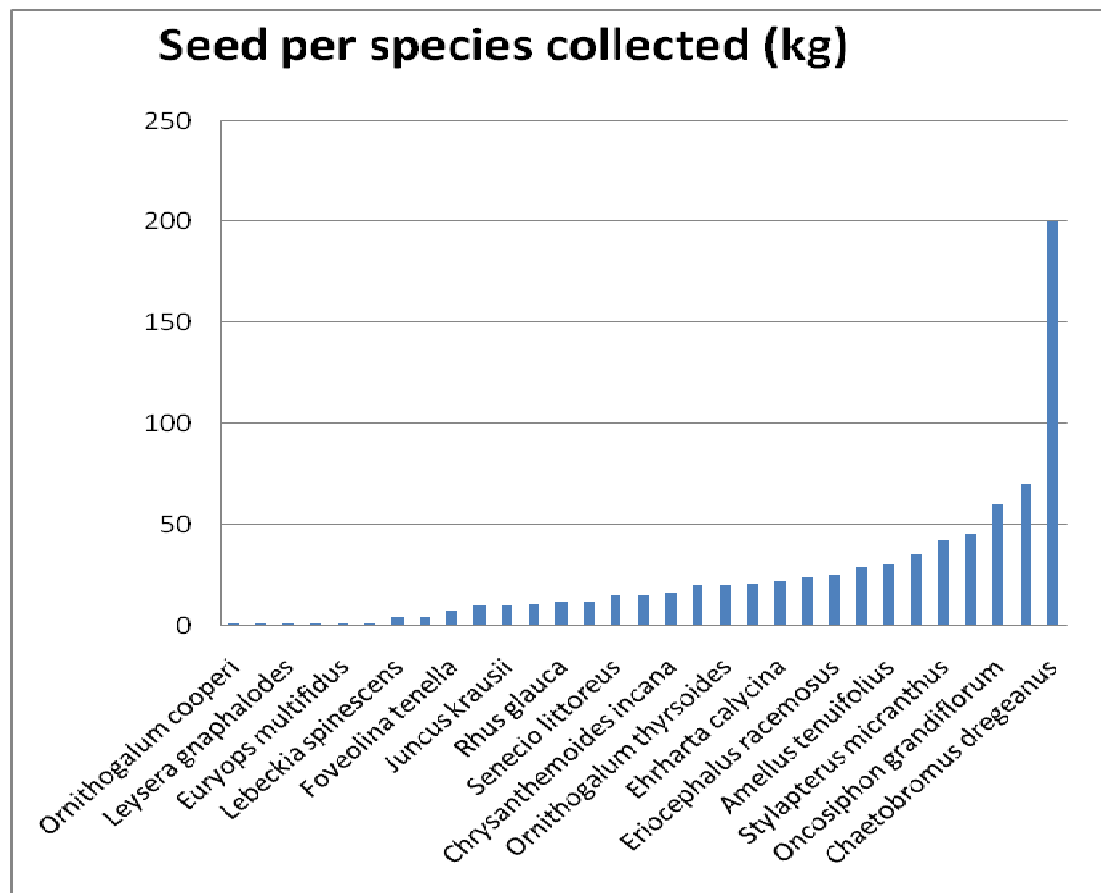


Figure 7.5: Mass of seed collected, kilograms per species.

Figure 7.5 depicts the seed collection per species in a typical year.

Seed collection from a limited range of species was planned and conducted throughout the rehabilitation programme. During 1996/7, however, the seed collections were explorative and a larger variety of seeds was collected in order to evaluate the collection, drying and processing techniques for the then unfamiliar seeds. The germination performance of the seeds was also monitored in a range of soil types and condition.

This information, together with the alien clearing programme, was used to determine the amount of seeds and the most suitable species that were required for the following season.

The targets of dry and processed seeds that were set were initially difficult to follow and frequent over collection occurred. This was due to the lack of data for the collection of seed.

Recording wet mass of collected material, the dry matter yield of the collected material as well as the final seed yield for cleaned as well as partially cleaned seed enabled us to monitor collections carefully and more accurately collect only the required amounts of seed. This was crucial as seed was not cold-stored and seed was only used in the season following collection. Excess seeds could not readily be sold on as the demand for the seeds in appropriate ecological systems did not exist.

The collection of vast amounts of *Chaetobromus dregeanus* and other successful pioneer species indicates that large areas of primary rehabilitation for required species were identified in the planning phase of the seed collection.

7.6 ALLOCATION OF COLLECTED SEED

7.6.1 Planning Seed Collection

The rehabilitation approach used at Chemfos was largely based on the re-introduction of vegetation by seeding of the rehabilitation sites with indigenous plants. After the initial 1996/7 phase when a variety of different sites were cleared and treated to gauge responses of the different treatments, a systematic approach was followed and the mine area was cleared from the east to the west. This resulted in a variety of different types of sites being treated throughout the rehabilitation period as discussed in Chapter 6. Seed collection priorities were thus informed by the alien vegetation clearing programme as the required appropriate seeds estimates were determined by the soil types and site conditions of areas to be rehabilitated.

Planning for seed collection and the monitoring of the seasonal phenological drift caused by subtle variations in rainfall and temperature patterns formed an important part of the daily management of the project. The formal record-keeping of these events became complex and tedious and was abandoned due to time constraints.

The relevance of a detailed record of this nature on this small scale is doubtful since it cannot, in our estimation, be used in useful predictions on most post-mining rehabilitation projects that are short-lived. It would, however, be possible to collect data correlating rainfall data including timing and amounts and seed set of some species such as *Ehrharta villosa*, *Dimorphotheca pluvialis* since there is anecdotal evidence of this correlation. This level of detail prediction of potential seed yield is also compromised by other events such as insect outbreaks, grazing or climatic events such as berg winds or rainfall events that can dramatically reduce the actual collection of seeds by causing pre-mature seed fall.

Daily monitoring and opportunistic collection is important in ensuring the collection of adequate quantities of a variety of suitable seeds for the purpose of rehabilitation.

Seed collection targets guided the collections. The targets were based on calculations of the amount of seed required to rehabilitate the areas programmed for clearing and preparation prior to seeding time in May of that year. The final allocations of the collected seeds were, however, only done once all the seeds for the year were processed and packed. The allocations were done based on the interpretation of the areas to be restored considering the soil types and physical characteristic of the particular sites.

Emphasis was on collecting seeds that would be effective in establishing initial cover that would persist, thus creating an environment into which more long-lived and woody species could develop as they were generally not successfully introduced into barren environments such as poor subsoils. The introduction of climax species such as *Euphorbia burchellii*, *Chrysanthemoides incana* and *Salvia lanceolata* through inter-planting the areas with nursery grown plants proved a more cost-effective way of introducing diversity into the restored areas when compared to the cost of their seed collection coupled with the low levels of establishment of mature plants through the means of seeding. This was probably due to the high number of seeds that were collected by termites and eaten by birds and rodents as well as the unfavourable conditions for germination during the initial seeding phase.

7.6.2 Allocation of Collected Seeds to Seeding Areas

Since the soils at Chemfos were greatly cross-zoned and mixed, the initial thinking was to use all the seeds evenly mixed across the rehabilitation areas. The classification of the soils and topography (Figure 7.4), however, revealed significant differences to instigate the selective application of seeds to specific areas of likely success (Appendix A).

Generalist species such as the pioneer *Oncosiphon suffruticosum* and the semi-woody *Amellus tenuifolius* were used in all the seed mixtures as they germinated readily and have a tolerance for most of the soil conditions found on site.

The use of *Ehrharta villosa* was restricted to the mobile sands where the contribution of this species was significant in stabilizing the areas.

Euryops linifolius was used in areas 2, 8 and 9 where the presence of calcareous material suggested that the species should do well. It was also included in the entrance road mix as this area contained mixed material.

Juncus kraussii was not used in the year of collection as none of the areas suitable to the species was rehabilitated in that season. *Nylandtia scoparia* and *Nylandtia spinosa* were collected, but germinated in the nursery only, since these seeds do not germinate when fresh or without the aid of being passed through the digestive system of a tortoise.

7.7 DISCUSSION

The emphasis on seed collection as a primary means of introducing suitable vegetation to ensure the development of a vegetative regime is largely due to the lack of fresh topsoil to be used for the purpose of introducing propagules.

The post-mining surface area consisted of primarily cross-zoned soils of mixed origin, exposed in-situ subsoil, processed sand and accumulated hard pan and calcrete. Some pockets of the natural aeolian sands still occurred in areas outside of the mine path. This complex modified environment was largely devoid of desirable vegetation for several years, resulting in a very low seed presence in the areas to be rehabilitated.

Since the objective of the rehabilitation of the mine was to establish a functional environment that could be managed as a Fossil Park, the use of commercial seeds was not seen as an option. Collecting local seed was the only option. Seed collectors such as NBI at Kirstenbosch have vast experience in collecting seeds of very desirable plants. The Veld reserve at Worcester has been propagating seed and has developed techniques for processing veld harvested seeds and this information provided the required insight in developing an approach that would suit the Chemfos seed collection approach.

Challenges relating to efficient seed collection included the time lag between collection date (i.e. optimal ripeness of seed) and the accurate determination of viability, and quantity of actual seed collected. Projections based on previous season ratios between seed collected and seed yield are used, but this may vary dramatically due to variation in seasonal growth, skill of seed collectors, etc.

Relative skill is required to collect seed. Not all seed collectors are equal. In the example below, the statistics are drawn from a select group of seed collectors. They are all female as

the men could not collect enough seed in a day to cover their standard wages. In contrast women earned 30% to 100% more than a basic wage for a day's work.

On a given day in a 5-person team, the most efficient collector would harvest 4.03 kilograms of *Lessertsia frutescens* within three hours and from the same area, the least effective collector could only harvest 1.69 kilograms. This represents an efficiency of 42% when compared to the better collectors. For this reason, it is recommended to pay staff for actual materials collected and not on an hourly rate. The variation in performance occurs regardless of species. The greatest difference in productivity by the collectors is found in easily collected material i.e. *Metalasia muricata*. The worst seed collector is 13% as effective as best performer.

In order to provide seed to rehabilitate one hectare of disused mine on the West Coast, allowance should be made to collect 15 kg of clean seed equivalent at R188.19 per kilogram excluding VAT. This amounts to R2822.81 per ha based on seed collected in 2007/8 for the 2008 sowing season. The cost of seed alone to rehabilitate land represents 40% of the purchase price of land in 2008. The rise in the cost of agricultural land has been steeper than the rise in the cost of seed collection and rehabilitation. In 1997 the average price per ha of farm land for a farm of 650 ha was in the order of R750/ha. In 2003 Anyskop, the adjacent farm was sold for R1642.86/ha. In 2008 Anyskop was sold subsequent to the re-zoning of the area as an industrial corridor for R7142.86/ha (V. Allen, pers. comm.).

By increasing collection and processing efficiencies, utilizing only seed appropriate to the soil types and specific area, the cost of introducing stable appropriate local vegetation was reduced to the minimum. This and the increasing cost of land brought two irreconcilable aspects, those being the cost of the land and the cost of rehabilitation, closer together than before.

CHAPTER 8. EFFECT OF SMOKE ON SEED GERMINATION AND THE DEVELOPMENT OF FIREGROW

This chapter shows how plant-derived smoke can be used as a germination trigger in the restoration of fynbos vegetation. This was achieved by the development of a technique for producing “liquid smoke”. The product was named “ FireGrow”. Experimental studies were used to assess the efficiency of this product compared with other smoke treatment. FireGrow is now being produced commercially.

8.1 INTRODUCTION

Plants of the Cape Floristic Kingdom number in excess of 8 500 species, and cover less than 90 000 km² (Meadows and Sugden, (1993)). Many of these plant species are found predominantly in the diverse types of fynbos vegetation found in the Cape Region. The influence of changing fire regimes is poorly understood, but it has been established that fires have been associated with fynbos since the Miocene and would have played a significant role in the evolution of the diversity of species and the variety of vegetation types of the fynbos (Deacon *et al*, 1992). Natural selection of taxa that have resistance to fire began during the Miocene epoch with the loss of the wet forests due to climate change and the relationship developed further during the Pliocene epoch (Le Maite and Midgley, 1992). This contributed to the diversity and complexity of the fynbos ecology as the nutrients status of the soil, climate and fire acted as selective factors during the development of the vegetation type (Le Maite and Midgley, 1992).

Plants in the fynbos biome have adapted flowering, seeding and seed dispersal patterns that are fire-dependent. Seed germination of hard seeds has long been known to be stimulated by burning. The direct result of charring is fracturing of hard seed coats, allowing moisture uptake leading (amongst other factors), to germination. The stimulating effect on germination of some species by smoke was discovered by De Lange and Boucher in 1990 and subsequent research has lead to a greater understanding of the response of specific species to chemical components in cold smoke and smoke concentrated in water.

The possible effect of smoke on nut-fruited Restionaceae and other species of climax vegetation is particularly important, as these species do not readily germinate in the nursery or laboratory and only occasionally in nature, usually subsequent to fire. These low germination rates are despite high seed viabilities ranging from 67% to 100% viability in

Cannomois virgata and 83% to 100% in *Wildenowia incurvata* (Newton, Bond & Farrant 2001). This would suggest that fire and smoke are amongst the cues for germination of these species of Restionaceae.

The Western Cape is developing rapidly. Great pressure is placed increasingly on natural environments due to man's increasing need for recreation, agriculture and living space. The combined effect of these impacts is that most veld types have become critically rare. In the case of Renosterveld, less than 10% of the veld type still exists (Winter 2002). Continuing development will reduce this figure further in future and it has become extremely important to minimize the impact of development.

Environmental management plans for development projects in sensitive areas have to make provision for restoration of impacted areas in order to be approved by the Cape Nature Conservation Board. These management plans often prescribe environmental restoration of areas such as road reserves and open spaces. The success or failure of the attempts greatly depends on the ingenuity of the contractor involved in the rehabilitation, as no industrial standards exist for the process of restoration or rehabilitation of the vegetation. Recreating species diversity in the fynbos biome by vegetation restoration is a complex process. Seed germination of fire-climax species is uncertain and the absence of these critical fynbos species from the restored lands indicates an incomplete restoration.

The development of a protocol for the effective treatment of large quantities of seed with smoke would lead to an increase in germination of climax and other smoke-stimulated seeds during environmental restoration. The accurate dosing of seed would lead to considerable savings as the efficiency of germination would be increased allowing for a saving in both seed and labour.

8.2 RESEARCH PROBLEM

Subsequently to the discovery that seed of a large number of plant species of the fynbos biome is stimulated to germinate by exposure to plant-derived smoke, attempts have been made to transfer the knowledge from the laboratory to the field of vegetation restoration. These attempts deliver erratic results and no industry standard exists. New research relating to the mechanisms of absorption may show why current techniques employed in exposing seed to smoke in the commercial rehabilitation field are inadequate.

Stimulation of seed germination using plant-derived smoke has been demonstrated under controlled conditions (de Lange & Boucher, 1996). Current adaptations of this principle to commercial rehabilitation are expensive, cumbersome and offer fluctuating results.

How can plant-derived smoke be used to stimulate seed germination of susceptible species during commercial vegetative rehabilitation of areas in the fynbos biome in a controlled, predictable and practical way?

This study will determine:

- The most efficient and cost-effective methods of stimulating germination of susceptible seeds by means of exposure to smoke during vegetative rehabilitation on a commercial scale.
- The most effective form and concentration of smoke water will be determined from a literature study.
- The most effective method of exposing seed to smoke water will be determined from a literature study.

Techniques used in the laboratory will be adapted and evaluated under nursery conditions on a variety of susceptible seeds to prove efficacy of the process. Field trials will be designed to test the adaptation of these laboratory techniques to in-situ sowing on a large scale. Methods of smoke treatment that will provide a guide to the Industry for the use of plant-derived smoke in commercial rehabilitation will be investigated.

8.3 A LABORATORY EVALUATION OF THE SMOKE TREATMENTS AND THE DEVELOPMENT OF FIREGROW

8.3.1 Introduction

Smoke can be used to stimulate fynbos seed germination (De Lange and Boucher, 1990) and standardizing the methods used in the industry will improve the success rate and provide a measurable benchmark for smoke trigger application. The development of efficient and cost-effective means of using plant-derived smoke to stimulate maximum germination of seeds of a greater variety of fynbos species will increase the viability of restoration and assist in demystifying the process. That is the general aim of this chapter.

The objective of this study is to evaluate available literature to determine the best practices used in the laboratory to expose susceptible seeds to smoke and achieve optimal germination. It will also evaluate the cost-effectiveness of these approaches. An important

aspect of this study is to develop an alternative to smoke water and test this product against the conventional techniques. An additional aim of this study is, therefore, to compare differently derived smoke solutions and their concentrations in laboratory seed-germination tests to determine the optimal concentration for use of each of these different products.

8.3.2 Methods

The products of two methods of preparing smoke water were evaluated.

8.3.2.1 Bubbled solutions

The standard used in the study (De Lange Standard) is a bubbled aqueous smoke solution. Another bubbled solution from the King's Park and Botanical Garden in West Perth, Australia was tested. This smoke solution was made according to the same method of production that was used by De Lange & Boucher (1990). Since the benefit of using smoke water has clearly been established and used in projects such as the rehabilitation of Du Toits Kloof Pass road reserves, it was decided to use smoke-derived germination cue where possible and appropriate at Chemfos. In order to enhance the germination potential of the seed, substantial quantities of bubbled smoke water was required. Obtaining the product was problematic since the production of the bubbled water was very slow. Smoke had to be generated by burning material and the smoke was then ducted and blown into a 25-litre container, where it bubbled through the water. This bubbling lasted approximately 30 minutes, thus yielding 450 litres a day under optimal conditions. Furthermore, the product was not available in an off-the-shelf format due to the cumbersome production methods and the limited and erratic demand for such a product at the time. This, as well as the cost of transporting the bulky product from Cape Town, led to local experiments with the manufacture of the bubbled water or finding alternative smoke treatments.

8.3.2.2 Distilled aqueous smoke solutions

Initial attempts were made to dry-smoke the seeds (Figure 8.1). We collected a supply of local thicket and restios, such as *Willdenowia incurvata*, which was abundantly available as material for combustion. Partially processed seeds were placed on shelves in a small store and the combustion able material was burned in the confined space. Problems associated with the uncontrolled temperatures of the open fires as well as the question of effectiveness led to the further development of an apparatus that could produce the bubbled smoke water.



Figure 8.1: Initial attempt to dry-smoke seeds.

It was found that the main limiting factor of the production of smoke water was the small volume of ducted smoke that could be captured and blown from the source of the combusting vegetation to the water. The pressure that was required to push the smoke through the water had to be balanced with the pressure in the combustion area.

In order to overcome the limitation, the process was reversed and a suction pump was used to create a negative pressure that could draw the smoke through the water from an enclosed combustion chamber with controllable air flow (Figure 8.2).

It was also found that setting light to the restios and other combustion able material was not an easy task, so a butane burner was added at the bottom of the combustion area. The induction heat facilitated rapid combustion, but the large volumes and higher temperature smoke yield was more smoke than could be absorbed by the water at the rate of smoke being drawn off. In attempting to increase the amount of smoke absorbed by the water, a coiled copper tube was added as a pre-cooler. Since free smoke was still noticeable after

passing through the water, the coil was then cooled by placing it in a water bath, thereby further reducing the temperature of the smoke. It was found that a liquid emerged from the copper pipe; essentially the moisture contained in the plant material that evaporated during combustion, and the moist smoke then condensed effectively in the cooled copper tube, resulting in what would later be called FireGrow or Distillate1 in the study to compare the results of bubbled smoke water and the distilled product (Meets and Boucher, 2001). The smoke distillate was captured in a steel vessel with a drain plug at the base, an inlet near the bottom and an outlet near the top. The smoke was sucked through this vessel by the vacuum pump. The product was extracted by draining the vessel once half full.

Distillate 2 was later derived from a secondary closed vessel that was introduced just before the vacuum pump in order to protect the mechanism from the oily build-up that occurred. The vessel was drained at the end of each day.



Figure 8.2: Apparatus designed to manufacture Firegrow, a smoke-derived, seed-germinating stimulant.

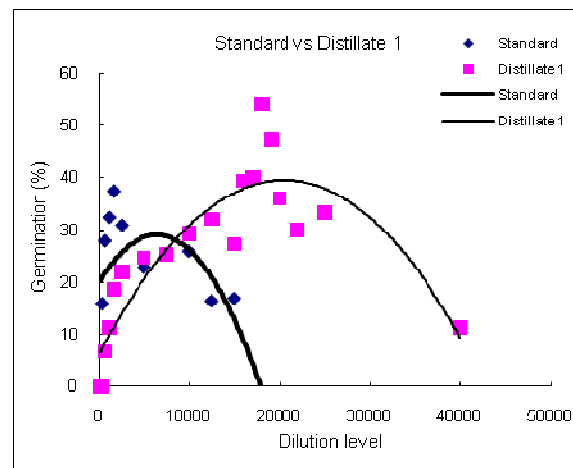
A single restio species, *Willdenowia incurvata* was used as the combustible material to produce two distillate solutions. Both preparations were distilled for the same duration. No

filter was used in the preparation of Distillate 1, but Distillate 2 was filtered and most of the undisclosed impurities were removed.

In another study, Meets and Boucher (2001) used Grand Rapids lettuce seed due to the rapid response and sensitivity of these seeds to the smoke cue and as the response of the lettuce seed could then be translated to a bioassay for fynbos. The seeds were exposed in innovative germination boxes to a continued supply of smoke water at a variety of concentrations of the different products and the results were tabulated. The trials were replicated and fifteen seeds per replicate were used per smoke preparation, as well as for a distilled water control. Germination was assessed after a period of 24 hours. Seeds were considered to have germinated once the radical and the seed length were equal, thus accounting for size variance in the seeds.

8.3.3 Results

The results of the germination studies (Meets and Boucher, 2001) were tabulated in graphs to show the response of the seed germination against the concentration of the distillate used (Figures 8.3 and 8.4). It will be noted as had been previously found that the increasing concentrations of the smoke treatment resulted in an increase in germination up to an optimum and then the treatment caused the inhibition of germination quite drastically. Figure 8.3 shows the response of the Distillate 1 against the De Lange Standard and Figure 8.4 compares the performance of lettuce seed germination for Distillate 2 against the Standard. The solid lines are trend lines fitted to these results showing the point where germination peaks and then drops off as the concentration is increased..



The solid lines are trend lines.

Figure 8.3: The germination stimulation achieved by Distillate 1 in comparison to the De Lange Standard (from Meets and Boucher, 2001).

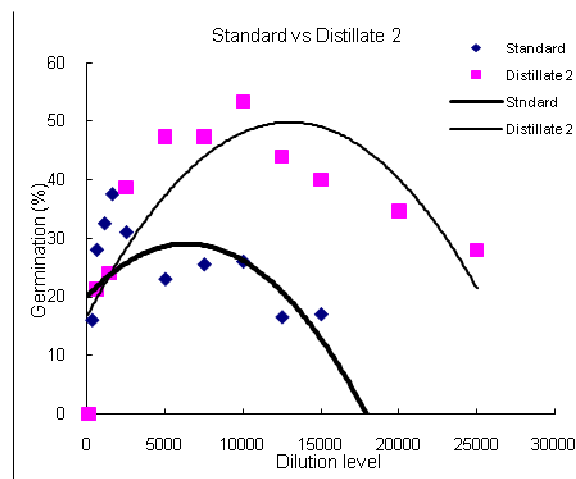
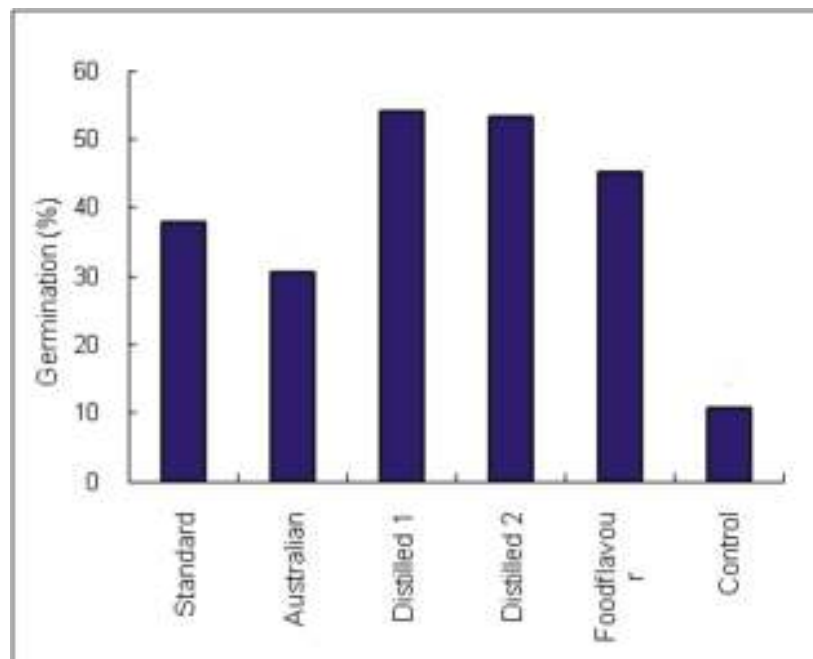


Figure 8.4: The germination stimulation achieved by Distillate 2 in comparison to the De Lange Standard (from Meets and Boucher, 2001).

Figure 8.5 compares the final maximum germination of lettuce seed with the various smoke treatments. It will be noted that:

- The control sample germination percentage was between 10% and 11.33%. The controls were exposed to distilled water and not to smoke water.
- The De Lange Standard yielded its best results (37% germination) at a dilution ratio of 1:1150 v/v
- The Australian bubbled smoke yielded its best results (30.67%) at 1:1300 v/v
- Distillate 1 yielded its best results (54% germination) at 1:18 000 v/v

- Distillate 2 (filtered) yielded 53.33 % germination at 1:10 000 v/v, indicating a loss of some active ingredients due to filtering.
- Smoke food flavourant yielded 45.33% germination at 1:80 000 v/v.
 - The maximum percentage germination for every product was achieved at dilutions unique to the products.



See text for more details on the various concentrations of the products.

Figure 8.5: The maximum percentage germination stimulation achieved per product as well as for the control (from Meets and Boucher, 2001)

8.3.4 Conclusion relating to commercial application

The unfiltered distillate is the best product to use for further evaluation, as it offers the best increase in seed germination of all the products evaluated.

8.3.5 Research into the dosages of smoke water and length of exposure

An Additional Question was raised:

Prolonged exposure of seed to low dosages of smoke water is impractical in vegetative rehabilitation. Can shorter durations of exposure to higher concentrations be substituted?

A literature review of an article reporting on the study of “Dual Regulation of Seed Germination by Smoke Solutions” (Light *et al*, 2002) indicated an alternative approach of exposing seed to smoke water. They reasoned that germination stimulation of Grand Rapids lettuce seeds by smoke water is influenced by the duration of the exposure of the seeds to the smoke, the concentration of the smoke water, the hydrated state of the seeds prior to exposure and the storage of the seeds after exposure.

To gain insight into the responses of the seed to smoke water under a range of controlled conditions they:

- Evaluated the effect of smoke water on dry seed and seed in various states of imbibition
- Determined the optimum duration of exposure
- Determined the effect of higher concentrations of smoke water on seed germination
- Evaluated the effect of storage on treated seed.

8.3.5.1 Methods and Results

They used Grand Rapids lettuce seeds, distilled water, smoke extract, in darkroom incubation at 25 °C in a series of trials and found that:

- Dry seed exposed to smoke shows a greater increase in germination
- Seeds exposed to 1:1000 smoke water responds best to longer exposures (6 to 24 h)
- Seeds exposed to 1:100 smoke water solutions respond better to short exposure (15 minutes to 1 h)
- Storage of treated seeds does not affect stimulation.

8.3.5.2 Conclusions from this study

From this study one could conclude that:

- The best product to use during evaluation of adaptations of the laboratory techniques of exposing seed to smoke is the unfiltered distilled preparation, i.e. FireGrow
- The most practical treatment of seed is by exposing dry seed for a short period to a high concentration of smoke water.

8.3.5.3 Shortcomings of this study

No reference to cost was given in any of these articles. Only Grand Rapid lettuce seeds were used during the evaluations.

8.4 COMMERCIAL AVAILABILITY OF SMOKE PREPARATIONS

In a telephonic survey conducted, known local academic and commercial sources of smoke preparations were contacted to determine availability, nature and price of preparations. The results are tabulated below (Table 8.1).

Table 8.1: Commercial availability of smoke preparations.

Institution	Do they have Bubbled smoke water	Do they sell Bubbled smoke water	Price per liter	Do they have Distilled Smoke	Do they sell Distilled Smoke	Price per liter
University of Stellenbosch Botany Department	yes	no		yes	no	
Agricultural Research Council Elsenburg	yes	no		yes	diluted	20.00
Kirstenbosch Botanical Gardens	yes	diluted	36.00	no	no	
University of Natal, Botany Department	yes	no		no	no	
Stark Ayers Wholesale suppliers	no	no		no	no	
Cape Nursery Supplies	no	no		no	no	
Habitat restoration Projects	yes	yes	12.00	no	no	
Vula Environmental Services	yes	no		yes	concentrate	450.00

8.4.1 Cost comparison

A direct comparison of prices is not possible since the products vary in concentration.

To get an indication of cost-effectiveness, the available product costs were evaluated at the best rate of application. (Price survey: March 2005).

Table 8.2: Cost comparison based on best rate of application.

Product	Price as sold	Liters of ready to use product	Cost per liter ready to use
Vula FireGrow Concentrate	450.00	1250.00	0.36
Elsenburg FireGrow	20.00	10.00	2.00
Habitat Smoke water	12.00	1.00	12.00
Kirstenbosch Smoke cue	18.00	1.00	18.00
			32.36
		Average Price/ liter	8.09

The FireGrow concentrate is the most cost-effective product to evaluate as the price of R0,36 of prepared product is a fraction of the cost of the other products

8.5 ADAPTATION OF THE METHODS TO REHABILITATION TECHNIQUES

8.5.1 Introduction

The objective of this study was to adapt the best laboratory practice for use under nursery conditions and evaluate the success on a variety of susceptible seeds.

The laboratory techniques provided proof of the effectiveness of the use of FireGrow in stimulating germination of susceptible seeds. For this evaluation, the FireGrow concentrate was used at a dilution rate of 1:100 in distilled water. Seeds of known fire-climax plants were used in this evaluation, as all the laboratory work was done on Grand Rapid lettuce seeds.

The selection of plant species for evaluation in the nursery trial was based on seed of four desirable plants generally used in rehabilitation. The first two species were selected because of their desirability and notorious difficulty in propagation. This represents a pilot study to be expanded during further evaluation of a wider range of species for the use in rehabilitation. Seeds for evaluation were selected from various categories.

Table 8.3: Selection of plant species for evaluation in the nursery trial.

Plant name	Fire climax re-seeder	Grown before
Nylandtia scoparia	yes	no
Willdenowia incurvata	yes	no
Thamnocortus specigerus	yes	yes
Leonotis leonuris	no	yes
Lycium ferocissimum	no	yes
Athanasia trifurcata	no	yes

8.5.2 Methodology

For the trial, seed of each species were separated from chaff. 1 200 healthy-looking seeds were selected per species. Non-viable seeds were discarded.

600 seeds per species were soaked at room temperature in a 1:100 dilution of FireGrow and the control of 600 seeds were soaked in water. Both batches were soaked for one hour and then sown in standard Eco Grow nursery mix in 200 cavity trays and placed in a growing tunnel for germination.

Previous attempts to grow *Nylandtia scoparia* in trays failed as tap-root development is rapid and sensitive to transplanting. For the trial, only 225 seeds were treated and 225 untreated and sown in individual pots. The results were recorded 120 days after sowing the seeds.

8.5.3 Results

Table 8.4: Germination results following the nursery trial 120 days after sowing.

Plant name	Fire Grow	Control
	% Germination	% Germination
Nylandtia scoparia	28	2
Willdenowia incurvata	0	0
Thamnocortus specigerus	85	15
Leonotis leonuris	97	92
Lycium ferocissimum	98	95
Athanasia trifurcata	92	83

The results indicate a marked increase in the germination of the trials in comparison to the control in two of the species. There is a marginal increase in percentage germination of three more species, notably non-fire-dependent species. It was interesting to note that although the overall percentage germination of the test seed did not vary much in the end, there was a marked increase in initial seed response and growth. The possible implications of this will be the subject for further study. One species, *Willdenowia incurvata*, failed to germinate at all. This plant is notoriously difficult to germinate and there are probably other factors playing a part in the germination response of this seed (Newton, Bond and Farrant, 2001).

8.5.4 Conclusion

The exposure of seed to smoke water at the given rates and durations is beneficial for the germination of most seeds tested. It has no negative influence on germination in relation to the controls. Some seeds may require other cues for germination.

8.6 AN ANALYSIS OF SMOKE TREATMENTS IN FIELD TRIALS

8.6.1 Introduction

During rehabilitation, the processes to expose seeds to the stimulating smoke entails applying smoke water to the content of a hydroseeder mixture containing the seed. This process utilizes 20 m³ water per hectare and requires 200 litres of smoke water or 20 litres of “FireGrow” smoke concentrate to prime the seeds effectively. The result in germination increase due to the addition of the smoke water has not been studied in field trials and the recommendations for use are based purely on laboratory work. The lack of evidence of any effective stimulation of seed germination on a commercial scale often exclude the methodology from use on commercial projects, resulting in low levels of plant diversity. Research done on the effect of smoke on seeds that were pretreated with water, could

explain why seeds hydrated in the hydroseeder tank could, under certain conditions, not benefit from the presence of the smoke cue (Light *et al.* 2001).

In a review of current practices relating to the use of smoke water for commercial use (see Para 8.3 above), it was found that many different documents exist prescribing products and methods of application. None of these documents were accepted throughout the horticultural industry as a standard as the industry as a whole is not coordinated. In addition, a literature search revealed no journal article that attempted to provide a standard for the use of smoke water in commercial rehabilitation projects.

Through past experience, it is known to us (Vula Environmental Services) that the specifications for cultivation of indigenous species are normally drawn up by landscape architects or engineers, at times with the aid of horticulturists or botanists. They generally follow the SA Roads Agency format of specifications. The Section 5800 specification of the SA Roads Agency for hydroseeding calls for the addition of seed to water already containing mulch (milled straw, cellulose or compost) fertilizers and smoke water. The concentration of the smoke water called for is not prescribed, though reference to specific suppliers and generally the quantity of smoke water is not stipulated. The duration of the exposure of the seeds to the smoke water is also not prescribed.

Consequently, the objective of this study was to conduct field trials to determine the success of the best practice under uncontrolled conditions on the use of smoke additives in rehabilitation using indigenous species.

8.6.2 Methodology

8.6.2.1 Site description

The field trials will be conducted at the Chemfos mine, Langebaanweg and the West Coast Shopping Village, Sunningdale. The terrain is an artificial berm made out of uniform subsoil with compost added. The berm has a north–south orientation resulting in three distinct areas, namely, an east-facing slope, a level top section and a west-facing slope. The sites will determine the layout of the sample plots used, as it is anticipated that the three different areas will yield different results. The area is irrigated and for the trial, hydroseeding of a broad seed mixture will be used. To ensure that only seed introduced by hydroseeding is recorded in the trial, the area was allowed to regrow naturally after soil preparation. The entire area was then sprayed with Roundup two months after tilling, killing all seedlings present. Light soil preparation to prepare a seedbed was done prior to hydroseeding.



Figure 8.6: Site: Berm at Sunningdale showing effect of herbicide application.

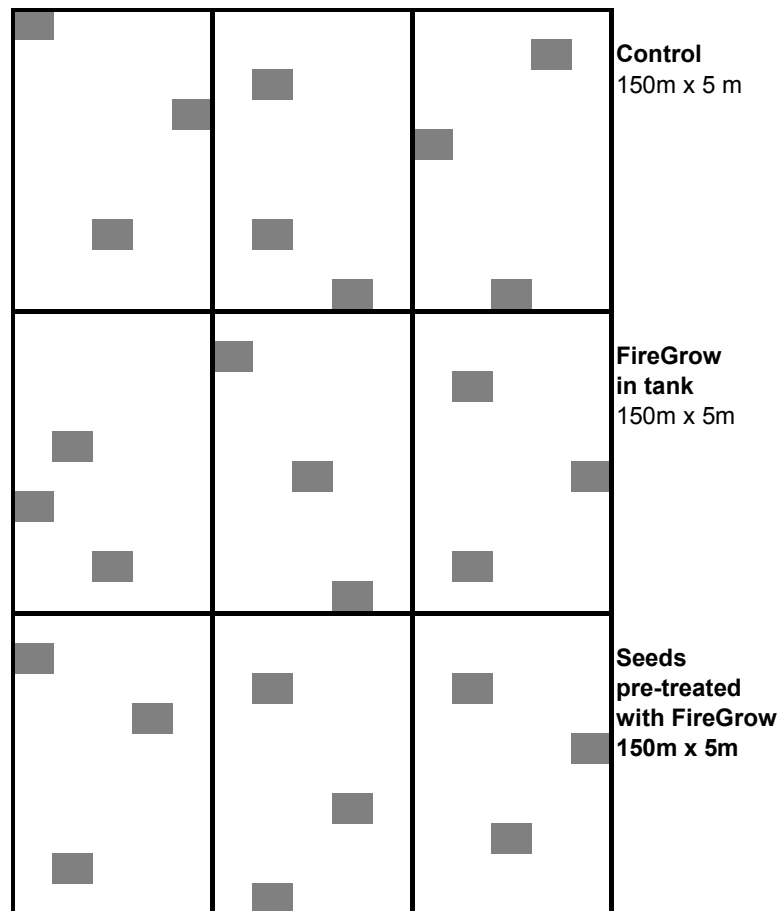
8.6.2.2 Trial layout

Three treatments were to be evaluated:

- Control application of hydroseeding without FireGrow.
- Conventional FireGrow application by adding FireGrow to the tank at 1:1250 v/v prior to adding the seed.
- Exposing all the seed to a 1:100 FireGrow solution for 1 hour prior to adding the seed to the hydroseeder.

All three treatments were applied from east to west across the berm using washed equipment.

The site was divided into the three main areas: east, central and west (Figure 8.7). Each of the main areas was subdivided into 1 000 mm x 1 000 mm grids. The total length of the berm is 450 m and this was divided into three areas of 150 m each. Each treatment thus consists of 150 blocks measuring 1 m x 1 m. A permanent sample block was established randomly in each treatment area on all three orientations. Each treatment was replicated 3 times.



NOTE: West site on the left, Central in the middle and East on the right. The randomly allocated sample plots are shaded.

Figure 8.7: Diagrammatic Layout of Site Showing Treatments and Proposed Fixed-point Sample Areas (Not to Scale).

8.6.2.3 Monitoring

The seed germination in each of the plots was to be monitored once a week for eight weeks and the results will be plotted (see Appendix B for data sheets for the evaluation of the results).

8.6.2.4 Cost of seed

Seed selection is based on current available seed suitable to the site from commercial supply (see Appendix C for costs of the seed).

8.6.2.5 Evaluation of the results

The following was envisaged at the design of the trials:

- Based on the weekly surveys of the fixed sample plots, all the germinating species would be recorded on the data sheets. Only presence would be recorded and no score would be given if the species is not represented.
- A summary sheet would be generated indicating the total germination per species achieved.
- The collected data at weekly intervals would be plotted to indicate any trends in germination comparing the control to the other two trials during the progressive period.
- The final cost per plant species per m² per treatment would be plotted and the results evaluated for significance.
- The cost per seedling germinated would be calculated for each species per replicate by dividing the total cost per species per m² by the number of seedlings present.
- The relationship, if any, between the number of seedlings and the use of the FireGrow will be established and evaluated.
- A report based on the outcome of the findings would be presented at a one-day workshop to engineers, consultants and contractors active in the field of rehabilitation in the Western Cape.

8.6.3 Results

Due to delays in the civil contract, the planned seeding could not be undertaken as scheduled during June 2003. The actual seeding took place during the third week of October 2003.

The late seeding resulted in the discontinuation of the formal trials since the majority of the species are winter growing. The dependence on irrigation for watering further limited the potential results. The trial was discontinued and an alternative site was sought to rerun the experiment.

8.6.4 Discussion

8.6.4.1 Limitations of this study

The last part of the study depended on the use of a commercial site where the time frame was not controlled by us, but by the developer who had different priorities. This resulted in the optimum season for germination being missed and this may compromise results.

The trial was redone in 2003 at Chemfos in management area no 1 (Table 8.5). The area was covered in *Cynodon dactylon* at the time, the top 100 mm was removed and the area

was reshaped and hydroseeded. The trial blocks measured 30 x 10 m each and were positioned side by side to form a seeded area of 30 m by 30 m. The trials were set out along an internal access road. The proposed monitoring for the Chemfos rerun of the trial was similar to the Sunningdale trials (see Appendix D, Figure D.8).

The entire trial failed as the areas were not fenced or protected. Large flocks of guinea fowl descended upon the trial area during May and removed virtually all the introduced seeds. The trials were not formally monitored since very little evidence of any germination of the seeded species could be found.

It is considered a priority to find a suitable site to conduct the trials again as no conclusive results have been obtained yet. The total exclusion of seed-feeding birds and small mammals that can feed on seedlings will be imperative. Furthermore, the sterilization of the soil is essential to ensure that no competition from undesirable species skew the results. Any approach formulated for industry implementation must be robust and flexible and must be able to withstand site and programme fluctuations. More research is required to evaluate a wider range of species susceptible to FireGrow in the nursery and in rehabilitation.

During November 2008 we commenced collecting seed as part of a Table Mountain Fund-supported field trial study to be conducted by Carly Cowell (SANBI) under supervision of Dr Pat Holms to evaluate Sand Fynbos sowing technique. Thanks to the funding received for fencing the site and the secluded nature of the proposed trial site situated in the Blaauwberg conservation area, it is hoped that more concrete results might be obtained where our previous studies failed to yield results.

Table 8.5: The Chemfos field trial plan and species used for the seeding.

Chemfos FireGrow trials 2005			Tank 1	Tank 2	Tank 3	Tank 4
		Quant				
Tank 1	NO FireGrow		No FG			
Tank 2	FireGrow @ 1:100, seeds soaked for 30 min prior to seeding			1:100		
Tank 3	FireGrow @ 1:1000, seeds soaked overnight				1:1000	
Tank 4	Add 12 Liters of FireGrow concentrate to tank prior to seeding (12 000 liters tank)	12				0.1% Drench
Seed Mix	<i>Paenocoma prolifera</i> (included as a marker since it responds to FireGrow)	0.07	0.0175	0.0175	0.0175	0.0175
	<i>Lessertia frutescens</i>	0.5	0.125	0.125	0.125	0.125
	<i>Ornithogalum thyrsoides</i>	0.4	0.1	0.1	0.1	0.1
	<i>Ornithogalum thyrsoides</i> (small)	0.2	0.05	0.05	0.05	0.05
	<i>Muraltia scoparia</i>	4	1	1	1	1
	<i>Chondropetalium tectorum</i>	4	1	1	1	1
	<i>Thamnochortus spicigerus</i>	2	0.5	0.5	0.5	0.5
	<i>Protea repens</i>	1	0.25	0.25	0.25	0.25
	<i>Chaetoromus dregianus</i>	2	0.5	0.5	0.5	0.5
	<i>Ehrharta calycine</i>	2	0.5	0.5	0.5	0.5
	<i>Oncosiphon suffruticosum</i>	1	0.25	0.25	0.25	0.25
	<i>Oncosiphon grandiflora</i>	1	0.25	0.25	0.25	0.25
	<i>Eriocephalus africanus</i>	4	1	1	1	1
	<i>Metalasia muricata</i>	4	1	1	1	1
	<i>Chrysanthemoides incana</i>	4	1	1	1	1
	<i>Rhus gluta</i>	2	0.5	0.5	0.5	0.5
		32.17	8.0425	8.0425	8.0425	8.0425

8.6.5 Conclusions

Although no results were achieved in the study, it is deemed important to include this information as the planning of the study was sound and the anticipated results would have

been a valuable asset to planning for the rehabilitation of fynbos sites on the West Coast by the horticultural industry. In 2008 the editor of *Restoration Ecology* stated in an editorial entitled *Looking for the Silver Lining: Making the Most of Failure*: “How many restoration projects do not go as planned for one reason or another? How many ecological experiments do not provide the expected answers or do not deliver statistically significant results? I am willing to guess that for every successful restoration project and every published study with significant effects resulting from a restoration treatment, there is at least one project and one study that failed utterly.” In this editorial he calls for authors to submit papers on failed projects (Hobbs, 2008).

The following can be learned and concluded from this study:

- The failed attempts at implementing and concluding large-scale on-site experiments over a period of three years on two different sites highlight the complex nature of merging empirical research, site management, budgets and time-frames.
- The timing of restoration trials and all rehabilitation projects must be informed by the practitioners or horticulturalists undertaking the study, because the critical element of timing is often not understood by engineers and project managers. In this case, it resulted in the optimum season for germination being missed and no results obtained.
- In the second case at Chemfos, the entire trial failed as the area was not fenced or protected. Large flocks of guinea fowl descended upon the trial area and consumed all the introduced seeds. Thus one must consider all eventualities in the planning of such experiments.
- Implementing research of this nature may be best done as part of a larger rehabilitation or research project, as the isolated nature of these experiments and the rigorous controls required for implementation and monitoring of replicated trials are not easily reconciled with the priorities of a construction site.
- It is necessary to obtain results from this planned study and thus a new proposed trial site will be situated in the Blaauwberg Hill conservation area. It is hoped that more concrete results might be obtained where our studies failed to yield results.
- Prior to commencement of the rehabilitation of the Chemfos Mine, attempts were made to determine what the best practices for rehabilitation were in order to avoid reinventing the wheel and also to learn from previous mistakes. The outcome of these attempts is discussed in Chapter 3. In the case of the most appropriate example, the rehabilitation attempts along the Sishen-Saldanha railway line, no published information relating to the failures or successes of the project could be found. In the case of the failed Chemfos

smoke stimulation experiments, the case is documented and the lessons learned are shared with peers and incorporated in the design of new trials, such as the case of the Blaauwberg Hill study.

- Although the formal outcome of the trials is not available yet, the thinking behind the experimental design has influenced the practice in the industry. The method of soaking the dry seed in the FireGrow prior to hydroseeding is now commonplace, reducing the cost of the use of the smoke stimulation substantially.

CHAPTER 9. SOCIO-ECONOMIC ASPECTS OF MINE CLOSURE: A RENEWABLE “END” TO A NON-RENEWABLE “START”

This chapter shows how natural capital can be restored to the benefit of the community. This goal has been achieved, with the assistance of the stakeholders in this mine village community, by the implementation of restoration plans with the appropriate resources and sound management. (This chapter was published in a different format in Aronson *et al*, 2007 (Van Eeden *et al* 2007)).

9.1 INTRODUCTION

This chapter will describe the socio-economic environment and the development of the rehabilitation plan with the local mine workers in mind.

In adapting methodologies for restoring the degraded environment, some of the former mine employees received training in a variety of skills, completely unrelated to their previous positions on the mine. This has led to the restoration of the livelihoods of many households and the dignity of the people in this region of the West Coast. Thus, the rehabilitation of the mine site for closure purposes, and the establishment of a Fossil Park, provided a post-mining socio-economic benefit not usually associated with abandoned mine sites.

The existence of phosphate (P_2O_5) in the Langebaanweg area has been known since before 1927. AMCOR, the African Metals Corporations Ltd, was initially the owner of the mining operations. During the 1970s, AMCOR merged with SA Manganese to form SAMANCOR that continued operations.

Through a series of mergers and acquisitions, Billiton acquired the de-commissioned and partly rehabilitated mine as part of the liabilities when it bought the mother company Genkor. Subsequent to Billiton and BHP merging, the SAMANCOR Foundation continued funding the rehabilitation and the establishment of the West Coast Fossil Park.

The Saldanha region of the West Coast was developed during the 1970s when the strategic importance of the natural harbour at Saldanha was realized and the construction of an iron ore export jetty and linking railway line to the Northern Cape town of Sishen commenced. Prior to this development, the phosphate mine and fishing represented industrial development on the West Coast.

Mining staff were recruited locally and from further afield and were housed in single quarters and a village, with management staff residing mainly in the nearby town of Vredenburg. During 1993, there were a total of 164 permanent employees. (Calitz, 1993)

When the mining operations were finally halted late in 1993, the single quarters closed down and the migrant workers left, either to return to their areas of origin or in search of employment elsewhere. The West Coast locals that were not transferred to other mines, stayed on in the old mine village, unemployed and destitute in a post-harbour-construction boom.

Realizing the plight of the former mine staff and the severity of unemployment in the area, the SAMANCOR Safety, Health and Environmental Management who were responsible to seek closure of the old mine, insisted that as many as possible of the former mine employees be re-employed to assist with the rehabilitation.

9.2 THE DEVELOPMENT OF THE MINE WORKERS' ACCOMMODATION: THE GREEN VILLAGE

With re-employment came hope and Billiton, through the SAMANCOR Foundation, developed a model for the mine village to become an independent community with a good asset base that could prosper.

Socio-economic realignment of the mine village (Figure 9.1) was implemented at a cost of R2 487 000 to the mining company. Together with the cost of upgrading the houses, this included transfer of assets such as the houses, church, community hall and 50 hectares of land to a newly formed Village Management Company consisting of residents as well as representatives of the mining company and the Fossil Park. The mining company accessed State subsidies for partial upgrading of facilities, and contributed the balance of the upgrade and the consultation and management process required during the five-year process.



Figure 9.1: The Green Village was established as an independent township subsequent to upgrading of mine housing and the transfer of assets to the governing body.

9.3 COMMUNITY INVOLVEMENT IN REHABILITATION: CAPACITY BUILDING

9.3.1 Emerging Wood-selling Contractors Clear Alien Vegetation

The wood of alien Acacia trees that were introduced to stabilize the sandy areas on the mine was seen as a potential stock as it is used locally for firewood. Wood sellers were given free access to managed woodlots to exploit for their own gain by cutting down trees and selling wood. This activity supported fifteen families for two years. In total, 4 500 m³ of firewood were sold by three contractors to a value of R125 000 over a two-year period. If this practice could be sustained on 650 ha of land, the resulting flow from firewood would support five families indefinitely, at the cost of the natural vegetation, which would be replaced by the alien wood lots.

The removal of alien vegetation with a commercial value was followed by the removal of the economically non-viable aliens and the disposal of seed-bearing brush by burning. Continued follow-up treatment of germinating seedlings was required for a minimum of five years. The total cost of the alien eradication programme amounted to R4 000/ha or R2 600 000 for the project. The flow generated by the consumption of the stock represents 0.045% of the cost of eradicating the problem. This was due to the large percentage of young plants in the alien plant population.

9.3.2 Community Involvement in Vegetation Restoration

SAMANCOR required that the local community from the mine village be trained to perform the rehabilitation of the natural vegetation. The establishment of a local skills base in these horticultural techniques led to the ability to apply restoration techniques developed at Chemfos to other restoration projects in the vicinity (Lubke and van Eeden, 2001). This in turn expanded the potential of vegetation restoration in this arid region as an economically viable and self-sustaining enterprise. It has also resulted in primary and secondary activities (such as commercial plant propagation and landscaping) supporting as many as 120 people for the past two years (Figure 9.2).

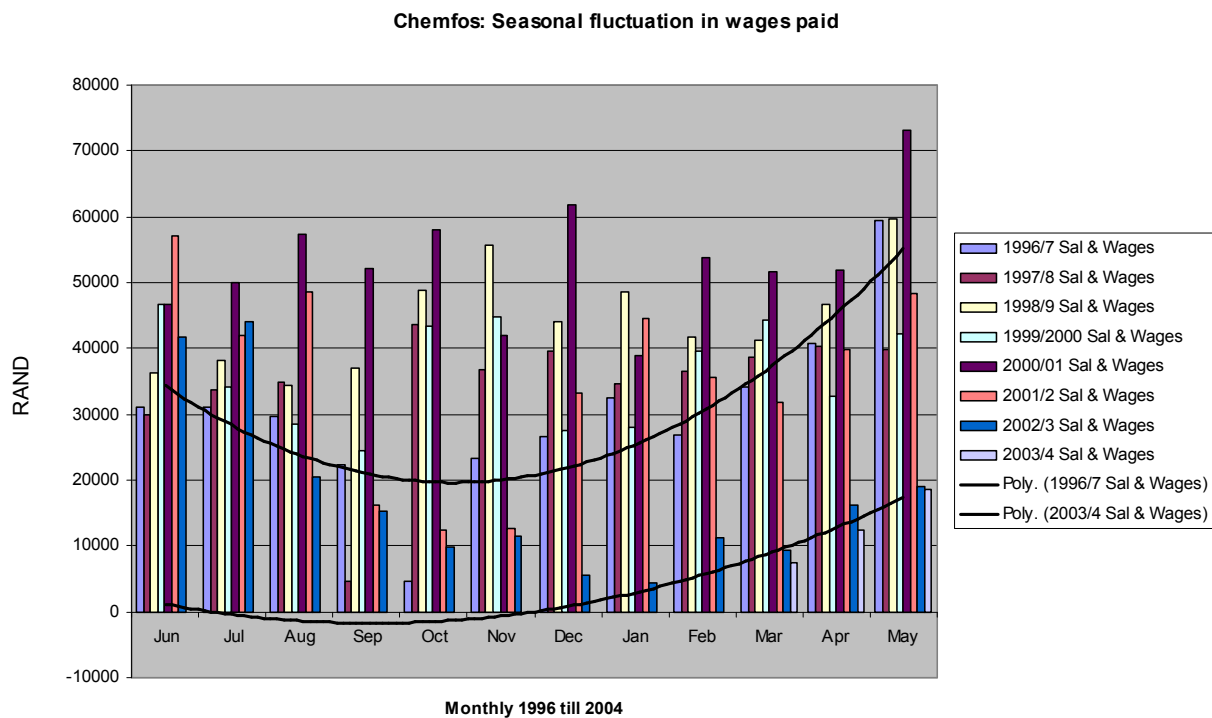


Figure 9.2: Seasonal trends in income flows from Chemfos and other projects.

9.3.3 Seasonality of Restoration Work: Threats to Disrupt the Flow

The seasonal nature of the restoration work under arid conditions results in a fluctuation in labour demand. This in turn leads to uncertainty in employment opportunities and this seasonal trend in manpower requirements for the Chemfos project is reflected in the monthly

salaries from 1996 until 2003/4. In autumn and winter, the monthly salaries were up to an average of R39 500 and in the summer season months only R19 000 (Figure 9.2).

Unstable income leads to hardship amongst workers and occasional loss of skilled and semi-skilled horticultural workers to other industries. In order to address this problem and to ensure a more consistent cash flow for the business undertaking the restoration work, other contract opportunities were sought to expand the income base of the workers, thus ensuring sustainability of the enterprise. It is important to retain the skills developed for the rehabilitation of the vegetation and thus a broad-based enterprise was developed, providing continued work throughout the year for all the permanent and most of the “seasonal” staff.

The sustainable uses of flows required for the restoration of plants on the mine site were first exploited. Seed collection and processing skills that were developed for the project provided work for more than 20 labourers. New regulations were obliging industries in this area to restore impacted land after construction, and thus an opportunity arose to supply seed by contract to these developments. The range of plants propagated for the project became increasingly popular for the use on other restoration projects and in industrial and domestic gardens. This is primarily due to the robust nature of these plants and their adaptability to low water requirements that make them a very valuable plant resource in this semi-arid environment. Approximately 300 000 plants are presently propagated annually for other contracts.

9.4 LIFE-SPAN OF THE PROJECT

9.4.1 General

Initially the project life-span was projected to be five years. This was based on the anticipated time it would take to clear all alien vegetation and introduce stable, self-sustaining vegetation to the site. Due to climatic constraints (below average rainfall for three years), a redevelopment of the original rehabilitation plan to a restoration plan, and the higher than anticipated maintenance requirement, the life-span of the project was extended. The ten-year plan included two more seasons to diversify vegetation by introduction of propagated geophytes and climax vegetation and two more years of maintenance providing continued control of alien vegetation. It is anticipated that at the end of year ten, the old mine could be managed as a conservation area, without risk of reverting to a degraded landscape and without specialized input.

9.4.2 Economic Life-span of a Restoration Project

It is unlikely that the restoration of the Chemfos mine would have been as successful if this project was the sole activity base for the team. The overhead and management cost of the business was in part covered by other projects that were solicited in the region, thus reducing this component cost to 50% in years four to six and to less than 15% in years seven to eight. The collection of seed of local plants was a valuable resource not easily obtainable in the region. Excess seed collected was sold to other projects and the money was added to the restoration budget. The contractor also paid rent for the use of the facilities as they were being used for other projects as well and the combined contribution of income from rent and sale of seed amounted to R198 000 between 1997 and 2002.

During the past 7 years, the amount invested in restoring vegetation at Chemfos has declined as the process ends. This influences the viability of the project as the initial agreement between client and contractor allowed for a cost plus 14% for overheads and profit and a limit on management cost. This is a very cost-effective arrangement, but has limited appeal for contractors who would generally be able to improve their company's earnings on projects elsewhere. The unique nature of the project and the contractor's commitment to success, however, lead to the exploration of other avenues of ensuring sustainability. Additional work was generated and this has increased the income and profitability for the company and has ensured the retention of the skills base for the project in the proximity of the mine.

It is vital to consider the financial viability of a restoration project for the duration of the process. Restoration costs must form a central part of the mine feasibility study. If restoration is undertaken during the active life-span of the mine, cost fluctuation and viability may not be problematic to the same extent, as is the case with post-mining restoration.

Viability of restoration as sustainable 'stand-alone' project reduces toward the end of the project life-span. Secondary projects are required to retain knowledge base and complete the original restoration.

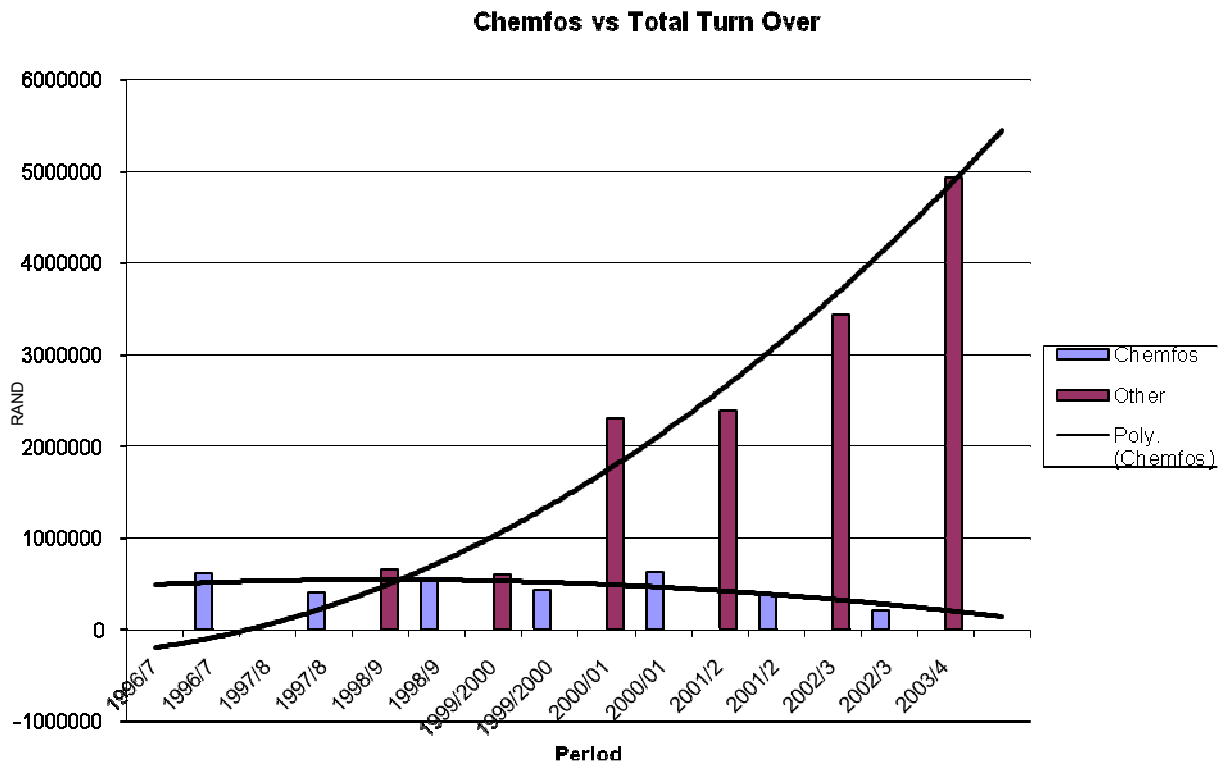


Figure 9.3: Economic Life-span of Chemfos Restoration Project.

9.5 COSTS AND BENEFITS OF RESTORING CHEMFOS

Cost of the restoration process of the mine was divided into the following:

- Decommissioning and demolition of mining infrastructure and the selective upgrading of retained infrastructure (R2 500 000 over a 2-year period).
- Environmental rehabilitation (R6 000 000 over a 10-year period). The average cost of all interventions, including alien vegetation control, amounts to less than R10 000/ha.
- The most cost-effective results were obtained from the restoration of the new slimes dam wall. The following actions were taken:
 - Alien vegetation (100% cover of trees taller than 2 m) were removed R4 750/ha) and the area was burned.
 - Dumped material intended for slimes dam wall core area was reprofiled and the area was ripped with a bulldozer (R3 000/ha).
- Hydroseeding at Chemfos was done at running cost only. The total cost for hydroseeding amounted to less than R3 000/ha. This is less than 50% of the standard commercial rate and it could only be achieved by cross-subsidising the activity.

The cost of the restoration process was not provided for during the active life-span of the mine. Costs were carried by the SAMANCOR Trust and later during the process of change of ownership, by the BHPBilliton development trust.

The primary beneficiaries of the different processes were the various contractors involved and the mine village inhabitants who were trained and employed during the various phases of the project (Figure 9.4). The long-term educational benefit to learners and scholars from a variety of disciplines will result along with the development of the Fossil Park. Tourism will continue to grow and in the long term will provide, through fees and donations, the support for the continued maintenance of the Fossil Park. Likewise, diversification of the restoration of the natural environment will be possible, whilst tourism, education and scientific training and research are intended as the main beneficiaries of the investment.

9.6 ESTABLISHMENT OF THE WEST COAST FOSSIL PARK

The Iziko Museums of Cape Town saw the opportunity for the establishment of a Fossil Park at the old mine as an opportunity to add “Public Paleontology” as an additional service to complement their traditional education and academic role. The well-collected curation housed in Cape Town (Hendey 1981b, 1982) is largely reserved for scientific purposes, with very few specimens on display. Establishing a new facility where the public has a rare opportunity to experience fossils on both display and in-situ at the fossil site, the unlocked sustainable non-consumptive flows from a previously unexploited stock.



Figure 9.4: Assistants in training for the Fossil Park, capitalising on sustained flows of the last layer of remaining capital.

Maximizing the potential flows that can be derived from the fossils, however, requires capital that cannot be generated by the project in the current format. The running cost of the park during 2003 was R839 600 and the earnings were R249 000. The resulting shortfall was funded mainly by the mining company (as part of the restoration process) and by other donors. To unlock the flows, a business plan has been developed that makes provision for new facilities that would be able to accommodate the increased numbers of tourists, students and educational parties. The enhanced visitor experience would prolong the duration of the visitor's stay and provide more opportunity to contribute to the flow.

Implementing the development plan would require an investment of R9 000 000 to be invested for a period of 6 years. The cumulative interest from this account in the South African market would yield the R3 730 860 required for the development of the facilities. Then after six years, the mining company could withdraw investment and the Fossil Park would be self-funding.

9.7 DISCUSSION

Restoration projects situated in remote areas can contribute greatly to the socio-economic wellbeing of local communities. The limited life-span of the restoration work may, however, result in hardship for those who remain behind if sustainable alternative activities are not sought. Though this not the primary concern of mining companies, the capital lost when people's expertise are not continued to be employed is as tragic a loss as that of the natural environment. Social decay leads to a negative impact on the surrounding natural areas through overexploitation of resources such as the natural vegetation and wildlife, through poaching and uncontrolled harvesting.

The restoration of natural capital at the old Chemfos mine may never be truly completed, as much of that capital has been consumed. The establishment and sustainable use of an alternative environment could, however, contribute greatly to mitigating the impact of prior degradation due to mining.

The de facto advantages of the restoration of natural capital are:

- The people living in the former mine village, now named Green Village, are benefiting by way of job creation opportunities connected with the Fossil Park (Figure 9.5). The Park now employs eight full-time staff from the Green Village.
- The environmental rehabilitation-based landscaping company that was established during the mine rehabilitation programme, continues renting the facilities utilized during the rehabilitation phase and continued utilizing staff from the Green Village, currently employing 8 full-time and several part-time personnel.
- It was fortunate that Top Turf, the company that was awarded the initial contract, decided to restructure the Cape Town-based operations and that mine rehabilitation was not seen as a lucrative component. This led to the development of a locally based enterprise that found ways and means of expanding the work repertoire whilst the Chemfos work diminished. The main advantage thereof was the retention of the intellectual capital in the region that could be allocated on an ad hoc basis.
- The project has also created job opportunities for the Green Village and the broader local community.
- The schools and universities are benefiting because they now have access to a working palaeontological site, where they can learn about fossilization and the relevance of fossils in understanding life changes on earth through time.

- The national and international palaeontological research community is benefiting because a world-renowned fossil site is being protected for posterity.
- The information generated by this research forms the basis for the tourism and education programmes.
- The West Coast region is benefiting because of a new tourism attraction being developed.

9.8 CONCLUSION

Costs and time frames of restoration projects can be underestimated during the conceptualization of a project. Continued re-evaluation and adequate flexibility is required to ensure success in the restoration of stocks and flows in a severely modified environment. Care and consideration must be given to all aspects of natural capital and then restoration can be to the benefit of the local community as has been shown in this chapter.

Vision is required to formulate a plan that integrates the rehabilitation phase of mining, the community and sustainable livelihoods. No two projects will be the same in this regard and the best practices of other examples may not be appropriate.

Outsourcing non-core functions to smaller focused companies with appropriate levels of technical and management skills has proven to be cost-effective. The greater flexibility of these smaller business units allows them to function and thus retain the trained staff under conditions not appropriate to corporate structures.



Figure 9.6: Core members of the Chemfos Rehabilitation Team that developed Vula Environmental Services and that were employed on subsequent projects.

CHAPTER 10. GENERAL DISCUSSION

10.1 HISTORY OF REHABILITATION

In the 1930s Ayers described the importance of controlling soil erosion and this work influenced international thinking (Ayers, 1936). During the 1950s, this change in thinking led to a focus on exploring methods of remediation of sites modified by mining. In South Africa, Acocks (1953), after extensive field studies, produced his *Veld types of South Africa*, in which he linked soil potential to vegetation types and described his agro-ecological units or veld types for the whole region. He also illustrated the impact of over-grazing and erosion on the slow or lack of reparability of the veld. These concepts were further developed into remedial solutions being applied to the environment with the Act 27 of 1956, which dealt with the establishment of vegetation on “mine dumps”. However, only during the 1980s was additional legislation introduced to ensure rehabilitation of mines. Consequently generalized revegetation strategies were developed and widely employed for mine “rehabilitation”. They focused primarily on introducing tolerant graminoids and agricultural pasture crops to stabilize the disturbed areas or mine tailings (Bradshaw, 1984). This practice was also adopted for the revegetation of disturbed areas along railway lines, such as the new line established for the transport of coal from Ermelo to Richards Bay.

The understanding that site-specific rehabilitation measures might yield better results than the more popular general revegetation approach, led to the development of rehabilitation strategies using indigenous grasses augmented by some indigenous seeds . By the 1990s, projects, such as the Du Toit’s Kloof Pass rehabilitation, had comprehensive strategies in place prior to the construction phase and detail monitoring of the re-establishment of local vegetation was in place (Anderson, 1997). The vision of forward planning for mining was aided by the publications of guidelines for prospecting and mining (DMEA 1992), but retrospective rehabilitation was still largely inadequately addressed in mining.

10.2 EARLY STUDIES AT CHEMFOS

Stabilization attempts at Chemfos were driven by a functional need to suppress dust generated by the mining operations during the months of strong south-easterly winds. Rehabilitation was not considered as a priority (Thomson, pers. com. 1999). The mind-set that prevailed was that the post-mine environment was “irreparable”. The Chemfos mine site was in a deplorable state at the time of closure of production in 1993. Contributing factors to the state of the environment that prevailed at that time were:

- The extended mine history dating back to the 1930s
- The change in ownership over time
- The isolation of the West Coast prior to the construction of the Sishen-Saldanha railway line and the R27 West Coast road in the early 1980s; as well as
- The marginal profits made and the delayed survival of the mine because of:
 - Low organic content of the tailings and rehabilitation sites.
 - Low moisture of the “soils”, and
 - The cross-zoned nature of the soils.

During the last years of the Chemfos operations, attempts were made to restore the site (CES 1996a). The primary mine area was systematically backfilled from north to south, so as to form a land bridge with a near-flat surface to facilitate hauling of the product from the cut face to the primary crusher. A small mined area of approximately 10 ha was filled adjacent to the haul road and adjacent to a previously constructed dump area. This filled section was later covered with topsoil and the natural recovery of vegetation from the topsoil was substantial, although not very diverse. The reason for the incomplete recovery probably relates to handling and storage of the topsoil prior to use (Holms 2001), but no evidence or accurate records could be found to substantiate this. The loss of information on the operations of the mine at and before closure is regrettable, as valuable information relating to the details and processes might well have contributed to the rehabilitation strategy.

In future at mine closure, it would be advantageous for the mine to establish an “Information time capsule” as part to the exit strategy. Information relating to soil, modifications and methods of mining and rehabilitation as well as anecdotal records of processes should be preserved together with all relevant maps and data. The integration of the rehabilitation with the mining phase would provide an efficient cross feed of information which would be advantageous to assist the formulation of the rehabilitation plan. This thinking is not new but the implementation has been lagging behind the theory. Wells (1986) in an article dealing with long-term planning for rehabilitation of open-cast mines stated that “A considerable amount of planning is required for the rehabilitation of land that has been disturbed by open-cast mining if it is to meet the legal constraints and the requirements of the Chamber's guidelines. In addition, if the planning is not done concurrently with other mine planning, the overall cost of rehabilitation will undoubtedly be higher than it would have been with proper planning.”

10.3 MINE TRIAL DESIGN

The initial aim of the trials implemented during the winter of 1996 was to review the success of the best known practices at the time, in order to find a practical way of restoring the post mining environment. It was not clear if all or any of the approaches implemented elsewhere such as in Du Toit's Kloof Pass (Chapter 3.4), would be appropriate under the more harsh West Coast conditions in very alkaline cross-zoned soils. From the onset, this was seen as a long-term project with a minimum program life of five years (CES 1996a). In order to obtain meaningful results that could inform the rehabilitation of the complex post-mining landform, trials had to be implemented in a range of conditions ranging from mobile processed sands to inset phosphate beds.

During preliminary discussions between Samancor and the DMEA at the start of the de-commissioning phase of the Chemfos mine, it was agreed that a Closure certificate would be issued if a tourist and research-based post-mine land use was established, the unusable mine plant and infrastructure be demolished, and dangerous slopes and cut faces be made safe. In addition, invasive alien plants had to be removed and local indigenous vegetation established. It was within this framework that the approach to and implementation of the rehabilitation for the mine was conducted (CES, 1996a, 2001).

10.4 MOBILE SANDS OF THE TAILINGS DAMS

The mobile sands presented unknown challenges since none of the known techniques had previously been demonstrated under the exact conditions that prevailed at Chemfos. Coastal Dune and Drift Sands, at the time, had been successfully stabilized in large parts of the Western Cape by using alien Australian wattles, *Acacia saligna*, *A. longifolia* and *A. cyclops* (Nyoka, 2003). These species have, however, caused problems by outcompeting local species and invading areas not intended for stabilisation. The eradication of rooikrans (*A. cyclops*) was one of the objectives that had to be achieved as part of the rehabilitation of the Chemfos site. The use of the eliminated wood of these trees, in the form of brushwood packing and the placement of chipped branches were integrated into the trial design (Chapter 5.6).

The use of Marram grass (*Ammophila arenaria*) has been demonstrated to be very effective in controlling mobile sands along the west and south coast and has been used extensively in stabilizing primary dune systems particularly in the proximity of human settlement in areas such as Blaauwbergstrand and Stilbaai (van der Putten, 2000). Being a European species,

from higher rainfall conditions it was uncertain if the Marram grass would be able to survive under the low rainfall conditions so far inland without the benefit of the coastal fog and associated higher humidity. Trials to evaluate the effectiveness of this grass in a combination with brushwood packing as well as a variety of seeding and planting regimes were implemented.

In a quest for finding an alternative to the use of exotic plants, namely *A. arenaria*, led to exploring the use of the local grass species, *Ehrhartra villosa* and *Chaetobromus dregeanus*. The former was planted from rooted rhizomes, plants produced in the nursery and the second was seeded directly on the mobile sands, from seed obtained from the Department of Agriculture, Worcester. These introductions, although small, represent the first recorded attempts in this specific region using these techniques. The success of the introduction of the local grass species led to the expansion of this approach and a concerted effort to harvesting seed was launched resulting in the wide spread use of these grasses which were introduced as seed during the rehabilitation phase.

There is thus no motivation to use the more expensive approaches. Marram planting in strips with brushwood between in areas over seeded with local species and annual grasses was on par with seeding with *C. dregeanus* and *E. villosa* in terms of cover. It can thus be concluded that in areas where the climatic conditions and physical characteristics will allow the establishment of *C. dregeanus* and or *E. villosa* it would be the preferred method of stabilization of mobile sands. In areas where the establishment of seeded grasses is unlikely, the use of *A. arenaria* (marram grass) is advocated.



Figure 10.1: (August 1996): *A. arenaria* in association with brushwood and associated seeding and understory planting..

10.5 TRIALS ON THE MINE FLOOR

Rehabilitation of the in-situ phosphate beds relied on exploring most logical approaches known such as introducing seed, transplanted and greenhouse produced plants, and brushwood, fertilizer and wood-chips. The design of the trials used a combination of the basic approaches in order to determine the minimum intervention required to achieve successful rehabilitation of a stable alternative ecosystem.

The use of extensive soil amelioration methods was not considered in these trials as it was thought that these techniques would be impractical because of the high cost of large scale implementation.

10.6 RESULTS OF THE TRIALS

The concept of the trials was to provide results that would inform the way forward in planning the detailed rehabilitation of the mine. The implementation of the trials late in the season (June & July) limited the amount of growth what could be achieved in a single season. It was realized that the trials would not be able to provide significant information on rehabilitation planning after the first two years after implementation. Furthermore, because of the late-in-

the-season commencement of the project, the limited selection of seeds available, the restricted numbers of species of plants available and other flaws that existed in the detail of the trials there was a limited early interpretation for large-scale rehabilitation from the results. Informal trials carried out in parallel, however, augmented the results for the short-term rehabilitation planning, although these trials are not formally recorded here.

The original baseline study was conducted in 1995 by CES (1996a) when they reviewed the vegetation status at 27 fixed points on the mine site. This study was subsequently repeated by Lubke in 2001 and then again by van Eeden in 2004. These 27 randomly placed sites do not correspond with the management units developed later or with the treatments or trials sites, and consequently the evaluation of these results has not been applied in this mine trial study.

It was a shortcoming in the development of a Chemfos Rehabilitation strategy that although monitoring of the trials was carried out, evaluation of the results did not form part of the deliverables of the strategy.

The trials were, however, monitored by Aneria Heydenrych and Piet Lombaard of Department of Agriculture, Elsenburg. Ms Heydenrych planned to monitor the field trials as part of her field work for post-graduate studies. The advantage of this strategy was that BHPBilaton did not have to pay for the studies, but the disadvantage was that the surveys were interrupted and the results were never published as she did not continue with her studies. Some of the trials were resampled in 2008 as part of the field work training of the BSc Honours students of Prof Tim Hoffman of the University of Cape Town. The value of the original data and the robust layout and marking of the trials became obvious. The decision to re-sample the remaining trials was taken and the results are discussed in Chapter 5.

Short-term vegetation dynamics observed under the trial conditions were very different from the long-term results that were obtained. Although some of the techniques, such as the introduction of local grasses from seed in the mobile sands found in the tailing dams, seemed to be of little significance in the short term, they have proved to be important in the long term in the redevelopment of the ecosystems. The local grasses played a major role of stabilizing the mobile sands and providing a suitable microclimate for the recruitment of seeds from surrounding indigenous plants and the subsequent tailings rehabilitation. The increase in cover and diversity over time has been shown to be a slow process under the prevailing conditions. The value of the long-term nature of the project and the monitoring and evaluation tools in feeding results into the decision-making process was thus

established. In retrospect, more manpower might have been deployed to evaluate the trials continuously and additional funding could have been procured for this study.

10.7 REHABILITATION TECHNIQUES

Mine rehabilitation techniques are in essence the implementation of a set of pre-determined ideas. In the introduction of the Australian Mine Rehabilitation Handbook, it is summarized as “Rehabilitation is the process by which the unavoidable impacts of mining on the environment are repaired. It is an essential part of developing mineral resources in accordance with the principles of sustainable development. The purpose of this handbook is to give field personnel in the mining industry some of the information needed to rehabilitate areas disturbed by mining in a sensible, scientifically based way. While it is impossible to give specific rehabilitation procedures suitable for all sites the handbook attempts to outline the broad principles and practices that should be used as the basis for rehabilitation (Warren 1999). In the case of Chemfos, the “pre-determined ideas” were borrowed from other sites and were adapted to local conditions and then implemented in the form of trials. The CES rehabilitation plan was adapted and produced before most of the findings of the trials were known (CES, 1996a).

At Chemfos, the basic components such as soil preparation for planting, plant propagation and seed collection have been identified but required considerable on-site adaptation due to the harsh local conditions and the unusual post mining topography as described in Chapter 2. The feedback from the trial assessments and the on-site lessons learned were incorporated into the planning of the roll-out of the rehabilitation and this process was sustained throughout the implementation phase.

Although the formalized trials provided guideline information for the implementation, additional components of the rehabilitation required investigation and refinement. These included the management and social aspects of the project. The management challenges not only included the development of adaptable implementation programmes to ensure, amongst others, timely and efficient seed collection but finding ways to keep staff functional at optimal levels through incentive schemes and flexi-time.

10.8 MANAGEMENT AND IMPLEMENTATION

The difference between the academic interest in the project and the management objectives of its implementation became clear with a pragmatic approach dominating in order to

achieve the desired goals. The management component was the most critical but relatively expensive (R10500 per month during 1998) so measures were taken to reduce the costs. A junior horticulturist was employed and trained in the implementation of various activities, thus reducing the management input and costs to around R3500 per month with some months being close to no costs at all. During this period the development and training of staff also significantly increased costs in comparison to that of using unskilled labour. A landscaping and rehabilitation company, Vula Environmental Services, was established at this time, and the staff were deployed on parallel projects and only brought on site during critical periods such as planting or seed harvesting. This would not have been possible had Chemfos been the only project on which Vula were involved, but a number of projects were running in parallel, making the company financially sustainable.

Should rehabilitation form part of the active mining process, such synergies are also possible. There is always the potential for the movement of staff between operational units of the mine. Because of the different seasonal needs for rehabilitation this may result in easier retention of staff, with the additional benefit of the transfer of specialized knowledge. Indeed there is evidence of the beneficial effect of integrated green approaches (rehabilitation to future sustainable land use) and the active rehabilitation phases are now common place during mining. Basil Read has demonstrated in the Cosmos Project in Gauteng that the integration of green thinking into the communities supporting the mine can lead to an improved quality of life. This approach can set the tone for a sustainable post-mining environment built on the foundations of a green culture that was developed in the community during the mining phase (http://basilread-ir.co.za/financials/basilread_ar2008/mining_opencast.htm, 2008).

In retrospect, the aims of the Chemfos rehabilitation were rather ambitious and did not fully acknowledge the complexity of the context of the project. The rehabilitation process was focused, but the lack of infrastructure associated with mining meant that none of the implied goodwill existed that is usually associated with an active mining environment. For example, all plant and equipment used was brought to site for specific purposes and this translated into a direct cost to the project. It was not possible to buffer some of the earthmoving and preparation cost by finding possible synergies that exists in the operational mining environment.

During the decommissioning phase the priorities and programme were largely driven by this need of a systematic approach depending on the availability of resources on the site. For

example, the bulldozer had to be used to reduce the severe slopes directly after the trimming of the old processing plant was completed. Consequently, this required a review of the initial programme which also assisted us in formulating the sequential programme and the introduction of modules of management. This modular management was later refined and form the basis of division of the mine into 54 Management units. In order to gain access to the slopes, we also had to experiment with dozing and covering the 10- to 20-year-old alien invasive trees or cutting and removing them before dozing. It became clear after experimental slope adjustments that the large mature acacia trees would cause severe complications if these dense stands of trees were not removed prior to the commencement of earthworks. This realization led to re-prioritizing of tasks to ensure that all the alien-infested slopes requiring slope adjustment were cleared prior to scheduled earthworks.

In addition, some of the post-mining topography such as the “High Wall” (Area 37 in Figure 6.4) was seen as an asset as it exposed the stratigraphy of the site adding value as a feature (Wells, 1986) and was thus treated in an unconventional way by preserving it.

Though insignificant in itself, this detail re-programming and the flexibility in approach set the tone for the entire project. The locally adopted motto of “stop and re-evaluate” served us well in continually finding new solutions to the problems that were encountered.

10.9 PLANT PROPAGATION

The main challenges encountered during the trail rehabilitation implemented in June 1996 related to timing. There was no time to produce plant material vegetatively to be used in the planned trials since the short growing season ends in August, leaving no time for the establishment of plants prior to the onset of summer. It was noted that indigenous vegetation on site had become established particularly in disturbed areas during the previous two years of low activity on the mine. For example, along the road verges numerous seedlings had emerged. Since transplants were effectively introduced in Du Toitskloof (Anderson, 1997) it was decided to harvest these seedlings for use in the trials. The methods were, however, changed and they were established in polystyrene trays to stabilize them in the nursery prior to planting them in the trial sites. This would ensure uniformity of diversity of the plants introduced in the trial planting. It did increase the cost due to double handling, but ensured optimal healthy transplants for the trials. Direct transplants were considered, but this idea was abandoned in favour of the temporary nursery establishment in order to minimize plant losses. The logistic arrangements for transplanting a variety of species into a large number of trial blocks were easier to manage ex-nursery as well, thus increasing productivity.

The initial rehabilitation plan that was drafted was not prescriptive on the production of plant material for the trials (CES, 1996a). This and other finer details of the rehabilitation procedure required further development once we were established on the site. Various short-term options were considered, including the outsourcing of cutting and seedling production to commercial nurseries in the Cape area.

The three-month trial contract saw the implementation of the trials and the traditional production of plant material to determine the way forward. Seed and plant material locations were identified and experimental production techniques on a wide range of plants commenced. Although horticultural techniques are well defined, (Hartman *et al*, 1990; and Brown and Duncan, 2006) the cultivation of the particular indigenous species of the Strandveld had not been widely practiced. A diversity of species was considered for use in the rehabilitation of Chemfos and locations and propagation techniques were evaluated. The plants were initially selected based on the perceived usefulness in rehabilitation, propagation potential, ease of seed collection and the potential to be easily established.

The plant production skills that were developed were expanded to include the growth and establishment of a range of diverse plants such as bulbous geophytes, e.g. *Gethyllis afra* (Figure 10.2) and other climax plant species of the Strandveld. The plants were introduced during the maintenance phase into the areas that were stable and functional enough to support these species. Although this was not one of the initial objectives, the diversification of the plants added depth to the vegetation structure which would be of interest to future tourist of the Fossil Park.



Figure 10.2: Seed pods of *Gethyllis afra*.



Figure 10.3: Three-year-old seedlings of *Gethyllis afra* prior to being planted into partially restored environments at Chemfos.

10.10 SEED COLLECTION AND SEED SALES

Recovery of disturbed environments can take place naturally in habitats such as grasslands (Coffin & Lauenroth, 1988) and in the fynbos complex (Saayman and Botha, 2008) providing that the topsoil that contains the propagules are in place. Rehabilitation processed soils, cross-zoned soils and subsoils thus either require the use of propagule-containing topsoil, a very scarce commodity at Chemfos, or the introduction of seeds into the systems to be rehabilitated as described in Chapter 7.

Seed collection, processing and storage practiced by amongst others, Kirstenbosch and the Veld Reserve in Worcester were considered and adapted for use at Chemfos, where the volume of seed required was significant.

Seed was collected from a range of functional species for direct sowing as well as for the purpose of plant production in the nursery (Figure 7.5). Since the seeds varied in physical properties and distribution as well as densities, hand collection and a variety of mechanical

means were employed to collect the required material based on a programme that monitored phenology to collect the targeted seed optimally.

Refinement of seed collection and processing methods lead to a reduction of the cost of the seed collected and established a new benchmark costing model for these seeds (Table 7.1). This reduced the overall rehabilitation cost, enabling the team to add aspects of vegetative diversification within the original budget. Excess seeds were sold to be used on other projects, allowing the procurement of equipment not budgeted for, as it was not envisaged at the start of the project. Flexibility in approach and continued re-evaluation of the approaches and methodologies employed resulted in the rehabilitation project evolving continuously.

A further improvement of the cost-effectiveness of the use of seed as a primary means of rehabilitation is illustrated in Appendix A. Based on the feedback loop used as part of the adaptive management strategy that was followed, seeds of particular species were allocated to areas with soils and topography that could in fact support the particular species. This targeted introduction yielded cost-effective results that supported the overall objective of the project by reducing the unit cost of interventions.

10.11 SMOKE TREATMENT

The use of a smoke germination stimulant was not provided for in the Conceptual Rehabilitation Plan (CES 1996a). The development of the technique of manufacturing large volumes of smoke bubbled water was under development in 1996. This posed a problem in obtaining product for use at Chemfos. Experimentation with improving the workflow of the smoke bubbling through water idea, led to the development of an entirely new approach to manufacturing of the smoke-based germination stimulant. The process of distilling the smoke, using the apparatus designed for this purpose (Figure 8.2), is described in Chapter 8. This breakthrough reduced the unit cost of the smoke trigger to R0.36 per litre or 5% of the average cost of the ready-to-apply product (R8.09/litre) as surveyed in 2005. This made it possible to utilize the best practice available at the time at no significant additional cost to the project.

Although several attempts to provide documented scientific proof of the hypotheses that a smoke cue such as FireGrow can meaningfully improve the germination of the susceptible seeds of the Strandveld in the field has failed, FireGrow yielded significant and encouraging laboratory results by increasing germination by 54% (Meets and Boucher, 2004). The attempts at conducting the field trials have demonstrated the complexities that can present

itself during the implementation phase. The integration of the lessons learned from these trials into the trial design of others has contributed to the knowledge base of the rehabilitation procedure. In Australia, post-mining smoke treatment of forest soils in conjunction with broadcast seeding has yielded a 56% increase in seed germination. The pre-treatment of seeds has yielded an 85% increase in the numbers of seeds that germinated in comparison to the controls (Roche *et al* 2007).

The pre-treatment of seeds has been consistently used since 2003 when the trials were designed in anticipation of the results based on the laboratory findings in this regard (Light *et al*, 2001). This represents a significant improvement over past techniques where seeds and large amounts of FireGrow (1.5 litres of concentrate) was added to a hydroseeder and applied. Pre-treated seeds, soaked in 10 ml FireGrow in 25 litres of water, are now added to the hydroseeder reducing the amount of product required.

10.12 MONITORING AND EVALUATION

The Chemfos rehabilitation trials were evaluated during the summer and winter that they were conducted to provide information regarding the development of the rehabilitation methods in different sites of the mine. We anticipated gathering meaningful results from the trials within months, but this was not the case. The initial rehabilitation trials were established on the site during June 1996 due to administrative and contractual constraints. This was halfway through the growing season on the West Coast so there was limited growth in this first season. Moreover, the trials were further compromised by the timing, as the selection of suitable seed and plants was not available for inclusion in the trials.

Significant variation and differences between the treatments only became apparent in later years and the initial assessments primarily indicated the successful introduction of plant cover on the bare sites. The effect of the different treatments on the resulting species diversity or richness only became apparent after the second year. Thus we primarily focused on establishing plant cover and ensuring stability of the bare rehabilitation sites using the information gathered on species response to specific conditions (Table 7.2). The introduction of a diverse species composition was seen as a secondary effect resulting from the introduction of selected woody successional species either as seed or as cluster planting. The importance of continued monitoring and evaluation is essential in this process as it facilitates timeous and effective planning. The information gathered for the monthly and annual reports on the rehabilitation success or failure served as an early warning system and contingency planning could then be considered (Figure 6.11).

The initial time frame of five years was deemed to be too short for the implementation of the complex rehabilitation plan. Therefore, an additional five years of maintenance and diversification was introduced, which allowed for the rehabilitation areas to become established and all mishaps such as erosion and die-backs could be resolved. This brought the general ecological condition of the rehabilitated Chemfos site to a point where it could withstand relative low or minimal maintenance that followed from 2006 until 2010.

10.13 SOCIO-ECONOMIC ASPECTS

The integration of the social needs of people still living in the old mine village three years after closure, were considered from the start of the development of the rehabilitation plan. This is in line with current trends in balancing the economic, social and environmental interest in mining (Mebratus 1998). It is obvious that the integration of all elements of mining and rehabilitation can best be served during the lifespan of the mine. Rehabilitation after closure cannot influence the initial environmental impact or contribute towards the economic optimization to the extent possible if rehabilitation was initiated during operation of the mine.

It was clear that the rehabilitation of a vast alien vegetation infested post-mining environment using retrenched mine workers and training them in new skills would hold some enormous challenges. SAMANCOR's closure programme was to sell the remaining phosphate that was in storage, as well as the movable infrastructure once demolished. The remaining buildings, roads, etc were to be upgraded to be used as facilities for use by IZIKO as hub of the Fossil Park which was the alternative land use plan developed for Chemfos. This formed part of the strategy to satisfy requirements by DME to obtain the closure certificate.

Social aspects in a post-mining environment, where there is little economic activity, differ considerably from those experienced in a functional mining environment. Retraining in new skills formed a considerable part of the staff development programme as it was found that insight into technical aspects of the project created a greater understanding amongst staff for the activities they were employed to perform. This training as well as community involvement by supporting woman's craft groups and vegetable gardening, integrated the staff, the village members and the project.

Various phases of development of the Fossil Park also benefitted from input from the rehabilitation contractors who have experience in resort planning and landscaping. The co-operation and goodwill that exists and the synergies experienced, raised the question of the opportunities lost due to rehabilitation being a post-mine-closure process. There is no

scientific information to comment on the potential of synchronistic opportunities lost due to the relatively isolated post-closure rehabilitation of the Chemfos Mine, in comparison to ongoing rehabilitation during the active mining phase. However, I would suggest that the interdependence and interactivity of mining with rehabilitation might contribute to greater influence of practices in both mining and rehabilitation. This may then lead to increased efficiency and cost savings in the final process.

BHPBilliton invested in upgrading the village during the initial pre-closure phase and supported the development of infrastructure and services up until 2010. The initially independent village was integrated into the Saldanha Bay Municipal structures when it was realized that the management challenges were greater than anticipated. This is consistent with the Australian expectation where communities form part of the closure plans. The Leading Practice Handbooks for Mine Rehabilitation states that: "Where components of the mine site have the potential to be used for agriculture or community-based activities, there will be a need for ongoing management. It is important to establish at an early stage the long-term capacity of the local community, its local council and community groups to undertake such activities. Without a long-term commitment and adequate resources, managed rehabilitation programmes may ultimately fail" (Mulligan, 2006).

In the case of Chemfos, the rehabilitation phase employed village members for a finite period of time with fluctuating seasonal demands for staff. Entrepreneurial thinking explored opportunities to market expertise developed for the rehabilitation and to establish a company that could employ more staff permanently, ensuring their own economic sustainability and retaining the knowledge base for assistance with maintenance in the long term.

The Mining Company further funded the establishment of the Fossil Park and provided long term for the fledgling business that was developed by academics around an international treasure. Although some members of the staff are from the Green Village, they number less than ten, thus limiting the ability of the Fossil Park to play a major role in its current form as employer.

It is clear from the fourteen years of experience since the commencement of the rehabilitation of the Chemfos mine, that the biggest challenge does not lie in finding technical solutions to rehabilitate an old mine site but, in fact, in developing a truly sustainable alternative use for the site and livelihood for those left behind. The significant contribution by Vula Environmental Services in providing employment in an area geographically isolated and with few opportunities, can be seen as a fortunate chance occurrence. This, together with

the chance discovery of fossils on the site, has greatly contributed to turning a potential post-closure headache into an opportunity to showcase what can be achieved by communal effort, support of the Mining Company and an inspired vision.

10.14 DEVELOPMENT OF THE BEST PRACTICES OF REHABILITATION

The development of a costing model for the rehabilitation poses a challenge, since every situation is unique. Detailed intervention models are driven by site-specific conditions and may vary greatly from site to site. In the Australian Mine Rehabilitation Handbook the view is also expressed that the degree of similarity between the original and post-mining environment should guide species selection in the case of the restoration of the post-mining environment to a near native state (Warren, 1998).

Retrospectively, many of the rehabilitation procedures could be reconsidered and the approaches reformulated. The clarity of hindsight is, however, not available to the researcher at the time that the approach is conceptualized. Thus the value of this work is in assisting future rehabilitation projects whereby the best approaches may be adapted early on, thus avoiding the pitfalls experienced in this study.

The challenge of environmental rehabilitation management lies in taking a rehabilitation concept or philosophy, interpreting it and then producing a successful rehabilitation project which achieves the principal objectives such as closure certification within time and budget constraints. Since the manager's role in this falls largely outside the scientific field, documenting and understanding the importance of his/her role in the integration of the science, methods and management is confined to the success of not only the individual project involved, but also in the broader field of post-project feedback in the rehabilitation industry. The continual interaction between all role players should be encouraged in order to prevent the repetition of mistakes and consequently to benefit from the lessons, techniques and procedures, whether successful or failures, that are learned.

10.15 GENERAL CONSIDERATION OF THE EFFICIENCY OF THE REHABILITATION PROGRAMME

The initial aim was to adapt known rehabilitation methods to the specific requirements of the Chemfos site in a cost-effective way. The cost-effectiveness was measured against benchmarks obtained from other projects in a process of determining approximate unit cost (CES, 1996a). The limitation of these estimates only became obvious midway through the

process when the feedback information from their implementation pointed to new streamlining methods. The process of restoring the mine site that developed, involved the client, the consulting team, the staff and the management within the context of uncontrollable variables of the site such as fluctuating rainfall and strong seasonality of climate.

Simple solutions to increasing productivity of felling alien vegetation were found by introducing flexi-time. Allowing staff to commence work at 05:30 in midsummer and to work to achieve pre-determined quantified goals resulted in increased staff morale and less stress and strain on the work force that would be able to complete a day task by 13:00, in time to avoid the worst of the high temperatures and the annoying seasonal insects.

Time-based seed collection, however, did not yield good results and the variation between eager workers and their less productive counterparts lead to the introduction of a set of norms for seed collection. These norms would vary between species and would also take time and seed abundance into consideration. It resulted in the average worker being used as a norm to determine production levels. This rate of collection was translated in a cost per seed per species collected per day and in turn, converted to a rate in Rand paid per kilogram of seed collected by the individuals. This innovative approach yielded more seed per day since productivity was directly rewarded. Initiative and problem-solving thinking was also rewarded by using ideas that were developed and suggested by the staff as the base of ad hoc training opportunities and paying a bonus for new ideas that would make life and work easier. Further incentives such as book prizes were also offered in order to create a team and competition spirit and to introduce an element of fun to the tedium of, for example, learning plant names. Although not dictated in the approach suggested in the Conceptual Plan, these activities translated in eagerness amongst the staff that certainly contributed towards the high productivity and that assisted in reducing the cost of the project.

At the time of the drafting the rehabilitation plan, the detail of the management of the rehabilitation project could not have been foreseen. Sourcing staff, equipment and training for a variety of activities including tree felling, nursery construction, fencing, seed collection and later plant propagation, required intimate involvement with every aspect of the rehabilitation process.

Critical thinking and problem-solving was required for almost every component as we explored new approaches and efficiencies to every aspect of the unfolding process. Traditional approaches to rehabilitation contracting in mining and the construction industry, involve a comprehensive, detailed plan being developed by consultants and the work being

described and quantified in the form of detail specifications. This quantified, itemized information is tabulated and presented in a “Bill of Quantity” format that together with a conditions of payment schedule, usually form the basis of an agreement between a Client and a Contractor. The latter would be overseen, supervised and monitored by an appointed technical consultant and often a Quantity Surveyor who would verify the work completed in terms of the contract document and who would then certify payment to the Contractor.

Such an approach works well when the scope of work is known and the process and steps of implementation are defined. In the case of the restoration of Chemfos, this was not the possible since the approach had to be developed based on the results of trials and the work could not be clearly quantified in advance. The implication was that a unique agreement had to be reached between the client, contractor and consultant, based on measurable outputs, clear record-keeping, innovative thinking and an adaptive management approach. This unusual approach allowed for the contractor to interpret the brief of restoring the mine and to formulate plans to achieve this in ways specific to the local environment and social context in response to the feedback received from the trial and work accomplished as recorded in periodic reports. This self-regulatory structure that was in place during the entire Chemfos rehabilitation project also obviated the need for an Environmental Control Officer (ECO), a requirement of many rehabilitation projects.

10.16 A FINAL OVERVIEW OF THE PROJECT

The rehabilitation of the degraded mine sites situated in a challenging environment (Chapter 2) formed a small part of the closure process. This was achieved by reviewing the best practices and adopting them to the local conditions within the framework of the Conceptual Rehabilitation Plan and then implementing the rehabilitation strategy whilst continually seeking improvements in techniques and efficiencies. This has been demonstrated in Chapter 3 to Chapter 8.

The initial aim of the project was to find the best rehabilitation methods known and to adapt and apply them to the Chemfos mine site after decommissioning in order to achieve closure (CES 1996a &b). This was achieved and the Closure Certificate was issued to BHP Billiton subsequent to the submission of the Chemfos Mine Site Closure Report in August 2003 (CES, 2003).

Good implementation practices, such as adaptive management and flexible budgeting, allowed the development of ideas and techniques not initially considered as part of the

design, to be included in the comprehensive rehabilitation approach. The main reason for this was the freedom to operate outside of corporate institutionalized structures. The costs and duration of restoration projects can be underestimated during the conceptualization and planning phase. Continued re-evaluation and all-round flexibility is required to ensure success in the restoration of stocks and flows in a severely modified environment. To simplify costs and apply these generally to rehabilitation, total cost can be divided by total area to provide a reference cost for the rehabilitation. In the case of Chemfos, the R6,728,500 budget was allocated to rehabilitate the 650 ha mine over a five-year period. The budget was underspent by nearly 10% or R669 541 and that over a 10-year period. This included the additional maintenance and diversification of vegetation. The underspending can directly be contributed to the judicious implementation of focused techniques rather than the application of generalized techniques on a large scale.

Although the original aim of the rehabilitation trials implemented during 1996 was to provide information and guidelines for the rehabilitation of the larger mine area in the short term, the long-term monitoring yielded valuable insights that were not obvious at first. In maintaining the well-marked trial plots and all the associated data, long-term monitoring now illustrates the development of the different populations over time (Chapter 5). This provides valuable insight in the ecosystem dynamics of the recovering mine. This knowledge can be integrated in the Management Plan of the Fossil Park and the costing models can assist in accurately predicting long-term maintenance and management cost of the Park.

Mine closure included demolishing the processing plant and stores, addressing the status of the ownership of the mine village and assisting IZIKO in becoming established with museum facilities in the transformed office complex and finally establishing a fully functional West Coast Fossil Park (Chapter 9). This holistic closure and rehabilitation process ensured a positive post-closure scenario at Chemfos. The rehabilitation of the site was the last action to be completed as part of the decommissioning of the mine and facilitated the transition from mine to Fossil Park. Various opportunities for unforeseen interaction lead to close ties between the restoration group and the incoming management of IZIKO. Staff trained in rehabilitation who worked on the programme for several years later found employment at the West Coast Fossil Park where their intimate knowledge of the history of the mine and rehabilitation served them well once they were trained as tour guides, for instance.

The project is also unique due to the commitment to resolve the complex post-mine closure issues that did exist and that to some extent still prevail. The baseline study conducted for

the mining sector found that: “Billiton PLC (2000) spent \$10.6 million on community initiatives in 2000, including small business development, health, education and training, community infrastructure and the environment. One example was the Mozal Community Development Foundation in Mozambique including compensation of local people relocated to make room for the smelter. This compensation was a combination of land, housing, seed and money. Another Billiton example was post-closure rehabilitation of land affected by open-cast mining at the Chemfos phosphate mine at Langebaanweg” (Granville (2001). Thus, because corporate responsibility rather than legislation was the driver of this post-closure scenario and the efforts of scientists, practitioners and the community were integrated in a holistic manner; an exemplary end result, namely a fully functional West Coast Fossil Park, was the conclusion. The rehabilitation of the degraded mine sites situated in a challenging environment (Chapter 2) formed a small part of the closure process. This was achieved by reviewing the best practices and adopting them to the local conditions within the framework of the Conceptual Rehabilitation Plan and then implementing the rehabilitation strategy whilst continually seeking improvements in techniques and efficiencies. This has been demonstrated in Chapter 3 to Chapter 8.

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integrated in a holistic manner; an exemplary end result, namely a fully functional West Coast Fossil Park, was the conclusion.

CHAPTER 11. SUMMARY AND CONCLUSIONS

11.1 INTRODUCTION

The initial aim of the Chemfos study was to determine the best practices of the day by reviewing available literature and other similar projects. In undertaking the reviews, the most significant discovery was that, despite the money and time invested in some of the projects, very few of these attempts were approached scientifically or recorded adequately. This invariably led to valuable knowledge being lost soon after project completion, resulting in anecdotal information being the only reference to what was tried before. Formalized information from projects such as the Sishen-Saldanha railway line might have obviated research in some of the aspects tested in the Chemfos trials. Available information of the best practices was interpreted along with a Conceptual Rehabilitation Plan (CES 1996) and trials were designed to be implemented in both the processed mobile sands of the Tailings dam and the phosphate beds or subsoils. Adaptation of the rehabilitation techniques were made by adjusting aspects such as species selection, seeding densities as well as planting techniques in order to make the approaches more suitable to the local soil and climatic conditions.

11.2 STUDY AREA

In reviewing the study area of the mine site it was apparent that:

- The terrain was very varied with the Pelletal Phosphorite Member as well as substantial sections of the Calcareous Sand Member exposed by mining. These substrates are not naturally exposed and in the general area (Chapter 2). There was thus no clear indication of potential vegetative cover or species composition for these soils. The Tailings dam also contained material not naturally found in the vicinity as it was filled with milled and processed tailings and was homogenous in particle size and contained no organic matter.
- The open-cast mining process had exposed the low-lying floor of the ancient riverbed or estuary in part and also accumulated excavated soils in several overburden dumps, resulting in greater variation in height than in the relatively flat surroundings. Several cut faces also remained as a result of the mining.
- The climate of the West Coast is harsh, with less than 300 mm of rain per annum mainly occurring from May till September. October until March is characterized by strong southerly and southwesterly winds frequently blowing between 3.5 and 10 m/s.

- The vegetation in the area is classified as Saldanha Flats Strandveld by Mucina & Rutherford (2006). Much of the area has been transformed by agriculture. Most of the vegetation on the mine site has been transformed over time and *A. cyclops* had been extensively utilized to stabilize the disturbed areas.
- The presence of the fossils on the site was recognized as an asset during the mining phase. The incorporation of the fossils in the post-mining socio-economic and physical environment served as a catalyst for the establishment of the Fossil Park and provided an anchor for a sustainable post-mining scenario.

SAMANCOR required a Closure Certificate for the mine from the Department of Mineral and Energy Affairs once production was terminated. This in turn required a rehabilitation plan to be implemented that included demolishing the old mining infrastructure and rehabilitation to an alternative land use.

11.3 HISTORY OF REHABILITATION

Work had been done on stabilizing mobile sands along sections of the Sishen–Saldanha railway line as well as along the frontal dunes in the Blaauwberg area. Significant advances were also made in approaching the rehabilitation of the road verges and other affected areas during construction of the Du Toitskloof Pass.

From these previous studies it was decided that the most appropriate techniques for Chemfos were:

- the use of the abundant brushwood to stabilize mobile sands over large areas,
- stabilizing mobile sands using *A. arenaria*,
- the establishment of diverse local vegetation into stable areas to ensure long-term stability using a variety of techniques including:
 - minimal earthworks to visually integrate new land forms into the landscape,
 - using micro-topography created during earthworks to create a conducive environment for the establishment of vegetation,
 - use of topsoil to improve the establishment of vegetation on in-situ cut slopes,
 - seeding with indigenous plant species,
 - planting of propagated plant material,
 - whole plant transplants from donor sites, and

- use of local vegetation in the restoration process selected for the new modified conditions.

These principles, together with the understanding derived from the early studies conducted at Chemfos (Chapter 4), were used to develop the trial design (Chapter 5).

11.4 EARLY STUDIES AT CHEMFOS

CES conducted the following studies during 1995 and 1996:

- A description of dominant plant communities.
- An evaluation of the post-mining topography and vegetation cover to determine rehabilitation required.
- Sampling of the vegetation on site in order to determine a possible vegetation change model and the maximum slope that can sustain vegetation.
- Formulation of an invasive vegetation strategy.
- Determined the relationship between soils and vegetation on the different sites such as the slimes dams, overburden dumps and mine floor areas.
- Reviewed the knowledge base and incorporated all the information into a rehabilitation plan.
- Consulted with interested and affected parties on the utilization of the area as a research and educational centre for Palaeontology.

These initial studies formed the basis for future work on rehabilitation techniques and goals by informing the trial design that, together with the Conceptual Rehabilitation Plan, influenced the implementation of large-scale rehabilitation.

11.5 CHEMFOS MINE TRIALS

Based on the early studies, a lack of knowledge was identified in dealing with the processed tailings and the in-situ soils at Chemfos.

The objective of the trials was to identify suitable techniques to rehabilitate these unnatural areas effectively. At the stabilization trial site, the objectives were to stabilize the mobile tailings and to establish a persistent vegetation cover. This idea was explored by:

- Using brushwood instead of nets.
- Introducing grasses such as *Ammophila arenaria* or *Ehrharta villosa* and *Chaetobromus dregeanus* while also evaluating propagation techniques,
- Establishing a diversity of indigenous species from harvested seed and propagated seedlings; and
- Considering the various permutations of the above-mentioned treatments.

11.5.1 Key findings relating to stabilizing the tailings

- Seed of *E. villosa* and *C. dregeanus* can be used effectively to stabilize areas of mobile sand
- The use of *A. arenaria* with brushwood may not be necessary. The cheapest stabilization trial was seeding with *C. dregeanus*,
- Planting *A. arenaria* was the second most expensive method, but it provided the most rapid stabilization of the mobile sand sites.
- Vegetatively propagated *E. villosa* yielded poor results initially. From year two *E. villosa* remained the best performer in terms of cover for the next ten years. In subsequent establishment from seed, the cost was the lowest, making *E. villosa* the preferred means of stabilizing mobile sand areas. Consequently, if time is not a critical consideration, *E. villosa* is the best treatment since establishment requires two growing seasons.
- Brushwood combination trials yielded less cover and were more expensive than the seeded and planted trials initially in the short and long term.
- It is useful to incorporate brushwood in rehabilitation if there is an excess available and if no alternative use can be found for it when it cannot be used for firewood.
- The species richness for all the trials was very low one year after introduction.
- An increase from 6 to 65 species on the trials (as recorded in the *E. villosa* trial) indicate that seed was brought into the tailings dam environment by other agents, such as wind, rodents and birds.
- The fact that so many seeds brought in by other agents germinated, can be attributed to the suitable microclimatic conditions created by the stabilization trials.

11.5.2 Trial Site on the Mine floor

At the subsoil trial site, the objectives were to identify means of establishing vegetation on in-situ material. This idea was explored by:

- Applying topsoil;
- Placing de-seeded *A. cyclops* brushwood over the surface;
- Applying chipped *A. cyclops* from the clearing process;
- Introducing indigenous plant seed;
- Introducing propagated and harvested plants;
- Using commercial fertiliser on the site;
- Considering various permutations of the above treatments.

11.5.3 Key findings relating to subsoil trial were:

- The topsoil trial had double the cover of the control site within 12 months.
- Similar results were recorded in plots that were seeded and fertilized.
- All the treatments recorded better cover and diversity results when compared to the control.
- There is an overall increase of cover in all the trials over time, including the control plot. This indicates an improvement of the general health of the system over time due to the applied treatments.
- There was an increase in number of species found that also indicates that the system (areas where the trials were implemented) has drawn benefit from the stability and ecological functioning associated with the improved cover of the closely spaced trial areas.
- There is a clear case for applying rehabilitation techniques to enhance cover and to assist establishment of vegetation on sub soil areas.
- The ad hoc trial (10a, thick brush packing for the purpose of de-seeding), that was only sampled in 2008, showed:
 - A cover rating comparable to the best of the other trials.
 - The highest number of species of all the trials.

This further supports the understanding that once an area is stable, birds and small mammals are drawn to the area that will bring seed from adjacent areas into the newly established habitat.

Thus, an understanding of the secondary impact zones of stabilized areas will provide information on the pattern of intervention of treatments that may be used under similar conditions. It may be possible to establish a matrix or patchwork of rehabilitation techniques across a landscape that will, in time, yield the same or similar results as a blanket single

treatment applied to the area. This will further reduce the cost per hectare of rehabilitation making it more viable under marginal economic conditions.

11.6 REHABILITATION TECHNIQUES

Initial results of the trials were used as basis for developing the rehabilitation techniques that were rolled out across the Chemfos landscape. The objectives were to incorporate lessons learned in the adaptive management approach that was followed. This would result in a significant step towards achieving the overall research objective of finding cost-effective approaches to rehabilitation.

The systematic approach that was followed included:

- The removing of alien vegetation using firewood harvesters as well as trained staff.
- Transforming the land shape where required to improve chances of successfully establishing vegetation and to make the areas safe for visitors.
- Introducing suitable pioneer and subclimax vegetation. Species selection was based on the lessons learned from the trials (Chapter 5), the soil and plant associations (Chapter 2) and the allocations were done within the framework of the soil and topographical assessment as illustrated in Appendix A.
- Diversification of the vegetation was undertaken parallel to the primary functions of clearing and stabilization.
- Diversification was primarily done by establishing clusters of propagated climax species. The propagated plants had a very high establishment rate and rapidly contributed to the available seed source in the rehabilitated areas.
- Introduction of biological controls of *A. cyclops* in order to suppress the development of seed in the area surrounding the mine as well as in two long-term trial populations on site.
- Maintenance of established areas was perpetually done and the localized problems were continually addressed to prevent further degradation and to ensure success.

11.7 SEED COLLECTION AND PROCESSING

The refinement of seed collection and processing techniques (Chapter 7) added to the efficiencies required to reduce the unit cost of the methods employed. Improved efficiencies were recorded in the following fields:

- Identifying species suitable for large-scale introduction by seeding and for propagation from seed (or cuttings) prior to introduction as plants.
- Hand-held vacuums were modified to be used as harvesters and species suitable for this method of collection were identified.
- Development of improved seed drying and processing techniques
- Establishment of clean seed equivalent norms to be used instead of completely processed and cleaned seed.
- Monitoring phenology in order to predict seed harvesting times and the incorporation of harvesting peaks with other activities.
- Matching soil and other physical properties to species requirements for effective establishment and selective allocation of suitable species to rehabilitation areas.
- Seed collection was incentivised.

The net result was a reduction of the unit cost of seed used and optimal application of the seeds collected. This had the added advantage as an excess of seed was produced that seed could be sold to offset rehabilitation costs at Chemfos.

11.8 SMOKE TREATMENTS OF SEED

The development of a new technique of manufacturing a smoke-derived germination stimulant contributed to enhanced seed germination. We also developed methods to ensure a reduction in the cost of using the product (Chapter 8). The new product, called FireGrow was the subject of research on its comparative effectiveness by Meets and Boucher (2001) who found that FireGrow yielded 54% germination at a 1:18 000 v/v compared to the 11.33% of a control and 37% of the De Lange Standard at 1:1 300 v/v.

Subsequent own studies found that based on the above, FireGrow, in a ready-to-use form, cost R0.36 per litre compared to the average cost of the other products of R8.09 per litre in a ready-to-use form.

Laboratory trials on determining exposure duration in relation to concentrations of smoke solution by Light *et al*, (2002) also indicated that seeds can be dried after exposure to the smoke-derived stimulants.

Field trials were implemented to test the laboratory hypotheses in the field and it was found that:

- Large-scale trials as part of a development are subject to variables, such as program delays and design changes that cannot be controlled, thus yielding no results.
- Large-scale trials without the possibility of excluding outside influences such as bird predation of the seeds, failed to yield results.

Although the formal trials to assess the effectiveness of the pre-exposure of seed to smoke extract failed twice, the approach was still integrated in the rehabilitation process since the cost was minimal due to the ability that was developed to manufacture the product ourselves.

11.9 SOCIO-ECONOMICAL ASPECTS

These were considered during the implementation of the closure as well as the post-closure phases of the rehabilitation. BHPBilliton invested (via the SAMANCOR Trust) in the development of livelihoods of staff that remained in the area and that lived in the mine village.

The following were amongst the socio-economic aspects of the project that developed over time with the support of BHPBilliton:

- Recruitment and training of mine village residents in alien vegetation eradication, seed collection, plant propagation and a range of rehabilitation techniques.
- Upgrading of the mine village and the assistance with the integration into the Saldanha Bay municipal structure.
- Establishment of the West Coast Fossil Park as an alternative land use of the mine site.
- Support for the West Coast Fossil Park Trust that manages the Park and trains and employs members of the Green Village in a range of professions.

The continued socio-economic development was brought about by the entrepreneurial approach that was followed by Vula Environmental Services who contracted to implement the rehabilitation for the mine. Vula contributed by:

- Providing advanced skills training to staff.
- Retained skilled staff and intellectual capacity by augmenting diminishing workflow from Chemfos.

- This was achieved through marketing the lessons learned at Chemfos to other relevant developments and by using the core trained staff to conduct skill transfer to locally recruited staff working on these projects.

The demography of the local population has changed over time and the Green Village as well as the inhabitants have evolved and benefited from the rehabilitation process. The new economic opportunities that were pursued have brought a new lease on life beyond the lifespan of the mine (Chapter 9).

Although the new business venture generates more turnovers and employs more staff than during the mine rehabilitation phase, it is not as significant as the understanding that prolonged rehabilitation time frame, in retrospect, provided the stability of the new business to establish itself.

It is thus important to integrate the business model for the rehabilitation unit into the long-term future vision of any operation that has sustainability in mind.

Outsourcing the rehabilitation has proven to be significantly more cost-effective and has resulted in a flexible and functional business that would not have flourished under the control of a mining operation even though the synergies of rehabilitation concurrent to the mining processes is acknowledged as extremely important.

11.10 CONCLUSION

In conclusion, the primary objective of the mine rehabilitation was to obtain a closure certificate. This was achieved through consideration of physical, financial and social factors and the continued interrogation and management of this interaction.

The feedback loop provided by the adaptive management approach that was followed ensured that cost-effective rehabilitation was continually improved and this resulted in the judicious allocation of the budget to restore the site using the most effective techniques.

Maintenance cost (primarily alien vegetation control) was reduced by 54% between 2005 (the last year of the official project) and the proposed 2006 budget. Due to the funding not being approved for this critical component, the maintenance was not conducted and continued growth and germination of *A.cyclops* was again assessed fifteen months later; and the cost in comparison with the initial quotations had risen by in excess of 350%.

The perpetual danger of continued seed germination from historical alien seed sources and plants approaching seed-bearing age will further increase cost of control and subsequent restoration once the alien plants have been removed. This highlights the importance of a post-rehabilitation strategy or management plan and associated budget.

The valuable contribution of a successfully rehabilitated site to the functioning of the operational environment of the new Fossil Park is significant. However, the fragile developing ecosystem that has been established requires continued nurturing for some time to come to prevent undue degradation and undermining of this valuable asset.

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19	<i>Euryops multifidus</i>	y	y	n	n		n			6.10	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1			4.90
20	<i>Felecia</i>	y		n	y	n	n			1.00											1.00
21	<i>Foveolina tenella</i>	y		n	n	n	n			20.10	0.4	1.5		1.5	1	0.2	1.5	1.5	0.1		8.90
22	<i>Gymnodiscus</i> (m)	y		n	y	y	n			65.00	2	2	2	2	2	2	2	2	2		43.00
23	<i>Helichysum odoratissimum</i>	y		y	n	n	n			2.50											2.50
24	<i>Helichysum revolutum</i>	y		y	n	n	n			3.09	0.1	0.1	0.2	0.1	0.2	0.1	0.1		0.1		1.89
25	<i>Juncus kraussii</i>	y		n	y	y	y			42.17											42.17
26	<i>Leysera graphalodes</i>	y		y	n	y	n			1.38	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.01		0.47
27	<i>Limonium peregrinum</i>	y			n	n	n			11.10	0.4	1.2		1		0.1	0.5				7.40
28	Mesem	y			n	y	y			2.05				0.1			0.3				1.65
29	Mesem (m) Pers vygie	y		y	n	n	y			63.00	4	4	4	4	4	4	4	4	4	4	19.00
30	<i>Mesem crystallinum</i> (m)	n		y	n	y	y			149.00	5	10	6	5	2	1	5	5	2	1	101.00
31	<i>Metalasia muricata</i>	y		y	n	n	n			76.37	4	12	5	2	1	0.5	4	4	1	0.1	37.77
32	<i>Nylandtia scoparia</i>	n		n	n	n	y			1.35										1.35	
33	<i>Nylandtia spinosa</i>	n		n	n	n	y			0.58										0.58	
34	<i>Oncosiphon grandiflorum</i>	y		y	n	n	y			76.36	5	15	6	5	1	1	5	8	1.5	0.5	22.36
35	<i>Oncosiphon suffruticosum</i>	y		y	n	y	n			113.00	5	15	6	5	1	6	5	8	1.5	0.5	59.00
36	<i>Oncosiphon grandiflorum</i> (m)	y		y	n	y	n			219.00	5	20	8	7	2	2	7	12	4	1	143.00
37	<i>Oncosiphon suffruticosum</i> (m)	y		y	n	y	n			78.00	5	20	8	7	2	2	7	12	4	1	2.00
38	<i>Pelargonium capitatum</i>	y		y	n	n	n			3.63	0.1	0.3	0.1	0.1	0.1	0.1	0.1				2.53
39	<i>Polypogon strictus</i>				n	n	n			1.12											1.12
40	<i>Prenia pallens</i> (m)	n		y	n	y	y			60.00	5	5	5	5	5	5	5	5	5		5.00
41	<i>Pteronia divaricata</i>	y		y	n	n	n			5.84	0.1	0.3	0.1	0.1	0.1	0.1	0.1				4.94
42	<i>Pteronia onobromoides</i>	y		y	n	n	n			4.30	0.1	0.3	0.1	0.1	0.1		0.1				3.40
43	<i>Pteronia ovalifolia</i>	y		y	n	n	n			1.92											1.92
44	<i>Rhus laevigata</i>	n		n	n	n	y			13.79	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.01		12.68
45	<i>Senecio elegans</i>	y		y	n	n	n			50.86	1.5	5	4		2	5	4	4	0.5	0.05	24.81
46	<i>Senecio halimifolius</i>	y		y	n	n	n			0.27									0.02		0.25
47	<i>Senecio littoreus</i>	y		y	n	n	n			31.41	1.5	2	2	2	2	4	1	0.5	0.1	0.05	16.06

[illegible]

APPENDIX B: FORMS FOR MONITORING THE RESULTS

B.1 Monitor Sheet 1: Control

Name	Replicate	Control East			Control Centre			Control West		
		1	2	3	1	2	3	1	2	3
		No of seedlings								
Aloe mitriformis										
Anthospermum spathulatum										
Aspalanthus sp										
Athanasia parviflora										
Athanasia trifurcata										
Athenasia crithmifolia										
Babiana spp										
Chaetobromus dregeanus										
Chondropetalum tectorum										
Chrysanthemoides incana										
Ehrhatra villios										
Eriocephalus africanus										
Euphorbia mauritanica										
Euryops multifidus										
Juncus krausii										
Limonium capense										
Limonium perigrinum										
Lycium ferocissimum										
Melianthus minor										
Nylandtia scoparia										
Nylandtia spinosa										
Oedera spp										
Orphium frutescens										
Protea repens										
Senecio spp										
Thamnocorthus erectus										
Thamnocorthus secigerus										
Wachendorfia										

B.2 Monitor Sheet 2: Conventional FireGrow Application

Name	Replicate	FireGrow tank East			FireGrow tank Centr			Fire Grow tank West		
		1	2	3	1	2	3	1	2	3
		No of seedlings								
Aloe mitriformis										
Anthospermum spathulatum										
Aspalanthus sp										
Athanasia parviflora										
Athanasia trifurcata										
Athenasia crithmifolia										
Babiana spp										
Chaetobromus dregeanus										
Chondropetalum tectorum										
Chrysanthemoides incana										
Ehrhatra villios										
Eriocephalus africanus										
Euphorbia mauritanica										
Euryops multifidus										
Juncus krausii										
Limonium capense										
Limonium perigrinum										
Lycium ferocissimum										
Melianthus minor										
Nylandtia scoparia										
Nylandtia spinosa										
Oedera spp										
Orphium frutescens										
Protea repens										
Senecio spp										
Thamnocorthus erectus										
Thamnocorthus secigerus										
Wachendorfia										

B.3 Monitor Sheet 3: Experimental FireGrow Application

Name	Replicate	Pre Treated East			Pre treatedCentral			Pre treated West		
		1	2	3	1	2	3	1	2	3
		No of seedlings								
Aloe mitriformis										
Anthospermum spathulatum										
Aspalanthus sp										
Athanasia parviflora										
Athanasia trifurcata										
Athenasia crithmifolia										
Babiana spp										
Chaetobromus dregeanus										
Chondropetalum tectorum										
Chrysanthemoides incana										
Ehrhatra villios										
Eriocephalus africanus										
Euphorbia mauritanica										
Euryops multifidus										
Juncus krausii										
Limonium capense										
Limonium perigrinum										
Lycium ferocissimum										
Melianthus minor										
Nylandtia scoparia										
Nylandtia spinosa										
Oedera spp										
Orphium frutescens										
Protea repens										
Senecio spp										
Thamnocorthus erectus										
Thamnocorthus secigerus										
Wachendorfia										

APPENDIX C: COST OF SEED

Name	kg of seed per ha	seed/kg	seeds per ha	cost of seed per kg	cost of seed per ha	cost of seed per m2
<i>Aloe mitriformis</i>	0.20	11000	2,200	350.00	70.00	0.007
<i>Anthospermum spathulatum</i>	0.50	700000	350,000	1,250.00	625.00	0.0625
<i>Aspalanthus</i> sp	0.50	45000	22,500	950.00	475.00	0.0475
<i>Athanasia parviflora</i>	0.50	20000	10,000	2,500.00	1,250.00	0.125
<i>Athanasia trifurcata</i>	0.50	3500000	1,750,000	1,850.00	925.00	0.0925
<i>Athenasia crithmifolia</i>	0.20	2500000	500,000	2,950.00	590.00	0.059
<i>Babiana</i> spp	0.10	215000	21,500	2,500.00	250.00	0.025
<i>Chaetobromus dregeanus</i>	1.00	45000	45,000	350.00	350.00	0.035
<i>Chondropetalum tectorum</i>	0.20	10550000	2,110,000	3,000.00	600.00	0.06
<i>Chrysanthemoides incana</i>	0.50	5000	2,500	1,250.00	625.00	0.0625
<i>Ehrhathra villiosa</i>	0.50	50000	25,000	650.00	325.00	0.0325
<i>Eriocephalus africanus</i>	0.50	55000	27,500	2,475.00	1,237.50	0.12375
<i>Euphorbia mauritanica</i>	0.50	37000	18,500	3,000.00	1,500.00	0.15
<i>Euryops multifidus</i>	0.50	55000	27,500	2,475.00	1,237.50	0.12375
<i>Juncus krausii</i>	0.30	600000	180,000	2,250.00	675.00	0.0675
<i>Limonium capense</i>	0.60	45000	27,000	1,750.00	1,050.00	0.105
<i>Limonium perigrinum</i>	0.60	42000	25,200	1,750.00	1,050.00	0.105
<i>Lycium ferocissimum</i>	0.50	80000	40,000	2,500.00	1,250.00	0.125
<i>Melianthus minor</i>	0.50	15000	7,500	1,250.00	625.00	0.0625
<i>Nylandtia scoparia</i>	0.75	1000	750	450.00	337.50	0.03375
<i>Nylandtia spinosa</i>	0.75	1200	900	450.00	337.50	0.03375
<i>Oedera</i> spp	0.50	100000	50,000	750.00	375.00	0.0375
<i>Orphium frutescens</i>	0.20	500000	100,000	3,500.00	700.00	0.07
<i>Oncosiphon grandiflorum</i>	1.00	6860000	6,860,000	650.00	650.00	0.065
<i>Protea repens</i>	1.00	11000	11,000	550.00	550.00	0.055
<i>Senecio</i> spp	0.50	3200000	1,600,000	3,500.00	1,750.00	0.175
<i>Thamnocorthus erectus</i>	0.50	150000	75,000	1,350.00	675.00	0.0675
<i>Thamnocorthus secigerus</i>	0.50	150000	75,000	1,350.00	675.00	0.0675
<i>Wachendorfia thyrsiflora</i>	0.60	70000	42,000	2,500.00	1,500.00	0.15
Totals	15			50100	22260	2.226

APPENDIX D: ADDITIONAL PLATES



Figure D.1: Seedlings harvested from disturbed areas on the mine were stabilized in trays before being planted in the trial areas (1996).



Figure D.2: Preparation for the smoke stimulant field trials (2003).



Figure D.3: Mine Village before upgrading commenced (1999).



Figure D.4: Green Village after upgrading (2002).



Figure D.5: Exposed subsoil (left) *A. cyclops* reserve (centre) and rehabilitated areas (right) (2000).



Figure D.6: *Ehrharta villosa* established from seed in tailings dump (1999).



Figure D.7: Chemfos Mine in operation (1970s).



Figure D.8: Mine area (March 1999).



Figure D.9: Mine area (September 2001).



Figure D.10: Mine area (September 2005).



Figure D.11: Mine area (September 2008).